WESTSIDE SUBWAY EXTENSION PROJECT
Contract No. PS-4350-2000

Century City Area Fault Investigation Report

Volume 1 of 2

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Metro

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November 30, 2011 (Rev 1)

Revision Log

Revision #	Revision Date	Revision
0	October 14, 2011	Original
1	November 30, 2011	• References Page 32 – added reference • Plate 3 Appendix B – Deleted Boring and Cone Penetrometer Test Locations not excavated. • Appendix C-2 – Added Rotary Wash Boring and Cone Penetrometer Test Logs, See Appendix Cover

Table of Contents

Volume 1

List of Figures

List of Tables

Table of Contents

Volume 2

Acronyms and Abbreviations

AA	Alternatives Analysis
ACE	Advanced Conceptual Engineering
AP	Alquist-Priolo
BHHS	Beverly Hills High School
CGS	California Geological Survey
CPT	Cone Penetrometer Test
EIR	Environmental Impact Report
EIS	Environmental Impact Statement
LPA	Locally Preferred Alternative
MDE	maximum design earthquake
ODE	operating design earthquake
PE	Preliminary Engineering
USGS	United States Geological Survey
WBHL	West Beverly Hills Lineament

EXECUTIVE SUMMARY

On October 28, 2010, the Metro Board approved the Draft Environmental Impact Statement/ Environmental Impact Report (EIS/EIR) for the Westside Subway Extension Project (the Project), which included two tunnel alignment options through the Century City area. The proposed station locations would be on either Constellation Boulevard or Santa Monica Boulevard, but both would be centered on the Avenue of the Stars. During the October 28 meeting, Metro staff expressed concerns related to the potential impact of the Santa Monica fault zone on the proposed Santa Monica Boulevard Station. (Additional investigations were being planned to locate the fault zone near the station.) Concerns were also expressed at the meeting regarding the safety of tunneling under Beverly Hills High School (BHHS), which would be required for the proposed Constellation Boulevard Station.

To address the tunneling safety concerns, the Metro Board approved the following motion from Supervisor Yaroslavsky to be undertaken during preparation of the Final EIS/EIR. Specific items in the Board motion included the following:

> *... that in the West Beverly Hills to Westwood area:*
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> - *Staff fully explore the risks associated with tunneling under the [Beverly Hills] High School, including but not limited to the following: risk of settlement, noise, vibration, risks from oil wells on the property, impact to use of the school as an emergency evacuation center, and overall risk to student faculty and community;*
> - *"Staff analyze the possibility of moving the subway tunnel in order to avoid all school buildings and avoid any future plans to remodel BHHS.*

In addition, Metro staff was directed to fully investigate the nature and location of faults in the Century City area and their potential impact on the proposed station locations. The resulting conclusions from both the tunnel safety and fault studies would provide a basis for the Board to make a decision on which proposed station to adopt. The resulting studies have been completed and presented in two separate reports: the *Century City Area Tunneling Safety Report*—which addresses the issues surrounding the safety of tunneling under and near BHHS, West Beverly Hills, Century City, and Westwood—and this report, the *Century City Area Fault Investigation Report.*

Purpose of Investigation

The purpose of this fault investigation was to determine the location of active faults in the vicinity of the Century City station options and tunnel alignments. The tunnel alignment options in the Century City/West Beverly Hills area cross two mapped fault zones—the Santa Monica fault zone and the West Beverly Hills Lineament (WBHL) fault zone. The Santa Monica fault zone is known to have had zones of ground rupture within the last 11,000 years (Holocene age). A prominent scarp (step in the topography) can be traced continuously from Century City to Pacific Palisades. It marks the active strand of the Santa Monica fault zone, and provides the most definitive evidence of the fault's Holocene activity. However, until this study was undertaken, the location of the active strand(s) of the Santa Monica fault zone in the Century City/West Beverly Hills area had not been specifically evaluated through subsurface geologic investigations. The WBHL, a linear topographic feature to the east of Century City, was suspected to be a fault and to be the northern extension of the Newport-Inglewood fault zone. Until this study was undertaken, no subsurface investigation had been conducted to determine its precise location or existence as an active fault.

Because the alignments for the Project will necessarily cross active fault zones, the tunnels will be designed to accommodate fault deformation. Neither the Santa Monica fault zone nor the WBHL have been mapped as active Fault Zones under the Alquist-Priolo Earthquake Fault Zoning Act. Since subway stations are structures for human occupancy, they should not be built on active fault/deformation zones because of life/safety concerns expressed in state regulations and in Metro design criteria.

Field Investigations

Geotechnical studies conducted during the Final EIS/EIR in 2011 consisted of 56 core boreholes and 192 Cone Penetrometer Test (CPT) soundings along 7 transects (study lines), and 5 seismic reflection profiles along the same 7 transects in the Century City area. This fieldwork focused on the two fault zones (the Santa Monica and the WBHL) that would potentially be intersected by the tunnel alignment options and would impact the proposed station locations.

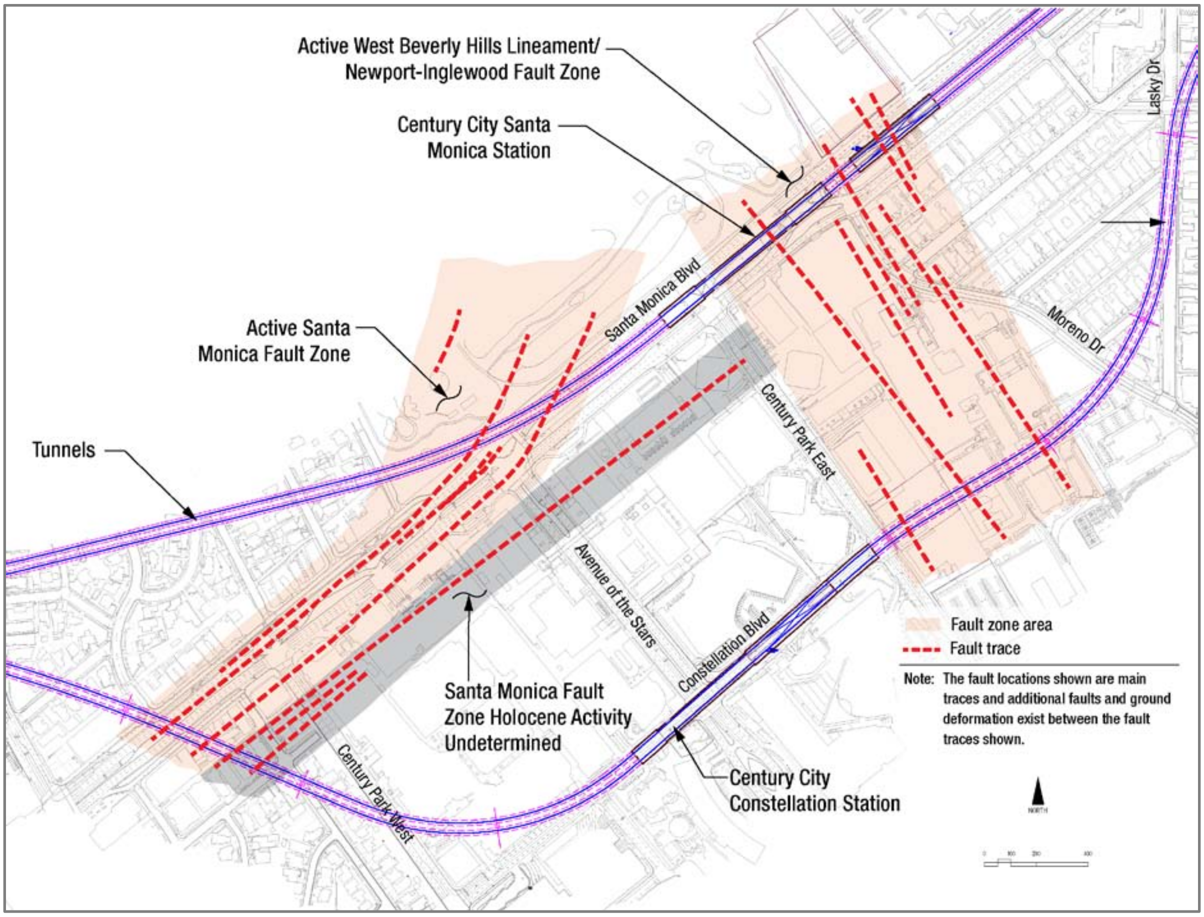
Analysis

Detailed analyses of the newly acquired geotechnical data (specifically, the CPTs and seismic reflection profiles that show displacements in the youngest strata present in the area) determined that the active traces of the Santa Monica fault zone (Figure 1) would pass through the proposed station location on Santa Monica Boulevard at Avenue of the Stars. For this reason, it was recommended that this station location no longer be considered an option. In contrast, no faulting was found passing through or in close proximity to the proposed Constellation Boulevard Station.

A subsequent station option was proposed to shift the station along Santa Monica Boulevard farther east, centered between about Century Park East and Moreno Drive. A section of a prominent scarp on the grounds of the Los Angeles Country Club suggested that the active traces of the Santa Monica fault zone might pass to the north of this proposed east-shifted station. However, the active strands could also be somewhat south of the scarp and closer to the proposed station location if erosion (by drainages emanating from Benedict Canyon) has modified the location of the scarp relative to the active traces.

Of more specific concern to the proposed Santa Monica Boulevard (east) Station is the WBHL. The new CPT and seismic data show clear evidence that the WBHL is a wide zone of faulting (Figure 1) that displaces the youngest (late Pleistocene) strata that are present in this area. The proposed Santa Monica Boulevard (east) Station would straddle the zone of faulting along the WBHL. In addition, the Santa Monica fault zone must intersect the WBHL in the vicinity of Santa Monica Boulevard near Moreno Drive or within the Los Angeles Country Club to the north. Zones of fault intersection are likely to be areas of significant structural complexity, including the likelihood of secondary faulting, folding, and distributed off-fault deformation. For these reasons, it is recommended that the proposed Santa Monica Boulevard (east) Station no longer be considered.

Figure 1: Fault Zone



With respect to the activity of the faults, both the Santa Monica fault zone and WBHL show clear evidence of post-middle to late-Pleistocene activity in the study area. Moreover, the topographic scarp associated with Holocene activity and characterizing the surface traces of the active strands of the Santa Monica fault zone has been studied west of the I-405 freeway, where trenching revealed evidence for a 300-foot-wide zone of faulting. There, geologists found definitive evidence of folding associated with slip on the main strand from 1,000 to 3,000 years ago, and surface slip on other strands of the fault from 10,000 to 17,000 years ago. If the WBHL is considered the northern extension of the Newport-Inglewood fault zone, then, by virtue of the Newport-Inglewood fault zone being Holocene active, it is also considered active.

Based on a regression analysis of maximum magnitude versus fault length for past earthquakes, the Santa Monica fault zone is capable of generating earthquakes in the magnitude range M6.9 to M7.2, with average surface displacements of approximately 3 to 6 feet. A major event on the WBHL might be between M6.4 (generally the lower end of the magnitude range for surface rupture) and M7.2, also with average surface displacements of up to 3 to 6 feet, depending on the length of rupture on the northern-most portion of the Newport Inglewood-WBHL fault zone.

