

T H E E A R T H T E C H N O L O G Y C O R P O R A T I O N

**GEOTECHNICAL INVESTIGATION
FOR LIMITED PRELIMINARY
ENGINEERING PROGRAM
SAN FERNANDO VALLEY EAST-WEST SEGMENT,
METRO RED LINE PROJECT**

VOLUME I

Prepared for:

ENGINEERING MANAGEMENT CONSULTANT
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Long Beach, California 90802

December 10, 1993
Project No.: 93-4955

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1.0 EXECUTIVE SUMMARY

1.1 GENERAL

This report presents the results of a limited preliminary geotechnical investigation for the proposed San Fernando Valley East-West segment of the Los Angeles Metro Rail Project. The purposes of this investigation were to gain a general understanding of the geologic and geotechnical conditions and associated engineering parameters and potential ground behavior along the alignment.

1.2 PROPOSED ALIGNMENT AND FACILITIES

The proposed alignment is about 14 miles long, running north of and subparallel to the Ventura Freeway. The alignment extends between the western terminus at Topanga Canyon Boulevard and the eastern terminus at the northeastern end of the North Hollywood Station at Lankershim Boulevard. The alignment follows Victory Boulevard from Topanga Canyon Boulevard to the proposed Winnetka Station. From Winnetka Station to the eastern terminus the alignment follows the existing Southern Pacific Railroad right of way. The alignment consists of about 9.8 miles of twin tunnels, 3 miles of aerial guideways, and 1.2 miles of at-grade guideway. Eleven stations are planned. These stations include seven cut-and-cover stations along the tunnel segment and four aerial stations along the aerial/at-grade guideway segment.

1.3 SCOPE

The scope of this work consisted of a review of available literature; site reconnaissance and preparation of geologic maps; performance of a field exploration program which included drilling and sampling of 14 test borings, conducting 14 cone penetrometer tests (CPT) soundings, installation of 6 monitoring wells, monitoring of groundwater levels and taking groundwater samples for chemical testing; performance of limited soil mechanics laboratory testing on selected soil samples and limited chemical testing on selected groundwater samples; evaluation

of the results, and preparation of this report documenting the findings, conclusions and recommendations.

1.4 GEOLOGIC SETTING

The proposed alignment is located in the southern part of the San Fernando Valley which represents a structural depression filled with alluvial sediments and is located within the Transverse Ranges physiographic province. The San Fernando Valley is a faulted, synclinal trough. Exposed bedrock units in the adjacent Santa Monica Mountains area are also folded and faulted. Bedrock units range in age and composition from pre-Tertiary crystalline basement to pre-Tertiary through Quaternary sediments and volcanic deposits. Alluvium has been deposited in the basin through erosion of bordering bedrock. Alluvial deposits in the eastern portion of the San Fernando Valley consist predominantly of coarse granular materials derived from erosion of granitic and metamorphic basement rocks of the western San Gabriel Mountains and Verdugo Mountains. In the western portion, alluvial deposits are generally finer grained, having been derived primarily from sedimentary rocks in the Santa Monica Mountains.

The alignment is located in a relatively high seismic potential area. The closest documented active faults to the alignment are the Northridge Hills and Verdugo faults located at their closest point about 4 miles east of the east end of the alignment, and the Hollywood fault located about 4 miles south of the alignment. A number of other documented active and potentially active faults are located within 15 miles of the alignment. Available aerial photographs and literature data indicate the possible presence of an unnamed fault crossing the eastern end of the alignment. This fault which may be active as recently speculated by some investigators.

Groundwater levels in the vicinity of the alignment are influenced by groundwater extraction for water supply. Historically, groundwater levels in the alignment area were shallower (in some cases more than 100 feet higher than current levels) than those present today. Thus, in addition to being affected by seasonal fluctuations, groundwater levels will be dependent on the groundwater extraction/recharging patterns in the future.

1.5 SUBSURFACE CONDITIONS

For ease of presentation, the alignment was divided into the following three segments on the basis of facility types and encountered subsurface conditions:

- Western tunnel segment, which consists of about 5.6 miles of twin-tunnels and 4 cut-and-cover stations, and extends easterly from the western terminus at Topanga Canyon Boulevard to the Los Angeles River
- Central aerial segment, which consists of about 3.0 miles of aerial and 1.2 miles of at-grade (including retained cuts and fills) guideway, and four aerial stations and extends easterly from the Los Angeles River to Hazeltine Avenue
- Eastern tunnel segment which consists of about 4.2 miles of twin-tunnels and 3 cut-and-cover stations and extends easterly from Hazeltine Avenue to the eastern terminus at Lankershim Boulevard (North Hollywood Station).

1.5.1 Western Tunnel Segment

Along the western tunnel segment, the subsurface materials below a shallow fill zone (approximately 5 feet thick) consists of alluvium overlying bedrock of the Miocene Modelo Formation. Alluvium is heterogeneous and nonuniform. Within the depths of exploration, alluvium consists predominantly of soft to hard clay, sandy clay, clayey silt, and sandy silt interlayered with loose to very dense granular alluvium which is primarily composed of silty sand and clayey sand with occasional poorly-graded, clean and relatively clean sand and gravel layers. In this investigation significant thicknesses (up to about 10 feet) of granular alluvium layers were primarily encountered near the western end and the eastern half of this tunnel segment. Bedrock consisting of sandstone, siltstone and claystone was encountered in three borings (LPE-1, LPE-2 and LPE-5) between the western end and central portion of this segment. These data indicate that the soil/bedrock contact (mixed face conditions for tunneling) appears

to be undulating and is anticipated to periodically occur in the tunnel envelope west of approximate Station 190+00. Groundwater levels measured in three monitoring wells in this segment range from about 15 feet to 38 feet below the ground surface, indicating that the groundwater table ranges from within the planned tunnel envelope to about 20 feet above the tunnel crown.

1.5.2 Central Aerial Segment

In this segment, the subsurface stratigraphy within the exploration depths (up to about 100 feet below ground surface), consists of an up-to 3-foot thick shallow fill zone over alluvium. No bedrock was encountered in any of the exploration locations. The heterogeneous and non-uniform alluvium in this segment consists predominantly of soft to very stiff clay, sandy clay, and silt of low to high plasticity interlayered with loose to very dense silty, clayey sand, poorly graded sand and gravel. The alluvium is predominantly fine-grained to a depth of about 25 to 35 feet. Below this depth, granular and fine-grained alluvium are interlayered. Measured groundwater levels along this segment range from about 30 feet to 80 feet below ground surface.

1.5.3 Eastern Tunnel Segment

Below a shallow fill zone up to 5-feet thick, the subsurface materials along the eastern tunnel segment consist of alluvium throughout the exploration depths (maximum 86 feet). The alluvium in this segment is predominantly coarse-grained, consisting primarily of loose to very dense gravel, poorly graded sand, gravely sand, and silty sand interlayered with medium stiff to stiff clay, sandy silt and clayey silt. Available data indicate that scattered zones of cobbles and boulders (up to 4 feet in size) can be anticipated in the tunnel envelope, especially near the eastern portion of this segment.

Groundwater was not encountered within this segment in this investigation. Regional groundwater data and data from a previous investigation (Universal City to North Hollywood Tunnel-Contract (331) suggest that the depth to present groundwater may range from about 140

to 165 feet below the ground surface (i.e., significantly below the planned tunnel inverts). The groundwater table is subject to change due to future groundwater extraction/recharge activities.

1.6 ANTICIPATED GROUND BEHAVIOR AND SUPPORT

Based on the results of this investigation, and design and construction experience under similar subsurface conditions, it is our opinion that the subsurface conditions along most of the western and eastern tunnel segments are favorable for conventional soft ground tunnel construction techniques using mechanical excavation methods within a shield similar to those used in the current tunnel construction along the Metro Red Line Segments 1 and 2. However, there exist a number of conditions in localized areas along the alignment which will either slow tunnel progress or create difficult face stability problems, unless special construction equipment and provisions are utilized. Along the western tunnel segment, these conditions include mixed face conditions (between alluvium and bedrock), shallow groundwater, large inflow (when granular alluvium is encountered), the local presence of granular alluvium (flowing and running conditions in relatively clean sand and gravel as well as ravelling conditions in silty sand and clayey sand). The conditions along the eastern tunnel segment include the presence of granular alluvium (running and ravelling conditions), boulders potentially up to 4 feet in size, and possibly localized perched groundwater. In addition to safety and stability concerns, large size boulders may require splitting in the face or on the mucking conveyor.

The subsurface conditions along the western and eastern tunnel segments indicate that cut-and-cover excavation/construction of the proposed stations can be accomplished at a relatively high rate using mechanical excavation methods with readily available equipment and conventional shoring provisions. Preconstruction dewatering will be required for most of the stations along the western tunnel segment, where groundwater levels are expected to be above the bottoms of the station excavations. Additionally, potentially liquefiable layers and pockets of granular alluvium are anticipated in the station areas in the western tunnel segment. Potential liquefaction will induce additional lateral pressure and settlement and will cause a reduction of vertical and lateral ground support. These effects should be considered in the station design.

Aerial guideways in the above-ground segment are anticipated to be supported by piles or caissons. Depending on the density and thickness of granular materials for end-bearing purposes, these pile/caisson supports will be designed as either end bearing or friction pile (caissons). Pockets and layers of liquefiable granular materials are anticipated at various locations and depths. Potential liquefaction effects will require consideration and incorporation in the future support design.

Embankments and retained earth fills underlain by fine grained alluvium will experience significant settlement. Measures such as preloading, surcharging and vertical drain installation may be necessary to limit post-construction settlements to acceptable levels.

Except for the proposed 400-foot span bridge crossing the Los Angeles River, conventional shallow foundation support for at-grade facilities are anticipated. Overexcavation of loose/soft materials and recompaction are also anticipated for subgrade preparation in some areas. Bridge abutments and piers will most likely be supported on end-bearing piles founded on the dense sand layer encountered about 50 feet below the ground surface.

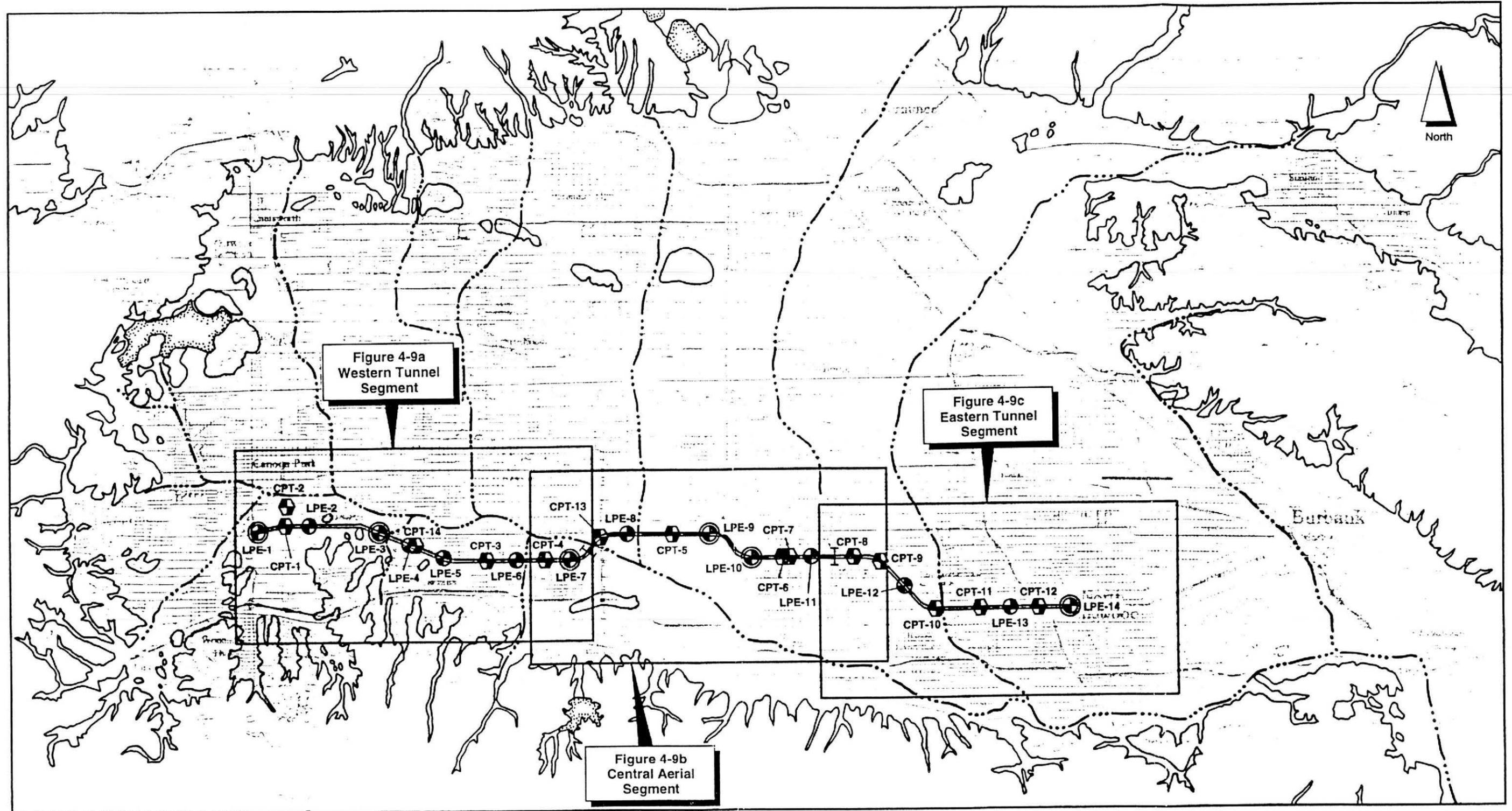
Available environmental site assessment data by others and limited chemical tests on groundwater samples obtained in this investigation indicate potential groundwater and soil contamination in some areas along the alignment, particularly along the western and central segments. In addition to impacting soil and groundwater disposal, the potential contamination will affect the details and requirements of construction dewatering, and should be addressed in the future engineering effort.

1.7 RECOMMENDATIONS

A more detailed investigation program consistent with the level of design (preliminary/final design) will be needed to provide additional site and structure-specific design recommendations. Future investigations should include geotechnical, geophysical, hydrogeologic and environmental assessments.

In addition to closely-spaced borings, CPT soundings and monitoring wells, it is recommended that the following programs be considered:

- A geophysical investigation program to evaluate the soil-bedrock contact along the western tunnel segment, especially the portion west of station 190+00
- A subsurface exploration program to evaluate the characteristics and potential effects of the unnamed fault located near the eastern terminus of the alignment
- An exploratory program consisting of large diameter boreholes to evaluate the extent and size distribution of boulders along the eastern portion of the eastern tunnel segment

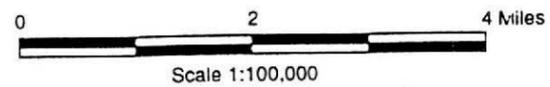


Explanation:

- LPE-2 LOCATION AND NUMBER OF BORING DRILLED IN THIS INVESTIGATION
- LPE-1 LOCATION AND NUMBER OF PEIZOMETER INSTALLED IN THIS INVESTIGATION
- CPT-1 LOCATION AND NUMBER OF CONE PENETROMETER TESTING SOUNDING CONDUCTED IN THIS INVESTIGATION

- LIMIT OF YOUNG VALLEY FILL ALLUVIUM
- RESERVOIR
- LIMIT OF SEGMENT

Sources:
 1. Dibblee (1991 A, B, C, D; 1992 A, B, C, D).
 2. U.S.G.S. Topographic Map 30 x 60 Minute Series, Los Angeles, CA (1979).



	Project No.: 93-4955
	Geotechnical Investigation East-West Segment Metro Red Line
Location Map and Exploration Plan	
12-93	Figure 2-1

A total of 11 stations, including seven underground stations (Topanga, Winnetka, Tampa, Reseda, White Oak, Fulton/Burbank, Laurel Canyon) to be constructed by cut and cover method, and four aerial stations (Balboa, Woodley, Sepulveda and Van Nuys), are proposed.

The East-West segment is bordered by older residential and commercial properties along most of its length. It will cross beneath the Hollywood and San Diego Freeways and pass over the Los Angeles River flood control channel. The alignment follows an existing (abandoned) Southern Pacific (SP) Railroad right-of-way from Lankershim Boulevard to Winnetka Avenue. The alignment west of Winnetka Avenue follows Victory Boulevard to its western terminus at Topanga Canyon Boulevard.

Based on preliminary information, we understand that the tunnels will consist of two single-track 18-foot diameter finished openings in a double-line configuration, located at depths of about 40 to 50 feet below existing grade. The tunnel is expected to be constructed using soft-ground tunneling methods. Tunnel support will likely consist of a permanent concrete liner, preceded by initial support during excavation. The cut and cover underground stations are expected to be approximately 50 to 60 feet deep, 450 to 600 feet long and 50 to 60 feet wide. The aerial section of the alignment will be supported on piers with the top of rail about 20 to 25 feet above existing grade. The piers will be supported on piles or caissons. The planned at-grade sections will be supported on subgrade prepared by cut-fill grading. Retained cut and retained fill sections are proposed at portal areas and transitions to the aerial guideways, respectively.

For ease of presentation and discussion proposes the proposed alignment has been broken into three segments:

- Western tunnel segment - from Station (Sta.) 0+00 to Sta. 282+00, and the spur line to the maintenance yard.
- Central aerial segment - from Sta. 282+00 to Sta. 524+90

- Eastern tunnel segment - from Sta. 524+90 to the eastern terminus at Sta. 739+80

The approximate limits of these segments are shown on Figure 2-1. The station numbers are based on the SP Burbank Branch Alternative, Plan and Profile Drawing Nos. BB-1SUB through BB-26SUB dated 6/1/89.

2.3 OBJECTIVES AND SCOPE

2.3.1 Objectives

This geotechnical investigation was limited in scope and performed for limited preliminary engineering purposes only. The objectives of this investigation were as follows:

- To gain an initial general understanding of the subsurface, groundwater and seismic conditions along the proposed alignment.
- To make preliminary evaluations of key geotechnical issues which may affect the design and construction of the proposed tunnels, stations and aerial guideways.
- To obtain limited information on potential subsurface contamination levels by monitoring soil samples with the organic vapor analyzer (OVA) readings, and by limited chemical analyses of selected groundwater samples.
- To identify potential areas that require further evaluation and make preliminary recommendations for a more detailed geotechnical investigation program needed for future effort.

2.3.2 Scope

The scope of this investigation consisted of the following:

1. Review of available literature and reports regarding the geologic and geotechnical conditions along the alignment.
2. Planning and coordination of field work, including:
 - Development of field procedures and manuals
 - Planning of the field investigation program
 - Procurement of necessary permits and licenses
 - Coordination with government agencies and utility companies prior to, during, and after the field work
 - Development and implementation of a project-specific Health and Safety Plan.
3. Performance of a field exploration program, including:
 - Drilling and sampling of 14 test borings
 - Performing cone penetrometer test (CPT) soundings at 14 locations
 - Obtaining OVA readings on soil samples and background environments
 - Installing 6 piezometers at selected boring locations
 - Monitoring groundwater levels and taking water samples for chemical testing
4. Performance of a laboratory testing program on selected representative soil and water samples to assess the index and engineering properties of soils, and to evaluate general chemical characteristics of the encountered groundwater.
5. Preparation of this report documenting the findings, conclusions, and recommendations.

2.4 PREVIOUS INVESTIGATIONS AND AVAILABLE DATA

The geologic maps of the eastern San Fernando Valley area published by the Dibblee Geological Foundation (1991a,b,c,d, 1992a,b,c,d) served as the geologic base for this project. Geologic information from this set of maps was compiled onto 1:100,000 base and 1:24,000 topographic strip maps. The maps illustrate the surficial distribution of general geologic units and structural features such as faults and folds.

Additional surficial soils mapping data and descriptions of surficial alluvial deposits in the vicinity of the proposed alignment were obtained from reports and maps prepared by various investigators including Army Corps of Engineers (1939 and 1987), State Water Rights Board Referee (1961 and 1962), Converse, et al (1981 and 1984), Holgun, Fahan and Associates (1990), and James M. Montgomery (1992).

Holgun, Fahan and Associates (1990) conducted a pre-acquisition Environmental Assessment investigation along the Burbank branch of the Southern Pacific Railroad, along which most of the proposed alignment is located. The investigation identified contaminated or suspected contaminated sites along the railroad right of way and provided recommendations for further investigations to evaluate lateral and vertical extent of contamination.

The geology and groundwater conditions of the upper Los Angeles River Area (ULARA) are discussed in detail in the Report of Referee (State Water Rights Board Referee, 1961 and 1962). This work was conducted to provide baseline groundwater conditions for the basins in the ULARA, including the San Fernando Valley to provide facts for Superior court Case No. 650074 entitled "The City of Los Angeles, a Municipal corporation, Plaintiff, vs. City of San Fernando, et al., "Defendants."

The Upper Los Angeles River Area (ULARA) Watermaster is required to submit reports for each wateryear (October 1 - September 30) covering all hydrologic interests within the area. The most recent report, published in May 1993, covers the wateryear October 1, 1991 to

September 30, 1992. This report deals with rainfall, groundwater extraction, outside water import, sewage and reclaimed water export, groundwater contours, and groundwater storage for the San Fernando Basin. The ULARA Watermaster also published a report on the "Management of the Upper Los Angeles Area Groundwater Basins" (1993). This report discusses the early history, ensuing legal battles, adjudication and contamination problems for the basin.

Subsurface geotechnical investigations were performed by the California Department of Transportation (Caltrans) for the several freeway crossing structures in the vicinity of the alignment. Data reviewed included the logs of test borings (Caltrans, 1961, 1963) developed for the Victory Boulevard Undercrossing of the 405 Freeway (vicinity of Sta. 415 \pm), and the Chandler Boulevard Overhead of the 170 Freeway (vicinity of Sta. 714 \pm).

Previous geotechnical investigations have been conducted by Converse Consultants in association with Earth Sciences Associates and Geo/Resource Consultants (1981 and 1984) for the Metro Rail Project. They conducted geotechnical investigations along the original 18-mile long tunnel alignment within the Los Angeles area. That alignment terminated at the intersection of Lankershim Boulevard and Chandler Boulevard, the eastern end of the alignment currently under study.

3.0 FIELD EXPLORATION AND LABORATORY TESTING

This section provides a description of the subsurface exploration and laboratory testing work performed in this program.

3.1 FIELD EXPLORATION

Field exploration consisted of drilling and sampling 14 borings, performing 14 CPT (cone penetrometer testing) soundings, installing standpipe piezometers in six borings, monitoring groundwater levels, and developing and sampling two monitoring wells. Approximate locations of the borings and CPTs along the proposed alignment are shown in Figure 2-1. Detailed location maps of borings and CPTs accompany the logs presented in Appendix A.

3.1.1 Borings

Exploratory borings were drilled by a Mayhew 1,000, mud rotary drill rig with a 4-7/8-inch diameter tricone drill bit which produces a nominal 5- to 6-inch diameter borehole. Borings were generally drilled to depths of about 20 feet or more below the planned tunnel invert elevation, and about 30 feet below the proposed bottom of slab for underground stations. Within the central above-ground segment of the alignment, borings were drilled to a depth of approximately 85 feet. Representative soil samples were obtained at 5-foot depth intervals and at changes in stratigraphy by alternately using a standard split-spoon sampler (Standard Penetration Test Method) and a California drive sampler lined with 2.4-inch diameter by 1-inch-high brass rings. The locations and penetration depths of the borings are shown in Table 3-1a. Boring logs are presented in Appendix A.

