GEOTECHNICAL IMPACT REPORT
BART WARM SPRINGS EXTENSION
CITY OF FREMONT, CALIFORNIA

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March 2003 | Job No.: 202122.PGR

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INTRODUCTION

The purpose of this report is to provide an evaluation of potential geotechnical impacts on the project, reasonable mitigation measures, and whether these mitigation measures can reduce the potential impacts to acceptable levels. Specifically, this report addresses the geotechnical and seismic impacts of the proposed project.

This report is based on research of available published and unpublished geological/geotechnical data and review of subsurface information in our files and elsewhere. No new borings were made for this study.

PROPOSED PROJECT

The Proposed Project consists of a 5.4-mile extension of the BART system, with a new station in the Warm Springs district of Fremont. An optional second station in the Irvington district of the city is also being proposed.

The Proposed Project alignment would generally parallel portions of the UP railroad corridor, which contains the former WP and SP railroad tracks, and I-680 and I-880 in southern Alameda County (Figure No. 1). The initial segment of the Proposed Project alignment would begin on an embankment at the south end of the existing Fremont BART Station. The Proposed Project alignment would pass over Walnut Avenue on an aerial structure and descend into a cut-and-cover subway north of Stevenson Boulevard. It would continue southward in a subway under Fremont Central Park and the eastern arm of Lake Elizabeth. The alignment would surface to at grade between the former WP and SP railroad alignments north of Paseo Padre Parkway. It would pass over a grade-separated Paseo Padre Parkway on a bridge structure, and then continue southward at grade, passing under a grade-separated Washington Boulevard. From Washington Boulevard, the Proposed Project alignment would occupy the former WP alignment south to a new terminus at Warm Springs and Grimmer Boulevards in the Warm Springs District. The railroad corridor configuration would consist of BART on the eastern side (operating on the former WP tracks) and UP on the western side (operating on the former SP tracks).

Facilities along the Proposed Project alignment would include the new and optional stations (Warm Springs Station and Irvington Station, respectively) and ancillary facilities spaced out along the alignment, including electrical substations, gap breaker stations, train control facilities, ventilation structures, and a maintenance facility.

The proposed Warm Springs Station would be the new terminus of BART's Fremont line. The station and parking lot site would occupy approximately 34 acres between Grimmer Boulevard to the north, Warm Springs Boulevard to the east, the northernmost portion of Warm Springs Court to the south, and the NUMMI UP railroad yard to the west.

The 2003 Proposed Project includes an optional Irvington Station. The Irvington Station is optional because funding for the station has not been secured at this time. The Irvington Station site would occupy approximately 18 acres. The site straddles the realigned rail corridor and is bounded by Washington Boulevard on the north, residences on Bruce Drive to the east, commercial development to the south, and residences west of the former SP alignment. The ruins of the former Gallegos Winery occupy the northeast corner of the proposed optional station site, but would not be affected.

SETTING AND EXISTING CONDITIONS

Regional Geology

The alignment of the proposed project is located near the eastern edge of the San Francisco Bay. The San Francisco Bay area is located within the Coast Range Geomorphic Province of California, a region shaped by complex and dynamic geologic processes. Deformation of the earth's crust has resulted from the interaction of mobile crustal plates ("tectonics"). Faulting, folding and erosion have produced the northwest-trending ridges and valleys, which characterize the Coast Ranges. The San Francisco Bay occupies a structural depression, which formed between the uplifted Diablo Range and Berkeley Hills (along the east side of the depression) and the hills of the San Francisco Peninsula (along the west side of the downdropped block). The structural depression has been partially filled in with sediment and inundated by seawater to form the San Francisco Bay.

The dominant structural feature within the region is the San Andreas Fault System. This system includes several major fault zones, including the San Andreas, Hayward, and Calaveras fault zones. The San Andreas Fault System is the seismically active crustal boundary along which northwestward movement of the Pacific plate west of the fault is taking place relative to the North American plate (located east of the fault).

Local Geology

The alignment of the proposed project is located near the eastern edge of the San Francisco Bay Plain. A break in slope to the east of the alignment forms the base of the foothills of the Diablo Range. The extent of the proposed project is shown in Figure 1.

Several published geologic maps[31, 32, 36] have been prepared and numerous geotechnical investigations have been completed in the area of the proposed project. In general, the deposits underlying the area are older and younger alluvium determined on the basis of geomorphic position and physical characteristics of the sediments. A geologic map showing the distribution of surfacial deposits is presented in Figure 2.

The northern portion of the proposed project crosses Latest Holocene Alluvial Fan Deposits (Qhfy) and Holocene Alluvial Fan Deposits, fine facies (Qhff)[36]. Qhfy sediments are considered to be of latest Holocene age (less than 1,000 years old) and may be composed of gravel, sand, silt and clay. Qhff are of Holocene age (less than 10,000 years old) and are clay rich deposits. In general, both these units are characterized as having high to very high liquefaction susceptibility.

The proposed alignment traverses the western trace of the Hayward Fault in the area of Walnut Avenue and crosses the eastern trace approximately 700 feet (200 m) southeast. The fault crossing is described in more detail in later sections of this document.

The sediments around Lake Elizabeth have been identified as Holocene Basin Deposits (Qhb) (less than 10,000 years old)[36]. These sediments consist of fine-grained alluvium with horizontal stratification, and they can be interbedded with lobes of coarser alluvium deposited between streams that drain into the basin. Interbed of peat may also be present. Ground water is high, often at the ground surface. These deposits may also contain irregular and discontinuous sand and silt layers/lenses. Thus, layers of liquefiable material may be present within this area.

Localized deposition of marsh deposits has occurred in shallow depressions along the Hayward Fault, commonly known as “sag ponds” (natural depressions formed along a fault as the result of surface deformation caused by movement along the fault). The marsh deposits consist of soft to firm clay, organic clay, and peat. Due to poor consolidation and high organic content, these deposits are highly compressible. Marsh deposits have been identified within and on the margins of Tule Pond (also called Tyson's Lagoon), located north and south of Walnut Avenue and east of the Fremont BART Station. Previous subsurface investigations for the Fremont BART Station indicate that the marsh deposits extend to depths of 20 to 30 feet (6 to 9 m) beneath the pond[15]. A similar "sag pond," Stivers Lagoon, was modified during construction of Lake Elizabeth. The identification of organic sediments in subsurface investigations[27] indicates that marsh deposits associated with this feature may be present in the area southeast of Lake Elizabeth to just south of Paseo Padre Parkway. These materials have a relatively high susceptibility to groundshaking. Although these materials are considered to have a low liquefaction potential, localized conditions that are conducive to liquefaction (including high groundwater levels) may be present within some marsh deposits[4]. Evidence of previous occurrence of liquefaction has been identified in the marsh deposits north of Tule[58].

Proceeding southward, the proposed project alignment crosses Holocene Alluvial Fan Deposits, fine facies (Qhff) again in the vicinity of Paseo Padre Parkway[36]. From the area just south of Paseo Padre Parkway to the location of the optionally proposed Irvington Station, the alignment traverses a portion of an older alluvial terrace, described as Latest Pleistocene Alluvial Fan Deposits (Qpf). The distribution of the older alluvium (Qpf) is shown on Figure 3.2-2. These alluvial sediments consist of interbedded deposits of very stiff to hard clays and silts, and medium dense to very dense sands and gravels, which are typically at least 150 feet (45 m) thick. These deposits are interpreted as being sediments deposited during the latest Pleistocene (10,000 to 30,000 years old). In general, the older alluvium is more “well-consolidated” and contains a higher percentage of sand and gravel than the younger alluvium in the area. The older alluvium has relatively higher density and lower plasticity, and is considered to have a low susceptibility to liquefaction.

The proposed project traverses the Hayward Fault Zone approximately three hundred feet north of Washington Boulevard centerline. The fault crossing is described in more detail in later sections of this document.

Southward from the location of the proposed Irvington Station to the southern terminus of the proposed project, the alignment alternates between Latest Pleistocene to Holocene Alluvial fan Deposits (Qf) and Latest Holocene Alluvial Fan Deposits (Qhfy) [36]. "Qf" deposits might be either latest Pleistocene or Holocene in age (less than 30,000 years). They include sand, gravel, silt and clay, are moderately to poorly sorted and moderately to poorly bedded. Liquefaction susceptibility is generally low for "Qf". Poorly drained areas with marsh deposits have not been identified along this portion of the alignment. However, during subsurface investigation for the Grimmer Boulevard overcrossing, layers of loose, granular sediments were encountered to a depth of approximately 30 feet (9 m).

Soils

Soil profiles have developed on the surface of the alluvial deposits in the area as a function of topography, climate, vegetation, biologic activity, the type of underlying materials and the passage of time. The surface soils along the alignment of the proposed project, mapped in detail by the United States Department of Agriculture Soil Conservation Service[56], reflect the properties and age of the underlying alluvial deposits. In general, the surface soils of the area are cohesive clays and silty clays which have moderately low to very low permeability, low strength, moderate to no erosion hazards, and moderate to high shrink-swell (expansion) potential.

The northernmost portion of the proposed alignment, including the area of the Fremont BART Station and northern Central Park, is mantled by the soils of the Batella and Yolo series soils. These soils, developed on Latest Holocene Alluvium (Qhfy) [36] are silt loams with moderate permeability and moderate to high shrink-swell potential. Due to the gentle topography of the area (0 to 2% slopes), velocities of runoff are slow and the erosion hazard is slight to none. The soils surrounding Lake Elizabeth are more clay-like and include Willows and Clear Lake mapping units. The mapped extent of these clays and clay loams coincide well with the mapped location of Holocene Basin Deposits (Qhb) and Holocene Alluvial Fan Deposits (Qhff)[36]. These fine-grained soils have very low permeability, low strength, and are considered highly expansive. Slopes range between 0 and 9%[56].

The soils developed on the Latest Pleistocene Alluvium (Qpf) along the north central portion of the alignment[36], between Paseo Padre Parkway and Washington Boulevard, include Tierra and Azule series loams and clay loams. These soils are typically deeply developed and moderately well drained with moderate to high shrink-swell potential and low to very low permeability. The erosion hazard is low on gentle to flat topography (Tiera Loam, 0-5%) but can be significant in cut slopes or in Azule Clay Loam unit (9 to 30% slopes)[56].

Silty clay loams of the Danville and Marvin series are found along the alignment from south of Washington Boulevard to just north of Grimmer Boulevard. Low permeability, low strength and moderate to high shrink-swell potential characterize these soils. The erosion hazard is typically low to none on flat terrains and moderate on steeper slopes (Danville silty clay loam, 2 to 9% slopes)[56].

From north of Grimmer Road to the south end of the proposed alignment the majority of the soil is mapped as Clear Lake clays[56]. The permeability of these fine-grained soils is low and the shrink-swell potential is considered high. Velocities of runoff are slow and there is no significant erosion hazard.

Slope Stability

Slope stability (or, more to the point, potential for slope failure) is controlled by complex interrelated factors, which include type and strength of geologic materials, angle of the slope, and hydrologic conditions. Within the San Francisco Bay region, the majority of landslides occur on slopes steeper than 15% underlain by unstable rock or sediments and where there is evidence of previous slope failures[44]. Landsliding hazards are increased during sustained high precipitation periods and by strong seismic shaking during earthquakes. Human activities such as grading can also contribute to the occurrence of landslides.