Conclusions

Analysis of borings, CPT data, and seismic reflection profiles along 7 transects, in conjunction with mapped topographic landforms, have identified two active fault zones in the Century City area: the northeast-southwest trending Santa Monica fault zone and the northwest-southeast trending WBHL. Santa Monica Boulevard effectively lies within the Santa Monica fault zone from west of Century Park West to east of Avenue of the Stars. The originally proposed Santa Monica Boulevard Station at Avenue of the Stars would be directly within the fault zone.

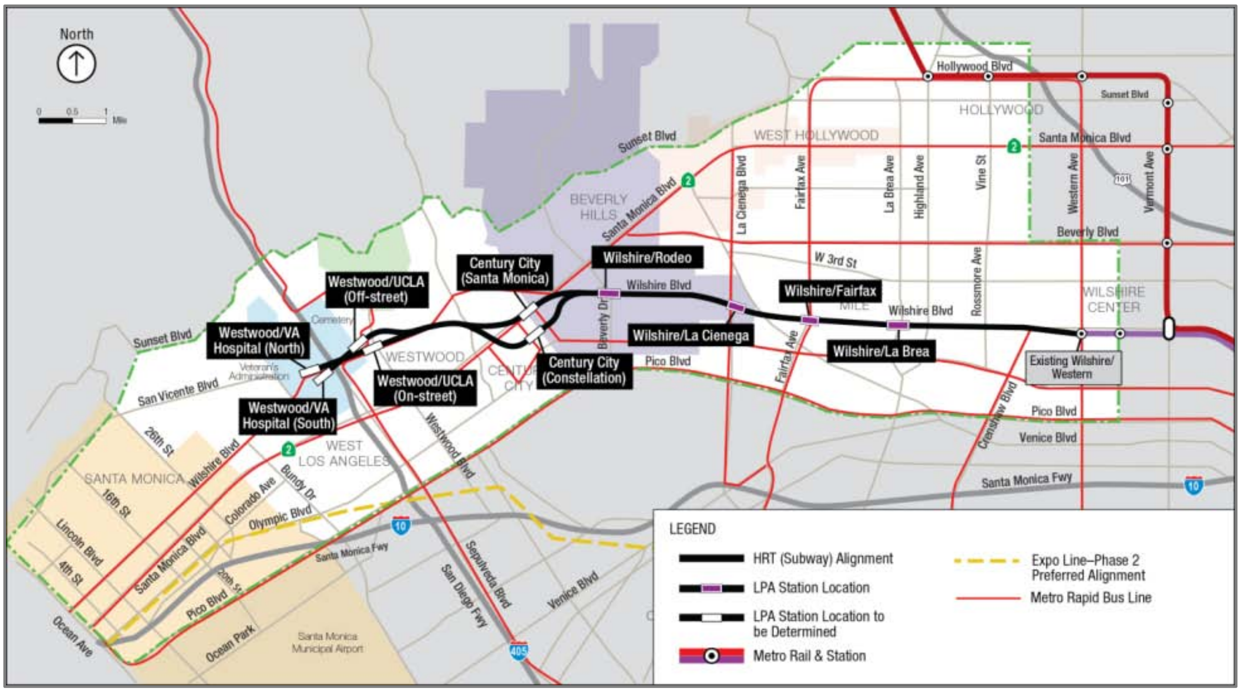
The WBHL is a wide fault zone with several well-defined strands situated along the eastern margin of Century City. It is the inferred northern extension of the active Newport-Inglewood fault zone. The WBHL terminates the active Santa Monica fault to the east. The location of the proposed Santa Monica (east) Station would straddle the WBHL.

No evidence of faulting was found on the proposed Constellation Boulevard Station site. Based on the results of these fault investigations, there is clear evidence that the proposed station locations on Santa Monica Boulevard (both east and west) would be in active fault zones, and are not viable options for station locations. The proposed station on Constellation Boulevard would not be within an active fault zone and is a viable option for a station location.

1.0 INTRODUCTION

Planning and engineering studies for the Westside Subway Extension Project (the Project) are considering two options for a Century City station: Constellation Boulevard and Santa Monica Boulevard (both centered on the Avenue of the Stars) and associated tunnel alignments. These two options remain after an analysis of more than 17 alternatives in the Alternatives Analysis [1] study and further consideration of the remaining options after circulation of the Draft Environmental Impact Statement/ Environmental Impact Report (EIS/EIR). The recommendation for the station location will be based primarily on planning and engineering technical studies. This report, in two volumes, presents results of an assessment of active faulting in the Century City area. Figure 2 shows a schematic plan of the Project and the options remaining for station locations. Other technical reports document studies for tunneling safety, ridership forecasting, land use, and other environmental studies, and are presented in the technical reports supporting the Administrative Draft Final EIS/EIR.

Figure 2: Westside Subway Extension Project Planned Alignment



1.1 Supervisor Yaroslavsky's Motion to Metro Board of Directors

The Alternatives Analysis identified potential station locations on both Santa Monica and Constellation Boulevards. Based on existing geologic and topographic evidence and fault maps, the station location on Santa Monica Boulevard was expected to be outside of the Santa Monica fault zone, a feature that has been studied in detail to the west of the Interstate 405 (I-405) freeway, but not until recently in the Century City area.

[1] Los Angeles Metropolitan Transportation Authority Alternatives Analysis and Study, Los Angeles Westside Extension Transit Corridor, January 2009

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To address the tunneling safety concerns, the Metro Board approved the following motion from Supervisor Yaroslavsky to be undertaken during preparation of the Final EIS/EIR. Specific items in the Board motion included the following:

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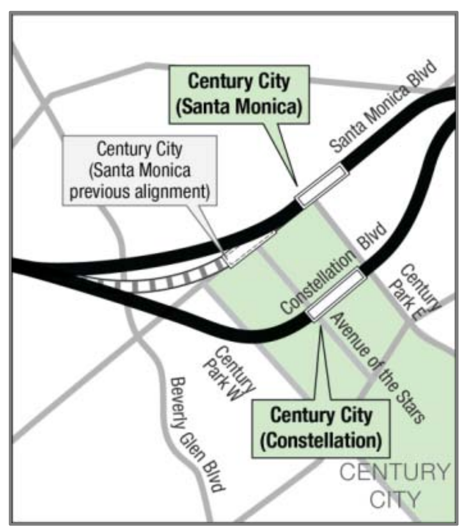
In addition, Metro staff was directed to fully investigate the nature and location of faults in the Century City area, and their potential impact on the proposed station locations. The resulting conclusions from both the tunnel safety and fault studies would provide a basis for the Board to make a decision on which proposed station to adopt. The resulting studies have been completed and presented in two separate reports: the *Century City Area Tunneling Safety Report*—which addresses the issues surrounding the safety of tunneling under and in the vicinity of BHHS, West Beverly Hills, Century City, and Westwood—and this report, the *Century City Area Fault Investigation.*

Subsequent geotechnical studies for the Project during the final environmental studies revealed that the initially proposed location of the Santa Monica Boulevard Station was within the (active) Santa Monica fault zone and, hence, not suitable for a public transit station. Based on fault zone topography that suggested the Santa Monica fault zone diverged from Santa Monica Boulevard to the northeast, east of the original station, the Santa Monica Boulevard Station was shifted to the east with an entrance near Century Park East (Figure 3) to allow for continued study of a station on Santa Monica Boulevard.

Figure 3: Century City Station Options



1.2 Status of Design and Environmental Documents

The current environmental study to extend the subway to the Westside was initiated in June 2007, and the AA was completed in January 2009. After a review of many alignment and modal options, five Build Alternatives, a No Build Alternative, and a Transportation System Management Alternative were carried forward for further environmental analysis in the Draft EIS/EIR. The Draft EIS/EIR contains the technical analysis to form the basis for selection of a Locally Preferred Alternative (LPA), which is the project that will be carried forward for final environmental clearance. The Draft EIS/EIR can be accessed at the following link: http://www.metro.net/projects/westside/draft-eis-eir-sept-2010/. The Final EIS/EIR will also be available on Metro's website at www.metro.net/projects/Westside.

The location for each of the station and related alignment options will be determined by the Metro Board at the time final action is taken on the Project. On October 28, 2010, the Metro Board authorized preparation of the Final EIS/EIR to further evaluate the No Build Alternative and the LPA. The Final EIS/EIR will incorporate findings from this report and other studies.

In support of the environmental documents, engineering design has progressed through the Advanced Conceptual Engineering (ACE) phase and is currently in the Preliminary Engineering (PE) phase. Entry into PE was approved by the Metro Board on October 28, 2010, and by the FTA in January 2011.

The following sections present background and the results of the Century City fault studies and the implications for subway station locations and tunnel alignments. The next section (2.0, Background) provides a summary of studies leading up to the Final EIS/EIR recommendations. Section 3.0 describes the new data acquisition in the 2011 studies together with the data interpretation, and Section 4.0 summarizes conclusions from the investigations.

2.0 BACKGROUND

2.1 Published Literature

Santa Monica Fault Zone

The 25-mile-long Santa Monica fault zone extends westward from the western edge of Beverly Hills across West Los Angeles and Santa Monica to Pacific Palisades (Figure 4), where it trends offshore and parallels the Malibu coast to near Point Dume (Dolan and Sieh, 1992; Dolan et al., 1995; 2000). The fault zone, which exhibits both reverse and left-lateral components of slip, extends eastward as the Hollywood Fault through a ¾-mile-wide left-step, or tear fault, which coincides with the northern part of the West Beverly Hills Lineament (WBHL) (Dolan and Sieh, 1992; Dolan et al., 1997; 2000). The Santa Monica and Hollywood fault zones are part of a much longer system of oblique left-lateral/reverse faults that form the more than 150 mile-long southern boundary of the Transverse Ranges.

The Santa Monica fault system is related to the Pliocene-Quaternary structural development of the Santa Monica Mountains. Prior to the late Miocene, the Santa Monica Fault was a normal fault that was reactivated as a reverse fault beginning in the Pliocene (Tsutsumi et al., 2001). In the Century City area, Tsutsumi et al. interpreted the Santa Monica fault zone to consist of three southern strands and one northern strand with only the northern strand being currently active. Other recent studies (Dolan et al., 2000; Dolan and Pratt, 1997; Hummon et al., 1992; Ziony et al., 1985) indicate that the northern segment of the Santa Monica fault zone is active and offsets or deforms Holocene sediments. Figure 5 shows a schematic view of surface and subsurface ground rupture and deformation resulting from major earthquakes on the active Santa Monica fault zone.