TABLE 3-1a. FIELD EXPLORATION PROGRAM – BORINGS AND PIEZOMETERS

BORING #	APPROXIMATE STATIONING ¹	LOCATION	PURPOSE	APPROXIMATE GROUND SURFACE ELEVATION (FEET)	APPROX. TUNNEL INVERT DEPTH (FEET) ¹	TOTAL PENETRATION DEPTH (FEET)	PIEZOMETER INSTALLATION
LPE-1	8 + 57	Owensmouth/Victory Blvd.	Topanga Station	805	50	80.5	Piezometer
LPE-2	54 + 10	De Soto Av /Victory Blvd.	Tunnel	790	50	70.8	-
LPE-3	105 + 70	Winnetka Av.	Winnetka Station	762	50	71.5	Piezometer
LPE-4	134 + 40	Corbin Av /Topham St.	Tunnel	760	50	72	-
LPE-5	162 + 20	Tampa Av./Topham St.	Tampa Station	758	50	80.8	-
LPE-6	216 + 20	Reseda Blvd./Topham St.	Reseda Station	748	50	81	-
LPE-7	273 + 57	White Oak Av./Oxnard	White Oak Station	729	50	81	Piezometer
LPE-8	335 + 78	Balboa Blvd./Victory Blvd.	Balboa Station ²	722.5	Above Grade	86	-
LPE-9	384 + 48	Woodley Av./Victory Blvd.	Woodley Station ²	717	Above Grade	86	Piezometer
LPE-10	445 + 58	Sepulveda Blvd.	Sepulveda Station ²	704.5	Above Grade	85.6	Piezometer
LPE-11	502 + 90	Van Nuys Blvd./Victory Blvd.	Van Nuys Station ²	697.5	Above Grade	86	-
LPE-12	592 + 56	Burbank Blvd./Fulton Av.	Fulton-Burbank Station	673.5	50	80.5	-
LPE-13	675 + 10	Laurel Canyon Blvd.	Laurel Canyon Station	649.5	50	81	-
LPE-14	739 + 60	Lankershim Blvd.	N. Hollywood Station	631.5	50	85.6	Piezometer

NOTES

¹ Stationing and Tunnel Invert depth based on SP Burbank Branch Alternative, LACTC Plan and Profile Drawings No. BB - 1 SUB through BB - 26 SUB dated 6-1-89

² Foundation for aerial guideways and stations

The borings were continuously logged by an experienced geologist or soils engineer under the direct supervision of a Certified Engineering Geologist (CEG), using the Unified Soil Classification System (USCS). The boring logs were prepared under the supervision of a CEG.

3.1.2 Cone Penetration Testing (CPT)

Cone penetration testing was performed at 14 locations using a 1.72-inch diameter cone assembly mounted at the end of a series of hollow sounding rods. The CPTs provide a continuous log of cone tip resistance and shaft resistance which is then used to interpret subsurface soil types and material properties based on established correlations. The CPT soundings were generally planned to depths of about 20 feet or more below the proposed invert within the tunnel sections, and to depths of approximately 85 feet within the aerial guideway section. At several locations, however, the CPT probe encountered refusal prior to reaching the planned depth. At one location within the aerial-guideway segment, the CPT was advanced to a depth of 100 feet. One of the CPTs was performed adjacent to a boring to establish site-specific calibration with boring logs. The locations and penetration depths of the CPT soundings are shown in Table 3-1b. CPT logs are presented in Appendix A.

3.1.3 Piezometer Installation

A total of six, 2-inch diameter piezometers were installed within Borings LPE-1, LPE-3, LPE-7, LPE-9, LPE-10 and LPE-14 to monitor groundwater levels and to obtain groundwater samples at selected station locations along the alignment. Piezometers LPE-1, LPE-3 and LPE-7 were screened within the assumed tunnel zone, approximately 5 feet below tunnel invert and 5 feet above tunnel crown. The two piezometers located within the aerial segment, LPE-9 and LPE-10, and the one located at the eastern end of the alignment, LPE-14, were screened from about 15 feet below ground surface to the total depth of boring. Piezometer installation diagrams are presented in Appendix A.

TABLE 3-1b. FIELD EXPLORATION PROGRAM – CONE PENETRATION TESTING (CPT)

CPT #	APPROXIMATE STATIONING ¹	LOCATION	PURPOSE	APPROXIMATE GROUND SURFACE ELEVATION (FEET)	APPROXIMATE TUNNEL INVERT DEPTH (FEET) ¹	TOTAL PENETRATION DEPTH (FEET)
CPT-1	23 + 25	Canoga/Victory	Tunnel	798	50	70.5
CPT-2	20 + 32	Vanowen	Spur Tunnel to Yard	791	45	65.5
CPT-3	190 + 70	Wilbur	Tunnel	757.5	50	70.5
CPT-4	245 + 70	Lindley	Tunnel	742	50	70.5
CPT-5	358 + 65	Hayvenhurst	Aerial Guideway Support	719.5	Above Grade	63
CPT-6	474 + 12	Kester	Aerial Guideway Support	700	Above Grade	100.5
CPT-7	486 + 30	Cedros	Aerial Guideway Support	698.5	Above Grade	85.5
CPT-8	539 + 90	Ranchito	Tunnel	692.5	50	48
CPT-9	559 + 80	Oxnard	Tunnel	689	50	68.5
CPT-10	622 + 60	Coldwater Canyon	Tunnel	665	60	53.5
CPT-11	648 + 80	Whitsett	Tunnel	661.5	60	63
CPT-12	712 + 50	Hollywood Frwy/Chandler	Tunnel	640	50	48.5
CPT-13	297 + 20	Flood Control Channel	Channel Crossing (Bridge)	725.5	Above Grade	75.5
CPT-14	134 + 50	Corbin/Topham	Tunnel & Comparison with B-4 Subsurface Data	760	50	70.5

NOTES:

¹ Stationing and Tunnel Invert Depth Based on SP Burbank Branch Alternative, LACTC Plan and Profile

Drawings NO. BB - 1 SUB Through BB - 26 SUB Dated 6-1-89

3.1.4 Groundwater Level Monitoring and Sampling

Groundwater levels were monitored in the piezometers using an electronic water-level indicator. Groundwater level readings were taken immediately following drilling and periodically thereafter, and are summarized in Table 3-2. Piezometers LPE-1 and LPE-7 were developed and groundwater samples obtained to evaluate the potential extent of groundwater contamination.

3.2 LABORATORY TESTING PROGRAM

A laboratory testing program (geotechnical and chemical testing) was developed and performed on selected soil and water samples obtained in this investigation. The geotechnical laboratory test program was intended to aid in soil classification and provide a general preliminary indication of subsurface conditions and associated engineering parameters. The chemical laboratory test program was performed to evaluate the potential extent of groundwater contamination at two selected piezometer locations within the alignment. The following sections provide a general description of the test program.

3.2.1 Geotechnical Laboratory Testing

All of the undisturbed and bulk samples obtained during the exploration program were brought to Earth Technology's Huntington Beach laboratory where they were visually examined to verify field classification. Samples of the various material types encountered were selected for laboratory testing. The laboratory test program was designed to classify the predominant soil types encountered at the site and to obtain the insitu conditions (moisture and density), gradation, shear strength, compressibility, and corrosion potential. All tests were performed in accordance with applicable standard test methods specified by the American Society for Testing Materials (ASTM), the Environmental Protection Agency (EPA) or the California Department of Transportation (Caltrans). The test program and applicable test standards are summarized in Table 3-3. Laboratory test results are summarized in Table 3-4 and are presented in Appendix B, or, in the case of insitu density and moisture content, on the boring logs included

TABLE 3-2. SUMMARY OF GROUNDWATER LEVEL READINGS

MONITORING WELL #	LOCATION	APPROXIMATE STATIONING ²	APPROXIMATE ELEVATION OF GROUND SURFACE (FEET)	TOTAL DEPTH (FEET)	WELL SCREEN INTERVAL (FEET)	APPROXIMATE DEPTH TO TUNNEL		GROUNDWATER ¹			
						CROWN (FEET)	INVERT (FEET)	DEPTH (FEET)		ELEVATION (FEET)	
								9/24/93	10/8/93	9/24/93	10/8/93
LPE-1	Owensmouth/Victory	8 + 57	805	80.5	30.0 - 55.0	30	50	14.9	16.9	790.1	788.1
LPE-3	Winnetka	105 + 70	762	71.5	28.0 - 53.0	30	50	15.0	15.2	747.0	746.8
LPE-7	White Oak/Oxnard	273 + 57	729	81	20.3 - 60.3	30	50	38.5	38.2	690.5	690.8
LPE-9	Woodley/Victory	384 + 48	717	86	12.8 - 82.8	Above Grade	-	46.9	46.6	670.1	670.4
LPE-10	Sepulveda	445 + 58	704.5	85.6	15.0 - 85.0	Above Grade	-	77.4	77.4	627.1	627.1
LPE-14	Lankershiem	739 + 60	631.5	85.6	13.7 - 83.7	30	50	WELL DRY	WELL DRY	-	-

NOTES:

¹ Groundwater depth measured on Sept. 24, 1993 (initial reading), Oct. 8 and Nov. 3, 1993. Groundwater depths measured on Oct. 8 and Nov. 3, 1993 are same.

² Stationing and Tunnel Invert Depth Based on SP Burbank Branch Alternative, LACTC Plan and Profile Drawing No. BB - 1 SUB through BB - 26 SUB dated 6-1-89

TABLE 3-3. GEOTECHNICAL LABORATORY TEST PROGRAM

TEST TYPE	NUMBER OF TESTS	TEST PROCEDURE
Visual Soil Classification	Every Sample	ASTM D2487 / D2488
Moisture Content	123	ASTM D 2216
Dry Density	123	ASTM D 2937
Grain Size Distribution	26	ASTM D 422
Grain Size Distribution (With Hydrometer Analysis)	8	ASTM D 422
Percent Passing #200 Sieve	56	ASTM D 1140
Atterberg Limits	21	ASTM D 4318
Specific Gravity	2	ASTM D 854
Direct Shear (3 Points)	10	ASTM D 3080
1-Dimensional Consolidation	2	ASTM D 2435
pH	14	EPA Method 9045
Chloride Content	14	CALTRANS Test 422
Sulphate Content	14	CALTRANS Test 417-B

TABLE 3-4. SUMMARY OF GEOTECHNICAL LABORATORY TEST RESULTS

Boring No	Sample No.	Depth (ft)	USCS/Visual Soil Classification ASTM D 2487/D 2488	Geological Unit	Equivalent SPT Value *	Moisture Content		Dry Density		Grain Size Distribution		Percent Passing #200 Sieve		Atterberg Limits		Specific Gravity ASTM D 854	Direct Shear		Consolidation Characteristics			Swell/Collapse (%)	pH US EPA Method 9045	Chloride Content DOT CA Test 422 (ppm)	Sulphate Content DOT CA Test 417-B (ppm)	Specific Gravity ASTM D 854			
						ASTM D 2216 (%)	ASTM D 2937 (pcf)	ASTM D 422 Gr. Sa:Fi (%)	ASTM D 1140 (%)	ASTM D 4318 LL, PL, PI (%)	Friction Angle' (degrees)	Cohesion Intercept' (psf)	Cc ?	Cs ?	Cx ?														
LPE - 1	D-1	5.0	CL	Qal	(5)	16.3	101.6																						
	S-2	10.0	CL		7																								
	D-3	15.0	CL		(4)	31.4	91.2	0.47-53				32,18,14			26	600													
	S-4	20.0	SC		21																								
	D-5	25.2	CL		(18)	15.9	112.5																	7.15	95	108			
	S-6	30.0	SP-SM		53								9.9																
	D-7	32.0	GP-GM		(76)	17.5	103.5						8.1																
	S-8	35.0	SM		61						23.59-18																		
	D-9	40.0	SM		(36)	20.6	106.7						30.1																
	S-10	42.0	CL		34																								
	D-11	45.0	CL		(20)	19.8	107.3						60.7																
	S-12	50.0	CL		25																								
	D-13	55.0	SM	(>100)	28.8	94.3						21.5																	
	S-14	60.0	SM	>100																									
	D-15	65.0	SM	(>100)																									
	S-16	72.0	SM	>100																									
	D-17	75.0	SM	(>100)																									
	S-18	80	SM	>100																									
LPE - 2	D-1	5.0	CL/CH	Qal	(8)	25.0	96.0																						
	S-2	10.0	CL		4																								
	D-3	15.0	CL		(7)	20.6	105.0					63.1																	
	S-4	20.0	SC		11							51.7																	
	D-5	25.0	SC/SM		(5)	21.5	102.2																						
	S-6	30.0	CL		25								87.7																
	D-7	35.0	SC		(13)	19.4	110.7						43.4																
	S-8	40.0	SM		48						23.57-20																		
	D-9	45.0	CL		(7)	26.7	96.4	0.39-61				36,20,16												7.15	109	45			
	S-10	50.0	CL		21																								
	D-11	55.0	CL		(8)	19.5	108.1																						
	S-12	60.0	SM		42																								
	D-13	65.0	SC	(15)	23.7	101.0																							
	S-14	70.0	ML	Tmc	>100																								
LPE - 3	D-1	5.0	CL	Qal	(4)	22.4	95.2																						
	S-2	10.0	CL		9																								
	D-3	15.0	CH		(4)	31.7	90.3	0.18-82			52,24,26													6.96	263	187			
	S-4	20.0	CL		11																								
	D-5	25.0	CL		(15)	25.4	101.7	0.18-82							26	900													
	S-6	30.0	CL		26								67.7																
	D-7	32.0	CL		(12)	26.1	98.8																						
	S-8	35.0	CL		17																								
	D-9	40.0	CL		(35)	24.0	105.5	0.42-56				26,19,9																	

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TABLE 3-4. SUMMARY OF GEOTECHNICAL LABORATORY TEST RESULTS

Boring No.	Sample No.	Depth (ft)	USCS/Visual Soil Classification ASTM D 2487/D 2488	Geological Unit	Equivalent SPT Value ²	Moisture Content		Grain Size Distribution	Percent Passing #200 Sieve	Atterberg Limits	Specific Gravity	Direct	Shear	Consolidation Characteristics			Swell/Collapse (%)	pH US EPA Method 9045	Chloride Content DOT CA Test 422 (ppm)	Sulphate Content DOT CA Test 417-B (ppm)	Specific Gravity ASTM D 854
						Friction Angle ¹ (degrees)	Cohesion Intercept ¹ (psf)					Cc ³	Cs ³	Cx ³							
LPE-3	S-10	45.0	CL	Qal	22																
	D-11	50.0	CL		(43)	30.9	94.9		73.2												
	S-12	52.0	CL		43																
	D-13	55.0	CL		(39)	27.7	95.7														
	S-14	60.0	CL		21																
	D-15	65.0	SM		(25)	33.6	93.4														
S-16	70.0	SM	26																		
LPE-4	D-1	5.0	CL	Qal	(8)	24.8	99.2														
	S-2	10.0	CL		2																
	D-3	15.5	ML		(7)																
	S-4	20.0	CL		14																
	D-5	25.0	CL		(8)	26.1	99.7														
	S-6	30.0	CL		14	28.3			69.3	36, 18, 18											
	D-7	35.0	CL		(11)	25.3	96.4														
	S-8	40.0	CL		11				59.3								7.28	505	77		
	D-9	43.0	CL		(15)	23.8	103.1														
	S-10	46.0	CL		18			0.35, 65		34, 17, 17											
	D-11	50.0	ML		(14)	21.6	106.3			55.5											
	S-12	53.5	CL		28					63.8											
	D-13	56.0	CL		(20)	19.7	107.7														
	S-14	60.0	CL		26																
	D-15	65.0	SM		(33)	19.9	106.4														
	S-16	71.0	SM		40																
LPE-5	D-1	5.0	CL	Qal	(4)	16.4	106.2														
	S-2	10.0	CL		6																
	D-3	15.0	CL		(8)	22.0	103.5			49, 21, 28											
	S-4	20.0	CL		5																
	D-5	25.5	CL		(20)	19.5	106.9	0.32, 68		36, 19, 19			24	2000							
	S-6	30.0	CL		20																
	D-7	35.0	CL	(11)	22.9	106.2			55.0												
	S-8	40.0	CH	18																	
	D-9	45.0	CH	(15)	30.6	91.2			84.9	50, 23, 27					6.97	259	42				
	S-10	48.0	CH	22																	
	D-11	51.0	CH	(19)	32.9	88.9	0.6, 94					20	2000								
	S-12	55.0	CH	35																	
	S-13	56.5	CH	35																	
	D-14	59.0	CH	(17)	35.6	85.0															
	S-15	65.0	CH	21																	
	D-16	70.0	CL	(35)	35.0	87.0															
	S-17	75.0	CL	54																	
	D-18	80.0	CL	(> 100)	16.3	101.1															

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TABLE 3-4. SUMMARY OF GEOTECHNICAL LABORATORY TEST RESULTS

Boring No.	Sample No.	Depth (ft)	USCS/Visual Soil Classification ASTM D 2497/D 2488	Geological Unit	Equivalent SPT Value ²	Moisture Content		Grain Size Distribution ASTM D 422 Gr:Sa:FI (%)	Percent Passing #200 Sieve ASTM D 1140		Atterberg Limits ASTM D 4318 LL, PL, PI (%)		Specific Gravity ASTM D 854	Direct Shear		Consolidation Characteristics			Swell/Collapse (%)	pH US EPA Method 9045	Chloride Content DOT CA Test 422 (ppm)	Sulphate Content DOT CA Test 417-B (ppm)	Specific Gravity ASTM D 854		
						ASTM D 2216 (%)	ASTM D 2937 (pcf)		ASTM D 422 (%)	ASTM D 1140 (%)	ASTM D 4318 (%)	ASTM D 854		Friction Angle ¹ (degrees)	Cohesion Intercept ¹ (psf)	Cc ²	Cs ²	Cx ²							
LPE-10	D-11	55.0	CL-ML	Qal	(34)	21.7	107.6			27,22.5		30	600												
	S-12	60.0	SM/SC		33																				
	D-13	65.0	SM		(76)	17.6	109.5																		
	S-14	70.0	SM		> 100																				
	D-15	75.0	SM		(93)	18.4	116.3																		
	S-16	80.0	CL		51																				
	D-17	85.0	SM		(93)	20.0	111.3																		
LPE-11	D-1	5.0	CL	Qal	(3)	19.6	97.2																		
	S-2	10.0	CL		7																				
	D-3	15.0	CL		(5)	17.5	104.1																		
	S-4	20.0	CL		4																				
	D-5	25.0	CL		(12)	22.4	105.2	0.46:54		28,15,13		28	600												
	S-6	30.0	CL		15																				
	D-7	35.0	CL-ML		(11)	17.2	105.2		56.7	23,17.6				0.13	0.01	0.0016		7.13	217	129					
	S-8	40.0	SC		21																				
	D-9	45.0	SM		(23)	10.1	123.6																		
	S-10	50.0	SP-SM		38			11.81:6																	
	D-11	55.0	SM		(18)	15.8	102.4																		
	S-12	60.0	SC		30																				
	D-13	65.0	SM		(40)	11.7	116.3		15.0																
	S-14	70.0	SM		165																				
	D-15	75.0	SM		(67)	12.7	123.6																		
	S-16	80.0	SC		38																				
	D-17	85.0	SM		(25)	18.9	109.7																		
LPE-12	D-1	5.2	SM	Qal	(4)	16.2	105.4																		
	S-2	13.0	ML/CL		6																				
	D-3	15.0	ML		(4)	16.6	101.9																		
	S-4	20.0	SM		10																				
	D-5	25.5	ML		(11)	21.1	106.1		62.8																
	S-6	28.2	SM		36			11:74:15																	
	D-7	33.0	SM/SC		(28)	15.7	116.7		42.1																
	S-8	38.0	ML		19			0.26:74																	
	D-9	43.0	SM/SC		(21)	15.0	119.7		38.1																
	S-10	47.0	SM/SC		31				38.1																
	D-11	50.0	ML		(27)	15.5	110.6	0.31:69		30,23.7															
	S-12	55.0	SM		160																				
	D-13	60.2	SP/SM		(70)	23.2	83.4																		
	S-14	65.5	SP		110																				
	D-15	70.0	SP		(76)	16.6	96.8																		
	S-16	75.0	SM		88																				
	D-17	80.0	SM		(78)	13.8	101.7																		

TABLE 3-4. SUMMARY OF GEOTECHNICAL LABORATORY TEST RESULTS

Boring No.	Sample No.	Depth (ft)	USCS/Visual Soil Classification ASTM D 2487/D 2488	Geological Unit	Equivalent SPT Value ²	Moisture Content		Grain Size Distribution		Percent Passing #200 Sieve ASTM D 1140 (%)	Atterberg Limits		Specific Gravity ASTM D 854	Direct Shear		Consolidation Characteristics			Swell/Collapse (%)	pH US EPA Method 9045	Chloride Content DOT CA Test 422 (ppm)	Sulphate Content DOT CA Test 417-B (ppm)	Specific Gravity ASTM D 854		
						ASTM D 2216 (%)	ASTM D 2937 (pcf)	ASTM D 422 Gr. Sa: Fi (%)	ASTM D 4318 LL, PL, PI (%)		Friction Angle ¹ (degrees)	Cohesion Intercept ¹ (psf)		Cc ²	Cs ²	Cx ²									
LPE-13	D-1	5.0	ML	Qal	(7)	19.0	90.2																		
	S-2	10.0	SP-SM		32			6.88.6																	
	D-3	14.9	SM		(16)	10.4	105.7																		
	S-4	20.0	ML		13					58.2															
	D-5	25.3	SM		(21)	9.1	120.5	3.72.25				NP										6.85	198	213	
	S-6	30.0	ML		16					54.5															
	D-7	34.0	CL		(25)	17.6	108.5			69.1															
	S-8	39.0	ML		32			0.36.64				NP													
	D-9	42.0	CL		(22)	19.5	110.6	0.37.63							24	1200									
	S-10	45.0	CL		18																				
	D-11	47.1	ML		(27)	20.0	112.8			62.7															
	S-12	53.5	SM		47																				
	D-13	56.2	SM		(77)	27.2	102.8																		
	S-14	60.5	SM		120																				
	D-15	65.2	SM		(46)	10.2	100.8																		
	S-16	70.0	SM		65																				
	D-17	75.3	SM		(67)	17.5	105.7																		
	S-18	80.0	SM		116																				
LPE-14	D-1	5.0	ML	Qal	(4)	13.6	96.2																		
	S-2	10.0	ML		4																				
	D-3	15.0	SM		(8)	14.8	104.9			48.6															
	S-4	20.0	SP-SM		37					6.7															
	D-5	25.0	SP/GP		(26)	10.9	114.6	20.75.5																	2.69
	S-6	30.0	SM		19					38.5															
	D-7	35.0	SM		(17)	18.4	112.3			36.0															
	S-8	40.0	SP-SM		64					6.0															
	D-9	45.0	SP		(44)	12.8	116.4			4.3															
	S-10	50.0	SP-SM		> 100			31.62.7		6.6															
	D-11	55.0	SP-SM		(83)	12.7	113.2			6.3															
	S-12	60.0	SP		> 100					6.0															
	D-13	70.0	SP		(87)	14.3	113.4																		
	S-14	75.0	SP		> 100																				
	D-15	80.0	SP		(> 100)																				
	S-16	85.0	SP		> 100																				

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Notes:

- ¹ - Corresponds to peak strength values
- ² - Cc, Cr, and Cs based on vertical strain - log stress plots
- ³ For California Drive Samples, Equivalent SPT values were obtained by applying the appropriate corrections for different hammer weights, hammer drop, sampler dimensions, and buoyancy and viscous drag within the drilling mud. Equivalent SPT - values corrected from Drive Sampler blowcounts are shown in parantheses ().

in Appendix A. A discussion of the engineering properties of subsurface materials is presented in Section 5.2.

