SEISMIC HAZARD ZONE REPORT 119

SEISMIC HAZARD ZONE REPORT FOR THE ALTAMONT 7.5-MINUTE QUADRANGLE, ALAMEDA COUNTY, CALIFORNIA

2009

DEPARTMENT OF CONSERVATION
California Geological Survey

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Seismic Hazard Zone Maps, Seismic Hazard Zone Reports, and related information are available on the California Geological Survey's (CGS) Internet page: http://www.consrv.ca.gov/cgs/shzp/Pages/Index.aspx.

The maps and reports are also available for reference at CGS offices in Sacramento, Menlo Park, and Los Angeles at the addresses presented below.

Paper copies of Official Seismic Hazard Zone Maps are available for purchase from:

BPS Reprographic Services
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The *Seismic Hazard Zone Report* documents the methods and data used to construct the *Seismic Hazard Zone Map* for each 7.5-minute quadrangle evaluated by CGS. The information should be particularly helpful to site investigators and local government reviewers of geotechnical reports. **NOTE:** *Seismic Hazard Zone Reports* are **not** available through BPS Reprographic Services.

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TABLE OF CONTENTS

FIGURES

TABLES

PLATES

Release and Revision History: Seismic Hazard Zone Map and Evaluation Report of the Altamont Quadrangle, SHZR 119	
August 27, 2008	Release of Preliminary Seismic Hazard Zone Map
September 2, 2008	Posting of evaluation report on CGS website
January 2009	Minor editorial revisions to Section 1 and Section 2.
January 2009	Minor change in Landslide Zone; SE1/4, Sec. 21, T.2S., R.3E.,
February 27, 2009	Release of Official Seismic Hazard Zone Map and Report.

EXECUTIVE SUMMARY

This report summarizes the methods and sources of information used to prepare the Seismic Hazard Zone Map for the Altamont 7.5-Minute Quadrangle, Alameda County, California. The topographic quadrangle map, which covers approximately 59 square miles at a scale of 1 inch = 2,000 feet (1:24000), displays the boundaries of preliminary *Zones of Required Investigation* for liquefaction and earthquake-induced landslides. The area subject to seismic hazard mapping includes part of the City of Livermore east of the City Civic Center complex.

About nine of the 20 square miles of valley floor within the Altamont quadrangle are designated *Zones of Required Investigation* for liquefaction hazard. Geologic mapping and subsurface logs of geotechnical test holes drilled in alluviated areas indicate the widespread presence of near-surface soil layers composed of saturated, loose sandy and silty sediments. Downhole soil tests and laboratory testing indicate that such soils generally have a moderate to high likelihood of liquefying, given the level of strong ground motions expected for this region.

About 14 of the 40 square miles of upland area within the Altamont Quadrangle are designated *Zones of Required Investigation* for earthquake-induced landslide hazard. Although the zones appear throughout the upland areas of the quadrangle, most are concentrated in the northeast, southeast, and southwest parts of the quadrangle, where slopes are generally steeper and/or rock strengths are generally weaker. In addition, numerous historically active landslides, including two of the largest mapped in the quadrangle, occur along the trace of the active Greenville Fault.

Seismic hazard maps are prepared by the California Geological Survey (CGS) using geographic information system (GIS) technology, which allows the manipulation of three-dimensional data. Information analyzed in these studies includes topography, surface and subsurface geology, borehole log data, recorded groundwater levels, existing landslide features, slope gradient, rock-strength measurements, geologic structure, and probabilistic earthquake shaking estimates. Earthquake ground 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. Calculations used in the seismic hazard evaluation of the Altamont Quadrangle were based on an earthquake of Moment Magnitude range of 6.6 to 7.0 with a Modal Distance of 3 to 15 kilometers.

City, county, and state agencies are required by the California Seismic Hazards Mapping Act to use the seismic hazard zone maps in their land-use planning and permitting processes. They must withhold building permits for sites being developed within *Zones of Required Investigation* 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 of real property within these zones to disclose that fact at the time such property is sold.

THE CALIFORNIA SEISMIC HAZARDS MAPPING PROGRAM

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the State Geologist to prepare maps that delineate seismic hazard zones. The purpose of the Act is to reduce the threat to public safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. City, county, 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 adopted by the California State Mining and Geology Board (SMGB) (DOC, 1997). The text of this report is online 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, the SMGB adopted initial criteria for delineating seismic hazard zones to promote uniform and effective statewide implementation of the Act. These initial criteria, which were published in 1992 as California Geological Survey (CGS) Special Publication 118, were revised in 2004. They provide detailed standards for mapping regional liquefaction and landslide hazards. The Act also directed the State Geologist 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 groundwater 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 is available on online at: http://gmw.consrv.ca.gov/shmp/webdocs/sp118_revised.pdf.

This Seismic Hazard Zone Report summarizes the development of the *Preliminary Seismic Hazard Zone Map* for the Altamont 7.5-Minute Quadrangle. The process of zonation for liquefaction hazard involves an evaluation of Quaternary geologic maps, groundwater level records, and subsurface geotechnical data. The process of zonation for earthquake-induced landslide hazard incorporates evaluations of earthquake loading, existing landslides, slope gradient, rock strength, and geologic structure. A statewide *Earthquake Shaking Potential Map*, based on probabilistic seismic hazard analysis (PSHA), has been prepared so that uniformly generated ground motion parameters (peak ground acceleration, mode magnitude, mode distance) are applied to all CGS liquefaction and earthquake-induced landslide hazard assessments.

SECTION 1:
EVALUATION REPORT FOR LIQUEFACTION HAZARD

in the

ALTAMONT 7.5-MINUTE QUADRANGLE,
ALAMEDA COUNTY, CALIFORNIA

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DEPARTMENT OF CONSERVATION
CALIFORNIA GEOLOGICAL SURVEY

INTRODUCTION

Background

The Seismic Hazards Mapping Act of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California State Geologist to compile maps that identify *Seismic Hazard Zones* consistent with requirements and priorities established by the California State Mining and Geology Board (SMGB) (California Department of Conservation, 1997). The text of the guidelines is available online at: http://www.conservation.ca.gov/cgs/shzp/webdocs/sp117.pdf. The Act requires that site-specific geotechnical investigations be performed for most urban development projects situated within seismic hazard zones before lead agencies can issue the building permit. The Act also requires sellers of real property within these zones to disclose that fact at the time such property is sold.

Following the release of the SMGB Guidelines, local government agencies in the Los Angeles metropolitan region sought more definitive guidance in the review of geotechnical investigations addressing liquefaction hazard. 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 (Southern California Earthquake Center, 2002). This text is also online at: http://www.scec.org/.

This section of the evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils in the Altamont 7.5-Minute Quadrangle. Section 2 (addressing earthquake-induced landslide hazard) and Section 3 (addressing ground shaking potential) complete the evaluation report, which is one of a series that summarizes seismic hazard zone mapping by CGS in developing areas of the state where there is potential for strong ground motion (Smith, 1996). Additional information on seismic hazards zone mapping in California can be accessed on CGS's web page: http://gmw.consrv.ca.gov/shmp/

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.

Localities most susceptible to liquefaction-induced damage are underlain by loose, water-saturated, granular sediment within 40 feet of the ground surface. These geological and groundwater conditions are widespread in the San Francisco Bay Area, most notably in some densely populated valley regions and alluviated floodplains. 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, including areas within the Altamont Quadrangle.

Methodology

CGS's evaluation of liquefaction potential and preparation of seismic hazard zone maps require the collection, compilation, and analysis of various geotechnical information and map data. The data are processed into a series of geographic information system (GIS) layers using commercially available software. In brief, project geologists complete the following principal tasks to generate a seismic hazard zone map for liquefaction potential:

- Compile digital geologic maps to delineate the spatial distribution of Quaternary sedimentary deposits

- Collect geotechnical borehole log data from public agencies and engineering geologic consultants.

- Enter boring log data into the GIS.

- Generate digital cross sections to evaluate the vertical and lateral extent of Quaternary deposits and their lithologic and engineering properties.

- Evaluate and digitize historically highest groundwater levels in areas containing Quaternary deposits.

- Characterize expected earthquake ground motion, also referred to as ground-shaking opportunity (see Section 3 of this report).

- Perform quantitative analyses of geotechnical and ground motion data to assess the liquefaction potential of Quaternary deposits.

- Synthesize, analyze, and interpret above data to create maps delineating *Zones of Required Investigation* according to criteria adopted by the SMGB (DOC, 2004).

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 Altamont Quadrangle consist mainly of alluviated valleys, floodplains, and canyons. CGS's liquefaction hazard evaluations are based on information on earthquake ground shaking, surface and subsurface lithology, geotechnical soil properties, and groundwater depth, which is gathered from various 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 groundwater, 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.

This section of the report is presented in two parts. Part I addresses the geographic and geologic setting of the study area while Part II documents the data and parameters used to evaluate liquefaction hazard and to delineate *Zones of Required Investigation* in the Altamont 7.5-Minute Quadrangle.

PART I: GEOGRAPHIC AND GEOLOGIC SETTING

PHYSIOGRAPHY

Location

The Altamont 7.5-minute quadrangle covers an area of approximately 60 square miles in eastern Alameda County. The center of the quadrangle is about 35 miles east of downtown Oakland. The quadrangle encompasses the eastern quarter of Livermore Valley. The City of Livermore, which partially lies in the west-central portion of the map area, is the only incorporated city within the quadrangle. The Lawrence Livermore National Laboratory occupies about a square mile near the east-central margin of the Livermore Valley.

The primary transportation route in the map area is the west-trending Interstate Highway 580. Additional access is provided by a network of paved county and private roads in developed areas and by fire roads and trails in undeveloped areas. Other notable roads outside the City of Livermore include Patterson Pass Road and Tesla Road, which follows Arroyo Seco through the Altamont Hills. Principal secondary north-trending roads include Vasco Road, which crosses the Livermore Valley, and Mines Road, which follows Arroyo Mocho.

Land Use

Land use in the Altamont Quadrangle historically was dominated by viticulture in valley areas and cattle grazing in the surrounding hills. However, in the last several decades competition for land use in the eastern part of Livermore Valley has increased substantially as urban development, mainly in the form of home construction, has continued to expand beyond the original boundaries of Livermore. The undeveloped area remaining on the valley floor is limited to land north of Dalton Avenue, east of Greenville Road, and south of Tesla Road.

Topography

Approximately two-thirds of the map area is occupied by foothills of the Diablo Range, a part of the Coast Ranges Geomorphic Province. The axis of the Diablo Range is aligned roughly parallel to the northwest-trending Greenville Fault, which diagonally traverses the quadrangle from the southeast corner to the northwest corner and forms the eastern boundary of Livermore Valley. The landscape of the uplands consists of moderately sloping, smooth, rounded hills and ridge crests in the northwest, northeast and east-central regions of the quadrangle; steep to very steep, sharp crested mountainous terrain in the southeast, highly dissected mountainous terrain with sharp-crested ridges in the southwest; and in the south-central portion of the quadrangle, by a triangular-shaped, flat-topped ridge with moderate slopes. The west-central portion of the map area is occupied by the eastern end of the Livermore Valley, which consists of a very gently sloping alluvial plain flanked on the east, northeast, and southeast by elevated alluvial fan and terrace surfaces dissected by modern streams.

The drainage divide between the San Francisco Bay and San Joaquin Delta runs through the Altamont Hills in the northeast corner of the quadrangle. Major streams in the southern part of the map area include Arroyo Mocho, Dry Creek, and Arroyo Seco, which flow north and west into Livermore Valley and eventually to San Francisco Bay. Mountain House Creek and Altamont Creek originate in the hills in the northeast corner of the map area. Altamont Creek flows south and west into Livermore Valley and Mountain House Creek flows eastward toward the San Joaquin Valley. Elevations within the quadrangle range from about 2140 feet on an unnamed ridge near the southeast corner of the quadrangle, to less than 500 feet at the west side of Livermore Valley near the central western edge of the quadrangle.

GEOLOGY

Geologic units that generally are susceptible to liquefaction are late Quaternary alluvial and fluvial sedimentary deposits and artificial fill. To evaluate the areal and vertical distribution of Quaternary deposits in the Altamont Quadrangle, geologic maps of the San Francisco Bay Area showing Quaternary deposits (Knudsen and others, 2000) and bedrock units (Graymer and others, unpublished) were obtained from the U.S. Geological Survey in digital form. The GIS maps and layers covering the Altamont quadrangle were combined, with minor modifications along the bedrock/Quaternary contact, to form a single, 1:24,000-scale *geologic materials map*. 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 susceptibility and prepare the Seismic Hazard Zone Map.

Air photos and limited field reconnaissance were used to validate minor modifications to bedrock/Quaternary contacts and to confirm the location of geologic contacts, observe properties of near-surface deposits, and characterize the surface expression of individual geologic units.

Bedrock Units

Although bedrock units are not generally considered subject to liquefaction, they are briefly described in this section because the composition and texture of sediments that accumulate in lowland basins such as the Livermore Valley are governed in large part by the lithology of older rocks exposed in surrounding highlands.

Bedrock exposed in the Altamont Quadrangle has been divided by Graymer and others (1996) into three stratigraphic assemblages that lie within fault-bounded blocks. These assemblages are believed to have originated in separate depositional basins or in different parts of large basins that were later juxtaposed by large offsets on strike-slip and dip-slip faults during Tertiary time.

