SEISMIC HAZARD ZONE REPORT 060 (REVISED)

SEISMIC HAZARD ZONE REPORT FOR THE MOUNTAIN VIEW 7.5-MINUTE QUADRANGLE, SANTA CLARA, ALAMEDA, AND SAN MATEO COUNTIES, CALIFORNIA

2006

DEPARTMENT OF CONSERVATION
California Geological Survey

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How to view or obtain the map

Seismic Hazard Zone Maps, Seismic Hazard Zone Reports and additional information on seismic hazard zone mapping in California are available on the California Geological Survey's Internet page: http://www.consrv.ca.gov/CGS/index.htm

Paper copies of Official Seismic Hazard Zone Maps, released by CGS, which depict *zones of required investigation* for liquefaction and/or earthquake-induced landslides, are available for purchase from:

BPS Reprographic Services
945 Bryant Street
San Francisco, CA 94103
(415) 512-6550

Seismic Hazard Zone Reports (SHZR) summarize the development of the hazard zone map for each area and contain background documentation for use by site investigators and local government reviewers. These reports are available for reference at CGS offices in Sacramento, San Francisco, and Los Angeles. **NOTE: The reports are not available through BPS Reprographic Services.**

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12/21/2000	Release of preliminary map and report (Santa Clara County only)
6/21/2001	Release of official map and report (Santa Clara County only)
1/2/2003	Release of revised preliminary map and report (addition of Alameda County)
7/2/2003	Release of revised official map and report (addition of Alameda County)
8/26/2005	BPS address corrected and web links updated
1/13/2006	Southern California and Bay Area Regional offices address update
4/18/2006	Release of preliminary revised map and report – Alameda, San Mateo and Santa Clara Counties
10/18/2006	Official Release for complete quadrangle – Alameda, San Mateo, and Santa Clara Counties

EXECUTIVE SUMMARY

This Official Seismic Hazard Zone Map for the Mountain View 7.5-Minute Quadrangle, San Mateo, Santa Clara and Alameda counties, California dated October 18, 2006, is a revision of an official map released in July 2003 that excluded San Mateo County, which occupies about a 4.5 square-mile area in the northwest part of the quadrangle. However, all but about one square-mile of the additional area consists of San Francisco Bay water, the remaining being mostly nature preserve marshland along with a small section of an East Palo Alto residential development east of Pulgas Avenue. The inclusion of San Mateo County completes zonation in the Mountain View Quadrangle by the California Geological Survey (CGS).

This report summarizes the methods and sources of information used to prepare the Seismic Hazard Zone map for the Mountain View 7.5-Minute Quadrangle, Santa Clara, Alameda, and San Mateo counties, California. The map displays the boundaries of *zones of required investigation* for liquefaction and earthquake-induced landslides over an area of approximately 55 square miles at a scale of 1 inch = 2,000 feet.

The cities of Los Altos, Los Altos Hills, Mountain View, Palo Alto, East Palo Alto, San Jose, and Sunnyvale occupy the intensively urbanized southern part of the study area. Salt evaporation ponds, levees and saltwater wetlands occupy the eastern and northern portions of the quadrangle, including parts of the cities of Fremont and Newark in Alameda County. The Santa Clara Valley slopes gently to the north, toward San Francisco Bay. Seven major creeks cross the Santa Clara Valley in this area. Elevations within the quadrangle range from sea level to about 265 feet in Los Altos Hills. U.S. Highway 101 and State Highways 82, 85 and 237 provide access in the area. Moffett Field Naval Air Station is on the San Francisco Bay margin, just southeast of the center of the quadrangle.

Liquefaction *zones of required investigation* covers most of the land portion of the Mountain View Quadrangle, including all of the additional land in San Mateo County. The southwestern limit of the zone, except for several narrow stream channels, coincides with the surface projection of area designated in the quadrangle as zone of required investigation for liquefaction is more or less coincidental with the northwest trending Alma Street and the Central Expressway. This boundary reflects the surface projection of the intersection of ground-water levels less than 40-feet deep and the base of Holocene alluvial fans composed of loose sandy material.

Analysis of rock strength and slope conditions within the Mountain View Quadrangle resulted in the zonation of only a minute percent of the map for earthquake-induced landslide hazard: one small area in the Los Altos Hills and another along the banks of Adobe Creek.

The map was prepared by employing geographic information system (GIS) technology, which allows the manipulation of three-dimensional data. Information considered includes topography, surface and subsurface geology, borehole data, historical ground-water levels, existing landslide features, slope gradient, rock-strength measurements, geologic structure, and earthquake shaking estimates. The shaking inputs are based upon probabilistic seismic hazard maps that depict peak ground acceleration, mode magnitude, and mode distance with a 10 percent probability of exceedance in 50 years.

INTRODUCTION

Note: This report and the seismic hazard zone map it accompanies are revisions of the Seismic Hazard Zone Map and Report of the same name and report number officially released in July 2003. The revised map and report now include land in San Mateo Count that was originally excluded from zonation.

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called California Geological Survey (CGS)] to delineate seismic hazard zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic hazard zone maps in their land-use planning and permitting processes. They must withhold development permits for a site within a zone until the geologic and soil conditions of the project site are investigated and appropriate mitigation measures, if any, are incorporated into development plans. The Act also requires sellers (and their agents) of real property within a mapped hazard zone to disclose at the time of sale that the property lies within such a zone. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (SMBG) (DOC, 1997); also available on the Internet at: http://gmw.consrv.ca.gov/shmp/webdocs/sp117.pdf.

The Act directs SMGB to appoint and consult with the Seismic Hazards Mapping Act Advisory Committee (SHMAAC) in developing criteria for the preparation of the seismic hazard zone maps. SHMAAC consists of geologists, seismologists, civil and structural engineers, representatives of city and county governments, the state insurance commissioner and the insurance industry. In 1991, SMGB adopted initial criteria for delineating seismic hazard zones to promote uniform and effective statewide implementation of the Act. These initial criteria provide detailed standards for mapping regional liquefaction hazards. They also direct CGS to develop a set of probabilistic seismic maps for California and to research methods that might be appropriate for mapping earthquake-induced landslide hazards.

In 1996, working groups established by SHMAAC reviewed the prototype maps and the techniques used to create them. The reviews resulted in recommendations that 1) the process for zoning liquefaction hazards remain unchanged and 2) earthquake-induced landslide zones be delineated using a modified Newmark analysis.

In April 2004, significant revisions of liquefaction zone mapping criteria relating to application of historically high ground-water level data in desert regions of the state were adopted by the SMGB. These modifications are reflected in the revised CGS Special Publication 118, which available on the Internet at: http://gmw.consrv.ca.gov/shmp/webdocs/sp118_revised.pdf

This report summarizes seismic hazard zone mapping for potentially liquefiable soils and earthquake-induced landslides in the Santa Clara County and Alameda County portions of the Mountain View 7.5-Minute Quadrangle. The process of zoning for liquefaction uses a combination of Quaternary geologic mapping, historical ground-water information, and subsurface geotechnical data. The process for zoning earthquake-induced landslides incorporates earthquake loading, existing landslide features, slope gradient, rock strength, and geologic structure. Probabilistic seismic hazard maps, which are the underpinning for delineating seismic hazard zones, have been prepared for peak ground acceleration, mode magnitude, and mode distance with a 10 percent probability of exceedance in 50 years (Petersen and others, 1996) in accordance with the mapping criteria.

SECTION 1

LIQUEFACTION ZONES OF REQUIRED INVESTIGATION IN THE MOUNTAIN VIEW 7.5-MINUTE QUADRANGLE (REVISED)

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Note: This report and the seismic hazard zone map it accompanies are revisions of the Seismic Hazard Zone Map and Report of the same name and report number that were officially released in July 2003. The revised map and report address land in San Mateo County that was originally excluded from zonation. The revised map includes land in San Mateo County now designated as a liquefaction zone of required investigation.

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called California Geological Survey (CGS)] to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use seismic hazard zone maps developed by CGS in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within seismic hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines adopted by the California State Mining and Geology Board (SMGB) (DOC, 1997). The text of this report is on the Internet at:
http://gmw.consrv.ca.gov/shmp/webdocs/sp117.pdf.

Following the release of DMG Special Publication 117 (DOC, 1997), agencies in the Los Angeles metropolitan region sought more definitive guidance in the review of geotechnical investigations addressing liquefaction hazards. The agencies made their request through the Geotechnical Engineering Group of the Los Angeles Section of the

American Society of Civil Engineers (ASCE). This group convened an implementation committee under the auspices of the Southern California Earthquake Center (SCEC). The committee, which consisted of practicing geotechnical engineers and engineering geologists, released an overview of the practice of liquefaction analysis, evaluation, and mitigation techniques (SCEC, 1999). This text is also on the Internet at: http://www.scec.org/

This evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils in the Mountain View 7.5-Minute Quadrangle. Section 2 (addressing earthquake-induced landslides) and Section 3 (addressing potential ground shaking), complete the report, which is one of a series that summarizes production of similar seismic hazard zone maps within the state (Smith, 1996). Additional information on seismic hazards zone mapping in California is on CGS's Internet web page: http://www.conservation.ca.gov/CGS/index.htm

BACKGROUND

Liquefaction-induced ground failure historically has been a major cause of earthquake damage in northern California. During the 1989 Loma Prieta and 1906 San Francisco earthquakes, significant damage to roads, utility pipelines, buildings, and other structures in the San Francisco Bay Area was caused by liquefaction-induced ground displacement.

Sites most susceptible to liquefaction-induced damage are underlain by loose, water-saturated, granular sediment within 40 feet of the ground surface. These geological and ground-water conditions are widespread in the San Francisco Bay Area, most notably in alluviated valley floodplains and around the margin of the bay. In addition, the potential for strong earthquake ground shaking is high because of the many nearby active faults. The combination of these factors constitutes a significant seismic hazard in the San Francisco Bay Area, including areas in the Mountain View Quadrangle.

METHODS SUMMARY

Characterization of liquefaction hazard presented in this report requires preparation of maps that delineate areas underlain by potentially liquefiable sediment. For this evaluation, the authors:

- Used existing geologic maps that provided an accurate representation of the spatial distribution of Quaternary deposits in the study area. Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial and fluvial sedimentary deposits and artificial fill

- Constructed shallow ground-water maps showing the historically highest known ground-water levels

- Performed quantitative analysis of geotechnical data to evaluate liquefaction potential of deposits

- Used information on potential ground shaking intensity based on CGS probabilistic shaking maps

The data collected for this evaluation were processed into a series of geographic information system (GIS) layers using commercially available software. The liquefaction zone map was derived from a synthesis of these data and according to criteria adopted by the SMGB (DOC, 2000).

SCOPE AND LIMITATIONS

Evaluation for potentially liquefiable soils generally is confined to areas covered by Quaternary (less than about 1.6 million years) sedimentary deposits. Such areas within the Mountain View Quadrangle mainly consist of alluvial fans and gently sloping areas bordering the San Francisco Bay. CGS's liquefaction hazard evaluations are based on information on earthquake ground shaking, surface and subsurface lithology, geotechnical soil properties, and ground-water depth. These data are gathered from a variety of sources. Although selection of data used in this evaluation was rigorous, the quality of the data used varies. The State of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data obtained from outside sources.

Liquefaction zone maps are intended to prompt more detailed, site-specific geotechnical investigations, as required by the Act. As such, liquefaction zone maps identify areas where the potential for liquefaction is relatively high. They do not predict the amount or direction of liquefaction-related ground displacements, or the amount of damage to facilities that may result from liquefaction. Factors that control liquefaction-induced ground failure are the extent, depth, density, and thickness of liquefiable materials, depth to ground water, rate of drainage, slope gradient, proximity to free faces, and intensity and duration of ground shaking. These factors must be evaluated on a site-specific basis to assess the potential for ground failure at any given project site.

Information developed in the study is presented in two parts: physiographic, geologic, and hydrologic conditions in PART I, and liquefaction and zoning evaluations in PART II.

PART I

PHYSIOGRAPHY

The Mountain View 7.5-Minute Quadrangle includes approximately 60 square miles covering portions of Santa Clara, San Mateo and Alameda Counties, along the southern margin of San Francisco Bay. The boundary between Santa Clara and Alameda counties trends east-west through the northeastern portion of the quadrangle. The boundary between Santa Clara and San Mateo counties follows San Francisquito Creek until it reaches San Francisco Bay, turns east/northeast, and continues until it meets the Alameda County line.

The cities of Los Altos, Los Altos Hills, Mountain View, Palo Alto, San Jose, and Sunnyvale occupy the southern portion of the quadrangle. Salt evaporation ponds, levees and saltwater wetlands occupy the northern portion of the quadrangle, along the San Francisco Bay margin and also portions of Fremont and Newark, within Alameda County.

Within the Mountain View Quadrangle, broad alluvial fans of the Santa Clara Valley slope gently to the north, toward San Francisco Bay, and cover most of the study area. Seven creeks, Adobe, Barron, Hale, Matadero, Permanente, San Francisquito, and Stevens, cross the Santa Clara Valley in this area, and flow northward into the tidal marshes at the margin of San Francisco Bay. All of these creeks originate in the Santa Cruz Mountains on the western margin of the Santa Clara Valley. A portion of the Santa Cruz Mountains occupies less than one-quarter square mile in the southwest corner of the quadrangle in the city of Los Altos Hills. Elevations within the quadrangle are modest, ranging from sea level along the bay, to a maximum elevation of about 265 feet in the Santa Cruz Mountains.

Four freeways and several other arterial roadways cross the map area. U.S. Highway 101 (Bayshore Freeway) and State Highway 82 (El Camino Real) trend northwest through the southwest quarter of the map area; State Highway 237 (Mountain View-Alviso South Bay Freeway) trends northeast in the southeastern quarter of the map area; and State Highway 85 (Stevens Creek) trends north-south through the center of the southern end of the map area. A network of secondary roads links these major highways. Moffett Field Naval Air Station is on the San Francisco Bay margin, just southeast of the center of the quadrangle.