Figure 4: Fault Locations Westside Study Area

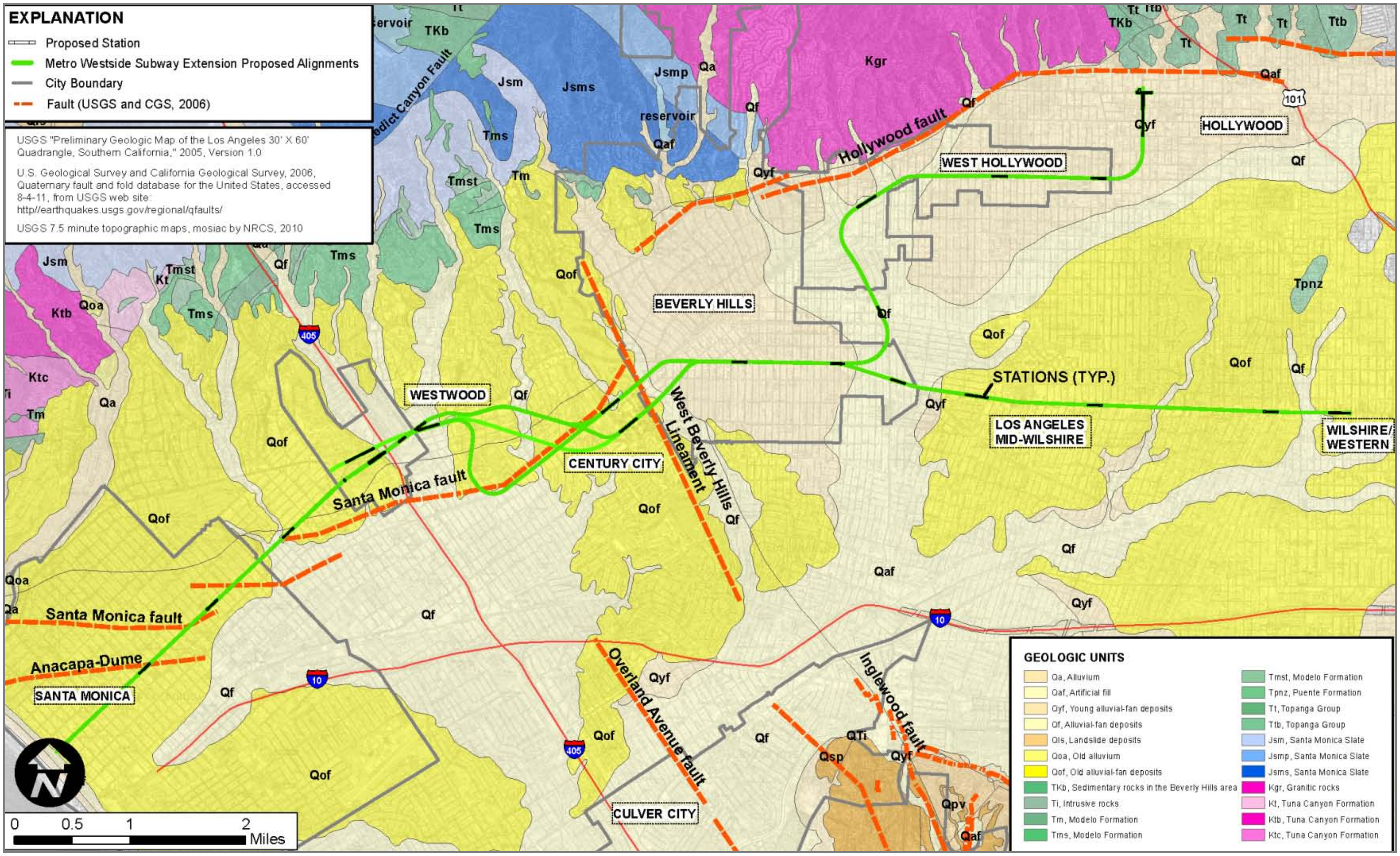
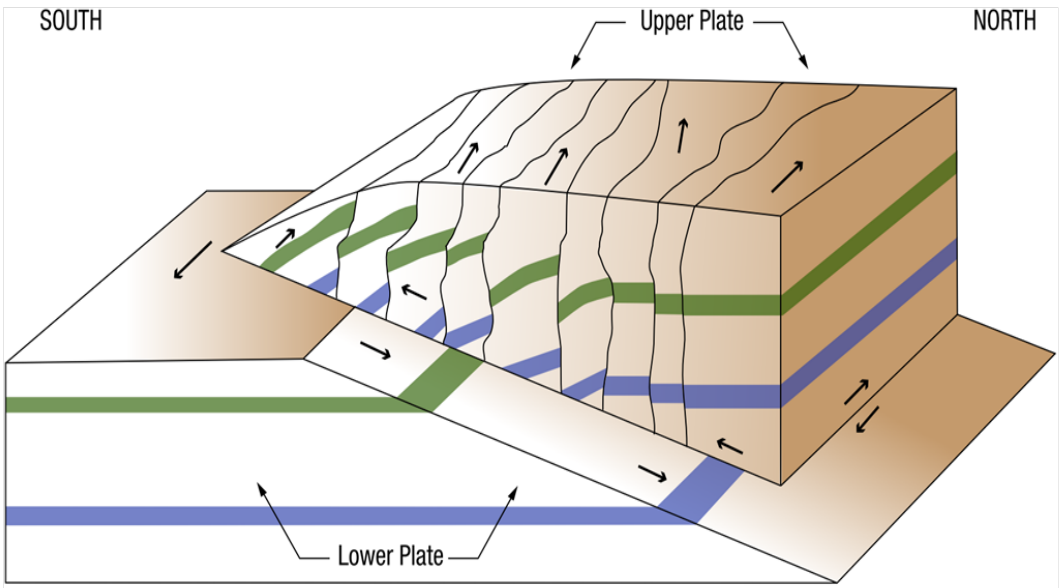


Figure 5: Schematic Cross Section of Santa Monica Fault Zone

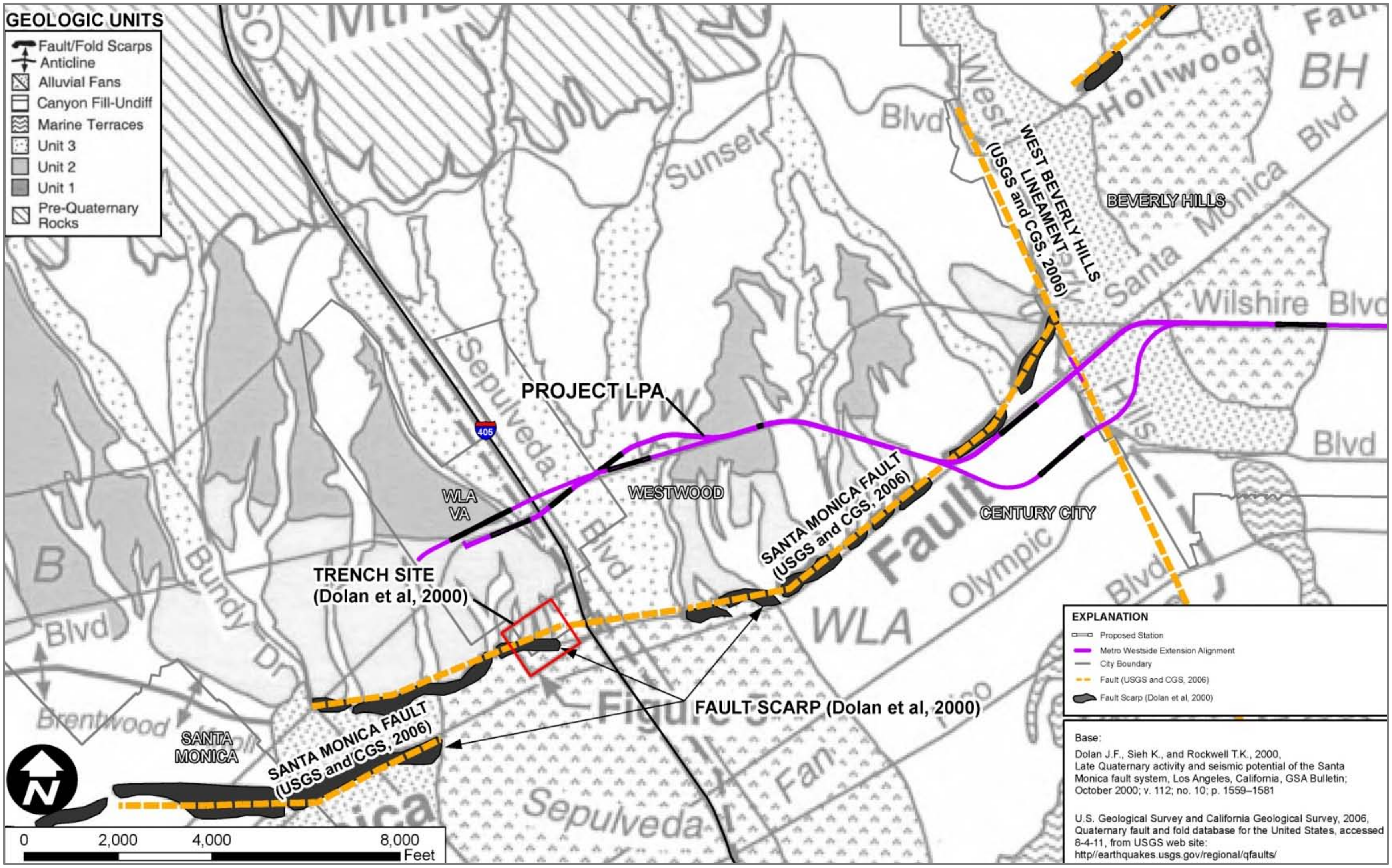


Schematic block diagram of the Santa Monica Fault Zone, an oblique left-lateral reverse fault zone.

A prominent, north-side-up topographic scarp (Figure 6) that can be traced continuously from the eastern end of the fault zone in Century City to Pacific Palisades, where the fault zone extends offshore, marks the active strands of the Santa Monica fault zone through Century City, West Los Angeles, and Santa Monica. This topographic scarp provides the most definitive evidence for the location of the active strands of the Santa Monica fault zone, although the locations of various active fault strands that make up the zone need to be determined when possible by detailed, site-specific studies such as detailed in this report for Century City.

Urbanization within west Los Angeles has limited the number of places the Santa Monica fault zone might be studied in detail in order to determine the locations of the active strands and, in turn, the fault's recent earthquake history. However, despite the dense development along the Santa Monica fault zone, the geomorphic signature of recent surface faulting, particularly the prominent scarp marking the active traces of the Santa Monica fault zone, is surprisingly well preserved (Dolan, et al., 2000). Dolan et al.'s (2000) analysis of tectonic landforms along the fault was greatly facilitated by a series of 1:24,000 topographic maps constructed for Los Angeles County by the USGS during the 1910s and early 1920s (the topographic maps were published in the mid-1920s. Plate 1, Appendix B, shows the portions of these maps in the Century city area. In Bryant (2005), a simplified trace of the Santa Monica fault that appears to have been largely based on the geomorphic mapping of Dolan and Sieh (1992) and Dolan et al. (2000) was published, shown in Figure 4 and Figure 6. The fault zone was rendered as a single line on the regional map, and placed largely along the top of the scarp identified by Dolan et al. (2000) (Figure 4). However, Dolan, et al. (2000) described that the north-dipping main strand of the Santa Monica fault zone is extending to the surface at, or to the south of the base of the topographic scarp.

Figure 6: Santa Monica Fault Zone and Topographic Scarp (2010 Alignments)



Santa Monica Fault Studies West of I-405 Freeway

Dolan et al. (2000) conducted the most detailed studies of the state of activity of the Santa Monica fault zone on the grounds of the Veterans Affairs property just west of I-405, about 1,000 feet south of the proposed Westwood/VA Hospital Station location (Figure 6). Trenches and high-resolution seismic reflection data collected during 1992 and 1993 revealed a complex zone of faulting that showed evidence for both contractional folding and reverse slip above a north-dipping thrust strand, as well as faulting on dozens of near-vertical, left-lateral strike-slip fault strands that merge downward with the main strand at a depth of 100 to 150 feet (Dolan and Pratt, 1997; Pratt et al., 1998). The total width of this complicated zone of faulting was more than 300 feet.