The proposed alignment is located within an area of gentle slopes and relatively stable alluvial deposits. The area along the alignment has been characterized as stable with respect to the stability of the slopes. To the east of the proposed alignment in the area south of Washington Boulevard, the topography of the Mission Uplands is considerably steeper. The slopes developed on the relatively older alluvial deposits (Qf) of this area are considered generally stable to marginally stable.

Seismicity

The seismicity of a region is defined by distribution, recurrence, and intensity of earthquakes over a period of time in that region. Earthquakes are the result of the sudden release of energy stored as accumulated strain in rock masses on both sides of a fault. In addition, gradual release of the stored strain can occur as slow slippage along the fault, or "fault creep". The rupture surface along which the earth is displaced, one side relative to the other, is called a fault. The fault trace is the linear zone where the fault plane intersects the ground surface. Surface rupture can occur along the fault trace during a moderate to large earthquake. Gradual deformation occurs where fault creep takes place.

The linearity of distinctively offset terrain features caused by past fault displacement is the primary source of evidence used by geologists to identify the location of faults. However, many historically damaging earthquakes have not produced recognized ground surface rupture. The time sequence of moderate to strong historic earthquakes (Richter magnitude equal to or greater than 5.5) within the San Francisco Bay Area since the early 19th century is shown in Figure 3[62].

The occurrence of an earthquake produces seismic waves, which radiate in all directions from the origin of the earthquake, or epicenter. The seismic waves cause groundshaking, which is typically strongest at the epicenter and diminishes (attenuates) as the waves move through the earth away from the source of the quake. The severity of groundshaking at any particular point is referred to as "intensity" and is a subjective measure of the effects of groundshaking on people, structures, and earth materials. Intensity is typically expressed by a Roman Numeral in the Modified Mercalli Scale. A description of the observable effects in each of the Modified

Mercalli Intensities (MMI) is presented in Table 1. The effect of ground shaking on structures depends on the design, quality of construction and foundation materials, as well as distance from the source and shaking characteristics of the site soils.

Seismic waves and associated ground motion generated by earthquakes can also be detected and measured by instruments called seismographs and accelerometers. The measurement of the energy released at any point of origin, or epicenter of an earthquake is referred to as the “magnitude” which is generally expressed by a number on the Richter Magnitude Scale. The Richter Scale is logarithmic; each successively higher integer step in Richter Magnitude reflects an increase of about 31.5 times the amount of energy released by an earthquake of the lesser integer. As such, the Richter Magnitude is a specific measurement of the power of an earthquake as it occurs. The record of measurement of Richter magnitudes began in the late 1930s after seismographs were invented.

Estimates of the magnitude of earthquakes occurring prior to the development of seismographs and the Richter Magnitude Scale are made on the basis of historical accounts of the intensity of seismic events. The extent of damage and description of effects near and away from the source of an earthquake provide a basis of comparison with the effects of seismic events, which have been more accurately measured in recent times.

Many faults considered capable of generating damaging earthquakes have not produced seismic events during historic time, much less within the more recent period during which instrumental measurements of seismic events are available. The time intervals between recurrence of individual earthquakes originating on many faults within California exceed the relatively short record of human history of the region. Estimates of the potential magnitude of future earthquakes on recognized faults are made by calculations based on the mapped distribution of earth materials in the area of the fault, measurement or estimation of the length of the fault and previous displacements along the fault (measured or inferred).

The proposed project will be located within the seismically active San Francisco Bay Area. The seismicity of the San Francisco Bay Area is primarily related to the San Andreas Fault System, which is considered to form the boundary between the North American and Pacific plates. The

San Andreas Fault System contains several major faults and fault zones including the San Andreas Fault Zone (SAFZ) and the San Gregorio-Hosgri Fault Zone, west of San Francisco Bay, and Hayward, Calaveras, Concord, and Greenville faults in the East Bay Hills and the Diablo Range. The rate of relative motion between the North American and Pacific Plates is estimated to be approximately 1.3 inches (32 millimeters)[46] per year. A portion of this motion is accommodated by movement along active faults in the region, expressed as earthquakes and fault creep. The remainder of the motion is stored as accumulated strain, which will eventually be released in future earthquakes. The major active and potentially active faults located in the area of the Warm Springs Extension project are shown in Figure 4. These faults and their seismic potential are listed in Table 2[10, 37, 39]. The table presents estimates of the moment magnitude of the largest earthquakes expected to be released by each of the faults. The maximum earthquake, which can be reasonably expected to occur within the present geologic framework along a fault, is typically referred to as the maximum credible earthquake (MCE). The probability of an earthquake occurring along a fault is a function of the estimated time interval between earthquakes, and the known or estimated date of the last major earthquake released by that fault.

For many faults, accurate determinations of the date of the last major earthquake have not been made. The following section describes the characteristics of each of the recognized or suspected active and potentially active faults, which could be the source of earthquake that may affect the proposed project.

Active Faults

The Alquist-Priolo Special Studies Zones Act of 1972 (the Act) was passed by the California legislature to address the hazards of surface rupture along seismically active faults within the state. Under the Act, the California Division of Mines and Geology (CDMG), recently changed to California Geological Survey, was charged with identifying active faults within the state and delineating Special Studies Zones (changed to Earthquake Fault Zones in 1994) within which surface fault rupture is more likely to occur. The State defines an active fault as a fault, which has evidence of surface displacement within the last 11,000 years[30]. Most of the recognized active faults within the San Francisco Bay Area are associated with the San Andreas Fault

System (SAFS). The SAFS includes several well-studied faults and fault zones and some less well-understood subsidiary faults. Each of the major regional active faults described below are considered capable of generating earthquakes, which could produce moderate to violent groundshaking in the project corridor.

Hayward Fault Zone

The Hayward Fault Zone (HFZ) is a right-lateral strike slip fault zone within the SAFS, which extends approximately 55 miles (88 km) from San Jose northwestward to Point Pinole. The fault zone is expressed by active seismicity, including large historic earthquakes, active fault creep, and abundant geomorphic evidence of fault rupture. The fault zone has been divided into the northern and southern segments on the basis of seismicity and fault rupture history[62].

In 1868, a major historic earthquake occurred along the HFZ. It had an estimated Richter Magnitude of 6.8[55]. Relatively little historic information is available regarding the effects of the 1868 earthquakes. An earthquake in 1836 had been attributed to the northern segment of Hayward Fault, centered in Oakland. However, it has recently been determined that the probable source of the 1836 earthquake was actually the San Andreas Fault near San Juan Bautista. Ground rupture was reported along the Hayward Fault from Oakland to Fremont following the 1868 earthquake[54]. Reportedly, a maximum of three feet of horizontal displacement occurred along the fault. Approximate MMI IX groundshaking was experienced in the Fremont area during this quake[55]. Reported accounts of the quake describe ground rupture in the area south of Niles and significant damage to the Southern Pacific Railroad tracks in the Irvington area. However, no detailed mapping is available of the 1868 rupture.

Observation of offset cultural features and geodetic measurements across the HFZ document constant slippage (creep) occurring along the fault. This slippage occurs along the fault, at a relatively constant rate, between large earthquakes and is referred to as "aseismic creep". Numerous investigations of the rate of creep have been conducted along the southern segment of HFZ in the last three decades[7, 8, 13, 40, 47]. A study of the historic slip rates along the HFZ suggests that although the fault zone has an overall average rate of 5.1 mm/yr, significant variations in the creep rate are documented[40]. Relatively high rates (8 to 10 mm/yr) characterize a 2.5 miles (4 km) stretch of the fault in southern Fremont, including the southern portion of the proposed project. In the Fremont Central Park Area, the creep rate is estimated to be about 6 mm/yr, consistent with local geodetic measurements and longer-term geologic and slip rates[8]. An area of low creep rate (3.5 to 4.0 mm/yr) has been identified in Oakland[40]. According to a recent study by California Earthquake Probabilities Working Group (1999), the mean slip rate for both Northern and Southern Hayward Fault is 9 mm/yr (Table 3)[62].

The long-term slip rate of the HFZ, as measured by offset of Pliocene (six to eight million year old) volcanic rocks, has been estimated to be between 5 to 7.5 mm/yr[24, 52]. If the more rapid creep rates measured at the surface (9 mm/yr) are assumed to represent the slip rate along the fault at depth, the segments of the fault with lower slip rates may represent area of strain accumulation. The release of this strain could generate large earthquakes along these "locked" segments of the fault[40].

The proposed project is located near the center of the southern segment of the Hayward Fault Zone. The fault zone trends northwest-southeast, crossing the northern portion of the proposed alignment just south of Walnut Avenue and again just north of Washington Boulevard. Southward from Washington Boulevard, the orientation of the fault and the proposed project alignment diverge, separated by a distance of approximately 3,000 feet (9100 m) at the southern end of the alignment.

In the Fremont area, the HFZ is expressed as a prominent structural feature with an abundant evidence of surface deformation. Linear fault scarps, pressure ridges, and tectonic depressions characterize a well-defined western fault trace. Accurate location of the western trace has been accomplished by numerous trenching investigations conducted in the area between the Fremont BART Station and Washington Boulevard. The locations of trenching investigations, showing the identified position of the fault, are presented in Figures 5A and 5B. In addition to the fault trenching studies, aseismic creep along the fault has resulted in observable displacement of artificial features including pavements and curbs,[21, 40, 43] a warehouse facility north of Washington Boulevard[14] and the former Fremont Community Center in Central Park[9]. In addition, a recent study by USGS (Map MF-2386, 2002) refers to a graben structure in the area of Tule Pond that has subsided at a rate of nearly 3 mm/yr[34]. The observable deformation along the western trace is typically restricted to a narrow zone of less than 50 feet (15 m) in width. On the basis of the substantial body of evidence collected to date, the western location of the trace is considered to be mapped with a moderate to high confidence through this area[4,8].

A subsidiary trace of the HFZ has been mapped subparallel to and east of the western trace. The eastern trace is mapped as extending southward from its juncture with the western trace just north of Tule Pond to just south of the intersection of Mission View Drive and Paseo Padre Parkway (Figure 5A)[12]. Unlike the western trace, the eastern trace is not expressed by prominent geomorphic features associated with faulting. Recent studies of the eastern trace near the north end of Tule Pond indicate repeated faulting during the last 2,000 years[58,59]. Trenching across the eastern trace in the area east of Tule Pond revealed minor offsets of young sediments[61]. At the south end of the pond, no evidence of fault rupture was observed in trenches across the mapped fault trace. Deformation in this area was expressed as low amplitude folding of the sediments. The lack of identifiable subsurface and geomorphic expression of a fault in this area has been interpreted as evidence that the eastern trace is no longer active[8]. However, there may be a potential for some deformation to occur in a future earthquake.

Recent investigation of the eastern trace south of Stevenson Boulevard, northeast of the Fremont Civic Center[25] uncovered evidence of fault rupture (including sediment displacements and deformation) in trenches excavated across the eastern trace. A recent study of the microseismicity of the area suggests that a previously unidentified trace of the Hayward Fault Zone may exist between the Hayward Fault and the base of the foothills to the east[60]. Evidence of faulting or fault-related deformation was not identified in extensive trenches excavated east of and perpendicular to the eastern trace during investigations for the California School of the Blind[41] and within Central Park[25]. The Hayward Fault has been zoned as an Alquist-Priolo Earthquake Fault Zone.