3.2.2 Analytical (Chemical) Testing of Groundwater

A limited analytical (chemical) testing program was performed on groundwater samples obtained from two of the piezometers, LPE-1 and LPE-7. Laboratory analyses were performed by Pace Incorporated, a state certified hazardous waste testing laboratory located in Huntington Beach. The test program and relevant test standards are summarized in Table 3-5.

The results of the analytical testing of groundwater are summarized in Table 3-6 and presented in Appendix C. An evaluation of the results and discussions of potential impacts on construction are presented in Sections 5 and 6, respectively.

TABLE 3-5. CHEMICAL LABORATORY TEST PROGRAM

Test Type	Number of Tests	Test Procedure
Total Petroleum Hydrocarbons (with carbon chain)	2	EPA 8015
Aromatic Volatile Organic Compounds (BTEX)	2	EPA 8020
Volatile Organic Compounds	2	EPA 8240
Semi-volatile Organic Compounds	2	EPA 8270
Inorganic Analysis (Arsenic)	2	EPA 7060
Inorganic Analysis (Selenium)	2	EPA 7740
Inorganic Analysis (ICP Metals)	2	EPA 6010
Total Sulfide	2	EPA 376.2

TABLE 3-6. SUMMARY OF ANALYTICAL TESTS ON GROUNDWATER SAMPLES

SAMPLE NO.	VOLATILE ORGANICS (µg/L)		SEMI-VOLATILE ORGANICS (µg/L)		METALS (mg/L)		TOTAL SULFIDES (mg/L)	TOTAL PETROLEUM HYDROCARBONS (µg/L)
	Compound (Concentration)	Threshold Level ⁽¹⁾	Compound (Concentration)	Threshold Level ⁽¹⁾	Compound (Concentration)	Threshold Level ⁽¹⁾		
LPE-1	Acetone (130)	NAL ⁽³⁾	Benzoic Acid (67)	NAL ⁽³⁾	Aluminum (0.19)	1.00	ND ⁽²⁾	2,980
	Benzene (0.4)	1	bis (2-Ethylhexyl) phthalate (74)	4	Arsenic (0.0028)	0.05		
	Tetrachloroethene (6.5)	5	Dimethylphthalate (24)	NAL ⁽³⁾	Barium (0.054)	1.00		
	Toluene (0.7)	1,000 ⁽⁵⁾			Boron (0.6)	0.60 ⁽⁵⁾		
	2-Butanone (26) ⁽⁴⁾	200 ⁽⁵⁾			Calcium (170)	NAL ⁽³⁾		
					Copper (0.04)	1.00		
					Iron (0.22)	0.3		
					Magnesium (37)	NAL ⁽³⁾		
					Manganese (0.093)	0.05		
					Molybdenum (0.033)	0.04 ⁽⁵⁾		
					Potassium (19)	NAL ⁽³⁾		
					Selenium (0.018)	0.01		
					Silicon (13)	NAL ⁽³⁾		
					Sodium (62)	2.00 ⁽⁵⁾		
					Strontium (0.88)	17 ⁽⁵⁾		
					Vanadium (0.017)	0.02 ⁽⁵⁾		
					Zinc (0.24)	5.00 ⁽⁵⁾		

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TABLE 3-6. SUMMARY OF ANALYTICAL TESTS ON GROUNDWATER SAMPLES

SAMPLE NO.	VOLATILE ORGANICS (µg/L)		SEMI-VOLATILE ORGANICS (µg/L)		METALS (mg/L)		TOTAL SULFIDES (mg/L)	TOTAL PETROLEUM HYDROCARBONS (µg/L)
	Compound (Concentration)	Threshold Level ⁽¹⁾	Compound (Concentration)	Threshold Level ⁽¹⁾	Compound (Concentration)	Threshold Level ⁽¹⁾		
LPE-7	Chloroform (5.4)	100	bis (2-Ethylhexyl) phthalate (10)	4	Arsenic (0.0034)	0.05	0.05	ND ⁽²⁾
	Toluene (0.4)	1,000 ⁽⁵⁾	Dimethylphthalate (16)	NAL ⁽³⁾	Barium (0.065)	1.00		
					Boron (0.6)	0.60 ⁽⁵⁾		
					Calcium (180)	NAL ⁽³⁾		
					Magnesium (53)	NAL ⁽³⁾		
					Manganese (0.011)	0.05		
					Molybdenum (0.015)	0.04 ⁽⁵⁾		
					Potassium (2.6)	NAL ⁽³⁾		
					Selenium (0.0087)	0.01		
					Silicon (16)	NAL ⁽³⁾		
					Sodium (100)	2.00 ⁽⁵⁾		
					Strontium (0.80)	17 ⁽⁵⁾		

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- Notes: (1) California Department of Health Services (CDHS) Maximum Contaminant Level (MCL) for Drinking Water.
 (2) ND = Not Detected
 (3) NAL = No published action level
 (4) Detected but below the Method Detection Limit, therefore, result is an estimated concentration.
 (5) Suggested No Adverse Response Level (SNARL) per EPA

µg/L - micrograms per liter, mg/L - milligrams per liter

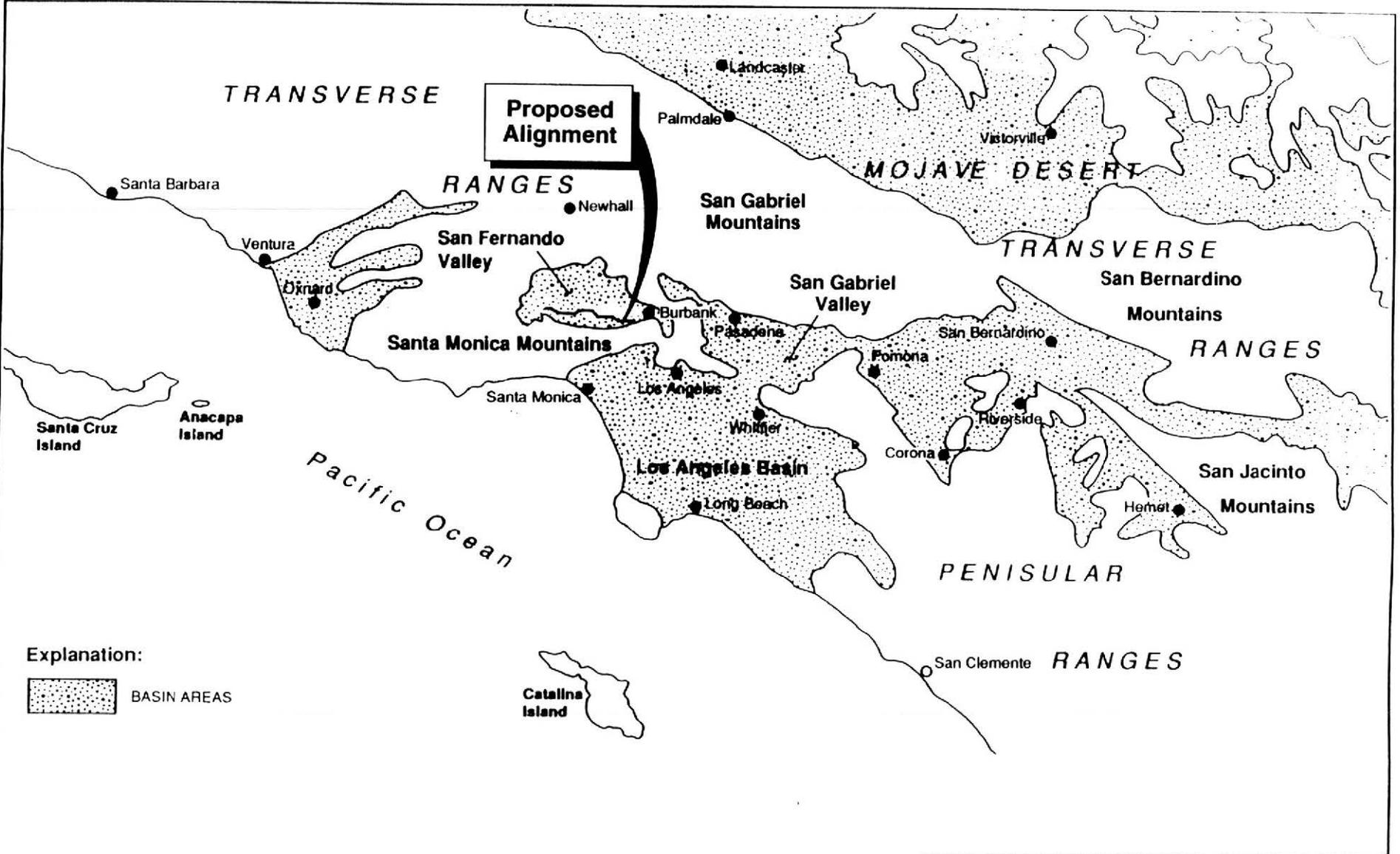
4.0 GEOLOGIC AND GROUNDWATER CONDITIONS

4.1 REGIONAL GEOLOGIC SETTING

The proposed alignment is located in the southern part of the San Fernando Valley near the north flank of the Santa Monica Mountains. The San Fernando Valley represents a structural depression filled with alluvial sediments situated within the Transverse Ranges physiographic province (Figure 4-1). The Transverse Ranges province consists of subparallel mountain ranges and intervening valleys that are oriented primarily in an east-west direction. Major geologic structures (faults and folds) associated with the province trend in a similar direction and they are characteristic of compressive tectonics.

The San Fernando Valley is a faulted, synclinal trough with numerous superimposed secondary anticlinal and synclinal folds. Exposed bedrock areas have also been folded and faulted, and subsequently uplifted to form the bordering mountain areas. Structural features associated with the San Fernando Valley are consistent with the compressive stress regime that formed the Transverse Ranges province. Geologic structures consist of anticlinal and synclinal folds, and movement on faults display a large reverse-slip component.

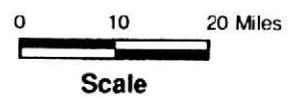
Bedrock units exposed in the mountain areas surrounding the San Fernando Valley generally range in age and composition from pre-Tertiary age crystalline basement to pre-Tertiary through Quaternary sedimentary and volcanic deposits. The distribution of these bedrock units with respect to the alignment is shown in Figure 4-2. Erosion of the bordering bedrock areas has generated alluvial sediment that has been deposited in the basin. The composition of the alluvium generally reflects the nearby bedrock source areas. Alluvial deposits in the eastern half of the San Fernando Valley are composed mostly of coarse granular material that was derived from the erosion of granitic and metamorphic basement rocks of the western San Gabriel Mountains and Verdugo Mountains. Alluvium in the western half of the valley is comparatively finer grained, having been derived mostly from Tertiary and pre-Tertiary sedimentary rocks in



Explanation:

 BASIN AREAS

Source:
 Modified from California Department of Water Resources,
 Southern District, 1961. Bulletin No. 104



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**Map of Regional Physiography
 in a Portion of
 Southern California**

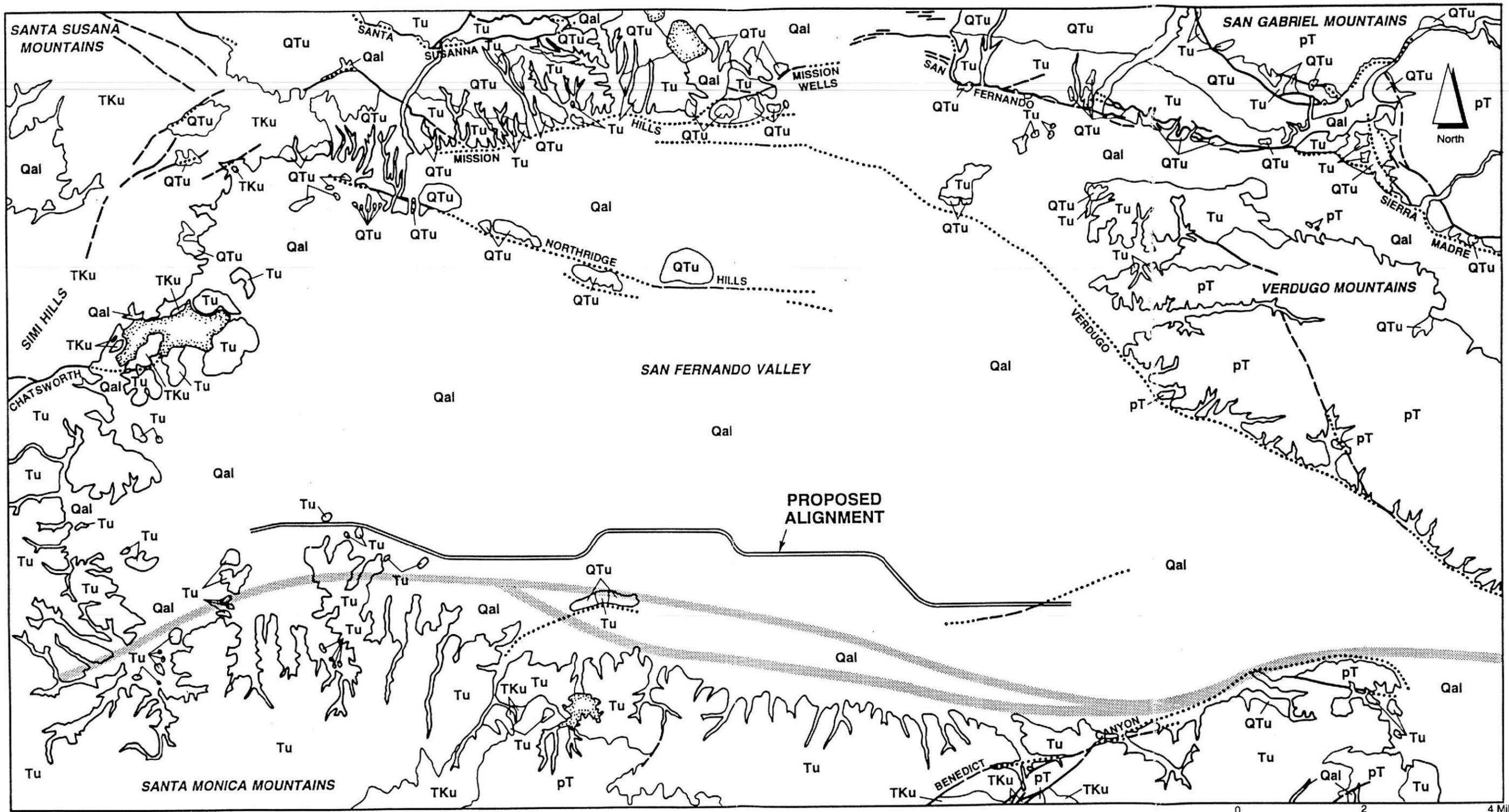
2.0 INTRODUCTION

2.1 GENERAL

This report by The Earth Technology Corporation (Earth Technology) presents the results of a limited preliminary geotechnical investigation for the proposed San Fernando Valley East-West segment of the Metro Red Line project. This investigation was performed to support the limited preliminary engineering (LPE) effort being undertaken by Engineering Management Consultant (EMC) for the Metropolitan Transit Authority (MTA). The primary purposes of this investigation were to gain a preliminary understanding of the geotechnical conditions along the proposed alignment, potential geotechnical constraints, and engineering parameters for the project. The results of this LPE investigation will be used for preliminary design purposes and for the development of a more detailed geotechnical investigation program to better define the subsurface conditions and geotechnical parameters along the alignment in support of the planned future engineering effort to be undertaken by EMC. This work was performed under contract to EMC in accordance with our proposal dated August 3, 1993.

2.2 PROJECT BACKGROUND

The proposed San Fernando Valley East-West segment alignment is about 14 miles long, running north of and approximately parallel to the Ventura Freeway, and extending between the North Hollywood Station on the east and Topanga Canyon Boulevard on the west, Figure 2-1. A 3,000-foot long Maintenance Facility Connector is also proposed near the western end of the alignment. About 0.8 miles of the alignment is proposed as a twin-tunnel subway; about 3 miles will be aerial guideway; and about 1 mile will be at grade.



Explanation:

UNITS

- Qal** YOUNG VALLEY FILL ALLUVIUM (SEE FIGURE 4-3 FOR GENERALIZED SUBDIVISIONS)
- QTu** QUATERNARY AND LATEST TERTIARY OLDER ALLUVIAL DEPOSITS, UNDIFFERENTIATED
- Tu** LATER TERTIARY SEDIMENTARY AND VOLCANIC ROCKS, UNDIFFERENTIATED
- TKu** CRETACEOUS AND EARLIER TERTIARY SEDIMENTARY AND VOLCANIC ROCKS, UNDIFFERENTIATED

- SYMBOLS**
- pT** PRE-TERTIARY CRYSTALLINE IGNEOUS AND METAMORPHIC ROCKS, UNDIFFERENTIATED
 - CONTACT BETWEEN YOUNG VALLEY FILL ALLUVIUM, OLDER DEPOSITS AND BEDROCK, APPROXIMATELY LOCATED
 - GEOLOGIC CONTACT, APPROXIMATELY LOCATED
 - FAULT, DASHED WHERE APPROXIMATELY LOCATED, DOTTED WHERE BURIED, DOCUMENTED ACTIVE AND POTENTIALLY ACTIVE FAULTS NAMED.

- PROPOSED RED LINE ALIGNMENT
- RESERVOIR
- PRESUMED FAULT ZONE BASED ON HYDROGEOLOGIC EVIDENCE

Sources:
 Modified From Dibblee (1991 A,B,C,D;
 1992 A,B,C,D), with Additional Faults from
 Hoots (1930), Weber (1980), Wentworth and
 Yerkes (1971), Slosson and Others (1993).

0 2 4 Miles
 Scale 1:100,000

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 East-West Segment
 Metro Red Line

**Generalized Geologic Map of
 the San Fernando Valley and
 Adjacent Uplands**
 12-93 Figure 4-2

the Santa Monica Mountains, Simi Hills and Santa Susana Mountains. Figure 4-3 shows the relative distribution and general textural character of the alluvial materials in the San Fernando Valley.

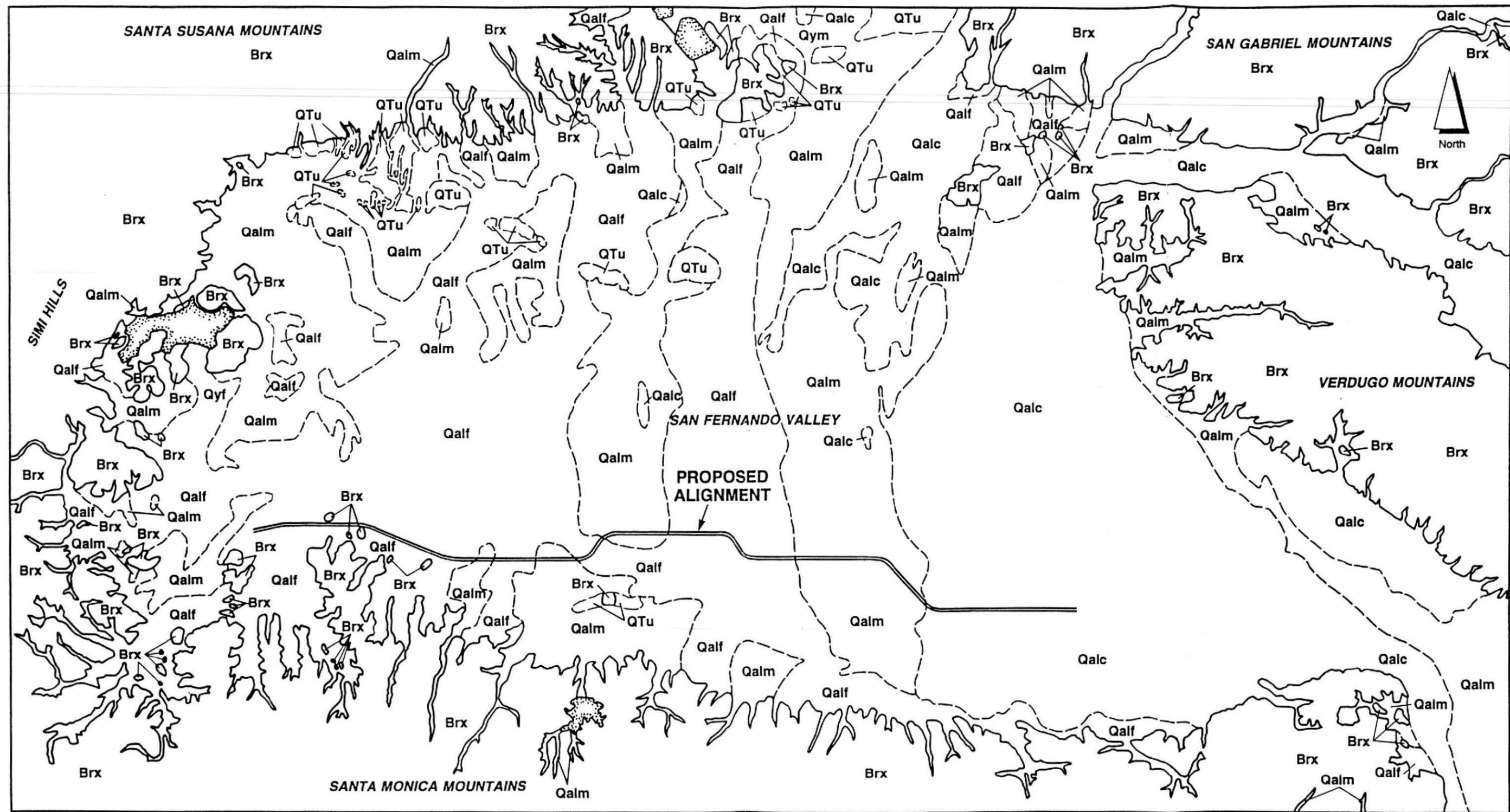
4.2 FAULTING AND SEISMICITY

4.2.1 Faulting

The proposed alignment is located in an area having a relatively high seismic potential and has experienced ground shaking from numerous large earthquakes in historical time. The earthquakes are being generated by two regional tectonic trends. These include the northwesterly-trending San Andreas fault system and the generally east-west trending faults associated with the Transverse Ranges.

Figure 4-4 shows the known major active and potentially active faults in the greater Los Angeles area associated with the San Andreas fault system and Transverse Ranges. According to the California Division of Mines and Geology (CDMG), the term "active" refers to any fault that has been active within Holocene time (past 11,000 years). Such activity is recognized by evidence for displacement of Holocene-age sediments or by direct association with seismic activity. The term "potentially active" refers to a fault that has been active within the Quaternary (past 2 to 3 million years). Such faults could have been active within Holocene time, but direct geologic evidence may not be available yet. The CDMG does not specifically define an inactive fault; however, they do indicate that a fault may be presumed to be inactive based on satisfactory geologic evidence (Hart, 1990).

The closest documented active faults to the alignment are the Northridge Hills and Verdugo faults located in the San Fernando Valley, and the Hollywood fault located along the southern base of the eastern Santa Monica Mountains. The Northridge Hills fault is located approximately four miles north of the alignment at the base of the Northridge Hills, and the Verdugo fault lies at the base of the Verdugo Mountains and is located approximately four miles



Explanation:

UNITS

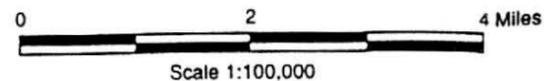
Qalf	FINE-GRAINED (MAINLY SILT AND CLAY)	} YOUNG VALLEY FILL ALLUVIUM
Qalm	MEDIUM-GRAINED (MAINLY SAND)	
Qalc	COARSE-GRAINED (MAINLY SAND AND GRAVEL)	
QTu	QUATERNARY AND LATEST TERTIARY OLDER ALLUVIUM DEPOSITS, UNDIFFERENTIATED	
Brx	UNDIFFERENTIATED BEDROCK (SEE FIGURE 4-2 FOR GENERALIZED SUBDIVISIONS)	

SYMBOLS

	CONTACT BETWEEN SUBUNITS OF YOUNG ALLUVIUM AND OLDER ALLUVIAL DEPOSITS, DASHED WHERE APPROXIMATELY LOCATED
	CONTACT BETWEEN ALLUVIUM AND BEDROCK
	PROPOSED RED LINE ALIGNMENT
	RESERVOIR

Sources:

- Adapted From Tinsley and Fumal (1985) and State Water Rights Board Referee (1961).
- Limits of Young Valley Fill Alluvium from Dibblee (1991 A,B,C,D; 1992 A,B,C,D).

