SEISMIC HAZARD ZONE REPORT 072

SEISMIC HAZARD ZONE REPORT FOR THE OJAI 7.5-MINUTE QUADRANGLE, VENTURA COUNTY, CALIFORNIA

2002

DEPARTMENT OF CONSERVATION
California Geological Survey

STATE OF CALIFORNIA
GRAY DAVIS
GOVERNOR

THE RESOURCES AGENCY
MARY D. NICHOLS
SECRETARY FOR RESOURCES

DEPARTMENT OF CONSERVATION
DARRYL YOUNG
DIRECTOR

CALIFORNIA GEOLOGICAL SURVEY
JAMES F. DAVIS, *STATE GEOLOGIST*

SEISMIC HAZARD ZONE REPORT 072

SEISMIC HAZARD ZONE REPORT FOR THE OJAI 7.5-MINUTE QUADRANGLE, VENTURA COUNTY, CALIFORNIA

CALIFORNIA GEOLOGICAL SURVEY'S PUBLICATION SALES OFFICES:

Southern California Regional Office
888 South Figueroa Street, Suite 475
Los Angeles, CA 90017
(213) 239-0878

Publications and Information Office
801 K Street, MS 14-31
Sacramento, CA 95814-3531
(916) 445-5716

Bay Area Regional Office
345 Middlefield Road, MS 520
Menlo Park, CA 94025
(650) 688-6327

List of Revisions – Ojai SHZR 72	
6/3/05	BPS address correction, web link updates
1/17/06	Regional office addresses updated

CONTENTS

ILLUSTRATIONS

EXECUTIVE SUMMARY

This report summarizes the methods and sources of information used to prepare the Seismic Hazard Zone Map for the Ojai 7.5-minute Quadrangle, Ventura County, California. The map displays the boundaries of Zones of Required Investigation for liquefaction and earthquake-induced landslides over an area of approximately 52 square miles at a scale of 1 inch = 2,000 feet. Approximately 10 square miles in the northwestern and northeastern corners of the quadrangle were not evaluated for zoning because the area is Los Padres National Forest land.

The Ojai Quadrangle, in southern Ventura County, includes the eastern portion of the City of Ojai and the unincorporated community of Summit near the eastern boundary. Steep, rugged terrain of the Santa Ynez-Topatopa Mountains covers the northern third of the area. Streams draining the mountains have built large alluvial fans on the northeastern side of Ojai Valley. The central part of the area contains Black Mountain (Lion Mountain) and Sulphur Mountain, which nearly surround Upper Ojai Valley on the northwest and south, respectively. Upper Ojai Valley drains in two directions –westward toward San Antonio Creek, and southeastward toward Santa Paula Creek. The rugged southern slopes of Sulphur Mountain occupy the southern part of the quadrangle. Elevations range from about 700 feet above sea level in the valleys to 5526 feet in the northeast corner. State Highway 150 traverses the center of the Ojai Quadrangle and it connects with State Highway 33 west of the map area. Residential development is concentrated in the valley areas with scattered development in the canyons, on the hillsides, and along Sulphur Mountain Road on the crest of Sulphur Mountain. Other land use includes oil fields, cattle grazing, citrus and avocado orchards, parkland, campgrounds, golf courses, and the national forest.

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.

In the Ojai Quadrangle the liquefaction zone is restricted to the central part of Ojai Valley with extensions along San Antonio, Thacher, and Reeves creeks, a small area under downtown Ojai, and in central part of Upper Ojai Valley along Lion Creek. The combination of steep, deeply dissected topography, intensive structural deformation, and weak marine sedimentary rock units has produced widespread and abundant landslides. These conditions contribute to an earthquake-induced landslide zone that covers about 56 percent of the evaluated portion of the 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 California Geological Survey's Internet page: http://www.conservation.ca.gov/CGS/index.htm

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

BPS Reprographic Services
945 Bryant Street
San Francisco, 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 CGS 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) [now called California Geological Survey (CGS)] to delineate seismic hazard zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic hazard zone maps in their land-use planning and permitting processes. They must withhold development permits for a site within a zone until the geologic and soil conditions of the project site are investigated and appropriate mitigation measures, if any, are incorporated into development plans. The Act also requires sellers (and their agents) of real property within a mapped hazard zone to disclose at the time of sale that the property lies within such a zone. Evaluation and mitigation of seismic hazards are to be conducted under guidelines adopted by the California State Mining and Geology Board (SMGB) (DOC, 1997). The text of this report is on the Internet at http://gmw.consrv.ca.gov/shmp/webdocs/sp117.pdf

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 CGS to develop a set of probabilistic seismic maps for California and to research methods that might be appropriate for mapping earthquake-induced landslide hazards.