A prominent feature observed in the trenches was a zone of south-tilted alluvial fan strata that extend upward to merge with the south-facing slope of the surface scarp. These observations, together with similar observations at other sites along the scarp (e.g., University High School, MACTEC, 2007; Hill, 1979; Hill et al., 1979; Crook et al., 1983), indicate that the topographic scarp is formed partially by folding above the main, north-dipping strand of the Santa Monica fault zone, which appears to accommodate mainly reverse faulting. High-resolution seismic reflection imagery of this fault zone indicated that the main strand dips northward at 30 degrees to 55 degrees, with a most likely dip of 30 degrees to 35 degrees (Dolan and Pratt, 1997; Pratt et al., 1998).

The geometry of these folded strata, which dip as steeply as 13 to 15 degrees to the south, is important because they were deposited at an alluvial fan slope of only 1 to 2 degrees. Thus, their tilting provides unequivocal evidence for slip on the main thrust strand of the Santa Monica fault zone. Bulk-soil radiocarbon ages indicate that the youngest of these folded strata were deposited approximately 1,000 to 3,000 years ago. The folded strata are onlapped by younger, flat-lying strata deposited by the same alluvial fan. The absence of deformation in these flat-lying strata demonstrates that they have not yet experienced tilting during deformation by an earthquake. Therefore, the approximately 1,000-year age from carbon dating the oldest of the flat-lying strata provides evidence for fault quiescence during at least the past approximately 1,000 years. Dolan et al. (2000) also determined the ages of past earthquakes that ruptured to the surface along the secondary, strike-slip faults that cut through the folded strata. Dating based on carbon from offset layers indicated definitive evidence for surface rupture on some of these faults between 10,000 and 17,000 years ago, as well as probable evidence for surface rupture on another strike-slip strand between approximately 1,000 and 3,000 years ago, consistent with evidence for slip on the main strand in the most recent earthquake approximately 1,000 to 3,000 years before present.

Dolan et al. (2000) determined a reverse-slip-only component of the slip rate of 0.6 mm/year on the Santa Monica fault zone based on the vertical separation of marine terraces offset by the fault zone in Pacific Palisades. (Slip rate is the rate the two sides of a fault are moving relative to one another, as determined from geodetic measurements, offset man-made structures, or offset geologic features whose age can be estimated. In most cases slip, or ground rupture, occurs not continuously in mm/year but episodically during and after large earthquakes. The estimated amount of ground rupture depends on the slip rate and the frequency of ground-rupturing earthquakes.) Slip on the Santa Monica fault system, however, is oblique, with an additional (and perhaps even dominant) component of left-lateral strike-slip movement (Dolan et al., 2000). Thus, the reverse-slip-only rate of 0.6 mm/year noted by Dolan et al. (2000) is a minimum rate, and the actual fault slip rate is likely to be significantly greater. However, the left-lateral strike-slip component of the total slip rate remains poorly constrained, because there are no suitable study sites in this densely urbanized area along the fault zone that would allow for the three-dimensional trench studies necessary to determine the strike-slip rate. Dolan et al. (1995) estimated a total slip rate for the Santa Monica fault zone of 1.0 to1.5 mm/year, and the California Geological Survey (CGS) and U.S. Geological Survey (USGS) estimate a rate of 1±0.5 mm/yr (Wills et al., 2008). Earthquakes in the magnitude range M6.9 to M7.2 with average surface displacements on the order of 3 to 6 feet are plausible scenarios for future events that rupture the entire 25-mile long fault zone from Point Dume to Beverly Hills (Wells and Coppersmith, 1994).

East of I-405 Freeway

The continuity of the topographic scarp associated with active faulting along the Santa Monica fault zone indicates that this record of fault activity should characterize the entire 7-mile onshore length of the fault zone, including the section of the fault in the Century City area. The scarp does not extend east of the WBHL, a northwesterly trending topographic rise present along the western boundary of the City of Beverly Hills (Dolan et al., 2000; Dolan and Sieh, 1992). Rather, the easternmost part of the scarp diverges from Santa Monica Boulevard, assuming a more northeasterly trend through the Los Angeles Country Club east of Club View Drive and merging with the WBHL about ¾ mile north of Santa Monica Boulevard. However, this section of the scarp appears to have been eroded by a southwestward-flowing drainage emanating from the main Benedict Canyon drainage to the east. Thus, although the scarp provides a robust northernmost possible location for the main trace of the north-dipping Santa Monica fault zone, the surface trace of the main, active strands of the Santa Monica fault zone responsible for generating the scarp may lie somewhat to the southeast of the surface scarp, and closer to Santa Monica Boulevard.

West Beverly Hills Lineament /Newport-Inglewood Fault Zone

The WBHL (Figure 4 and Figure 6) is a north-northwest-trending topographic feature that appears to cross Santa Monica Boulevard in the vicinity of South Moreno Drive. The WBHL marks a pronounced boundary between uplifted and highly dissected older sedimentary units to the west and a gently sloping, younger alluvial plain in Beverly Hills to the east. Identified by Dolan and Sieh (1992) and Dolan et al. (1997; 2000) on the basis of this pronounced topographic dissimilarity, the lineament exhibits a semi-continuous series of east-facing topographic scarps. These scarps have been eroded and modified by the south-flowing drainage emanating from Benedict Canyon.

Various tectonic interpretations have been proposed for the WBHL. In the absence of previous fault subsurface exploration, the location and characteristics of the WBHL, including whether it is a fault zone, was not well defined. To the north of its intersection with the Santa Monica fault zone, the WBHL acts as a connection between the Santa Monica and Hollywood fault zones, transferring slip between these two oblique-slip fault systems (Dolan and Sieh, 1992; Dolan et al., 1997; 2000). Dolan et al. (1997) speculated that this northern part of the WBHL might represent an east-dipping normal fault associated with extension along the left step between these faults. To the south of its intersection with the Santa Monica fault zone, Dolan and Sieh (1992) and Dolan et al. (1997; 2000) considered the WBHL to be the northern continuation of the active Newport-Inglewood fault zone located approximately 3 miles to the south-southeast. The Newport-Inglewood fault zone is composed of a series of discontinuous, northwest-trending *en echelon* faults and pressure ridges extending from the Baldwin Hills southeastward to Newport Beach and continuing offshore to the south (Barrows, 1974). Lang (1994) expressed the opinion that subsurface mapping within the Cheviot Hills and Beverly Hills oil fields, constrained by dense subsurface control, precluded the existence of the WBHL as a fault zone.

In 1933, the southern Los Angeles basin section of the Newport-Inglewood fault zone ruptured to produce the M6.4 Long Beach earthquake (Hauksson and Gross, 1991). The seismic hazard from the northern section of this major fault system in the Los Angeles region has been long known; for example, the California Division of Mines and Geology (now the CGS) chose to model a hypothetical M7.0 earthquake on the northern Newport-Inglewood fault zone as one of their first non-San Andreas earthquake scenarios (Toppozada et al., 1988). By virtue of its assumed connection to the active Newport-Inglewood fault zone, the WBHL is now considered by the CGS to be an active fault (Bryant, 2005).

The slip rate on the Newport-Inglewood fault zone is not well established, but is believed to be in the 1 mm/yr range (reported as 1$\pm$0.5 mm/yr in Wills et al., 2008). Farther south, the Rose Canyon fault zone is interpreted to be the southern extension of the Newport-Inglewood fault zone, and has been attributed a rate of 2$\pm$1 mm/yr (Rockwell et al., 2010). Given the segmented nature of the northern Newport-Inglewood fault zone north of Newport Beach, earthquakes between M6.4 (smallest event likely to have surface rupture) and M7.2 (rupture of the entire northern Newport-Inglewood fault zone) are possible, with average surface displacements of 3 to 6 feet or more (Wells and Coppersmith, 1994).

2.2 Previous Geotechnical Studies—Century City

Extensive subsurface geotechnical investigations in the Century City area have been performed over the past 60-plus years by AMEC and its predecessor companies. The locations of the boreholes from these investigations are shown on Plate 2 in Appendix B. Information on the geotechnical logs from these previous studies were compiled and analyzed in support of this investigation.

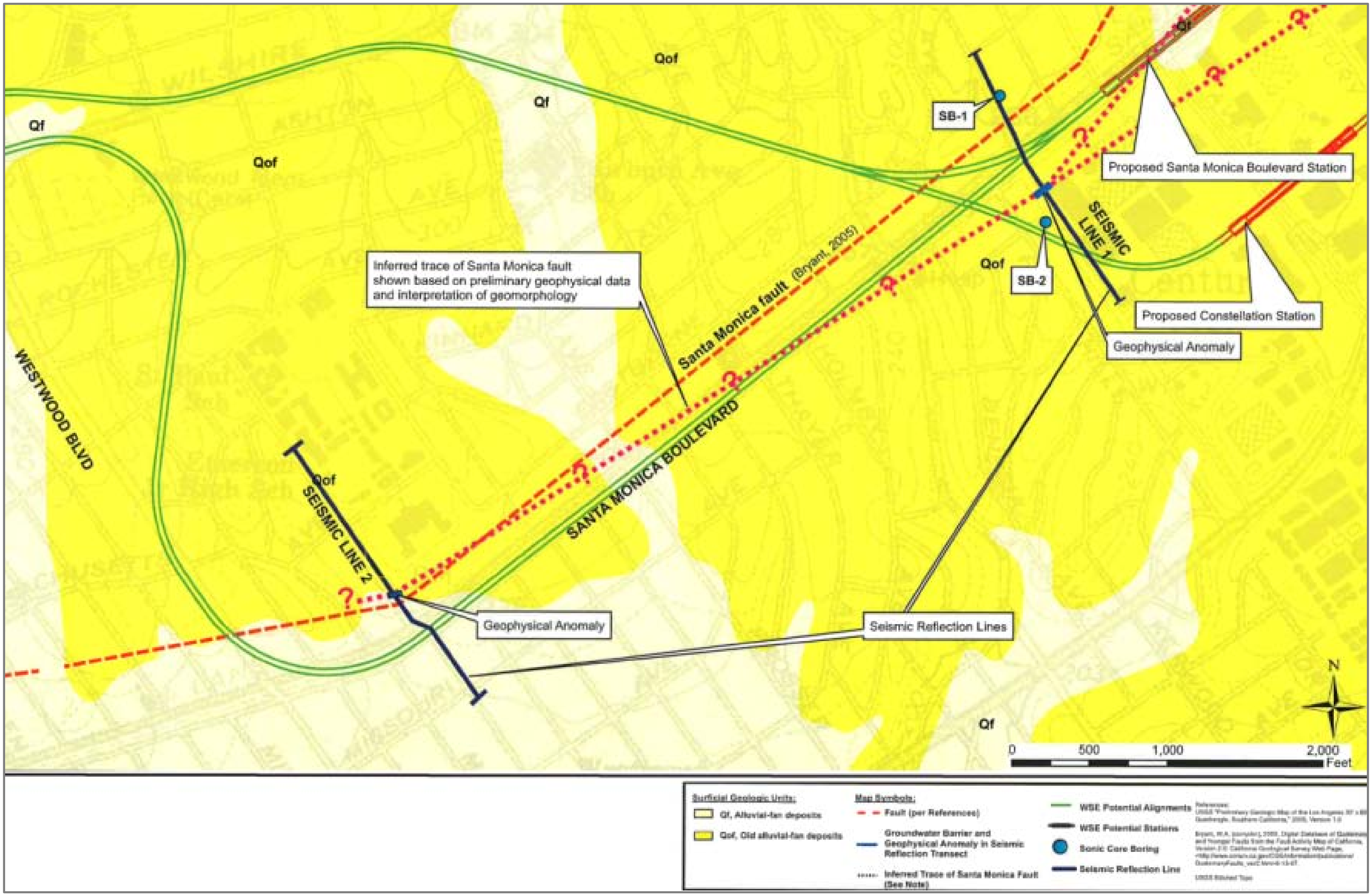
2.3 Metro Investigations

The AA study (2007–2009) identified potential station locations on Santa Monica Boulevard and Constellation Boulevard, with both centered at Avenue of the Stars. Several tunnel alignments were considered between the Century City and Westwood studied tunnel alignments. Those studies identified the Santa Monica fault zone and the WBHL as being in the Century City area and that further geologic study was necessary to more precisely locate and characterize these features.