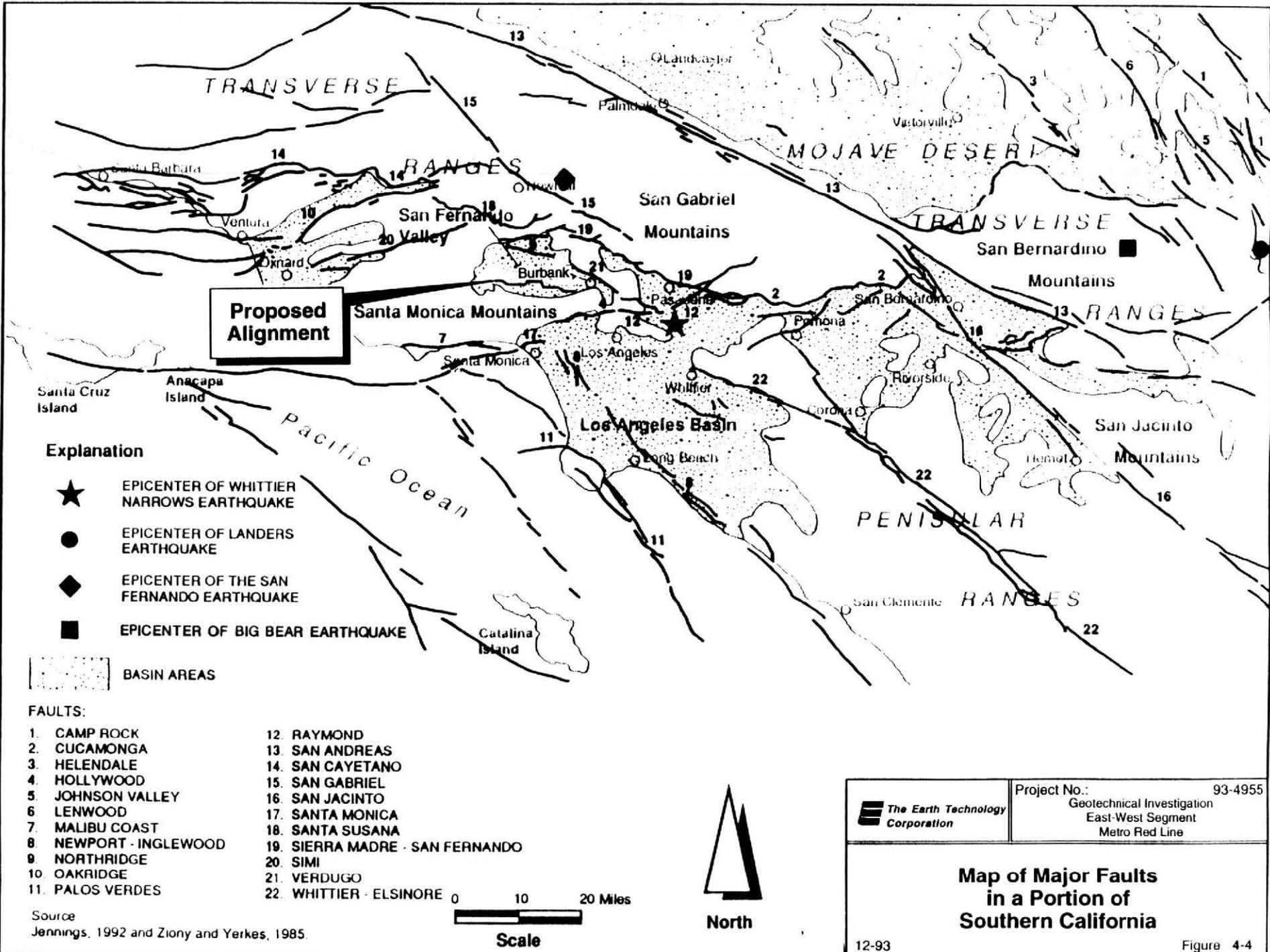


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	Geotechnical Investigation East-West Segment Metro Red Line

Generalized Geologic Map of Alluvial Deposits in the San Fernando Valley

12-93

Figure 4-3



Proposed Alignment

Explanation

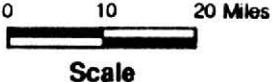
- ★ EPICENTER OF WHITTIER NARROWS EARTHQUAKE
- EPICENTER OF LANDERS EARTHQUAKE
- ◆ EPICENTER OF THE SAN FERNANDO EARTHQUAKE
- EPICENTER OF BIG BEAR EARTHQUAKE

 **BASIN AREAS**

FAULTS:

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

Source
Jennings, 1992 and Zion and Yerkes, 1985.



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**Map of Major Faults
in a Portion of
Southern California**

east of the east end of the alignment (Figure 4-2). The Hollywood fault is located about four miles south of the alignment. Other documented active and potentially active faults that are located within 20 miles of the alignment are listed in Table 4-1.

In addition to the documented fault traces shown in Figure 4-4, other features having a possible tectonic origin have been identified in the vicinity of the alignment. Weber (1980) postulates a possible fault based on the presence of an east-northeast trending linear break in topography apparent on quadrangle maps published in 1901 and 1926 by the U.S. Geological Survey. This feature is also visible on historical aerial photographs (specifically, Fairchild Collection Flight C113, Frame 117, dated August 1927). Other aerial photographs providing coverage of this feature that we reviewed are listed in Table 4-2. The lineament is located directly south of the eastern end of the alignment and it projects across the alignment near the proposed North Hollywood Station at Lankershim Boulevard (Figure 4-2). Because this feature possibly offsets young alluvial deposits, Jennings (1992) has assigned it a Holocene age.

Slosson and others (1993) infer the existence of a fault system located near the northern base of the Santa Monica Mountains. They speculate that the presence of aligned pressure ridges, artesian springs and warm water wells combined with other geologic and hydrogeologic evidence indicate the "probable existence of a fault system." The postulated trace of this fault is shown on Figure 4-2.

The Benedict Canyon Fault, located about 2.5 miles south of the eastern end of the alignment, crosses the Santa Monica Mountains from near Beverly Hills to near Universal City. From the Universal City area, the fault is projected northeastward beneath the alluvium of the San Fernando Valley near the north base of the Santa Monica Mountains (Figure 4-2). Although the fault has been classified by Jennings (1992) as not having recognized Quaternary displacement, water-well data suggest that the base of the valley-fill alluvium near the eastward to southward bend in the Los Angeles River is displaced downward to the north along a possible projection of the fault (State Water rights Board Referee, 1961).

TABLE 4-1. ESTIMATED SEISMIC CHARACTERISTICS OF PRINCIPAL FAULTS

Fault Name	Approximate Distance from Alignment ⁽¹⁾ (miles)			Magnitude of Maximum Credible Earthquake ⁽²⁾	Age of Most Recent Displacement ⁽³⁾
	West End	Center	East End		
Chatsworth	4	8	14	7 ⁽⁴⁾	Late Quaternary
Hollywood	12	8	4	7 1/2	Holocene
Malibu Coast	10	10	13	7 1/2	Holocene
Mission Hills	6	7	9	6 1/2 ⁽⁴⁾	Late Quaternary; Holocene
Newport-Inglewood	16	12	9	7	Holocene
Northridge Hills	6	4	7	7 1/2	Late Quaternary; Holocene
Palos Verdes Hills	15	17	18	7	Late Quaternary; Holocene
Raymond	15	18	12	7 1/2	Holocene
San Gabriel	16	13	12	7 1/2	Late Quaternary; Holocene
Santa Monica	13	8	7	7 1/2	Late Quaternary; Holocene
Santa Susana	8	9	13	7	Late Quaternary; Historic (1971)
San Fernando	9	8	8	7 1/2	Historic (1971)
Sierra Madre	18	13	8	7 1/2	Late Quaternary; Holocene
Simi	10	14	20	7 1/2	Late Quaternary
Verdugo	11	6	4	6 3/4	Late Quaternary; Holocene

- (1) Distance measurements are based on fault traces shown in Jennings, 1992.
- (2) Maximum Credible Earthquake Magnitudes from Mualchin and Jones, 1992.
- (3) Age of Most Recent Displacement from Jennings, 1992.
- (4) Based on earthquake magnitude-length of surface rupture relationship presented in Greensfelder, 1974.

TABLE 4-2. AERIAL PHOTOGRAPHS REVIEWED

Source	Date of Photography	Flight No.	Frame
Fairchild	08-27	C-113	117
Fairchild	1928	C-300	K15, 38, 39
Fairchild	05-16-37	C-4573	17
Fairchild	10-06-40	C-6630	94, 95
Fairchild	11-40	C-8730	1:6-10
Fairchild	1-45	C-9220	1-37, 38, 39
Fairchild	1-45	C-9298A	1
Fairchild	6-49	C-13775	F:11-14, G:13-16

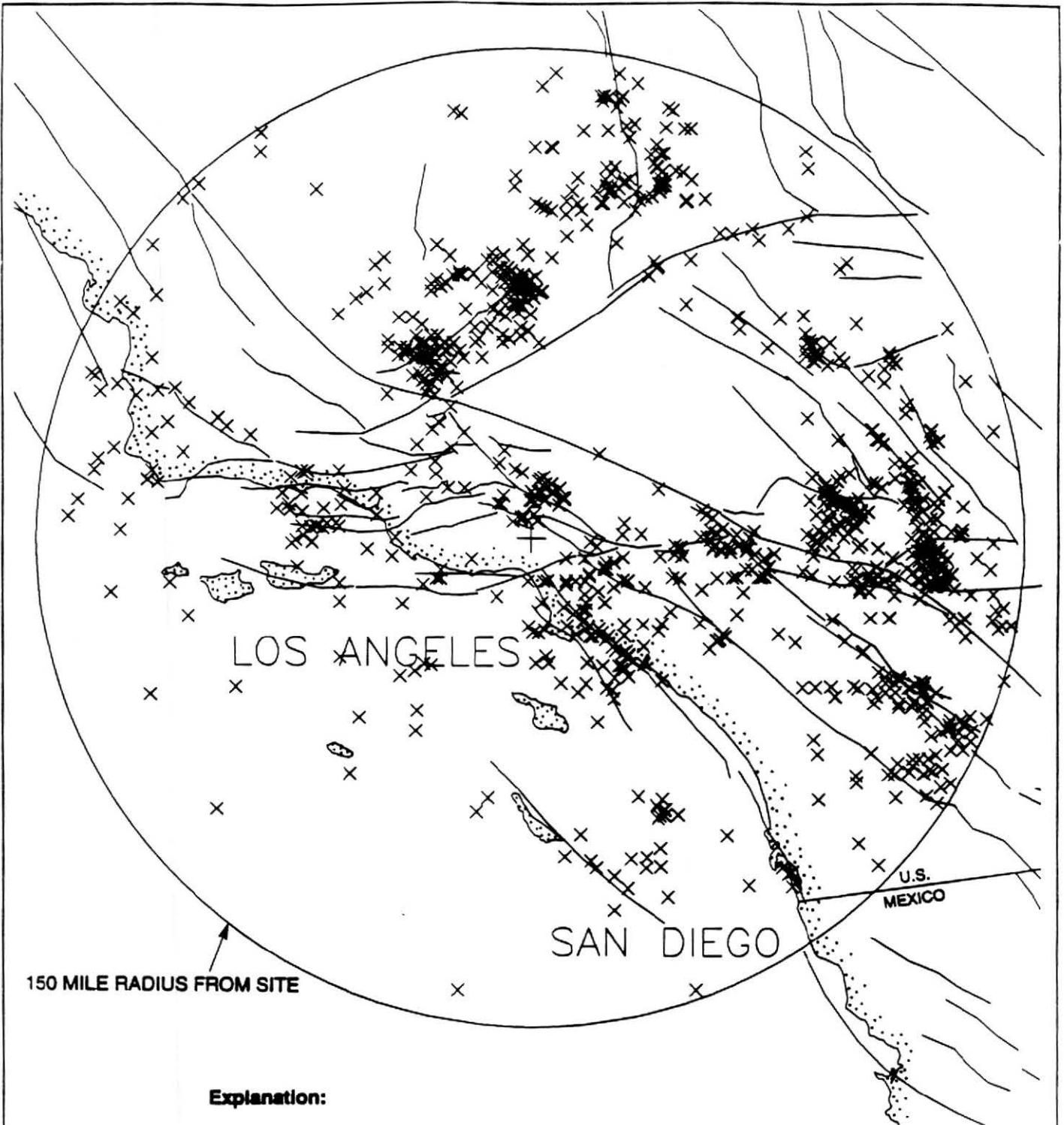
4.2.2 Seismicity

Earthquakes are expected to periodically occur in the site region during the life of the project. In the event that a nearby fault were to experience slip and produce a major earthquake, very strong ground motions could occur locally.

An earthquake computer search (Blake, 1992) was performed to illustrate the locations of historical earthquake epicenters with respect to the alignment. A search radius of 150 miles from the approximate mid-point of the alignment was selected in order to include the larger magnitude earthquakes that have occurred in Southern California. Catalogued earthquakes within the selected search radius with magnitudes ranging from 4 to 8+ that have occurred since the year 1800 are shown in Figures 4-5 and 4-6. The largest historical earthquake was a Magnitude 7.9 event on the San Andreas fault (1857 Fort Tejon earthquake) located about 110 miles northwest of the proposed alignment. The epicenter of the closest moderate-sized historic earthquake (Magnitude 6.4, 1971 San Fernando earthquake) was located about 16 miles north-northeast of the center of the alignment.

4.3 REGIONAL HYDROGEOLOGY

The hydrogeology of the greater Los Angeles area consists of two general types of groundwater regimes that include bedrock uplands and broad alluvial lowland 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 agricultural, domestic and commercial water supply. The proposed alignment is situated entirely in the lowland basin of the San Fernando Valley which is part of the Upper Los Angeles River Area (ULARA). The ULARA encompasses all of the watershed of the Los Angeles River and its tributaries above Arroyo Seco (Figure 4-7; ULARA Watermaster, 1993). Three other groundwater basins occur in the ULARA in addition to the San Fernando Basin. These include the Sylmar, Verdugo and Eagle Rock basins; the San Fernando Basin is the largest of the four.



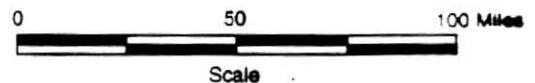
Explanation:

x M = 4.0-4.9

SITE LOCATION (+):

Latitude - 34.1900 N
 Longitude - 118.4800 W

Source:
 Epicenters from Blake, 1992.

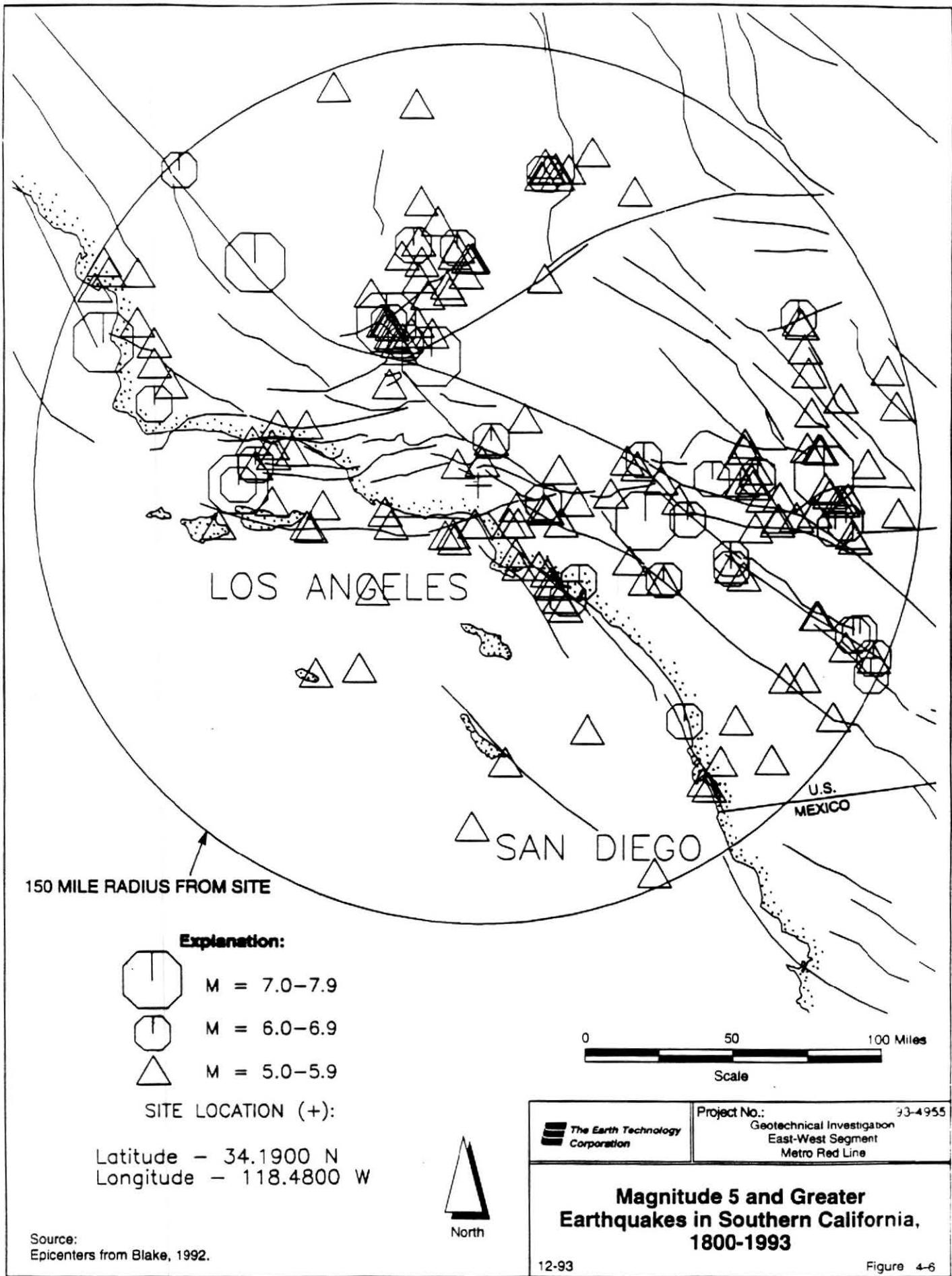


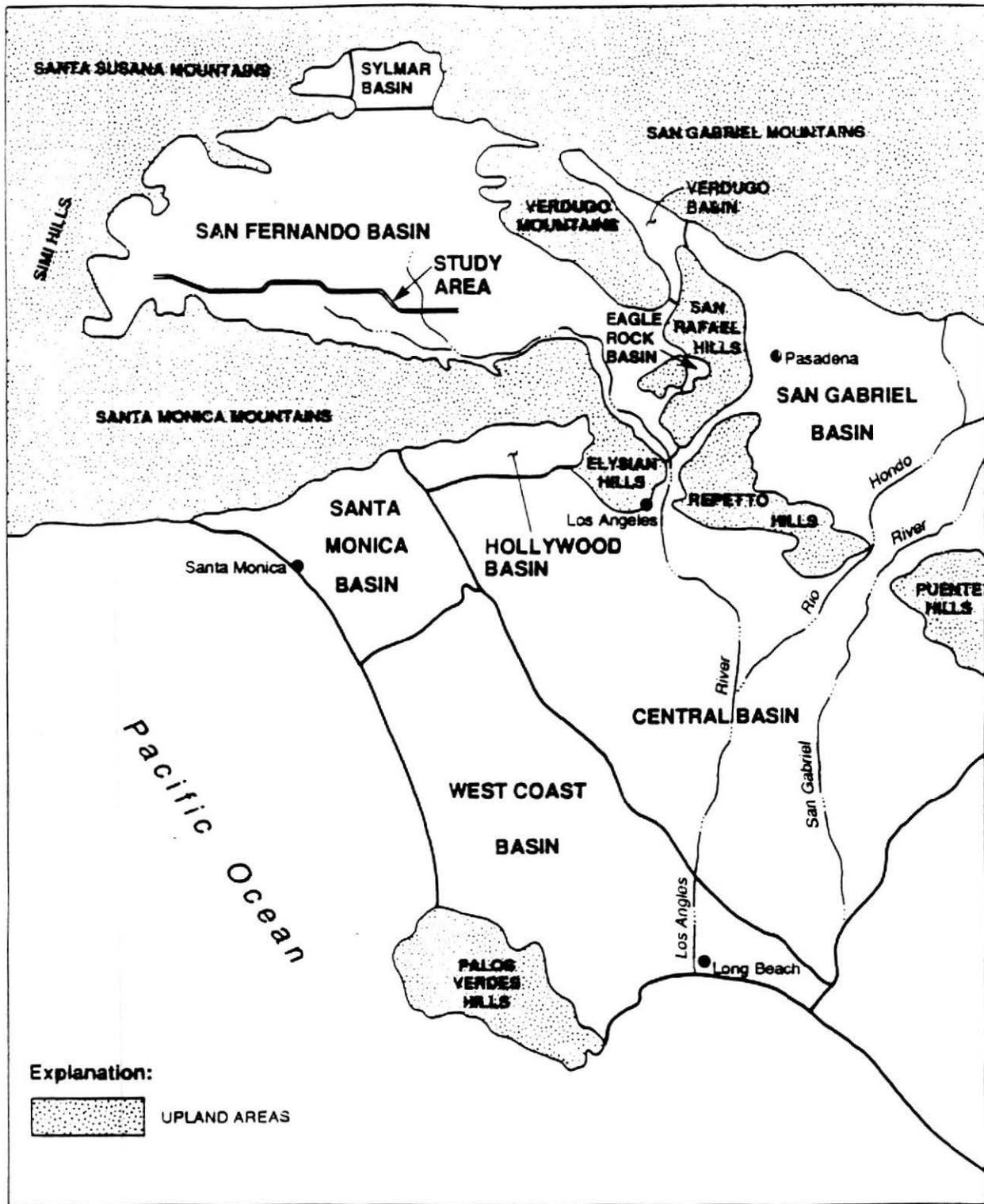
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**Magnitude 4.0-4.9
 Earthquakes in Southern California,
 1800-1993**

12-93

Figure 4-5

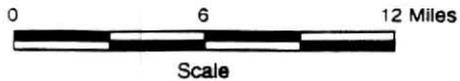




Explanation:



UPLAND AREAS



North

Source:
Modified from California Division of Water Resources, 1961,
and Watermaster, 1993.