The oldest bedrock exposed in the stratigraphic assemblages in the Altamont Quadrangle consists of weakly to strongly metamorphosed, locally highly sheared rocks of the Jurassic to Cretaceous Franciscan Complex and sandstone, siltstone, shale, and graywacke of the Cretaceous Great Valley sequence. These units are unconformably overlain in some of the assemblages by Eocene to Miocene marine and brackish water sandstone, siltstone, and claystone belonging to the Tesla Formation, Cierbo Sandstone, and Neroly Sandstone. In turn, these units are overlain in some of the assemblages by Miocene and Pliocene non-marine sandstone, siltstone, and conglomerate of the Green Valley/Tassajara Formation, silt, sand, and gravels of the Oro Loma Formation, and Plio-Pleistocene cobble conglomerate, sandstone, and siltstone of the Livermore Gravels. A more detailed description of the bedrock units is presented in Section 2 of this report, *Evaluation Report for Earthquake-Induced Landslide Hazard*.

Quaternary Sedimentary Deposits

Roughly, one third of the Altamont Quadrangle is covered by Quaternary alluvial sediment shed from the foothills of the surrounding Diablo Range. Knudsen and others (2000) divided such deposits exposed within the quadrangle into eight mappable units (Plate 1.1). The Quaternary geologic mapping methods described by Knudsen and others (2000) include interpretation of topographic maps, aerial photographs, and soil surveys, as well as examination of 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. 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.

Geologic Unit	Knudsen and others (2000)	Graymer and others, unpublished Stockton 100k	Sowers, unpublished Livermore Quadrangle	Wentworth and others (1999)	CGS GIS database
artificial fill	af	af	af	af	af
Latest Holocene alluvial deposits, undifferentiated	Qhay	--	Qhay/Qhi	--	--
Holocene alluvial fan deposits	Qhf	--	Qhfy	Qhf, Qhfp	Qhf
Holocene alluvial fan deposits, fine grained facies	Qhff	--	Qhff	--	Qhff
Late Pleistocene to Holocene alluvial fan deposits	Qf	--	Qf	--	Qf
Late Pleistocene to Holocene stream terrace deposits	Qt	--	Qt	--	Qt
Late Pleistocene alluvial fan deposits	Qpf	Qpaf	Qpf	Qpf	Qpf
Early to middle Pleistocene undifferentiated alluvial deposits	Qoa	Qpaf/Qpoaf	Qoa	Qpa	Qoa

Table 1.1. Correlation chart of Quaternary stratigraphic nomenclatures for geologic units in the Altamont Quadrangle by previous earlier mappers working in the San Francisco Bay Area.

Note: CGS has adopted the nomenclature of Knudsen and others (2000) for this study.

Older Quaternary Units

Early to middle Pleistocene alluvium (undifferentiated Qoa) is mapped along the base of the hills adjacent to the upstream portions of Arroyo Mocho and Arroyo Seco. Remnants of late Pleistocene stream terrace deposits (Qpt) are found at the outside edges of the flood plain adjacent to the upstream portion of Arroyo Mocho at the south central boundary of the map area. Large areas of late Pleistocene alluvial fan deposits (Qpf) are mapped at the base of the hills near the center of the quadrangle.

Young Quaternary Units

Latest Pleistocene to Holocene alluvium (undifferentiated Qa) is mapped in long narrow bands in the upland valleys of the hills throughout the quadrangle. Small areas of late Pleistocene to Holocene stream terrace deposits (Qt) are mapped in the vicinity of the down stream portion of Arroyo Seco at the western central boundary of the quadrangle. Large areas of late Pleistocene to Holocene alluvial fan deposits (Qf) are mapped in the western half of the Altamont quadrangle.

Small areas of Holocene alluvium (undifferentiated Qha) are mapped in long, narrow bands in the hills in the southern half of the map area as well as in the northwest corner of the map area. Holocene stream terrace deposits (Qht) and latest Holocene stream terrace deposits (Qhty) are mapped adjacent to Arroyo Mocho in the southwestern corner of the map area. Holocene alluvial fan (Qhf) deposits cover the floor of the Livermore Valley, at the central western edge of the map area and, in the northwest portion of the valley, grade into Holocene alluvial fan deposits, fine facies (Qhff).

Modern stream channel deposits (Qhc), defined as fluvial deposits within active, natural stream channels (Knudsen and others, 2000) are mapped along Arroyo Mocho and virtually the entire length of Arroyo Seco. To accommodate larger flows in the winter months, the down stream end of Arroyo Seco has been engineered within concrete-lined structures and is mapped as artificial channel (ac). Small areas of artificial fill (af) associated with infrastructure such as highways and rail lines, and other construction projects, are mapped throughout the quadrangle.

Structure

The Altamont Quadrangle lies in a tectonically active region associated with movement along the boundary of the Pacific and North American plates. The two plates are moving past each other in a right lateral sense at the rate of about 4.8 centimeters per year (Petersen and others, 1996). At the latitude of the San Francisco Bay area, about three-fourths of this relative movement is accommodated by shearing that is distributed across a broad, complex belt marked by major northwest-trending faults, including the San Andreas, Hayward, and Calaveras, along with many parallel secondary faults such as the Greenville, Green Valley, and San Ramon-Concord. Differential strike-slip movement among these faults locally generates thrust faulting, folding, and related structures throughout this tectonic belt, including the area encompassed by the Altamont Quadrangle. From the Livermore Valley region north through the Diablo Range, this intense zone of deformation is referred to by Unruh and Sawyer (1997) as the Mt. Diablo fold and thrust belt. The Livermore Valley is a synclinal basin formed by such tectonism within the Mt. Diablo fold and thrust belt. It is bounded on the east by the Greenville Fault and on the west by the Calaveras Fault. The basin is also bounded on the southeast by the westerly-trending Las Positas Fault and on the southwest by hills lying above the northeast-dipping Verona Thrust Fault. The northern edge of the basin is bounded by the westerly-trending Mocho Fault (Unruh and Sawyer, 1997).

Holocene active faults extend through or are contained within the Altamont Quadrangle: these include the Greenville and the North and South Las Positas faults. The Greenville Fault, which forms the eastern boundary of Livermore Valley, crosses the approximate center of the quadrangle from the northwest to the southeast corners. The northwest-trending Las Positas and South Las Positas Faults flank the west-southwest- to east-northeast-trending, triangular shaped uplands in the south-central portion of the quadrangle.

The California Geological Survey, under the Alquist-Priolo Earthquake Fault Zoning Act, has identified some of the strands of these faults as “Earthquake Fault Zones” (Hart, 1981a). The Greenville Earthquake Fault Zone within the Altamont quadrangle is marked by a roughly 1-km-wide zone of discontinuous surface fault traces. The mapped extents of the Las Positas and

South Las Positas Earthquake Fault Zones fall entirely within the Altamont quadrangle. These faults form a groundwater barrier with shallower groundwater on the south side where the Las Positas Fault crosses Holocene alluvium (Qhf) west of the intersection of Tesla Road and Vasco Road (Herd, 1977).

The two other named faults in the quadrangle are the Carnegie Fault and a short strand of the Tesla Fault. Both faults are interpreted as high angle dip-slip and are currently truncated on their west ends by the Greenville Fault. There are also a number of unnamed northeast-trending faults, particularly in the northeast quarter of the quadrangle that are parallel or subparallel to the Greenville Fault. These appear to be high angle, thrust and reverse faults that reflect compression directed parallel to plate motion (Graymer and others, 1996).

ENGINEERING GEOLOGY

Groundwater

Saturated soil conditions are required for liquefaction to occur, and the susceptibility of a soil to liquefaction varies with the depth to groundwater. Saturation reduces the effective normal stress of near-surface sediment, thereby increasing the likelihood of earthquake-induced liquefaction (Youd, 1973). CGS compiles and interprets current and historical groundwater data to identify areas presently or potentially characterized by near-surface, saturated soils. For purposes of seismic hazard zonation, "near-surface" means groundwater level at a depth less than 40 feet.

During the course of this study, groundwater conditions were investigated for alluvial basins within the Altamont Quadrangle. The evaluation was based on first-encountered, unconfined water noted in geotechnical borehole logs acquired from the City of Livermore, Alameda County, and the California Department of Transportation (CalTrans). Additional data were also collected from the State Water Resources Control Board (SWRCB), and the Alameda County Flood Control and Water Conservation District Zone 7 Water Agency (Zone 7 Water Agency). Natural hydrologic processes and human activities can cause groundwater levels to fluctuate over time. Therefore, it is impossible to predict depths to saturated soils when future earthquakes strike. One method of addressing time-variable depth to saturated soils is to establish an anticipated high groundwater level based on historical groundwater data. CGS thus develops contour maps to depict depths to groundwater that are either currently near-surface or could return to near-surface levels within a land-use planning interval of 50 years (Plate 1.2). Therefore, it is important to note that the contour lines on Plate 1.2 do not generally represent present-day conditions as usually presented on typical groundwater contour maps. Also, keep in mind that large-scale, artificial recharge programs, such as the ones already established in Livermore Valley, could significantly affect future groundwater levels. In such cases, CGS will periodically evaluate their impact relative to liquefaction potential and revise official seismic hazard zone maps if necessary.

According to a recent study of sequence stratigraphy in the Livermore basin prepared by Figures and Ehman (2004) for the Zone 7 Water Agency, “The current subsurface geologic model of the Livermore basin was developed by the California Department of Water Resources (DWR) in the early 1970’s (California Department of Water Resources 1966, 1974). A large amount of surface and subsurface data has been collected since the DWR model was developed, but there has been no reevaluation or modification of the basin geologic model." The Zone 7 Water Agency, which is responsible for managing both surface and ground water supplies in the Livermore Valley basin, has been monitoring ground water levels for over 30 years. Well data cover the period from 1900 through 2005 and show significant fluctuation in overall water depth during that period. It is the practice of the Zone 7 Water Agency to use water levels measured in 1983-1984 as the historical maximum ground water depth for basin management purposes (Jones & Stokes, 2006). CGS reviewed the ground water elevation map prepared by Zone 7 Water Agency with respect to ground water elevations recorded on geotechnical boring logs collected for this liquefaction study, as well as well data from the State Water Resources Control Board (SWRCB), and Zone 7 Water Agency. CGS notes that overall groundwater elevations from individual boring/well data agree with historical high ground water elevations on the map prepared by the Zone 7 Water Agency depicting 1983-1984 water elevations. CGS digitized ground water elevation contours from the map produced by the Zone 7 Water Agency and constructed a 10-meter grid of ground water elevation values from the ground water contours on the figure. CGS assigned a ground water elevation value to each boring in the study area by reading the value off of the ground water elevation grid at the location of each boring. In order to convert ground water *elevation* to ground water *depth*, CGS subtracted the ground water elevation at each boring location from the ground surface elevation at the top of the boring, and thus created a contour map based on the depth of groundwater from the surface.

The boundary of the Zone 7 Water Agency map of historical high ground water elevations roughly coincides with the base of the foothills that surround the Livermore Valley. Borings located in the foothills and in alluviated upland valleys fall outside the ground water basin boundary and are not included in the historical high ground water elevation grid described above. For borings located in areas outside the ground water basin boundary as defined by the Zone 7 Water Agency, we were guided by data and analysis of shallow ground water as recorded on geotechnical boring logs, where available.

Historical high ground water depths in the Altamont Quadrangle range from approximately 2 to 87 feet (Plate 1.2). Historical high ground water depths become shallower toward the basin boundary. Depth to ground water for many of the borings located in the foothills outside of the ground water basin are greater than 60 feet.

Soil Testing

A total of sixty-two borehole logs were collected for this investigation from the files of Alameda County, CalTrans, and the City of Livermore. Information from these borehole logs was entered into a CGS geotechnical GIS database (Plate 1.2). As stated above, soils that are particularly susceptible to liquefaction are late Quaternary alluvial and fluvial sedimentary deposits and non-engineered artificial fill. Deposits that contain saturated loose sandy and silty soils are the most susceptible to liquefaction. Lithologic descriptions and soil test results reported in geotechnical borehole logs provide valuable information regarding subsurface geology, groundwater levels, and the engineering characteristics of sedimentary deposits. Furthermore, the application of GIS technology greatly enhances the ability to synthesize and manipulate large volumes of geotechnical data. For example, Table 1.2 characterizes the various depositional environments present in the Livermore Valley by showing proportions of the different subsurface sediment types penetrated by the boreholes and recorded on logs.

Of critical value in liquefaction evaluations are logs that report the results of downhole standard penetration tests in alluvial materials. The standard penetration test (SPT) provides a standardized measure of the penetration resistance of soil and, therefore, is commonly used as a tool to index soil density. For this reason, SPT results are also a critical component of the Seed-Idriss Simplified Procedure, a method used by CGS and commonly by the geotechnical community to quantitatively analyze liquefaction potential of sandy and silty material (see Liquefaction Analysis in Part II of this section). SPT is an *in-situ* test that is based on counting the number of blows required to drive a split-spoon sampler (1.375-inch inside diameter) one foot into the soil. The driving force is provided by dropping a 140-pound hammer weight a distance of 30 inches. The SPT method is formally defined and specified by the American Society for Testing and Materials in test method D1586 (American Society for Testing and Materials, 2004). 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 D1586-99), are converted to SPT-equivalent blow counts, if reliable conversions can be made. The actual and converted SPT blow counts are normalized to a common reference, effective-overburden pressure of one 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 $(N_1)_{60}$.

