SEISMIC HAZARD ZONE REPORT 059

SEISMIC HAZARD ZONE REPORT FOR THE TRIUNFO PASS 7.5-MINUTE QUADRANGLE, LOS ANGELES AND VENTURA COUNTIES, CALIFORNIA

2002

DEPARTMENT OF CONSERVATION
Division of Mines and Geology

STATE OF CALIFORNIA
GRAY DAVIS
GOVERNOR

THE RESOURCES AGENCY
MARY D. NICHOLS
SECRETARY FOR RESOURCES

DEPARTMENT OF CONSERVATION
DARRYL YOUNG
DIRECTOR

DIVISION OF MINES AND GEOLOGY

JAMES F. DAVIS, *STATE GEOLOGIST*

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EXECUTIVE SUMMARY

This report summarizes the methods and sources of information used to prepare the Seismic Hazard Zone Map for the Triunfo Pass 7.5-minute Quadrangle, Los Angeles and Ventura counties, California. The map displays the boundaries of Zones of Required Investigation for liquefaction and earthquake-induced landslides over an area of approximately 38 square miles at a scale of 1 inch = 2,000 feet.

The Triunfo Pass Quadrangle lies along the coast on the boundary between Los Angeles and Ventura counties. The area includes the western part of the City of Malibu. Rising to the north of the narrow coastal strip of beaches are the rugged, east-west trending Santa Monica Mountains, which reach 3111 feet at Sandstone Peak, near the northern quadrangle boundary. The principal drainages are south-flowing Arroyo Sequit and Little Sycamore Canyon, which empty directly into the Pacific Ocean. The City of Malibu represents the principal developed (residential) area, but its western end is currently only modestly developed. The entire quadrangle lies within the Santa Monica Mountains National Recreation Area, which comprises noncontiguous tracts of public lands, including the easternmost part of Point Mugu State Park, Leo Carrillo State Beach, Robert H. Meyer Memorial State Beach, and Charmlee Natural Area.

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

Liquefaction zones of required investigation in the Triunfo Pass Quadrangle are restricted to the beaches and a few scattered canyon-bottom localities. The bedrock geology of the quadrangle primarily consists of Miocene marine sedimentary rocks of the Topanga Formation and a large variety of extrusive and intrusive volcanic rocks of the Conejo Volcanics. The deeply dissected terrain has produced widespread and abundant landslides regardless of rock type, although landslides are uncommon in the Conejo Volcanics in the eastern part of the quadrangle. These conditions contribute to earthquake-induced landslide zones of required investigation that cover about 26 percent of the land in the Triunfo Pass Quadrangle.

How to view or obtain the map

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

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

> BPS Reprographic Services
> 945 Bryant Street
> San Francisco, California 94105
> (415) 512-6550

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

INTRODUCTION

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

The Act also directs SMGB to appoint and consult with the Seismic Hazards Mapping Act Advisory Committee (SHMAAC) in developing criteria for the preparation of the seismic hazard zone maps. SHMAAC consists of geologists, seismologists, civil and structural engineers, representatives of city and county governments, the state insurance commissioner and the insurance industry. In 1991 SMGB adopted initial criteria for delineating seismic hazard zones to promote uniform and effective statewide implementation of the Act. These initial criteria provide detailed standards for mapping regional liquefaction hazards. They also directed DMG 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.

This Seismic Hazard Zone Report summarizes the development of the hazard zone map. The process of zoning for liquefaction uses a combination of Quaternary geologic mapping, historical ground-water information, and subsurface geotechnical data. The process for zoning earthquake-induced landslides incorporates earthquake loading, existing landslide features, slope gradient, rock strength, and geologic structure. Probabilistic seismic hazard maps, which are the underpinning for delineating seismic hazard zones, have been prepared for peak ground acceleration, mode magnitude, and mode distance with a 10% probability of exceedance in 50 years (Petersen and others, 1996) in accordance with the mapping criteria.

This report summarizes seismic hazard zone mapping for potentially liquefiable soils and earthquake-induced landslides in the Triunfo Pass 7.5-minute Quadrangle.

SECTION 1
LIQUEFACTION EVALUATION REPORT

Liquefaction Zones in the Triunfo Pass 7.5-Minute Quadrangle, Los Angeles and Ventura Counties, California

By
Marvin Woods

California Department of Conservation
Division of Mines and Geology

PURPOSE

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

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

BACKGROUND

Liquefaction-induced ground failure historically has been a major cause of earthquake damage in southern California. During the 1971 San Fernando and 1994 Northridge earthquakes, significant damage to roads, utility pipelines, buildings, and other structures in the Los Angeles 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 ground-water conditions exist in parts of southern California, 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 in the southern California region in general, including areas in the Triunfo Pass Quadrangle.

METHODS SUMMARY

Characterization of liquefaction hazard presented in this report requires preparation of maps that delineate areas underlain by potentially liquefiable sediment. The following were collected or generated for this evaluation:

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

- Construction of shallow ground-water maps showing the historically highest known ground-water levels

- Quantitative analysis of geotechnical data to evaluate liquefaction potential of deposits

- Information on potential ground shaking intensity based on DMG probabilistic shaking maps

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

SCOPE AND LIMITATIONS

Evaluation for potentially liquefiable soils generally is confined to areas covered by Quaternary (less than about 1.6 million years) sedimentary deposits. Such areas within the Triunfo Pass Quadrangle consist mainly of narrow beaches and canyon bottoms. DMG's liquefaction hazard evaluations are based on information on earthquake ground shaking, surface and subsurface lithology, geotechnical soil properties, and ground-water 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 ground water, rate of drainage, slope gradient, proximity to free faces, and intensity and duration of ground shaking. These factors must be evaluated on a site-specific basis to assess the potential for ground failure at any given project site.

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

PART I

PHYSIOGRAPHY

Study Area Location and Physiography

The Triunfo Pass Quadrangle covers approximately 38 square miles of land (plus 24 square miles of ocean) in western Los Angeles and eastern Ventura counties. Approximately 14 square miles of land in the east-southeast part of the quadrangle lie within Los Angeles County. The City of Malibu is the only incorporated jurisdiction within the quadrangle; the western end of the city occupies the southeastern corner of land within the quadrangle. The rugged, deeply dissected Santa Monica Mountains, which rise abruptly from a narrow coastal strip of rocky or sandy beaches, cover nearly the entire on-land area of the quadrangle. The highest elevation within the quadrangle is 3111 feet at Sandstone Peak, near the northern boundary of the map.

South-flowing Arroyo Sequit and Little Sycamore Canyon are the principal drainages in the quadrangle, both of which empty directly into the Pacific Ocean. A very short segment of Big Sycamore Canyon cuts across the extreme northwestern corner of the quadrangle. Other significant drainages are San Nicholas and Los Alisos canyons, which also drain directly into the Pacific Ocean, and an unnamed creek in the northeastern corner of the quadrangle that drains into Lake Sherwood, which is located in the southwestern corner of the Thousand Oaks quadrangle. Principal travel routes within the Triunfo Pass Quadrangle are the Pacific Coast Highway (State Highway 1) and Mulholland Highway; other important routes are Decker Road (State Highway 23) and Yerba Buena Road. The City of Malibu represents the principal developed (residential) area, but its western end is currently only modestly developed. The entire quadrangle lies within the Santa Monica Mountains National Recreation Area, which comprises noncontiguous tracts of public lands, including the easternmost part of Point Mugu State Park, Leo Carrillo State Beach, Robert H. Meyer Memorial State Beach, and Charmlee County Park.

GEOLOGY

Bedrock and Surficial Geology

Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial and fluvial sedimentary deposits and artificial fill. To evaluate the areal and vertical distribution of shallow Quaternary deposits and to provide information on subsurface geologic, lithologic and engineering properties of the units in the Triunfo Pass Quadrangle, we relied on a 1:24,000-scale geologic map published by the Dibblee Geological Foundation (Dibblee and Ehrenspeck, 1990). This map was digitized by staff of DMG's Regional Geologic Mapping Program and incorporated into DMG's GIS. 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 develop the Seismic Hazard Zone Map.

Table 1.1 summarizes the Quaternary map units recognized by Dibblee and Ehrenspeck (1990) within the Triunfo Pass Quadrangle. Omitted from Table 1.1 and also from Plate 1.1 are landslide deposits (Qls). Approximately 5 percent of the land area in the quadrangle is covered by unconsolidated to moderately consolidated deposits of Quaternary age (excluding Qls deposits). Within approximately one-quarter mile of the coast east of Little Sycamore Canyon, Pleistocene "older surficial sediments" rest on one or more coastal terraces cut into older bedrock (**Qoa** in Table 1.1). West of Little Sycamore Canyon, these deposits are rare. Three small, isolated occurrences of Qoa within the interior of the quadrangle are presumably stream terrace deposits. All of the terrace deposits consist of "dissected, weakly indurated alluvial gravel, sand and silt" (Dibblee and Ehrenspeck, 1990) that, because of their relatively old age, we infer to be compact and dense. We expect ground water to be relatively deep within them because these deposits tend to occur in areas elevated above modern drainages.

The remaining Quaternary deposits are relatively young and considered by Dibblee and Ehrenspeck (1990) to be of Holocene age. These Holocene sediments occur either as beach deposits (unconsolidated, cohesionless sand; **Qs** in Table 1.1) or as undifferentiated alluvium (stream-deposited, unconsolidated, generally cohesionless gravel, sand, and silt; **Qa**). Alluvium fills the bottoms of all canyons mentioned previously, as well as local stretches of many other unnamed canyons.

Pre-Quaternary bedrock exposed in the Triunfo Pass Quadrangle is almost entirely of Miocene age (Dibblee and Ehrenspeck, 1990). The youngest Tertiary rocks (middle Miocene) are unconformably overlain by Pleistocene terrace deposits. Strata of Pliocene age are not present within the quadrangle. Marine clastic sedimentary rocks of the middle Miocene Upper (?) Topanga Formation overlie the Conejo Volcanics, a thick sequence of submarine and subaerial extrusive and related intrusive rocks of middle Miocene age. The Conejo Volcanics are widespread within the western Santa Monica Mountains but within the Triunfo Pass Quadrangle they are exposed only in the northern part of the quadrangle. The Conejo Volcanics overlie middle and lower Miocene marine clastic sedimentary rocks of the Lower Topanga Formation, which in turn rests on Oligocene nonmarine clastic sedimentary rocks of the Sespe Formation. In the southeastern corner of the quadrangle Paleocene marine sedimentary rocks, unnamed by Dibblee and Ehrenspeck (1990) but mapped as Coal Canyon Formation by Campbell and others (1996) in the adjoining Point Dume Quadrangle, are the oldest rocks exposed in the map area. See the Earthquake Induced Landslide portion (Section 2) of this report for further details.