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Geotechnical Investigation
East-West Segment
Metro Red Line

**Map of Groundwater Basins
in the Los Angeles Area**

12-93

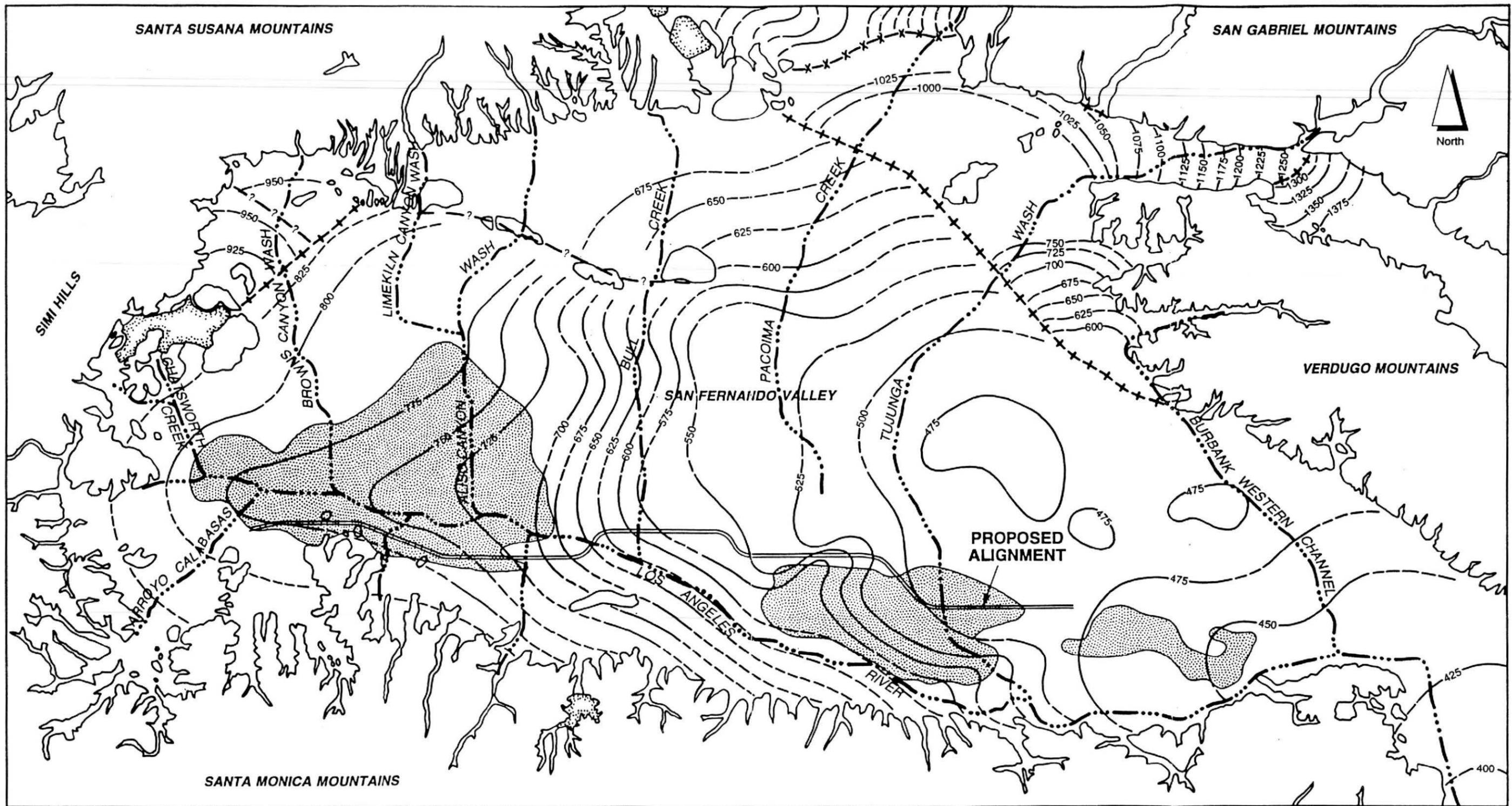
Figure 4-7

Sediment eroded from the mountains bordering the San Fernando Basin has filled the basin with alluvial materials that compositionally reflect their bedrock source areas. As described in Section 4.1, alluvium in the western portion of the basin is mostly fine grained with low permeabilities. Mostly coarse-grained alluvium having higher permeabilities occurs in the eastern portion of the basin. J.M. Montgomery (1992) has subdivided the coarse-grained alluvium into upper, middle, lower and deep aquifer zones. These subdivisions probably are not applicable to the mostly fine-grained sediments in the western part of the basin.

Maps showing groundwater elevation contours are prepared annually by the Watermaster for the ULARA. A portion of the Spring 1992 groundwater contour map is presented in Figure 4-8. The contours indicate that groundwater occurs in the western portion of the basin at depths that are much shallower than those in the east. Depths across the basin range from less than 5 feet to over 300 feet below the present ground surface. Data also indicate that groundwater occurs under both unconfined and confined conditions, with confined conditions being more evident in the western part of the basin due to the presence of permeable granular deposits enclosed by finer-grained sediments characteristic of this area (State Water Rights Board Referee, 1961).

Historically, groundwater in the eastern half of the basin once occurred at shallower depths than those present today. Pumping from water-supply well fields, the majority of which are located in this area, has resulted in declining water levels, in some cases up to 100 feet or more, since the middle 1940s (State Water Rights Board Referee, 1961; J.M. Montgomery, 1992). Areas of historically high groundwater (less than 10 feet from the surface) occurring in this area and in other parts of the San Fernando Basin are indicated in Figure 4-8. As shown in Figure 4-8, a large area of historical shallow groundwater generally corresponds with existing shallow groundwater conditions in the western part of the basin (covering most of the western tunnel segment). Another historical shallow groundwater area underlies a portion of the eastern tunnel segment, and a third area is located to the east of the alignment.

Under natural conditions, groundwater in the San Fernando Basin flows eastward across the valley in the west, and southeastward in the east towards the Los Angeles River narrows, where

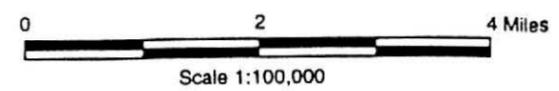


Explanation:

- 400 — — — GROUNDWATER ELEVATION CONTOUR, IN FEET
- X-X-X-X-X-X- IMPEDIMENT TO GROUNDWATER FLOW
- + + + + - GROUNDWATER CASCADE
- ? — ? — QUESTIONABLE GROUNDWATER IMPEDIMENT OR CASCADE
- ··· — ··· MAJOR DRAINAGE

- — — — — LIMIT OF YOUNG VALLEY FILL ALLUVIUM
- [Stippled Area] AREAS OF HISTORICALLY HIGH GROUNDWATER, LESS THAN 10 FEET DEPTH
- [Dotted Area] RESERVOIR

- Sources:
1. Groundwater Data Adapted From ULARA Watermaster Report (May 1993).
 2. Limits of Young Valley Fill Alluvium from Dibblee (1991 A,B,C,D; 1992 A,B,C,D).



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Groundwater Contours
Spring 1992

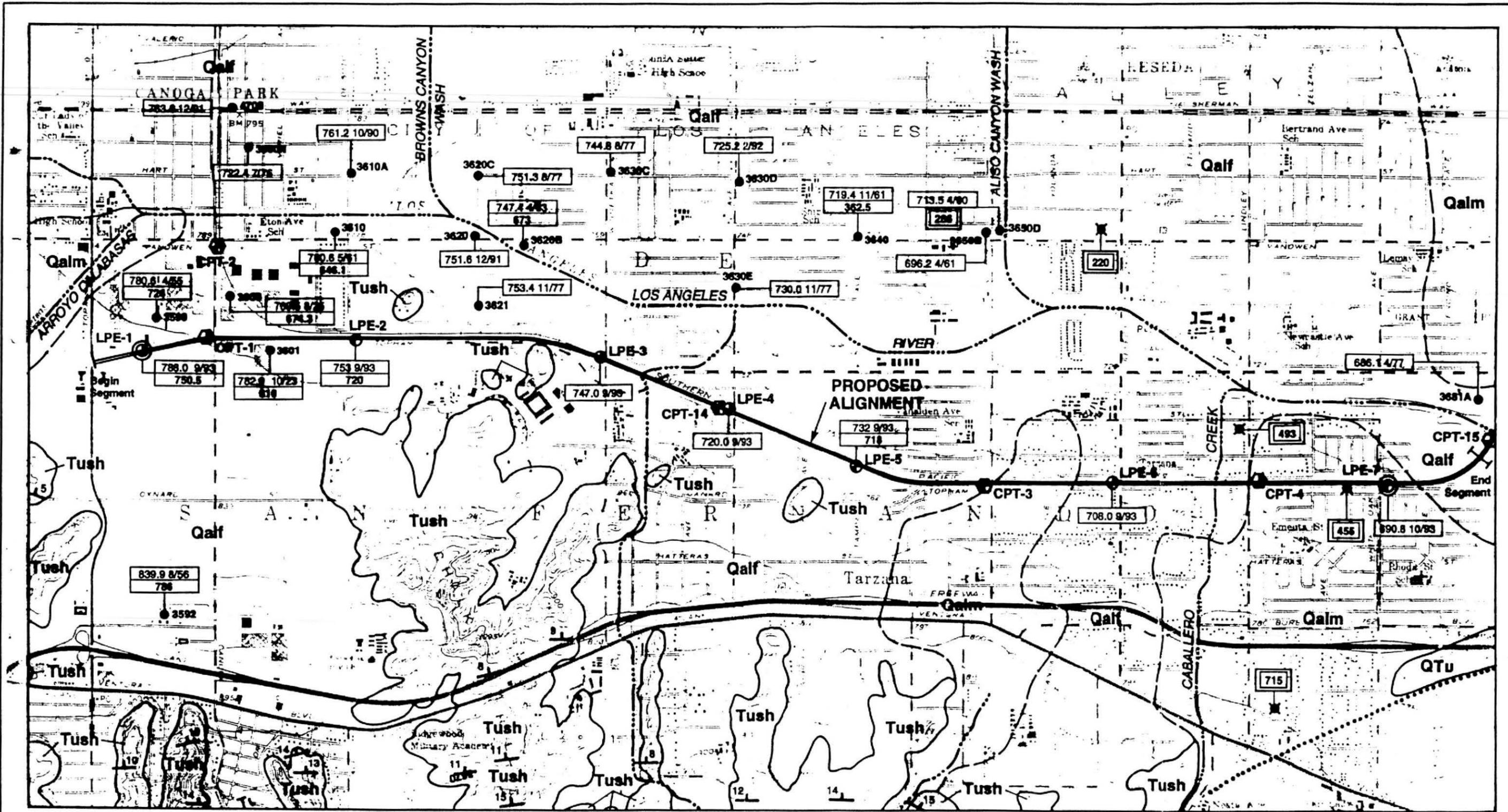
it discharges from the basin. Local flow patterns in the east are influenced by groundwater extraction for water supply.

4.4 LOCAL GEOLOGIC CONDITIONS

Alluvial sediments of Quaternary age and Tertiary aged bedrock materials will be encountered during construction of the proposed segment of the Metro Red Line. All of the subsurface explorations conducted during this investigation were entirely in the alluvial sediments, except for three borings (LPE-1, LPE-2 and LPE-3) penetrating through the alluvium into the underlying bedrock. Surficial geologic conditions in the vicinity of the alignment are shown in Figures 4-9a, 4-9b, and 4-9c corresponding to the western, central and eastern segments, respectively. These figures also show the locations of subsurface data (explorations from this investigation and other investigations in the vicinity) located in the vicinity of the alignment. Figures 4-10a, 4-10b and 4-10c, illustrate the subsurface conditions along the alignment for each of the three segments based on results from exploratory borings.

4.4.1 Local Topographic Conditions

The proposed alignment crosses the southern part of the San Fernando Valley from near Arroyo Calabasas to slightly beyond the central branch of Tujunga Wash (Figures 4-9a, 4-9b and 4-9c). The Los Angeles River intersects near the midpoint of the alignment. West of the Los Angeles River, the alignment traverses a northeasterly sloping surface developed on alluvial fan deposits emanating from the Santa Monica Mountains. East of the Los Angeles River, the alignment crosses a surface that slopes gradually to the southeast. This surface is underlain by alluvium derived from the mountainous areas bordering the northern part of the San Fernando Valley. Near its western end, the alignment crosses just north of the Chalk Hills, a group of low bedrock hills projecting northward from the Santa Monica Mountains (Figure 4-9a).

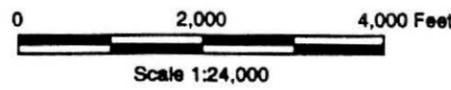


Sources:
 U.S.G.S. Topographic Maps, 7.5 Minute Series,
 Canoga Park Quadrangle, Photorevised 1967,
 and Van Nuys Quadrangle, Photorevised 1972.

Note:
 See Figure 4-9d for Explanation.



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 Metro Red Line



**Generalized Geologic Map of the
 Western Tunnel Segment**

12-93

Figure 4-9a

- 678 1/87 ← GROUNDWATER ELEVATION AND DATE MEASURED
- ⊕ LPE-1 ROTARY WASH BORING WITH PEIZOMETERS
 - ⊕ LPE-14 ROTARY WASH BORING
 - ⊕ CPT-3 CONE PENETRATION TEST
- GROUNDWATER ELEVATION AND DATE MEASURED
- 732 4/87 ←
- 635 ←
- 3521 ← EXISTING WELL MONITORED BY L.A. CO. DEPT. OF WATER AND POWER
- ELEVATION OF TOP OF BEDROCK FROM WELL RECORDS
- <426.7 12/80 ←
- <426.7 ←
- CEG-38 ROTARY WASH BORING
- ⊕ 38-A BUCKET AUGER BORING
- ⊕ 87-7 BUCKET AUGER BORING
- 678 1/87 ← GROUNDWATER ELEVATION AND DATE MEASURED
- 687 1939 ← GROUNDWATER ELEVATION AND DATE MEASURED
- 53-1684:B-1 ROTARY BORING
- ⊕ 2-R AUGER BORING
- ⊕ 7-X CHURN DRILL BORING
- ⊕ TP-1 TEST PIT
- Well Number Unknown
- 583 ← ELEVATION OF TOP OF BEDROCK

This Investigation

Converse Consultants (1984)

U.S. Army Corps. of Engineers (1987)

Caltrans (1961-1963)

U.S. Army Corps. of Engineers (1939)

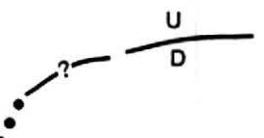
WELL REFERENCED BY U.S. ARMY CORPS OF ENGINEERS (1939)

UNITS

- Qalf ← FINE-GRAINED (CHIEFLY CLAY AND SILT)
- Qalm ← MEDIUM-GRAINED (CHIEFLY SAND)
- Qalc ← COARSE-GRAINED (CHIEFLY SAND AND GRAVEL)
- QTu ← QUATERNARY AND LATEST TERTIARY OLDER ALLUVIAL DEPOSITS
- Tush ← UNNAMED MIOCENE SHALE OF DIBBLEE (1992); MODELO FORMATION OF HOOTS (1930)

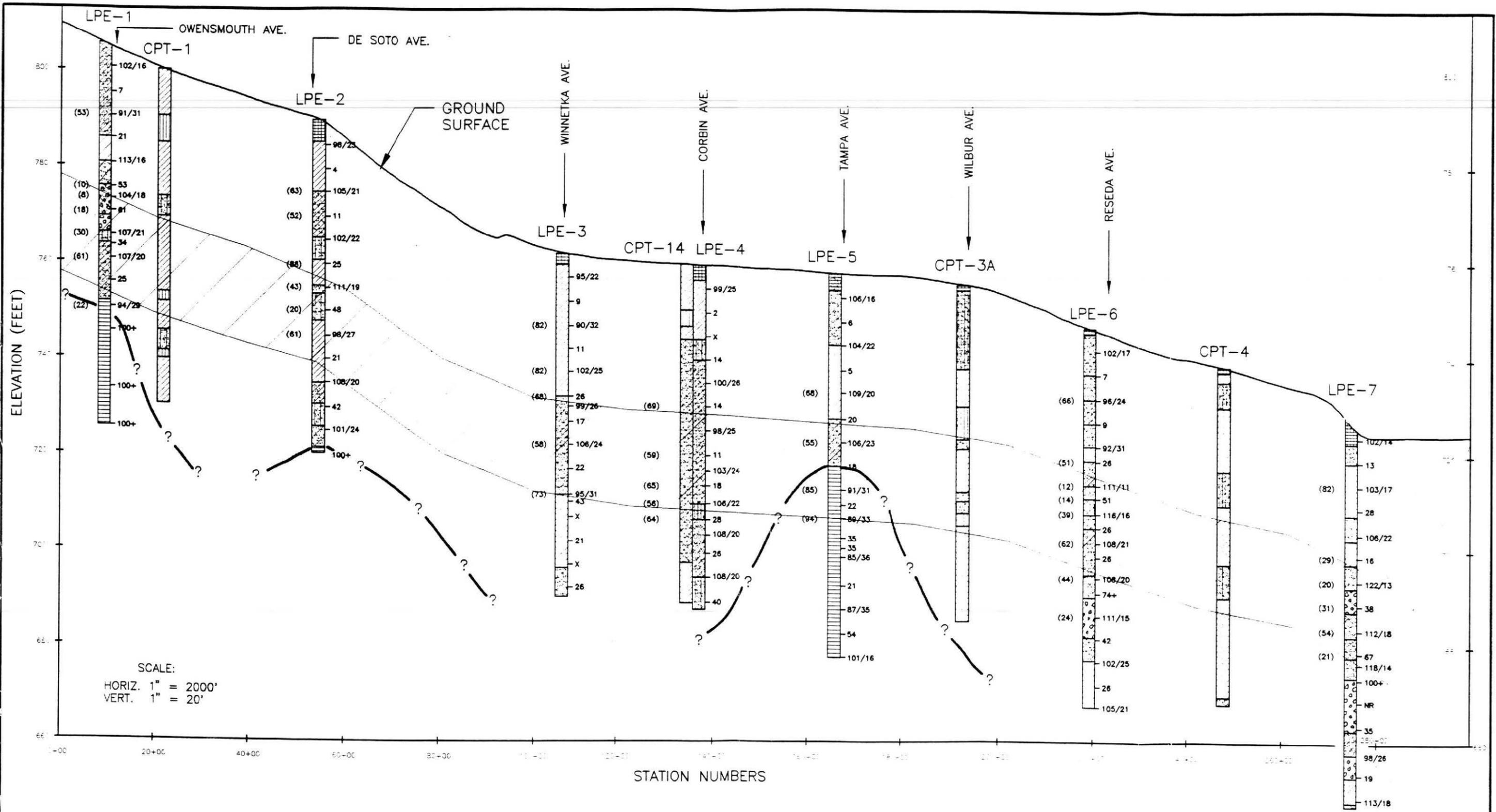
Young Valley Fill Alluvium

SYMBOLS

-  GEOLOGIC CONTACT BETWEEN UNITS
-  GEOLOGIC CONTACT BETWEEN SUBUNITS OF Qal
-  FAULT; U AND D INDICATE UP-THROWN AND DOWN-THROWN SIDES. SOLID WHERE POSITIVELY IDENTIFIED AND ACCURATELY LOCATED; LONG-DASHED WHERE POSITIVELY IDENTIFIED AND RELATIVELY WELL-LOCATED; SHORT DASHED WHERE APPARENT BUT NOT POSITIVELY IDENTIFIED; QUERIED WHERE HYPOTHETICAL; DOTTED WHERE CONCEALED.
-  STRIKE AND DIP OF BEDS

	Project No.: 4-55
	Geotechnical Investigation East-West Segment Metro Red Line

Explanation of Symbols Used in Figures 4-9a Through 4-9c



SCALE:
 HORIZ. 1" = 2000'
 VERT. 1" = 20'

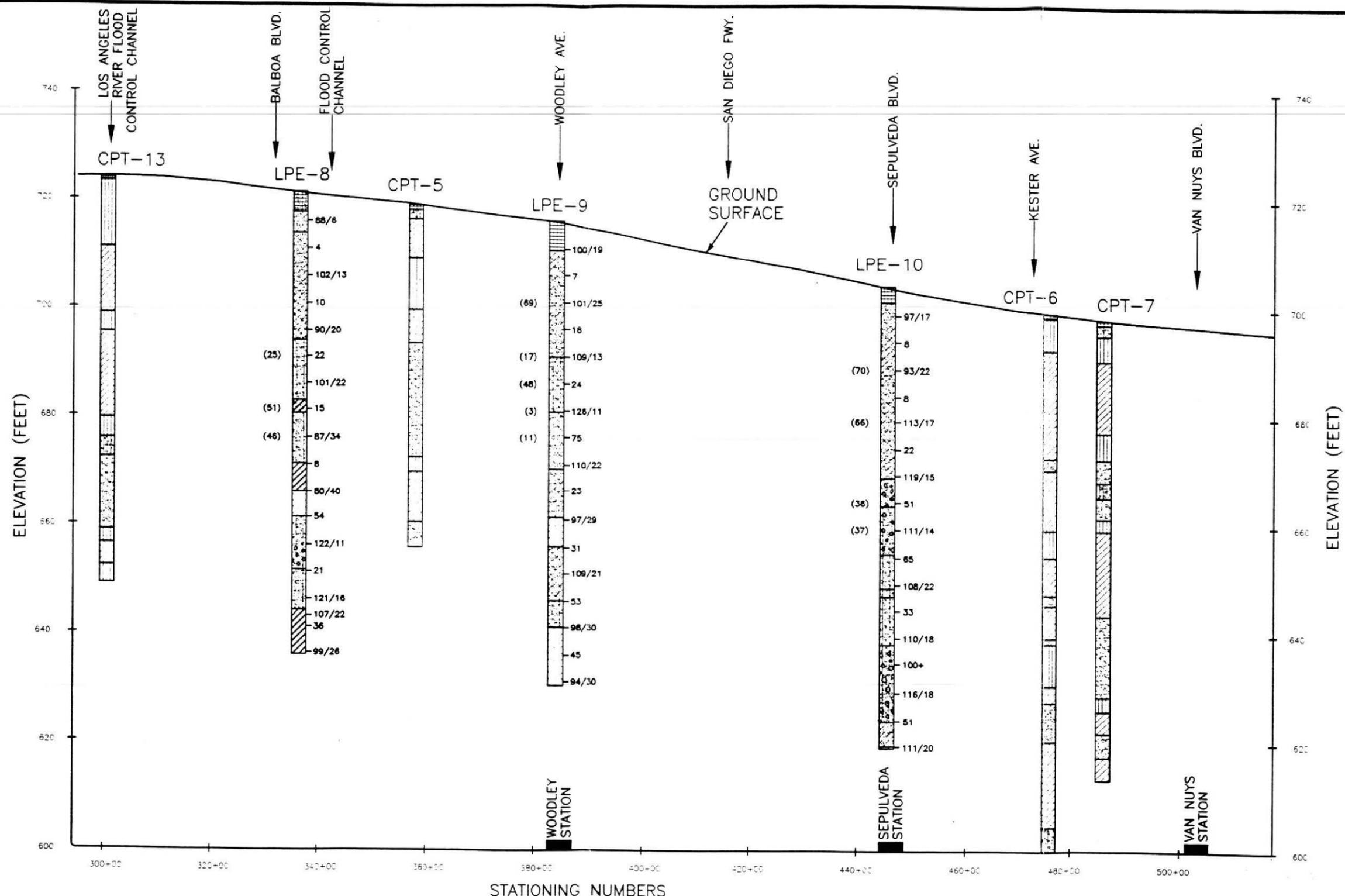
SYMBOLS

- | | | | |
|----------------|--------------------|--------------------------|--|
| ML: SILT | CH: FAT CLAY | SM: SILTY SAND | GC: CLAYEY GRAVEL |
| ML: SANDY SILT | CH: SANDY FAT CLAY | SC: CLAYEY SAND | FILL |
| CL: LEAN CLAY | SP: SAND | GP: GRAVEL, SANDY GRAVEL | BEDROCK |
| CL: SANDY CLAY | SP: GRAVELLY SAND | GM: SILTY GRAVEL | BEDROCK CONTACT, QUERIED WHERE UNCERTAIN |

(68) -102/16 = MOISTURE CONTENT (%) / DRY DENSITY (PCF)
 -21 = SPT BLOW COUNT FOR FINAL 12" OF PENETRATION
 = PERCENT PASSING #200 SIEVE INDICATED IN PARENTHESES