GEOLOGY

Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial and fluvial sedimentary deposits and artificial fill. To identify and characterize deposits susceptible to liquefaction in the Mountain View Quadrangle, recently completed maps of the nine-county San Francisco Bay Area showing Quaternary deposits (Knudsen and others, 2000) and bedrock units (Brabb and others, 1998) were obtained from the U.S. Geological Survey in digital form. These GIS maps were combined, with minor modifications along the bedrock/Quaternary contact, to form a single, 1:24,000-scale geologic map of the Mountain View Quadrangle. The distribution of Quaternary deposits on this map (summarized on Plate 1.1) was used in combination with other data, discussed below, to evaluate liquefaction potential and develop the Seismic Hazard Zone Map.

Other geologic maps and reports were reviewed to evaluate the areal and vertical distribution of shallow Quaternary deposits and to provide information on subsurface geologic, lithologic and engineering properties of the units. Among the references consulted were: California Department of Water Resources (1967); Helley and Brabb (1971); Poland (1971); Brown and Jackson (1973); Cooper-Clark and Associates (1974); Rogers and Williams (1974); Atwater and others (1976); Helley and others (1979); Falls (1988); Helley (1990); Geomatrix Consultants Inc. (1992a, 1992b); Helley and others (1994); and Iwamura (1995). Limited field reconnaissance was conducted to confirm the location of geologic contacts, map recently modified ground surfaces, observe properties of near-surface deposits, and characterize the surface expression of individual geologic units.

In the Mountain View Quadrangle there are 12 Quaternary map units mapped by Knudsen and others (2000). The Quaternary geologic mapping methods described by Knudsen and others (2000) consist of interpretation of topographic maps, aerial photographs, and soil surveys, as well as compiled published and unpublished geologic maps. The authors estimate the ages of deposits using landform shape, relative geomorphic position, cross cutting relationships, superposition, depth and degree of surface dissection, and relative degree of soil profile development. The authors also reviewed all available maps dating back to 1850, to map the early historical shoreline and to differentiate artificial fill that has been placed on Bay Mud from artificial fill that has been placed on terrestrial deposits. Table 1.1 compares stratigraphic nomenclature used in Knudsen and others (2000) and the CGS GIS database, with that of several previous studies performed in northern California.

Quaternary deposits generally grade from coarser to finer, corresponding with the decline in gradient from the southwestern corner of the quadrangle, northeastward toward San Francisco Bay. Coarse late Pleistocene alluvial fan deposits (Qpf) are mapped along the range front at the higher elevations of the Santa Clara Valley. Holocene alluvial fan deposits (Qhf) and Holocene alluvial fan, fine-facies deposits (Qhff) are mapped on the broader, more gently sloping portions of the Santa Clara Valley. Holocene alluvial fan levee deposits (Qhl) are mapped adjacent to San Francisquito Creek, where overbank sediment has been deposited adjacent to the channel. Where creeks empty into the San Francisco Bay, alluvial material interfingers with San Francisco Bay Mud deposits (Qhbm).

Modern stream channel deposits (Qhc) are mapped in narrow bands along creeks that flow across the Santa Clara Valley and out to San Francisco Bay. Artificial levee fill (alf), and artificial stream channels (ac) are mapped along most of the major creeks. To accommodate larger flows in the winter months, some reaches of these watercourses have been engineered within concrete-lined structures as much as 30 feet deep that commonly have artificial levees along their banks. Artificial fill over Bay Mud (afbm) consisting of engineered and/or non-engineered fill is mapped in relatively large areas at various localities along the margin of San Francisco Bay. Artificial fill over Bay Mud (afbm) is mapped bayward of the 1850's-era shoreline. Artificial fill (af) that does not overlie Bay Mud is mapped landward of the 1850's shoreline (Knudsen and others, 2000). The differentiation of these units is significant because afbm historically has been more susceptible to liquefaction. Gravel quarries and percolation ponds (gq) are mapped east of the intersection of Foothill Expressway and Stevens Creek Freeway.

Bedrock exposed in the Mountain View Quadrangle consists of Plio-Pleistocene Santa Clara Formation (Brabb and others, 1998). This unit is exposed in the Santa Cruz Mountain foothills in the southwestern part of the quadrangle and consists of fluvial boulder to pebble conglomerate, sandstone, and siltstone. See the Earthquake Induced Landslide portion (Section 2) of this report for additional discussion of bedrock geology.

UNIT	Knudsen and others (2000)	Helley and others (1994)	Helley and others (1979)	Brabb and others, 1998)	CGS GIS database
Artificial fill	af			af	af
Artificial fill over Bay Mud	afbm				afbm
Artificial fill, levee	alf			alf	alf
Gravel quarries and percolation ponds	gq	PP,GP			gq
Artificial stream channel	ac			Qhasc	ac
Modern stream channel deposits	Qhc	Qhsc	Qhsc	Qhsc	Qhc
Holocene San Francisco Bay Mud	Qhbm	Qhbm	Qhbm	Qhbm	Qhbm
Holocene alluvial fan deposits	Qhf	Qhaf, Qhfp	Qham, Qhac	Qhaf, Qhfp	Qhf
Holocene alluvial fan deposits, fine grained facies	Qhff	Qhb	Qhaf	Qhb	Qhff
Holocene alluvial fan levee deposits	Qhl	Qhl		Qhl	Qhl
Late Pleistocene alluvial fan deposits	Qpf	Qpaf	Qpa	Qpaf	Qpf
bedrock	br	br			

Table 1.1. Correlation of Quaternary Stratigraphic Nomenclatures Used within the Southern San Francisco Bay Area. For this study, CGS has adopted the nomenclature of Knudsen and others (2000).

Structural Geology

The Mountain View Quadrangle is within the active San Andreas Fault system, which distributes shearing across a complex system of primarily northwest-trending, right-lateral, strike-slip faults that include the San Andreas, Hayward, and Calaveras faults. The San Andreas fault lies approximately 4 miles west of the Mountain View Quadrangle and the Hayward and Calaveras faults are approximately 1.5 miles and 2 miles to the east, respectively. Historical ground surface-rupturing earthquakes have occurred on all of these faults (Lawson, 1908; Keefer and others, 1980). Several oblique and reverse slip faults, including the Berrocal, Shannon, Monte Vista, and Santa Clara, are west of the quadrangle along or within the foothills at the base of the Santa Cruz Mountains (McLaughlin and others, 1991; Hitchcock and others, 1994; Campbell and others, 1995).

ENGINEERING GEOLOGY

Information on subsurface geology and engineering characteristics of flatland deposits was obtained from borehole logs collected from reports on geotechnical and environmental projects. For this investigation, data from 86 borehole logs collected from the files of the California Department of Transportation (CalTrans) and the cities of Los Altos, Los Altos Hills, Mountain View, Palo Alto, San Jose, and Sunnyvale were entered into a CGS geotechnical GIS database (Plate 2). No additional data were found for the Alameda County portion of the quadrangle. The available data were used to summarize characteristics of the Quaternary map units (Tables 1.2 and 1.3).

Standard Penetration Tests (SPTs) provide a standardized measure of the penetration resistance of geologic deposits and are commonly used as an index of soil density. This in-field test consists of counting the number of blows required to drive a split-spoon sampler (1.375-inch inside diameter) 1foot into the soil at the bottom of a borehole at chosen intervals while drilling. The driving force is provided by dropping a 140-pound hammer weight 30 inches. The SPT method is formally defined and specified by the American Society for Testing and Materials in test method D1586 (ASTM, 1999). Recorded blow counts for non-SPT geotechnical sampling where the sampler diameter, hammer weight or drop distance differs from that specified for an SPT (ASTM D1586), are converted to SPT-equivalent blow counts. The actual and converted SPT blow counts are normalized to a common-reference, effective-overburden pressure of 1 atmosphere (approximately 1 ton per square foot) and a hammer efficiency of 60 percent using a method described by Seed and Idriss (1982) and Seed and others (1985). This normalized blow count is referred to as $(N_1)_{60}$.

Analysis of the data in Tables 1.2 and 1.3 reveals certain characteristics of and contrasts among the units, including: 1) an abundance of fine-grained (greater percentage passing the #200 sieve) material within the Holocene units; 2) Holocene materials are somewhat less dense and more readily penetrated than Pleistocene materials; 3) late Pleistocene to Holocene alluvial fan deposits (Qf) are predominantly fine-grained; and 4) late Pleistocene alluvial fan deposits (Qpf) are predominantly coarse-grained. Although Holocene units primarily consist of fine-grained materials, sand lenses are present that have the potential to liquefy.

GEOLOGIC MAP UNIT		DRY DENSITY (pounds per cubic foot)						STANDARD PENETRATION RESISTANCE (blows per foot, $(N_1)_{60}$)					
Unit (1)	Texture (2)	Number of Tests	Mean	CV (3)	Median	Min	Max	Number of Tests	Mean	CV (3)	Median	Min	Max
Af	ine	3	96.3	0.13	103.0	2.(	04.	6	39	0.45	36	[illegible]	69
	oars	3	115.3	0.15	124.0	6.(	26.	5	22	0.80	19	[illegible]	51
afbm	Fine	-	-	-	-	-	-	-	-	-	-	-	-
	Coarse	-	-	-	-	-	-	-	-	-	-	-	-
alf	ine	-	-	-	-	-	-	-	-	-	-	-	-
	oars	-	-	-	-	-	-	-	-	-	-	-	-
gq	Fine	-	-	-	-	-	-	-	-	-	-	-	-
	Coarse	-	-	-	-	-	-	-	-	-	-	-	-
Ac	ine	-	-	-	-	-	-	-	-	-	-	-	-
	oars	-	-	-	-	-	-	-	-	-	-	-	-
Qhc	Fine	-	-	-	-	-	-	-	-	-	-	-	-
	Coarse	-	-	-	-	-	-	-	-	-	-	-	-
Qhb	ine	1	74	-	-	-	-	2	5	0.65	5	[illegible]	7
	oars	-	-	-	-	-	-	-	-	-	-	-	-
Qhf	Fine	96	102.4	0.09	103.0	73.7	129.0	156	22	0.68	18	3	93
	Coarse	35	113.9	0.10	113.2	91.0	135.0	74	26	0.53	23	4	56
Qhf	ine	57	99.7	0.09	100.7	7.(	19.	81	32	0.73	28	[illegible]	9
	oars	-	-	-	-	-	-	-	-	-	-	-	-
Qhl	Fine	-	-	-	-	-	-	-	-	-	-	-	-
	Coarse	-	-	-	-	-	-	-	-	-	-	-	-
Qf	ine	31	101.0	0.07	100.0	9.9	22.	41	22	1.05	16	[illegible]	9
	oars	2	102.3	0.16	102.3	1.(	13.	3	25	0.81	16		49
Qpf	Fine	40	101.8	0.07	102.0	88.5	117.0	69	20	0.72	15	5	80
	Coarse	13	116.5	0.09	115.0	98.0	132.1	79	35	0.68	30	6	>99

Notes:

(1) See Table 1.3 for names of the geologic map units listed here.

(2) Fine soils (silt and clay) contain a greater percentage passing the #200 sieve (<.0.074 mm); coarse soils (sand and gravel) contain a greater percentage retained by the #200 sieve.

(3) CV = coefficient of variation (standard deviation divided by the mean).

Table 1.2. Summary of Geotechnical Characteristics for Quaternary Geological Map Units in the Mountain View 7.5-Minute Quadrangle.

GROUND WATER

Liquefaction hazard may exist in areas where depth to ground water is 40 feet or less. CGS uses the highest known ground-water levels because water levels during an earthquake cannot be anticipated due to the unpredictable fluctuations caused by natural processes and human activities. A historical-high ground-water map differs from most

Geologic Map Unit (1)	Description	Number of Records	Composition by Soil Type (Unified Soil Classification System)	Depth to ground water (feet) and liquefaction susceptibility category assigned to geologic unit (2)			
				<10	10 to 30	30 to 40	>40
af	Artificial fill (3)	25	CL 32%; SM 16% SC 12%; other 40%	VH-L	H-L	M-L	VL
afbm	Artificial fill over Bay Mud	0	n/a (4)	VH	H	M	VL
alf	Artificial fill, levee (3)	0	n/a (4)	VH-L	H-L	M-L	VL
gq	Gravel quarries and percolation ponds	0	n/a (4)	VH-L	H-L	M-L	VL
ac	Artificial stream channel	0	n/a (4)	VH-L	H	M	VL
Qhc	Modern stream channel deposits	0	n/a (4)	VH	H	M	VL
Qhbm	Holocene San Francisco Bay Mud	1	OH 100%	H	M	L	VL
Qhf	Holocene alluvial fan deposits	223	CL 48%; SC 12%; SM 10% SP 10%; other 20%	H	M	L	VL
Qhff	Holocene alluvial fan deposits, fir grained facies	69	CL 64%; CH 30%	M	M	L	VL
Qhl	Holocene alluvial fan levee deposits	0	n/a (4)	H	M	L	VL
Qf	Late Pleistocene to Holocene alluvial fan deposits	16	CL 81%; other 19%	M	L	L	VL
Qpf	Late Pleistocene alluvial fan deposits	159	CL 46%; SC 11%; ML 9% SM 8%; SP 8%; other 26%	L	L	VL	VL
B	Bedrock	n/a (4	n/a (4)	VL	VL	VL	VL

Notes:
(1) Susceptibility assignments are specific to the materials within the Mountain View 7.5-Minute Quadrangle.
(2) Based on the Simplified Procedure (Seed and Idriss, 1971; Youd and Idriss, 1997) and borehole analyses for some units. For units where subsurface information is not available, susceptibility is based on soil characteristics of similar deposits.
(3) The liquefaction susceptibility of artificial fill ranges widely, depending largely on the nature of the fill, its age, and whether it was compacted during emplacement.
(4) n/a = not applicable

Table 1.3. Liquefaction Susceptibility for Quaternary Map Units within the Mountain View 7.5-Minute Quadrangle. Units indicate relative susceptibility of deposits to liquefaction as a function of material type and ground-water depth within that deposit. VH = very high, H = high, M = moderate, L = low, and VL = very low to none.

ground-water maps, which show the actual water table at a particular time. Plate 1.2 depicts a hypothetical ground-water surface within alluviated areas.