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

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 Ojai 7.5-minute Quadrangle.

SECTION 1
LIQUEFACTION EVALUATION REPORT

Liquefaction Zones in Part of the Ojai 7.5-Minute Quadrangle, Ventura County, California

By
Marvin Woods

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

Following the release of DMG Special Publication 117 (DOC, 1997), agencies in the Los Angeles metropolitan region sought more definitive guidance in the review of geotechnical investigations addressing liquefaction hazards. The agencies made their request through the Geotechnical Engineering Group of the Los Angeles Section of the American Society of Civil Engineers (ASCE). This group convened an implementation committee under the auspices of the Southern California Earthquake Center (SCEC).

The committee, which consisted of practicing geotechnical engineers and engineering geologists, released an overview of the practice of liquefaction analysis, evaluation, and mitigation techniques (SCEC, 1999). This text is also on the Internet at: http://www.scec.org/

This section of the evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils in part of the Ojai 7.5-minute Quadrangle. Approximately one third of the quadrangle (the northern part) is within the Los Padres National Forest land. Most of this land was not evaluated. Section 2 (addressing earthquake-induced landslides) and Section 3 (addressing potential ground shaking), complete the report, which is one of a series that summarizes production of similar seismic hazard zone maps within the state (Smith, 1996). Additional information on seismic hazards zone mapping in California is on CGS's Internet web page: http://www.conservation.ca.gov/CGS/index.htm

BACKGROUND

Liquefaction-induced ground failure historically has been a major cause of earthquake damage in 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 Ojai 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 CGS probabilistic shaking maps

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

SCOPE AND LIMITATIONS

Evaluation for potentially liquefiable soils generally is confined to areas covered by Quaternary (less than about 1.6 million years) sedimentary deposits. Such areas within the Ojai Quadrangle consist mainly of alluviated valleys, floodplains, and canyons. CGS's liquefaction hazard evaluations are based on information on earthquake ground shaking, surface and subsurface lithology, geotechnical soil properties, and 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 include 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 Ojai Quadrangle covers approximately 61 square miles in southern Ventura County and includes most of the City of Ojai along the western boundary and the unincorporated community of Summit near the eastern boundary. The City of Ojai is located about 12 miles north of the county seat at Ventura. Approximately 10 square miles in the northwestern and northeastern corners of the quadrangle were not evaluated for zoning because the land lies within Los Padres National Forest.

The northern third of the Ojai Quadrangle is dominated by steep mountainous terrain of the Santa Ynez-Topatopa Mountains. Ojai Valley lies along the southern edge of the mountain range. Numerous streams draining the southern slopes of the mountains have built large alluvial fans on the northeastern side of Ojai Valley. Drainage in Ojai Valley is toward the southwest via San Antonio Creek to the Ventura River. The central part of the map area is characterized by hilly and mountainous terrain of Black Mountain (Lion Mountain) and Sulphur Mountain, which nearly surround the gently sloping lowlands of Upper Ojai Valley on the northwest and south, respectively. Upper Ojai Valley drains in two directions –westward via Lion Creek to San Antonio Creek and southeastward from Sisar Creek to Santa Paula Creek. The rugged southern slopes of Sulphur Mountain, which are cut by several wide, flat-bottomed canyons, occupy the southern part of the quadrangle. Drainage from Sulphur Canyon and Hammond Canyon on the west flows to the south-southwest via Cañada Larga to the Ventura River. Drainage from Aliso Canyon and Wheeler Canyon on the east flows south to the Santa Clara River. Elevations range from about 700 feet above sea level in the valleys and canyons in the central and southern part of the quadrangle to 5526 feet in the northeast corner of the quadrangle.

State Highway 150 traverses the center of the Ojai Quadrangle and is the major east-west transportation route through the Upper Ojai and Ojai valleys. West of the map area, it connects with State Highway 33, which follows the Ventura River south to Ventura. East of the quadrangle, Highway 150 curves to the south and follows Santa Paula Creek to Santa Paula. Access to less developed areas is provided by fire roads, ranch roads, and oil field roads.