Geotechnical borehole logs provide information on lithologic and engineering characteristics of Quaternary deposits in and around Livermore Valley. The characteristics reported in Table 1.2 summarize conditions in the Altamont 7.5-Minute Quadrangle while the characteristics reported in Table 1.3 summarize conditions in the entire Livermore Valley (Dublin, Livermore and Altamont 7.5-Minute Quadrangles). The Seed-Idriss Simplified Procedure for liquefaction evaluation was developed primarily 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 significant liquefaction because the high permeability of these soils presumably would allow the dissipation of pore pressures before liquefaction could occur.

However, liquefaction in gravel has been reported during earthquakes and recent laboratory studies have confirmed the phenomena (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 artificially high. They are likely to lead to over-estimation of the density of the soil and, therefore, result in an underestimation of the liquefaction susceptibility. To identify potentially liquefiable units where blow counts appear to have been affected by gravel content, correlations are made with boreholes in the same unit where the tests do not appear to have been affected by gravel content.

Of the sixty-two geotechnical borehole logs analyzed in this study (Plate 1.2), most include blow-count data from SPTs or penetration tests that allow reasonable blow count conversions to SPT-equivalent values. Few of the borehole logs collected, however, include all of the information (e.g. soil density, moisture content, sieve analysis, etc.) required for an ideal analysis using the Seed-Idriss Simplified Procedure. For boreholes having acceptable penetration tests, liquefaction analysis is performed using recorded density, moisture, and sieve test values or averaged test values of similar materials.

Geologic Unit [1]	**Description**	**Total layer Thickness (ft)**	**Composition by Soil Type**
af	Artificial fill	12	Other 100%
Qhay	Latest Holocene alluvial deposits, undifferentiated	67	CL 74%; SC 23%; Other 3%
Qhf	Holocene alluvial fan deposits	192	CL 48%; SC 16%; Other 36%
Qhff	Holocene alluvial fan deposits, fine grained facies	64	CL 42%; SM 23%; SC 16%; Other 19%
Qf	Late Pleistocene to Holocene alluvial fan deposits	763	CL 41%; SC 12%; Other 47%
Qt	Latest Pleistocene to Holocene stream terrace deposits	24	CL-ML 66%; GM-SM 34%
Qpf	Late Pleistocene alluvial fan deposits	224	CL 50%; Other 50%
Qoa	Early to Late Pleistocene undifferentiated alluvial deposits,	14	SP 64%; GP 21%; ML 14%; Other 1%

Table 1.2. Summary of lithology types for Quaternary map units in the Altamont 7.5-Minute Quadrangle.

Notes: [1] See Table 1.1 for unit names listed above.

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	C[3]	Median	Min	Max	Number of Tests	Mean	C[3]	Median	Min	Max
af	Fine	0	-	-	-	-	-	0	-	-	-	-	-
	Coarse	0	-	-	-	-	-	0	-	-	-	-	-
Qhay	Fine	0	-	-	-	-	-	0	-	-	-	-	-
	Coarse	10	109.6	0.1	107.5	103.0	124.0	15	19.0	0.4	17.7	5.0	30.5
Qhf	Fine	16	113.0	0.1	113.5	100.0	124.2	26	22.0	0.6	18.5	7.9	67.9
	Coarse	4	104.3	0.1	103.5	95.0	115.0	4	28.3	0.3	25.8	19.9	41.6
Qhff	Fine	7	111.8	0.0	110.8	106.0	121.0	9	25.1	0.3	24.6	14.3	37.4
	Coarse	1	-	-	-	-	-	4	16.5	0.4	16.2	9.3	24.2
Qha	Fine	0	-	-	-	-	-	0	-	-	-	-	-
	Coarse	0	-	-	-	-	-	0	-	-	-	-	-
Qf	Fine	63	110.8	0.1	111.0	91.4	124.5	127	35.0	0.8	26.9	6.4	>99
	Coarse	8	115.1	0.1	116.4	105.1	125.0	24	43.4	0.7	36.7	6.2	>99
Qt	Fine	0	-	-	-	-	-	2	13.7	0.5	13.7	9.2	18.2
	Coarse	0	-	-	-	-	-	2	50.6	0.3	50.6	41.2	60
Qpf	Fine	8	112.3	0.1	109.0	103.0	131.0	40	42.0	0.6	40.7	10.2	>99
	Coarse	1	-	-	-	-	-	8	46.2	1.0	26.2	13.8	>99
Qoa	Fine	3	116.0	0.0	117.0	114.0	117.0	0	-	-	-	-	-
	Coarse	0	-	-	-	-	-	0	-	-	-	-	-

Table 1.3. Summary of geotechnical characteristics for Quaternary units in the entire Livermore Valley.

1 See Table 1.1 for names of the units listed here.

2 Fine soils (silt and clay) contain a greater percentage passing the #200 sieve (<.074 mm); coarse soils (sand and gravel) contain a greater percentage not passing the #200 sieve.

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

PART II: LIQUEFACTION HAZARD ASSESSMENT

MAPPING TECHNIQUES

Liquefaction may occur in water-saturated sediment during moderate to great earthquakes. When this occurs, 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, whereas liquefaction opportunity is a function of potential seismic ground shaking intensity.

The method applied in this study to evaluate liquefaction potential is similar to that Tinsley and others (1985) used to map liquefaction hazards in the Los Angeles region. These investigators, in turn, applied a combination of the techniques developed by Seed and others (1983) and Youd and Perkins (1978). CGS's method combines geotechnical analyses, geologic and hydrologic mapping, and probabilistic earthquake shaking estimates employing criteria adopted by the SMGB (California Department of Conservation, 2004).

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 from the surface 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 specifically addressed in this investigation. Soil characteristics that result in higher measured penetration resistances generally indicate lower liquefaction susceptibility. In summary, soils that lack resistance (susceptible soils) typically are saturated, loose, and granular. Soils resistant to liquefaction include all soil types that are dry, cohesive, or sufficiently dense.

CGS's inventory of areas containing soils susceptible to liquefaction begins with evaluation of geologic maps and historical occurrences, cross-sections, geotechnical test data, geomorphology, and groundwater hydrology. Soil properties and soil conditions such as type, age, texture, color, and consistency, along with historical depths to groundwater are used to identify, characterize, and correlate susceptible soils. Because Quaternary geologic mapping is based on observable similarities between soil units, liquefaction susceptibility maps typically are often similar to Quaternary geologic maps, depending on local groundwater levels.

Much of the surface area of the Livermore Valley floor is covered by an indeterminate thickness of Holocene sediment. Holocene sediment in the Livermore Valley is composed primarily of clays and silts with interbedded layers of loose sands and gravels. Locally, the composition of some geologic units differs from average basin-wide composition for the same unit. For example, Holocene alluvial fan deposits (Qhf), Holocene alluvial fan fine facies (Qhff) deposits and early to Late Pleistocene undifferentiated alluvial deposits in the Altamont Quadrangle have a higher percentage of sand and/or gravel than the basin-wide average. Late Pleistocene to Holocene stream terrace deposits (Qt) and late Pleistocene alluvial fan deposits (Qhf) have a higher percentage of clay than the basin-wide average.

GROUND SHAKING OPPORTUNITY

Ground shaking opportunity is a calculated measure of the intensity and duration of strong ground motion normally expressed in terms of *peak horizontal ground acceleration* (PGA). Ground motion calculations used by CGS exclusively for regional liquefaction zonation assessments are currently based on the *2002 California Probabilistic Seismic Hazard Assessment (PSHA) Model* developed jointly by the CGS and USGS (Frankel and others, 2002; Cao and others, 2003). The model is set to calculate ground motion hazard at a 10 percent in 50 years exceedance level. CGS calculations of probabilistic peak ground acceleration deviate slightly from the model by incorporating additional programming that weights each earthquake's estimated ground shaking contribution by a scaling factor derived as a function of its magnitude. The function is simply the inverse of the liquefaction threshold-scaling factor used in the Seed-Idriss Simplified Procedure, the quantitative analysis method used by CGS to generate seismic hazard zone maps for liquefaction (see Liquefaction Analysis). The result is a magnitude-weighted, pseudo-PGA that CGS refers to as *Liquefaction Opportunity* (LOP). LOP is then used to calculate cyclic stress ratio (CSR), the seismic load imposed on a soil column at a particular site. This approach provides an improved estimate of liquefaction hazard in a probabilistic sense, ensuring that large, infrequent, distant earthquakes, as well as smaller, more frequent, nearby events are appropriately accounted for (Real and others, 2000).

Calculated LOP for alluviated areas in the Altamont Quadrangle range from 0.33 to 0.38 g (see Section 3, Figure 3.3). These values were obtained by applying the NEHRP corrections (FEMA, 1994; Table 3.1) to the firm-rock LOP values derived from the CGS liquefaction application of the 2002 probabilistic ground motion model. The calculations are based on an earthquake of Moment Magnitude of 6.6 with a Modal Distance of 3 to 15 kilometers.

LIQUEFACTION ANALYSIS

CGS performs quantitative analysis of geotechnical data to evaluate liquefaction potential using an in-house developed computer program based on 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; Youd and others, 2001). The procedure first calculates the resistance to liquefaction of each soil layer penetrated at a test-drilling site, expressed in terms of cyclic resistance ratio (CRR). The calculations are based on standard penetration test (SPT) results, groundwater level, soil density, grain-size analysis, moisture content, soil type, and sample depth. The procedure then estimates the factor of safety relative to liquefaction hazard for each of the soil layers logged at the site by dividing their calculated CRR by the pseudo PGA-derived CSR described in the previous section.

CGS uses a factor of safety (FS) of 1.0 or less, where CSR equals or exceeds CRR, to indicate the presence of potentially liquefiable soil layers. The 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. In addition to FS, consideration is given to the proximity to stream channels, which accounts in a general way for factors such as sloping ground or free face that contribute to severity of liquefaction-related ground deformation.

ZONATION CRITERIA: LIQUEFACTION

Areas underlain by materials susceptible to liquefaction during an earthquake are included in liquefaction zones using criteria developed by the Seismic Hazards Mapping Act Advisory Committee and adopted by the SMGB (California Department of Conservation, 2004). Under those guideline criteria, liquefaction zones are areas meeting one or more of the following:

- Areas known to have experienced liquefaction during historical earthquakes
- All areas of uncompacted artificial fill that are saturated, nearly saturated, or may be expected to become saturated
- Areas where sufficient existing geotechnical data and analyses indicate that the soils are potentially liquefiable
- Areas where existing subsurface data are not sufficient for quantitative evaluation of liquefaction hazard. Within such areas, zones may be delineated by geologic criteria as follows:
- Areas containing soil deposits of late Holocene age (current river channels and their historic 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 anticipated depth to saturated soil is less than 40 feet; or
- 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 anticipated depth to saturated soil is less than 30 feet; or

- 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 anticipated depth to saturated soil is less than 20 feet.

Application of the above criteria allows compilation of *Zones of Required Investigation* for liquefaction hazard, which are useful for preliminary evaluations, general land-use planning and delineation of special studies zones (Youd, 1991).

DELINEATION OF SEISMIC HAZARD ZONES: LIQUEFACTION

Upon completion of a liquefaction hazard evaluation within a project quadrangle, CGS applies the above criteria to its findings in order to delineate *Zones of Required Investigation*. Following is a description of the criteria-based factors that governed the construction of the Seismic Hazard Zone map for the Altamont Quadrangle.

Areas of Past Liquefaction

There is no documentation of historical surface liquefaction or paleoseismic liquefaction in the Altamont Quadrangle.

Artificial Fills

Non-engineered fill placements are often composed of uncompacted, silty or sandy material and, therefore, are generally considered to have a high potential for liquefaction when saturated. No significant placements of non-engineered artificial fill, other than aggregate extraction waste piles, were identified in the study area. Conversely, significant amounts of engineered artificial fill, which by definition are designed to resist liquefaction, have been used in the construction of river levees and elevated freeways in Livermore Valley. In such cases, seismic hazard zonation for liquefaction does not depend on the fill, but on soil properties and groundwater levels in underlying strata.

Areas with Sufficient Existing Geotechnical Data

Most of the 62 plus geotechnical logs evaluated for this study represent boreholes drilled into the floor of Livermore Valley. Collectively, these logs provided the level of subsurface information needed to conduct a regional assessment of liquefaction susceptibility with a reasonable level of certainty. Analysis of blow count values and other soil property measurements reported in the logs indicate that most of the boreholes penetrated one or more layers of liquefiable material where seismic stress ratio (CSR) is greater than the soils' seismic resistance ratio (CRR). Accordingly, all areas covered by Holocene alluvium that is saturated within 40 feet of the surface are designated *Zones of Required Investigation*.

The majority of the boundary for the *Zones of Required Investigation* is defined by the contact between Holocene and late Pleistocene deposits and/or bedrock, and extends along base of the foothills that surrounds the Livermore Valley. Although the groundwater conditions in the center of the Livermore Valley have been complicated by the ongoing gravel mining operations, groundwater increases toward the center of the valley. Analysis of blow count values and other soil property measurements reported in the logs of boreholes drilled inside the zone boundary indicate that most penetrated one or more layers of liquefiable material where seismic stress ratio (CSR) is greater than the soils' seismic resistance ratio (CRR). Accordingly, all areas covered by Holocene alluvium that is saturated within 40 feet of the surface are designated *Zones of Required Investigation*.