Structural Geology

The Triunfo Pass Quadrangle lies within the Santa Monica Mountains, the southernmost range of the east-west trending Transverse Ranges geomorphic province. The Santa Monica Mountains have undergone fairly rapid uplift during the Quaternary as evidenced by the deeply incised stream canyons and by thrust faulting near the coast that places Tertiary bedrock over Quaternary marine and nonmarine terrace deposits in the adjacent Point Dume Quadrangle to the east (Campbell and others, 1996). Leveling surveys and GPS data indicate that the mountains are continuing to rise. Faults across which this uplift has been accommodated include the Malibu Coast Fault, an unnamed high-angle fault in the middle of Triunfo Pass Quadrangle (Dibblee and Ehrenspeck, 1990), and the Malibu Bowl Fault, Zuma Fault, and Escondido Thrust Fault, all of which are north-over-south reverse faults located within the adjoining Point Dume Quadrangle (Campbell and others, 1996).

ENGINEERING GEOLOGY

We obtained information on subsurface geology and engineering characteristics of sedimentary deposits from borehole logs collected from reports on geotechnical projects. For this investigation, we collected seven borehole logs from the files of the City of Malibu and the Ventura County Public Works Department (via William Lettis and Associates). We entered the data from these borehole logs into a DMG geotechnical GIS database.

Standard Penetration Test (SPT) data provide a standardized measure of the penetration resistance of a geologic deposit and commonly are used as an index of density. Many geotechnical investigations record SPT data, including the number of blows by a 140-pound drop weight required to drive a sampler of specific dimensions one foot into the soil. Recorded blow counts for non-SPT geotechnical sampling, where the sampler diameter, hammer weight or drop distance differ from those specified for an SPT (ASTM D1586), were converted to SPT-equivalent blow count values and entered into the DMG GIS. The actual and converted SPT blow counts were normalized to a common reference effective overburden pressure of one atmosphere (approximately one ton per square foot) and a hammer efficiency of 60% using a method described by Seed and Idriss (1982) and Seed and others (1985). This normalized blow count is referred to as $(N_1)_{60}$. Of the seven borehole logs entered into DMG's GIS database, only four had SPT or SPT-equivalent data.

Geotechnical borehole logs, as well as the geologic map by Dibblee and Ehrenspeck (1990), provided information on lithologic and engineering characteristics of Quaternary deposits within the study area. Geotechnical characteristics of the Quaternary map units are generalized in Table 1.1.

Geologic Map Unit	**Material Type**	**Consistency**	**Age**	**Liquefaction Susceptibility***
Qa, alluvium	sand, gravel, & silt	loose	Holocene	very high to high
Qs, beach deposits	fine- to medium-grained sand, locally with rounded pebble gravel	loose	Holocene	very high
Qoa, older alluvium	gravel, sand, & silt	weakly indurated	Pleistocene	low to very low

(*when saturated)

Table 1.1. Quaternary Map Units Used in the Triunfo Pass Quadrangle (Dibblee and Ehrenspeck, 1990) and Their Geotechnical Characteristics and Liquefaction Susceptibility

GROUND-WATER CONDITIONS

Liquefaction hazard may exist in areas where depth to ground water is 40 feet or less. DMG uses the highest known ground-water levels because water levels during an earthquake cannot be anticipated because of the unpredictable fluctuations caused by natural processes and human activities. A historical-high ground-water map differs from most ground-water maps, which show the actual water table at a particular time. Plate 1.2 depicts a hypothetical ground-water table within alluviated areas.

Ground-water conditions were investigated in the Triunfo Pass Quadrangle to evaluate the depth to saturated materials. Saturated conditions reduce the effective normal stress, thereby increasing the likelihood of earthquake-induced liquefaction (Youd, 1973). The evaluation was based on first-encountered water noted in geotechnical borehole logs acquired from the City of Malibu and the Ventura County Public Works Department. The depths to first-encountered unconfined ground water were plotted onto a map of the project area to constrain the estimate of historically shallowest ground water. Water depths from boreholes known to penetrate confined aquifers were not utilized.

We estimated depth to historical-high ground water though a process of applying professional judgement, as constrained by basic principles of ground-water and surface-water hydrology and by a conservative bias. For example, in small stream valleys that drain a correspondingly small area, we anticipate that young alluvium deposits will not be saturated except for the several hours or few days during which these streams are in flood during storm events. On the other hand, stream valleys that drain large areas are more likely to have permanent baseflow within the alluvium even during relatively dry parts of the year. In many areas where observed ground-water depths were available, we generally simply rounded those depths up to the next higher five-foot increment. We then contoured areas of Quaternary deposits based on estimated historical-high ground-water level (Plate 1.2).

The only source of data on ground-water depths within the Triunfo Pass Quadrangle was the set of boreholes discussed previously and posted on Plate 1.2. Of the seven borehole logs acquired, four encountered the water table on the date they were drilled. Observed depths to ground water ranged from 3 feet to 41 feet, over a period of time ranging from December 1992 to January 2000. The other three were dry to their total depth (35 to 64 feet) on the date they were drilled.

We estimate historical-high ground-water depth along the beach to be no greater than five feet and within stream canyon alluvium to be approximately 10 feet.

PART II

LIQUEFACTION POTENTIAL

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

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

LIQUEFACTION SUSCEPTIBILITY

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

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

DMG's map inventory of areas containing soils susceptible to liquefaction begins with evaluation of geologic maps and historical occurrences, cross-sections, geotechnical test data, geomorphology, and ground-water hydrology. Soil properties and soil conditions such as type, age, texture, color, and consistency, along with historical depths to ground water are used to identify, characterize, and correlate susceptible soils. Because Quaternary geologic mapping is based on similar soil observations, liquefaction susceptibility maps typically are similar to Quaternary geologic maps. DMG's qualitative relations between susceptibility and geologic map unit are summarized in Table 1.1.

LIQUEFACTION OPPORTUNITY

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

For the Triunfo Pass Quadrangle, PGAs of 0.55 g to 0.57 g, resulting from an earthquake of magnitude 7.3, were used for liquefaction analyses. The PGA and magnitude values were based on de-aggregation of the probabilistic hazard at the 10% in 50-year hazard level (Petersen and others, 1996; Cramer and Petersen, 1996). See the ground motion section (3) of this report for further details.

Quantitative Liquefaction Analysis

DMG performs quantitative analysis of geotechnical data to evaluate liquefaction potential using the Seed-Idriss Simplified Procedure (Seed and Idriss, 1971; Seed and others, 1983; National Research Council, 1985; Seed and others, 1985; Seed and Harder, 1990; Youd and Idriss, 1997). Using the Seed-Idriss Simplified Procedure one can calculate soil resistance to liquefaction, expressed in terms of cyclic resistance ratio (CRR), based on SPT results, ground-water level, soil density, moisture content, soil type, and sample depth. CRR values are then compared to calculated earthquake-generated shear stresses expressed in terms of cyclic stress ratio (CSR). The Seed-Idriss Simplified Procedure requires normalizing earthquake loading relative to a M7.5 event for the liquefaction analysis. To accomplish this, DMG's analysis uses the Idriss magnitude scaling factor (MSF) (Youd and Idriss, 1997). It is convenient to think in terms of a factor of safety (FS) relative to liquefaction, where: FS = (CRR / CSR) * MSF. FS, therefore, is a quantitative measure of liquefaction potential. DMG uses a factor of safety of 1.0 or less, where CSR equals or exceeds CRR, to indicate the presence of potentially liquefiable soil. While an FS of 1.0 is considered the "trigger" for liquefaction, for a site specific analysis an FS of as much as 1.5 may be appropriate depending on the vulnerability of the site and related structures. The DMG liquefaction analysis program calculates an FS for each geotechnical sample for which blow counts were collected. Typically, multiple samples are collected for each borehole. The lowest FS in each borehole is used for that location. FS values vary in reliability according to the quality of the geotechnical data used in their calculation. FS, as well as other considerations such as slope, presence of free faces, and thickness and depth of potentially liquefiable soil, are evaluated in order to construct liquefaction potential maps, which are then used to make a map showing zones of required investigation.

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

The Seed-Idriss Simplified Procedure for liquefaction evaluation was 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 a significant amount of gravel. In the past, gravelly soils usually were considered not to be susceptible to liquefaction because the high permeability of these soils presumably would allow the dissipation of pore pressures before liquefaction could occur. However, liquefaction in gravelly soils has been observed during earthquakes, and recent laboratory studies have shown that gravelly soils are susceptible to liquefaction (Ishihara, 1985; Harder and Seed, 1986; Budiman and Mohammadi, 1995; Evans and Zhou, 1995; and Sy and others, 1995). SPT-derived density measurements in gravelly soils are unreliable and generally too high. They are likely to lead to overestimation of the density of the soil and, therefore, result in an underestimation of the liquefaction susceptibility. To identify potentially liquefiable units where the N values appear to have been affected by gravel content, correlations were made with boreholes in the same unit where the N values do not appear to have been affected by gravel content.

LIQUEFACTION ZONES

Criteria for Zoning

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

1. Areas known to have experienced liquefaction during historical earthquakes

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

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

4. Areas where existing geotechnical data are insufficient

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

a) 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% probability of being exceeded in 50 years is greater than or equal to 0.10 g and the water table is less than 40 feet below the ground surface; or

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

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

Application of SMGB criteria to liquefaction zoning in the Triunfo Pass Quadrangle is summarized below.

Areas of Past Liquefaction

In the Triunfo Pass Quadrangle, no areas of documented historical liquefaction are known. Areas showing evidence of paleoseismic liquefaction have not been reported.

Artificial Fills

Artificial fill was not mapped by Dibblee and Ehrenspeck (1990) in the Triunfo Pass Quadrangle. Except for roads and scattered residential sites there has been little modification of the natural terrain and placement of fill. In other quadrangles, artificial fill areas large enough to show at the scale of mapping tend to consist of engineered fill for river levees and elevated freeways. Since these fills are considered to be properly engineered, zoning for liquefaction in such areas depends on soil conditions in underlying strata. Non-engineered fills are commonly loose and uncompacted, and the material varies in size and type.

Areas with Sufficient Existing Geotechnical Data

Borehole logs that include penetration test data and sufficiently detailed lithologic descriptions were used to evaluate liquefaction potential. Given that we could find only four boreholes with SPT or SPT-equivalent data, there are essentially no areas within the Triunfo Pass Quadrangle that have truly "sufficient" geotechnical data. Areas (geologic units) represented by the few boreholes with geotechnical data were evaluated for zoning based on the liquefaction potential determined by the Seed-Idriss Simplified Procedure. These areas containing saturated potentially liquefiable material with corresponding depths as shown in Table 1.1 are included in the zone.