Ground-water conditions were investigated in the Mountain View Quadrangle to evaluate the depth to saturated materials. Saturated conditions reduce the effective normal stress, thereby increasing the likelihood of earthquake-induced liquefaction (Youd, 1973). The evaluation was based on first-encountered water noted in geotechnical borehole logs acquired from the California Department of Transportation (CalTrans) and the cities of Los Altos, Mountain View, Palo Alto, Sunnyvale and San Jose and water-level data provided by the Santa Clara Valley Water District. The Regional Water Quality Control Board provided water-level data for Alameda County. However, none of these data were located in the Mountain View Quadrangle. Ground-water conditions in the Alameda County portion of the Mountain View Quadrangle were inferred from ground-water measurements in adjacent quadrangles. The depths to first-encountered unconfined ground water were plotted onto a map of the project area to constrain the estimate of historically shallowest ground water. Water depths from boreholes known to penetrate confined aquifers were not used.

Ground-water levels are currently at or near their historical highs in many areas of the Santa Clara Valley. Many wells recently have become artesian, which is reflective of rising ground-water levels (Seena Hoose, Santa Clara Valley Water District, oral communication, 2000). Regional ground-water contours on Plate 1.2 show historical-high water depths, as interpreted from borehole logs from investigations between the 1950’s and the year 2000.

Depths to first-encountered water range from 2 feet to deeper than 100 feet below the ground surface (Plate 1.2). In general, the proximity of San Francisco Bay to the north and west influences ground-water levels for most of the lower elevations within the quadrangle. Ground water in the Alameda County part of the quadrangle is generally within 5 to 10 feet of the ground surface. Ground-water levels are deepest, greater than 40 feet, in the southwestern corner of the quadrangle along the base of the foothills (Plate 1.2).

PART II

LIQUEFACTION POTENTIAL

Liquefaction may occur in water-saturated sediment during moderate to great earthquakes. Liquefied sediment loses strength and may fail, causing damage to buildings, bridges, and other structures. Many methods for mapping liquefaction hazard have been proposed. Youd (1991) highlights the principal developments and notes some of the widely used criteria. Youd and Perkins (1978) demonstrate the use of geologic criteria as a qualitative characterization of liquefaction susceptibility and introduce the mapping technique of combining a liquefaction susceptibility map and a liquefaction opportunity map to produce a liquefaction potential map. Liquefaction susceptibility is a function of the capacity of sediment to resist liquefaction. Liquefaction opportunity is a function of the potential seismic ground shaking intensity.

The method applied in this study for evaluating liquefaction potential is similar to that of Tinsley and others (1985). Tinsley and others (1985) applied a combination of the techniques used by Seed and others (1983) and Youd and Perkins (1978) for their mapping of liquefaction hazards in the Los Angeles region. CGS’s method combines geotechnical analyses, geologic and hydrologic mapping, and probabilistic earthquake shaking estimates, but follows criteria adopted by the SMGB (DOC, 2000).

LIQUEFACTION SUSCEPTIBILITY

Liquefaction susceptibility reflects the relative resistance of a soil to loss of strength when subjected to ground shaking. Physical properties of soil such as sediment grain-size distribution, compaction, cementation, saturation, and depth govern the degree of resistance to liquefaction. Some of these properties can be correlated to a sediment's geologic age and environment of deposition. With increasing age, relative density may increase through cementation of the particles or compaction caused by the weight of the overlying sediment. Grain-size characteristics of a soil also influence susceptibility to liquefaction. Sand is more susceptible than silt or gravel, although silt of low plasticity is treated as liquefiable in this investigation. Cohesive soils generally are not considered susceptible to liquefaction. Such soils may be vulnerable to strength loss with remolding and represent a hazard that is not addressed in this investigation. Soil characteristics and processes that result in higher measured penetration resistances generally indicate lower liquefaction susceptibility. Thus, blow count (SPT) and cone penetrometer (CPT) values are useful indicators of liquefaction susceptibility.

Saturation is required for liquefaction, and the liquefaction susceptibility of a soil varies with the depth to ground water. Very shallow ground water increases the susceptibility to liquefaction (soil is more likely to liquefy). Soils that lack resistance (susceptible soils) typically are saturated, loose and sandy. Soils resistant to liquefaction include all soil types that are dry, cohesive, or sufficiently dense.

CGS's map inventory of areas containing soils susceptible to liquefaction begins with evaluation of geologic maps and historical occurrences, cross-sections, geotechnical test data, geomorphology, and ground-water hydrology. Soil properties and soil conditions such as type, age, texture, color, and consistency, along with historical depths to ground water are used to identify, characterize, and correlate susceptible soils. Because Quaternary geologic mapping is based on similar soil observations, liquefaction susceptibility maps typically are similar to Quaternary geologic maps. CGS's qualitative relations among susceptibility, geologic map unit and depth to ground water are summarized in Table 1.3.

Most Holocene materials within the quadrangle, where water levels are within 30 feet of the ground surface, have susceptibility assignments of high (H) to very high (VH) (Table 1.3). Holocene alluvial fan, fine facies deposits (Qhff) primarily are fine-grained material and have moderate (M) susceptibility assignments where saturated within 30 feet of the ground surface. However, these units may contain lenses of material with higher liquefaction susceptibility. Holocene alluvial fan deposits (Qhf) and alluvial fan levee deposits (Qhl) have a moderate susceptibility assignment where ground water reaches 10 to 30 feet below the ground surface. Late Pleistocene to Holocene alluvial fan deposits (Qf) are primarily fine-grained but have low densities along with lenses of potentially liquefiable material and therefore are assigned moderate susceptibility where ground water is within 10 feet of the ground surface. Late Pleistocene alluvial fan deposits (Qpf) generally are considered to have very low (VL) susceptibility, but are assigned a low (L) susceptibility assignment where ground water is shallower than 30 feet beneath the ground surface.

LIQUEFACTION OPPORTUNITY

Liquefaction opportunity is a measure, commonly expressed in probabilistic terms, of the potential for strong ground shaking. Analyses of in-situ liquefaction resistance require assessment of liquefaction opportunity. The minimum level of seismic excitation to be used for such purposes is the level of peak ground acceleration (PGA) with a 10 percent probability of exceedance over a 50-year period (DOC, 2000). The earthquake magnitude used in CGS's analysis is the magnitude that contributes most to the calculated PGA for an area.

For the Mountain View Quadrangle, PGAs of 0.52g to 0.68g, resulting from earthquakes of magnitude 7.1 to 7.9, were used for liquefaction analyses. The PGA and magnitude values were based on de-aggregation of the probabilistic hazard at the 10 percent in 50-year hazard level (Petersen and others, 1996). See the ground motion portion (Section 3) of this report for additional discussion of potential ground motions.

Quantitative Liquefaction Analysis

CGS performs quantitative analysis of geotechnical data to evaluate liquefaction potential using the Seed-Idriss Simplified Procedure (Seed and Idriss, 1971; Seed and others, 1983; National Research Council, 1985; Seed and others, 1985; Seed and Harder, 1990; Youd and Idriss, 1997). Using the Seed-Idriss Simplified Procedure one can calculate soil resistance to liquefaction, expressed in terms of cyclic resistance ratio (CRR), based on SPT results, ground-water level, soil density, moisture content, soil type, and sample depth. CRR values are then compared to calculated earthquake-generated shear stresses expressed in terms of cyclic stress ratio (CSR). The Seed-Idriss Simplified Procedure requires normalizing earthquake loading relative to a M7.5 event for the liquefaction analysis. To accomplish this, CGS's analysis uses the Idriss magnitude-scaling factor (MSF) (Youd and Idriss, 1997). It is convenient to think in terms of a factor of safety (FS) relative to liquefaction, where: FS = (CRR / CSR) * MSF. FS, therefore, is a quantitative measure of liquefaction potential. CGS uses a factor of safety of 1.0 or less, where CSR equals or exceeds CRR, to indicate the presence of potentially liquefiable soil. While an FS of 1.0 is considered the "trigger" for liquefaction, for a site-specific analysis an FS of as much as 1.5 may be appropriate depending on the vulnerability of the site and related structures.

The CGS liquefaction analysis program calculates an FS for each geotechnical sample where blow counts were collected. Typically, multiple samples are collected for each borehole. The program then independently calculates an FS for each non-clay layer that includes at least one penetration test using the minimum $(N_1)_{60}$ value for that layer. The minimum FS value of the layers penetrated by the borehole is used to determine the liquefaction potential for each borehole location. The reliability of FS values varies according to the quality of the geotechnical data. FS, as well as other considerations such as slope, presence of free faces, and thickness and depth of potentially liquefiable soil, are evaluated in order to construct liquefaction potential maps, which are then used to make a map showing zones of required investigation.

Of the 86 geotechnical borehole logs reviewed in this study (Plate 1.2), 79 include blow-count data from SPTs or from penetration tests that allow reasonable blow count translations to SPT-equivalent values (Table 1.2). Non-SPT values, such as those resulting from the use of 2-inch or 2½-inch inside-diameter ring samplers, were translated to SPT-equivalent values if reasonable factors could be used in conversion calculations. The reliability of the SPT-equivalent values varies. Therefore, they are weighted and used in a more qualitative manner. Few borehole logs, however, include all of the information (e.g. soil density, moisture content, sieve analysis, etc.) required for an ideal Seed-Idriss Simplified Procedure. For boreholes having acceptable penetration tests, liquefaction analysis is performed using recorded density, moisture, and sieve test values or using averaged test values of similar materials.

The Seed-Idriss Simplified Procedure for liquefaction evaluation was primarily developed for clean sand and silty sand. As described above, results depend greatly on accurate evaluation of in-situ soil density as measured by the number of soil penetration blow counts using an SPT sampler. However, many of the Holocene alluvial deposits in the study area contain a significant amount of gravel. In the past, gravelly soils were considered not to be susceptible to liquefaction because the high permeability of these soils presumably would allow the dissipation of pore pressures before liquefaction could occur. However, liquefaction in gravelly soils has been observed during earthquakes, and recent laboratory studies have shown that gravelly soils are susceptible to liquefaction (Ishihara, 1985; Harder and Seed, 1986; Budiman and Mohammadi, 1995; Evans and Zhou, 1995; and Sy and others, 1995). SPT-derived density measurements in gravelly soils are unreliable and generally too high. They are likely to lead to overestimation of the density of the soil and, therefore, result in an underestimation of the liquefaction susceptibility. To identify potentially liquefiable units where the N values appear to have been affected by gravel content, correlations were made with boreholes in the same unit where the N values do not appear to have been affected by gravel content.

LIQUEFACTION ZONES

Criteria for Zoning

Areas underlain by materials susceptible to liquefaction during an earthquake were included in liquefaction zones using criteria developed by the Seismic Hazards Mapping Act Advisory Committee and adopted by the SMGB (DOC, 2000). Under those guideline criteria, liquefaction zones are areas meeting one or more of the following:

1. Areas known to have experienced liquefaction during historical earthquakes

2. All areas of uncompacted artificial fill containing liquefaction-susceptible material that are saturated, nearly saturated, or may be expected to become saturated

3. Areas where sufficient existing geotechnical data and analyses indicate that the soils are potentially liquefiable

4. Areas where existing geotechnical data are insufficient

In areas of limited or no geotechnical data, susceptible areas may be identified by geologic criteria as follows:

a) Areas containing soil deposits of late Holocene age (current river channels and their historical floodplains, marshes and estuaries), where the M7.5-weighted peak acceleration that has a 10 percent probability of being exceeded in 50 years is greater than or equal to 0.10 g and the water table is less than 40 feet below the ground surface; or

b) Areas containing soil deposits of Holocene age (less than 11,000 years), where the M7.5-weighted peak acceleration that has a 10 percent probability of being exceeded in 50 years is greater than or equal to 0.20 g and the historical high water table is less than or equal to 30 feet below the ground surface; or

c) Areas containing soil deposits of latest Pleistocene age (11,000 to 15,000 years), where the M7.5-weighted peak acceleration that has a 10 percent probability of being exceeded in 50 years is greater than or equal to 0.30 g and the historical high water table is less than or equal to 20 feet below the ground surface.

Application of SMGB criteria to liquefaction zoning in the Mountain View Quadrangle is summarized below.

Areas of Past Liquefaction

Tinsley and others (1998) compiled observations of evidence for liquefaction for the 1989 Loma Prieta earthquake, and Youd and Hoose (1978) compiled them for earlier earthquakes, including the 1868 Hayward and 1906 San Francisco earthquakes. Knudsen and others (2000) have completed a digital compilation of data from these two previous sources. This digital database differs from earlier compilation efforts in that the observations were located on a 1:24,000 scale base map versus the smaller scale base maps used in the earlier publications. Sites were reevaluated and some single sites were broken into two or more where the greater base map detail allowed. These sites of past liquefaction-related occurrences are shown on Plate 1.2.

Within the Santa Clara County portion of the Mountain View Quadrangle, Youd and Hoose (1978) compiled four instances of historical liquefaction, recorded following the 1906 earthquake by Lawson and others (1908). Three incidents occurred in Holocene alluvial fan, fine-facies deposits (Qhff) and a fourth in San Francisco Bay Mud deposits (Qhbm). One instance in Qhff occurred in the vicinity of Crittenden Lane in the city of Mountain View (site 146), where a “disturbed well” suddenly became artesian. Another instance involved both a "disturbed well" and ground settlement at the former site of the Ynigo Ranch (site 147), currently occupied by the Moffett Field Naval Air Station. That well produced black sand, became artesian, and had its well casing displaced upward 2 feet. A third instance occurred near Jagel Landing Road (site 147), where a "disturbed well" is documented by increased pressure in two artesian wells, and an abandoned artesian well, backfilled with stones, that began flowing for the first time in several years. A fourth instance of liquefaction (site 145), classified as miscellaneous effects, occurs in San Francisco Bay Mud deposits (Qhbm) in the slough near Cooley's Landing. One unconfirmed report of "new holes" forming was recorded at this site. Tinsley and others' (1998) compilation of observations following the 1989 earthquake included examinations of earthen dikes at two sites in the Mountain View Quadrangle. One at Bay Lands Park, on East Embarcadero Road in Palo Alto (site 24) and one at Shoreline Park in Mountain View (site 25). Liquefaction was not evident at either site. However, within Alameda County, Tinsley and others (1998) include observations of ground cracks in fill embankments of the Southern Pacific Railroad, at Dumbarton Point (site 51A). Some differential settlement of 0.1 m within fill was also observed.