Available published information used during early planning studies discussed in the previous sections indicated that the Santa Monica fault zone extends from the Santa Monica coastline through Santa Monica, West Los Angeles, and Century City. The most recent geologic maps published by the CGS were used for planning studies. The mapped fault runs approximately parallel to Santa Monica Boulevard in the Century City area, and diverges from Santa Monica Boulevard to the north, as shown in Figure 6.

Geotechnical fault studies for the Project during the ACE in support of the Draft EIS/EIR in 2009-2010 (MACTEC, 2010) were performed at two locations: a P-wave seismic reflection line on Selby Avenue and a P-wave seismic reflection line and two continuous sonic core borings on Century Park West (Figure 7). These studies indicated that the Santa Monica fault zone includes strands that are farther south than previously mapped (shown as geophysical anomalies on Figure 7) and, consequently, the proposed Santa Monica Boulevard Station (centered on Avenue of the Stars) could be within the Santa Monica fault zone. The (2005) traces of the Santa Monica fault zone relative to the station alignments are shown on Figure 6. The Century City Constellation Station is south of the fault zone. For all alignments, the subway tunnels would need to cross the Santa Monica fault zone in the Century City vicinity to proceed to the Westwood area.

Figure 7: Fault Studies during Draft EIS/EIR



The Draft EIS/EIR stated that during design, further geotechnical investigations would be undertaken to study the fault characteristics (location, width, and expected offset, etc.). During the PE phase, in support of the Final EIS/EIR and 2010 Metro Board action, Metro undertook the additional investigations in 2011 to more precisely locate the Santa Monica fault zone, as well as the WBHL.

Early in the PE phase (spring 2011), fault transects (geophysical and drilling studies) at Century Park West and Avenue of the Stars confirmed the presence of the Santa Monica fault zone crossing Santa Monica Boulevard at approximately Avenue of the Stars. To avoid placement of the station within the Santa Monica fault zone, the Santa Monica Boulevard Station was shifted to the east (Figure 3).

2.4 Station Locations Relative to Faults

Hazards due to the presence of a fault near a structure include:

- Shaking generated during the earthquake event, which impacts structures in the vicinity of the fault.
- Rupture (a tearing of the ground as shown schematically in Figure 5 (for the Santa Monica Fault), which only impacts structures directly located within a fault zone.

Structures are routinely designed to handle ground shaking; however, a station structure located within the fault zone itself would be subject to ground rupture displacement and deformations in uplift and shear zones. As discussed in the following, relocating the station away from the site is the optimal mitigation.

The Alquist-Priolo Earthquake Fault Zoning Act

The California Alquist-Priolo Earthquake Fault Zoning Act (the AP Act) was passed in 1972 to mitigate the hazard of surface faulting to structures for human occupancy. The intent of the AP Act is to prevent major damage to structures and potential loss of life resulting from ground rupture and associated ground deformations in an active fault zone and to disallow the construction of structures used for human occupancy in an active fault zone. Currently the Santa Monica fault zone and WBHL are not included on Alquist-Priolo active fault zone maps because the state did not have sufficient data to accurately locate the fault zones at the time the maps were prepared.

3.0 NEW DATA ACQUISITION AND INTERPRETATION

3.1 Field Program

The field program for this fault investigation was implemented to evaluate the locations and trends of faults near the proposed Century City stations and tunnel alignment alternatives, and to determine where active faults may cross or extend along the proposed stations and tunnel alignments. Available information about known or suspected faults was obtained from previous studies that included geomorphology, groundwater patterns, and the geometry of subsurface units was used to design the field investigation. The Santa Monica fault zone and WBHL were specifically researched.

The exploration plan consisted of seven transects for continuous core boreholes and CPTs and five transects for seismic reflection profiles. The locations are shown on Plate 3 in Appendix B. The full data set consists of:

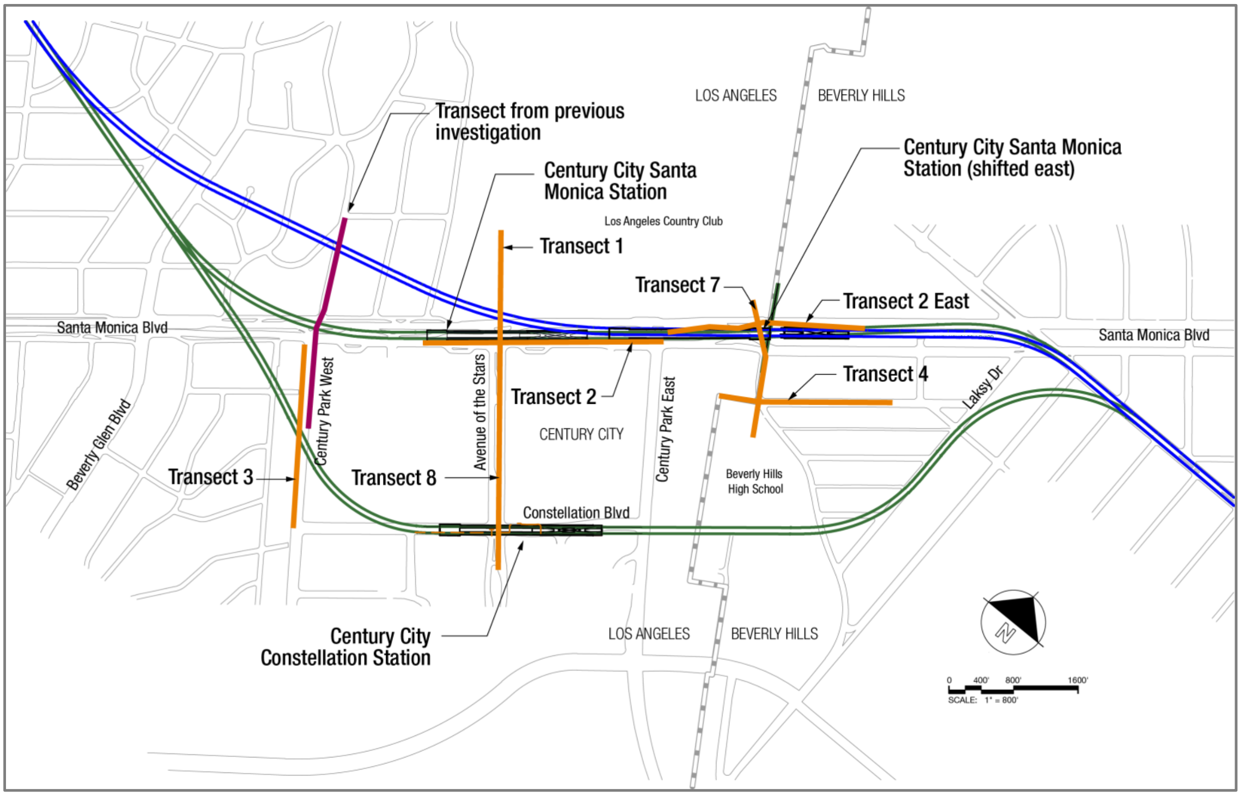
- 7 rotary-wash continuous core boreholes
- 49 hollow stem auger continuous core boreholes
- 192 CPTs
- 5 P-wave seismic reflection profiles
- 5 S-wave seismic reflection profiles
- 5 down hole suspension PS velocity measurements

Fieldwork was performed from January 4 through July 7, 2011, at the locations shown on Plate 3 and shown schematically on Figure 8. The upper 4 to 10 feet below ground surface of the exploratory boreholes and CPTs were excavated by hand auger prior to drilling to avoid hitting underground utilities. Continuous core samples were collected in the boreholes to planned depths, except where no recovery or refusal was encountered. The cores retrieved were preliminarily logged by the field personnel and were then transported to the laboratory for detailed descriptions and logging. CPTs were pushed to planned depths, except where refusal was encountered.

High-resolution P-wave and S-wave seismic reflection surveys were performed along the 7 transects in five surveys (by combining Transects 1 and 8 and Transects 2 and 2E). The data were processed into record sections. The P-wave data provided acceptable resolution and useful information on the locations and subsurface geometries of faults to depths of several hundred feet in spite of the noisy urban environment. However, the S-wave data generally did not provide the hoped-for increased resolution in the near surface. Transects are described as follows:

- Boring/CPT Transect 1 is a north-south transect extending from its north end in the south course of the Los Angeles Country Club to approximately 500 feet south of the intersection with Santa Monica Boulevard, and was intended to intersect the Santa Monica fault zone.
- Boring/CPT Transect 8 is the southerly extension of the north-south seismic reflection Transect 1 crossing the Constellation Boulevard area.
- Geophysical seismic reflection survey Line 1, both S-wave and P-wave, extends from the northern end of Transect 1 to the southern end of Transect 8.

Figure 8: Transect Plan



- Boring/CPT Transects 2 and 2E are east-west transects extending along Santa Monica Boulevard from approximately 450 feet west of Avenue of the Stars to approximately 950 feet east of South Moreno Drive, and was intended to intersect the Santa Monica fault zone as it changes direction to the northeast and the WBHL.
- Geophysical seismic reflection survey Line 2 extends from the western end of Transect 2 to the eastern end of Transect 2E.
- Boring/CPT Transect 3 is a north-south transect extending from its north end of Warnall Avenue across Santa Monica Boulevard approximately 1,100 feet south along Century Park West to its intersection with Constellation Boulevard, and was intended to intersect the Santa Monica fault zone.
- Geophysical seismic reflection survey Line 3, both S-wave and P-wave, extends from south of the intersection of Century Park West and Santa Monica Boulevard south to the intersection with Constellation Boulevard.
- Boring/CPT Transect 4 is an east-west transect extending along Durant Drive from approximately 350 feet west of its intersection with South Moreno Drive an additional approximately 900 feet east. It was intended to intersect the WBHL.
- Geophysical seismic reflection survey Line 4, both S-wave and P-wave, are approximately coincident with Boring/CPT Transect 4.

- Boring/CPT Transect 7 is a north-south transect along South Moreno Drive extending from its north end approximately 300 feet north of Santa Monica Boulevard for an additional approximately 750 feet to the south.
- Geophysical seismic reflection survey Line 7, both S-wave and P-wave, extends from the north side of Santa Monica Boulevard along South Moreno Drive for approximately 750 feet to the south.