Areas with Insufficient Existing Geotechnical Data

Younger alluvium deposited in stream channel areas generally lacks adequate geotechnical borehole information. The soil characteristics and ground-water conditions in these deposits are assumed to be similar to deposits where subsurface information is available, including within adjacent quadrangles. The Holocene stream channel and beach deposits, therefore, are included in the liquefaction zone for reasons presented in criterion 4a above.

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SECTION 2
EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

Earthquake-Induced Landslide Zones in the Triunfo Pass 7.5-Minute Quadrangle, Los Angeles and Ventura Counties, California

By
Michael A. Silva and Mark O. Weigers

California Department of Conservation
Division of Mines and Geology

PURPOSE

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

This section of the evaluation report summarizes seismic hazard zone mapping for earthquake-induced landslides in the Triunfo Pass 7.5-minute Quadrangle. This section, along with Section 1 (addressing liquefaction), and Section 3 (addressing earthquake shaking), form a report that is one of a series that summarizes the preparation of seismic hazard zone maps within the state (Smith, 1996). Additional information on seismic hazard zone mapping in California can be accessed on DMG's Internet web page: http://www.conservation.ca.gov/CGS/index.htm.

BACKGROUND

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

METHODS SUMMARY

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

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

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

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

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

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

SCOPE AND LIMITATIONS

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

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

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

PART I

PHYSIOGRAPHY

Study Area Location and Physiography

The Triunfo Pass Quadrangle covers approximately 38 square miles of land (plus 24 square miles of ocean) in western Los Angeles and eastern Ventura counties. Approximately 14 square miles of land in the east-southeast part of the quadrangle lie within Los Angeles County. The City of Malibu is the only incorporated jurisdiction within the quadrangle; the western end of the city occupies the southeastern corner of land within the quadrangle. Rising behind the narrow southern coastline are the rugged, east-west trending Santa Monica Mountains. The highest elevation within the quadrangle is 3111 feet at Sandstone Peak, near the northern quadrangle boundary.

South-flowing Arroyo Sequit and Little Sycamore Canyon are the principal drainages in the quadrangle; both empty directly into the Pacific Ocean. A very short segment of Big Sycamore Canyon occurs in the extreme northwest corner of the quadrangle. Other significant drainages are San Nicholas and Los Alisos canyons, which also drain directly into the Pacific Ocean, and an unnamed creek in the northeastern corner of the quadrangle that drains into Lake Sherwood (which is located in the southwestern corner of the Thousand Oaks Quadrangle). Principal travel routes within the Triunfo Pass Quadrangle are the Pacific Coast Highway (State Highway 1) and Mulholland Highway. Other important routes are Decker Road (State Highway 23) and Yerba Buena Road. The City of Malibu represents the principal developed (residential) area, but its western end is currently only modestly developed. The entire quadrangle lies within the Santa Monica Mountains National Recreation Area, which comprises noncontiguous tracts of public lands, including the easternmost part of Point Mugu State Park, Leo Carrillo State Beach, Robert H. Meyer Memorial State Beach, and Charmlee Natural Area.

Digital Terrain Data

The calculation of slope gradient is an essential part of the evaluation of slope stability under earthquake conditions. An accurate slope gradient calculation begins with an up-to-date map representation of the earth's surface in the form of a digital topographic map. Within the Triunfo Pass Quadrangle, a Level 2 digital elevation model (DEM) was obtained from the USGS (U.S. Geological Survey, 1993). This DEM, which was prepared from the 7.5-minute quadrangle topographic contours that are based on 1947 aerial photography, 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 DEM was also used to make a slope aspect map. The manner in which the slope and aspect maps were used to prepare the zone map will be described in subsequent sections of this report.

GEOLOGY

Bedrock and Surficial Geology

The bedrock and surficial geologic mapping used in this slope stability evaluation was obtained from the Dibblee Geological Foundation (Dibblee and Ehrenspeck, 1990) and digitized by DMG staff for this study. Bedrock units are described in detail in this section. Quaternary geologic units are only described briefly here, but are discussed in more detail in Section 1.

The digitized geologic map was modified by DMG geologists in the following ways. Landslide deposits were deleted from the map so that the distribution of bedrock formations and the landslide inventory would exist on separate layers for the hazard analysis. Contacts between bedrock and surficial units were revised to better conform to the topographic contours of the U.S.G.S. 7.5-minute quadrangle. Air-photo interpretation and field reconnaissance were performed to assist in adjusting contacts between bedrock and surficial geologic units and to review geologic unit lithology and geologic structure.

Bedrock units exposed in the Triunfo Pass Quadrangle range in age from Paleocene to late Miocene. The rocks consist of marine sedimentary rocks, extrusive volcanic rocks and intrusive dikes and sills. Surficial deposits are limited to areas along active stream channels and on coastal terraces. Modern beach sand is present along the coast.

The Santa Monica Mountains consist of two distinct geologic terranes that are juxtaposed along the Malibu Coast Fault. North of the fault, the basement consists of Santa Monica Slate and granodiorite that is overlain by Upper Cretaceous through upper Miocene rocks. South of the fault, the basement consists of Catalina Schist that is overlain by Miocene and younger rocks. Within the Triunfo Pass Quadrangle, the Malibu Coast Fault extends westerly along the coast and then continues offshore west of Sequit Point. The metamorphic and crystalline basement rocks and Upper Cretaceous strata are not exposed in the Triunfo Pass Quadrangle. Bedrock exposed along the south side of the fault consists of upper(?) Topanga Formation sandstone and sedimentary breccia (San Onofre Breccia) (Dibblee and Ehrenspeck, 1990).

The Cenozoic rocks in the central part of the Santa Monica Mountains east of the Triunfo Pass Quadrangle are complexly deformed and also exhibit complex facies changes and intertonguing relationships. This geologic complexity has led to differences in stratigraphic terminology used by some of the geologists who have mapped in the region (Yerkes and Campbell, 1979, 1980; Dibblee and Ehrenspeck, 1990, 1993). Fritsche (1993) reviews the evolution of stratigraphic terminology used in the region in detail. For this study, the stratigraphic terminology used by Dibblee and Ehrenspeck (1990, 1993) is adopted.

The oldest geologic unit mapped in the study area consists of unnamed marine sedimentary rocks of Paleocene age (Tsu) consisting of gray, vaguely bedded micaceous siltstone and light gray, fine grained sandstone (Dibblee and Ehrenspeck, 1990). On previous maps, this unit has been mapped as the Martinez (?) Formation (Cambell and others, 1970) and the Santa Susana Formation (Colburn and Novak, 1989).

The Paleocene rocks in the study area are overlain by early to middle Miocene marine sedimentary rocks of the Lower Topanga Formation. This formation is subdivided into four units (Ttlc, Ttls, Ttlcv, Ttlsv) by Dibblee and Ehrenspeck (1993). Ttlc consists of dark to light gray, thin-bedded micaceous clay shale with a few thin interbeds of hard, semi-siliceous shale or sandstone. Ttls consists of gray to tan, moderately hard sandstone with thin interbeds of gray micaceous shale. Ttlcv and Ttlsv are lithologically identical, respectively, to the other two units but contain fossils of early Miocene age. These two latter units have been mapped previously as the Vaqueros Formation (Yerkes and Campbell, 1979).

The Lower Topanga Formation is overlain by the middle Miocene Conejo Volcanics. The Conejo Volcanics includes both extrusive and intrusive volcanic rocks. The extrusives are subaqueous volcanic rocks capped by subaerial volcanic rocks that apparently represent the growth and emergence of a volcanic landmass from the sea. The subaerial volcanic rocks are strong and resistant and form steep jagged ridges along the crest of Santa Monica Mountains, including Boney Mountain in the Triunfo Pass Quadrangle. The intrusive volcanic rocks include dikes, sills, plugs and pods that were injected into both the underlying Topanga Formation and the Conejo extrusive rocks along vents and fissures that fed the extrusive volcanic pile.

The extrusive volcanic rocks of the Conejo Volcanics are divided into five map units (Tcvdb, Tcvab, Tcvbb, Tcva, Tcvb) by Dibblee and Ehrenspeck (1990). Tcvdb consists of dacitic breccias that were deposited as volcanic debris flows (lahars). These rocks are crudely stratified, hard and resistant and are composed of light pinkish gray to tan unsorted granular fragments of dacite-andesite in a hard detrital matrix of similar composition. Tcvab consists of andesitic breccias that were deposited as lahars and fanglomerates. These rocks are crudely bedded, moderately coherent and are composed of gray, maroon-gray and brown angular andesite fragments in a detrital andesite matrix. Tcvbb consists of basaltic breccias that were deposited as lahars and flow breccias. These rocks consist of angular basaltic fragments in a detrital basalt matrix. Tcva consists of andesite flows and flow breccias. These rocks are unstratified and consist of aphanitic to slightly porphyritic adesite. Tcvb consists of basaltic rocks. These rocks include dark olive-gray to black dense to vesicular flows, pillowed submarine flows and pillow breccias and tuffaceous marine sediments.

The intrusive volcanic rocks of the Conejo Volcanics also were divided into five map units (di, ai, bi, api, db) by Dibblee and Ehrenspeck (1990). The unit di consists of light gray to tan aphanitic to fine-grained dacite to andesite that forms dikes, plugs and pods. This unit may be in part extrusive. The unit ai consists of gray to light brown, aphanitic to fine-grained andesite that forms a large mass in the northeast part of the Triunfo Pass Quadrangle and several smaller dikes. The unit bi consists of gray-black, fine-grained basalt in dikes pods and plugs. The unit api consists of gray to dark olive-gray porphyritic andesite with white feldspar phenocrysts in a fine-grained groundmass. This unit forms dikes and sills. The unit db consists of gray to dark olive-brown, fine- to coarse-grained diabase that forms many lenticular sills and feeder dikes.

Rocks mapped as Upper (?) Topanga Formation by Dibblee and Ehrenspeck (1990) are exposed in a limited area along the coast on the south side of the Malibu Coast Fault. These rocks are divided into two map units (Ttus, Ttub) by Dibblee and Ehrenspeck (1990). Ttus consists of light-gray, thick-bedded to massive sandstone that locally contains blueschist fragments. Ttub is a sedimentary breccia (San Onofre Breccia) composed of subangular blueschist, greenschist, and quartzite cobbles and boulders in a matrix of fragmented schist. These rock units are equivalent to Trancas Formation strata, mapped by Yerkes and Campbell (1979), which also contain lenses of San Onofre Breccia in the Point Dume Quadrangle.