Artificial Fills

In the Mountain View Quadrangle, the three kinds of artificial fill mapped by Knudsen and others (2000) are: artificial fill (af); artificial fill over Bay Mud, (afbm); and artificial fill, levee (alf). Artificial fill areas large enough to show at the scale of mapping primarily consist of engineered fill for river levees and elevated freeways. Since these fills are considered to be properly engineered, zoning for liquefaction in such areas depends on soil conditions in underlying strata. Non-engineered fills are commonly loose and uncompacted, and the material varies in size and type. Deposits of likely non-engineered artificial fill (af) exist within and along the margin of San Francisco Bay and in the area occupied by Moffett Field Naval Air Station.

The San Francisco Bay is defined by an active margin that has been, and continues to be, modified by both natural processes and human activities. Knudsen and others (2000) reviewed historical maps of the San Francisco Bay shoreline and tidal marshes to map the extent of artificial fill overlying Bay Mud (afbm) that has been placed since the 1850's. These bodies of artificial fill historically have been particularly susceptible to liquefaction. Large deposits of artificial fill over Bay mud in the Mountain View Quadrangle are restricted to the margins of the bay. In the city of Palo Alto, these deposits occur in several locations: the vicinity of the Santa Clara County Airport; adjacent to, and southwest of Highway 101 between the Oregon Expressway and Adobe Creek; and northeast of Highway 101 between Adobe Creek and Charleston Road. In the city of Mountain View, there is artificial fill over Bay Mud deposits northeast of Highway 101 between Charleston Slough and Broderick way, and in the vicinity of Shoreline at Mountain View Park, between MountainView slough and Stevens Creek. In Sunnyvale, artificial fill over Bay mud occurs at the north end of the main runway at Moffett Field, along the eastern border between Sunnyvale and Moffett Field, and north of the intersection of Caribbean Drive and Crossman Road. These areas all are included in the zone of required investigation.

Areas with Sufficient Existing Geotechnical Data

Borehole logs that include penetration test data and sufficiently detailed lithologic descriptions were used to evaluate liquefaction potential. These areas with sufficient geotechnical data were evaluated for zoning based on the liquefaction potential determined by the Seed-Idriss Simplified Procedure. In Holocene alluvial deposits that cover much of the Mountain View Quadrangle, most of the borehole logs that were analyzed contain sediment layers that may liquefy under the expected earthquake loading. These areas containing saturated potentially liquefiable material are included in the zone.

The liquefaction zone boundary extending from the western border to the southeastern corner of the Mountain View Quadrangle (excluding the sections along stream channels) is the surface projection of the contact between ground water and the top of late Pleistocene alluvial fan deposits (Qpf). Where lower density, younger material is above the water table (i.e. unsaturated) and only denser Pleistocene material is saturated, these areas are excluded from the zone.

Areas with Insufficient Existing Geotechnical Data

Adequate geotechnical borehole information for Quaternary geologic units including artificial and modern stream channel deposits (af and Qhc) generally is lacking. These deposits, therefore, are included in the liquefaction zone for reasons presented in criterion 4-a, above. The Alameda and San Mateo counties part of the quadrangle did not have any available geotechnical borehole information. However, because the entire landmass in these two counties is characterized by shallow ground water and the presence of saturated Holocene deposits (all Qhbm), all of it is included within a zone of required investigation.

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SECTION 2

EARTHQUAKE-INDUCED LANDSLIDE ZONES OF REQUIRED INVESTIGATION IN THE MOUNTAIN VIEW 7.5-MINUTE QUADRANGLE

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California Department of Conservation
California Geological Survey

Note: This report and the seismic hazard zone map it accompanies are revisions of the Seismic Hazard Zone Map and Report of the same name and report number that were officially released in July 2003. The revised map and report now include land in San Mateo County that was originally excluded from zonation. However, no areas in addition to those appearing in the original map are designated earthquake-induced landslide zones of required investigations.

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called California Geological Survey (CGS)] to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use seismic hazard zone maps prepared by CGS in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (DOC, 1997). The text of this report is on the Internet at http://gmw.consrv.ca.gov/shmp/webdocs/sp117.pdf

Following the release of DMG Special Publication 117 (DOC, 1997), agencies in the Los Angeles metropolitan region sought more definitive guidance in the review of geotechnical investigations addressing landslide hazards. The agencies made their request through the Geotechnical Engineering Group of the Los Angeles Section of the American Society of Civil Engineers (ASCE). This group convened an implementation committee in 1998 under the auspices of the Southern California Earthquake Center (SCEC). The committee, which consisted of practicing geotechnical engineers and engineering geologists, released an overview of the practice of landslide analysis, evaluation, and mitigation techniques (SCEC, 2002). This text is also on the Internet at: http://www.scec.org/

This section of the evaluation report summarizes seismic hazard zone mapping for earthquake-induced landslides in the Santa Clara County portion of the Mountain View 7.5-Minute Quadrangle. Section 1 (addressing liquefaction) and Section 3 (addressing earthquake shaking) complete the report, which is one of a series that summarizes the preparation of seismic hazard zone maps within the state (Smith, 1996). Additional information on seismic hazard zone mapping in California can be accessed on CGS's Internet web page: http://www.conservation.ca.gov/CGS/index.htm

BACKGROUND

Landslides triggered by earthquakes historically have been a significant cause of earthquake damage. In California, large earthquakes such as the 1971 San Fernando, 1989 Loma Prieta, and 1994 Northridge earthquakes triggered landslides that were responsible for destroying or damaging numerous structures, blocking major transportation corridors, and damaging life-line infrastructure. Areas that are most susceptible to earthquake-induced landslides are steep slopes in poorly cemented or highly fractured rocks, areas underlain by loose, weak soils, and areas on or adjacent to existing landslide deposits. These geologic and terrain conditions exist in many parts of California, including numerous hillside areas that have already been developed or are likely to be developed in the future. The opportunity for strong earthquake ground shaking is high in many parts of California because of the presence of numerous active faults. The combination of these factors constitutes a significant seismic hazard throughout much of California, including hillsides and creek banks of the Mountain View Quadrangle.

METHODS SUMMARY

The mapping of earthquake-induced landslide hazard zones presented in this report is based on the best available terrain, geologic, geotechnical, and seismological data. If unavailable or significantly outdated, new forms of these data were compiled or generated specifically for this project. The following were collected or generated for this evaluation:

- Digital terrain data were used to provide an up-to-date representation of slope gradient and slope aspect in the study area

- Geologic mapping was used to provide an accurate representation of the spatial distribution of geologic materials in the study area. In addition, a map of existing landslides, whether triggered by earthquakes or not, was prepared

- Geotechnical laboratory test data were collected and statistically analyzed to quantitatively characterize the strength properties and dynamic slope stability of geologic materials in the study area

- Seismological data in the form of CGS probabilistic shaking maps and catalogs of strong-motion records were used to characterize future earthquake shaking within the mapped area

The data collected for this evaluation were processed into a series of GIS layers using commercially available software. A slope stability analysis was performed using the Newmark method of analysis (Newmark, 1965), resulting in a map of landslide hazard potential. The earthquake-induced landslide hazard zone was derived from the landslide hazard potential map according to criteria developed in a CGS pilot study (McCrink and Real, 1996; McCrink, 2001) and adopted by the State Mining and Geology Board (DOC, 2000).

SCOPE AND LIMITATIONS

The methodology used to make this map is based on earthquake ground-shaking estimates, geologic material-strength characteristics and slope gradient. These data are gathered from a variety of outside sources. Although the selection of data used in this evaluation was rigorous, the quality of the data is variable. The State of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data gathered from outside sources.

Earthquake-induced landslide zone maps are intended to prompt more detailed, site-specific geotechnical investigations as required by the Act. As such, these zone maps identify areas where the potential for earthquake-induced landslides is relatively high. Due to limitations in methodology, it should be noted that these zone maps do not necessarily capture all potential earthquake-induced landslide hazards. Earthquake-induced ground failures that are not addressed by this map include those associated with ridge-top spreading and shattered ridges. It should also be noted that no attempt has been made to map potential run-out areas of triggered landslides. It is possible that such run-out areas may extend beyond the zone boundaries. The potential for ground failure resulting from liquefaction-induced lateral spreading of alluvial materials, considered by some to be a form of landsliding, is not specifically addressed by the earthquake-induced landslide zone or this report. See Section 1, Liquefaction Evaluation Report for the Mountain View Quadrangle, for more information on the delineation of liquefaction zones.

The remainder of this report describes in more detail the mapping data and processes used to prepare the earthquake-induced landslide zone map for the Santa Clara County and Alameda County portions of the Mountain View Quadrangle. The information is presented in two parts. Part I covers physiographic, geologic and engineering geologic conditions in the study area. Part II covers the preparation of landslide hazard potential and landslide zone maps.

PART I

PHYSIOGRAPHY

Study Area Location and Physiography

The Mountain View 7.5-Minute Quadrangle covers approximately 62 square miles at the south end of San Francisco Bay and includes parts of Santa Clara, Alameda and San Mateo counties. This evaluation report addresses earthquake-induced landslide zones of required investigation only for the Santa Clara County and Alameda County part of the Mountain View Quadrangle, which consists of approximately 90 percent of the quadrangle. The study area includes parts of the cities of Los Altos, Los Altos Hills, Mountain View, Palo Alto, Sunnyvale, Santa Clara, San Jose, Fremont, and Newark, as well as unincorporated Santa Clara County and Alameda County land.

The gently sloping floor of the Santa Clara Valley and the southernmost extent of San Francisco Bay occupy most of the map area. Tidal marshes and salt evaporation ponds extend along the margin of the bay. Several streams extend across the valley floor and drain into the bay, including Barron, Adobe, Permanente, Plummer and Stevens creeks. The lower portions of these creeks become tidal sloughs near the margins of the bay. The southwestern corner of the map area includes a very small area of hilly terrain that is part of the Santa Cruz Mountains. Elevations in the map area range from sea level along the shore of San Francisco Bay to about 285 feet in the southwestern corner of the quadrangle.

Much of the valley floor is developed for residential, commercial and industrial uses. Several highways and major roads extend across the valley floor in the map area, including U.S. Highway 101, State Highway 237, Central Expressway, Foothill Expressway and El Camino Real. Much of the original tidal marsh along the shore of San Francisco Bay has been intensively altered by the construction of dikes and salt evaporation ponds. The low hills in the southwestern corner of the map area have been developed for single-family residential use.

Digital Terrain Data

The calculation of slope gradient is an essential part of the evaluation of slope stability under earthquake conditions. An accurate slope gradient calculation begins with an up-to-date map representation of the earth’s surface. For the Mountain View Quadrangle, a Level-2 digital elevation model (DEM) was obtained from the U.S. Geological Survey (1993). This DEM, which was prepared from the 7.5-minute quadrangle topographic contours that are based on 1948 aerial photography, has a 10-meter horizontal ground sample distance (GSD; commonly called pixel size) and a 7.5-meter vertical accuracy.

A slope map was made from the DEM using a third-order, finite difference, center-weighted algorithm (Horn, 1981). The manner in which the slope map has been used to prepare the zone map is described in subsequent sections of this report.

GEOLOGY

The primary source of bedrock geologic mapping used in this slope stability evaluation was prepared by the U.S. Geological Survey (Brabb and others, 1998). The surficial or Quaternary geologic map of the Mountain View Quadrangle was prepared by Knudsen and others (2000) at a scale of 1:24,000. CGS geologists merged the digital bedrock and surficial geologic maps. In addition, CGS geologists performed geologic field reconnaissance to check geologic contacts and observe the lithology and structure of geologic units.

The majority of the study area is nearly flat and is underlain by unconsolidated Quaternary units. These include: late Pleistocene alluvial fans (Qpf); Holocene alluvial fans (Qhf), fine-grained alluvial fans (Qhff), alluvial fan levees (Qhl) and Bay mud (Qhbm); and modern stream channels (Qhc). Units mapped as artificial fill (af), artificial fill over Bay mud (afbm), artificial levee fill (alf), gravel quarry and percolation pond (gq), and artificial stream channel (ac) are also in the study area. These units are discussed in more detail in Section 1, Liquefaction Evaluation Report. Due to their low relief, Quaternary deposits in the map area are generally not subject to earthquake-induced landslides.

The only significant slopes in the map area occur in the southwestern corner of the quadrangle. These slopes are underlain by Plio-Pleistocene Santa Clara Formation (Brabb and others, 1998). The Santa Clara Formation (QTsc) consists of nonmarine, gray to red-brown, poorly indurated conglomerate, sandstone and mudstone in irregular and lenticular beds. Clay in the bedrock, as well as residual soils developed from the bedrock, typically contain expansive montmorillonite clays (Rogers and Armstrong, 1973). Montmorillonite-bearing materials are potentially unstable on slopes.

Structural Geology

Undeformed late Quaternary alluvial sediments and bay mud that underlie the floor of the San Francisco Bay basin underlie most of the map area. Deformed Plio-Pleistocene sedimentary rocks of the Santa Clara Formation underlie a small area of hilly terrain in the southwestern corner of the map area. This hilly terrain is on the northeastern edge of the Santa Cruz Mountains, the main mass of which lies west and southwest of the map area. The Santa Clara Formation beds, in and adjacent to the map area, dip gently to moderately to the northeast. Measured dips range from 10 to 40 degrees (Cotton and Associates, 1978). These beds are on the northeastern limb of a northwest-trending anticline. The axis of this anticline lies several hundred feet southwest of the study area. Two reverse faults with Quaternary displacement, the Monte Vista and Berrocal faults, are less than a mile southwest of the map area. The historically active San Andreas Fault is about 3 miles southwest of the map area.

Landslide Inventory

As a part of the geologic data compilation, an inventory of existing landslides in the Mountain View Quadrangle was conducted by field reconnaissance, analysis of stereopaired aerial photographs and a review of previously published landslide mapping by William Cotton and Associates (1978).

At a scale of 1:24,000, at which this work was performed, it is generally possible to identify and display landslide features that are at least 100 to 200 feet across. Although it is possible that there may be landslides smaller than about 100 feet that were not identified, we did not identify any existing landslides in the Mountain View Quadrangle. William Cotton and Associates (1978) also do not show any landslides in the portion of the Mountain View Quadrangle covered by their mapping.