3.2 Stratigraphic Units

This section describes the stratigraphic units encountered by the boreholes and CPTs that were used to identify discontinuities associated with faulting in the subsurface along the various transects. Artificially placed fill soils of generally limited thickness form surface cover over the natural geologic units throughout much of the study area. Holocene alluvial deposits appear to have limited aerial extent and thickness and generally were not identified in the cores. The surficial deposits are underlain by variably thick, older alluvial fan deposits and shallow marine/estuarine deposits of apparent Pleistocene age. Shallow marine and locally nonmarine sediments of the Pleistocene Lakewood formation, where present, underlie the alluvial fan and estuarine deposits. Marine sediments of the Middle Pleistocene San Pedro formation underlie the Lakewood formation. In the northern portion of the study area, the Lakewood formation appears to have been largely removed and the alluvial fan/estuarine deposits rest directly on the San Pedro formation. The base of the older alluvial fan/estuarine deposits was not reached in the deep boreholes in the eastern portions of Transects 2/2E and 4. The table below summarizes the stratigraphic units.

3.2.1 Artificially Placed Fill (symbol: af)

Artificially placed fill was identified in the cores by the presence of glass, chunks of concrete, and other historical debris, as well as by the presence of “lifts” of soil that indicate mechanical emplacement. Furthermore, within the soil itself, chunks of extraneous soil could be identified, indicating local mixing of different soil units, and many of the lifts exhibited evidence of mechanical compaction based on their density. Based on these criteria, the artificially placed fill was distinguished from natural soil units.

In some areas along Avenue of the Stars, the artificial fill is as much as 45 feet in thickness. Analyses of the detailed 1920s-vintage topographic maps (Plate 1) show that most of the deep fill encountered in this study was emplaced in stream channels and ravines to level the ground surface prior to early development. This is corroborated by the thicknesses of the artificial fill encountered.

3.2.2 Younger Alluvium (symbol: Qf/Qal)

Young alluvial deposits interpreted to be Holocene in age were generally not encountered during the fault investigation since hand auguring to a depth of at least 6 to 10 feet (depth of utilities) makes identification of soil structure difficult. Younger alluvium may be locally present at shallow depths within the north-south-trending channel that underlies much of Transect 1.

Table 1: Stratigraphic Units

Epoch	Time Scale
Holocene	11,000 years ago to present
Pleistocene	1.8 million to 11,000 years ago

Symbol	Stratigraphic Unit (Age) Description
af	ARTIFICIAL FILL (undocumented)
Qf/Qal	YOUNGER ALLUVIUM (Holocene)—predominantly sand, silt and clay
Qfo	OLDER ALLUVIAL SAND DEPOSITS (late Pleistocene)—sandy silt, clay, and sand with gravel
Qe	ESTUARINE DEPOSITS (late Pleistocene)—thin bedded to massive silty and clay with fine sand and occasional gravel
Qlw	LAKEWOOD FORMATION (late Pleistocene)—interbedded silty sands, silts, and clays with clayey sand and gravel layers
Qsp	SAN PEDRO FORMATION (mid Pleistocene)—predominantly greenish gray and bluish gray fine-grained Sands, medium to coarse Sands and some Silt Layers.

3.2.3 Older Alluvial Fan and Fluvial Deposits (symbol: Qfo)

The older alluvial fan deposits encountered in the study area appear to consist primarily of alluvial fan deposits laid down during the Pleistocene by debris flows, stream channels, and other alluvial processes. Estuarine and shallow marine deposits locally interfinger with the non-marine alluvial fan deposits, representing episodic marine transgressions and regressions. These older alluvial deposits are relatively heterogeneous and consist of sandy silt and clay with variable amounts of sand and fine gravel, and localized sandy gravel deposits interpreted to represent buried channels. Most of the silty and clayey deposits contain at least a trace of coarse sand and fine gravel. The source area for the alluvial fan deposits was the Santa Monica Mountains to the north, as shown by the presence of clasts and fragments of Santa Monica Slate in the alluvial sand and gravel layers.

3.2.4 Estuarine Deposits (symbol: Qe)

Shallow marine/estuarine deposits are interbedded with the alluvial fan deposits. These deposits consist of thinly bedded to laminated silts and clays and frequently exhibit a varve-like character. These strata commonly grade upward and downward into fine silty sand and sand. The sand strata are commonly thinly bedded to crudely laminated. Minor amounts of fine gravel are also present, and the estuarine strata are locally interbedded with pulses of alluvial deposits that probably represent individual depositional (storm) events.

3.2.5 Lakewood Formation (symbol: Qlw)

Shallow marine deposits of the Pleistocene Lakewood formation were encountered beneath the alluvial fan/estuarine deposits predominately to the south of Santa Monica Boulevard. The Lakewood formation in the study area consists primarily of silty sand and poorly graded sand, with local sandy silt and gravelly beds. These beds generally exhibit relatively uniform lateral thickness. Some beds containing bivalve shell fragments were encountered near the base of the Lakewood formation in Transect 3. The lateral continuity of the Lakewood formation, and the presence of distinct marker beds such as a gravel bed, a shell bed, and a thin clay layer, allowed the stratigraphy to be mapped with a high degree of confidence over relatively large lateral distances.

3.2.6 San Pedro Formation (symbol: Qsp)

Marine deposits of the Pleistocene San Pedro formation underlie the Lakewood formation in the southern portion of the study area, and older alluvium/estuarine deposits in the northern portion. The depth of the upper San Pedro formation contact encountered in the study ranges from about 60 feet near the north end of Transect 1 to about 180 feet near the intersection of Transects 2 and 7. In the eastern portions of the study area, the San Pedro formation was not encountered.

The San Pedro formation encountered in the northern portion of the study area consists of interbedded gray to dark gray to greenish-gray, poorly graded sand, silty sand, sandy silt, and variable clay/silt mixtures with scattered gravelly beds. In the southern portion of the study area it consists mainly of pale gray to gray, poorly graded sand and silty sand. Sandy strata are generally fine grained and micaceous. A number of fossiliferous beds containing bivalve shell fragments were encountered, as well as concretionary beds cemented with calcium carbonate cement.

3.3 Groundwater

In the Century City area, groundwater levels vary considerably where observed. Along Century Park West and Avenue of the Stars, a groundwater barrier is present just south of the intersections with Santa Monica Boulevard. Groundwater was measured at depths as shallow as 5.4 feet below ground surface in boreholes and CPTs to the north, whereas groundwater is not present to the southeast in boreholes drilled as deep as 94 feet (see Transect 1 and 3 profiles, Plates 4 and 6 in Appendix B). This groundwater barrier is almost certainly related to the presence and location of subsurface faults. It is reflected in the older geotechnical boreholes as well as in deep excavations for buildings south of Santa Monica Boulevard in the Century City area where rare groundwater inflows were encountered during construction activities.

To the east of Avenue of the Stars, groundwater levels vary widely (see Plates 5, 7, and 8 in Appendix B). East of Century Park East, depth to groundwater ranged from around 17 to around 85 feet in recent and historical borings, and the distinct groundwater barrier found to the west appears to be more diffuse or absent in the eastern part of the study area.

Groundwater-level measurements in core boreholes drilled in the Santa Monica fault zone on the northern portion of University High School, located at Texas and Barrington Avenues in West Los Angeles (about 2.5 miles west of Century City), indicated groundwater depths at approximately 20 to 25 feet below ground surface with apparent localized zones of perched water as shallow as 5 to 10 feet (MACTEC, 2007). The shallow ground-water-level measurements were collected from the north side of the Santa Monica fault zone. These and other observations (Dolan et al., 2000) suggest that a groundwater barrier is present in the vicinity of the Santa Monica fault zone along much or all of its onshore length. These observations aided in the interpretation of locating faults.

3.4 Transects: Data and Analysis

The borehole stratigraphy and CPT signatures have been plotted on the transect profiles (Figures L-1 through L-13 in Appendix A and Plates 4 through 8 in Appendix B). Locations of the transect lines are shown on Plate 3. Borehole/CPT Transects 1 and 8 are presented as one continuous profile (Transect 1/8, Plate 4) to correspond to the P-wave geophysical seismic reflection survey section, reported as Transect 1 (Plates 10 and 11) in Appendix B and Ledger Size Figures L-1, L-2, and L-3 in Appendix A). Transects 2 and 2E are presented as one continuous profile (Transect 2 and 2E, Plate 5 in Appendix B and Figures L-4, L-5, L-6, and L-7) to correspond to the P-wave geophysical seismic reflection survey section, reported as Transect 2 in Plates 12 and 13. Transect 3 (Transect 3, Plate 6 and Figures L-8 and L-9) includes the P-wave geophysical seismic reflection survey, reported as Transect 3 on Plates 14 and 15, as well as the P-wave geophysical seismic reflection survey performed in 2009 (Line 1 of the 2010 MACTEC report, and 9464 Line 1 P-wave Seismic Section on Plates 16 and 17 in Appendix B). Borehole/CPT Transects 4 and 7 profiles (Plates 7 and 8 and Figures L-10, L-11, L-12, and L-13) correspond to their respective P-wave geophysical seismic reflection survey sections presented on Plates 18, 19, 20, and 21. The ends of the transect profile lines generally do not correspond exactly to the ends of the geophysical sections. (Transect profiles are shown as orange lines and seismic sections are shown as green or purple lines on Plate 3) The shot point locations of the P-wave seismic reflection surveys have been plotted along the green seismic reflection survey lines on Plate 3, and are shown on the transect profiles and seismic sections for reference. The station numbers are shown on the bottom of the profiles.

The CPT signatures (tip resistance and side friction) were analyzed for evidence for the presence of faulting and deformation. Particular care was taken to distinguish gradual lateral changes in CPT signatures along any particular layer, which might reflect lateral facies changes, from laterally abrupt changes in CPT character and vertical separations of beds, which were taken as evidence for faulting. The seismic reflection profiles were analyzed independently for the presence of faulting and deformation. Specifically, the reflection data were used to identify zones of faulting, individual major fault strands, and areas of folding on the basis of reflector truncations, vertical offsets of major reflectors, and/or significant lateral changes in reflector amplitude. These geophysical data provide the deeper structural context for the major faults identified in this study, as well as their subsurface geometries. Finally, the borehole cores were then used to describe the characteristics of the imaged strata and to corroborate the structures identified by the CPTs and geophysical surveys in a joint analysis that combined evidence from all three data sources.

3.4.1 Transect 1/8

Plate 4 shows the profile for Transect 1/8. Northwest is to the right on the profile. The profile is also shown on Figures L-1, L-2, and L-3. Plates 10 and 11 show the results of the P-wave geophysical survey line, as referenced to Plate 3. It is generally parallel to the profile line, but diverges slightly at the intersection of Santa Monica Boulevard and Avenue of the Stars.

Transect 1/8 is subparallel to, and partially located above, a stream channel that is present on the 1925 vintage topographic map (Plate 1) and which has been buried by artificial fill. There may be Holocene alluvium present in the buried stream channel that was not removed prior to placement of artificial fill, although it is not obvious in the cores.