	Project No. 93-4955
	Geotechnical Investigation East - West Segment Metro Rail Red Line

**Subsurface Profile
 Western Tunnel Segment**



SCALE:
 HORIZ. 1" = 2000'
 VERT. 1" = 20'

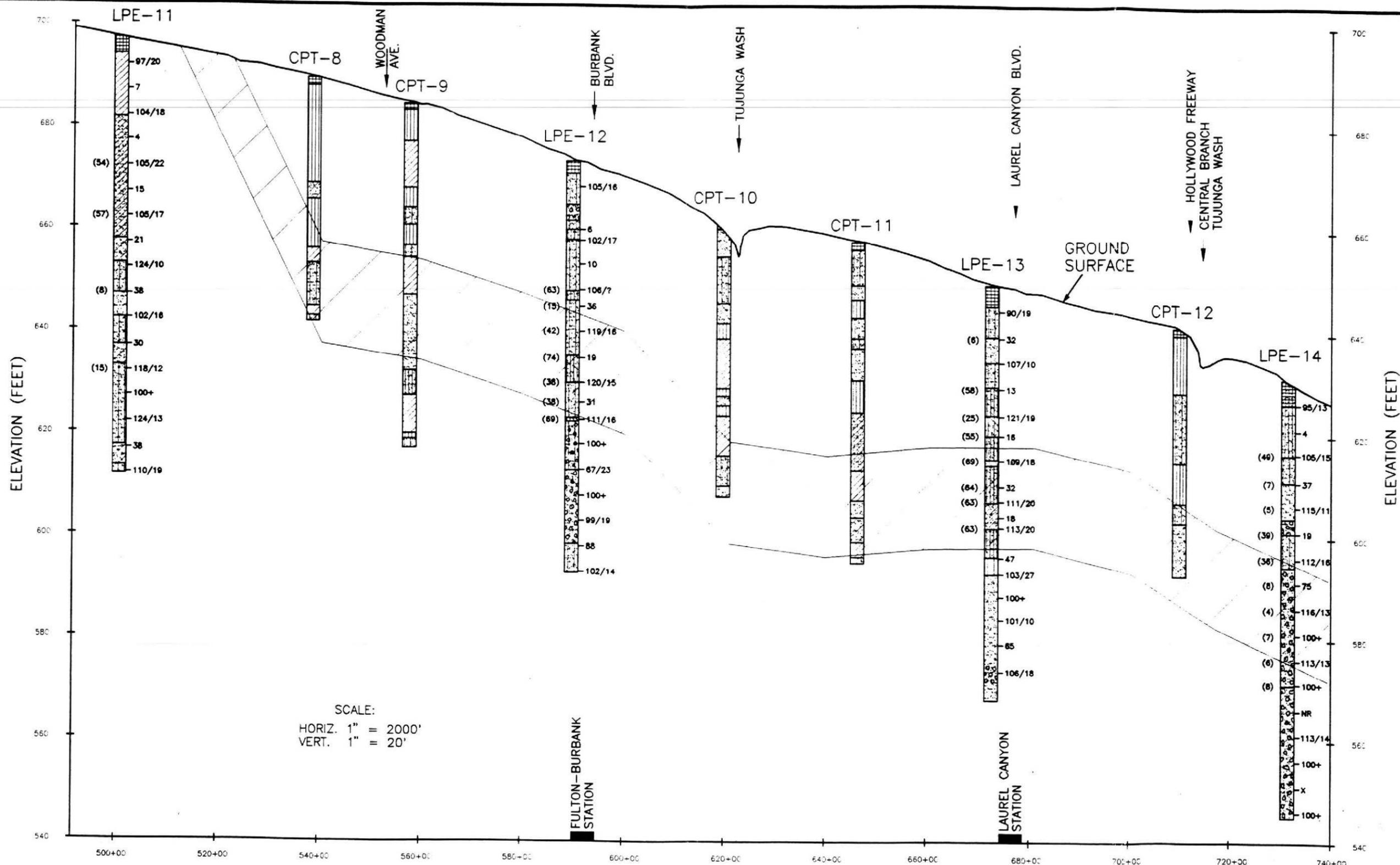
SYMBOLS

- | | | | |
|----------------|--------------------|--------------------------|--|
| ML: SILT | CH: FAT CLAY | SM: SILTY SAND | GC: CLAYEY GRAVEL |
| ML: SANDY SILT | CH: SANDY FAT CLAY | SC: CLAYEY SAND | FILL |
| CL: LEAN CLAY | SP: SAND | GP: GRAVEL, SANDY GRAVEL | BEDROCK |
| CL: SANDY CLAY | SP: GRAVELLY SAND | GM: SILTY GRAVEL | BEDROCK CONTACT, QUERIED WHERE UNCERTAIN |

(88) -102/16 = MOISTURE CONTENT (%) / DRY DENSITY (PCF)
 -21 = SPT BLOW COUNT FOR FINAL 12" OF PENETRATION
 = PERCENT PASSING #200 SIEVE INDICATED IN PARENTHESES

The Earth Technology Corporation
 Project No. 93-4955
 Geotechnical Investigation
 East-West Segment
 Metro Red Line

**Subsurface Profile -
 Central Aerial Segment**



SCALE:
 HORIZ. 1" = 2000'
 VERT. 1" = 20'

SYMBOLS

- | | | | |
|--|--|--|--|
| | | | |
| | | | |
| | | | |
| | | | |

- (68) -102/18 = MOISTURE CONTENT (%) / DRY DENSITY (PCF)
 -21 = SPT BLOW COUNT FOR FINAL 12" OF PENETRATION
 = PERCENT PASSING #200 SIEVE INDICATED IN PARENTHESES

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 Geotechnical Investigation
 East-West Segment
 Metro Red Line

**Subsurface Profile
 Eastern Tunnel Segment**

The ground surface along the alignment decreases to the east from an approximate elevation of 810 feet MSL at Topanga Canyon Boulevard to an elevation of about 630 feet MSL at Lankershim Boulevard (Figures 4-9a, 4-9b and 4-9c).

The Los Angeles River system carries surface water runoff eastward out of the valley. The drainage network includes several tributaries that cross the alignment. From west to east these are Caballero Creek, Bull Creek, and Tujunga Wash.

4.4.2 Bedrock

Bedrock, probably of the Miocene Modelo Formation, was encountered in three borings (LPE-1, LPE-2 and LPE-5) drilled near the western end of the alignment in the vicinity of the Chalk Hills. The Modelo Formation should be anticipated to periodically occur in the tunnel envelope west of approximate Station 190+00. The formation is also exposed in the nearby Chalk Hills and extensively along the northern flank of the Santa Monica Mountains (Figure 4-9a).

Within the borings, the Modelo Formation consists of indistinctly bedded claystone with intervals of fine-grained sandstone. Interbeds of diatomaceous shale, hard siliceous shale and coarse-grained sandstone are also reported to be present in the formation (Hoots, 1931; Dibblee, 1992a). Bedding was not apparent in the samples obtained from the borings. Available literature, however, indicates that the formation is typically well bedded, and that in the vicinity of the alignment, the beds are inclined at low angles (less than 20 degrees) to the north (Figure 4-9a).

Sandstone was encountered in Boring LPE-1 at a depth of approximately 50 feet. The material was fine grained and variably cemented. The presence of thin cemented beds, lenses or nodules (most less than 1/4 inch thick) resulted in frequent rig chatter and slow progress during drilling. Siltstone and claystone were encountered in Borings LPE-2 and LPE-5 at depths of approximately 70 feet and 40 feet, respectively. Hard siltstone was encountered at the bottom of Boring LPE-2. The upper part of the formation is highly to moderately weathered. The

material in the weathered zone behaves, in an engineering sense, similarly to the overlying alluvium. In Boring LPE-5, the claystone was weathered to a depth of about 80 feet where very dark gray, unweathered claystone was encountered. The upper five feet of bedrock in this boring was intensely weathered.

Considering the presence of bedrock ridges extending from the base of the Santa Monica Mountains and numerous isolated bedrock knobs projecting from the alluvial deposits in the vicinity of the western end of the alignment, an irregular, buried bedrock surface should be anticipated and may significantly affect the design and construction of the proposed facilities. Additional exploration is needed to better define the subsurface configuration of the bedrock surface along the alignment west of Station 190+00 (near Wilbur Avenue).

4.4.3 Alluvium

Alluvial sediments underlie the entire alignment. Alluvial sediments along the western portion of the alignment have been supplied by streams draining areas of sedimentary rocks, resulting in predominantly fine-grained cohesive materials. Larger streams, such as Tujunga Wash in the eastern area, drain crystalline rocks of high relief and have produced deposits of granular materials with gravel and cobbles. The transition between these contrasting alluvial deposits generally occurs in the vicinity of Pacoima and Tujunga washes (Figure 4-3), east of Boring LPE-11 (Figure 4-9b).

Much of the fine-grained alluvial deposits encountered in the borings consist of silty clay, sandy clay and clayey sand. Based on the visual inspection of samples recovered from the borings, these materials appear to be generally massive with infrequent stratified zones. Periodically, interbeds of granular material are encountered west of Boring LPE-7. These interbeds consist of sand and gravel deposits in discontinuous layers up to about 10 feet thick. The sand generally is fine-grained with infrequent intervals of coarse-grained sand present. Gravels are usually fine to coarse grained, with isolated 3-inch diameter cobble clasts present. East of Boring LPE-7,

the granular materials become more frequently interbedded, occurring in intervals more than 10 feet thick. These materials predominate east of the vicinity of Boring LPE-11.

The granular deposits underlying the eastern portion of the alignment (generally east of Boring LPE-11) encountered by the borings consist of silt, sand, and gravel mixtures with intervals of sandy silt and some sandy clay occasionally interbedded. The sand ranges from fine- to coarse-grained with coarse-grained gravel intervals common. Cobbles and small boulders are abundant below a depth of about 47 feet in borings drilled for the North Hollywood Station area (Converse Consultants, 1984).

5.0 SUBSURFACE CONDITIONS

5.1 SUBSURFACE STRATIGRAPHY AND GROUNDWATER CONDITIONS

5.1.1 General

The proposed alignment crosses mostly Quaternary-aged alluvium and local areas of claystone or sandstone bedrock. The thickness of alluvium ranges from less than 40 feet near the western end of the alignment to in excess of 600 feet at the eastern end. Review of the regional geologic data (Section 4) indicates that the alluvial deposits underlying the western portion of the alignment contain a relatively high percentage of fine grained clayey materials while the deposits underlying the eastern portion of the alignment include a relatively higher fraction of coarser materials (sands, gravels and cobbles). Bedrock of the Modelo Formation consisting of claystone, siltstone and sandstone is anticipated irregularly within the tunnel zone near the western end of the alignment.

For ease of presentation and discussion the proposed alignment was broken into three segments: the western tunnel segment; the central above-ground segment; and the eastern tunnel segment. The subsurface conditions for these three segments are discussed below.

5.1.2 Western Tunnel Segment

The western tunnel segment extends approximately 5.6 miles from the western terminal at Topanga Canyon Boulevard to the Los Angeles river flood control channel (Figure 4-9a). The western tunnel segment also includes an approximately 3,000-foot long spur alignment (of which approximately 1,200 feet is at grade) to the proposed maintenance yard adjacent to Canoga Avenue. The western tunnel segment runs below Victory Boulevard from Topanga Canyon Road to Winnetka Avenue, beyond which it follows the abandoned Southern Pacific Railroad alignment. Much of the spur line also follows the Southern Pacific Railroad alignment.

Figure 4-10a, presents a generalized cross sectional profile of the western tunnel segment based on data from seven borings (LPE-1 through LPE-7) and four CPT soundings (CPT 1, CPT 14, CPT 3 and CPT 4) in the area.

The subsurface stratigraphy, in general, consists of a shallow fill zone (up to 5 feet thick) underlain by alluvium. Well cemented old alluvium or sandstone bedrock was encountered below the alluvial deposits at a depth of approximately 55 feet below ground surface (BGS) at Borehole LPE-1. Siltstone and claystone were encountered within Boreholes LPE-2 and LPE-5 at approximate depths of 70 and 40 feet BGS, respectively. Regional geologic information indicates that the depth to bedrock ranges from less than 40 feet near the western end to more than 230 feet near the Los Angeles River crossing.

The alluvium is heterogeneous and non uniform in this area. Within the depth of exploration, the alluvium consists predominantly of soft to hard clays, sandy clays, sandy silts and clayey silts of low to medium plasticity interlayered with loose to very dense granular alluvium consisting of silty sands, clayey sands, and occasionally poorly graded sands and gravels (maximum particle size estimated at approximately 3 inches). Significant thicknesses of granular alluvium were mainly encountered in LPE-1, CPT-1, and LPE-2 near the western end of the alignment and in CPT-3, LPE-6, CPT-4, LPE-7 of the eastern half of the western tunnel segment.

The sandstone bedrock encountered in LPE-1 was well indurated and cemented as evidenced by the frequent drill rig chatter and high blowcounts. Boring LPE-2 barely penetrated a hard siltstone layer at a depth of 70 feet. The claystone encountered in Boring LPE-5 was moderately weathered and consisted of medium to high plasticity clay with some fine sand.

The groundwater levels in this segment were monitored in three monitoring wells (LPE-1, LPE-3 and LPE-7) screened approximately within the tunnel envelope zone as indicated in Table 3-2. Groundwater levels were also estimated from the sample moisture conditions in the other boreholes within this segment (LPE-2, LPE-4, LPE-6). In general, the groundwater levels

appear to be relatively shallow (approximately 15 feet BGS) near the western end of the segment (LPE-1 and LPE-3) and drop to 35 to 40 feet BGS elsewhere. The regional groundwater levels, as shown in Figure 4-8, appear to support the field observations. The groundwater levels are anticipated to experience seasonal fluctuations on the order of a few feet. Groundwater may be partially confined as suggested by the presence of permeable granular units enclosed by clayey sediments and "wet" sediments occurring below the measured groundwater levels. "Wet" zones, for example, were observed in Boring LPE-3 below a depth of about 30 feet, with the soils above described as being moist. The static water level measured in the piezometer installed in this boring stabilized at an elevation approximately 15 feet above the first encountered wet sediments. Similarly, wet, granular deposits were observed in Boring LPE-1 beginning at a depth of about 30 feet. Groundwater in this boring similarly stabilized at a higher elevation, approximately 15 feet below the ground surface.

5.1.3 Central Aerial Segment

The central above-ground segment runs from the Los Angeles River Flood Control channel north of the Sepulveda basin to Hazeltine Avenue (east of the Van Nuys station) (Figure 4-9b). This section consists of approximately 3.0 miles of elevated aerial guideway and approximately 1.2 miles of at-grade guideway including retained cuts and fills. The entire segment follows the existing Southern Pacific Railroad alignment.

Figure 4-10b, presents a generalized cross sectional profile of the central above-ground segment based on data from four borings (LPE-8 through LPE-11) and four CPT soundings (CPT-13 and CPT-5 through CPT-7) in the area.

The subsurface stratigraphy consists of a shallow fill zone (up to 3 feet thick) underlain by alluvium. Bedrock was not encountered in any of the boreholes (maximum penetration depth of 86 feet). CPT-5 met refusal at a depth of 63 feet. CPT-6 was advanced to a depth of 100 feet into alluvium. Regional geologic information indicates that depth to bedrock may range

from approximately 230 feet at the western end of this segment to approximately 500 feet at the eastern end.

The alluvium is non uniform and heterogeneous in this area. Within the depths of exploration (maximum penetration depth of 100 feet BGS) the alluvium consists predominantly of soft to very stiff clay, sandy clay and silt of low to high plasticity interlayered with loose to very dense silty sands, clayey sands, and poorly graded sands with varying amounts of medium to coarse gravel. The alluvium appears to be predominantly fine grained to a depth of 25 to 35 feet. Below this depth granular and fine grained alluvium is interlayered. Existing Caltrans borings (Caltrans, 1963) in the vicinity of the 405 Freeway and Victory Boulevard indicate that the alluvium consists of medium stiff to stiff sandy silt layers interbedded with loose to dense sands and silty sands with varying amounts of gravel. The Caltrans logs indicate that very dense sand and gravel layers were encountered below a depth of approximately 60 feet BGS.

The groundwater levels in this segment were monitored in two piezometers installed in LPE-9 and LPE-10. The two piezometers were screened from a depth of approximately 15 feet BGS to the bottom of each boring at approximately 85 feet. Groundwater levels were measured at depths of approximately 46 and 77 feet BGS in Boreholes LPE-9 and LPE-10, respectively. Based on sample moisture conditions and approximate measurements within CPT soundings, the groundwater depths were estimated at 33, 40 and 45 feet BGS in LPE-8, CPT-5 and LPE-11, respectively. Regional groundwater trends (Figure 4-8) indicate that the depth to the regional groundwater table ranges from 30 feet at the western end to greater than 100 feet BGS over most of the segment. The shallower groundwater level measured in the boreholes may therefore indicate a perched groundwater condition. This segment is located immediately to the north of the Sepulveda basin, which is estimated to experience significant seasonal groundwater level fluctuations. As a result the groundwater levels below the alignment could also show corresponding fluctuations.

5.1.4 Eastern Tunnel Segment

The eastern tunnel segment extends approximately 4.2 miles from Hazeltine Avenue to the eastern terminal at Lankershim Boulevard (Figure 4.9c). The entire segment with the exception of a small portion at the eastern end follows the existing Southern Pacific Railroad alignment. Figure 4-10c, presents a generalized cross sectional profile of the eastern tunnel segment based on data from three borings (LPE-12 through LPE-14) and five CPT soundings (CPT-8 through CPT-12) in the area.

The subsurface stratigraphy consists of a shallow fill zone (up to 5 feet thick) underlain by alluvium. Bedrock was not encountered in any of the borings (maximum depth of 86 feet). Regional geologic maps indicate that bedrock in this area is 500 to 600 feet deep.

The alluvium is non-uniform and heterogeneous in this area. As indicated by the regional geology map (Figure 4-3), the alluvium within the eastern tunnel segment is coarser than that in the western tunnel segment. Within the depth of exploration (maximum depth of 86 feet), the alluvium consists predominantly of loose to very dense, silty sands, gravelly sands, clayey sands, poorly graded sands and medium to coarse gravels, interlayered with medium stiff to stiff sandy silts, silts and clays. The CPT soundings CPT-8 through CPT-12 met refusal at depths ranging from 48 to 68.5 feet, probably due to the presence of very dense sand, gravel or cobbles. Caltrans data (1961) for the Chandler Boulevard Overhead Structure of Freeway 170, indicates that the alluvium consists of loose to dense fine to coarse grained sands and sandy silts to a depth of approximately 40 feet BGS, underlain by dense to very dense coarse sands and gravels. Previous work (Converse, Ward, Davis and Dixon, 1984) performed in the vicinity of the eastern end of the segment (Lankershim Boulevard) indicates that the upper 45 to 50 feet of the alluvium consists primarily of sands, silty sands and gravelly sands with some scattered cobbles or small boulders and thin discontinuous layers of clays, silts and clayey sands. The alluvium below this depth reportedly consisted of gravelly sand and sandy gravel with cobbles and boulders (estimated to be on the order to 1 to 4 feet in size). Large diameter boreholes in this

area reportedly experienced minor raveling from 10 to 15 feet and significant caving below 50 feet (Converse, Ward, Davis and Dixon, 1984).

A piezometer installed in Borehole LPE-14 (depth of 86 feet) has remained dry since installation (Table 3-2). No indications of groundwater were observed in any of the other boreholes drilled in this segment. A piezometer installed previously at Lankershim Boulevard indicated groundwater at a depth of approximately 140 feet BGS at about Elevation 490 feet (Converse, Ward, Davis and Dixon, 1984). This is in agreement with the regional groundwater data (Figure 4-8) which suggests that the depth to groundwater ranges from 140 to 165 feet BGS. Fluctuations of groundwater in this area are driven primarily by pumping/recharge patterns. Within the period October 1991 to September 1992 the groundwater levels below this portion of the alignment fluctuated by approximately 10 feet (ULARA Watermaster, 1993). Historical groundwater data indicates that the groundwater level was relatively shallow in this area at one time (Section 4-3). The groundwater levels subsequently dropped dramatically, probably as a result of drawdown due to pumping.

5.2 ENGINEERING PROPERTIES OF SUBSURFACE MATERIALS

The engineering properties of subsurface materials as obtained from results of laboratory tests are summarized in Table 3-4. Blowcount data (equivalent SPT N_1 -values) from standard penetration tests and drive sampling are shown in the borehole logs and presented in Table 3-4. Interpretations drawn from the CPT soundings are presented with the CPT logs in Appendix B.

Table 5-1 presents a summary of the measured ranges of relevant geotechnical parameters for the various material types encountered within the three segments. For purposes of presentation, the predominant subsurface material, alluvium, has been broadly categorized into fine grained and coarse grained alluvium. The fine and coarse grained alluvium is interlayered and occurs within all three segments. The alluvium tends to be coarser (higher granular materials content) within the eastern half of the alignment than the western half.

TABLE 5-1. SUMMARY OF ESTIMATED ENGINEERING PROPERTIES

ENGINEERING CHARACTERISTICS	WESTERN TUNNEL SEGMENT				CENTRAL ABOVE-GROUND SEGMENT		EASTERN TUNNEL SEGMENT	
	FINE-GRAINED ALLUVIUM	COARSE-GRAINED ALLUVIUM	SILTSTONE/CLAYSTONE	SANDSTONE	FINE-GRAINED ALLUVIUM	COARSE-GRAINED ALLUVIUM	FINE-GRAINED ALLUVIUM	COARSE-GRAINED ALLUVIUM
USCS Classification	CL, CH, ML	SM, SC, SP, SP-SM, GP-GM	ML, CL, CH	SM	CL, CH, ML	SP, SM, SW, SC	CL, ML	SP, SM, SC, SP-SM, GP
Equivalent SPT Blowcounts	2 - 43	5 - 100	15 - >100	>100	3 - 51	5 - 165	4 - 32	4 - 240
Moisture Content (percent)	14 - 34	11 - 24	16 - 36	29	6 - 40	10 - 22	14 - 27	9 - 19
Dry Density (pcf)	90 - 113	101 - 122	85 - 101	94	80 - 113	101 - 126	83 - 113	99 - 121
Fines Content (% passing #200 Sieve) (percent)	51 - 88	8 - 44	85 - 94	22	51 - 70	3 - 48	65 - 74	4 - 49
Specific Gravity	2.68							2.69
Liquid Limit (percent)	28 - 52		50		23 - 48		30	
Plasticity Index (percent)	9 - 28		27		5 - 22		7	
Peak Shear Strength from Laboratory Tests Cohesion, (psf)	600 - 2,000		2,000		500 - 1,000	600	1,200	
Friction Angle, (degrees)	23 - 26		20		18 - 30	26	24	
Undrained Shear Strength (Interpreted from CPT soundings) (psf)	540 - 23,480				620 - 17,780		1,020 - 25,320	
Friction Angle (Interpreted from CPT and SPT) (degrees)		30 - 45		45		30 - 45		30 - 45
pH	6.96 - 7.28	6.9	6.97		6.82 - 7.35			6.85 - 7.32
Chloride Content (ppm)	95 - 505	215	259		92 - 394			198 - 343
Sulphate Content (ppm)	45 - 187	217	42		69 - 129			96 - 271
Compression Index Cc'					0.13 - 0.20			
Swelling Index Ce'					0.01 - 0.03			
Rate of Secondary Compression Cx'					0.0018 - 0.0047			
Swelling / Collapse					-0.17 - +0.29			

NOTES:

- 1) Based on vertical strain - log stress plots
- 2) Only one laboratory test result is available wherever range of properties is not shown
- 3) Western Tunnel Segment corresponds to Borings LPE-1 through LPE-7 and CPT Soundings CPT-1, CPT-14, CPT-3, and CPT-4
- 4) Central Above-Ground Tunnel Segment corresponds to Borings LPE-8 through LPE-11 and CPT Soundings CPT-13 and CPT-5 through CPT-7
- 5) Eastern Tunnel Segment corresponds to Borings LPE-11 through LPE-14 and CPT Soundings CPT-8 through CPT-12

The key laboratory soil engineering properties relevant to the design and construction of the tunnel and aerial guideways include the following:

- Gradation (fines content), index tests and classification of materials to be encountered within the tunnel envelope and the station excavations.
- Shear strength characteristics of materials anticipated within cut and cover station excavations and of materials supporting aerial guideway foundations.
- Compressibility of soils below aerial guideway supports and embankment fills.
- Corrosivity of soils within the tunnel and station zone.