Areas with Insufficient Existing Geotechnical Data

Adequate geotechnical borehole information is lacking for most parts of canyons in the hilly to mountainous terrain surrounding Livermore Valley. These, along with other isolated deposits of Holocene and undifferentiated Holocene alluvium (Qha), Holocene alluvial fan (Qhf) in upland areas, as well as the narrow bands of Holocene deposits in the Altamont Quadrangle associated with active stream channels (ac, Qhty, Qhc, Qha, Qhf) are young, loose, granular and saturated. Those conditions, along with the strong ground motions expected for the region, combine to form a sufficient basis for designating areas underlain by these types of deposits as *Zones of Required Investigation* for liquefaction.

ACKNOWLEDGMENTS

The author wishes to thank Matt Katen and Tom Rooze at Alameda County Flood Control and Water Conservation District Zone 7 Water Agency, as well as the planning and building department staff at the City of Livermore. The author also appreciates the assistance and support provided by CGS staff; particularly, Keith Knudsen, Teri Mcguire, Barbara Wanish, Candace Hill, Bob Moscovitz, Rick Wilson, Marvin Woods, Elise Mattison, Tully Simoni, and Jackie Bott.

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SECTION 2:

EVALUATION REPORT FOR EARTHQUAKE-INDUCED LANDSLIDE HAZARD

In the

ALTAMONT 7.5-MINUTE QUADRANGLE, ALAMEDA COUNTY, CALIFORNIA

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INTRODUCTION

Purpose

The Seismic Hazards Mapping Act of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California State Geologist to compile maps that identify *Seismic Hazard Zones* consistent with requirements and priorities established by the California State Mining and Geology Board (SMGB; California Department of Conservation, 1997). The text of the guidelines is available online at http://www.conservation.ca.gov/cgs/shzp/webdocs/sp117.pdf. The Act requires that site-specific geotechnical investigations be performed for most urban development projects situated within seismic hazard zones before lead agencies can issue the building permit. The Act also requires sellers of real property within these zones to disclose that fact at the time such property is sold.

Following the release of the SMGB Guidelines, local government agencies in the Los Angeles metropolitan region sought more definitive guidance in the review of geotechnical investigations addressing liquefaction hazard. 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 (Southern California Earthquake Center, 2002). This text is also online at: http://www.scec.org/

This report is one of a series that summarizes the preparation of seismic hazard zone maps within the state (Smith, 1996). This particular part of the report, Section II, summarizes seismic hazard zone mapping for earthquake-induced landslides in the Altamont 7.5-minute Quadrangle. Section 1, which addresses liquefaction hazard, and Section 3, which addresses earthquake-shaking hazard, complete the report. Additional information on seismic hazard zone mapping in California can be accessed online at: http://gmw.consrv.ca.gov/shmp/.

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 lifeline infrastructure. Areas that are most susceptible to earthquake-induced landslides are steep slopes in poorly cemented or highly fractured rocks, sloped 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 the upland areas within the Altamont Quadrangle.

Methodology

The delineation 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 collected or generated to provide an up-to-date representation of slope gradient and slope aspect in the study area.

- Geologic mapping was compiled to provide an accurate representation of the spatial distribution of geologic materials in the study area. In addition, a map of existing landslides, whether or not triggered by earthquakes, 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 compiled and 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 (Newmark, 1965), in order to generate a map showing 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 subsequently adopted by the State Mining and Geology Board (California Department of Conservation, 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 run out areas 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.

This section of the report is presented in two parts. Part I addresses the natural setting of the area covered by the Altamont Quadrangle, namely the physiographic, geologic and engineering geology conditions. Part II covers the preparation of landslide hazard potential and landslide zone maps.

PART I: GEOGRAPHIC AND GEOLOGIC SETTING

PHYSIOGRAPHY

Location

The Altamont 7.5-minute quadrangle covers an area of approximately 60 square miles in eastern Alameda County. The center of the quadrangle is about 35 miles east of downtown Oakland. The quadrangle encompasses the eastern quarter of Livermore Valley. The City of Livermore, which partially lies in the west-central portion of the map area, is the only incorporated city within the quadrangle. The Lawrence Livermore National Laboratory occupies about a square mile near the east-central margin of the Livermore Valley.

The primary transportation route in the map area is the west-trending Interstate Highway 580. Additional access is provided by a network of paved county and private roads in developed areas and by fire roads and trails in undeveloped areas. Other notable roads outside the City of Livermore include Patterson Pass Road and Tesla Road, which follows Arroyo Seco through the Altamont Hills. Principal secondary north-trending roads include Vasco Road, which crosses the Livermore Valley, and Mines Road, which follows Arroyo Mocho.

Land Use

Land use in the Altamont Quadrangle historically was dominated by viticulture in valley areas and cattle grazing in the surrounding hills. However, in the last several decades competition for land use in the eastern part of Livermore Valley has increased substantially as urban development, mainly in the form of home construction, has continued to expand beyond the original boundaries of Livermore. The undeveloped area remaining on the valley floor is limited to land north of Dalton Avenue, east of Greenville Road, and south of Tesla Road.

Topography

Approximately two-thirds of the map area is occupied by foothills of the Diablo Range, a part of the Coast Ranges Geomorphic Province. The axis of the Diablo Range is aligned roughly parallel to the northwest-trending Greenville Fault, which diagonally traverses the quadrangle from the southeast corner to the northwest corner and forms the eastern boundary of Livermore Valley. The landscape of the uplands consists of moderately sloping, smooth, rounded hills and ridge crests in the northwest, northeast and east-central regions of the quadrangle; steep to very steep, sharp-crested mountainous terrain in the southeast, highly dissected mountainous terrain with sharp-crested ridges in the southwest; and in the south-central portion of the quadrangle, by a triangular-shaped, flat-topped ridge with moderate slopes. The west-central portion of the map area is occupied by the eastern end of the Livermore Valley, which consists of a very gently sloping alluvial plain flanked on the east, northeast, and southeast by elevated alluvial fan and terrace surfaces dissected by modern streams.

The drainage divide between the San Francisco Bay and San Joaquin Delta runs through the Altamont Hills in the northeast corner of the quadrangle. Major streams in the southern part of the map area include Arroyo Mocho, Dry Creek, and Arroyo Seco, which flow north and west into Livermore Valley and eventually to San Francisco Bay. Mountain House Creek and Altamont Creek originate in the hills in the northeast corner of the map area. Altamont Creek flows south and west into Livermore Valley and Mountain House Creek flows eastward toward the San Joaquin Valley. Elevations within the quadrangle range from about 2140 feet on an unnamed ridge near the southeast corner of the quadrangle, to less than 500 feet at the west side of Livermore Valley near the central western edge of the quadrangle.

Digital Topography

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 in the form of a digital topographic map. A Level-2 digital elevation model (DEM) was obtained from the U.S. Geological Survey (USGS) for the Altamont Quadrangle. The USGS prepared this DEM in 1993 from 7.5-minute quadrangle topographic contours based on 1953 aerial photography and from 1955 plane table surveys. It has a 10-meter horizontal resolution 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 was used to prepare the zone map is described in Section II of this report.

GEOLOGY

The primary source of 1:24,000-scale bedrock geologic mapping used in the slope stability evaluation of the Altamont Quadrangle was the digital database of geologic mapping of the Stockton 1:100,000-scale quadrangle by Graymer (unpublished). Additional information on the bedrock geology was obtained from Graymer and others (1996) and Lamarre and others (1990). Quaternary sedimentary units were compiled from Knudsen and others (2000) at a scale of 1:24,000. The Quaternary units are discussed in more detail in Section 1 of this report and are summarized on Plate1.1.

CGS geologists digitally merged the bedrock geologic units from Graymer (unpublished) and the Quaternary surficial map units from Knudsen and others (2000). Contacts between surficial and bedrock units on the merged map were then modified in some areas by air-photo interpretation to resolve differences between the two maps. Geologic field reconnaissance was performed to assist in adjusting geologic contacts and to review the lithology and structure of the various rock units. In addition, the relationship of the rock units to the development and abundance of landslides was noted.

Modifications made to the geologic maps produced a GIS "digital worksheet" layer generally referred to as a *Geologic Materials* map. The map layer was further digitally processed to generate a rock strength map, one of the several critical GIS layers needed to construct the *Seismic Hazard Zone Map for Earthquake-Induced Landslides* for the Altamont Quadrangle.

Bedrock Units

The bedrock geology of Alameda County has been divided by Graymer and others (1996) into nine individual stratigraphic assemblages, each lying within a discrete, fault-bounded block. Three of these, Assemblages V, VI and XI, partially fall within the Altamont Quadrangle (Plate 2.1). The concept of individual fault-bounded stratigraphic assemblages in the San Francisco Bay Area was introduced by Jones and Curtis (1991) and then defined further by Graymer and others (1994). These investigators believe that the individual stratigraphic assemblages originated in separate depositional basins or in different parts of large basins that were later juxtaposed by large offsets on strike-slip and dip-slip faults during Tertiary time.

In Alameda County, the oldest rocks exposed in the fault-bounded assemblages belong to two slightly to highly deformed Mesozoic rock complexes: the Jurassic Coast Range ophiolite and overlying Cretaceous Great Valley sequence, and the Jurassic to Cretaceous Franciscan Complex (Graymer and others, 1996). The Coast Range ophiolite is not exposed in the Altamont quadrangle, but elsewhere in the County is composed of serpentinite, gabbro, diabase, and basalt, which represent accreted and deformed remnants of oceanic crust and overlying arc volcanic rocks. The Great Valley sequence consists of a thick sequence of interbedded sandstone and shale deposited on the ocean floor by turbidity currents (Graymer and others, 1996). Rocks of the Franciscan Complex are composed of sheared and metamorphosed mudstone, siltstone, sandstone, greywacke, conglomerate, chert, and minor pillow basalt, which represent Jurassic oceanic crust and pelagic deposits overlain by Late Jurassic to Late Cretaceous turbidites (Graymer and others, 1996). The Franciscan Complex was subducted beneath the Coast Range ophiolite during Cretaceous time and, therefore, the contact between the two complexes is everywhere faulted (Bailey and others, 1964) and the Franciscan Complex presumably underlies the entire county (Graymer and others, 1996).

The Mesozoic rocks in Alameda County are overlain with angular unconformably by Tertiary marine and non-marine strata (Graymer and others, 1996). The following is a summary of bedrock map units exposed in the Altamont Quadrangle based on the work of Graymer and others (1996).

Assemblage V

Assemblage V underlies the entire area of the quadrangle west of the Greenville Fault, covering about two-thirds of the quadrangle, including Livermore Valley, where rocks of the assemblage have been buried beneath Quaternary sediments (Plate 2.1). Mesozoic rocks within Assemblage V include both the Franciscan Complex, which is exposed over a large area in the south-central part of the quadrangle, and the Great Valley sequence, which forms a small band along the west side of the Greenville Fault at the northern boundary of the quadrangle. Rocks of the Jurassic to Late Cretaceous Eylar Mountain terrane of the Franciscan Complex (KJfe) are the oldest rocks exposed in the quadrangle and consist of metamorphosed graywacke, argillite, limestone, basalt, serpentinite, and chert. The Eylar Mountain terrane forms steep to very steep, sharp-crested mountainous terrain, with higher relief and steeper slopes relative to the general topography in the region. Rocks of the Cretaceous Great Valley Sequence (Kslt) consist mainly of siltstone interbedded with minor shale, claystone and sandstone, forming moderately sloping, smooth rounded hills and ridges.

Tertiary rocks of Assemblage V include the late Miocene Cierbo Sandstone and Neroly Sandstone, and the Miocene/Pliocene Green Valley and Tassajara Formation. The Cierbo Sandstone (Tc) consists of massive marine sandstone beds with conglomerate near the base. The Neroly Sandstone (Tn) consists of massive marine sandstone beds with abundant clasts of volcanic rocks. The Neroly and Cierbo sandstone units crop out along the west side of Greenville Fault where they form moderately sloping, smooth rounded hills and ridges. The Green Valley and Tassajara Formation (Tgvt) is composed of non-marine sandstone, siltstone, and conglomerate and is exposed primarily south and east of the Lawrence Livermore National Laboratories (LLNL) facility as well as in the southwest corner of the quadrangle. This unit forms the moderately sloping, smooth-topped, triangular-shaped hills near LLNL and intricately dissected terrain with steep slopes in the southwest corner of the quadrangle.

The Pliocene-Pleistocene Livermore Gravels unit (QTl) is exposed only within Assemblage V. Material in this unit accumulated in shallow braided stream and alluvial-fan depositional environments and consists primarily of poorly to moderately consolidated, poorly bedded, cobble conglomerate, conglomeratic sandstone, and coarse-grained sandstone, with minor siltstone and claystone. Clasts are composed primarily of graywacke, chert, and metamorphic rocks likely derived from the Franciscan complex (Anderson and others, 1955; Sawyer, 1999). Livermore Gravel deposits are typically in angular unconformity, or in fault contact, with the underlying Green Valley and Tassajara Formation. The Livermore Gravels characteristically form intricately dissected (high to very high drainage density), sharp-crested ridges with steep to very steep slopes, or low knolls and small hills on the floor of Livermore Valley.