In the southern portion of the profile, the top of the Lakewood and San Pedro formations and overlying estuarine deposits are conformable and dip gently to the north. This is seen in the CPT data and corroborated by the borehole cores. A gravel bed designated in the profile as unit M_C, within the Lakewood formation, was identified in the cores and extends uninterrupted to the north to approximately profile Station 12+50, as illustrated on Figure L-2. This clearly shows there is no faulting at the proposed Constellation Boulevard Station alternative location and for over 800 additional feet to the north. A fault identified in the geophysical survey (Plate 11) at approximately geophysical Seismic Station 180 in deep strata clearly does not extend up into the strata encountered by the boreholes or CPTs. The top of the San Pedro formation is not faulted by this structure, thus indicating that the fault identified in the geophysical profile is pre-Middle Pleistocene and therefore not active.

North of profile Station 6+00 (Figure L-1), older alluvial fan deposits identified in borehole T8-B5 have eroded the estuarine deposits, the M_E clay bed, and the upper portion of the Lakewood formation. However, the M_C gravel bed and top of San Pedro formation are not interrupted.

A fault is interpreted to be present at approximately profile Station 12+50, as shown on Figure L-2, where there is a strong discontinuity between the CPT signatures of T1-C8, T1-C9, and T1-C10. This corresponds to the faulting interpreted in the geophysical survey at approximately Seismic Station 350. The large offset of lithologic units in the cores of boreholes T1-B8 and T1-B3, along with a drop in ground water levels in this area, also indicates the presence of a fault at this location.

At approximately profile Station 15+00, as shown on Figure L-2, there is a strong discontinuity between CPT signatures of T1-C15, T1-C17, and T1-C18, which is also interpreted as evidence for a fault. This corresponds to the interpreted faulting identified in the geophysical survey at approximately Seismic Station 370. The offset of lithologic units in the cores of boreholes T1-B3 and T2-B4 also indicates the presence of a fault at this location.

Finally, at the north (right) end of the profile (see Figure L-3), there are discontinuities across a series of the CPT signatures that correspond to interpreted faults in the geophysical survey at approximate Seismic Stations 450 and 500. The offset of lithologic units in the boreholes also indicates the presence of faults in this area.

3.4.2 Transect 3

Plate 6 shows the profile for Transect 3, which is parallel to and west of Transect 1. Northwest is to the right on the profile. The profile for Transect 3 is also shown on Figures L-8 and L-9. Plates 14and 15 show the results of the P-wave seismic reflection survey line performed south of Santa Monica Boulevard (green line on Plate 3). The purple line on Plate 3 is the location of the P-wave seismic reflection line performed in 2009, presented as Plates 16 and 17, titled Line 1 P-wave Data.

At the south end of Transect 3, the tops of the Lakewood and San Pedro formations and marker beds within the formations are conformable and dip gently to the north. Based on the CPTs and the lithologic units in the borehole cores, bedding is uninterrupted from the south end of the profile until approximately profile Station 9+00 (Figure L-8)—a distance of nearly 900 feet—which is similar to the findings in Transect 1.

At approximately profile Station 9+00, as shown on Figure L-9, there are a series of sharp discontinuities between the CPT signatures of T3-C18 through T3-C22. This corresponds to the interpreted fault at approximate Seismic Station 300 on the geophysical survey on Plate 15 approximate Seismic Station 200 on Plate 17. The offset of lithologic units in the cores of boreholes T3-B5 and T3-B6, along with a sharp drop in groundwater indicating the presence of a groundwater barrier in this area, indicates a fault at this location.

At approximate profile Station 11+00, as shown on Figure L-9, there are discontinuities between the CPT signatures of T3-C24 and T3-C25 and boreholes T3-B6 and T3-B7, indicating faulting in this area.

At approximately profile Station 13+00, as shown on Figure L-9, there are sharp discontinuities between the CPT signatures of T3-C29, T3-30, and T3-C31, and south dipping lithologic units are truncated, indicating the presence of a fault at this location. The offset of lithologic units in the cores of boreholes also indicates the presence of a fault, which corresponds to the interpreted fault at about Seismic Station 220 on Plate 17.

3.4.3 Transect 2/2E

Plate 5 shows the profile for Transect 2/2E. The profile is also shown on Figures L-4, L-5, L-6, and L-7. Northeast is to the right on the profile. Plates 12 and 13 show the P-wave geophysical survey for T2/2E. The profile and geophysical survey are generally coincident for this transect.

At the west end of the profile, there is a general lack of continuity in the CPT signatures. There is no correlation of the lithologic units between boreholes T2-B3 and T2-B4. Beds defined in the cores and CPTs are truncated and offset in the zone between approximate profile Stations 3+00 and 9+00 (Figure L-4). These observations, in conjunction with the findings of Transect1 to the north-south, all indicate that the entire western part of Transect 2/2E is disrupted by faulting. This is supported by a feature that is present in the west end of the geophysical seismic survey (Plate 12). Keeping in mind that the north-dipping Santa Monica fault zone runs roughly parallel to the trend of Transect 2/2E, some faults that may have been imaged in the seismic data may appear as sub-horizontal reflectors. This will also be true between CPT holes, where the apparent dip of faults will be very low angle because the fault is oriented almost parallel to the line of the CPT transect. Thus, the apparent continuity in the lithologic units observed in the CPTs and borehole cores and geophysical survey between T2-B6 and T2E-B2 (Figures L-4 and L-5) may actually have faulting present that has not been identified.

Disruptions in the CPT signatures are present to the east of approximately profile Station 18+00 (Figure L-7). Distinct faults are interpreted on the geophysical profile (Plate 12) in this area (between about Seismic Survey Stations 451 and 610). There are zones of disruption encompassing the faults indicating the presence of additional folding and faulting within this zone. The lithologic units in the borehole cores show offsets between boreholes T2E-B2, T2E-B3, T2E-B4, and T2E-B5 (profile Stations 18+00 to 25+50). Taken together, these observations indicate the presence of a major zone of faulting in the eastern portion of Transect 2/2E.

3.4.4 Transect 4

Plate 7 shows the profile for Transect 4. Northeast is to the right of the profile. The profile is also shown on Figures L-10 and L-11. The geophysical seismic survey is shown on Plates 18 and 19. Based on the cores and CPT signatures, distinct stratigraphic units in the older alluvial fan deposits are juxtaposed at approximate profile Stations 1+00, 3+00, 4+00, and 4+75 (see Figure L-10) indicating faulting. These areas correspond to faults interpreted in the geophysical seismic reflection survey (Plate 19 in Appendix B). Offset beds are observed in the CPT signatures as far east as Station 5+80.

Based on the CPT signatures and the borehole core data, lithologic units in the older alluvium east of Station 5+10 dip gently to the east. This fold structure is also observed in the seismic reflection data.

3.4.5 Transect 7

Plate 8 shows the profile for Transect 7. Northwest is to the right in the profile. The transect profile is also shown on Figures L-12 and L-13. An apparent vertical offset of the top of the San Pedro formation occurs between boreholes T7-B1 and T7-B2 (Figure L-12). Possible faults were identified in the geophysical seismic reflection survey at the south end of the survey. In addition to the offsets of the San Pedro formation, based on the CPT signatures and borehole cores, there appear to be offsets and truncations of units in the older alluvial fan and estuarine deposits across these faults.

3.4.6 Constellation Profile

Plate 9 and Figures L-14 and L-15 show the profile for the Constellation Boulevard Station alignment south of Transect 4 in the area of the lacrosse field at BHHS extending westward to the west end of the proposed Constellation Boulevard Station. Boreholes for the geotechnical investigation of the tunnel alignment, of which this fault investigation is a part, and boreholes from prior geotechnical investigations in the Century City area were used in the analysis. The subsurface soils were characterized and correlated by their lithology. Characteristic lithologic features were identified as marker beds to assess lateral continuity along the profile.

Gravel zones and concretionary beds, as well as some layers with shell deposits are present in the San Pedro formation. An upper gravel zone in the San Pedro formation is laterally continuous from borehole A71174-2A on the west to borehole 69036-5 on the east. A second gravel zone is laterally continuous from borehole G-169 on the west to borehole 69036-1 on the east. A concretionary bed and local shell deposits below the lower gravel zone are laterally continuous from boreholes 69036-5 on the west to borehole 69036-1 on the east. Although the contact between the alluvial deposits and the Lakewood formation varies across this area, the lateral continuity of the gravel and concretionary beds below indicates that the contact is erosional, as observed in the surrounding geotechnical boreholes.

In borehole G-166B to the east, the contacts between the alluvial fan deposits and the Lakewood formation and the Lakewood and San Pedro formations are offset compared to those in borehole 69036-1. Calcium carbonate nodules are present near the base of the alluvial deposits, which is offset. There are two closely spaced gravel beds present in G-166B not seen in 69036-1. In borehole G-165, the contacts are again offset, as are the two closely spaced gravel beds. This stratigraphic offset aligns with faults observed in Transects 2/2E and 4 to the north (Plate 3 and Figure 3-2). In borehole S-111, the contacts are offset from those in G-165. The two gravel beds are not present in the San Pedro and the lithology is different than observed to the west. The stratigraphic offset aligns with the fault observed in Transect 4 to the north. This zone of faulting is interpreted to be the southern extension of the WBHL/NIFZ observed in Transects 2E and 4 to the north. Because of the limited number of data points in this area, it is not possible to determine at this time how many fault strands are present.

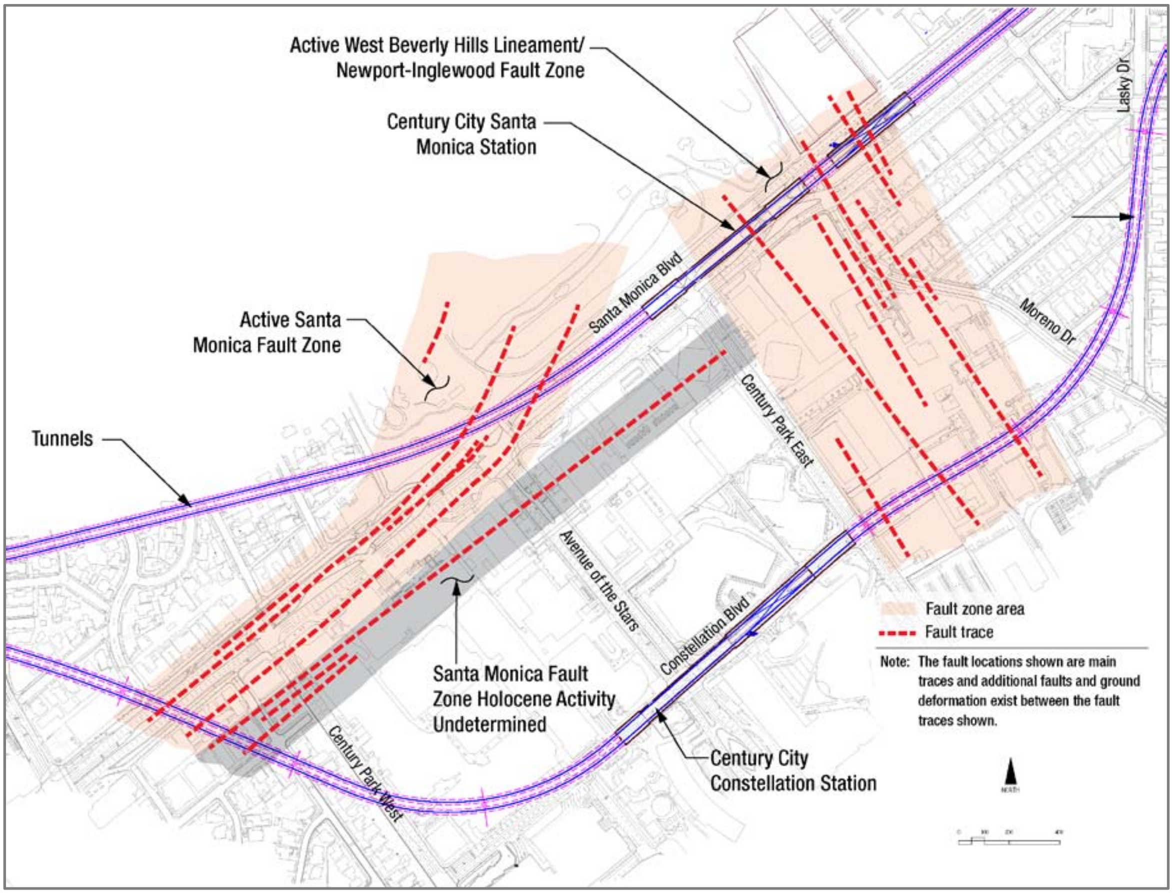
3.5 Discussion

The transect CPT, continuous core borehole, geophysical seismic reflection, and geotechnical borehole data clearly demonstrate the presence and location of significant faulting of both the Santa Monica fault zone and the northern extension of the Newport-Inglewood fault zone, referred to in the literature and previously and herein as the WBHL.