Grain Size Distribution

Results of grain size distribution and fines content (percentage passing #200 sieve) tests are summarized in Table 3-4 and in Table B-1 of Appendix B. The bulk of the gradation and fines content tests were performed on selected samples from the tunnel zone (extending approximately 5 feet above the crown and 5 feet below invert of the proposed tunnel excavation). This was done primarily to identify areas of cohesionless sands and gravels which may be potentially susceptible to ravelling/running/flowing conditions.

Classification of Fine Grained Soils

Sample classifications as per USCS and ASTM guidelines accompany the borehole logs and laboratory test summary tables. Results of Atterberg Limit tests are presented in Table 3-4 and Table B-2 of Appendix B. Results show that the bulk of the fine grained material consist of clays, sandy clays and silt of low to medium plasticity with liquid limits ranging from 23 to 52, and plasticity indices ranging from 5 to 28.

Shear Strength

Laboratory direct shear tests (Table 3-4 and Table B-3 of Appendix B) performed on selected representative samples of fine grained alluvium showed peak cohesion values ranging from 500 to 2,000 psf and peak friction angles ranging from 18 to 30 degrees. The tests were performed on relatively undisturbed medium stiff to very stiff samples from depths ranging from 15 to 55 feet. Undrained shear strengths of the fine grained materials as interpreted from the CPT soundings typically range from 400 psf to greater than 20,000 psf.

Shear strength of granular soils may be estimated based on equivalent SPT blowcounts or interpreted from CPT data. Based on the CPT and SPT data, friction angles range from about 30 degrees for the loose silty sands to 45 degrees for the very dense sands and gravels.

Corrosivity

Results of corrosivity tests summarized in Table 3-4 and Table B-4 of Appendix B show that representative samples of clay, silty sand, clayey sand and silts from the 15-to 45-foot depth range are typically non-corrosive to mildly corrosive to concrete (sulfate content ranging from 32 to 187 ppm, chloride content ranging from 92 to 505 ppm, and pH ranging from 6.8 to 7.4).

Compressibility

Consolidation tests were performed on one representative sample of medium stiff clay from a depth of 55 feet and one representative sample of stiff sandy-silty clay from a depth of 35 feet, obtained from borings drilled in the aerial segment. The test results summarized in Table 5-1 indicate that the compressibility is consistent with the type of materials tested.

5.3 LIQUEFACTION POTENTIAL

The east-west segment is located in a high seismicity zone in close proximity to the Hollywood and Northridge Hills faults, each one of which has the potential for a Maximum Credible Earthquake (MCE) of Magnitude 7.5. Based on the attenuation relationship of Joyner and Boore (1982), the peak ground surface acceleration (PGA) associated with the MCE on either one of these faults is estimated to range from 0.5 to 0.6 along the alignment. The CDMG Open-File Report 92-1 (California Department of Conservation, 1992) which provides contours of estimated PGA value from MCEs in California, indicates peak accelerations ranging from 0.45 to 0.55 for the alignment.

A significant effect associated with earthquake induced ground shaking is soil liquefaction. Soil liquefaction is a phenomenon in which saturated soils (typically silts or sands) undergo a temporary loss of strength during vibrations caused by earthquakes. In extreme cases, the soil particles can become suspended in groundwater and the soil deposits become mobile with fluid like behavior. The factors known to influence liquefaction potential include: grain size, relative density of soil, groundwater level, degree of saturation, confining pressures and both intensity and duration of ground shaking.

Several areas within the project limits, where groundwater is relatively shallow, have been identified by various agencies as being potentially liquefiable (Tinsley and Others, 1985; County of Los Angeles, 1990). Significant portions of the western tunnel segment (approximately from Topanga Canyon Boulevard to Wilbur Avenue) and the central aerial segment (Los Angeles river channel area and the Sepulveda basin area) have been identified as areas of moderate liquefaction susceptibility. These areas generally correspond to areas of shallow groundwater.

A site-specific liquefaction potential evaluation based on the available borehole, CPT and groundwater information was performed, for anticipated PGAs of 0.5g and 0.55g (from a Magnitude 7.5 earthquake) for the western and central/eastern segments, respectively. The evaluation was carried out using procedures outlined by Seed et al (1983) and Seed (1987) for

liquefaction under level ground. The groundwater level was assumed to be at a depth of 15 feet BGS from Topanga Canyon Boulevard to Wilbur Avenue (western half of the western tunnel segment), and 30 feet BGS from Wilbur Avenue to the eastern end of the western segment. A seasonally high perched groundwater level 15 feet BGS was assumed for the central above-ground segment. Within the eastern tunnel segments the groundwater level was assumed to be very deep (> 100 feet).

Results of the liquefaction evaluation are presented in Table 5-2. Within the western tunnel segment, pockets of potentially liquefiable sandy layers, 5 to 10 feet thick, are evident, particularly at Borehole/CPT locations LPE-1 (Topanga Station), LPE-2, LPE-6 (Reseda station), CPT-4 and LPE-7 (White Oak Station). The potentially liquefiable layers typically occur within the 15 to 50-foot depth range.

Within the central above-ground segment, potentially liquefiable layers of silty sands and poorly graded sands are evident particularly at the Boring/CPT locations LPE-8 (Balboa Station), LPE-9 (Woodley Station), LPE-16 (Sepulveda Station) and LPE-11 (Van Nuys Station). The potentially liquefiable layers which are estimated to be up to 15 feet thick, typically appear within the 30 to 55-foot depth range. A relatively deep medium dense sand layer with the potential to liquefy and/or experience loss of strength was found from a depth of 65 to 75 feet at LPE-8.

Liquefaction is not considered likely in the eastern tunnel segment provided the groundwater levels remain relatively deep.

5.4 SOIL AND GROUNDWATER CONTAMINATION

5.4.1 Regional Soil and Groundwater Contamination in San Fernando Valley

Soil and groundwater in some portions of the eastern end of the San Fernando Valley basin, between the San Gabriel and Santa Monica mountains have been found to be contaminated with

TABLE 5-2. ALLUVIAL LAYERS WITH A POTENTIAL FOR LIQUEFACTION OR STRENGTH LOSS

(Page 1 of 2)

Alignment Segment	Borehole No./ CPT No.	Assumed Groundwater Depth	Depth Range (feet, BGS)	Material Type	Potential for Liquefaction/ Strength Loss
Western Tunnel Segment	LPE-1	15	20 - 25	clayey sand (SC)	Low
	CPT-1	15	28 - 31	sand to silty sand (SP-SM) and sandy silt (ML) layers	Low
	CPT-2 (spur line)	15	15 - 16	silty sand to sandy silt (SM-ML)	High
			32 - 40	sand to silty sand (SP-SM) interbedded with thin clayey silt (MH) layers	High
	LPE-2	15	25 - 30	clayey sand/silty sand layers (SC/SM)	Low
	LPE-3	15	65 - 71	silty sand (SM)	Moderate
	LPE-4	15	15 - 20	sandy silt/silty sand (ML/SM)	Moderate
			50 - 53	silt (ML)	Low
			65 - 72	silty sand (SM)	Low
	CPT-3	30	30 - 31	sand to silty sand (SP-SM)	Moderate
	LPE-6	30	33 - 36	silty sand (SM)	Moderate
			39 - 42	clayey sand (SC)	Low
	LPE-7	30	30 - 40	clayey sand (SC) and clayey gravel (GC) layers	Moderate
	Central Aerial Segment	CPT-13	15	50 - 57	sand to silty sand (SP-SM)
LPE-8		15	27 - 38	silty sand (SM)	High
			41 - 50	silty sand (SM)	High
			65 - 77	Sand (SP) and silty sand (SM) layers	High
LPE-9	15	25 - 35	clayey sand/silty sand (SC/SM)	High	

TABLE 5-2. ALLUVIAL LAYERS WITH A POTENTIAL FOR LIQUEFACTION OR STRENGTH LOSS

(Page 2 of 2)

Alignment Segment	Borehole No./ CPT No.	Assumed Groundwater Depth	Depth Range (feet, BGS)	Material Type	Potential for Liquefaction/ Strength Loss
Central Aerial Segment	LPE-9	15	45 - 55	clayey sand (SC)	Moderate
	LPE-10	15	35 - 40	clayey sand (SC)	Moderate
			45 - 50	Silty sand (SM)	Low
			57 - 65	Silty sand/clayey sand (SM/SC)	Moderate
	LPE-11	15	40 - 50 55 - 60	Sand (SP) silty sand (SP-SM) and clayey sand (SC) layers	High
			79 - 86	Clayey sand (SC) and silty sand (SM) layers	Low

- Peak ground accelerations of 0.5g and 0.55g were used for liquefaction analysis for the western tunnel segment and central aerial segment respectively. These accelerations which correspond to the peak ground accelerations from the MCE on adjacent faults were obtained from the CDMG Open-File Report 92-1, Peak Accelerations from Maximum Credible Earthquakes (California Department of Conservation, 1992).

total petroleum hydrocarbons (TPH), volatile organics (trichloroethene and perchloroethylene) and nitrates, according to a U.S. Environmental Protection Agency (EPA) report published in the Watermaster Service Report (ULARA Watermaster, 1993). The report indicated that four sites (North Hollywood, Crystal Springs, Pollock and Verdugo) in the region are included on the National Priorities List (NPL) as Superfund sites. Options on groundwater remediation at these sites are being considered by the EPA. Groundwater flow direction in the valley area is generally towards the southeast.

5.4.2 Review of Existing Data

In 1990, The Los Angeles County Transportation Commission conducted a pre-acquisition Phase I and Phase II Environmental Assessment (Holguin, Fahan and Associates, 1990) for the Burbank branch of the Southern Pacific Transportation Company railroad, along which most of the currently proposed alignment is located. The two phase assessment was conducted on sites located adjacent to the railroad right-of-way. The Phase I assessment included review of existing data and site reconnaissance. Based on the Phase I assessment results, 31 sites adjacent to the railroad property were selected for Phase II work. A review of the Phase II site assessment which included 2 geophysical surveys, 24 soil vapor surveys, and 48 soil borings conducted within and adjacent to the railroad right-of-way, indicated the following:

- Results of soil vapor survey and analytical testing on soil samples showed that the soil is contaminated with volatile organics (VOCs) and total petroleum hydrocarbons (TPH) at some sites located west of Canoga Avenue at Sherman Way and Saticoy Street (adjacent to the proposed spur tunnel alignment to the maintenance yard), and north and south of the railroad tracks at Van Nuys Boulevard, Hazeltine Avenue, Woodman Avenue and Lankershim Boulevard.
- Analytical tests on near surface (up to 5 feet deep) soil samples collected at a site located southwest of the railroad at Hazeltine Avenue indicated the presence of benzene, toluene, xylenes, TPH, Diesel 2 and solvents at concentrations well

above the Los Angeles City Fire Department's (LACFD) action levels for maximum concentration in soil.

- The results of a soil vapor survey performed at a site located southwest of the railroad at Lankershim Boulevard showed that VOC contamination in the soil extended south into the railroad property. A 30-foot deep boring located near the highest soil vapor concentration, however, did not show any detectable soil contamination.
- Further assessments including additional soil vapor surveys, borings, and monitoring wells are needed to evaluate lateral and vertical extent of contamination along the railroad tracks.

During field explorations we also learned that groundwater contamination (including floating product) exists at a site located immediately to the south of the alignment along Victory Boulevard, between Owensmouth and Canoga Avenues. We understand that a remediation program which includes a product extraction and flaring unit, is currently underway at this site.

5.4.3 Summary of Findings of Present Study

The environmental monitoring and testing performed during this study was limited to screening borehole samples with the OVA and some limited chemical testing of groundwater samples from two selected station locations. Our scope did not include performing a Phase I environmental assessment for the project. Previous environmental assessment performed by others (Holguin, Fahan and Associates, 1990) studied the central and eastern sections of the alignment (which follow the existing Southern Pacific Railroad right-of-way).

Soil Contamination

Soil samples collected during the subsurface investigations were visually examined and tested for volatile organics in the field using a portable Organic Vapor Analyzer (OVA). Observations of soil samples in the field did not indicate any gasoline/oil stains or odor. Also, headspace OVA readings of the samples were not significantly different from the OVA readings of the background environment. The OVA readings are presented in the boring logs (Appendix A).

Groundwater Contamination

Groundwater samples collected from two monitoring wells LPE-1 (vicinity of proposed Topanga Station) and LPE-7 (vicinity of proposed White Oak Station) were tested in an analytical laboratory to evaluate the extent of potential groundwater contamination at these sites. The analytical test results on groundwater samples are summarized in Table 3-4 and presented in Appendix C. The analytical results indicate the following:

- The groundwater sample from LPE-1 showed the presence of volatile organics [Acetone (130 ppb), Benzene (0.4 ppb), Tetrachloroethane (6.5 ppb), Toluene (0.7 ppb) and 2-Butanone (26 ppb)], semi-volatile organics [(Benzoic Acid (67 ppb), bis (2-ethylhexyl) phthalate (74 ppb) and dimethylphthalate (24 ppb)], metals and total petroleum hydrocarbons (2,980 ppb). However, only Tetrachloroethane (6.5 ppb) and bis (2-ethylhexyl) phthalate (74 ppb) exceeded the California Department of Health Services (CDHS) Maximum Drinking Water Contaminant Levels (MCLs) of 5 ppb and 4 ppb, respectively.
- The sample from LPE-7 showed the presence of volatile organics [chloroform (5.4 ppb) and toluene (0.4 ppb)], semi-volatile organics [(bis (2-ethylhexyl) phthalate (10 ppb) and dimethylphthalate (16 ppb)], metals and sulfides (0.05 ppb). However, only bis (2-ethylhexyl) phthalate (10 ppb) exceeded the CDHS MCL of 4 ppb.

6.0 DESIGN AND CONSTRUCTION CONSIDERATIONS

6.1 GENERAL

General subsurface conditions and relevant geotechnical parameters along the alignment are discussed in Section 5. This section provides a description of the key geotechnical issues and constraints that should be considered in the design and construction of the tunnel, station, and above-ground guideways. The scope of the LPE investigation carried out during this phase was limited to characterizing subsurface conditions by widely spaced borings. The current alignment is still in the planning stage and various alignment elements require further design. Therefore, the findings and discussions presented in this section are preliminary in nature and will require further refinement when additional information becomes available.

The proposed tunnels and underground stations will be within alluvium except within the western portion of the western tunnel segment, where bedrock consisting of siltstone, claystone and sandstone is anticipated within the tunnel zone, and mixed face conditions may be encountered. Soft ground/soft rock tunneling methods will be generally applicable for both of the tunnel segments except when mixed face conditions require special provisions (i.e., equipment capable of excavating higher strength sandstone and siltstone bedrock). Previous tunneling experience on other sections of the Metro Red Line in subsurface conditions similar to those in the San Fernando Valley segment indicate that the tunnel can be advanced economically and rapidly using mechanical excavation methods within a shield and with initial support consisting of precast concrete liners. The tunnel will be finished with a final lining of cast-in-place concrete. The below-ground station will be constructed by cut and cover operations with shored vertical cuts. Due to the relatively large anticipated design loads and the presence of compressible alluvial layers near the surface, the aerial guideways and aerial stations will probably be supported on deep piles or caissons bearing in the dense/stiff alluvium. The at-grade segments will be supported on existing subgrade, subgrade prepared by overexcavation and recompaction, fill embankments, or retained fills and cuts.

Key design and construction considerations associated with tunnels, discussed in this section include the following:

- Subsurface conditions and soil properties that impact tunnel design and construction (presence of bedrock, groundwater, potential running/flowing conditions, presence of cobbles and boulders, undrained shear strength, corrosivity, etc.).
- Excavation methods and temporary support
- Groundwater Control
- Impact of potential liquefaction
- Potential soil/groundwater contamination
- Potential for gas infiltration

Key geotechnical issues associated with cut and cover station design and construction, discussed in this section include the following:

- Subsurface conditions and soil properties that affect design and construction (material types, shear strength, lateral earth pressures, groundwater, corrosivity, etc.)
- Excavation methods
- Groundwater control
- Impact of potential liquefaction
- Foundation support
- Potential for soil/water contamination
- Potential for gas infiltration

Key geotechnical issues associated with the above-ground portions of the alignment that are discussed in this section include the following:

- Subsurface soil conditions and properties that affect design and construction (in situ conditions of near surface soils within at-grade portion, presence of dense/stiff alluvial layers for support of piles and caissons, corrosivity).
- Pile/caisson support
- Subgrade preparation for at-grade sections and embankments
- Impact of potential liquefaction
- Settlements
- Retained earth fills at transitions to aerial guideways and retained cuts at portals

6.2 WESTERN TUNNEL SEGMENT

The western tunnel segment will be driven primarily through fine and coarse grained alluvium, except at the western end (particularly from the Topanga Canyon Boulevard to Tampa Station) where bedrock is anticipated at various depths within the tunnel zone. Alluvial materials anticipated within the tunnel zone (approximately 30 to 50 feet BGS) are heterogeneous and will consist predominantly of medium stiff to hard clays and sandy clays interlayered with medium dense to very dense silty sands, clayey sands, poorly graded sands and gravels. The sandy materials were encountered particularly near the western (LPE-1, CPT-1, LPE-2) and eastern (CPT-3, LPE-6, CPT-4 and LPE-7) ends of the segment. Typically the sands appear to have a significant fines content (10 to 45 percent). However, several layers of poorly graded sands and gravels (up to 3 inches in size) with fines content less than 10 percent were encountered within the tunnel zone particularly at LPE-1, CPT-3 and LPE-7.

The measured groundwater levels are relatively shallow, ranging from 15 feet BGS near the western end (Topanga Canyon Boulevard to Winnetka Station) to approximately 40 feet BGS elsewhere. In some of the borings the groundwater appears to be perched within granular alluvial layers overlying clay layers. Existing data also suggests that the groundwater may fluctuate by a few feet seasonally and that some of the groundwater within the sand and gravel

layers may be under confined conditions. Groundwater should be anticipated within the tunnel excavation over the entire western tunnel segment.

The stiff to hard clay alluvium within the tunnel zone is estimated to have undrained shear strengths ranging from 1,600 to 20,000 psf (based on CPT correlations and laboratory direct shear tests). Moisture content of the alluvium measured within the tunnel zone ranges from 11 to 33 percent.

The claystone of the Modelo Formation encountered within LPE-5 was found to be moderately weathered with a consistency equivalent to very stiff to hard clays. The sandstone encountered in LPE-1 was found to be cemented and indurated and had equivalent SPT blow counts in excess of 100.

Soluble sulfate content within this segment ranges from 42 to 217 ppm. These results indicate that Type II cement should be adequate for concrete in contact with site soils.

6.2.1 Tunnel

Tunnel Excavation and Groundwater Control

It is anticipated that tunneling through most of the segment can be advanced at a relatively high rate using mechanical excavation methods within a shield. Mixed-face (alluvium - Modelo Formation bedrock) conditions are anticipated near the western end of the alignment (west of approximately Sta. 190+00) where an undulating alluvium-bedrock contact is estimated. Additional work will be required to estimate alignment intervals over which bedrock is anticipated within the tunnel zone. The claystone bedrock encountered in LPE-4 is similar in characterization to the very stiff or hard alluvium and should be excavatable with a soft rock excavator. The sandstone and siltstone bedrock (LPE-1, LPE-2) is considerably stronger. The strength of the sandstone and siltstone if encountered in the tunnel, will significantly affect the

design of the tunneling machine and advance rates, and will require evaluation in the future design effort.

Large inflows of water are possible due to the presence of groundwater (up to 35-40 feet of head) and relatively permeable coarse grained alluvial layers. Flowing sand conditions are likely where layers of poorly graded sands and gravels are encountered particularly in the vicinity of LPE-1, CPT-3 and LPE-7. Ravelling conditions should be anticipated in areas with silty and clayey sands (vicinity of LPE-1, CPT-1, LPE-2, CPT-3, LPE-6, CPT-4 and LPE-7)

Slow raveling conditions should not be a concern in a properly conducted shielded mechanical excavation, provided the initial lining support and backfilling of the tail voids are applied in a timely fashion. Fast raveling and flowing conditions will require alleviation by one or a combination of the following provisions:

- Dewatering from the surface or ahead of the excavation (the feasibility, design and cost of the dewatering system will depend upon the level of groundwater contamination, if any. Potential for groundwater contamination is discussed in Section 6.2.3)
- Use of a shield with a pressure regulated trap door
- Use of suitable earth pressure balance (EPB) machine
- Stabilization of the granular soil zones near and around the tunnel crown by chemical grouting from the tunnel face or compaction grouting (cost effective if the granular zones are localized)

The undrained shear strength of the clay layers within the tunnel zone range from 1,600 to 20,000 psf. The corresponding stability number ($N_p = \gamma z/c$) ranges from 0.17 to 3.7. This indicates that the fine grained alluvium should be relatively stable and no rapid squeezing conditions are anticipated.

Effects of Potential Liquefaction

Potentially liquefiable zones of limited thickness were identified within LPE-1, LPE-2, LPE-6, CPT-4 and LPE-7 (Section 5.3). Typically the liquefiable zones are less than 10 feet thick and occur above and within the tunnel zone. Some thin zones with a lower potential for liquefaction were also encountered below the tunnel zone. Potential impacts of liquefaction may include localized loss of support around the tunnel, and settlements on the order of a couple of inches. The lined tunnel is not expected to experience any significant adverse impacts due to potential liquefaction. Liquefaction is not considered a significant factor in the design of the tunnel.

6.2.2 Cut-and-Cover Stations

Five cut and cover stations (Topanga, Winnetka, Tampa, Reseda and White Oak) are proposed within this segment. The proposed Topanga Station will be located below Victory Boulevard. The other four stations will be located below the abandoned Southern Pacific Railroad right-of-way. A portion of the Winnetka Station will be located below Winnetka Avenue. The subsurface conditions (Figure 4-10a) indicate that the foundation slab for the Topanga and Tampa stations may be partially or totally founded on bedrock of the Modelo Formation. Bedrock may also be exposed within the excavation for the Winnetka Station, although none was encountered in the boring (LPE-3) at this location. The remaining stations will be supported entirely within the alluvium. The subsurface conditions along this alignment portion and the planned excavation depth indicate that cut-and-cover excavation can be rapidly and economically achieved using mechanical excavation methods and readily available equipment.

Shoring Requirements

Shoring will be required due to the proximity of the stations to existing buildings and roads and limited construction space along the alignment. Various shoring systems may be applicable. These include various temporary walls (sheet pile, soldier pile, precast, slurry, etc.) supported by tiebacks, anchors, or internal bracing struts. The most appropriate shoring system depends

on subsurface conditions, excavation geometry, the dewatering scheme, construction procedures, characteristics of nearby buildings, and local experience. Based on local practice in the Los Angeles area with subsurface conditions similar to those encountered within the site area, soldier piles and lagging walls with tiebacks or internal bracing (struts and wales) are the most likely shoring systems. Since most of the needed data for shoring designs are either preliminary in nature or yet to be defined, further work will be required for final design of appropriate shoring systems.