Assemblage VI

Assemblage VI includes rocks exposed in the area east of the Greenville Fault and north of the Carnegie Fault in the east-central and northeast region of the quadrangle (Plate 2.1). About two-thirds of the exposed portion of Assemblage VI consists of the Great Valley Sequence, mainly in the northeast part of the block. The Great Valley Sequence consists primarily of sandstone (Kd) and interbedded sandstone and shale (Kcus). The remaining third of Assemblage VI within the quadrangle consists of massive marine sandstone and basal conglomerate of the late Miocene Cierbo Sandstone (Tc). Much of the terrain underlain by this assemblage consists of smooth rounded hills with moderate slope, drainage density, and relief. These characteristics progressively increase toward the southeast. Slopes are typically convex in plan and profile and dip slopes are typically less steep than anti-dip slopes where ridge crests parallel the strike of bedrock units.

Assemblage XI

Assemblage XI covers a fault-bounded wedge-shaped area of less than two square miles near the southeast corner of the quadrangle. It is bounded on the north by the Carnegie Fault, on the west by the Greenville Fault, and on the south by the Tesla Fault. About one tenth of the assemblage area is underlain by the Cretaceous Great Valley Sequence, which locally consists of dark shale and thin sandstone beds of the Early Cretaceous Horsetown Formation (Kkh), and the Late Cretaceous unnamed sandstone and shale (Ksu), unnamed sandstone (Ksus), and unnamed shale (Ksuh). Spherical weathering of these units is common in outcrop.

The other nine tenths of this assemblage consists of Tertiary sedimentary deposits including the Eocene marine to brackish water Tesla Formation (Tte), composed of white and buff sandstone, siltstone, anauxitic claystone, and carbonaceous shale with minor coal; the marine sandstones of the late Miocene Cierbo (Tc) and Neroly sandstone (Tn); and the Pliocene Oro Loma Formation (Tol), composed of poorly consolidated reddish silt, sand, and gravel.

Characteristic landforms associated with Assemblage XI are generally steep to locally very steep slopes, with greater relief and steeper slopes relative to the general topography in the region.

Slopes are generally concave in plan and profile topography. Dip slopes tend to be less steep than anti-dip slopes where ridge crests parallel the strike of bedrock units.

Quaternary Sedimentary Deposits

Roughly, one third of the Altamont Quadrangle is covered by Quaternary alluvial sediments that were eroded from surrounding hills, then transported and deposited into Livermore Valley. Within the Altamont Quadrangle, Knudsen and others (2000) have divided these deposits into eight mappable units, including Holocene and Pleistocene alluvium, alluvial fan, stream channel, and stream terrace deposits (see Section 1 and Plate 1.1 for descriptions and distribution of Quaternary units).

Structure

The Altamont Quadrangle falls within in a tectonically active region associated with movement along the boundary of the Pacific and North American plates. Stresses built up by plate motion are periodically released predominantly by strike slip movement along the San Andreas Fault system, which in the San Francisco Bay Area includes the San Andreas, Hayward, Calaveras, and Greenville faults. In turn, differential movement of these faults causes thrust faulting and folding of intervening rocks. Livermore Valley is a product of tectonism, formed as synclinal basin bounded on the west by the Calaveras Fault and on the east by the Greenville Fault. Basin rocks and sediments are also cut by several westerly-trending thrust faults.

Three major active faults are mapped in the Altamont quadrangle: the Greenville, Las Positas, and South Las Positas faults. The California Geological Survey, as required by the Alquist-Priolo Earthquake Fault Zoning Act, has delineated parts of these faults within the quadrangle as *Earthquake Fault Zones* (Smith, 1981a,b). The Greenville Fault diagonally crosses the approximate center of the quadrangle trending northwest (refer to Plate 2.1). It is a right lateral strike-slip fault (Hart, 1981a,b; Bryant and Cluett, 2002), which forms the boundary between Assemblages V on the west and Assemblages VI and XI on the east (Plate 2.1). North of Highway 580 minor surface fault rupturing associated with the January 1980 Livermore Valley earthquakes occurred along the Greenville fault.

The Las Positas and South Las Positas faults flank the triangular-shaped hills rising on the south and southeast of LLNL, with the Las Positas Fault on the north and the South Las Positas Fault on the south. The Las Positas Fault, as mapped by Herd (1977) and (Graymer and others, 1996), extends westward past the west boundary of the quadrangle and eastward to Greenville Fault. The South Las Positas Fault Earthquake Fault Zone consists of a single continuous trace. These faults are mapped as vertical, left lateral strike-slip, although Herd (1977) interpreted them both as being dip slip. Where it crosses Holocene alluvial fan deposits (Qhf), the Las Positas Fault forms groundwater barriers (Herd, 1977). Possible minor surface fault rupturing associated with the January 1980 Livermore Valley earthquakes were observed where this fault crosses Tesla, Mines, Vasco, and Greenville roads (Smith, 1981a,b).

Two other faults in the quadrangle are the Carnegie Fault and the Tesla Fault (Plate 2.1). The Carnegie Fault forms the boundary between Assemblage VI and XI. The Tesla Fault forms the boundary between Assemblage V and XI in the southeast corner of the quadrangle. Both are considered high-angle reverse faults truncated on their west ends by the Greenville Fault.

Landslide Inventory

Approximately two-thirds of the Altamont Quadrangle (about 40 square miles), representing that portion characterized by hilly to mountainous terrain, was evaluated for landslide occurrences. First, CGS staff prepared an inventory map of existing landslides in the quadrangle at a scale of 1:24,000 through field reconnaissance, analysis of stereo-paired aerial photographs (see "Air Photos" section in References) and review of previously published landslide mapping. Landslide distribution and characteristics from this inventory were compared to the previous landslide inventories of Majmundar (1991) and T.H. Nilsen (*in* Roberts and others, 1999), and compared with the previous landslide inventory maps and the geologic maps of Herd (1977) and Dibblee (1980), as these last two sources included a large number of landslides.

For each landslide included on the map, a number of characteristics (attributes) were compiled. These characteristics include the confidence of interpretation (definite, probable and questionable) and other properties, such as activity, thickness, and associated geologic unit(s). Landslides rated as definite and probable were carried into the landslide zone as described later in this report. Landslides rated as questionable were not carried into the zone map. The completed landslide map was digitized and the attributes were entered into a database. A small-scale version of this landslide inventory is included on Plate 2.1.

Approximately 500 landslides were identified in the landslide inventory of the Altamont Quadrangle, covering about 20% of the upland terrain within the quadrangle. The distribution and density of landslides mapped in the quadrangle (Plate 2.1) differ among the three assemblages, mainly as a function of areal distribution of various rock types, along with variations in rock strength, topography, and structure.

About 190 landslides cover about 10% of the upland area present within Assemblage V. Most of these slides occur on steep to very steep slopes underlain by the Livermore Gravels (QTl). About half, categorized as moderately large to large rock slides, occur on dip slopes with adverse bedding conditions. The majority of the other slope failures in Livermore Gravels are small, coalescing debris slides that occur along the steep inner gorge slopes. Most landslides mapped in areas of Assemblage V underlain by the Green Valley and Tassajara Formation are moderate to large rock slides with fewer small to moderate sizes debris slides on steep to very steep anti-dip slopes, indicating that slope gradient is the predominant controlling factor. Landslides were mapped along the inner gorges of Arroyo Seco tributaries in Franciscan Complex as moderate-size rock slides and fewer small debris slides. These slides do not appear to be dip slope failures, as the dip of strata generally greatly exceeds slope inclination and therefore, the controlling factor seems to be steep slopes.

About 240 landslides were identified, covering about 20% of the uplands in Assemblage VI (Plate 2.1). This assemblage is characterized by predominantly moderate-size landslides, although a few large slides exist. Landslides within Assemblage VI generally occur on moderate slopes typically composed of sandstone and shale of the Great Valley sequence (northern half of assemblage) and the Tertiary Cierbo Sandstone (southern half). Almost one-half of the landslides in Assemblage VI, including most of the largest mapped in the quadrangle, occur near the Greenville, Carnegie, and other faults. Approximately, one third of landslides occur on dip slopes characterized by adverse bedding conditions. Small rockslides and debris slides also commonly occur along steep inner gorge slopes near stream level.

Of the three assemblages mapped in the Altamont Quadrangle, Assemblage XI exhibits the greatest density of landslides. Here, the combined mapped extent of approximately 70 landslides cover about 60% of the two square-mile area in the quadrangle where rocks of Assemblage XI are exposed. About half of these landslides are classified as moderate to large rockslides, most of which occur in areas underlain by Tertiary units, mainly the Neroly Sandstone (Tn), Oro Loma Formation (Tol), Tesla Formation (Tte), and to a lesser degree the Cierbo Sandstone (Tc). Landslides occur on both dip and anti-dip slopes, but dips typically exceed the slope gradient on the dip slopes. Additionally, almost half of the landslides occur near the intersection of the Greenville and Carnegie faults. Based on these observations, proximity to major faults and presence of steep slopes appear to be the prominent causes of landslides within Assemblage XI.

ENGINEERING GEOLOGY

Geologic Material Strength

To evaluate the stability of geologic materials during earthquake shaking, the geologic map units described above are ranked and grouped according to shear strength and/or lithological similarities. Generally, the primary source for shear-strength measurements is the filed collection of geotechnical reports prepared by consultants available at a local government permitting department. Unfortunately, despite efforts to collect shear strength data from the cities of Livermore and Dublin, the County of Alameda and CalTrans, not enough data are available for the bedrock units identified in the Altamont Quadrangle geologic map. Consequently, shear-strength data from adjacent Dublin and Livermore quadrangles are used in the slope stability analysis (see Appendix A). Shear strength groups of Cretaceous rock units on the Niles and Hayward quadrangles that are similar in age, lithology and depositional environment to that of Altamont Quadrangle are also used as a basis in assigning strength groups. Furthermore, the percentage of area affected by slides for each rock unit was also considered in the strength ranking.

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

Existing Landslides

As discussed later in this report, the criteria for landslide zone mapping state that all existing landslides that are mapped as definite or probable are automatically included in the landslide zone of required investigation. Therefore, an evaluation of shear strength parameters for existing landslides is not necessary for the preparation of the zone map. However, in the interest of completeness for the material strength map, to provide relevant material strength information to project plan reviewers, and to allow for future revisions of our zone mapping procedures, we have collected and compiled shear strength data considered representative of existing landslides within the quadrangle

The strength characteristics of existing landslides (Qyls) must be based on tests of the materials along the landslide slip surface. Ideally, shear tests of slip surfaces formed in each mapped geologic unit would be used. However, this amount of information is rarely available. We collect and compile primarily “residual” strength parameters from laboratory tests of slip surface materials tested in direct shear or ring shear test equipment. Back-calculated strength parameters, if the calculations appear to have been performed appropriately, have also been included in our compilation. For the Altamont Quadrangle, strength parameters applicable to existing landslide planes were not available.

ALTAMONT QUADRANGLE						
SHEAR STRENGTH GROUPS						
	Formation Name	**Number Tests**	**Mean/Median Phi (deg)**	**Mean/Median Group Phi (deg)**	**No Data: Similar Lithology**	**Phi Values Used in Stability Analyses (deg)**
GROUP 1	**Great Valley Sequence (sandstone units)**			**32/35*** **	**Kcm, Kcus, Kd, Ksu, Ksus, Tc**	**32**
GROUP 2	**Great Valley Sequence (shale units), Franciscan complex**			**28/32*** **	**Kjfe, Kcu, Kkh, Kslt, Ksuh, Tn,**	**28**
	QTl	**36** **	**27/26**	**27/27**	**Tgvt, Qpf, Qpt, Qt, af**	
		5*	**31/27**			
	Qoa2	**6** **	**27/26**			
		7*	**29/28**			
	Qoa1	**14** **	**24/27**			
	Qf	**27***	**25/26**			
GROUP 3	**Qhf**	**25** **	**24/24**	**24/24**	**Tol, Tte, ac, Qhay, Qhc, Qht1, Qht2, Qhty**	**24**
		4*	**27/26**			
	Qha	**15** **	**24/21**			
	Qhff	**3** **	**23/23**			
		3*	**23/24**			
	Qht	**5** **	**23/25**			
Includes Shear Strength Data from: Dublin Quadrangle*, Livermore Quadrangle**, Niles/Hayward Quadrangle***.						

Table 2.1. Summary of the shear strength statistics for the Altamont Quadrangle.

SHEAR STRENGTH GROUPS FOR THE ALTAMONT 7.5-MINUTE QUADRANGLE		
GROUP 1	**GROUP 2**	**GROUP 3**
Kcm, Kcus, Kd, Ksu, Ksus, Tc	**Kjfe, Kcu, Kkh, Kslt, Ksuh, Tgvt, Tn, QTl, Qa, Qf, Qoa1, Qoa2, Qpf, Qpt, Qt, af**	**Tol, Tte, ac, Qha, Qhay, Qhc, Qhf, Qhff, Qht, Qht1, Qht2, Qhty**

Table 2.2. Summary of shear strength groups for the Altamont Quadrangle.

PART II: EARTHQUAKE-INDUCED LANDSLIDE HAZARD ASSESSMENT

GROUND SHAKING OPPORTUNITY

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 Altamont 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% probability of being exceeded in 50 years (Cao and others, 2003). The parameters used in the record selection are:

Modal Magnitude:	6.8
Modal Distance:	2.5 to 9.9 km
PGA:	0.49 to 0.54 g

The strong-motion record selected for the slope stability analysis in the Altamont Quadrangle is the Corralitos record from the 1989 magnitude 6.9 Loma Prieta earthquake (Shakal and others, 1989). This record had a source to recording site distance of 5.1 km and a peak ground acceleration (PGA) of 0.64. The selected strong-motion record was not scaled or otherwise modified prior to its use in the analysis.