The Hayward Fault zone is considered capable of producing the next major earthquake in the San Francisco Bay Area. Estimates of the maximum credible earthquakes on the northern and southern segments of the Hayward Fault zone range from magnitude 6.8 to 7.3[53]. It has been estimated that a maximum credible earthquake of magnitude 7.5 may occur[39,54]. Considering the fact that the distance of the project site from the HFZ is essentially zero, the estimated Peak Ground Acceleration (PGA) produced at the site during the expected magnitude 7.5 MCE should be 0.7 g, assuming soil type "D" for the entire project alignment[10, 37]. The estimated probability for earthquakes of magnitude equal to or greater than 6.7 in the next 30 years (2000 to 2030) on Hayward Fault/Rodgers Creek Fault system is 32%[62].

The average recurrence interval for a Magnitude 7.0 earthquake on the Northern Hayward fault is unknown. Working Group on California Earthquake Probabilities (1990) assumed an interval of 167 years. The 1996 Working Group on Northern California Earthquake Potential estimated approximately 210 years, based on extrapolations from southern Hayward paleoseismological studies and a revised estimate of 1868 slip on the southern Hayward Fault[33]. The Working Group on California Earthquake Probabilities (1999) estimated the mean annual occurrence rate and recurrence intervals for several earthquake events that may occur on a segment of or a combination of segments of Hayward Fault (see Table No. 4)[62].

San Andreas Fault Zone

The San Andreas Fault Zone (SAFZ), a complex right-lateral strike slip fault zone, extends over more than 600 miles (960 km) from the Gulf of California in Mexico to Cape Mendocino in northern California. The SAFZ has been divided into discrete segments on the basis of historic seismicity and evidence of ground surface rupture. Segments of the SAFZ capable of generating earthquakes, which could affect the project site, include the North Coast North segment, the North Coast South segment, the San Francisco Peninsula segment, and the Santa Cruz Mountains segment. The SAFZ is located approximately 18 miles (29 km) southwest of the proposed project[39].

An earthquake in 1836 had previously been attributed to the Hayward Fault. However, recent studies have determined that it probably originated on the San Andreas Fault near San Juan Bautista. It has been estimated that the 1836 earthquake had a Richter Magnitude of 6.4.

An earthquake in 1838 is believed to have originated on the Peninsula segment of the San Andreas Fault. It has been estimated that the 1838 earthquake had a Richter Magnitude of 7.4.

The 1906 San Francisco Earthquake originated on the San Andreas Fault. This earthquake has been estimated to have had a Richter Magnitude of 8.3 and it produced intense ground shaking (MMI VII to X) in the Fremont area[38]. The Loma Prieta Earthquake in 1989 occurred along a fault within the southern Santa Cruz Mountain segment of the SAFZ. It had a measured Richter Magnitude of 7.1 and produced MMI VI in the area of the proposed project alignment in Fremont[57]. An Alquist-Priolo Earthquake Fault Zone has been established by the State Geologists along the San Andreas Fault. The San Francisco segment of the SAFZ is expected to produce an earthquake of Richter Magnitude 6.7 or greater, with a probability of 21%, between now and the year 2030[62]. According to the California Seismic Hazard Map by Mualchin (1996), the Maximum Credible Earthquake (MCE) for SAFZ is on the order of Magnitude 8.0[39].

Based on the distance of the project site from the SAFZ, the estimated Peak Ground Acceleration (PGA) produced at the proposed project alignment during the expected Magnitude 8.0 MCE should be 0.32 g[10, 37]. The expected maximum MMI along the proposed alignment associated with this event would be VIII to IX.

Calaveras Fault Zone

The Calaveras Fault Zone (CFZ) is located east of the HFZ at a distance of approximately 5 miles (8 km) east of the project corridor[39]. This right-lateral strike slip system extends approximately 75 miles (120 km) northwestward from Hollister as a complex zone of faulting. Recorded seismicity in the vicinity of the fault includes more than 50 earthquakes with MMI of V or greater in the period 1930 to 1972. Historic earthquakes of Richter Magnitude 6 or greater originated from CFZ include events in 1897, 1911, 1979, and 1984. The Calaveras Fault has been zoned as an Alquist-Priolo Earthquake Fault Zone. According to the California Seismic Hazard Map by Mualchin (1996), the MCE for CFZ would be on the order of Magnitude 7.5[39]. The range of expected magnitudes reflects the potential for events to occur on discrete segments of the fault zone and possible rupture of the entire zone. Using the higher estimate for the MCE, the expected PGA at the site would be 0.48 g[10, 37] with associated MMI IX effects. The CFZ is expected to produce an earthquake event of Richter Magnitude 6.7 or greater, with a probability of 18%, between now and the year 2030[62].

Seal Cove-San Gregorio-Hosgri Fault Zone

The Seal Cove-San Gregorio-Hosgri Fault zone (SC-SG-HFZ), alternatively referred to as San Gregorio-Palo Colorado Fault Zone, forms a belt of faulting and seismicity located west of and unparallel to the San Andreas Fault Zone. Although the majority of the fault zone's nearly 240-mile (385 km) length lies offshore, the San Gregorio segment of the zone offsets late Quaternary deposits in the Pigeon Point area north of Santa Cruz. The Seal Cove-San Gregorio-Hosgri Fault has been zoned as an Alquist-Priolo Earthquake Fault Zone. A MCE of Richter Magnitude 7 has been estimated for the San Gregorio segment[29]. Rupture of the entire length of the SC-SG-HFZ could potentially generate an earthquake of Magnitude 8.5[17]. The California Seismic Hazard Map by Mualchin (1996) indicates that the MCE for this fault could be on the order of Magnitude 7.5. The fault zone lies approximately 28 miles (45 km) west of the project alignment[39]. A MCE could produce MMI intensity VIII shaking and 0.18 g ground acceleration along the project alignment[10, 37]. The San Gregorio Segment of the fault is expected to produce an earthquake of Richter Magnitude 6.7 or greater, with a probability of 10%, between now and the year 2030[62].

Sargent Fault

The Sargent fault forms the southwest boundary of broad belt of southwest-dipping thrust and high-angel reverse fault on the eastern flank of the southern Santa Cruz Mountains, east of the San Andreas Fault Zone (SAFZ). Evidence of Late Pleistocene and possibly Holocene displacement and high microseismicity has been identified for the SAFZ. The southern portion of the Sargent Fault has been zoned as an Alquist-Priolo Earthquake Fault Zone. The 4.9 Magnitude Gilroy Earthquake of May 13, 2002 originated on the Castro Fault, a strand of the Sargent Fault. The MCE on the Sargent Fault is estimated to be Moment Magnitude 7.1 on the basis of fault length and estimated slip rate[19]. The Caltrans Seismic Hazard Map (1996) indicates a MCE of 6.75 for Sargent Fault. The recognized active portion of the fault is located approximately 25 miles (40 km) southwest of the project site alignment[39]. The estimated groundshaking along the project alignment associated with a MCE of the Sargent Fault is expected to be equivalent to a PGA of approximately 0.14g[10, 37].

Greenville Fault Zone

The Greenville Fault Zone (GFZ) has been interpreted as being the easternmost of the major branches of the SAFS. The GFZ is a 90-mile (144 km) long system of northwest trending fault segments, which include the Clayton, Marsh Creek, Greenville, and Arroyo Mocho segments. Historic seismicity within the GFZ includes a swarm of earthquakes in January 1980, which included Richter magnitude 5.5 and 5.8 events, which produced surface rupture along 30 miles (50 km) of the fault zone. The relationship of the GFZ to several faults considered to be potentially active, including the Telsa, Corral Hollow, Carnegie, and Patterson Pass Faults, is not well studied[19]. The Greenville Fault has been zoned as an Alquist-Priolo Earthquake Fault Zone.

Estimates of the MCE for the Greenville Fault Zone range from Moment Magnitude 6.8 to 7.25. The Caltrans Seismic Hazard Map indicates a MCE for 7.25 to Greenville Fault[39]. The occurrence of a Magnitude 7.25 earthquake on this fault, located approximately 19 miles (30 km) east of the project alignment, would generate a PGA of approximately 0.23g[10, 37]. The associated MMI could be as high as VIII. This fault has a probability of 6% to produce an earthquake event of Richter Magnitude 6.7 or greater, between now and the year 2030[62].

Green Valley-Concord Fault Zone

The Green Valley and Concord Faults are the primary faults of a two-mile wide complex fault zone located approximately 25 miles (40 km) northeast of the proposed project alignment. The fault zone extends from east of Benicia to east of Walnut Creek. Active seismicity and fault creep (noted in Concord) have been observed along the zone[22]. Historic seismicity in the fault zone includes a Richter Magnitude 5.4 event in 1955. A swarm of earthquakes in 1989, centered near Alamo, appears to have occurred on a fault between the Concord and Calaveras faults, suggesting a link between the two major fault zones[45]. The Green Valley-Concord Fault has been zoned as an Alquist-Priolo Earthquake Fault Zone. The estimated MCE for the Concord Fault is estimated to be 6.5[39], and the associated PGA is expected to be 0.11 g along the proposed project alignment.[10, 37]. There is a probability of 6% for Green Valley and Concord Faults to produce an earthquake event of Richter Magnitude 6.7 or greater, between now and the year 2030[62].

Monte Vista East-Monte Vista West Fault Zone (MVE/MVW)

The Monte Vista East/West faults compose a system of reverse faults located on the southwest side of the Santa Clara Valley, just east of the San Andreas Fault Zone (SAFZ). The Caltrans Seismic Hazard Map (1996) indicates that the MCE for MVE/MVW faults is expected to be Magnitude 6.5. The recognized active portions of MVE/MVW faults are located approximately 12.5 and 14 miles respectively (20 and 23 km) southwest of the proposed project alignment[39]. The estimated groundshaking along the proposed project alignment associated with a MCE occurring on these faults should be equivalent to a PGA of approximately 0.24 g and 0.21 g, for the east and west segments, respectively[10, 37].

Potentially Active and Inactive Faults

Numerous potentially active faults have been identified within the San Francisco Bay area. The potentially active faults significant to the assessment of seismic risks in the Fremont area include the Silver Creek, Mission, and Shannon faults. These potentially active faults may be the source of moderate to large earthquake at some time in the future. However, there is currently insufficient data to specify MCEs for these faults.

The Silver Creek Fault has been mapped subparallel to and west of the Hayward Fault. Although suspected as having recent activity, the fault is not zoned on the current Alquist-Priolo Earthquake Fault Zone maps (1982) [19].

The Mission Fault is mapped at the base of the foothills east of the northern portion of the project alignment[18]. This fault was initially identified as active, and an Alquist-Priolo Special Studies Zone was delineated along the fault trace in 1974. However, sufficient evidence of activity was not established and the Special Studies Zone for the fault was removed on a revised Special Studies Zone map in 1980. A linear trend of microseismicity has been identified which has been interpreted as coinciding with the subsurface projection of the Mission Fault[22]. One interpretation of the microseismicity of the area suggests that the seismicity is located about 1 mile (1.6 km) west of the Mission Fault and may indicate the presence of a previously unidentified branch of the Hayward Fault zone[60].

The Shannon Fault, located about 14 miles (22 km) southwest of the project alignment, forms a 29 mile (46 km) long, northwest-trending topographic and structural boundary extending from

Coyote to the Los Altos Hills. Possible Quaternary displacement and clusters of seismicity have been identified along the fault[51].

Subsurface conditions

Published and unpublished geotechnical exploration data along the proposed alignment were reviewed in order to obtain a general idea of the subsurface conditions underlying the project site.