The bedrock units are overlain locally by Pleistocene and Holocene surficial deposits. Pleistocene deposits include dissected alluvial gravel, sand, and silt primarily located on coastal terraces (Qoa). Holocene deposits include beach sand (Qs) and alluvium (Qa). Additional discussion of Quaternary units in the Triunfo Pass Quadrangle can be found in Section 1.

Structural Geology

The Triunfo Pass Quadrangle is within the Santa Monica Mountains which, along with the northern Channel Islands, forms a structural block known as the western Transverse Ranges uplift (Dibblee and Ehrenspeck, 1993). The Santa Monica Mountains portion of this uplift has been squeezed up essentially anticlinally along the north side of the east-trending, north-dipping Malibu Coast-Santa Monica Fault Zone.

A prominent structure in the Triunfo Pass Quadrangle is the east-trending Sequit Anticline. The axis of the Sequit Anticline is several thousand feet inland from the coast and trends roughly parallel to the coast. On the southern limb of the anticline, sandstone and shale beds of the Upper Topanga Formation generally dip southward. Dips range from less than 10 degrees near the axis of the anticline to as much as 70 degrees in some areas near the coast, several thousand feet south of the axis. On the northern limb of the anticline, sedimentary beds of the Upper Topanga Formation as well as volcanic strata of the Conejo Volcanics generally dip northward, typically less than 35 degrees. Dip slope conditions within the map area are more widespread on the south limb of the anticline than on the north limb because some of the south-facing slopes are underlain by south-dipping beds. In addition to the Sequit Anticline, there are a couple of smaller subsidiary folds at the east edge of the map area.

The primary fault in the map area is the Malibu Coast Fault. The Malibu Coast Fault is an east-west trending, north-dipping reverse fault that also has significant left-lateral displacement (Treiman, 1994). The Malibu Coast Fault is part of a larger left-lateral, reverse-oblique fault system that forms the southern boundary of the Transverse Ranges Province. There are several other faults that displace Cenozoic rocks in the map area, including the Boney Mountain Fault and additional unnamed faults (Dibblee and Ehrenspeck, 1990).

Landslide Inventory

As a part of the geologic data compilation, an inventory of existing landslides in the Triunfo Pass Quadrangle was prepared by field reconnaissance, analysis of stereo-paired aerial photographs and a review of previously published landslide mapping (Weber and Wills, 1983; Dibblee and Ehrenspeck, 1990; Irvine, 1994).

Landslides were mapped at a scale of 1:24,000. 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 slope stability analysis. Landslides rated as questionable were not carried into the slope stability analysis due to the uncertainty of their existence. The completed landslide map was scanned, digitized, and the attributes were compiled in a database. A version of this landslide inventory is included with Plate 2.1.

In general, landslides are relatively abundant in the map area along some of the steep canyons that drain the south flank of the Santa Monica Mountains. Landslides are also abundant on the coastal bluffs along the Pacific Coast Highway. The majority of these landslides occur on slopes underlain by folded and faulted rocks of the Lower Topanga Formation (Dibblee and Ehrenspeck, 1990). Landslides developed on these slopes range from shallow failures such as soil and/or rock creep, rock falls, soil and debris slumps, and debris flows to large rotational and translation bedrock landslides, some of which are relatively old and deeply eroded.

Landslides are generally less abundant on slopes underlain by the Conejo Volcanics. The dacite and andesite breccias of the Conejo Volcanics are particularly competent and form resistant outcrops along the crest of Boney Mountain and on some of the other ridge tops in the map area. The subaqueous basalts are somewhat less resistant and are generally more weathered. Landslides developed in the Conejo Volcanics are generally shallow and include debris slides and rock falls that are mostly confined to very steep slopes. Deep-seated bedrock landslides are rare in the Conejo Volcanics in the map area.

ENGINEERING GEOLOGY

Geologic Material Strength

To evaluate the stability of geologic materials under earthquake conditions, the geologic map units were ranked on the basis of their shear strength. Shear strength data for rock units identified on the geologic map were obtained from the City of Malibu, Los Angeles County, and Ventura County (Appendix A). The locations of rock and soil samples taken for shear testing are shown on Plate 2.1. Shear tests from the adjacent Newbury Park and Point Dume quadrangles were used to augment data for several geologic formations that had little or no available shear test information.

To evaluate the stability of geologic materials under earthquake conditions, the geologic map units were ranked on the basis of their shear strength. Shear strength data for rock units identified on the geologic map were obtained from the City of Malibu, Los Angeles County, and Ventura County (Appendix A). The locations of rock and soil samples taken for shear testing are shown on Plate 2.1. Shear tests from the adjacent Newbury Park and Point Dume quadrangles were used to augment data for several geologic formations that had little or no available shear test information.

Shear strength data gathered from the above sources were compiled for each geologic map unit. Geologic units were grouped on the basis of average angle of internal friction (average phi) and lithologic character. Average (mean and median) phi values for each geologic map unit and corresponding strength group are summarized in Table 2.1. Within the Triunfo Pass Quadrangle, no shear tests were found for ai, api, di, Qoa, Qs, Tcvab, Tcvbb, Tcvdb, Ttlcv and Ttub. Shear tests for Tcvab from the Newbury Park Quadrangle were used in the analysis. In additon, shear tests from Point Dume and Newbury Park were used to augment Qa, Tcub, Ttlc, Ttlsv and Tsu. Units with no shear tests were added to existing groups on the basis of lithologic and stratigraphic similarities. A geologic material strength map was made based on the groupings presented in Tables 2.1 and 2.2. This map provides a spatial representation of material strength for use in the slope stability analysis.

One map unit, a member of the Lower Topanga Formation (Ttlsv), was subdivided further, as discussed below.

Adverse Bedding Conditions

Adverse bedding conditions are an important consideration in slope stability analyses. Adverse bedding conditions occur where the dip direction of bedded sedimentary rocks is roughly the same as the slope aspect, and where the dip magnitude is less than the slope gradient. Under these conditions, landslides can slip along bedding surfaces due to a lack of lateral support.

To account for adverse bedding in our slope stability evaluation, we used geologic structural data in combination with digital terrain data to identify areas with potentially adverse bedding, using methods similar to those of Brabb (1983). The structural data, derived from the geologic map database, was used to categorize areas of common bedding dip direction and magnitude. The dip direction was then compared to the slope aspect and, if the same, the dip magnitude and slope gradient categories were compared. If the dip magnitude category was less than or equal to the slope gradient category, but greater than 25% (4:1 slope), the area was marked as a potential adverse bedding area.

Ttlsv, which contains interbedded sand and clay, was subdivided based on shear strength differences between coarse-grained (higher strength) and fine-grained (lower strength) lithologies. Shear strength values for the fine- and coarse-grained lithologies were then applied to areas of favorable and adverse bedding orientation, which were determined from structural and terrain data as discussed above. It was assumed that coarse-grained material strength dominates where bedding dips into a slope (favorable bedding) while fine-grained material strength dominates where bedding dips out of a slope (adverse bedding). The geologic material strength map was modified by assigning the lower, fine-grained shear strength value to areas where adverse bedding was identified. The favorable and adverse bedding shear strength parameters for Ttlsv are included in Table 2.1.

Existing Landslides

The strength characteristics of existing landslides (Qls) 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, and for the preparation of the earthquake-induced landslide zone map it has been assumed that all landslides within the quadrangle have the same slip surface strength parameters. We collect and use 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 used. Within the Triunfo Pass Quadrangle, no strength values for landslide slip surfaces were available. Instead, a phi value of 12^{o} was assumed, and this value is shown in Table 2.1.

TRIUNFO PASS QUADRANGLE SHEAR STRENGTH GROUPS

	Formation Name	Number of Tests	Mean/Median Phi (degrees)	Mean/Median Group Phi (degrees)	Mean/Median Group C (psf)	No Data: Similar Lithology	Phi Values Used in Stability Analysis
GROUP 1	Tcvab	8	40/39	40/39	481/400	di	39
						Tcvdb	
GROUP 2	bi	4	34/3734	35	464/400	ai	35
	db	5	35/40			api	
	Tcva	6	37/35			Tcvbb	
	Tcvb	46	35/36			Ttub	
	Tsu	47	34/35				
	Ttls	3	34/38				
	Ttlsv (fbc)	25	34				
	Ttus	10	36/35				
GROUP 3	af	1	30	28/30	464/425	Qoa	28
	Qa	6	28/25			Qs	
	Qt	2	20			Ttlcv	
	Ttlc	22	29/30				
	Ttlsv(abc)	17	28/30				
GROUP 4	Qls						12
	fbc = Favorable bedding conditions						
	abc = Adverse bedding conditions						
	Formations for strength groups from Dibblee and Ehrenspeck, 1993						

Table 2.1. Summary of the Shear Strength Statistics for the Triunfo Pass Quadrangle.

SHEAR STRENGTH GROUPS FOR THE TRIUNFO PASS 7.5-MINUTE QUADRANGLE			
GROUP 1	**GROUP 2**	**GROUP 3**	**GROUP 4**
di	ai	af	Qls
Tcvab	api	Qa	
Tcvdb	bi	Qoa	
	db	Qs	
	Tcva	Qt	
	Tcvb	Ttlc	
	Tcvbb	Ttlcv	
	Tsu	Ttlsv(abc)	
	Ttls		
	Ttlsv(fbc)		
	Ttus		
	Ttub		
fbc = favorable bedding conditions			
abc = adverse bedding conditions			

Table 2.2. Summary of Shear Strength Groups for the Triunfo Pass Quadrangle.

PART II

EARTHQUAKE-INDUCED LANDSLIDE HAZARD POTENTIAL

Design Strong-Motion Record

To evaluate earthquake-induced landslide hazard potential in the study area, a method of dynamic slope stability analysis developed by Newmark (1965) was used. The Newmark method analyzes dynamic slope stability by calculating the cumulative down-slope displacement for a given earthquake strong-motion time history. As implemented for the preparation of earthquake-induced landslide zones, the Newmark method necessitates the selection of a design earthquake strong-motion record to provide the "ground shaking opportunity." For the Triunfo Pass 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 DMG for a 10% probability of being exceeded in 50 years (Petersen and others, 1996). The parameters used in the record selection are:

Modal Magnitude:	7.3
Modal Distance:	2.5 to 3.7 km
PGA:	0.46 to 0.61 g

The strong-motion record selected for the slope stability analysis in the Trinufo Pass Quadrangle was the Southern California Edison (SCE) Lucerne record from the 1992 magnitude 7.3 Landers, California, earthquake. This record had a source to recording site distance of 1.1 km and a peak ground acceleration (PGA) of 0.80g. Although the distance and PGA values of the Lucerne record do not fall within the range of the probabilistic parameters, this record was considered to be sufficiently conservative to be used in the stability analyses. The selected strong-motion record was not scaled or otherwise modified prior to its use in the analysis.