LANDSLIDE 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 threshold yield accelerations of 0.086, 0.133 and 0.234 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 Altamont Quadrangle.

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 0.086g, Newmark displacement greater than 30 cm is indicated, and a HIGH hazard potential was assigned.

2. If the calculated yield acceleration fell between 0.086g and 0.133g, 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 0.133g and 0.234g, 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 0.234g, 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.

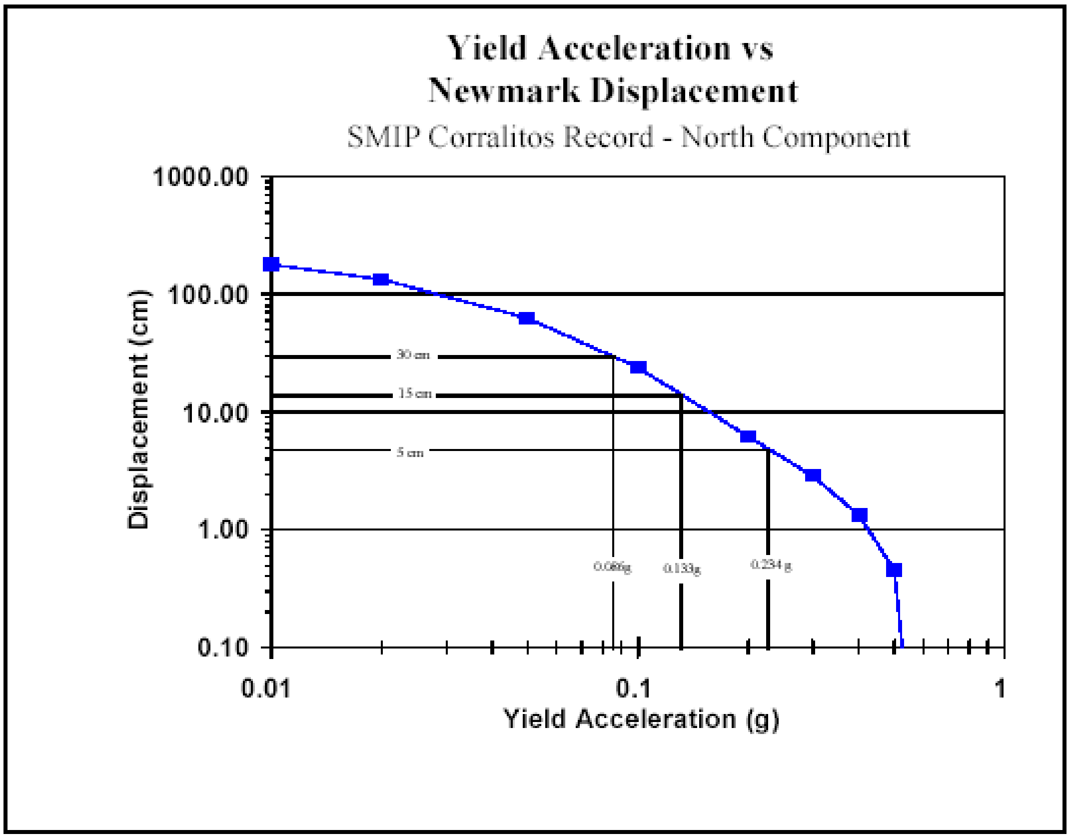

Figure 2.1. Yield acceleration vs. Newmark displacement for the Corralitos record of the 1989 Loma Prieta Earthquake.

Note: Record from California Strong Motion Instrumentation Program (CSMIP) Station 57007.

ALTAMONT QUADRANGLE HAZARD POTENTIAL MATRIX				
Geologic Material Strength Group (Average Phi) (deg)	HAZARD POTENTIAL (Percent Slope)			
	Very Low	Low	Moderate	High
1 (32)	0 to 39	40 to 47	48 to 51	>51
2 (28)	0 to 29	30 to 39	40 to 43	>43
3 (24)	0 to 20	21 to 29	30 to 35	>35

Table 2.3. Hazard potential matrix for earthquake-induced landslides in the Altamont Quadrangle.

Note: Values in the table show the range of slope gradient (expressed in percent) corresponding to calculated Newmark displacement ranges from the design earthquake for each material strength group.

ZONATION CRITERIA: EARTHQUAKE-INDUCED LANDSLIDES

Earthquake-induced landslide zones were delineated using criteria adopted by the California State Mining and Geology Board (California Department of Conservation, 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.

DELINEATION OF SEISMIC HAZARD ZONES: EARTHQUAKE-INDUCED LANDSLIDES

Upon completion of an earthquake-induced landslide hazard evaluation within a project quadrangle, CGS applies the above criteria to its findings in order to delineate *Zones of Required Investigation*. Following is a description of the criteria-based factors that governed the construction of the *Seismic Hazard Zone* map for the Altamont Quadrangle.

Existing Landslides

Existing landslides typically consist of disrupted soils and rock materials that are generally weaker than adjacent undisturbed rock and soil materials. Previous studies indicate that existing landslides can be reactivated by earthquake movements (Keefer, 1984). Earthquake-triggered movement of existing landslides is most pronounced in steep head scarp areas and at the toe of existing landslide deposits. Although reactivation of deep-seated landslide deposits is less common (Keefer, 1984), a significant number of deep-seated landslide movements have occurred during, or soon after, several recent earthquakes. Based on these observations, all existing landslides with a definite or probable confidence rating are included within the earthquake-induced landslide hazard zone.

Hazard Potential 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 five centimeters or greater. Areas with a Very Low hazard potential, indicating less than five 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:

Geologic Strength Group 3 is included for all slopes steeper than 20 degrees.

Geologic Strength Group 2 is included for all slopes steeper than 29 degrees.

Geologic Strength Group 1 is included for all slopes greater than 39 degrees.

This results in 21.7 percent of the quadrangle lying within the earthquake-induced landslide hazard zone for the Altamont Quadrangle.

ACKNOWLEDGMENTS

The authors thank the following individuals and organizations for their assistance in obtaining the data necessary to complete this project: Rob Barry and John Curless of DWR, and Mark Wiegers and Timothy Dawson of CGS for providing valuable insights on the geology and landsliding in the area during a field reconnaissance survey. The former also provided access to the DWR canal and pipeline rights-of-way. Mike Silva assisted in the grid overlaying. Terilee McGuire, Diane Vaughan, Lee Wallinder, and Bob Moskovitz provided GIS support. Barbara Wanish prepared the final landslide hazard zone maps and the graphic displays for this report. Candace Hill assisted in preparing the report for distribution to local government agencies.

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Google Earth Pro DigitalGlobe, 1-m resolution, 2006, covering Altamont Quadrangle, color, vertical.

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WAC Corporation, Inc. dated 4-24-84, Flight No. WAC84C, Photo Nos. 16-190 through 195, black and white, vertical, scale 1:24,000.

WAC Corporation, Inc. dated 3-28-02, Flight No. WAC-C-02CA, Photo Nos. 4-1 through 7, 4-28 through 35, 4-57 through 62, and 3-238 through 245, color, vertical, scale 1:24,000.

APPENDIX A: SOURCES OF ROCK STRENGTH DATA

SOURCE	**NUMBER OF TESTS SELECTED**
Dublin Quadrangle	46
Livermore Quadrangle	104
Total Number of Shear Tests	**150**

SECTION 3:

GROUND SHAKING ASSESSMENT

for the

ALTAMONT 7.5-MINUTE QUADRANGLE, ALAMEDA COUNTY, CALIFORNIA

using the

2002 Probabilistic Seismic Hazard Assessment Model

By

Charles R. Real

R.G.P. 968

and

Marvin Woods

P.G. 6876 C.E.G. 2438 C.H.G. 655

DEPARTMENT OF CONSERVATION
CALIFORNIA GEOLOGICAL SURVEY

INTRODUCTION

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation, 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 located within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines adopted by the California State Mining and Geology Board (CGS, 2008). The guidelines are available on the Internet at

http://gmw.consrv.ca.gov/shmp/webdocs/sp117.pdf

This section of the evaluation report summarizes the calculations of ground motions used to evaluate liquefaction and earthquake-induced landslide potential for zoning purposes. Included are ground motion 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 as a basis for comparing levels of ground motion determined by other methods with the statewide standard. Site ground motion levels from the 2002 seismic hazard model are also available interactively online:

http://eqint.cr.usgs.gov/deaggint/2002 or
http://www.consrv.ca.gov/cgs/rghm/pshamap/pshamain.html.

This section and Sections 1 and 2, which address 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 the California Geological Survey's Internet page: http://conservation.ca.gov/CGS/shzp.

2002 PROBABILISTIC SEISMIC HAZARD ANALYSIS MODEL

The estimated ground shaking is derived from the revised statewide Probabilistic Seismic Hazard Analysis (PSHA) model released cooperatively by the California Geological Survey and the U.S. Geological Survey (Cao et al., 2003; Frankel et al., 2002). This model replaces the previous ground-motion model of Peterson and others (1996) used in previous Official Seismic Hazard Zone Maps. Like the previous model, the 2002 model is the product of an extensive effort to obtain consensus within the scientific and engineering communities 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 2002 model improves the way energy is partitioned among fault types and source areas and significantly narrows the gap that has existed between the earlier model and historical recurrence rates of earthquakes in the M6.5 to M7.0 range.

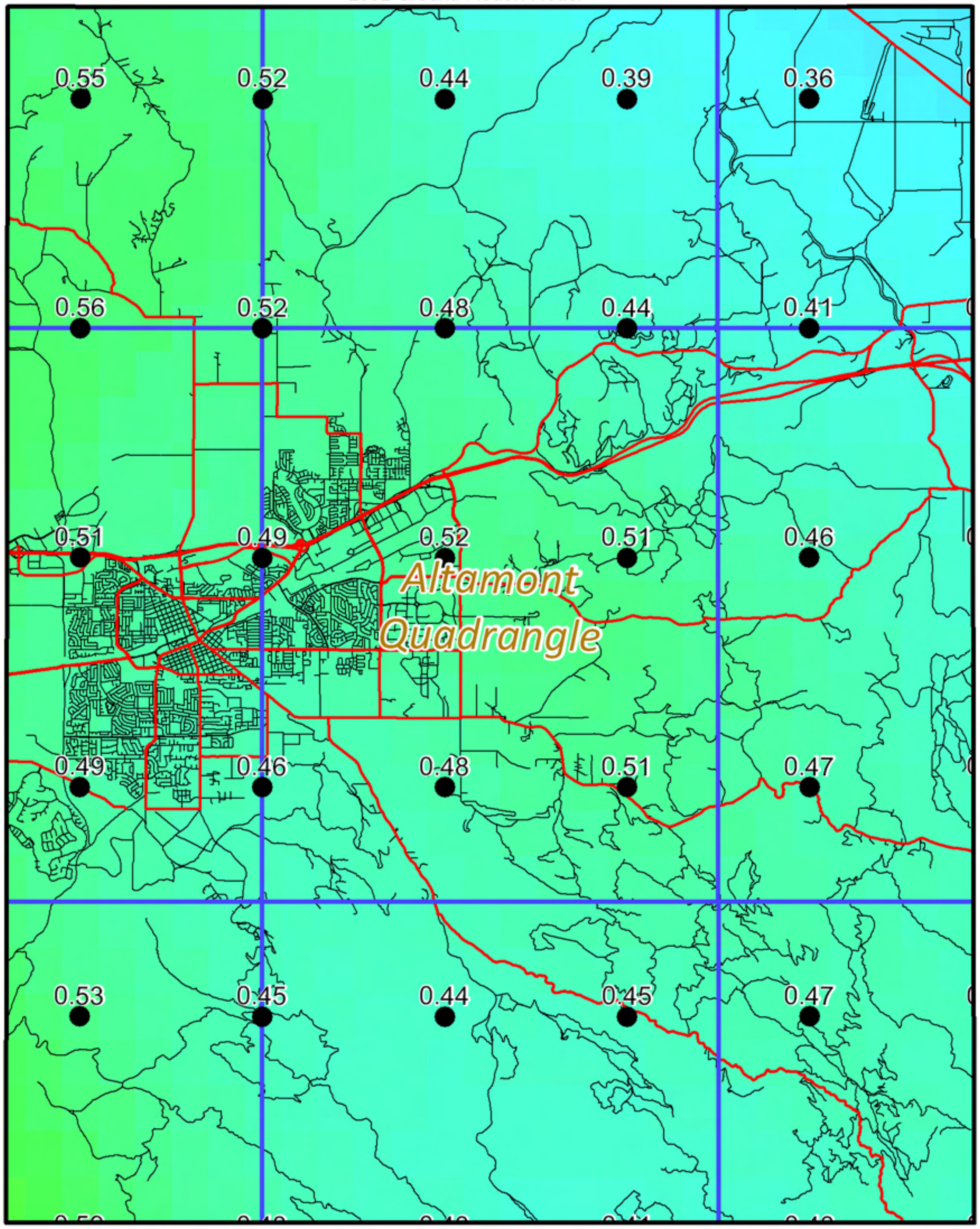
The ground shaking levels are estimated for each of the sources included in the seismic source model using attenuation relations that relate earthquake shaking with magnitude, distance from the earthquake and type of fault rupture (strike-slip, reverse, normal, or subduction). Unlike the previous model, which used attenuation relations for various soil types, the current model considers only uniform firm-rock site conditions. In a separate post-PSHA step, we apply the NEHRP soil profile type D factor for PGA (FEMA, 1994) to adjust for alluvial soil conditions. Cao and others (2003) and Frankel and others (2002) provide more details on changes in the new PSHA model..