Residential development is concentrated in the valley areas with scattered development in the canyons, on the hillsides, and along Sulphur Mountain Road on the crest of Sulphur Mountain. Other land use in the area includes oil drilling and production in the Ojai Oil Field (Lion Mountain, Sisar Creek, North Sulphur Mountain, Sulphur Mountain, and Sulphur Crest areas), cattle grazing, citrus and avocado orchards, parkland, campgrounds, golf courses, and several small reservoirs. The northern third of the quadrangle lies within Los Padres National Forest.

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 Ojai Quadrangle, we obtained 1:24,000-scale digital Quaternary maps from William Lettis & Associates, Inc. (WLA, 2001) and digitized a 1:24,000-scale geologic map from the

Dibblee Geological Foundation (Dibblee, 1987). These GIS maps were combined, with minor modifications along the bedrock/Quaternary contact, to form a single geologic map of the Ojai Quadrangle. The distribution of Quaternary deposits on this map (summarized on Plate 1.1) was used in combination with other data, discussed below, to evaluate liquefaction susceptibility and develop the Seismic Hazard Zone Map.

Sedimentary deposits of Quaternary age cover approximately 33 percent of the Ojai Quadrangle. These relatively young deposits occur chiefly within Ojai Valley, Upper Ojai Valley, Senior Canyon, and several smaller canyons located mostly within the southern part of the quadrangle.

Characteristics of Quaternary sedimentary deposits mapped within the Ojai Quadrangle are summarized in Table 1.1. One third of the Quaternary sedimentary deposits within the evaluation area are "older," or Pleistocene age units. These include alluvial valley deposits (Qoa), stream terrace deposits (Qoat), alluvial fan deposits (Qof), and pediment gravel deposits (Qog, Qop). All of these deposits may contain a wide range of material, from cobble gravel to clay. The older units tend to be weakly to well consolidated and dense, with little to no susceptibility to liquefaction. These older units are well expressed chiefly in the area of the City of Ojai, in the east end of Ojai Valley, among the hillsides flanking Sisar Creek, and in the Lion Canyon area.

Active and historical stream wash deposits (Qw1, Qw2), consisting of gravel, sand, and silt, mark the drainages of most of the named creeks within the quadrangle. Young (Holocene to late Pleistocene) axial valley deposits (Qya1, Qya2) of gravel, sand, and silt occur within historical stream valleys, in particular the valleys of Reeves, Wilsie, Thacher, and San Antonio creeks of Ojai Valley, and Wheeler Canyon in the southeast corner of the quadrangle. In all of these cases, the Qya deposits flank Qw deposits. Qya deposits also occur within the remaining southern border canyons (Aliso, Hammond, and Sulphur) where they dominate the Quaternary deposits. Both the axial valley and stream wash deposits tend to be loose and, when saturated, susceptible to liquefaction. Alluvial fan deposits (Qyf1, Qyf2) of Holocene to late Pleistocene age are widespread throughout Ojai Valley, including the small upland valley separated from the north side of Ojai Valley by Ladera Ridge. Young alluvial fan deposits also flank the southern margin of Upper Ojai Valley and are prominent in the eastern end of Upper Ojai Valley, around Summit School. Young stream terrace deposits (Qyat1, Qyat2) dominate Upper Ojai Valley, and are well developed along San Antonio and Thacher creeks. These deposits also occur as small patches flanking younger Qya, Qw, or Qyf deposits within Lion, Hammond, Aliso, Wheeler, Senior, and Sisar canyons.

Pre-Quaternary bedrock exposed in the Ojai Quadrangle, as mapped by Dibblee (1987), consists of clastic sedimentary rocks of Tertiary age (Eocene through Pliocene) deposited within the Ventura Basin. The entire sequence of pre-Quaternary rocks consists of marine sandstone, shale, and some siltstone, except for the Oligocene Sespe Formation (Dibblee, 1987). The Sespe is a non-marine redbed unit that includes pebble-cobble conglomerate in addition to shale and sandstone. See the earthquake-induced landslide portion (Section 2) of this report for further details on pre-Quaternary geology.