According to a soil report for Civic Center Office Park[49], located close to the north end of the proposed project alignment (intersection of Walnut Avenue and Civic Center Drive), that site is underlain by a layer of 10 to 30 feet (3 to 9 m) of stiff clay/silty clay/silt. Underneath this layer, loose to medium dense sand ranging in thickness between 10 and 25 feet (3 to 8 m) was encountered. Medium dense to dense gravel was encountered at greater depths. The exploration was terminated at a depth of approximately 60 feet (18.3 m), and no groundwater was encountered.

Based on water well information provided by the Alameda County Water District (ACWD) [2], at the location just north of Lake Elizabeth towards the proposed extension alignment, the soil conditions consist of 20 to 30 feet (6 to 9 m) of clay, underlain by gravel with clay interbeds to an approximate depth of 200 feet (60 m).

Unpublished geotechnical information by Parikh Consultants, Inc. (PCI) for Paseo Padre Parkway Underpass, Washington Boulevard Overhead and the proposed Union Pacific Railroad (UPRR) tracks realignment was utilized[47]. Based on this information, the subsoils consist of firm to very stiff silt/lean clay/fat clay, with interbeds of medium dense silty sand/clayey sand/poorly-graded sand. Shallow groundwater on the order of 4 to 8 feet (1.2 to 2.4 m) was encountered within the area bounded by lake Elizabeth in the north and the beginning of the proposed cut in the south (approx. Station 2318+00). The exploration was terminated at a depth of 90 feet (27.5 m).

The Hayward Fault has been found to be a significant groundwater barrier, with depths to the groundwater differing by as much as 50 feet (15 m) on opposite sides of the fault (shallower to the east of the fault).

POTENTIAL GEOTECHNICAL, GEOLOGIC AND SEISMIC IMPACTS WITH PROPOSED MITIGATION MEASURES

Direct Impacts

Under CEQA, exposure of people or structures to major geologic hazards is considered a significant adverse impact[13]. Geologic hazards include the effects of earthquakes. Major seismic hazards potentially affecting the proposed project alignment include fault rupture and fault creep along the HFZ as well as strong groundshaking with associated ground failure phenomena and/or liquefaction during a large earthquake originating on the HFZ or SAFZ. The effects of these seismic hazards could include potential human injury or loss of life and substantial damage to proposed project structures and significant adverse impacts under CEQA.

Other geologic hazards potentially affecting the integrity of structures proposed by the project include compressible and expansive soils. In general, potential damage caused by these adverse soil conditions would not be catastrophic but may result in significant structural damage over time. The possible effects of the adverse soil conditions on the proposed project and alternatives to the project are significant impacts to this type of construction project if not avoided or mitigated.

Fault Rupture

The proposed project alignment crosses the HFZ just south of Walnut Avenue. The alignment trends southwestward from the existing Fremont BART Station and traverses the western fault trace approximately 500 feet (150 m) from the station (Figure 5A). The western fault trace in this area has been identified in trenches excavated to investigate the sites of previous development projects[34, 61] and for paleotectonic research conducted by the USGS. The proposed project alignment transects the fault trace at an angle of about 30 degrees. Fault rupture occurring along the southern segment of the Hayward Fault Zone (HFZ) could result in risk of injury to persons on or near the proposed project alignment and potential damage to proposed structures. This would be a significant impact.

Further southeast of the intersection with the western fault trace, the proposed project alignment crosses the projected trace of the eastern trace of the Hayward fault (Figure 5A). Although the closest previous trenching investigation of the eastern trace did not identify evidence of the fault trace,[20] evidence of fault-related deformation along the eastern fault trace has been identified at other sites located to the north and south of this location[61].

The proposed project alignment also crosses the HFZ several hundred feet north of the alignment's intersection with Washington Boulevard (Figure 5B). The location of the fault trace in this area is well-documented by trenching[26, 48]. The proposed platform at the Irvington Station would be located approximately 400 feet (122 m) south of this fault trace crossing. The fault would pass through the station's proposed parking lot located east of Osgood Drive.

The 1999 Working Group estimated a 32% probability of a Moment Magnitude 6.7 earthquake originating on the Hayward Fault – Rodgers Creek Fault system over the next 28 years[62]. This seismic event would be similar in magnitude to the earthquake that occurred in 1868. During the 1868 earthquake, a maximum of 3 feet (0.9 m) of horizontal and 3 feet (0.9 m) of vertical surface displacement was reported along the fault. For the purpose of planning for the effect of a Maximum Credible Earthquake (Mw 7.5) during which both the northern and southern segments of the HFZ rupture, a maximum right-lateral horizontal displacement of 10 feet (3 m) has been suggested[54]. An evaluation of potential fault rupture, prepared for a development project at the north end of the proposed alignment estimated a maximum credible displacement of up to 7 feet (2.1 m) horizontal and up to 1.5 feet (0.45 m) vertical distributed within a zone 10 to 20 feet (3 to 6 m) wide along the Hayward fault [61]. Structures located within this zone are likely to sustain significant damage, including displacement or rotation of rigid elements.

Evidence of previous surface displacement, both vertical and horizontal, has been identified on both the western and eastern traces of the fault. According to Woodward-Clyde investigation (1970), secondary faulting within the fault zone at the northern end of the alignment is not expected to extend more than about 200 feet (61 m) away from the known fault trace nor produce displacements of more than a few inches[61]. The expected displacements along secondary faults could cause minor repairable damage to rigid structures.

The impacts of fault rupture would include potential damage to the rails crossing the western and eastern traces of the fault, and damage to structures crossing the fault, if any (possibly at Walnut Avenue). It would also involve displacements of pavement planned for the Irvington Station. In addition, underground utility pipes and cables extending across the main fault trace would be deformed and could rupture, causing consequential hazards. "Secondary" rupture of utilities located nearby should also be expected.

Mitigation of Fault Rupture

In general, embankments would be more tolerant of differential movement expected to occur along the fault than would rigid structures that could be constructed to support the elevated track[4]. Therefore, it would be preferable to have the BART tracks cross the fault trace on an engineered fill embankment. The embankment design should be prepared in accordance with the BART Extensions Program Design Criteria, Volume II, 1990, and specific recommendations developed for the fault crossing near Walnut Avenue[4]. The design criteria established for the Walnut Avenue crossing should include adequate crest width to accommodate track realignment that could become necessary due to fault rupture and/or fault creep, 2:1 side slopes, and removal of unstable foundation materials. Although these design criteria for embankment structures will reduce potential damage and will facilitate repair in the event of fault rupture, the impacts of fault rupture should remain significant. Extensive geotechnical and geological reconnaissance should be conducted in order to precisely locate the primary and secondary traces of the Hayward Fault relatively to the project alignment. Realignment may have to be considered, since it is recommended that the crossing with HFZ occur in an embankment rather than a structure (e.g. crossing over Walnut Avenue).

Where the proposed project alignment crosses the fault approximately 300 feet (90 m) north of Washington Boulevard,[26,48] it is planned to be located within a cut approximately 4 to 6 feet (1.2 to 1.8 m) below the ground surface[35]. The cut at the vicinity of the fault crossing should be wide enough to accommodate the total amount of track realignment that could eventually be required to repair track deformation caused by future fault rupture and/or fault creep. The cut slopes should be constructed at two horizontal to one vertical inclination in compliance with BART seismic design criteria. These design criteria will minimize damage and facilitate repair in the event of seismic shaking. However, the potential impacts of seismic shaking on the cut slopes would remain significant.

The proposed site of the Irvington Station is located within the Alquist-Priolo Earthquake Fault Zone established for the HFZ. Geotechnical Consultants, Inc. conducted an investigation of the Hayward fault in the area of the proposed Irvington Station in 1993. Their report presents a detailed map showing the location of the fault trace in the vicinity of the planned station. If the adopted project includes the Irvington Station, any structures that would be occupied by workers or passengers should be located outside the zone of potential fault rupture. (The typical recommended minimum setback from an identified fault is 50 feet (15 m) and 100 feet (30 m) from an inferred or suspected fault trace[6]). A station platform relocated outside of the area identified as potentially affected by fault rupture should reduce, to below a level of significance, the risk of damage to the station structure. Damage to the parking area should still be expected where it would be constructed across the identified fault trace. No practical mitigation is available to prevent fault rupture-related damage from occurring in the parking area. However, the pavements could be repaired quickly after such an event; thus, the impact could be reduced to a less-than-significant level in paved areas.

The potential of derailment of a passing train following a ground rupture event should be partially mitigated by implementation of redundant emergency response measures of the BART Emergency Plan. Groundshaking during the expected MCE should set off alarms operated by BART[23]. Seven strong motion sensors are currently operated throughout the BART system and sensor installations are proposed for each passenger station within BART extension projects. The strong motion sensor alarms trigger an operation procedure, which prescribes that all trains proceed in manual operation at a maximum speed of 25 miles per hour to the nearest station. The trains are held at the stations until a complete inspection of the tracks and structures throughout the area affected by a seismic event is completed by the BART engineering staff and subcontractors. If fault rupture or seismically induced ground failures result in rupture of the track, power is automatically cut off to trains in the affected area. Alternatively, a power outage caused by disruption of Pacific Gas and Electric service would shut off power to the trains.

The seismic design criteria and emergency procedures would not reduce the potential impacts of surface rupture to an insignificant level where the tracks cross the fault traces. The maximum expected horizontal displacement of ten feet would likely cause significant displacement of the tracks. Displacement of the tracks could result in derailment of passing trains causing risks of personal injury, damage to equipment and loss of use until repair.

Fault Creep

Active fault creep has been monitored along the HFZ in the area of the Proposed project alignment. Fault creep occurs between earthquakes within the Fremont area at a mean rate of 9 mm/yr (0.35 in/yr.)[62]. The rate of creep can vary along a fault both with respect to location and time. Accelerated creep (known as afterslip) can be expected to occur for sometime after a large earthquake occurs on that fault segment.

The continued, incremental horizontal displacement of the ground surface along the HFZ has resulted in significant cracking and deformation of buildings near Washington Boulevard ("Union Street" warehouse), in Fremont Central Park, and several pavement displacements.

Over the last 30 to 40 years, rail deformation has been observed along the UPRR tracks near Shinn Road, and on the former Southern Pacific railroad tracks just north of Washington Boulevard. Special heavy equipment is used by the railroad companies to periodically realign the tracks. The realignment procedures tend to spread the deformation over a long distance of track (several hundred feet) [19]. There is not sufficient data available to determine if active creep is occurring along both the western and eastern traces of fault in this area. Conservatively, both traces would be expected to experience active creep.

Fault creep can be expected to continue throughout the operational life of the project. Active creep and/or subsidence on the western and eastern traces of the HFZ could result in incremental displacement and deformation of the proposed trackway where the proposed alignment will cross the HFZ. The cumulative deformation of the tracks could present safety hazards, particularly for trains operating at high speeds. If not corrected by realignment, the deformation of the track caused by fault creep could result in train derailment, which is a significant impact.

Mitigation of Fault Creep

The potential impact of fault creep along the proposed alignment can be mitigated to an insignificant level by implementation of BART's track maintenance program. The detection of incremental rail displacements should be performed by periodic track and structure inspection, track alignment surveys, and reports of adverse track conditions by train operators. Accelerated creep should also be identified by these procedures.