The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figure 3.1 shows the hazard for PGA at 10 percent probability of exceedance in 50 years assuming the entire map area is firm rock (NEHRP B/C boundary soil condition). The sites where the hazard is calculated are represented as dots and ground motion.

ALTAMONT 7.5-MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

PEAK GROUND ACCELERATION FOR FIRM ROCK NEHRP B/C CONDITIONS (Vs30 = 760 m/sec) AT 10 PERCENT EXCEEDENCE IN 50 YEARS

2002 Ground Motion Model



Basemap from GDT

Department of Conservation
California Geological Survey

0 1 2 3 4 Miles

Figure 3.1

Soil Profile Type	**NEHRP (1994) Correction Factors for Different PGA Values (g)**				
	0.1	**0.2**	**0.3**	**0.4**	**0.5**
B	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**
C	**1.2**	**1.2**	**1.1**	**1.0**	**1.0**
D	**1.6**	**1.4**	**1.2**	**1.1**	**1.0**
E	**2.5**	**1.7**	**1.2**	**0.9**	**-**

Table 3.1. 1994 NEHEP soil factors for peak ground acceleration

contours as shaded regions. The quadrangle of interest is outlined by bold lines and centered on the map. Portions of the eight adjacent quadrangles are also shown so that the trends in the ground motion may be more apparent. We recommend estimating PGA by interpolating ground motion from the calculated values of PGA rather than the contours, since the points are more accurate, and adjusting the value to site conditions using the NEHRP soil factors (Table 3.1).

APPLICATION TO LIQUEFACTION AND LANDSLIDE HAZARD ASSESSMENT

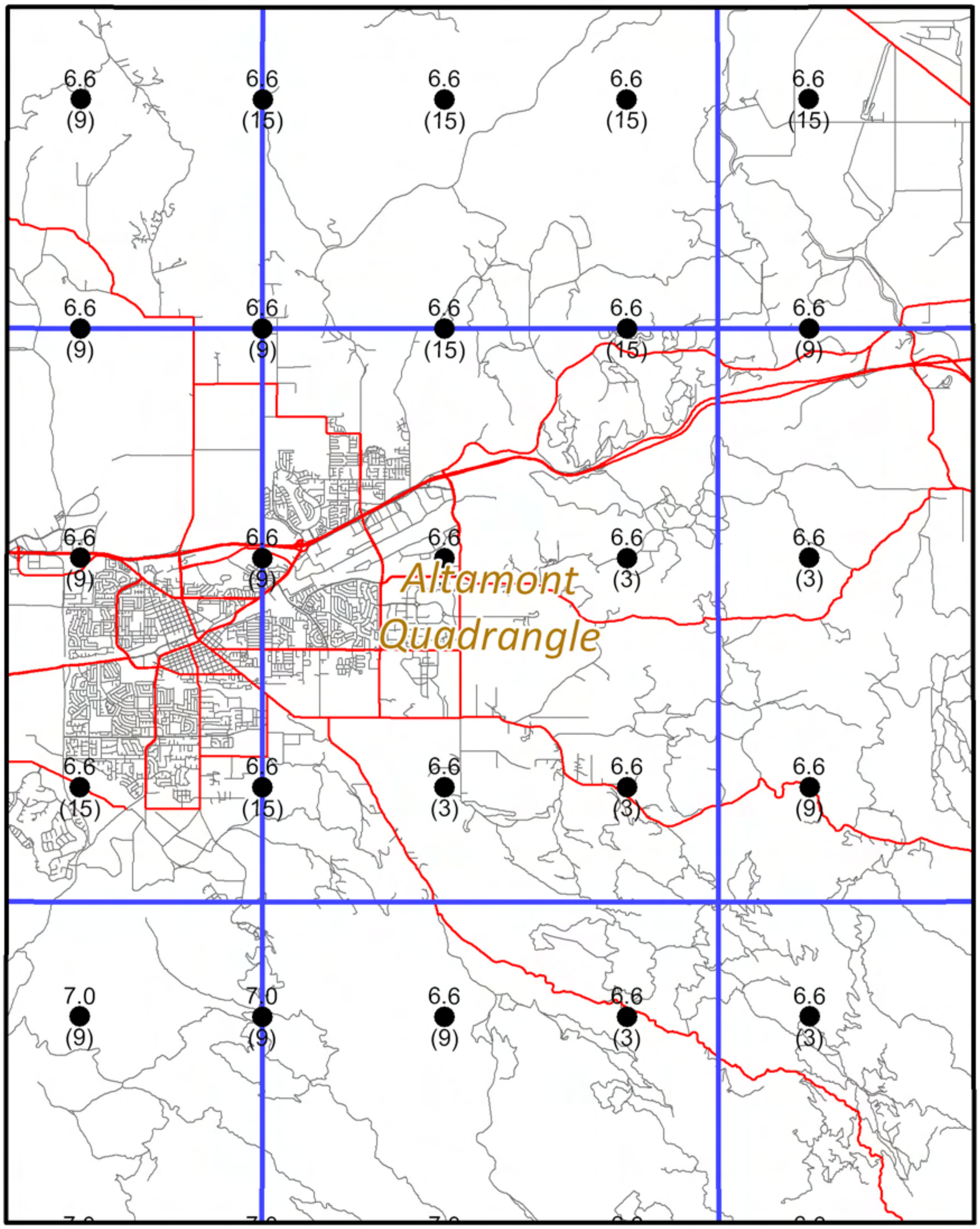
Deaggregation of the seismic hazard identifies the contribution of each earthquake source (various magnitudes and distances) in the model to the ground motion hazard for a particular exposure period (Cramer and Petersen, 1996). The map presented in Figure 3.2 identifies the magnitude and the distance (value in parentheses) of the earthquake that contributes most to the hazard at 10 percent probability of exceedance in 50 years (*predominant earthquake*). This information provides a rationale for selecting seismic records or ground motion level for evaluating ground failure potential. For zoning earthquake-induced landslide hazard, the predominant earthquake distance and magnitude is used to select ground motion recordings that are consistent with the hazard for calculating landslide displacement using the simple rigid sliding-block approach (Wilson and Keefer, 1983) described more fully in Section 2 of this report.

Predominant earthquake information shown in Figure 3.2 can also be used with more complex fully coupled-compliant models for site-specific estimates of landslide displacement (Rathje and Bray, 2000). It can also be used with the Seed-Idriss simplified procedure (Youd et al., 2001) to estimate seismic demand (cyclic stress ratio) for site-specific assessment of liquefaction hazard.

ALTAMONT 7.5-MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

MAGNITUDE OF AND DISTANCE TO (VALUE IN PARENTHESES, IN KILOMETERS) THE PREDOMINATE EARTHQUAKE AT10 PERCENT EXCEEDENCE IN 50 YEARS

2002 Ground Motion Model



Basemap from GDT

Department of Conservation
California Geological Survey

1 0 1 2 3
Miles

Figure 3.2

The predominant earthquake is used to identify the causative fault, and then an appropriate attenuation relation and predominant magnitude are used to estimate PGA at the site. The predominant magnitude is then used to adjust the liquefaction cyclic stress ratio threshold curves by a scaling factor in the final calculation of factor of safety according to the simplified procedure.

When selecting the predominant earthquake magnitude and distance 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. 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.

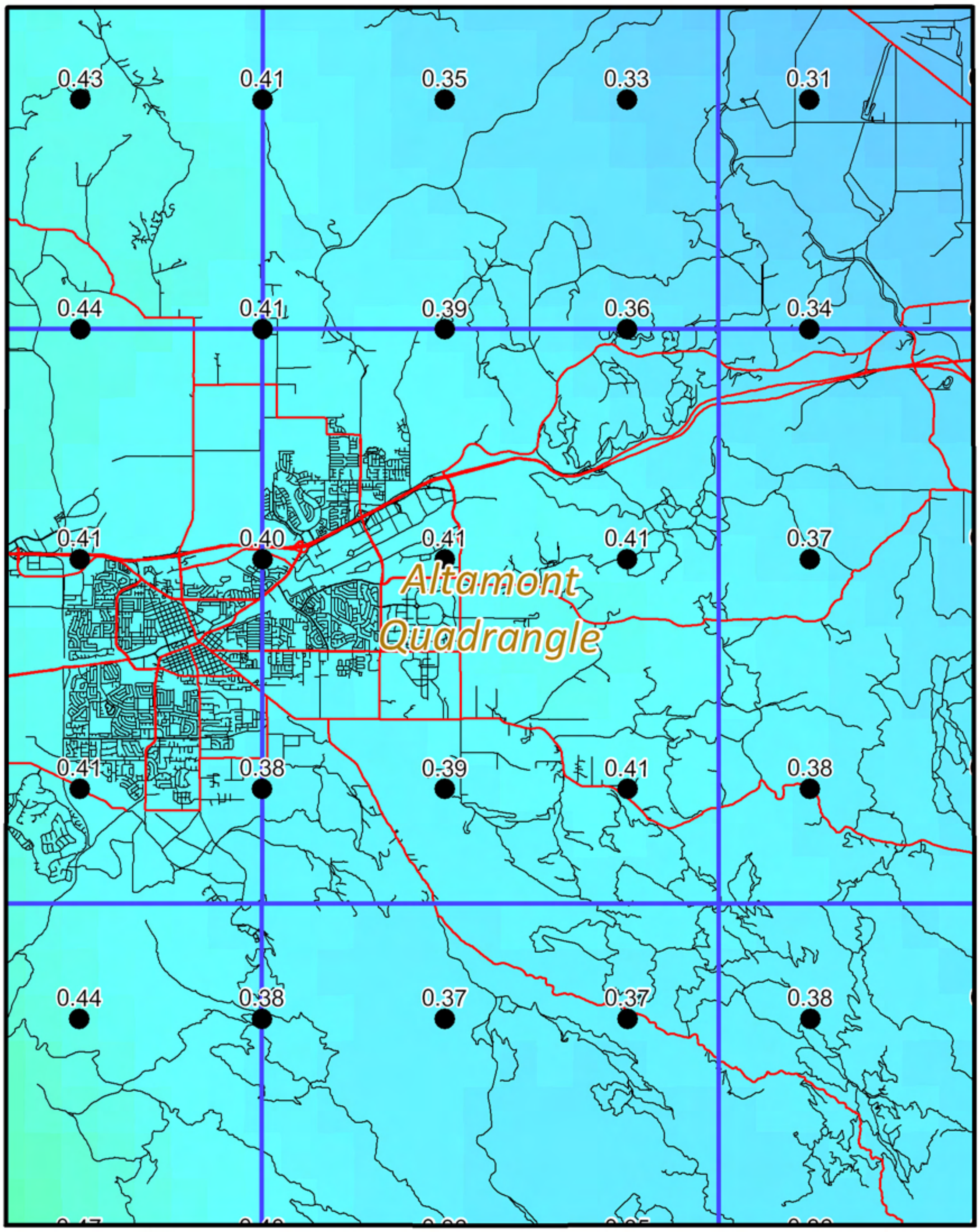
When calculating probabilistic peak ground acceleration for purposes of zoning liquefaction hazard, we weight each earthquake's contribution to the hazard estimate by a factor that is a function of its magnitude. The function is simply the inverse of the liquefaction threshold-scaling factor mentioned previously. The result is a "magnitude-weighted" ground motion that we then adjust for NEHRP alluvial conditions and use directly in the calculation of the induced cyclic stress ratio demand and thus the estimate of the factor of safety against liquefaction. Unlike the predominant–earthquake approach described previously, this approach provides an improved estimate of liquefaction hazard in a probabilistic sense. All magnitudes contributing to the hazard estimate are used to weight the probabilistic calculation of peak ground acceleration, effectively causing the cyclic stress ratio liquefaction threshold curves to be scaled probabilistically when computing factor of safety. This procedure ensures that large, distant earthquakes that occur less frequently but contribute *more*, and smaller, more frequent events that contribute *less* to the liquefaction hazard are appropriately accounted for (Real et al., 2000).

Figure 3.3 shows the magnitude-weighted alluvial PGA based on the Idriss scaling function (Youd et al., 2001). It is important to note that the values obtained from this map are pseudo-accelerations and should be used only in the simplified formulas for computing liquefaction factor of safety without applying any additional magnitude-scaling factor. We refer to this parameter as "liquefaction opportunity."

ALTAMONT 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES LIQUEFACTION OPPORTUNITY MAP

VALUES ARE MAGNITUDE-WEIGHTED PSEUDO-PEAK GROUND ACCELERATION FOR ALLUVIAL CONDITIONS AT 10 PERCENT EXCEEDENCE IN 50 YEARS

2002 Ground Motion Model



Basemap from GDT

Department of Conservation
California Geological Survey

1 0 1 2 3
Miles

CGS
CALIFORNIA GEOLOGICAL SURVEY

Figure 3.3

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***. The ground shaking maps provided here should only be used for purposes of *general comparison* with results obtained using site-specific methods. When making such comparisons the following limitations should be kept in mind:

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 range from about +/- 10 to 30 percent of the ground motion value at two standard deviations for most of California (Cao et al., 2005). It may be as high as 50 percent in some locations where the earthquake source parameters have higher uncertainty.