ENGINEERING GEOLOGY

To evaluate the stability of geologic materials under earthquake conditions, the geologic map units described above were ranked and grouped on the basis of their shear strength. Generally, the primary source for rock shear-strength measurements is geotechnical reports prepared by consultants on file with local government permitting departments. Shear-strength data for the units identified on the Mountain View geologic map were obtained from Cotton, Shires and Associates; the cities of Los Altos, Mountain View, Palo Alto and Sunnyvale; and California Department of Transportation (CalTrans), as listed in the Appendix. The 30 locations of rock and soil samples taken in the Mountain View Quadrangle by consultants for shear testing are shown on Plate 2.1. In addition, shear tests from the adjoining portions of the Palo Alto, Mindego Hill, Cupertino, and San Jose West quadrangles have been used to augment data for several geologic formations for which little or no shear test information was available within the Mountain View Quadrangle.

Shear strength data gathered from the above sources were compiled for each geologic map unit. Geologic units were grouped on the basis of average angle of internal friction (average phi) and lithologic character. Average (mean and median) phi values for each geologic map unit and corresponding strength group are summarized in Table 2.1. For each geologic strength group in the map area, the average shear strength value was assigned and used in our slope stability analysis. A geologic material strength map was made based on the groupings presented in Tables 2.1 and 2.2, and this map provides a spatial representation of material strength for use in the slope stability analysis.

Because lithologies are similar, afbm was grouped with af, and Qhc with Qhl, in the statistical evaluation. The geomorphic units, ac and gq, were grouped with their most common hosting geologic units, Qhf and Qhff respectively. The median value of phi has been assigned for each group except Group 4, in which the sample population of 36 was large enough to justify using the mean.

MOUNTAIN VIEW QUADRANGLE SHEAR STRENGTH STATISTICS							
	Formation Name (1)	Number of Tests	Mean/Median Phi (deg)	Mean/Median Group Phi (deg)	Mean/Median Group C (2) (psf)	No Data: Similar Lithology	Phi Values Used in Stability Analyses
GROUP 1	Qpf	8	30.2 / 28.5	30.2 / 28.5	529 / 500	- - -	28.5
GROUP 2	QTsc	21	27.2 / 26.0	26.2 / 25.5	671 / 610	- - -	25.5
	alf	3	19.7 / 24.0				
GROUP 3	Qhl	6	22.8 / 21.5	22.8 / 21.5	302 / 300	Qhc	21.5
GROUP 4	Qhf	17	16.9 / 18.0	18.0 / 19.0	823 / 673	ac	18.0
	Qhff	9	18.3 / 19.0			afbm	
	af	10	19.8 / 19.5			gq	
GROUP 5	Qhbm	2	13.0 / 13.0	13.0 / 13.0	450 / 450	- - -	13.0

(1) Formation abbreviations from Brabb and others (1998); Knudsen and others (2000)
(2) Cohesion

Table 2.1. Summary of Shear Strength Statistics for the Mountain View Quadrangle.

MOUNTAIN VIEW QUADRANGLE SHEAR STRENGTH GROUPS				
GROUP 1	GROUP 2	GROUP 3	GROUP 4	GROUP 5
Qpf	alf	Qhc	ac, gq	Qhbm
	QTsc	Qhl	af, afbm	
			Qhf	
			Qhff	

Table 2.2. Summary of Shear Strength Groups for the Mountain View Quadrangle.

PART II

EARTHQUAKE-INDUCED LANDSLIDE HAZARD POTENTIAL

Design Strong-Motion Record

To evaluate earthquake-induced landslide hazard potential in the study area, a method of dynamic slope stability analysis developed by Newmark (1965) was used. The Newmark method analyzes dynamic slope stability by calculating the cumulative down-slope displacement for a given earthquake strong-motion time history. As implemented for the preparation of earthquake-induced landslide zones, the Newmark method necessitates the selection of a design earthquake strong-motion record to provide the "ground shaking opportunity." For the Mountain View Quadrangle, selection of a strong motion record was based on an estimation of probabilistic ground motion parameters for modal magnitude, modal distance, and peak ground acceleration (PGA). The parameters were estimated from maps prepared by CGS for a 10 percent probability of being exceeded in 50 years (Petersen and others, 1996). The parameters used in the record selection are:

Modal Magnitude:	7.1 – 7.9
Modal Distance:	8.0 – 17.1 km
PGA:	0.52 – 0.69 g

The strong-motion record selected for the slope stability analysis in the Mountain View Quadrangle is the Lucerne record of the 1992 Landers earthquake, which had a moment magnitude (M_W) of 7.3. This record had a source to recording site distance of 1.1 km and a PGA of 0.73 g. The selected strong-motion record was not scaled or otherwise modified prior to its use in the analysis.

Displacement Calculation

The design strong-motion record was used to develop a relationship between landslide displacement and yield acceleration (a_y), defined as the earthquake horizontal ground acceleration above which landslide displacements take place. This relationship was prepared by integrating the design strong-motion record twice for a given acceleration value to find the corresponding displacement, and the process was repeated for a range of acceleration values (Jibson, 1993). The resulting curve in Figure 2.1 represents the full spectrum of displacements that can be expected for the design strong-motion record. This curve provides the required link between anticipated earthquake shaking and estimates of displacement for different combinations of geologic materials and slope gradient, as described in the Slope Stability Analysis section below.

The amount of displacement predicted by the Newmark analysis provides an indication of the relative amount of damage that could be caused by earthquake-induced landsliding. Displacements of 30, 15 and 5 cm were used as criteria for rating levels of earthquake-induced landslide hazard potential based on the work of Youd (1980), Wilson and Keefer (1983), and a CGS pilot study for earthquake-induced landslides (McCrink and Real, 1996; McCrink, 2001). Applied to the curve in Figure 2.1, these displacements correspond to yield accelerations of 0.14, 0.18 and 0.24 g. Because these yield acceleration values are derived from the design strong-motion record, they represent the ground shaking opportunity thresholds that are significant in the Mountain View Quadrangle.

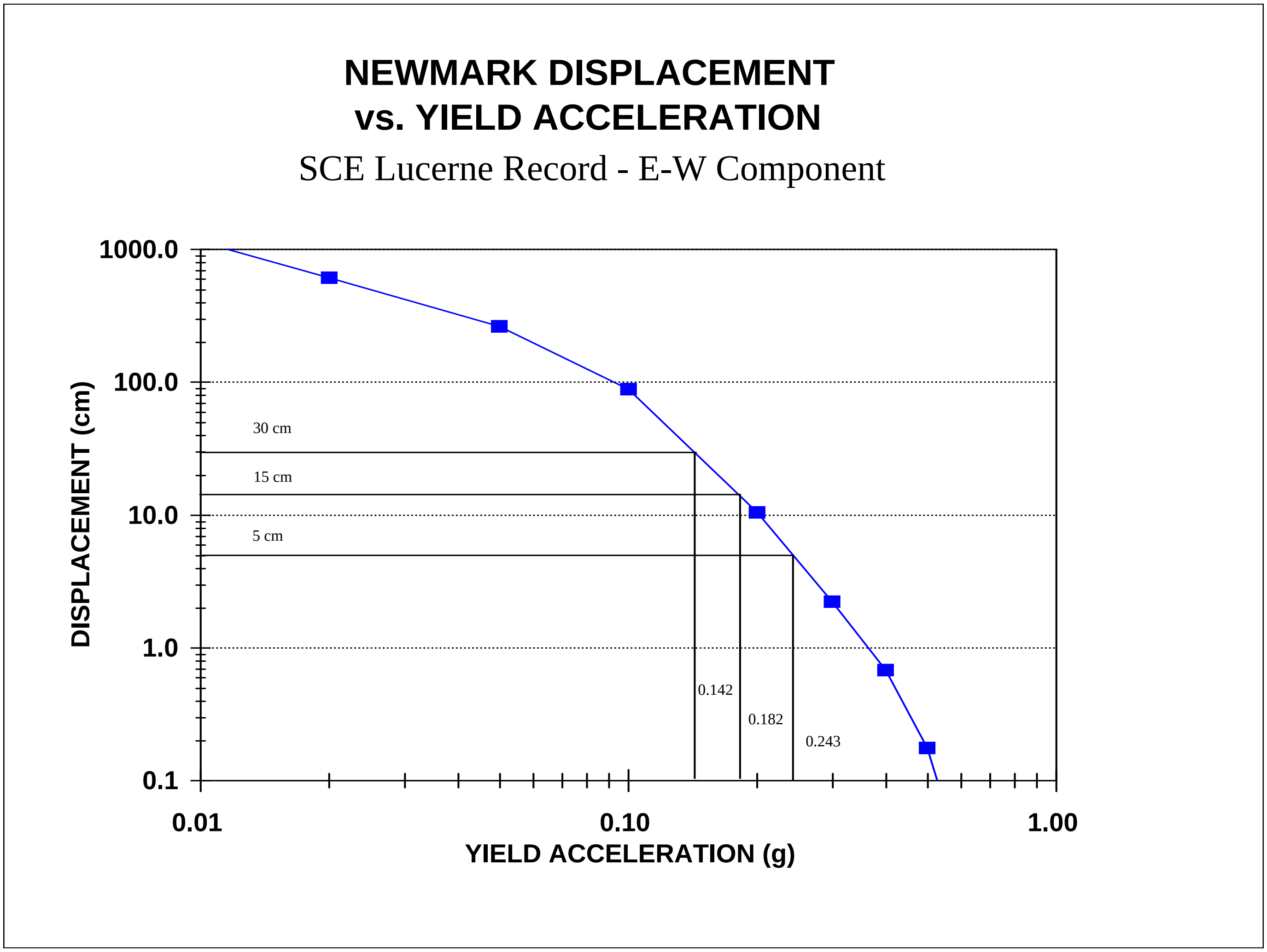

Figure 2.1. Yield Acceleration vs. Newmark Displacement for the Lucerne Record from the 1992 Landers Earthquake.

Slope Stability Analysis

A slope stability analysis was performed for each geologic material strength group at slope increments of 1 degree. An infinite-slope failure model under unsaturated slope conditions was assumed. A factor of safety was calculated first, followed by the calculation of yield acceleration from Newmark's equation:

$$a_y = (FS - 1)g \sin \alpha$$

where FS is the Factor of Safety, g is the acceleration due to gravity, and α is the direction of movement of the slide mass, in degrees measured from the horizontal, when displacement is initiated (Newmark, 1965). For an infinite slope failure α is the same as the slope angle.

The yield accelerations resulting from Newmark's equations represent the susceptibility to earthquake-induced failure of each geologic material strength group for a range of slope gradients. Based on the relationship between yield acceleration and Newmark displacement shown in Figure 2.1, hazard potentials were assigned as follows:

1. If the calculated yield acceleration was less than 0.14 g, Newmark displacement greater than 30 cm is indicated, and a HIGH hazard potential was assigned

2. If the calculated yield acceleration fell between 0.14 g and 0.18 g, Newmark displacement between 15 cm and 30 cm is indicated, and a MODERATE hazard potential was assigned

3. If the calculated yield acceleration fell between 0.18 g and 0.24 g, Newmark displacement between 5 cm and 15 cm is indicated, and a LOW hazard potential was assigned

4. If the calculated yield acceleration was greater than 0.24 g, Newmark displacement of less than 5 cm is indicated, and a VERY LOW potential was assigned

Table 2.3 summarizes the results of the stability analyses. The earthquake-induced landslide hazard potential map was prepared by combining the geologic material-strength map and the slope map according to this table.

MOUNTAIN VIEW QUADRANGLE HAZARD POTENTIAL MATRIX

Geologic Material Strength Group (Average Phi)	HAZARD POTENTIAL (Percent Slope)			
	Very Low	Low	Moderate	High
1 (28.5)	0 to 29%	29 to 35%	35 to 39%	> 39%
2 (25.5)	0 to 22%	22 to 28%	28 to 33%	> 33%
3 (21.5)	0 to 14%	14 to 20%	20 to 24%	> 24%
4 (18)	0 to 7%	7 to 14%	14 to 18%	> 18%
5 (13)	0 to 1%	1 to 4%	4 to 9%	>9%

Table 2.3. Hazard Potential Matrix for Earthquake-Induced Landslides in the Mountain View Quadrangle. Values in the table show the range of slope gradient (expressed as percent slope) corresponding to calculated Newmark displacement ranges from the design earthquake for each material strength group.

EARTHQUAKE-INDUCED LANDSLIDE HAZARD ZONE

Criteria for Zoning

Earthquake-induced landslide zones were delineated using criteria adopted by the California State Mining and Geology Board (DOC, 2000). Under these criteria, earthquake-induced landslide hazard zones are defined as areas that meet one or both of the following conditions:

1. Areas that have been identified as having experienced landslide movement in the past, including all mappable landslide deposits and source areas as well as any landslide that is known to have been triggered by historic earthquake activity

2. Areas where the geologic and geotechnical data and analyses indicate that the earth materials may be susceptible to earthquake-induced slope failure

These conditions are discussed in further detail in the following sections.

Geologic and Geotechnical Analysis

Based on the conclusions of a pilot study performed by CGS (McCrink and Real, 1996; McCrink, 2001), it has been concluded that earthquake-induced landslide hazard zones should encompass all areas that have a High, Moderate or Low level of hazard potential (see Table 2.3). This would include all areas where the analyses indicate earthquake displacements of 5 centimeters or greater. Areas with a Very Low hazard potential, indicating less than 5 centimeters displacement, are excluded from the zone.

As summarized in Table 2.3, all areas characterized by the following geologic strength group and slope gradient conditions are included in the earthquake-induced landslide hazard zone:

1. Geologic Strength Group 5 is included for all slopes steeper than 1 percent.

2. Geologic Strength Group 4 is included for all slopes steeper than 7 percent

3. Geologic Strength Group 3 is included for all slopes steeper than 14 percent

4. Geologic Strength Group 2 is included for all slopes steeper than 22 percent

5. Geologic Strength Group 1 is included for all slopes greater than 29 percent

This results in significantly less than one percent of the Santa Clara County portion of the Mountain View Quadrangle lying within the earthquake-induced landslide hazard zone. The areas are in the southwestern part of the quadrangle in steeper portions of Los Altos Hills and banks of Adobe Creek. There are no landslide zones in the Alameda County portion of the quadrangle.