Track inspections are currently conducted throughout the BART system on a weekly schedule by a professional maintenance staff[19]. These inspections should identify loosened track pins and evidence of potential metal fatigue caused by deformation associated with creep. Track alignment surveys should be conducted semiannually by BART survey crews to evaluate when track alignment displacements are approaching tolerance levels established by BART. Measurement of track displacements should also be performed monthly by a specially designed "laser geometry car" currently used by BART to monitor track conditions at the Berkeley Hills tunnel, the location of an existing track-crossing of the HFZ. All monitoring of track displacements should be documented and compiled in a file maintained by BART surveying staff. In addition to regular track alignment inspection, reports by BART train operators of suspected track conditions that could adversely affect train performance should be evaluated by immediate inspection of affected sections of track.

In order to reduce the potential of train derailments, repairs to or realignment of the track should be made immediately after unacceptable amounts of deformation are detected. These measures would not decrease the potential for creep along the HFZ, but would reduce the impact of creep-related deformation to below a level of significance. Another possible mitigation measure is that trackways could be designed to accommodate fault creep. As an example, the present BART line through the Berkeley Hills will allow some repositioning of the tracks when necessary because of the creep along the Hayward Fault.

If a structure is to be placed directly across the fault trace (e.g. Walnut Avenue Underpass), it should be structurally capable of accommodating incremental displacements due to fault creep.

Groundshaking and Liquefaction

The expected maximum credible earthquake on the HFZ would cause severe to violent groundshaking throughout the area of the proposed extension alignment. Because the Proposed project alignment crosses the active Hayward Fault Zone, the project would be considered to be at the epicentral location of the MCE. Estimates for the near-field (close to the epicenter) horizontal ground accelerations during the MCE range up to 0.7 g along the extension alignment[39].

The Proposed project includes aerial track spans from the north end of the project passing over Walnut Avenue. Other aerial structures that are being proposed are the Paseo Padre Underpass and Washington Avenue Overhead, both with BART alignment at grade (by others). In addition, the following structures already exist: Auto Mall Parkway Overhead and Grimmer Boulevard Underpass, both having BART alignment at grade[35].

The response of structures to strong groundshaking is dependent on the foundation materials, structural design and strength and duration of shaking. The susceptibility of the earth materials to failure along the proposed alignments during seismic shaking is variable.

Liquefaction is a phenomenon in which saturated cohesionless soils are subject to a temporary but essentially total loss of shear strength due to the increased pore pressures caused by the reversing, cyclic shear stresses associated with earthquake shaking. Submerged cohesionless sands and silts of low relative density are the type of soils usually susceptible to liquefaction. Clays are generally not susceptible to liquefaction.

The Latest Holocene Alluvial Fan Deposits (Qhfy) and Holocene Alluvial Fan Deposits, fine facies (Qhff), located at the northern portion of the proposed project (discussed previously in the "Local Geology" section of this report) are both characterized as having high to very high liquefaction potential[36]. Sand and silty sand interbedded layers/lenses may exist within the marsh deposits in the vicinity of Tule Pond and Lake Elizabeth. Thus, liquefiable layers may exist within these deposits. Evidence of previous occurrence of liquefaction has been identified in the sediments at the north end of Tule Pond[59]. The dense, older alluvial deposits in the area of the proposed Irvington station (Qpf) and further south (Qf) are expected to have a low susceptibility to liquefaction. Liquefaction-

The proposed cut and cover section in the area of Lake Elizabeth could also be adversely affected by strong groundshaking and liquefaction. Differential settlement along the tunnel in response to liquefaction or tectonic settlement could impact train operation. Cracking of the subway structure could cause significant groundwater seepage into the subway tunnel.

Mitigation of Groundshaking and Liquefaction

All structures proposed for the proposed project should be designed and constructed in accordance with the BART Extensions Program Design Criteria[5]. The design criteria were revised in 1990, following the 1989 Loma Prieta earthquake; they require specific design procedures to evaluate the seismic loading caused by 0.7 g horizontal ground acceleration generated by the MCE on the HFZ. The design criteria consider the properties of the soil expected or known to be encountered at the location of each design element.

All aerial structures should be supported on deep foundations supported into dense older alluvium. Earth pressures, including seismic loading, should be determined for all retaining walls and subsurface structures (including the proposed cut and cover tunnel) by the Mononobe-Okabe method as specified in the BART Design Criteria. The seismic design of all concrete structures should also conform to the provisions of the American Concrete Institute's Building Code requirements. All buildings should be designed and constructed in accordance with the 1997 Uniform Building Code or subsequent updates.

The proposed project's alignment is in close proximity to and crosses the HFZ, which is considered possible of generating a major seismic event. Therefore, should an earthquake originate within the fault zone, the implementation of the proposed project could result in increased exposure of people, including BART workers and passengers, to the risk of injury related to structural damage or derailment of trains caused by seismic shaking hazards. Appropriate emergency planning, safety procedures, and public education may reduce the impacts of these risks to an insignificant level. BART has developed specific safety procedures for reducing potential train derailment as described earlier. BART posts instructions for earthquake emergency procedures at each station and in BART train cars. Train operators have been trained to respond to potential emergencies related to a large earthquake. Public address systems in the stations and trains allow BART personnel to communicate specific instructions to passengers in the event of an emergency.

Strong groundshaking during an earthquake should trigger strong motion alarms controlled by the sensors operated by BART[19]. Train operation should be delayed until all damage is assessed and necessary repairs are completed. Low intensity shaking reported by BART personnel, who does not trigger the alarms, would lead to a five-minute hold on all trains. Track inspection should be performed by operating trains at reduced speed. The inspection of trackway and structures could reduce the consequential impacts of groundshaking effects to a less than significant level.

Expansive Soils

The surface soils along the proposed alignment have been identified as having a moderate to high shrink-swell potential. The impact of high shrink-swell potential on the project would be the development of high soil pressures when these soils are wetted and consequently swell. The resulting high soil pressures can cause damage to structures such as foundations, pavements, and retaining walls. Without appropriate mitigation, these effects would be significant to the proposed project.

Mitigation of Impact of Expansive Soils

There are several options available for mitigation of the effects of expansive soils. The structures that could be affected can be designed and constructed to withstand the increased earth pressures exerted by the expansive clays. Alternatively, the expansive clays can be treated with lime to reduce the shrink-swell potential in localized areas. The removal of expansive soils and replacement with a non-expansive fill material is another mitigation option. Expansive soil should not be used as fill behind retaining structures or beneath building foundations. Appropriate design and site preparation should mitigate the impacts of expansive soils to an insignificant level.

Compressible Soils

Poorly consolidated, organic sediments have a relatively high potential to compress when surface load is applied. Organic topsoil, where not previously removed along the proposed alignment, is considered a relatively compressible material. The marsh deposits in the area of Tule Pond and Lake Elizabeth contain potentially compressible sediment layers. Construction of fill over these areas could cause settlement as the result of compression of the organic-rich sediments. Potential damage to structures caused by settlement of compressible sediments is a significant impact.

Mitigation of Compressible Soils

Prudent earthwork construction practice requires that all vegetation and organic topsoil be removed prior to placement of fill or structure. Organic clay and silt deposits underlying the location of the proposed embankment at the Walnut Avenue area and elsewhere should be removed and replaced with inorganic compacted engineered fill. Alternatively, other more recent mitigation techniques may be used, including wick drain installation, Cement Deep Soil Mixing (CDMG) or surcharge.

The organic-rich sediments should not be used as fill beneath engineered structures. The construction of the embankment should be performed in accordance with the requirements of the BART Extension Program Design Criteria, the UBC 1997 (or subsequent updates) and the Alameda County Grading Ordinance. Following construction of the embankment, settlement should be monitored by BART surveying staff to evaluate if the track alignment is affected. These mitigations should reduce the potential impact of settlement (such as damage to the trackway) to an insignificant level.

Cumulative Impacts

Exposure to Seismic Hazards

Implementation of the proposed project may result in the development of increased population densities in proximity to rapid transit service. Increased population and development within the corridor would result in increased exposure of people and structures to the seismic hazards associated with the HFZ.

Mitigation of Exposure to Seismic Hazards

The potential exposure of people and structures to fault rupture hazards along the HFZ should mitigated to a less than significant level by the investigation and mitigation requirements of the Alquist-Priolo Earthquake Fault Zones Act. The provisions of the Act require that permits for all development within the Earthquake Fault Zones established by the California Division of Mines and Geology not be granted by local agencies until a geological investigation of fault rupture hazards is conducted. The impact of strong seismic shaking expected within the areas on buildings and other structures should be partially mitigated by the design criteria of the UBC 97 or subsequent updates. These mitigations can reduce but not eliminate risks from ground shaking due to a major earthquake they will remain unavoidable significant impacts.

Construction Impacts

Slope Instability

According to the plans, moderately deep excavation is required for the cut sections between Paseo Padre Parkway and Washington Boulevard (up to 20 feet (6 m) below grade)[35]. In addition, the fill embankment at the northern portion of the alignment is expected to be on the order of up to 25 feet (7.5 m) in height. Other less significant cut and/or fill sections exist along the project alignment. Slopes are expected in cut and fill sections.

Mitigation of Slope Instability

All excavations and fills should be designed in accordance with UBC 97 requirements (or subsequent updates) and the design criteria of the BART extension program. In general, cut and fill slopes exposed to weather are expected to be grossly stable at 2:1 (horizontal to vertical). Embankment slopes on soft clay may need to be flatter due to the weak foundation material. This can be further confirmed during the design phase. However, for preliminary design 1V: 2H slope gradient may be assumed. Proper drainage and erosion control measures are important to maintain the overall stability of the slopes.

Cut and Cover Tunnel Construction

According to the project plans and profiles[35], moderately deep excavation is required for construction of cut-and-cover tunnel near Lake Elizabeth (up to 35-40 feet (10 to 13 m) below existing ground surface). The groundwater table is expected to be encountered at shallow depths in young sediments in the northern portion of the alignment located east of the HFZ. Loose, saturated sediments may be exposed in Central Park around Lake Elizabeth. These unstable conditions, and potentially unstable conditions in more competent materials, may result in failure of excavation sidewalls, which could threaten the safety of construction workers and cause damage to adjacent improvements.

Mitigation of Cut and Cover Tunnel Construction

All excavation should be designed in accordance with UBC 97 (or subsequent updates) requirements and the design criteria of the BART extension program. A dewatering program should be necessary to control groundwater seepage (and associated pore water pressure) into any excavation below the groundwater table. All trenching should be required to meet the shoring requirements of the California Occupational Safety and Health Administration (CAL/OSHA). Potential discharge of water (generated during dewatering) pumped into surface waters of the state should be regulated by the Regional Water Quality Control Board under the National Pollutant Discharge Elimination System (NPDES) requirements. Alternatively, the water could be discharged into the sanitary sewer system if the wastewater discharge requirements of the Union Sanitation District are met.

Retaining structures for a cut-and-cover tunnel construction should conform to the BART seismic design criteria established for the seismic effects of the maximum credible earthquake on the HFZ. All excavation and slope construction should be performed under inspection by a qualified engineering professional, as required under the UBC. Conformance with these guidelines should reduce the impacts of cuts and slope instability below a significant level.

Erosion

The construction of cut slopes associated with the excavation of the cut and cover and permanent open subgrade sections of the alignment would create steep localized slopes in the existing gentle topography of the proposed alignment. These steep slopes would increase the erosion potential of the soils, which is low under existing conditions[56]. The impact could be significant on newly excavated slopes during heavy rainfall.

Mitigation of Erosion Hazard

Erosion control on cut and fill slopes should be provided in accordance with the Alameda County Grading Ordinance (Ordinance #82-17). The slopes should be benched if slope height exceeds 30 feet and vegetated as soon after construction as possible. Concentrated surface flow should be diverted away from the slopes or conveyed by appropriate drains. The slopes should be inspected periodically after periods of heavy rainfall by BART personnel. Observed gullying should be repaired and bare slopes revegetated as soon as possible. These mitigations should reduce the impacts of erosion hazard below a level of significance.