Dewatering Requirements

All of the station excavations extend below measured groundwater levels. Thick layers of relatively permeable silty sands, sands and gravels are anticipated below the groundwater level particularly at the Topanga, Reseda and White Oak stations. Therefore, substantial groundwater inflows are likely to occur during the station excavation.

Groundwater control provisions (dewatering) prior to and during excavation in this area will likely be required. Additional field exploration, field permeability testing and water quality testing will be required prior to designing a suitable dewatering system. The feasibility, design and cost of the dewatering system will be governed by the type and extent of groundwater contamination, if any. Groundwater contamination potential is discussed in Section 6.2.3.

Bottom Stability and Foundation Support

In general, the materials exposed at the bottom of the excavations will predominantly consist of stiff to very stiff fine grained alluvium, medium dense to dense coarse grained alluvium and weathered to fresh Modelo Formation bedrock. Layers or pockets of medium dense to very dense granular alluvium (silty sands, clayey sands, sands, and gravels) may be exposed at the bottom of the station excavations particularly at Topanga, Reseda, and White Oak stations. Due to the shallow groundwater conditions, the potential exists for bottom instability due to heaving,

hydraulic uplift or piping, unless the groundwater is lowered or appropriate sheetpiling techniques are used.

In general, the materials encountered at the foundation level will provide adequate foundation support for the proposed structure. However, foundations may straddle transitions between bedrock and alluvium (sands and clays), with varying bearing (strength) and compressibility characteristics. Under such conditions, some foundation preparation measures such as overexcavation and recompaction may be necessary to limit potential differential settlements. Appropriate foundation types will depend on structure-loading characteristics which are not defined at this time. Foundation design should be performed after further structural and station-specific subsurface information becomes available.

Most of the planned stations along this alignment portion will be close to existing structures and/or streets generally supported on foundations located above the planned depths of station excavation. Thus, provisions to protect these existing structures from damages due to station construction must be considered in the design and construction of the planned stations.

Other Design Considerations

Potentially liquefiable granular alluvium layers were encountered in the vicinity of the Topanga, Reseda and White Oak stations (Table 5-2, Section 5.3). Potentially liquefiable layers or pockets may also occur at other station locations. Most of the liquefiable layers encountered appear to be located above the station bottom elevation. Impacts of potential liquefaction may include loss of vertical and lateral support, increased lateral earth pressures, increased buoyancy and settlement. A more detailed liquefaction evaluation should be performed at these station locations. Station design should take into consideration the impacts of potential liquefaction.

6.2.3 Soil/Groundwater Contamination

Limited chemical tests on groundwater samples from LPE-1 (Topanga Station area) and LPE-7 (White Oak station area) indicated the presence of volatile and semi volatile organics slightly above the maximum contaminant levels for drinking water. The dewatering system design for these two stations should take into consideration the water quality and how it impacts disposal options. The groundwater quality should also be evaluated at all of the other stations within this segment. We are aware of groundwater contamination and presence of floating product at a site immediately to the south of the alignment on Victory Boulevard between Owensmouth Avenue and Canoga Avenue. Additional monitoring wells should be installed within the alignment in this area to evaluate the quality of groundwater within the tunnel alignment. The presence and extent of contamination will determine the type of tunnel excavation/dewatering system planned for this segment. The contaminant plume at this location may also have the potential to impact groundwater quality at the Topanga Station.

Headspace monitoring of soil samples did not indicate the presence of volatile organic compounds. Pre-acquisition environmental assessment for the Southern Pacific Railroad indicated the potential for soil contamination adjacent to the spur line, where the railroad intersects Vanowen Street and Sherman Way. The portal area for the spur line tunnel is located near Vanowen Street and may be impacted by the contamination in the area. In the vicinity of Sherman Way the spur line is proposed as an above-ground section.

A detailed environmental site assessment should be performed to identify areas of potential soil and/or groundwater contamination, evaluate contaminant levels and limits of contamination along the alignment. Based on these studies, proper procedures for disposal of contaminated spoils and groundwater should be developed.

OVA readings were not significantly above background levels (generally less than 5 ppm above background readings) within this segment. However, the potential for encountering hydrocarbon gases (especially methane) is present over a large portion of the Los Angeles area. Our scope of work did not include such evaluations.

6.3 CENTRAL AERIAL SEGMENT

The upper 25 to 35 feet of alluvium underlying this segment appears to consist predominantly of medium stiff to very stiff clays, sandy clays and silts with occasional sand layers. The fine grained alluvium is underlain by of medium dense to very dense sand layers and stiff to hard silt and clay layers. The thickness of individual sand layers ranges from a few feet in some areas (CPT-6, CPT-7) to 15 to 25 feet over most of the segment (CPT-13, LPE-8, CPT-5, LPE-9, LPE-10, LPE-11). The depth to bedrock in this area is anticipated to range from 230 to 500 feet. Perched groundwater was encountered at depths of 35 to 45 feet BGS. Considerable fluctuations of the perched water level are anticipated.

The loose and medium dense sands are vulnerable to liquefaction and/or strength loss particularly under the maximum credible earthquake. Layers with a potential for liquefaction and strength loss occur in CPT-13, LPE-8, LPE-9, LPE-10 and LPE-11. Some of these layers occur at significant depths (up to 55 to 75 feet BGS). Pile foundations should therefore extend below these depths in this area.

Results of corrosivity tests indicate that site soils are not excessively corrosive to concrete. Therefore, Type II cement should be adequate for concrete in contact with on site soils. Additional corrosivity tests including electrical resistivity tests should be performed to evaluate corrosion potential towards metals.

6.3.1 Aerial Guideway Support

Aerial guideways and above-ground stations are planned from Sta. 324+60 to Sta 401+00 and from Sta. 439+00 to 512+30. Due to the relatively high structural loads and the presence of relatively compressible near-surface clay layers, the aerial guideway columns will most likely have to be supported on driven piles or caissons.

The boring data indicate that a bearing layer capable of supporting piles in end bearing does not exist at a uniform depth over the entire segment. At some of the borehole locations relatively thick, dense to very dense sand layers capable of supporting large diameter piles/caissons in end bearing were encountered at depths ranging from about 30 feet (at CPT-5) to about 70 feet (at LPE-10, CPT-7, LPE-11). At other locations, the sand layers were either medium dense and potentially liquefiable, or not thick enough to support such piles within this depth range (CPT-13, LPE-8, LPE-9, CPT-10). In these areas pile foundations options may include the following: use of friction piles that mobilize their capacity primarily from shaft resistance; use of smaller diameter piles that do not require a very thick sand layer for bearing support; and use of very long piles (up to 100 feet or more in length).

Other geotechnical constraints to be considered in the design and construction of pile foundations include the following:

- Caving conditions should be anticipated within sand layers (particularly below the water table) in drilled holes. The use of casing or slurry construction techniques may therefore be required for cast-in-place pile construction.
- Presence of gravel layers (particularly towards the eastern end of the segment) above the design tip elevation may impede driving (particularly in the case of concrete piles).
- Local noise abatement requirements may restrict or limit pile driving by impact hammers

Different pile types may be necessary over various portions of this segment. Additional subsurface information and design load data will be required before pile design recommendations can be made.

The design of the aerial guideway system should take into consideration the relatively high peak ground accelerations associated with the design earthquake.

6.3.2 At-Grade Sections

At-grade sections are proposed approximately from the Los Angeles River Flood Control Channel to Balboa Boulevard, and approximately from the San Diego Freeway crossing to Sepulveda Boulevard. At-grade sections, as referred to herein, include sections of the alignment that are proposed at existing grades, sections where embankment fills up to 10 feet thick are planned, and transition sections to aerial guideways (retained fill guideways with up to 15 feet of fill) and tunnel portals (retained cut sections up to 40 feet below ground). The at-grade section will also include a bridge crossing over the Los Angeles River flood Control Channel.

The foundation for sections proposed at the existing grade can be prepared by overexcavating the underlying loose/soft fill or alluvial materials until a suitable layer such as medium dense to dense sands or medium stiff to stiff clays is reached, and by replacing the overexcavated materials by granular non-expansive fill compacted to a minimum 90 percent relative compaction. The depth of overexcavation may vary, but, in general, is expected to be on the order of 5 feet. Some of the overexcavated materials may consist of expansive clays that would not be suitable as replacement fill.

The embankment portions of this segment may be constructed by placing compacted fill embankments on subgrade prepared as specified above. Embankment fills should consist of granular non-expansive materials compacted to a minimum relative compaction of 90 percent. In general, fill slopes should be constructed no steeper than 2:1 (horizontal to vertical). The alluvial materials immediately underlying the fill consist predominantly of medium stiff to very

stiff clays and silts (up to a depth of approximately 25 to 35 feet). Total estimated settlements of fine grained alluvium would be in the order of 12 inches. These settlement estimates are preliminary. Additional investigations and laboratory testing and analyses should be performed to refine the settlement estimates.

Most of the aforementioned settlement is anticipated to occur during construction. If post-construction settlements are found to be excessive, measures to limit these settlements to within acceptable range include one or a combination of the following:

- a) allow sufficient waiting period after grading of embankment before construction of improvements
- b) Preload the embankment area with a surcharge
- c) Accelerate settlement by installing vertical drains

Because of space limitations, transitions from the at-grade segments to the aerial guideways are anticipated to be retained earth fills. Retained earth fills would require construction of retaining walls up to 15 feet in height. Pile foundations may be required for these retaining walls. As a cost-effective alternative, near-vertical fill slopes may be constructed by using reinforced earth fills. Reinforced earth fills are constructed using granular fill materials reinforced by metal reinforcing strips or geosynthetic grids, and a concrete facing. Retained earth fills would experience consolidation settlements similar to the earthfill embankments, as discussed above.

Tunnel portal transitions are planned as retained earth cuts. This will require retaining walls up to 40 feet in height. As a cost effective alternative to retaining walls, vertical or near vertical soil nail walls may be considered. Soil nail walls are constructed by grouting small diameter rebars at relatively close spacing into the vertical cut face. The face of the excavation is then protected by concrete facing.

Effects of liquefaction on the at-grade portions are expected to be minor, and would consist primarily of settlements. Maximum cumulative thickness of liquefiable layers is estimated to be on the order of 10 to 15 feet. Liquefaction-induced settlement in these areas are estimated at approximately 2 to 4 inches.

An approximately 400-foot span bridge will be required to cross the Los Angeles River Flood Control Channel. The upper 45 feet of material underlying the channel banks consist predominantly of medium stiff to very stiff fine-grained materials (CPT-13). This is underlain by a 15-foot thick dense sand layer. Bridge abutments and piers will most likely be supported on pile foundations. Piles may be supported on the dense sand layer approximately 50 feet BGS provided this layer is continuous over the entire bridge site. Additional field investigations will be required for the design of the bridge.

6.3.3 Potential Soil/Groundwater Contamination

In general, headspace OVA measurements on soil samples in this segment did not indicate presence of significant volatile organics contamination (OVA readings were no more than 5 ppm above background levels). However, results of the pre-acquisition Phase I site assessment along the Southern Pacific Railroad right-of-way within this segment (Holguin, Fahan and Associates, 1990) indicated the presence of near-surface volatile organic soil vapor in the vicinity of Van Nuys Boulevard and Hazeltine Avenue. Analytical tests on near-surface (up to 5 feet deep) soil samples near Hazeltine Avenue indicated presence of benzene, toluene, xylene, TPH, Diesel and solvents above LACFD action levels. At Van Nuys Boulevard the alignment is an elevated guideway. Near Hazeltine Avenue the alignment will be located within a retained cut guideway (portal to eastern tunnel segment). Construction activities (possible caisson excavations near Van Nuys Boulevard and partial excavation near Hazeltine Avenue) at the above locations have a high potential for being impacted by soil contamination. An environmental site assessment is recommended to characterize, and delineate areal and vertical extent of contamination in these and other potentially contaminated areas.

6.3.4 Potential for Gas Infiltration

Design and construction considerations associated with the potential for gas infiltration discussed in Section 6.2.4 for the Western tunnel segment apply for tunnel portal and caisson excavations in this segment also.

6.4 EASTERN TUNNEL SEGMENT

The Eastern tunnel segment will be driven entirely through the alluvium. Alluvium within the tunnel zone (approximately 30 to 50 feet BGS) in this segment is heterogeneous and predominantly consists of medium dense to very dense silty sands, clayey sands, gravelly sands, poorly graded sands, and gravels interlayered with stiff to hard sandy silt, clayey silt and sandy clays. Significant thicknesses of poorly graded, relatively clean sands were encountered in CPT-9 near the western end of the segment, and in CPT-12 and LPE-14 near the eastern end of the segment. Isolated thinner layers of poorly graded sands were also encountered elsewhere along the alignment. Available data indicate that the sands at the eastern end of the segment had fines content in the range of 4 to 8 percent. CPT-8, CPT-10, CPT-11 and CPT-12 encountered refusal within or slightly below the tunnel zone, indicating the presence of gravels or cobbles. Previous investigations near the eastern end (Lankershim Boulevard) of the segment indicated the presence of gravelly sands, sandy gravels, cobbles and boulders (estimated to be up to 4 feet in size) within the proposed tunnel zone particularly below a depth of approximately 40 feet).

The silty sands and clayey sands encountered within the tunnel zone had fines contents ranging from 25 to 50 percent. The stiff to hard silts and clays within the tunnel zone are estimated to have undrained shear strengths ranging from 2,000 to 25,000 psf (based on CPT correlations and laboratory direct shear tests). Moisture content of the alluvium measured within the tunnel zone ranges from 13 to 20 percent.

The only piezometer installed in this segment (LPE-4) has remained dry since the investigation. Groundwater was also not apparent in any of the other boreholes in this segment. The regional

groundwater is relatively deep in this area, and was measured at approximately 140 feet BGS at the eastern end. However, historically this was an area of high groundwater, which was lowered dramatically due to groundwater pumping in this area. Therefore, the potential exists for a large increase in groundwater levels in this area over the long term, if pumping/recharging patterns change. Also, there may be a potential for perched groundwater zones particularly towards the western portions of the segment where clay layers are present. Additional piezometer installation and monitoring are recommended for this segment.

Available aerial photographs and literature indicate the possible presence of an unnamed fault that projects across the alignment near the eastern end of this segment. This fault may be active as recently speculated by some investigators. Additional investigations including field explorations are required to evaluate this fault.

Soluble sulfate content within the tunnel zone ranges from 96 to 271 ppm. These results indicate that Type II cement should be adequate for concrete in contact with site soils.

6.4.1 Tunnel

Tunnel Excavation

Tunneling can be advanced at a relatively high rate using mechanical excavation within a shield. Running conditions should be anticipated in the vicinity of CPT-9, CPT-10, CPT-12, and LPE-14 where poorly graded sands and gravels are present. Slow raveling conditions may exist everywhere else within this segment due to the presence of silty sands and clayey sands. Slow raveling conditions should not be a concern in a properly conducted shielded mechanical excavation, provided the initial lining support and backfilling of the tail voids are accomplished in a timely fashion. Running conditions may require stabilization measures ahead of the tunnel face. The potential for encountering coarse gravels (up to 3 inches in size) and cobbles exists over most of this segment, but increases towards the eastern end. Boulders up to 4 feet in size should be anticipated near the eastern end of the segment. The presence of boulders will

significantly reduce the rate of advance. The zone over which boulders are present and their size distribution should be evaluated.

The undrained shear strengths of the clay and silt layers within the tunnel zone range from 2,000 to 25,000 psf. The corresponding stability number ($N_p = \gamma z/c$) ranges from 0.16 to 3.3. This indicates that the fine grained alluvium should be stable and no rapid squeezing conditions are anticipated.

Other Considerations

The tunnel segment crosses underneath the Chandler Boulevard overhead of the 170 Freeway. Tunnel excavations may be within the zone of influence of overhead structure foundations. The types and locations of these foundations should be considered in planning the tunnel excavations, and designing underpinning measures, if needed.

6.4.2 Cut-and Cover Station

Two cut-and-cover stations (Fulton-Burbank and Laurel Canyon) are proposed within this segment. Portions of the Fulton-Burbank Station will be located below Fulton Avenue and Burbank Boulevard, while part of the Laurel Canyon station will be located below Laurel Canyon Boulevard. Dense silty sands and/or hard sandy silts are anticipated at the bottom of the excavation (LPE-12 and LPE-13). The excavation will be predominantly through loose to dense silty sands, clayey sand, poorly graded sands and gravels, and stiff to very stiff sandy silts and clays. Piezometers or monitoring wells were not installed at either of these station locations. However, as discussed above, the regional groundwater table in this section is relatively deep. Piezometers should be installed at both station locations to record potential presence and fluctuation of perched groundwater. Cut and cover excavations can be rapidly and economically achieved under these conditions using mechanical excavation methods and readily available equipment. The excavation method should take into consideration the presence of very dense gravel layers and cobbles.

Shoring Requirements

The excavation for the cut-and-cover station will extend to a maximum depth of about 60 feet below the ground surface. The proximity of the excavation to adjacent roads and buildings, limited construction space, and the subsurface conditions in the general area indicate that shoring will be required.

Various shoring systems exist in engineering practice. These include sheet pile, soldier pile walls with tiebacks or internal bracing, and structural slurry. Based on local practice in the Los Angeles area and for subsurface conditions similar to those encountered at the site, soldier pile and lagging walls with tiebacks or internal bracing (struts and wales) are the most likely shoring systems. Design and construction of the shoring system should take into consideration the presence of caving sands, gravel layers and cobbles. Additional investigations including monitoring for presence of perched groundwater will be necessary prior to final design of an appropriate shoring system.

Foundation Support

The dense silty sands and/or hard sandy silts anticipated at the foundation level will provide adequate foundation support for the station structures. However, some foundation preparation such as overexcavation and recompaction may be necessary where pockets of relatively compressible materials exist or where the foundation spans a transition between very dissimilar materials.

Appropriate foundation types will depend on structure loading characteristics which are not defined at this time. Thus, appropriate foundation design should be performed after further structural and station-specific subsurface information becomes available.

The planned stations along this alignment portion will be very close to existing streets and/or structures. Most of these structures are generally supported on foundations located above the

planned depths of station excavation. Thus, provisions to protect these existing streets and structures from potential damage due to station construction must be considered in the design and construction of the planned stations.

6.4.3 Soil/Groundwater Contamination

Headspace monitoring of samples within this segment did not indicate the presence of significant levels of volatile organic vapors (in general OVA readings were no higher than 2 ppm above background levels). The Phase II environmental assessment for the Southern Pacific Railroad right-of-way (Holguin, Fahan and Associates, 1990) indicated the presence of volatile organic soil vapors in the vicinity of Woodman Avenue and Lankershim Boulevard. Further investigations should be performed to evaluate the nature and extent (areal and vertical) of contamination in these areas.

The groundwater within the North Hollywood area is known to be contaminated. However, the groundwater levels in the area of this proposed tunnel segment are well below the proposed tunnel depths.

6.4.4 Potential for Gas Infiltration

Design and construction considerations associated with potential gas infiltration, discussed in Section 6.2.4 for the Western tunnel segment, apply for this segment also.

7.0 CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

Although more detailed geotechnical investigation programs will be needed to support the future engineering effort for the proposed San Fernando Valley East-West Segment, the results of this limited preliminary engineering investigation have provided a needed database for a general understanding of the geologic and geotechnical conditions, and a preliminary understanding of associated engineering parameters and potential ground behavior along the alignment.

As previously described, the alignment can be divided into the following three segments based on facility types and subsurface conditions.

- Western tunnel segment, consisting of about 5.6 miles of twin-tunnels and extending easterly from the western terminus at Topanga Canyon Boulevard to the Los Angeles River.
- Central aerial segment consisting of about 3.0 miles of aerial guideway and 1.2 miles of at-grade guideway extending easterly from the Los Angeles River to Hazeltine Avenue.
- Eastern tunnel segment consisting of about 4.2 miles of twin tunnels extending easterly from Hazeltine Avenue to the eastern terminus at Lankershim Boulevard.

Based on the results of this investigation, and design and construction experience under similar subsurface conditions, it is our opinion that the subsurface conditions along most of the western and eastern tunnel segments are favorable for conventional soft ground tunnel construction techniques using mechanical excavation methods within a shield similar to those used in the current tunnel construction along the Metro Red Line Segments 1 and 2. However, there exist

a number of concerns in localized areas along the alignment which will either slow tunnel progress or create difficult face stability problems requiring special construction equipment and provisions. Along the western tunnel segment, these conditions include mixed face conditions (between alluvium and bedrock), shallow groundwater, large inflow (when granular alluvium is encountered), and the local presence of granular alluvium (flowing and running conditions in relatively clean sand and gravel as well as ravelling conditions in silty sand and clayey sand). The conditions along the eastern tunnel segment include the presence of granular alluvium (running and ravelling conditions), the presence of boulders potentially up to 4 feet in size, and possibly the presence of localized perched groundwater. In addition to safety and stability concerns, large size boulders may require splitting in the face or on the mucking conveyor.

The subsurface conditions along the western and eastern tunnel segments indicate that cut-and-cover excavation/construction of the proposed stations can be accomplished at a relatively high rate using mechanical excavation methods with readily available equipment and conventional shoring provisions. Preconstruction dewatering will be required for most of the stations along the western tunnel segment, where groundwater levels are expected to be above the bottoms of the station excavations. Additionally, potentially liquefiable layers and pockets of granular alluvium are anticipated in the station areas in the western tunnel segment. Potential liquefaction will induce additional lateral pressure and settlement and will cause a reduction of vertical and lateral ground support. These effects should be considered in the station design.

Available environmental site assessment data by others and limited chemical tests on groundwater samples obtained in this investigation indicate potential groundwater and soil contamination in some areas along the western tunnel segment. In addition to impacting soil and groundwater disposal, the contamination will affect the details and requirements of construction dewatering, and should be addressed in the next phase of the studies.

Aerial guideways in the above-ground segment are anticipated to be supported by piles or caissons. Depending on the density and thickness of granular materials for end-bearing purposes, these pile/caisson supports will be designed as either end bearing or friction piles/

caissons. Pockets and layers of liquefiable granular materials are anticipated at various locations and depths. Potential liquefaction effects will require consideration and incorporation in the future support design.

Embankments and retained earth fills underlain by fine-grained alluvium will experience significant settlements. Measures such as preloading, surcharging and installation of vertical drains may be necessary to limit post-construction settlements to acceptable levels.

Except for the proposed 400-foot span bridge crossing the Los Angeles River, conventional shallow foundation support for at-grade facilities are anticipated. Overexcavation of loose/soft materials and recompaction are also anticipated for subgrade preparation in some of the areas. Bridge abutments and piers will most likely be supported on end-bearing piles founded on the dense sand layer encountered about 50 feet below the ground surface.

7.2 RECOMMENDATIONS

A more detailed investigation program consistent with the level of design (preliminary/final design) will be needed to develop additional site- and structure-specific design recommendations. The details of future investigations should include geotechnical, geophysical, hydrogeologic and environmental assessments. It is recommended that these investigation programs include, but not be limited to, the following:

- Performing closely spaced geotechnical borings and CPT soundings along the entire alignment for a more detailed understanding of the subsurface soil conditions.
- Conducting a geophysical investigation program to evaluate the soil-bedrock contact along the western tunnel segment, especially the portion west of Station 190+00.

- Performing subsurface explorations to evaluate the unnamed fault located near the eastern end of the Eastern tunnel segment.

- Installing additional monitoring wells to better define the groundwater regime including groundwater levels and quality along the entire alignment with emphasis on the western tunnel segment and the eastern tunnel segment (perched conditions).

- Drilling a number of large diameter boreholes using bucket augers to further evaluate the extent and size distribution of boulders along the eastern portion of the eastern tunnel segment.



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