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.

As a final note, the Simple Prescribed Parameter Values (SPPV) method of estimating site-specific ground shaking described in the previous version of SP 117 "Guidelines for Evaluating and Mitigating Seismic Hazards in California" should no longer be used. Site investigations triggered by the Seismic Hazards Mapping Act should consult the most current version of the California Building Code when selecting ground motions for evaluating ground failure hazards at proposed construction sites.

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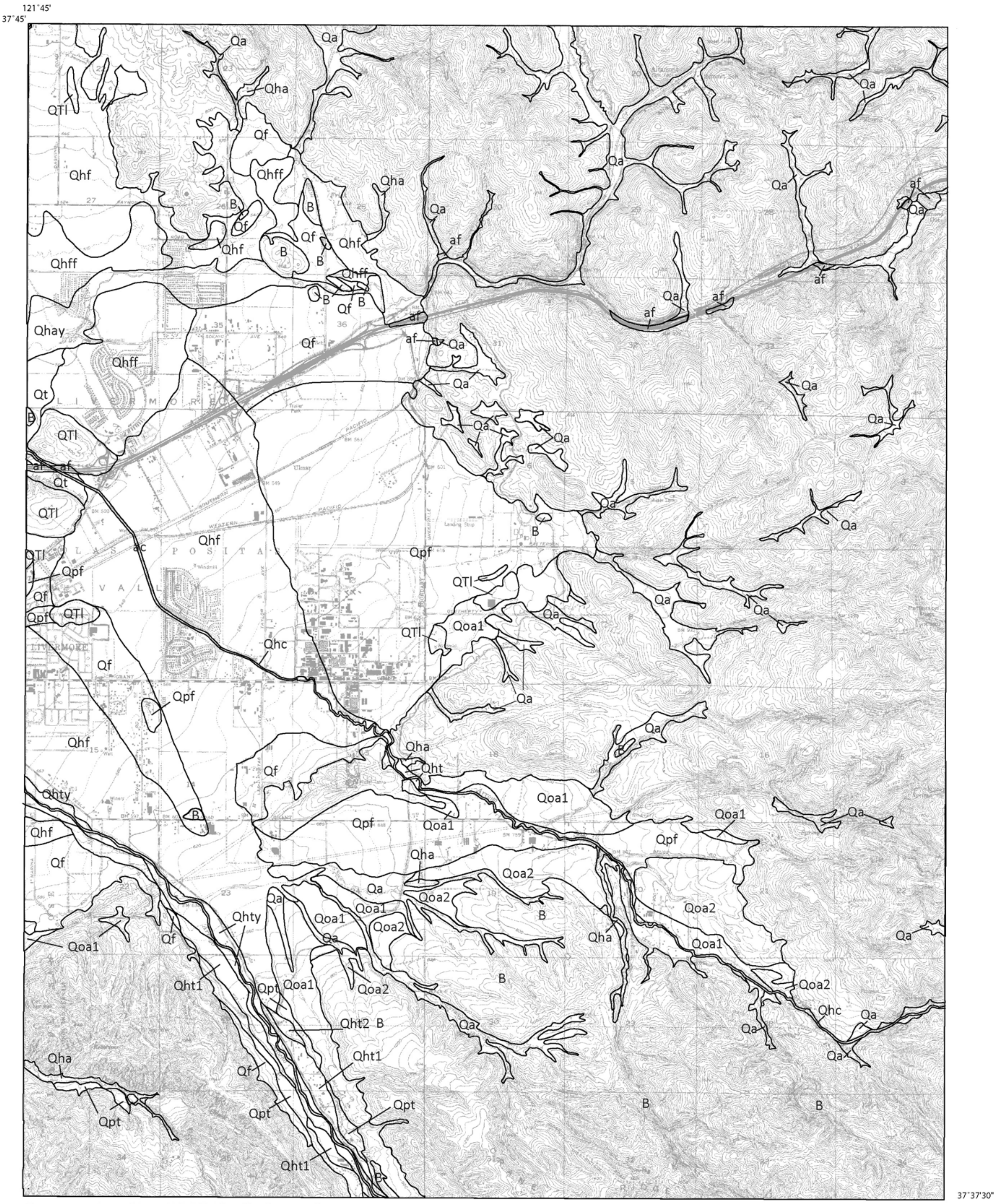
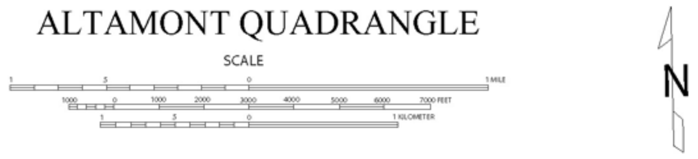


Base map enlarged from U.S.G.S. 30 x 60-minute series

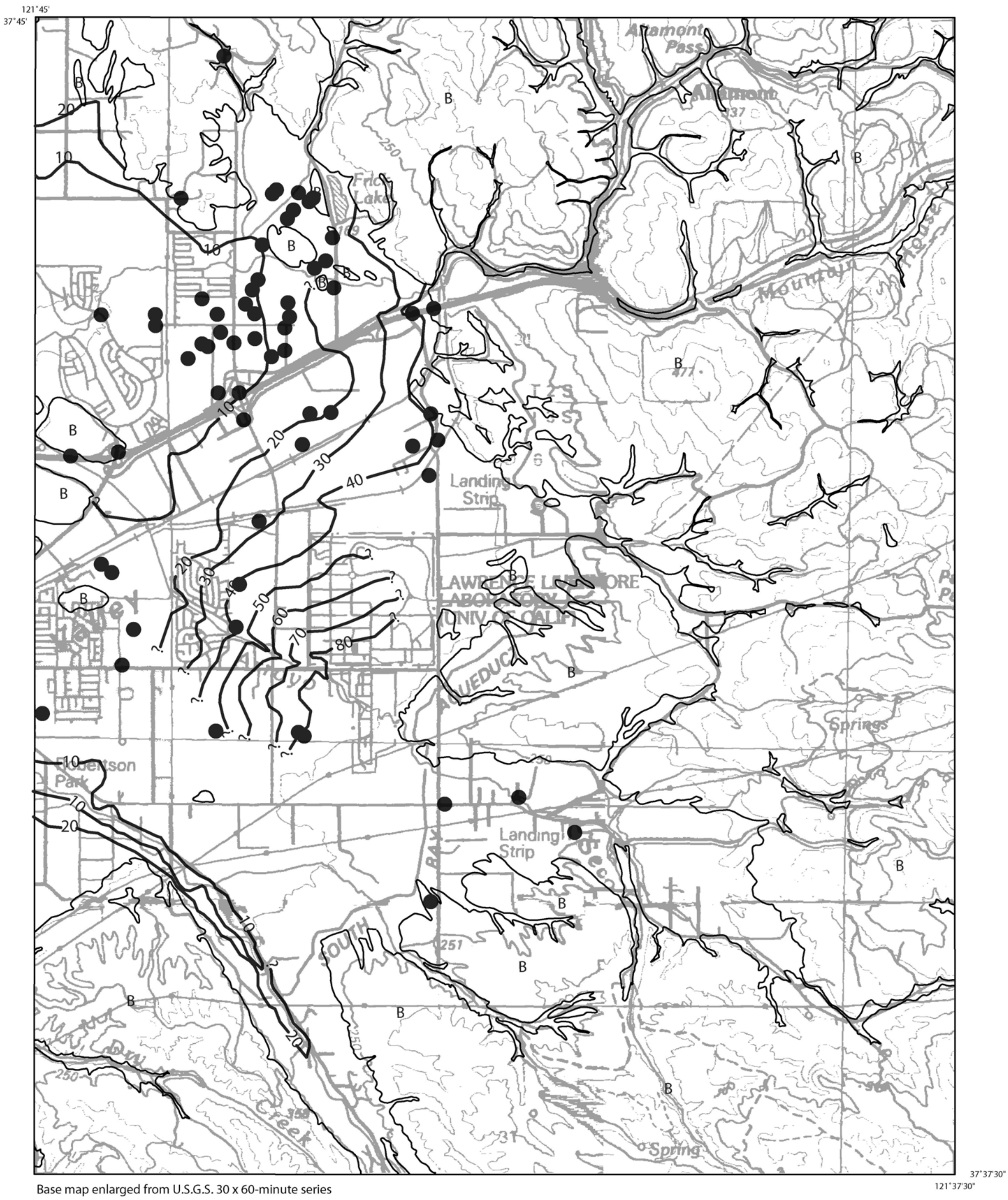
121°37'30"

ALTAMONT QUADRANGLE



See "Geology" in Section 1 of report for descriptions of units.
B = Pre-Quaternary bedrock.

Plate 1.1 Quaternary Geologic Map of the Altamont 7.5-minute quadrangle.



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

ALTAMONT QUADRANGLE

SCALE

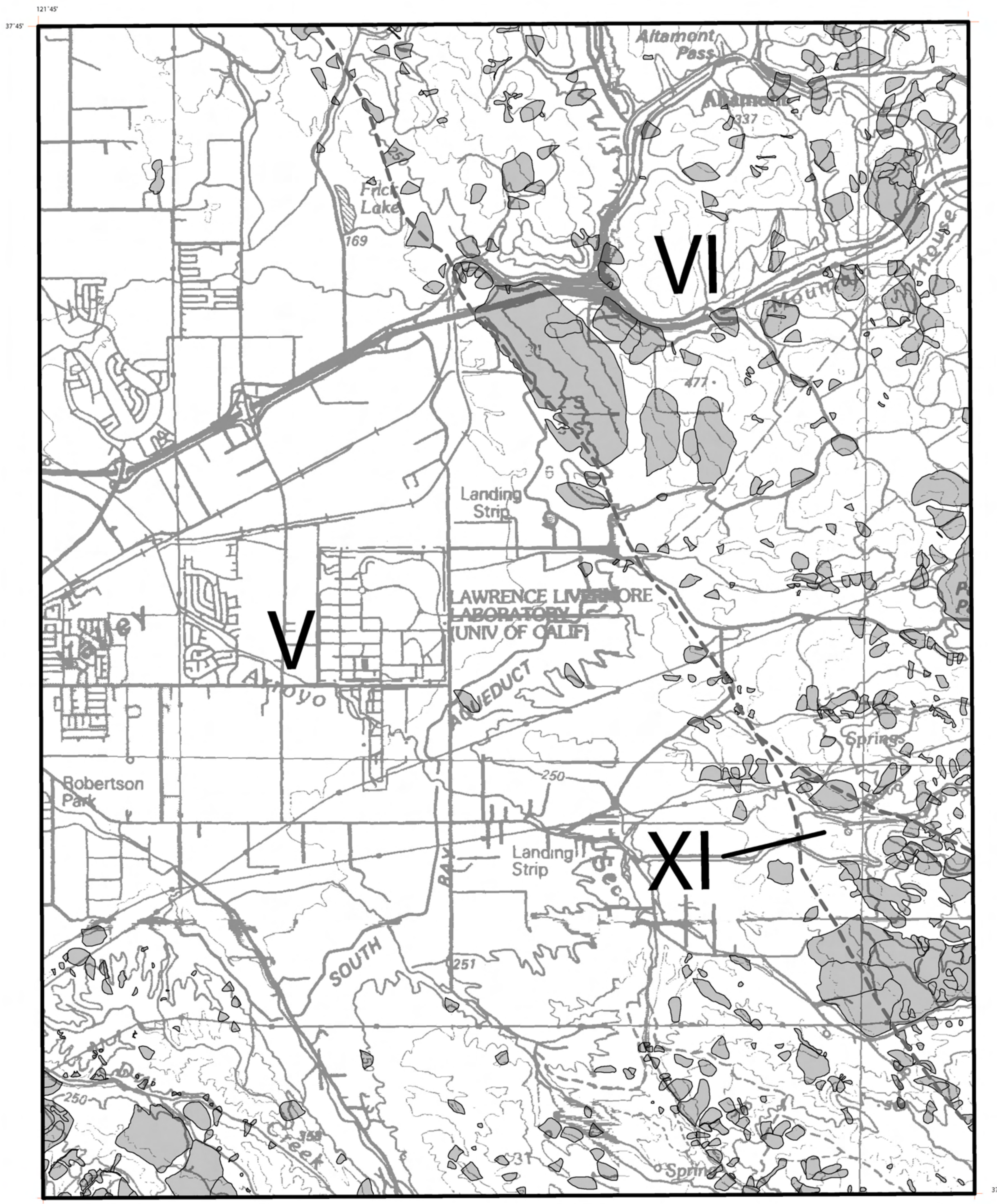
N

50 Depth to ground water, in feet

B = Pre-Quaternary bedrock.
See "Bedrock and Surficial Geology" in Section 1 of report for descriptions of units.

● Geotechnical borings used in liquefaction evaluation

Plate 1.2 Depth to historically high ground water, and locations of boreholes used in this study, Altamont 7.5-minute Quadrangle, California



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

ALTAMONT QUADRANGLE

SCALE

0 .5 0 1 MILE

1000 0 2000 4000 6000 FEET

1 .5 0 1 KILOMETER

N

Landslide

VI Fault-bounded bedrock assemblage (see Geology section of report)

Plate 2.1 Landslide inventory, Altamont 7.5-Minute Quadrangle, California.