ACKNOWLEDGMENTS

The California Department of Transportation (CalTrans); the cities of Los Altos, Mountain View, Palo Alto and Sunnyvale; and Cotton, Shires and Associates assisted by allowing us access to their files to compile shear-strength data. At CGS, Elise Mattison made available geotechnical reports from the liquefaction study. Ellen Sander updated the shear-test database. Barbara Wanish, Terilee McGuire, Ross Martin, Lee Wallinder, and Bob Moscovitz provided invaluable GIS and database support.

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AIR PHOTOS

United States Department of Agriculture (USDA), dated 8-1-39, photo no. CIV-286-8 and 286-9.

WAC Corporation, Inc., dated 4-13-99, flight no. WAC-C-99CA, photo no. 3-64 and 3-65.

APPENDIX A
SOURCE OF ROCK STRENGTH DATA

SOURCE	NUMBER OF TESTS SELECTED
California Department of Transportation (CalTrans)	5
Cotton, Shires and Associates	2
City of Los Altos	9
City of Mountain View	12
City of Palo Alto	11
City of Sunnyvale	1
Total Number of Shear Tests	40

SECTION 3

POTENTIAL GROUND SHAKING IN THE MOUNTAIN VIEW 7.5-MINUTE QUADRANGLE

By

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PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called California Geological Survey (CGS)] to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the Seismic Hazard Zone Maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (DOC, 1997); also available on the Internet at http://gmw.consrv.ca.gov/shmp/webdocs/sp117.pdf

This section of the evaluation report summarizes the ground motions used to evaluate liquefaction and earthquake-induced landslide potential for zoning purposes. Included are ground motion and related maps, a brief overview on how these maps were prepared, precautionary notes concerning their use, and related references. The maps provided herein are presented at a scale of approximately 1:150,000 (scale bar provided on maps), and show the full 7.5-minute quadrangle and portions of the adjacent eight quadrangles. They can be used to assist in the specification of earthquake loading conditions ***for the analysis of ground failure*** according to the “Simple Prescribed Parameter Value” method (SPPV) described in the site investigation guidelines (DOC, 1997). Alternatively, they can be used as a basis for comparing levels of ground motion determined by other methods with the statewide standard.

This section and Sections 1 and 2 (addressing liquefaction and earthquake-induced landslide hazards) constitute a report series that summarizes development of seismic hazard zone maps in the state. Additional information on seismic hazard zone mapping in California can be accessed on CGS's Internet homepage: http://www.conservation.ca.gov/CGS/index.htm

EARTHQUAKE HAZARD MODEL

The estimated ground shaking is derived from the statewide probabilistic seismic hazard evaluation released cooperatively by the California Department of Conservation, California Geological Survey, and the U.S. Geological Survey (Petersen and others, 1996). That report documents an extensive 3-year effort to obtain consensus within the scientific community regarding fault parameters that characterize the seismic hazard in California. Fault sources included in the model were evaluated for long-term slip rate, maximum earthquake magnitude, and rupture geometry. These fault parameters, along with historical seismicity, were used to estimate return times of moderate to large earthquakes that contribute to the hazard.

The ground shaking levels are estimated for each of the sources included in the seismic source model using attenuation relations that relate earthquake shaking with magnitude, distance from the earthquake, and type of fault rupture (strike-slip, reverse, normal, or subduction). The published hazard evaluation of Petersen and others (1996) only considers uniform firm-rock site conditions. In this report, however, we extend the hazard analysis to include the hazard of exceeding peak horizontal ground acceleration (PGA) at 10 percent probability of exceedance in 50 years on spatially uniform conditions of rock, soft rock, and alluvium. These soil and rock conditions approximately correspond to site categories defined in Chapter 16 of the Uniform Building Code (ICBO, 1997), which are commonly found in California. We use the attenuation relations of Boore and others (1997), Campbell (1997), Sadigh and others (1997), and Youngs and others (1997) to calculate the ground motions.

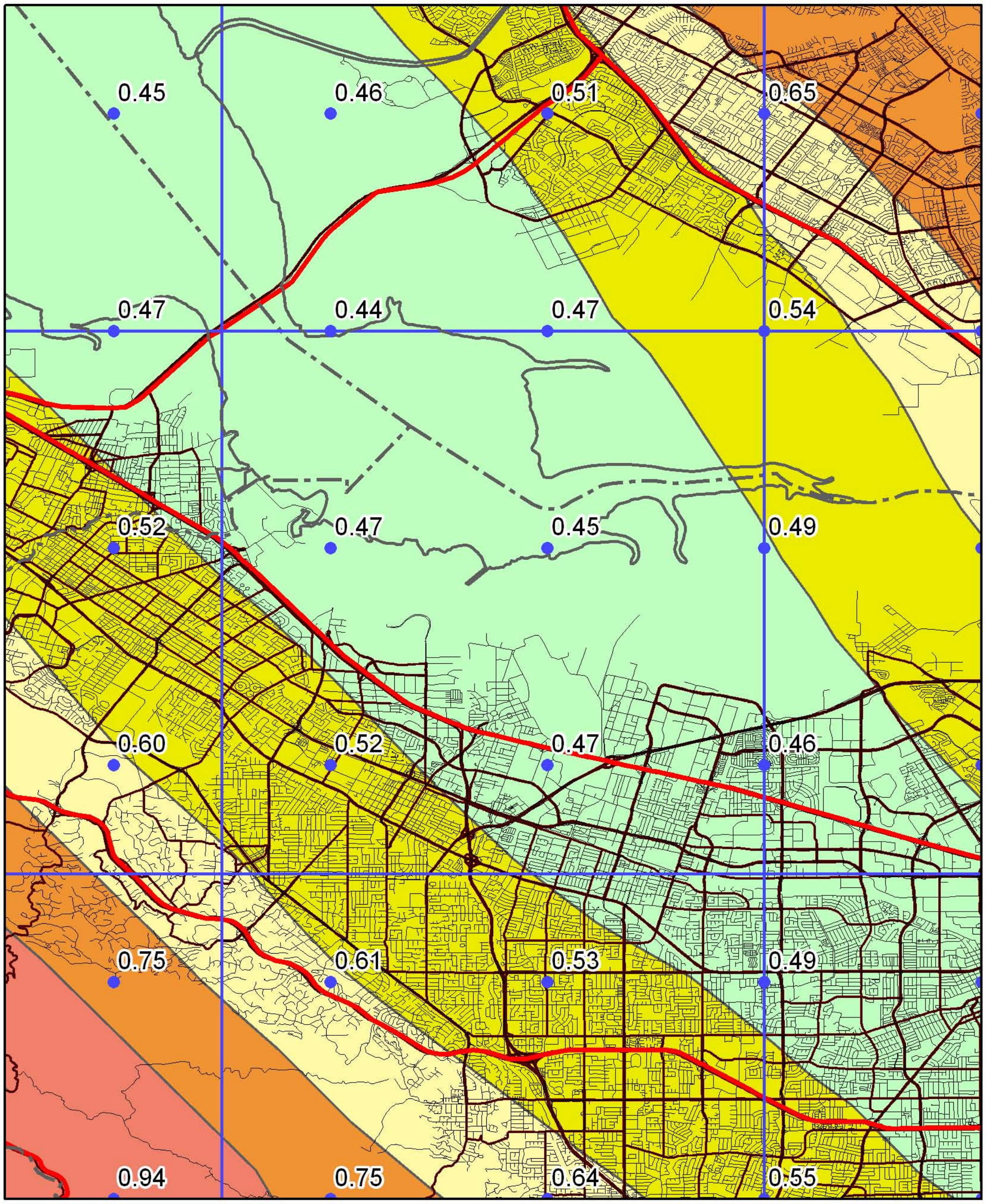
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10 percent probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively. The sites where the hazard is calculated are represented as dots and ground motion contours as shaded regions. The quadrangle of interest is outlined by bold lines and centered on the map. Portions of the eight

MOUNTAIN VIEW 7.5-MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDENCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

FIRM ROCK CONDITIONS



Base map from GDT

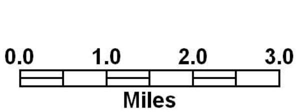


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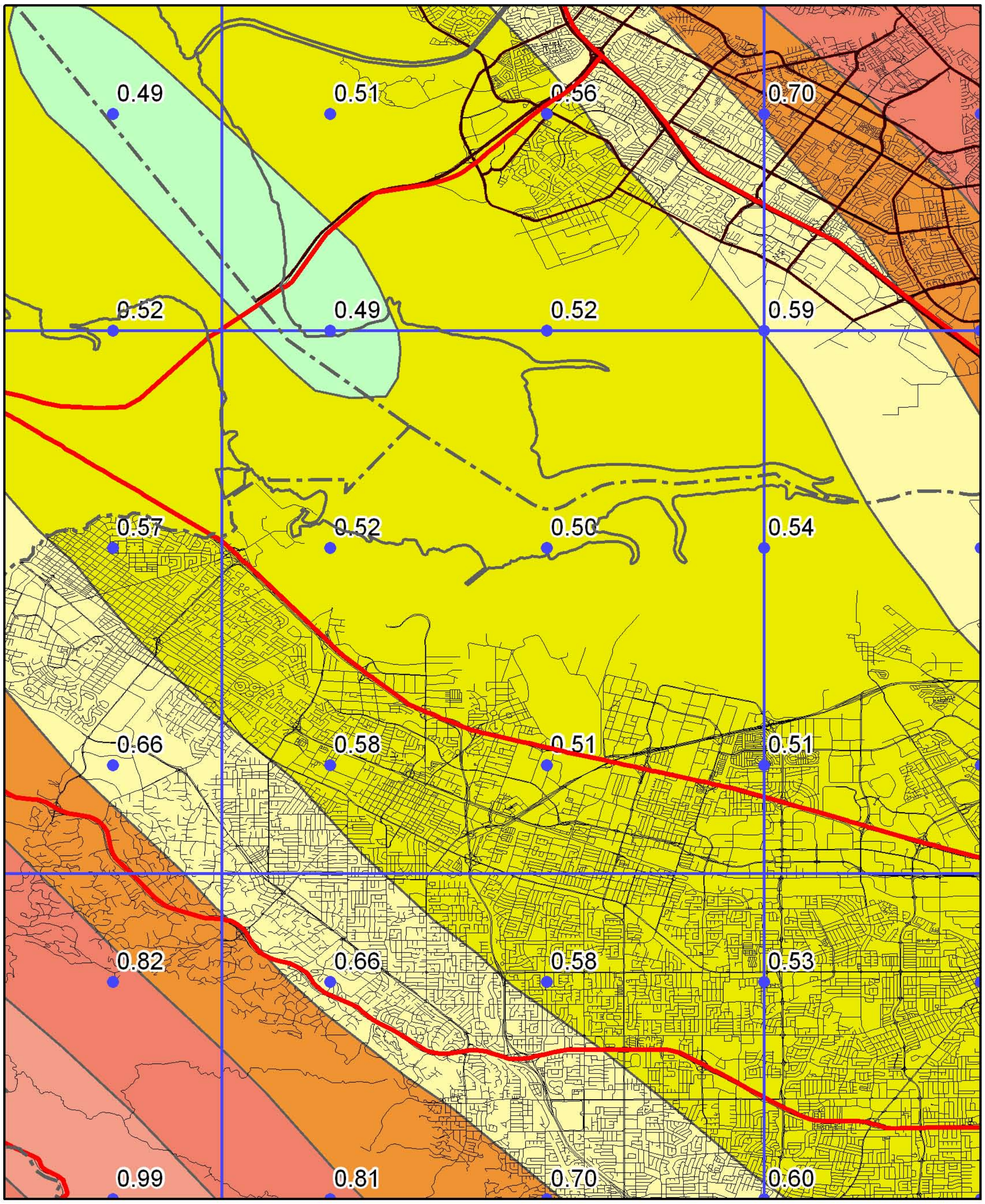
Figure 3.1

MOUNTAIN VIEW 7.5-MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDENCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

SOFT ROCK CONDITIONS



Base map from GDT

0.0 1.0 2.0 3.0
Miles

Department of Conservation
California Geological Survey

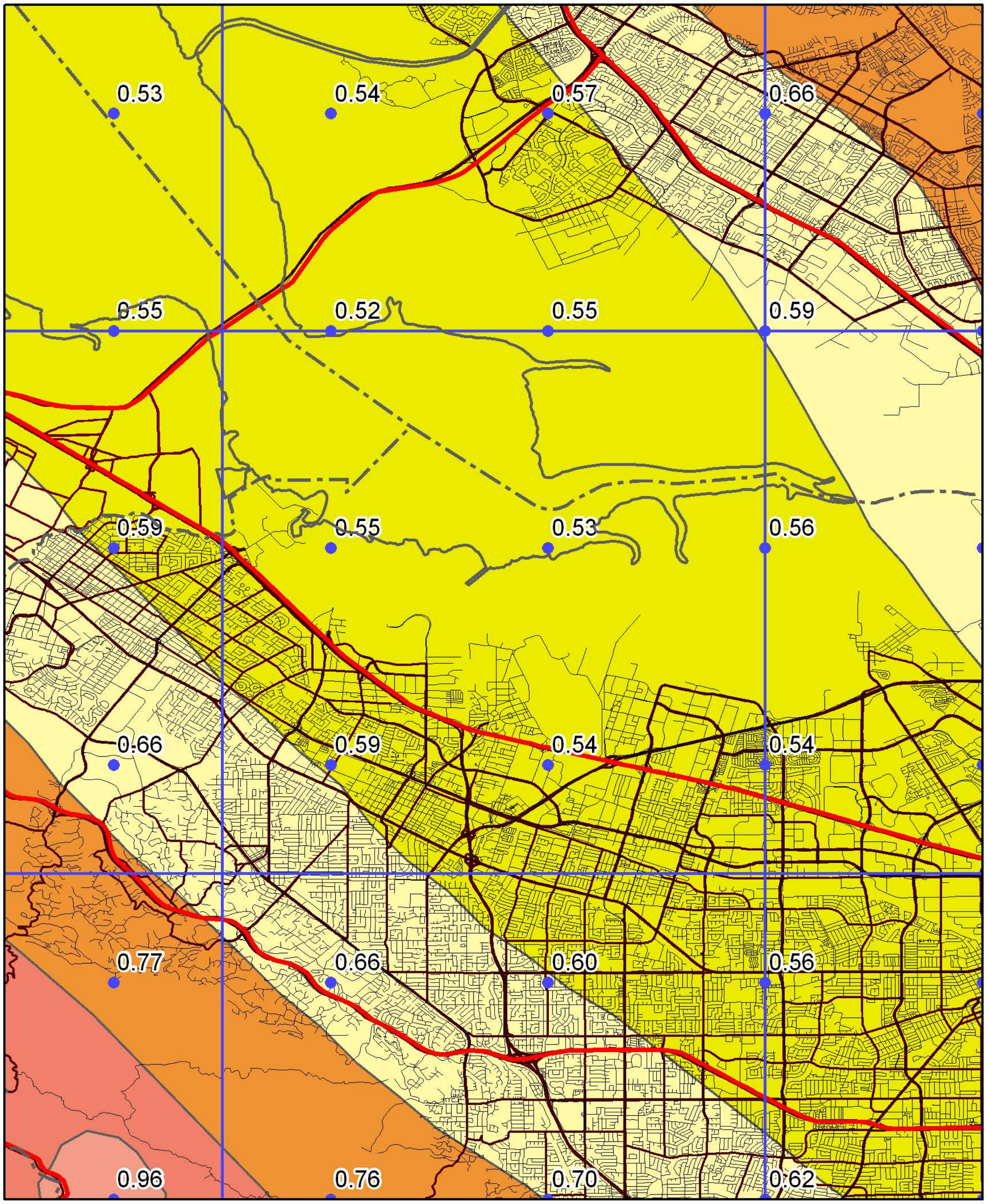
Figure 3.2

MOUNTAIN VIEW 7.5-MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDENCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

ALLUVIUM CONDITIONS



Base map from GDT

0.0 1.0 2.0 3.0

Miles

Department of Conservation
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Figure 3.3

adjacent quadrangles are also shown so that the trends in the ground motion may be more apparent. We recommend estimating ground motion values by selecting the map that matches the actual site conditions, and interpolating from the calculated values of PGA rather than the contours, since the points are more accurate.