STUDY LIMITATIONS

Our services consist of professional opinions based on our site reconnaissance, researched data and the assumption that the subsurface information does not deviate from observed/researched conditions. All work done is in accordance with generally accepted geotechnical engineering principles and practices. No warranty, expressed or implied, of merchantability or fitness, is made or intended in connection with our work or by the furnishing of oral or written reports or findings.

The geotechnical evaluation provided in this report is intended for project design planning. The contents of this report are not intended for design input, nor directly form the basis in preparation of construction cost estimates for bidding purposes. The scope of our services did not include any detail geotechnical investigations (such as bridge foundation report or materials report, California Test Method 130), or any environmental assessment/investigation for the presence or absence of hazardous or toxic materials in structures, soil, surface water, groundwater or air, below or around this site. Unanticipated subsurface conditions are commonly encountered and cannot be fully determined without taking soil samples and drilling/excavating test borings. Additional expenditures should be allowed during the design phase for investigation services so that a properly designed project can be attained.

The findings in this report are valid as of the present date. However, changes in environmental conditions in the project area can occur with the passage of time, whether they are due to natural processes or to the works of man, on this or adjacent properties. In addition, changes in applicable or appropriate standards may occur, whether they result from legislation or from the broadening of knowledge. Accordingly, the findings in this report might be invalidated, wholly or partially, by changes outside of our control.

Respectfully submitted,
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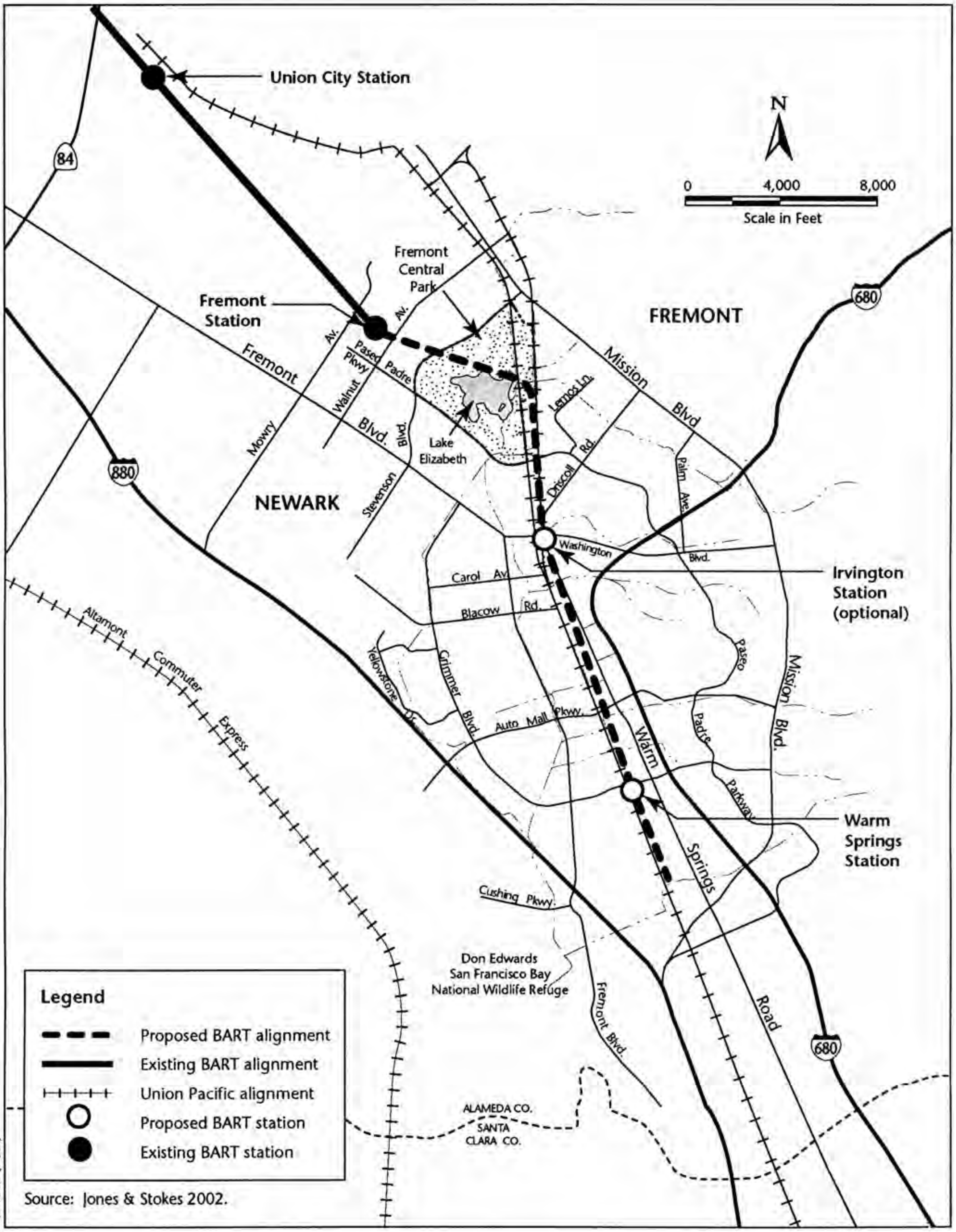
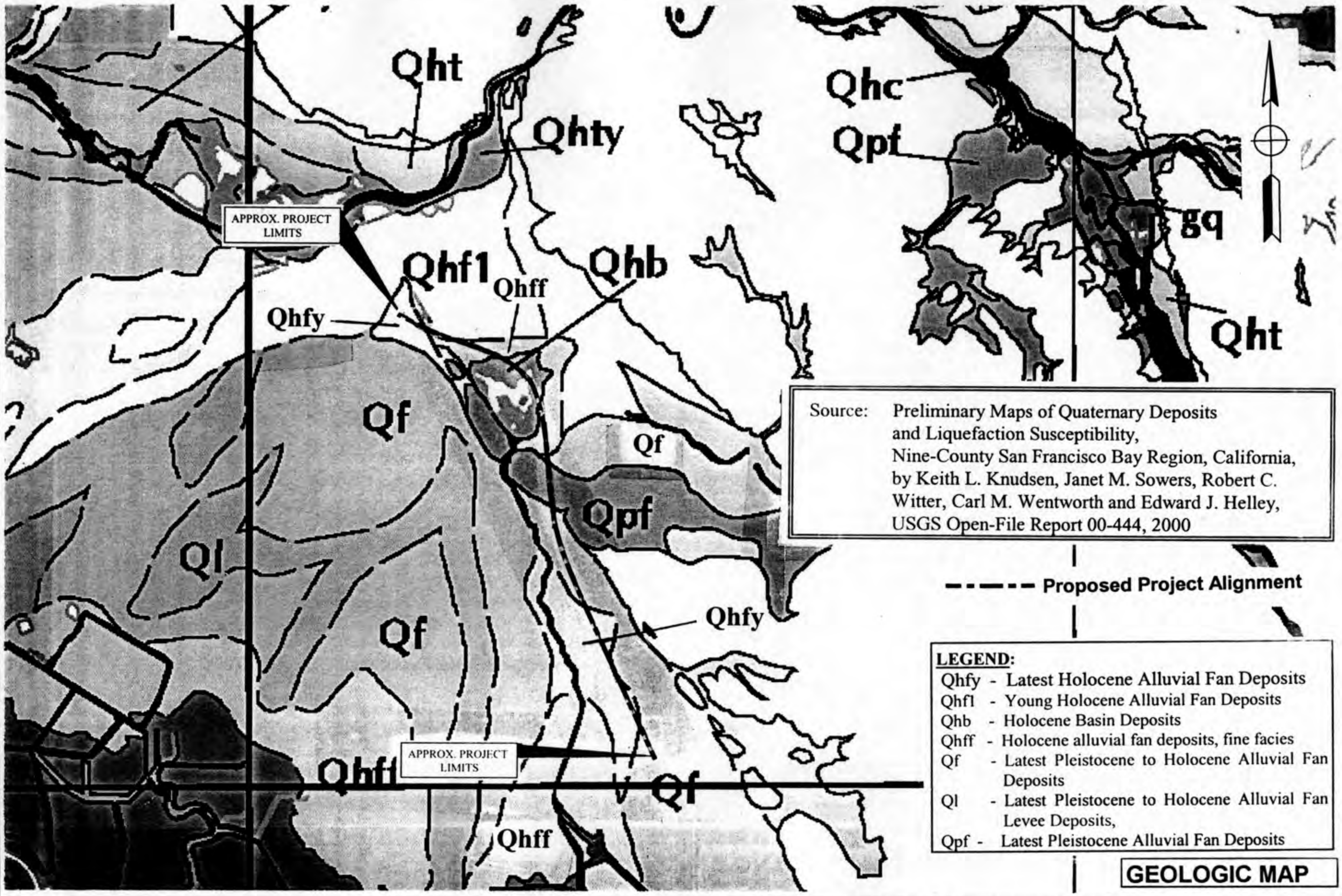