Displacement Calculation

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

The amount of displacement predicted by the Newmark analysis provides an indication of the relative amount of damage that could be caused by earthquake-induced landsliding. Displacements of 30, 15 and 5 cm were used as criteria for rating levels of earthquake-induced landslide hazard potential based on the work of Youd (1980), Wilson and Keefer (1983), and a DMG pilot study for earthquake-induced landslides (McCrink and Real, 1996). Applied to the curve in Figure 2.1, these displacements correspond to yield accelerations of 0.142, 0.182, and 0.243 g. Because these yield acceleration values are derived from the design strong-motion record, they represent the ground shaking opportunity thresholds that are significant to the Triunfo Pass Quadrangle.

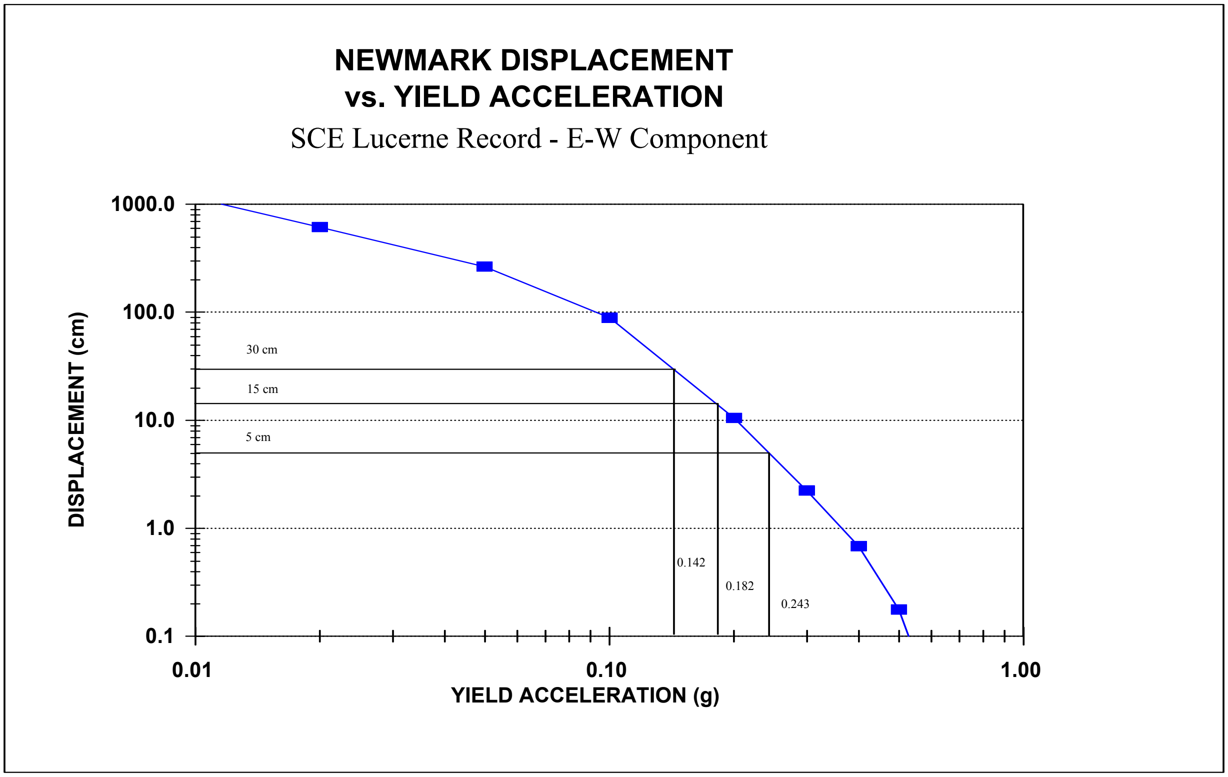

Figure 2.1. Yield Acceleration vs. Newmark Displacement for the 1992 Landers Earthquake SCE Lucerne Record.

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 0.142g, Newmark displacement greater than 30 cm is indicated, and a HIGH hazard potential was assigned (H on Table 2.3)

2. If the calculated yield acceleration fell between 0.142g and 0182.g, Newmark displacement between 15 cm and 30 cm is indicated, and a MODERATE hazard potential was assigned (M on Table 2.3)

3. If the calculated yield acceleration fell between 0.182g and 0.243g, Newmark displacement between 5 cm and 15 cm is indicated, and a LOW hazard potential was assigned (L on Table 2.3)

4. If the calculated yield acceleration was greater than 0.243g, Newmark displacement of less than 5 cm is indicated, and a VERY LOW potential was assigned (VL on Table 2.3)

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.

TRIUNFO PASS QUADRANGLE HAZARD POTENTIAL MATRIX

Geologic Material Group	MEAN PHI	SLOPE CATEGORY (% SLOPE)										
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI
		0-3	3-8	8-28	28-34	34-38	38-46	46-50	50-55	55-60	60-64	>64
1	39	VL	VL	VL	VL	VL	VL	VL	VL	L	M	H
2	35	VL	VL	VL	VL	VL	VL	L	M	H	H	H
3	28	VL	VL	VL	L	M	H	H	H	H	H	H
4	12	L	M	H	H	H	H	H	H	H	H	H

Table 2.3. Hazard Potential Matrix for Earthquake-Induced Landslides in the Triunfo Pass Quadrangle. Shaded area indicates hazard potential levels included within the earthquake-induced landslide hazard zone. H = High, M = Moderate, L = Low, VL = Very Low.

EARTHQUAKE-INDUCED LANDSLIDE HAZARD ZONE

Criteria for Zoning

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

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

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

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

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.

Geologic and Geotechnical Analysis

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

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

1. Geologic Strength Group 4 is included for all slope gradient categories. (Note: Geologic Strength Group 4 includes all mappable landslides with a definite or probable confidence rating).

2. Geologic Strength Group 3 is included for all slopes steeper than 28 percent.

3. Geologic Strength Group 2 is included for all slopes steeper than 46 percent.

4. Geologic Strength Group 1 is included for all slopes steeper than 55 percent.

This results in 26 percent of the Triunfo Pass Quadrangle lying within the earthquake-induced landslide hazard zone.

ACKNOWLEDGMENTS

The authors would like to thank the following individuals and organizations for their assistance in obtaining the data necessary to complete this project. Geologic material strength data were collected at the City of Malibu with the assistance of Christopher Dean and Jeffrey Wilson (Bing Yen and Associates, geotechnical consultants to the City of Malibu), and Victor Peterson and Martha Graham (City of Malibu). Greg Johnson and Robert Larson (Los Angeles County) provided assistance with data collection for Los Angeles County. James O'Tousa, Larry Cardozo, and LaVonne Driver (Ventura County Public Works) provided assistance with data collection for Ventura County. Randy Jibson of the U.S. Geological Survey provided digital terrain data. Pamela Irvine reviewed the landslide inventory mapping. GIS support was provided by Terilee McGuire and Bob Moscovitz. Barbara Wanish and Ross Martin prepared the final landslide hazard zone maps and the graphic displays for this report.

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AIR PHOTOS

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I.K. Curtis Services, Inc., Malibu Fire Photos, November 19, 1993; Frames 1-1 through 1-9, 2-1 through 2-9, 3-1 through 3-9, 4-1 through 4-9, Color, Vertical, scale 1: ~14,400.

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USGS (NAPP Photos), Roll 6860, June 1994, Frames 20-22 and 260-262, Black and White, Vertical, scale 1:40,000.

APPENDIX A
SOURCE OF ROCK STRENGTH DATA

SOURCE	NUMBER OF TESTS SELECTED
City of Malibu	39
County of Los Angeles	39
County of Ventura	14
Point Dume Quadrangle	80
Newbury Park Quadrangle	27
Total Number of Shear Tests	199

SECTION 3
GROUND SHAKING EVALUATION REPORT

Potential Ground Shaking in the Triunfo Pass 7.5-Minute Quadrangle, Los Angeles and Ventura Counties, California

By

Mark D. Petersen*, Chris H. Cramer*, Geoffrey A. Faneros, Charles R. Real, and Michael S. Reichle

California Department of Conservation
Division of Mines and Geology
***Formerly with DMG, now with U.S. Geological Survey**

PURPOSE

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

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

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

EARTHQUAKE HAZARD MODEL

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

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

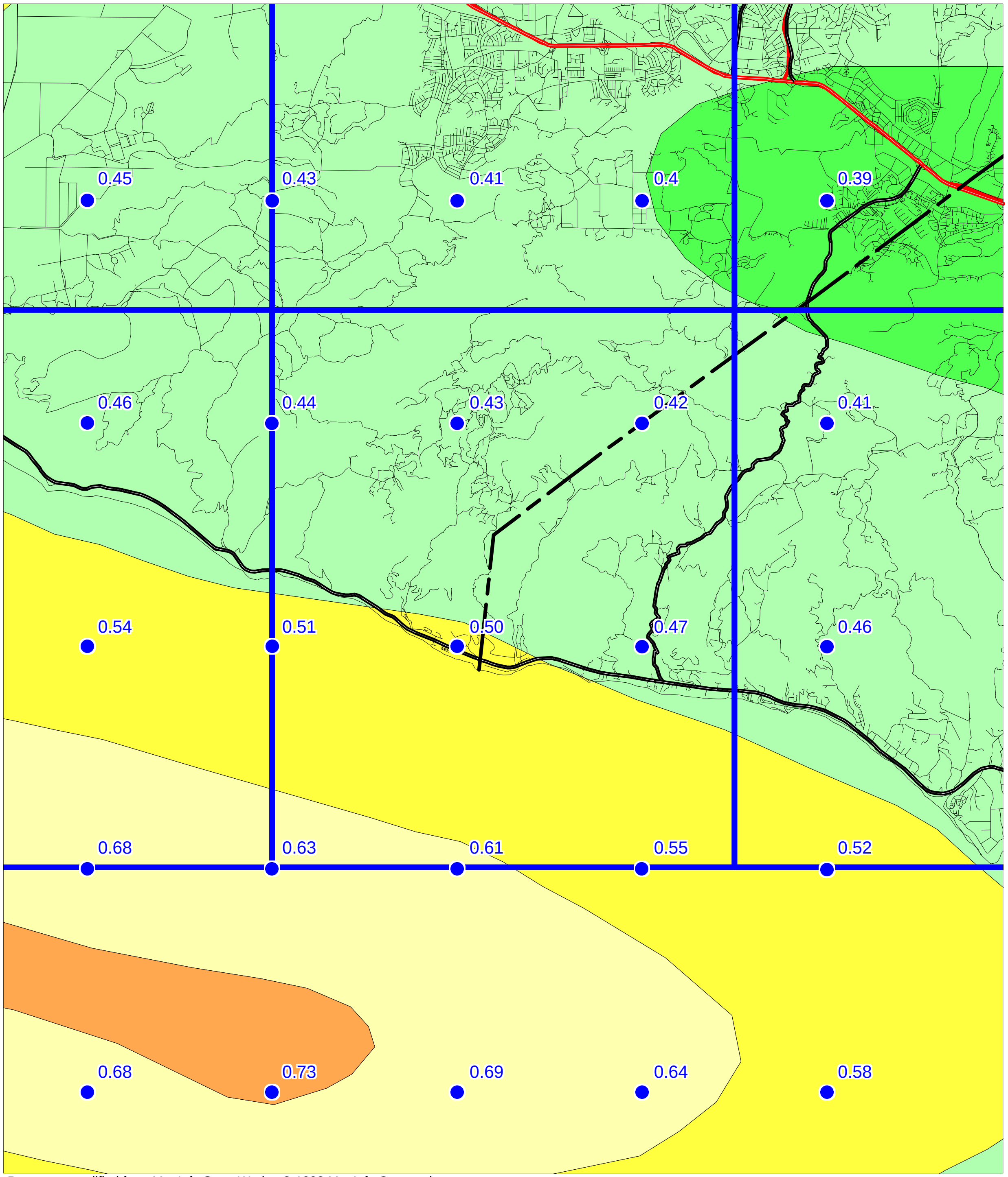
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10% probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively.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