APPLICATIONS FOR LIQUEFACTION AND LANDSLIDE HAZARD ASSESSMENTS

Deaggregation of the seismic hazard identifies the contribution of each of the earthquakes (various magnitudes and distances) in the model to the ground motion hazard for a particular exposure period (see Cramer and Petersen, 1996). The map in Figure 3.4 identifies the magnitude and the distance (value in parentheses) of the earthquake that contributes most to the hazard at 10 percent probability of exceedance in 50 years on alluvial site conditions (*predominant earthquake*). This information gives a rationale for selecting a seismic record or ground motion level in evaluating ground failure. However, it is important to keep in mind that more than one earthquake may contribute significantly to the hazard at a site, and those events can have markedly different magnitudes and distances. For liquefaction hazard the predominant earthquake magnitude from Figure 3.4 and PGA from Figure 3.3 (alluvium conditions) can be used with the Youd and Idriss (1997) approach to estimate cyclic stress ratio demand. For landslide hazard the predominant earthquake magnitude and distance can be used to select a seismic record that is consistent with the hazard for calculating the Newmark displacement (Wilson and Keefer, 1983). When selecting the predominant earthquake magnitude and distance, it is advisable to consider the range of values in the vicinity of the site and perform the ground failure analysis accordingly. This would yield a range in ground failure hazard from which recommendations appropriate to the specific project can be made. Grid values for predominant earthquake magnitude and distance should **not** be interpolated at the site location, because these parameters are not continuous functions.

A preferred method of using the probabilistic seismic hazard model and the “simplified Seed-Idriss method” of assessing liquefaction hazard is to apply magnitude scaling probabilistically while calculating peak ground acceleration for alluvium. The result is a “magnitude-weighted” ground motion (liquefaction opportunity) map that can be used directly in the calculation of the cyclic stress ratio threshold for liquefaction and for estimating the factor of safety against liquefaction (Youd and Idriss, 1997). This can provide a better estimate of liquefaction hazard than use of predominate magnitude described above, because all magnitudes contributing to the estimate are used to weight the probabilistic calculation of peak ground acceleration (Real and others, 2000). Thus, large distant earthquakes that occur less frequently but contribute *more* to the liquefaction hazard are appropriately accounted for.

Figure 3.5 shows the magnitude-weighted alluvial PGA based on Idriss’ weighting function (Youd and Idriss, 1997). It is important to note that the values obtained from this map are pseudo-accelerations and should be used in the formula for factor of safety without any magnitude-scaling (a factor of 1) applied.

MOUNTAIN VIEW 7.5-MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

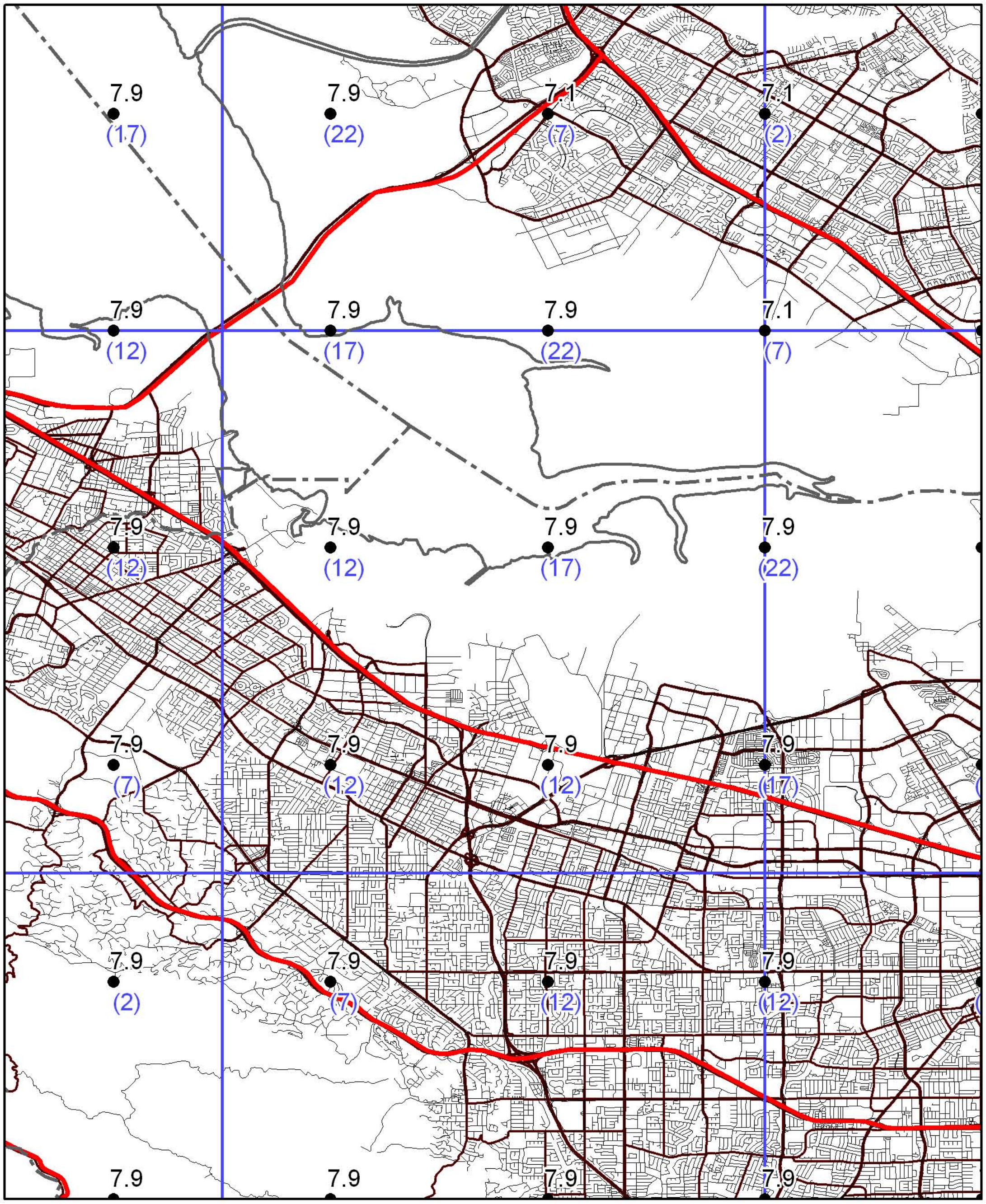
10% EXCEEDENCE IN 50 YEARS PEAK GROUND ACCELERATION

1998

PREDOMINANT EARTHQUAKE

Magnitude (Mw)

[Distance (km)]



Base map from GDT

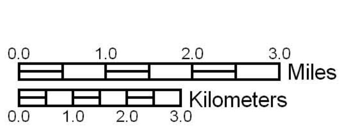


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Figure 3.4

MOUNTAIN VIEW 7.5-MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDENCE IN 50 YEARS MAGNITUDE WEIGHTED PSEUDO-PEAK ACCELERATION (g)

1998

LIQUEFACTION OPPORTUNITY

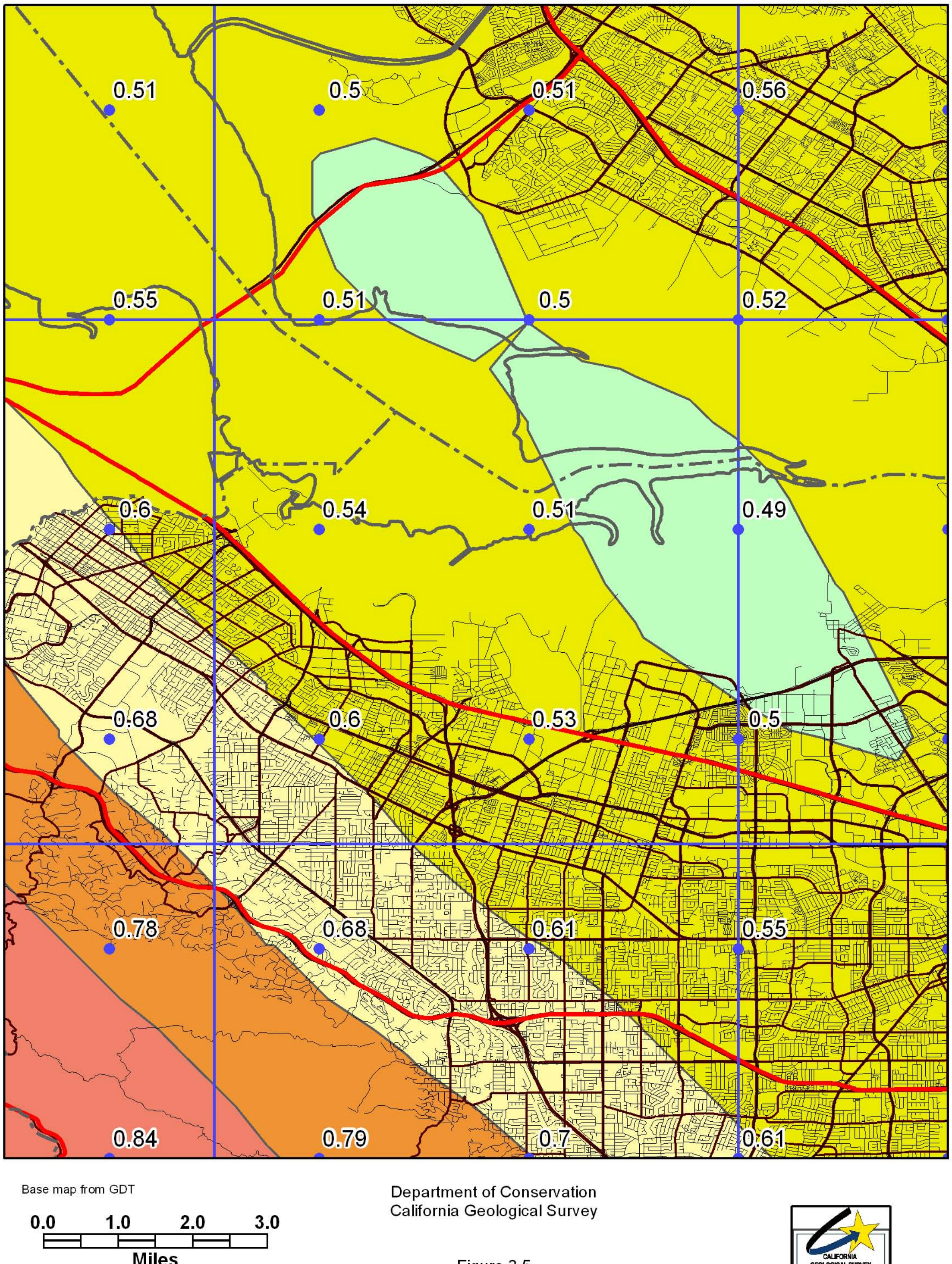

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Figure 3.5

USE AND LIMITATIONS

The statewide map of seismic hazard has been developed using regional information and is ***not appropriate for site specific structural design applications***. Use of the ground motion maps prepared at larger scale is limited to estimating earthquake loading conditions for preliminary assessment of ground failure at a specific location. We recommend consideration of site-specific analyses before deciding on the sole use of these maps for several reasons.

1. The seismogenic sources used to generate the peak ground accelerations were digitized from the 1:750,000-scale fault activity map of Jennings (1994). Uncertainties in fault location are estimated to be about 1 to 2 kilometers (Petersen and others, 1996). Therefore, differences in the location of calculated hazard values may also differ by a similar amount. At a specific location, however, the log-linear attenuation of ground motion with distance renders hazard estimates less sensitive to uncertainties in source location.

2. The hazard was calculated on a grid at sites separated by about 5 km (0.05 degrees). Therefore, the calculated hazard may be located a couple kilometers away from the site. We have provided shaded contours on the maps to indicate regional trends of the hazard model. However, the contours only show regional trends that may not be apparent from points on a single map. Differences of up to 2 km have been observed between contours and individual ground acceleration values. *We recommend that the user interpolate PGA between the grid point values rather than simply using the shaded contours*.

3. Uncertainties in the hazard values have been estimated to be about +/- 50 percent of the ground motion value at two standard deviations (Cramer and others, 1996).