Figure 1
2003 Proposed Project



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MATERIALS TESTING

BART EXTENSION TO WARM SPRINGS
CITY OF FREMONT, CA

JOB NO.: 202122.10

FIGURE NO.: 2

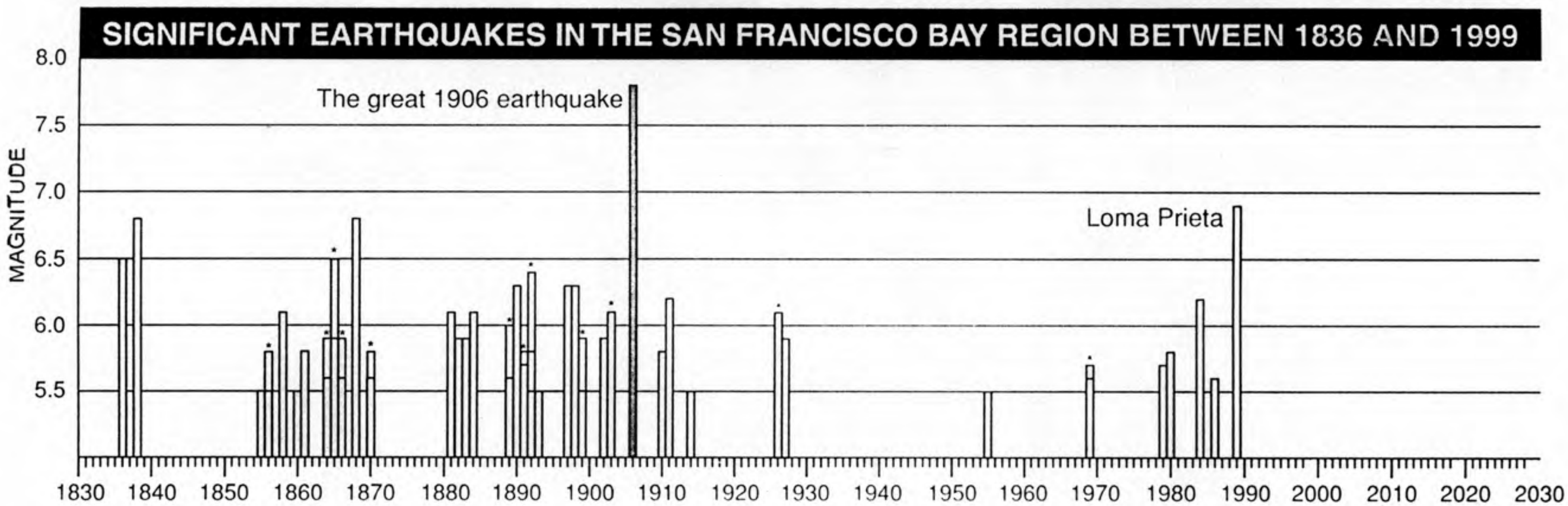
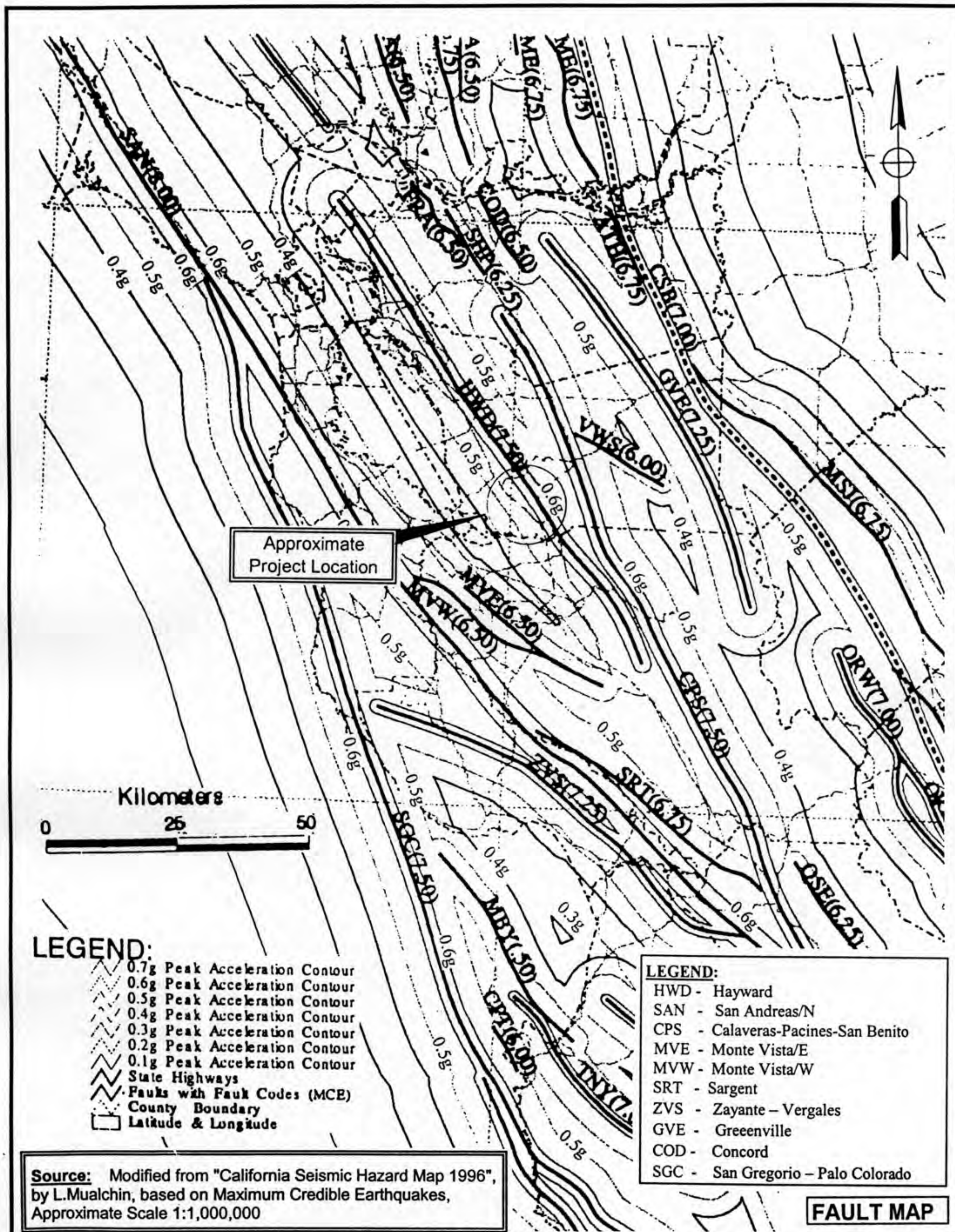


Figure 6. Time sequence of earthquakes M >= 5.5 in the SFBR since the early 19th century, from the catalog of Bakun (1999) The catalog is believed to be complete for such magnitude earthquakes since 1850. A high rate of earthquake activity in the late 1800's was followed by relatively little activity after 1906. Asterisk indicates more than one earthquake occurred that year.

Source: Earthquake Probabilities in the San Francisco Bay Region: 2000 to 2030 – A summary of Findings, USGS, Working Group on California Earthquake Probabilities, Open-File report 99-517, 1999

REGIONAL SEISMICITY

PARIKH CONSULTANTS, INC. GEOTECHNICAL CONSULTANTS MATERIALS TESTING	**BART EXTENSION TO WARM SPRINGS** **CITY OF FREMONT, CA**
	JOB NO.: 202122.10 | **FIGURE NO.: 3**



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CITY OF FREMONT, CALIFORNIA

JOB NO.: 202122.10	FIGURE NO.: 4

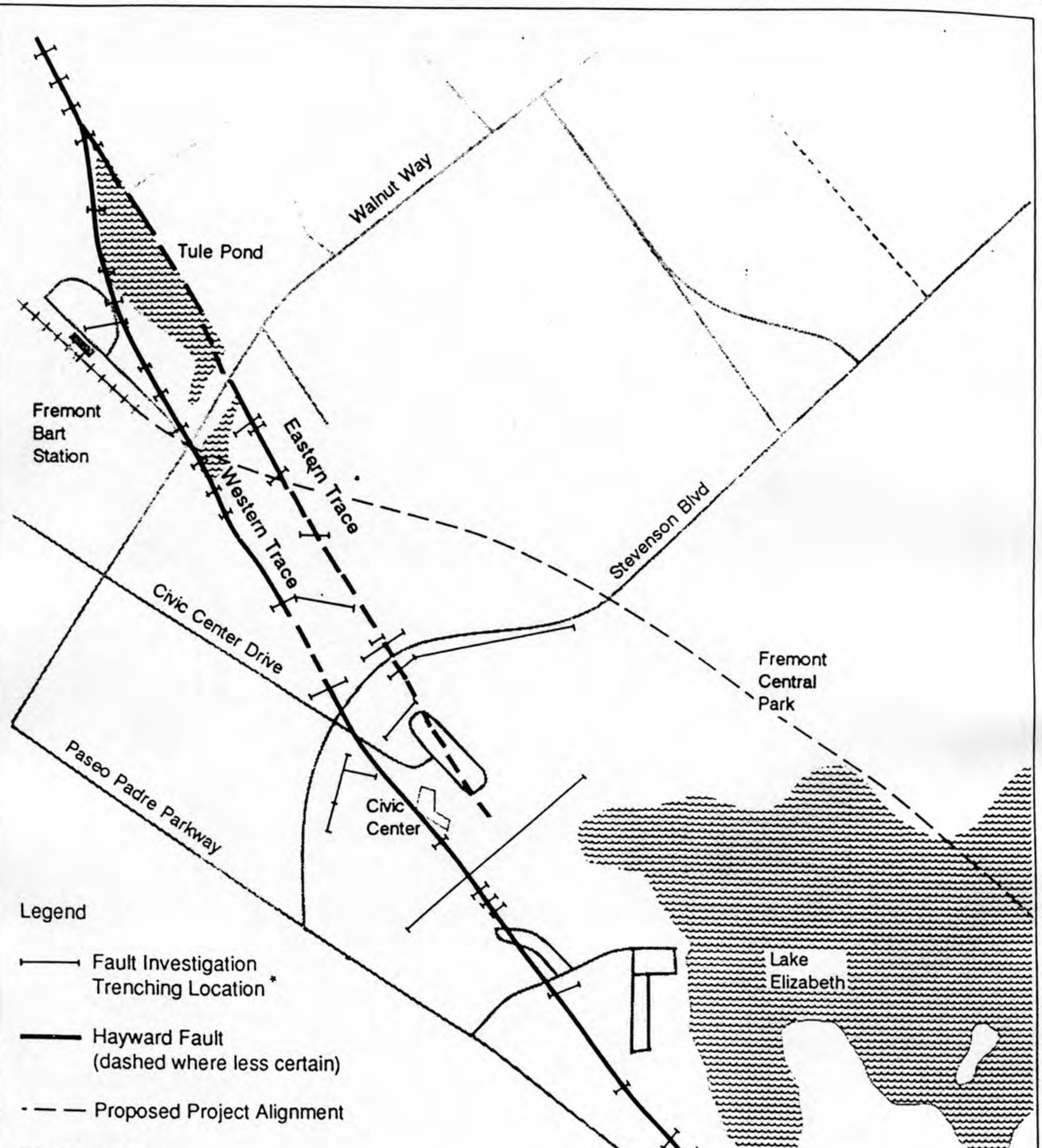
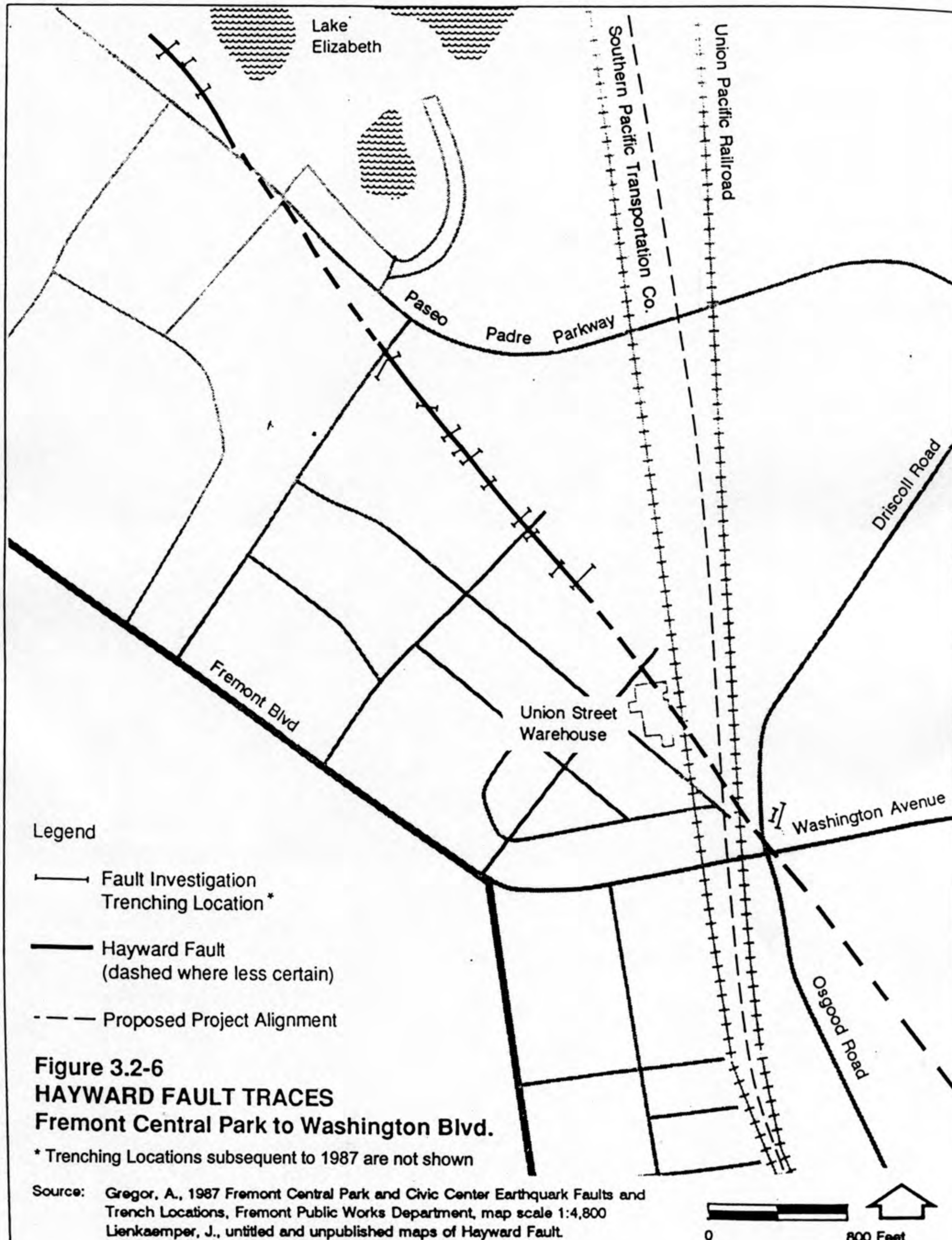