TRIUNFO PASS 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

FIRM ROCK CONDITIONS



0 2.5 5

Kilometers

Department of Conservation
Division of Mines and Geology

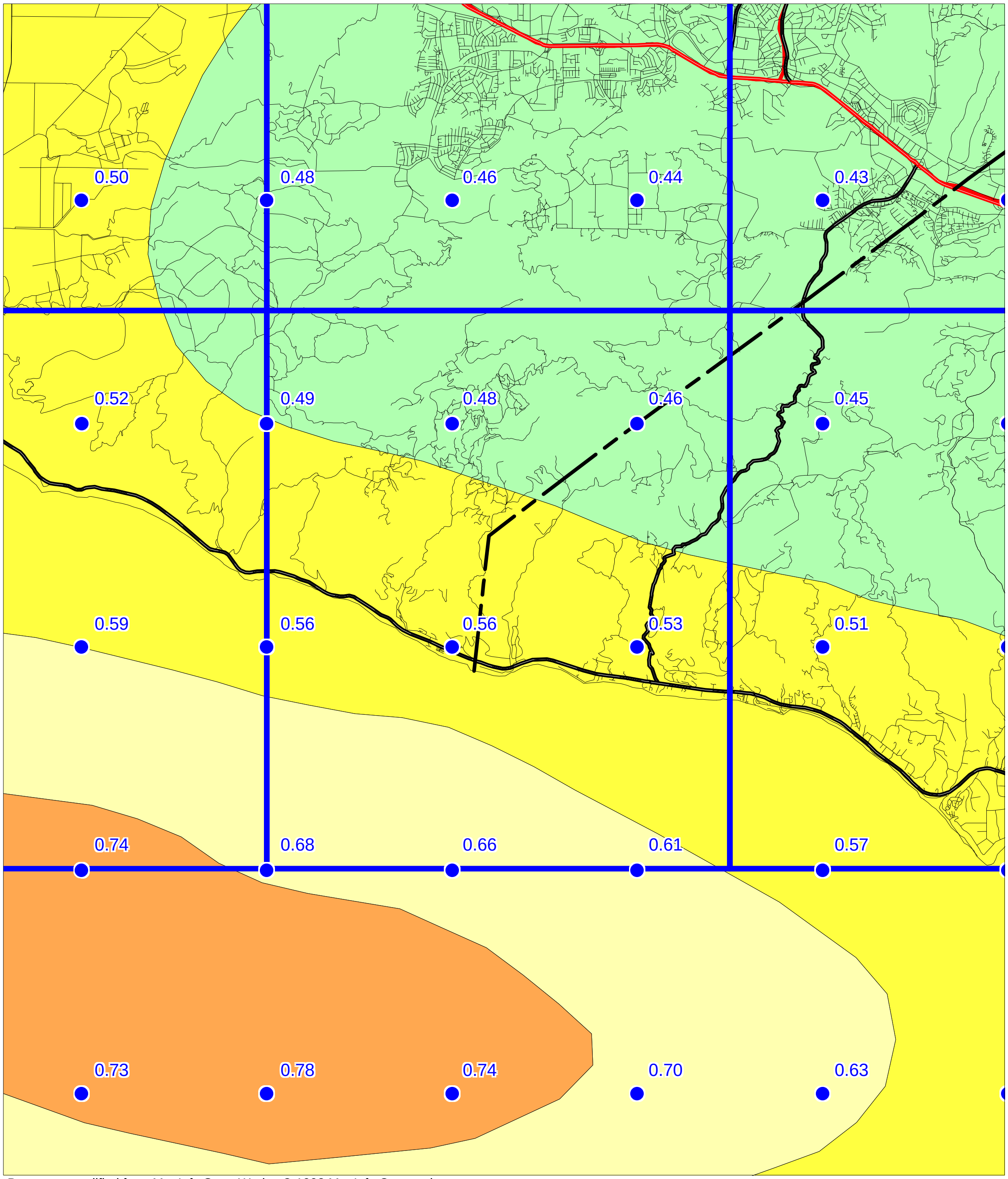
Figure 3.1

TRIUNFO PASS 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

SOFT ROCK CONDITIONS



0 2.5 5
Kilometers

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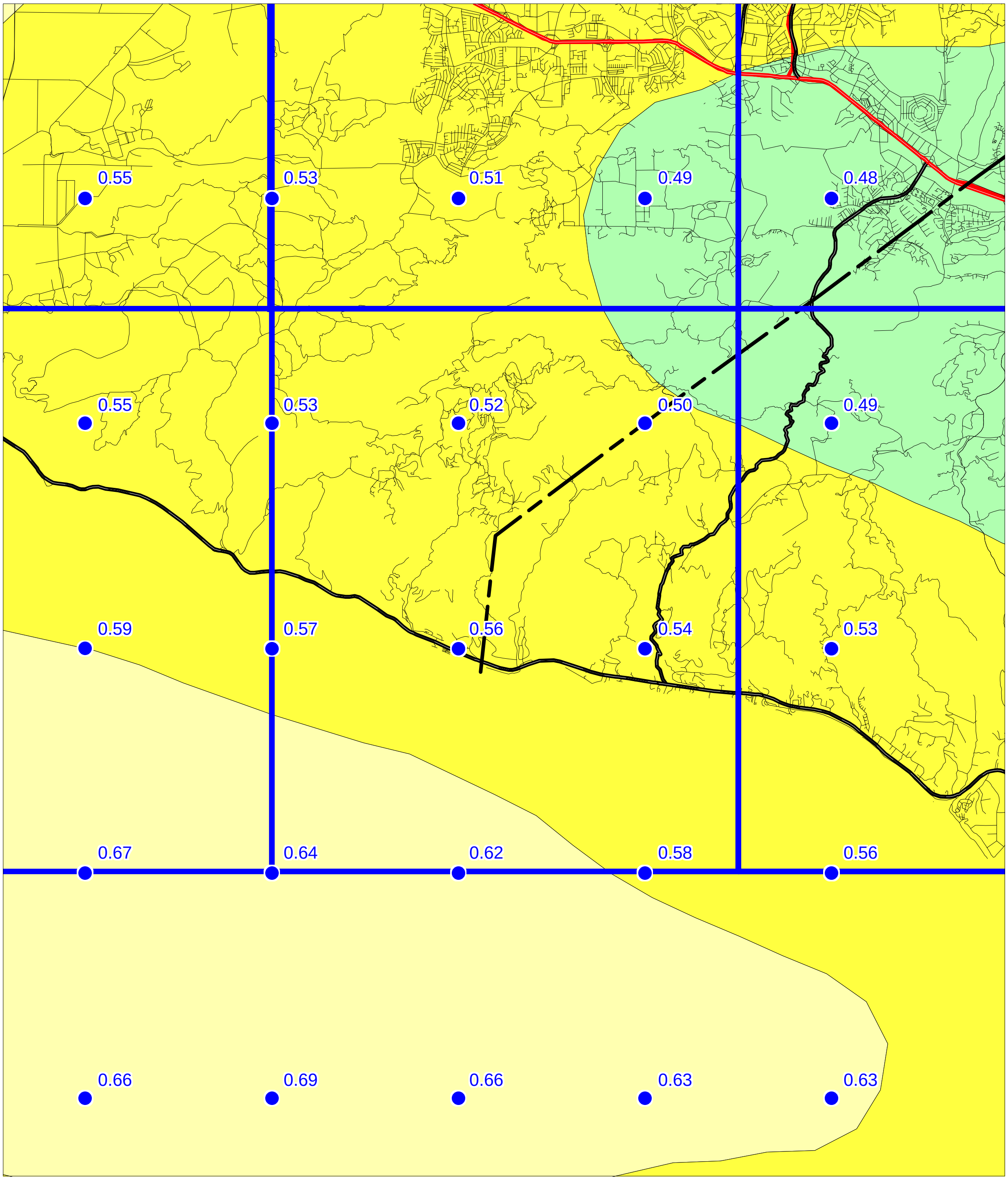
Figure 3.2

TRIUNFO PASS 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

ALLUVIUM CONDITIONS



Base map modified from MapInfo Street Works ©1998 MapInfo Corporation

0 2.5 5
Kilometers

Department of Conservation
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Figure 3.3