4. Not all active faults in California are included in this model. For example, faults that do not have documented slip rates are not included in the source model. Scientific research may identify active faults that have not been previously recognized. Therefore, future versions of the hazard model may include other faults and omit faults that are currently considered.

5. A map of the predominant earthquake magnitude and distance is provided from the deaggregation of the probabilistic seismic hazard model. However, it is important to recognize that a site may have more than one earthquake that contributes significantly to the hazard. Therefore, in some cases earthquakes other than the predominant earthquake should also be considered.

Because of its simplicity, it is likely that the SPPV method (DOC, 1997) will be widely used to estimate earthquake shaking loading conditions for the evaluation of ground failure hazards. It should be kept in mind that ground motions at a given distance from an earthquake will vary depending on site-specific characteristics such as geology, soil properties, and topography, which may not have been adequately accounted for in the regional hazard analysis. Although this variance is represented to some degree by the recorded ground motions that form the basis of the hazard model used to produce Figures 3.1, 3.2, and 3.3, extreme deviations can occur. More sophisticated methods that take into account other factors that may be present at the site (site amplification, basin effects, near source effects, etc.) should be employed as warranted. The decision to use the SPPV method with ground motions derived from Figures 3.1, 3.2, or 3.3 should be based on careful consideration of the above limitations, the geotechnical and seismological aspects of the project setting, and the "importance" or sensitivity of the proposed building with regard to occupant safety.

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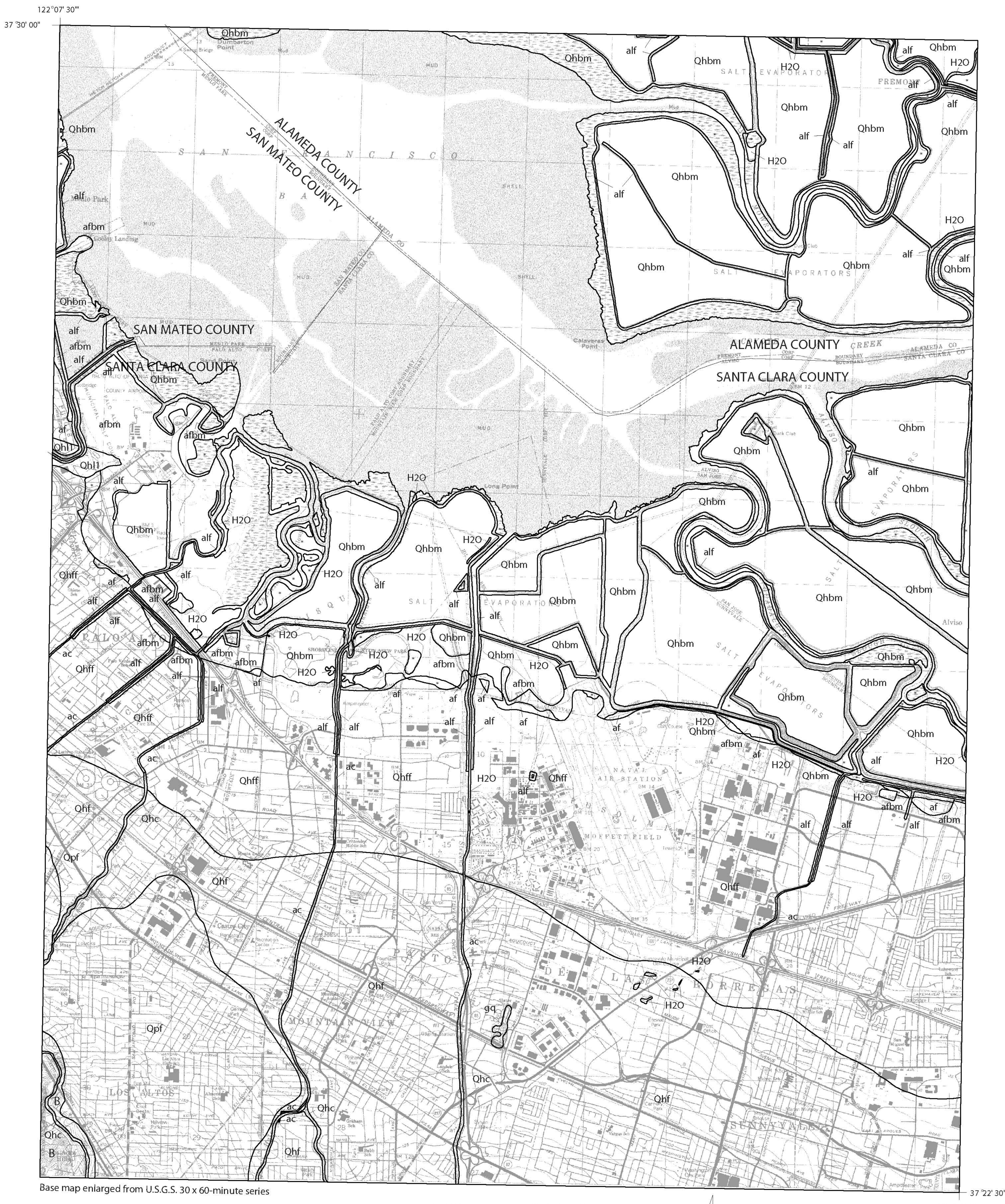


Base map enlarged from U.S.G.S. 30 x 60-minute series

MOUNTAIN VIEW QUADRANGLE

SCALE

N

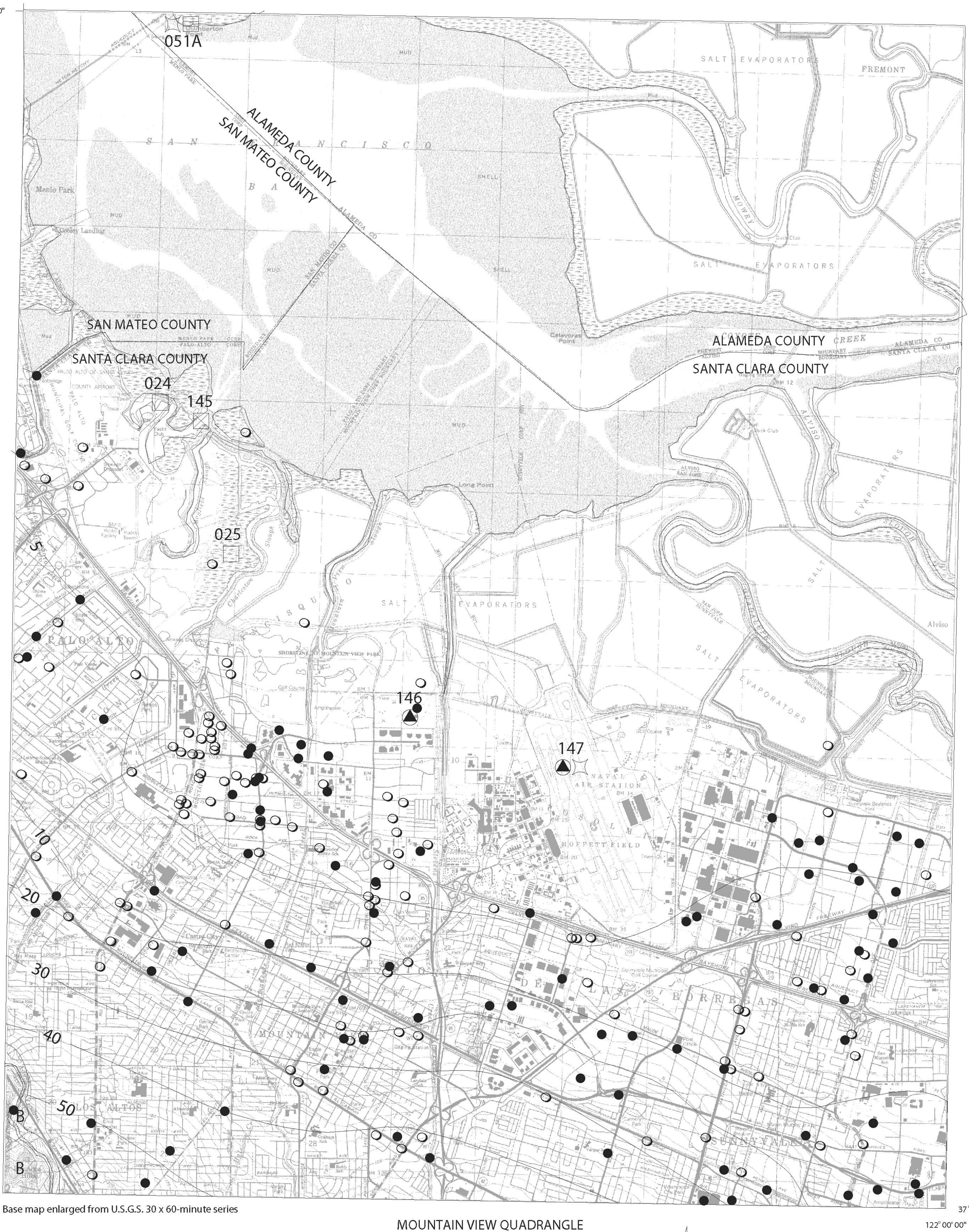
• Qhbm

B = Pre-Quaternary bedrock (Santa Clara Formation).

See "Bedrock and Surficial Geology" in Section 1 of report for descriptions of units.

Plate 1.1. Quaternary geologic map of the Mountain View 7.5-Minute Quadrangle, California. See text for explanation of units. Modified from Knudsen and others (2000).

122° 07' 30"
37° 30' 00"



Base map enlarged from U.S.G.S. 30 x 60-minute series

37° 22' 30"
122° 00' 00"

MOUNTAIN VIEW QUADRANGLE

SCALE

N

Historical Ground Failures (From Knudsen and others, 2000)

- x Location of multiple ground effects. (See corresponding symbols)
- Ground settlement
- Disturbed well
- Miscellaneous effects
- Absence of ground failure noted
- Ground cracks
- 147 Number assigned to ground failure site (adapted from Youd and Hoose (1978) and Tinsley and others (1998) by Knudsen and others (2000))
- 50 Depth to ground water, in feet
- Geotechnical borings used in liquefaction evaluation
- Ground-water level data provided by the Santa Clara Valley Water District
- B Bedrock (Santa Clara Formation)

Plate 1.2 Historical liquefaction sites, depth to historically high ground water, and locations of boreholes used in this study, Mountain View 7.5-Minute Quadrangle, California.

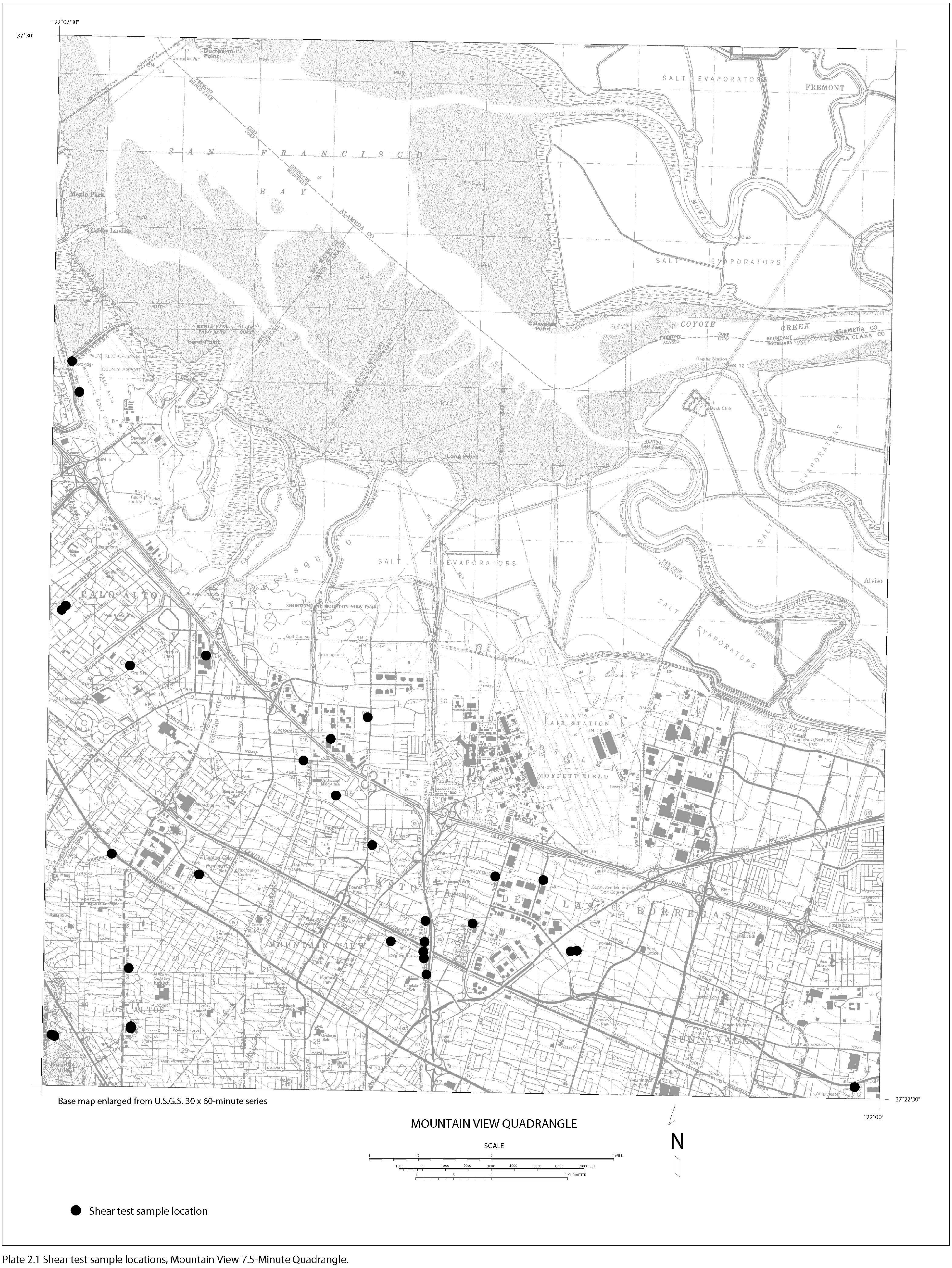


Plate 2.1 Shear test sample locations, Mountain View 7.5-Minute Quadrangle.