Figure 3.2-5
HAYWARD FAULT TRACES
Tule Pond to Fremont Central Park

* Trenching Locations subsequent to 1987 are not shown

Source: Gregor, A., 1987 Fremont Central Park and Civic Center Earthquark Faults and Trench Locations, Fremont Public Works Department, map scale 1:4,800
Lienkaemper, J., untitled and unpublished maps of Hayward Fault.
U.S.G.S. Geological Survey Map, map scale 1: 6,000.

PARIKH CONSULTANTS, INC. GEOTECHNICAL ENGINEERING MATERIALS TESTING	BART EXTENSION TO WARM SPRINGS CITY OF FREMONT, CALIFORNIA	
	JOB NO.: 202122.10	FIGURE NO.: 5A



Legend

Fault Investigation Trenching Location *

Hayward Fault (dashed where less certain)

Proposed Project Alignment

Figure 3.2-6
HAYWARD FAULT TRACES
Fremont Central Park to Washington Blvd.

* Trenching Locations subsequent to 1987 are not shown

Source: Gregor, A., 1987 Fremont Central Park and Civic Center Earthquark Faults and Trench Locations, Fremont Public Works Department, map scale 1:4,800
Lienkaemper, J., untitled and unpublished maps of Hayward Fault.
U.S.G.S. Geological Survey Map, map scale 1: 6,000.

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JOB NO.: 202122.10	FIGURE NO.: 5B

MODIFIED MERCALLI INTENSITY SCALE*
(After Housner, 1970)

I. - Detected only by sensitive instruments.

II. - Felt by few persons at rest, especially on upper floors; delicate suspended objects may swing.

III. - Felt noticeably indoors, but not always recognized as an earthquake; standing cars rock slightly, vibration like passing truck.

IV. - Felt indoors by many, outdoors by a few; at night some awaken; dishes, windows, doors disturbed; cars rock noticeably.

V. - Felt by most people; some breakage of dishes, windows and plaster; disturbance of tall objects.

VI. - Felt by all; many are frightened and run outdoors; falling plaster and chimneys; damage small.

VII. - Everybody runs outdoors. Damage to buildings varies, depending on quality of construction; noticed by drivers of cars.

VIII. - Panel walls thrown out of frames; fall of walls, monuments, chimneys; sand and mud ejected; drivers of cars disturbed.

IX. - Buildings shifted off foundations, cracked, thrown out of plumb; ground cracked, underground pipes broken; serious damage to reservoirs and embankments.

X. - Most masonry and frame structures destroyed; ground cracked; rail bent slightly; landslides.

XI. - Few structures remain standing; bridges destroyed; fissures in ground; pipes broken; landslides, rails bent.

XII. - Damage total; waves seen on ground surface; lines of sight and level distorted; objects thrown into the air; large rock masses displaced.

***The intensity is a subjective measure of the effect of the ground shaking, and is not an engineering measure of the ground acceleration.**

Table 3.2-2
Major faults potentially affecting BART Extension to Warm Springs Project

Fault	Distance from Project		Maximum Credible Earthquake (MCE)	Years of Historic Damaging Earthquake	Expected Peak Bedrock Acceleration along the project alignment during MCE (g) (PBA)	Expected Peak Ground Acceleration along the project alignment during MCE (g) (PGA)
	miles	km				
Hayward	0	0	7.5	1868	0.7	0.7
San Andreas	18	29	8.0	1836*, 1838, 1906, 1989	0.25	0.32
Calaveras	5	8	7.5	1897, 1911, 1979, 1984	0.48	0.48
Concord	25	40	6.5	1955	0.07	0.11
Greenville	19	30	7.25	1980	0.16	0.23
Sargent-Castro	25	40	6.75	2002	0.08	0.14
San Gregorio-Palo Colorado	28	45	7.5	None known	0.12	0.18
Monte Vista East	12.5	20	6.5	None known	0.17	0.24
Monte Vista West	14	23	6.5	None known	0.14	0.21

Notes
1) Distances and Maximum Credible Earthquake (MCE) based on California Seismic Hazard Map by Mualchin (1996)
2) Peak Bedrock Acceleration (PBA) as per Sadigh et al. (1997)
3) Peak Ground Acceleration (PGA) as per Caltrans Seismic Design Criteria, Version 1.2 (2001)

* Previously attributed to Hayward Fault; recently attributed to San Andreas Fault

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TABLE NO.: 2

[The Mount Diablo blind thrust is modeled as an inclined trapezoid, top edge at 8 km depth and deepest corner at 18.8 km depth (Fig. 2b). Three options are modeled for the most recent recent earthquake on the Northern Calaveras Fault: pre-1776, 1897, and 1984, with weights 0.2, 0.5, and 0.3, respectively.]

Fault Segment		Length (km)		Seismic Width (km)		Slip Rate (mm/yr)		Seismic Slip Factor			Most recent event
System	Code	Mean	±2σ	Mean	±2σ	Mean	±2σ	Mean	±2σ	wts.	
San Gregorio North	SGN	109	±13	13	±2	7	±3	1	–	–	pre 1776
San Gregorio South	SGS	66	±10	12	±2	3	±2	1	–	–	pre 1776
SAF - North Coast North	NCN	137	±11	11	±2	24	±3	1	–	–	1906
SAF - North Coast South	NCS	190	±11	11	±2	24	±3	1	–	–	1906
SAF - Peninsula	PN	85	±13	13	±2	17	±4	1	–	–	1906
SAF - Santa Cruz Mtns	SCZ	62	±8	15	±2	17	±4	1	–	–	1906
Rodgers Creek	RC	63	±5	12	±2	9	±2	1	–	–	1670-1776
Northern Hayward	NH	35	±8	12	±2	9	±2	0.6	±0.3	.2/.4/.4	1640-1776
Southern Hayward	SH	52	±9	12	±2	9	±2	0.8	±0.2	.1/.8/.1	1868
Northern Calaveras	NC	45	±5	13	±2	6	±2	0.9	±0.1	.2/.6/.2	see notes
Central Calaveras	CC	59	±5	11	±2	15	±3	0.4	±0.3	.1/.8/.1	pre 1776
Southern Calaveras	SC	19	±5	11	±2	15	±3	0.4	±0.3	.1/.8/.1	pre 1776
Northern Green Valley	NGV	14	±4	14	±2	5	±3	0.5	±0.5	thirds	pre 1776
Southern Green Valley	SGV	22	±3	14	±2	5	±3	0.5	±0.5	thirds	pre 1776
Concord	CON	20	±4	16	±2	4	±2	0.5	±0.5	thirds	pre 1776
Northern Greenville	NG	20	±8	15	±3	2	±1	1	–	–	pre 1776
Central Greenville	CG	20	±5	15	±3	2	±1	1	–	–	pre 1776
Southern Greenville	SG	33	±8	15	±3	2	±1	1	–	–	pre 1776
Mount Diablo thrust	MTD	25	±5	14.2	±2	3	±2	1	–	–	pre 1776

Source: Earthquake Probabilities in the San Francisco Bay Region: 2000 to 2030 – A summary of Findings, USGS, Working Group on California Earthquake Probabilities, Open-File report 99-517, 1999

FAULT SEGMENT PARAMETERS

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CITY OF FREMONT, CA

JOB NO.: 202122.10

TABLE NO.: 3

(See table 3.2-3 for explanation of segment codes)

Fault system	Rupture source	Mean mag.	Mean rate (yr^{-1})	Recurrence time (yr)
San Gregorio	SGS	7.08	0.00060	1,653
	SGN	7.34	0.00107	930
	SGS+SGN	7.53	0.00077	1,296
	Floating **M**6.9	6.90	0.00074	1,351
San Andreas	SCZ	7.15	0.00073	1,372
	PN	7.23	0.00053	1,872
	NCS	7.51	0.00016	6,223
	NCN	7.36	0.00025	4,075
	SCZ+PN	7.49	0.00097	1,028
	NCS+NCN	7.74	0.00132	759
	SCZ+PN+NCS	7.80	0.00003	34,965
	PN+NCS+NCN	7.86	0.00009	11,765
	SCZ+PN+NCS+NCN	7.94	0.00277	361
	Floating **M**6.9	6.90	0.00094	1,062
Hayward–RC	SH	6.88	0.00269	371
	NH	6.63	0.00258	387
	SH+NH	7.08	0.00191	523
	RC	7.06	0.00349	286
	NH+RC	7.21	0.00051	1,973
	SH+NH+RC	7.37	0.00022	4,446
	Floating **M**6.9	6.90	0.00022	4,539
Calaveras	SC	6.07	0.00990	101
	CC	6.55	0.00562	178
	SC+CC	6.69	0.00183	546
	NC	6.95	0.00278	359
	C+NC	7.11	0.00001	135,135
	SC+CC+NC	7.15	0.00058	1,733
	Floating **M**6.2	6.20	0.00381	262
	Floating (SC+CC only)	6.20	0.01336	75
Concord–GV	CON	6.53	0.00072	1,398
	SGV	6.51	0.00038	2,626
	CON+SGV	6.68	0.00045	2.241
	NGV	6.31	0.00093	1,075
	SGV+NGV	6.58	0.00066	1,518
	CON+SGV+NGV	6.76	0.00143	701
	Floating **M**6.2	6.20	0.00201	497
Greenville	SG	6.90	0.00070	1,437
	CG	6.65	0.00040	2,496
	SG+CG	7.10	0.00022	4,450
	NG	6.63	0.00080	1,249
	CG+NG	6.95	0.00038	2,636
	SG+CG+NG	7.23	0.00017	5,811
	Floating **M**6.2	6.20	0.00008	13,004
Mt Diablo	MTD	6.73	0.00197	508

Source: Earthquake Probabilities in the San Francisco Bay Region: 2000 to 2030 – A summary of Findings, USGS, Working Group on California Earthquake Probabilities, Open-File Report 99-517, 1999

MAGNITUDES AND RECURRENCE INTERVALS

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CITY OF FREMONT, CALIFORNIA

JOB NO.: 202122.10 | **TABLE NO.: 4**