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

APPLICATIONS FOR LIQUEFACTION AND LANDSLIDE HAZARD ASSESSMENTS

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

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

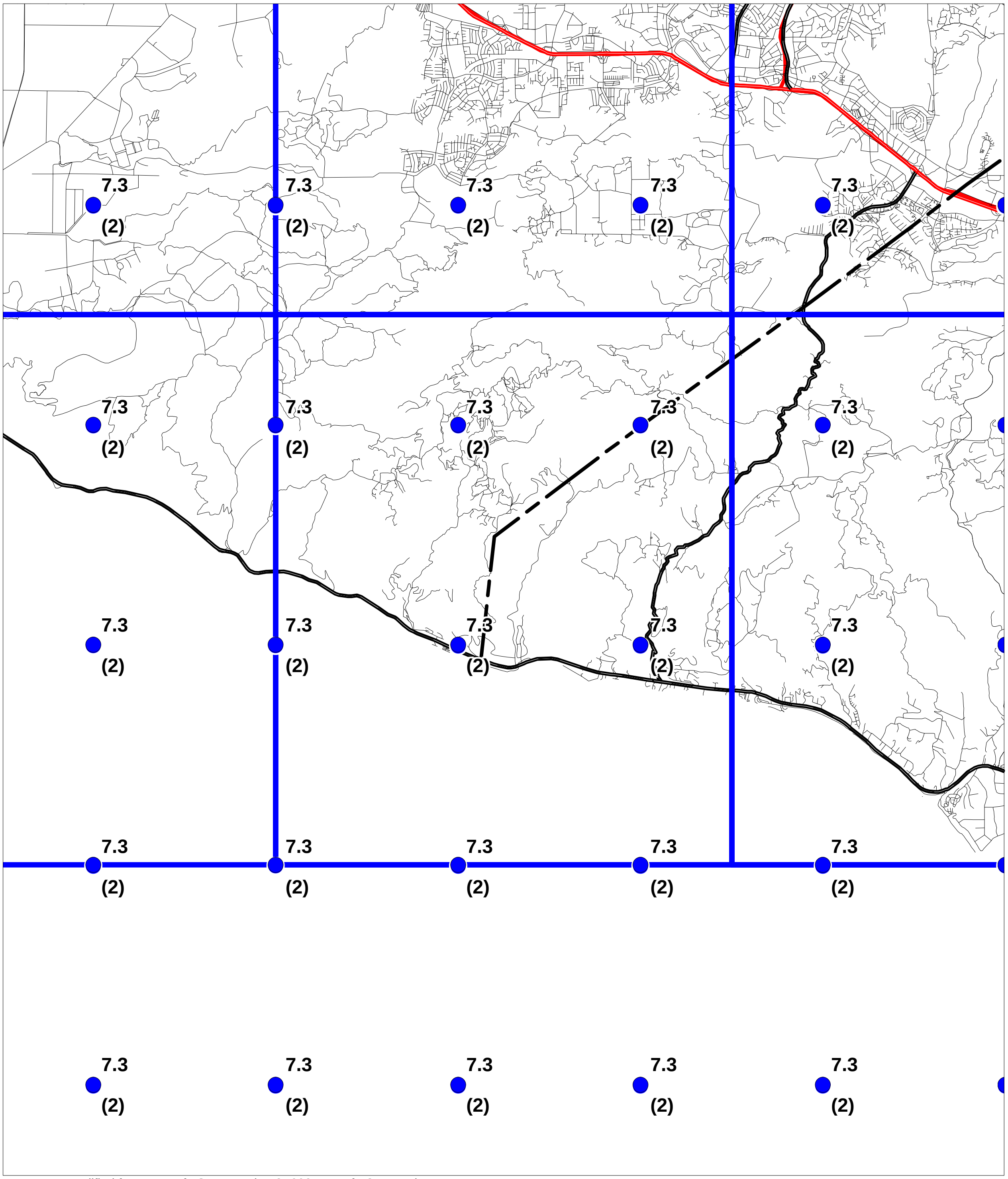
Figure 3.5 shows the magnitude-weighted alluvial PGA based on Idriss' weighting function (Youd and Idriss, 1997). It is important to note that the values obtained from this map are pseudo-accelerations and should be used in the formula for factor of safety without any magnitude-scaling (a factor of 1)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

TRIUNFO PASS 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION

1998

PREDOMINANT EARTHQUAKE
Magnitude (Mw)
(Distance (km))



Base map modified from MapInfo StreetWorks ©1998 MapInfo Corporation

0 2.5 5
Kilometers

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Division of Mines and Geology

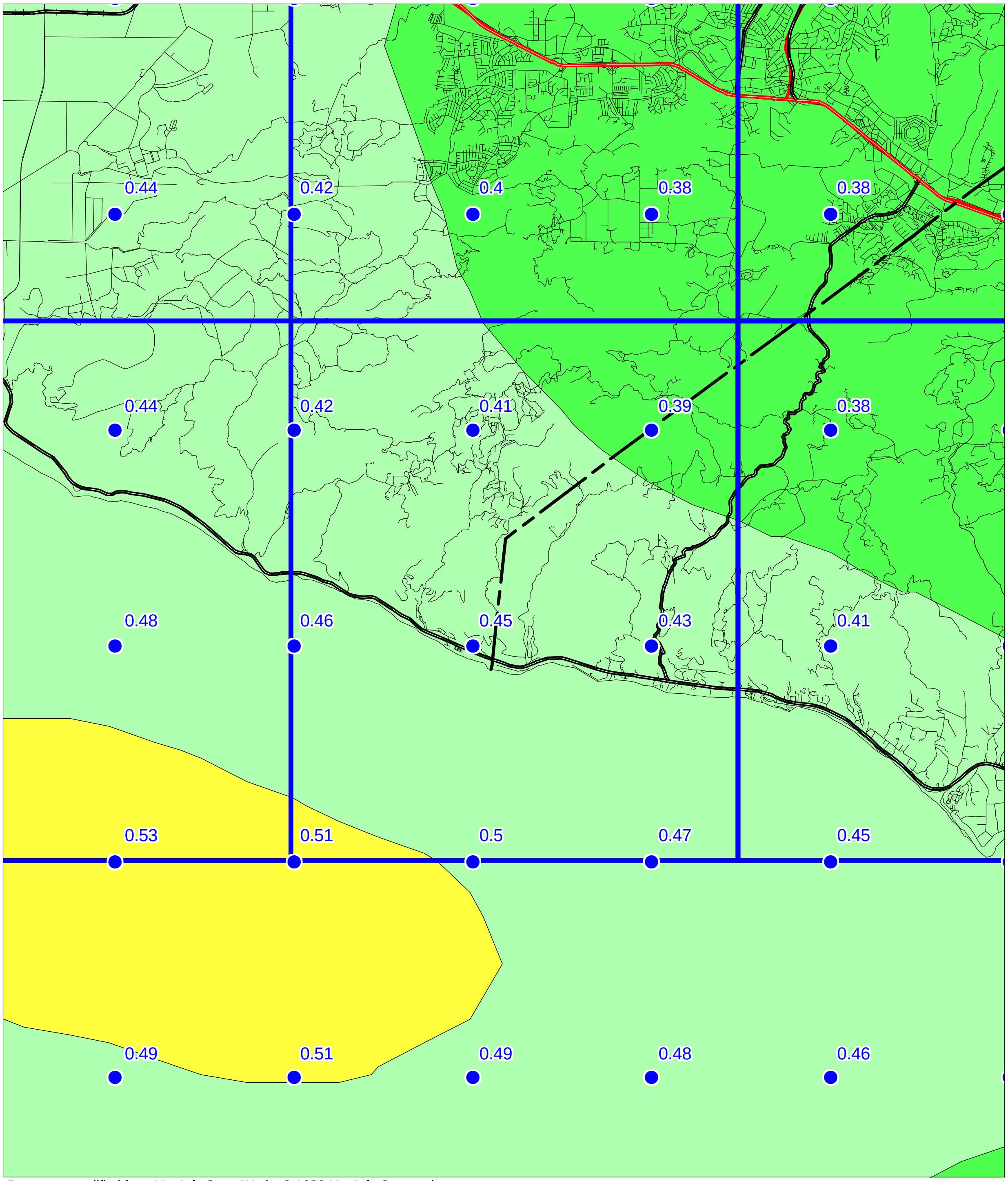
Figure 3.4

TRIUNFO PASS 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS MAGNITUDE-WEIGHTED PSEUDO-PEAK ACCELERATION (g) FOR ALLUVIUM

2001

LIQUEFACTION OPPORTUNITY



Base map modified from MapInfo StreetWorks © 1998 MapInfo Corporation

0 1.5 3
Miles

Department of Conservation
Division of Mines and Geology

Figure 3.5

USE AND LIMITATIONS

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

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

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

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

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

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

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

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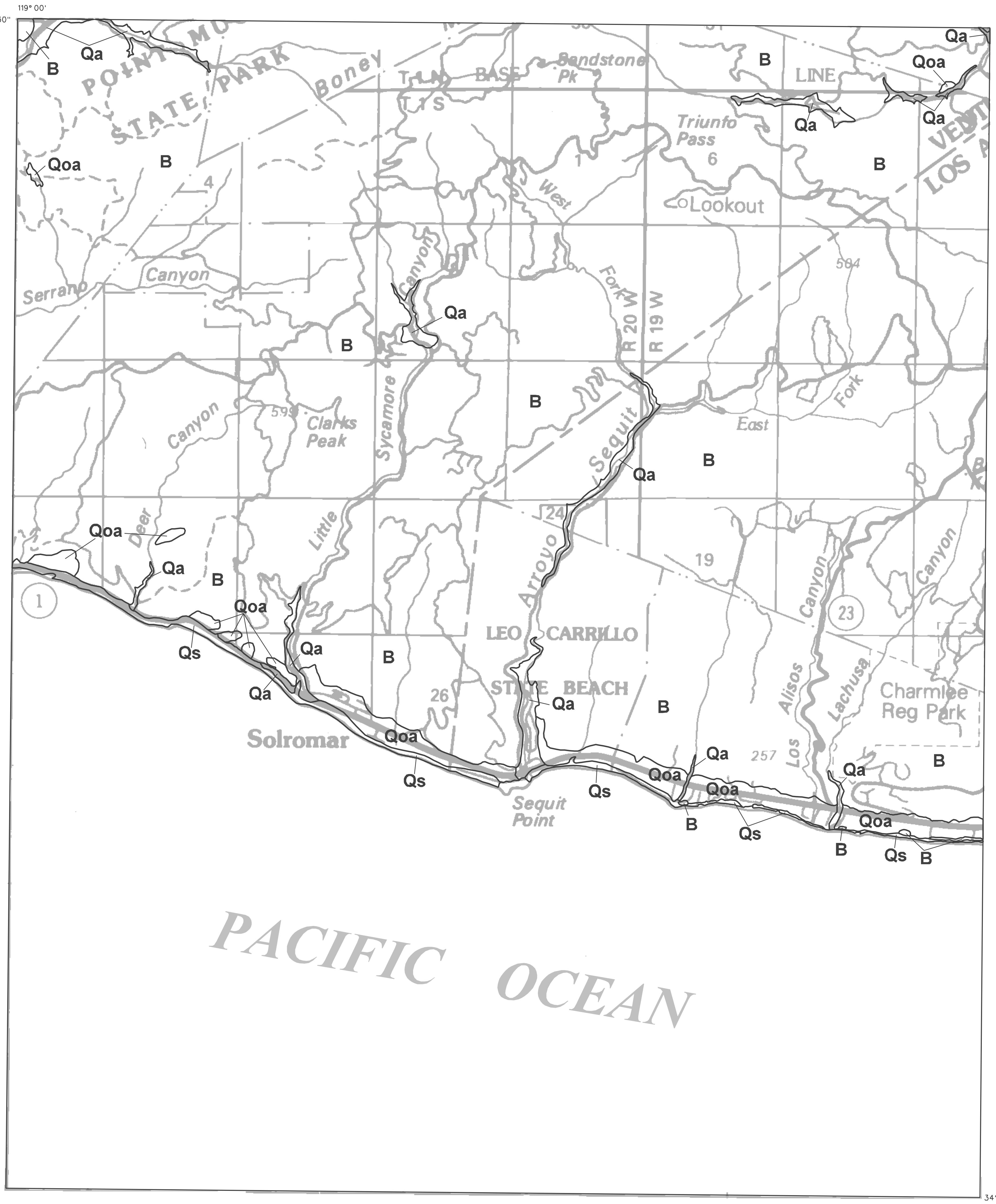