The Santa Monica fault zone is clearly identified in the northern portions of Transects 1/8 and 3. The major fault traces identified in the transects, when plotted on the fault map, Plate 3 and Figure 9, extend northeast from Transect 3 to Transect 1/8. Figure 9 presents the fault zones without the detailed transect data. At Transect 3 the northern major fault traces are in Santa Monica Boulevard and are coincident and slightly south of the geomorphic scarp. At Transect 1/8, the major traces splay, crossing through the originally proposed Santa Monica Boulevard (west) station location and subparallellng the geomorphic scarp. The locations of these traces are projected between Transects 3 and 1/8 as shown on Plate 3. The fault zone identified on the west end of Transect 2/2E corresponds to that of Transect 1/8. These results demonstrate that this area lies above the tip of the hanging wall of the north-dipping main thrust strand of the active Santa Monica fault zone. Such hanging-wall tip locations have been shown to experience extreme ground motions in some reverse-fault earthquakes (e.g., Allen et al., 1999).

The western portion of Transect 2/2E is subparallel to the main traces of the northeast-southwest trending Santa Monica fault zone. Fault traces with that trend would appear near-horizontal on the transect profile and consequently would be difficult to identify in the subsurface data. Thus, without northwest-southeast transects across the area to the northeast of Transect 1/8, faulting associated with the Santa Monica fault zone cannot be precluded in this area. The northern main traces of the Santa Monica fault zone identified in this investigation are considered to be active based on their stratigraphic relationships and their spatial relationship to the geomorphic scarp, determined to be formed in the Holocene by the paleoseismic investigation of Dolan et al.(2000).

Figure 9: Fault Zones Century City



Major northeast-southwest trending faults have been identified on Transects 1/8 and 3 south of Santa Monica Boulevard. There is significant apparent vertical offset of formation contacts and alluvial fan/estuarine units across these fault traces, although with an apparent opposite sense of movement from the current direction of slip along this fault zone (Plates 4 and 6). Although these more southerly strands of the Santa Monica fault system trend subparallel to the active fault traces identified to the north, they do not have geomorphic expression (Plates 2 and 3). Where the active traces diverge to the northeast at Transect 1/8, these faults continue eastward parallel to and south of Santa Monica Boulevard. The strata faulted by these southerly strands are mid- to late-Quaternary. They are at least 100,000 years old and are probably on the order of several hundred thousand years old. Holocene sediments have not been identified in the borehole cores of Transects 1/8 and 3, so it has not been possible to preclude that these fault traces are Holocene active. Therefore, the potential fault zone related to these major fault traces is delineated on Plate 3 as “Holocene fault activity undetermined”.

The faulting identified in Transect 4, Figures L-10 and L-11 and Plate 7, corresponds to the same zone of faulting encountered towards the eastern end of Transect 2/2E to the north (Figures L-8 and L-9 and Plate 5), as does the fault zone responsible for the vertical offsets observed between boreholes 69036-1, G-165, G-166, and S-111 from prior and current geotechnical investigations in the area east of Century Park East and in BHHS. Many of the fault traces project from Transect 2/2E southward to Transect 4 and two of the traces project southward from Transect 4 to the Constellation Profile (Plate 9 and

Figure L-14). In addition to this evidence of north-south faulting, folding is observed east of the fault zone in the seismic reflection data and on the profiles of both Transects 2/2E and 4 (Figures L-9 and L-11, and Plates 5, 7, 13, and 19). Taken together, these observations document the presence of a north-northwest-trending zone of late-Quaternary faulting and folding along the WBHL that extends through the Santa Monica Boulevard (east) Station alternative (Plate 3 and Figure 9). In contract, both Transects 1/8 and 3 (Figures L-1, L-2, and L-8 and Plates 4 and 6) show continuity of stratigraphy and an absence of active faulting for all of the southern halves of these transects. Moreover, the Constellation Profile (Plate 9 and Figures L-14 and L-15) shows continuity of stratigraphy and an absence of faulting west of Century Park East Boulevard at the Constellation station alternative location.

In summary, the detailed locations and subsurface geometries of major strands of the Santa Monica and West Beverly Hills/Newport-Inglewood fault zones have been identified in this study. However, as along most major fault systems, additional secondary fault strands and zones of possible distributed near-surface deformation are also likely to occur in association with these faults. The methods of investigation used in this study may not detect such smaller features. Thus, a zone extending approximately 100 feet beyond the detected main traces of the faults was established to include areas that may be subject to the ground rupture, folding, secondary faulting, and off-fault, distributed deformation expected during an earthquake. Such features are likely to be particularly common within the structurally complex zone of intersection of the East-Northeast-trending Santa Monica and North-trending WBHL/Newport-Inglewood fault zones near or just north o the intersection of Santa Monica Boulevard and Moreno Drive.

Metro Tunnel Design

Metro design criteria uses two levels of ground shaking hazard and fault offset: the operating design earthquake (ODE), having a 50-percent probability of exceedance in 100 years; and the maximum design earthquake (MDE), having a 4-percent probability of exceedance in 100 years. This two-level approach follows that outlined in the Recommended Load and Resistance Factor Design Guidelines for the Seismic Design of Highway Bridges (ATC-49) published by the Applied Technology Council and the Multidisciplinary Center for Earthquake Engineering Research.

The probability of exceedance is the chance that the size of the earthquake will be exceeded during the timeframe specified. One hundred years is considered the design life of the Metro underground structures. The guiding philosophy of earthquake design for the Project is to provide a high level of assurance that the overall system will continue operating safely during and after an ODE and will provide a high level of assurance that public safety will be maintained during and after an MDE. It is expected that repairs will be required after the MDE.

Current seismic design criteria for building in the U.S. and for tunnels, stations and bridges associated with Metro Rail Systems, use the concept of seismic design for life safety and no structural collapse for an MDE. In addition, to avoid significant disruption to transit services, Metro design criteria require damage to be repairable after MDE earthquake events.

For MDE events on the Santa Monica or Newport Inglewood fault zones, fault displacements could be of the order of 3 to 6 feet. Design of Metro’s underground stations (complex two-story structures up to 1,000 feet long, including systems and ventilation equipment) to withstand such displacements without significant damage and potential loss of life, would be impractical and without precedent. Damage levels would require a complete rebuild of the stations and associated tunnel sections, with a construction time frame of several years.

The approach for design of tunnels through active faults is documented in Metro Seismic Design Criteria and has a well-established precedent. As discussed in the *Century City Area Tunnel Safety Report*, potential tunnel damage is repairable. A similar philosophy is adopted for transportation infrastructure in general, such as highways, bridges and pipelines. These structures of necessity have to cross faults, and design approaches minimize damage and allow for repair.

For the Century City tunnels, the MDE and ODE fault displacements for detailed final design of the tunnel will be determined using a probabilistic approach during subsequent phases of design. In addition, further exploration will be required to refine the fault zone locations with respect to the selected tunnel alignment.

4.0 SUMMARY AND CONCLUSIONS

This study was conducted to evaluate the potential for active faults intersecting the Project's Century City station options and tunnel alignments along Santa Monica and Constellation Boulevards. The current investigation included 56 continuous core borings and 192 CPT soundings along 7 transects, and 5 geophysical seismic reflection lines along the same 7 transects, consolidated into the 5 seismic lines. Transects were aligned to intersect previously inferred locations of the Santa Monica fault zone and the WBHL, which is the inferred northern extension of the Newport-Inglewood fault zone.

Clear geomorphic evidence of late-Pleistocene to Holocene activity exists along both fault zones, and these observations were used as the primary basis of earlier mapping. In particular, a well-developed scarp along the Santa Monica fault zone, seen on early topographic maps and aerial photographs and still generally discernible on the ground, can be traced continuously from Century City to the southern portion of the VA Hospital property in West Los Angeles. Between Century Park West and Avenue of the Stars, the scarp-forming Santa Monica fault zone is approximately coincident with Santa Monica Boulevard. Detailed subsurface investigations in the vicinity of the proposed Santa Monica Boulevard Station, centered on Avenue of the Stars, demonstrated that the station would be located within the active fault zone. Thus, it was recommended that this station location no longer be considered an option, and subsequently, the station was shifted to the east, between about Century Park East and S. Moreno Drive.

In addition to the Santa Monica fault zone, clear evidence for a wide zone of north-northwest-trending faulting is observed along the WBHL. Multiple lines of evidence from three different east-west transects show faulting, forming a fault zone that is on the order of 550 feet wide, that crosses through the proposed Santa Monica Boulevard Station site shifted east to Moreno Drive. Given that this fault zone apparently constitutes the northward extension of the Newport-Inglewood fault system, it must be considered an active fault. Thus, this proposed Santa Monica Boulevard Station near Century Park East is also not suitable for a public transit station.

In addition to the clear evidence for faulting along both the Santa Monica and WBHL/Newport-Inglewood fault zones described in this report, the zone of intersection between these major fault systems—located in the vicinity of Santa Monica Boulevard near South Moreno Drive or within the Los Angeles Country Club immediately to the north—is likely to be an area of significant structural complexity, which would include folding, secondary faulting and off-fault, and distributed deformation; therefore, the area is not recommended for a station site.

In summary, this investigation has shown that both the Santa Monica fault zone and WBHL are active fault zones. Each fault zone is capable of generating earthquakes of M7 or greater with average surface displacements of 3 to 6 feet. Moreover, there is no knowledge of where either of these faults resides in their respective seismic cycles. Both of the proposed Santa Monica Boulevard Station options are located within these active fault zones. This study also found that the proposed Constellation Boulevard Station site is located outside zones of active faulting and can be considered a viable option.

Tunnel crossings of the fault zones will require special designs to accommodate fault movement. During subsequent design phases, exploration will continue to evaluate the location of the fault zones more precisely with respect to the tunnel alignment selected and the fault characteristics for design.

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