Base map enlarged from U S G S 30 x 60–minute series

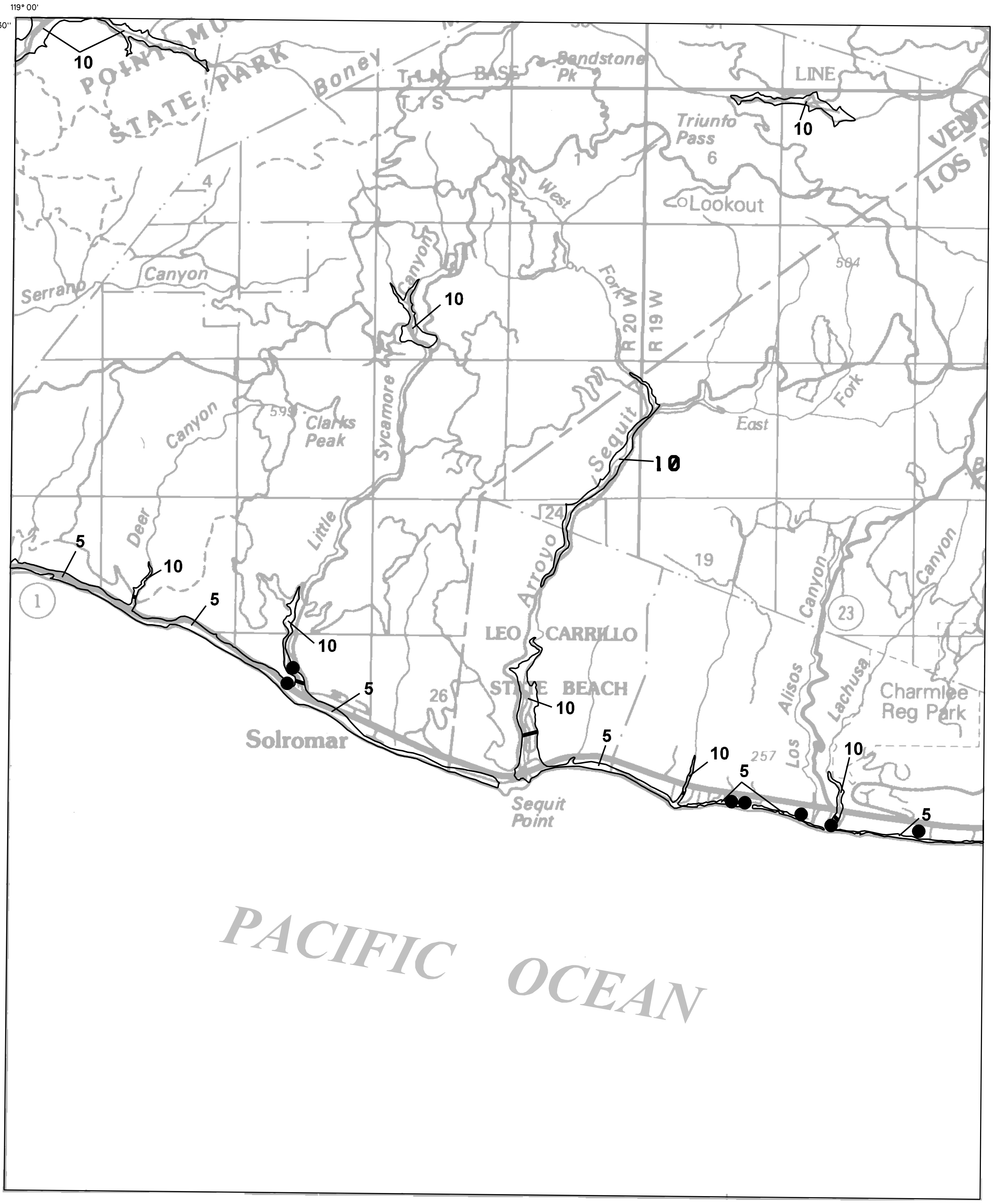
TRIUNFO PASS QUADRANGLE

SCALE

B = Pre-Quaternary bedrock

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

Plate 1.1 Quaternary Geologic Map of the Triunfo Pass 7.5-minute Quadrangle (from Dibblee & Ehrenspeck, 1990)



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

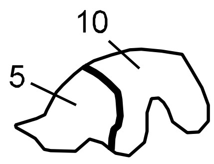
TRIUNFO PASS QUADRANGLE

SCALE

1 MILE; 1000 0 1000 2000 3000 4000 5000 6000 7000 FEET; 1 KILOMETER

N

● Borehole Site



Alluviated valley and zones of estimated historically highest ground-water depth (in feet)
B = Pre-Quaternary bedrock

Plate 1.2 Historically highest ground water within alluviated valleys, and borehole locations, Triunfo Pass 7.5-minute Quadrangle.

DIVISION OF MINES AND GEOLOGY
JAMES F. DAVIS, STATE GEOLOGIST

STATE OF CALIFORNIA-GRAY DAVIS, GOVERNOR
THE RESOURCES AGENCY-MARY D. NICHOLS, SECRETARY
DEPARTMENT OF CONSERVATION-DARRYL W. YOUNG, DIRECTOR

Truinfo Pass Quadrangle Plate 2.1
SEISMIC HAZARD ZONE REPORT 059

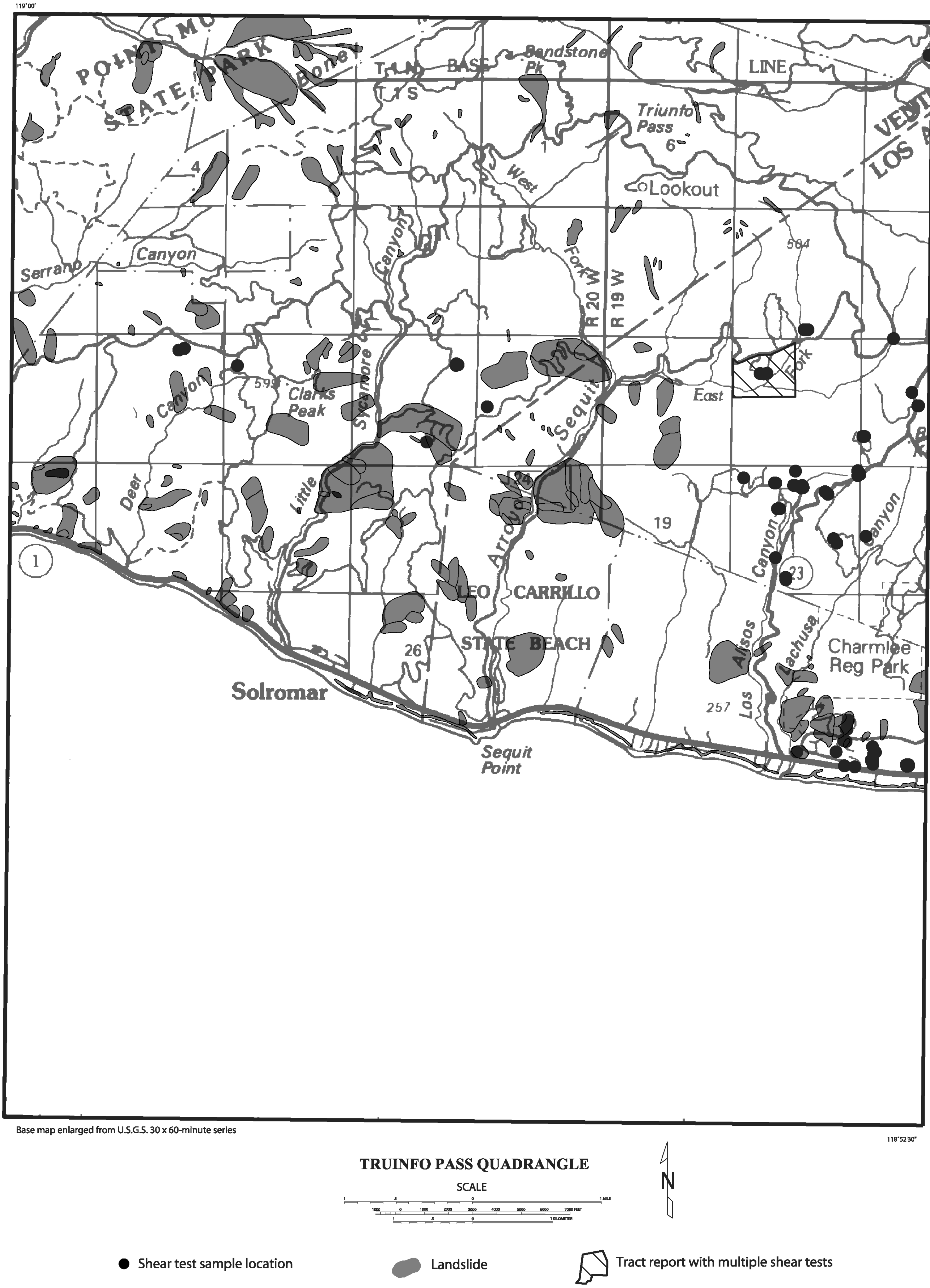


Plate 2.1 Landslide inventory and shear test sample locations, Truinfo Pass 7.5-minute quadrangle.