Geologic Map Unit	Sediment Type	Environment of Deposition	Consistency	Age	Susceptible To Liquefaction? *
Qyf1, Qyf2	gravel, sand, silt, clay	Alluvial fans	loose to moderately dense	Historical to Pleistocene	yes**
Qw	gravel, sand, silt	Stream channels	loose	Active & Historical	yes
Qya1, Qya2	gravel, sand, silt	young axial-valley deposits	loose to moderately dense	Late Holocene to Pleistocene	yes
Qyat1, Qyat2	Sand, silt, clay	young stream terrace	loose to moderately dense	Late Holocene to Pleistocene	yes**
Qoa	gravel, sand, silt, clay	old alluvial valley deposits	moderately dense to very dense	Pleistocene	not likely
Qoat1, Qoat2	gravel, sand, silt, clay	old stream terrace	moderately dense to very dense	Pleistocene	not likely
Qof	gravel, sand, silt, clay	old alluvial fan deposits	moderately dense to very dense	Pleistocene	not likely
Qog, Qop	cobble-boulder gravel, sand	old pediment gravel deposits	dense to very dense	Pleistocene	no

* when saturated ** Not likely if deposit is mostly clay or sand and silt layers are clayey

Table 1.1. Quaternary Map Units Used in the Ojai 7.5-Minute Quadrangle and Their Geotechnical Characteristics and Liquefaction Susceptibility

Structural Geology

The Ojai Quadrangle is within the western Transverse Ranges. Uplift, folding, and faulting, which began in Tertiary time, continues to the present. The sequence of Cretaceous and Tertiary rocks is folded and faulted, with fold axes and faults trending east-west to northeast-southwest. Rock units older than the Sespe Formation occur only in the northern third of the quadrangle and form the main part of the Santa Ynez Mountains. They are mostly overturned, with northward dips as low as 50 degrees. Several steeply south-dipping reverse faults (among them the San Cayetano, Santa Ana, Lion, Big Canyon, and Sisar faults) pass through the middle of the quadrangle, generally separating older (pre-Sespe) rocks in the north from younger (Sespe and younger) rocks in the south. In the Ojai Valley / Upper Ojai Valley area, Rockwell (1988) documented Holocene movement along the San Cayetano Fault where rocks of the Miocene Monterey Formation have been faulted over Holocene colluvium. Rockwell (1988) also mapped numerous uplifted Pleistocene and Holocene alluvial terrace surfaces. Keller and others (1981) also mapped tilted and/or faulted geomorphic surfaces.

ENGINEERING GEOLOGY

Information on subsurface geology and engineering characteristics of young sedimentary deposits was obtained from borehole logs collected from reports on geotechnical and environmental projects. For this investigation, 20 borehole logs were collected from the files of the Ventura County Public Works Agency and the California Department of Transportation. Data from all of these borehole logs were entered into a CGS 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. SPTs record the number of blows by a 140-pound weight dropped 30 inches required to drive a sampler of specific dimensions one foot into the soil. The SPT method is formally defined and specified by the American Society for Testing and Materials in test method D1586 (ASTM, 1999). Recorded blow counts for non-SPT geotechnical sampling, where the sampler diameter, hammer weight and/or drop distance differ from those specified by ASTM D1586, were converted to SPT-equivalent blow count values and entered into the CGS 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 $(N_1)_{60}$.

Geotechnical and environmental borehole logs provided information on lithologic and engineering characteristics of Quaternary deposits within the study area. Geotechnical characteristics of the Quaternary map units mapped by WLA (2001) within the evaluated part of the Ojai Quadrangle are generalized in Table 1.1.

GROUND-WATER CONDITIONS

Liquefaction hazard may exist in areas where depth to ground water is 40 feet or less. CGS uses the historically highest ground-water levels because water levels during an earthquake cannot be anticipated owing to 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 water table level at a particular time. Plate 1.2 depicts a hypothetical ground-water table within alluviated areas.

Ground-water conditions were investigated in the Ojai 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). Preliminary water depths were determined based on first-encountered water noted in geotechnical borehole logs acquired from the Ventura County Public Works Agency (Leaking Underground Fuel Tank Program and the Water Resources & Engineering 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.

Turner (1971) investigated ground-water occurrence and quality within the Ventura River system (the Ventura River, San Antonio Creek, and Ojai valleys). He showed that the aquifer is unconfined. His well data cover the period 1951 through 1970 and showed significant fluctuation in overall water depth during that period. We selected the dataset from spring 1969 as representing the highest overall water levels. We digitized ground-water elevation contours from Turner's Plates 6A & 6B, formed a 10-meter grid of ground-water *elevation* values from the contours, then subtracted that grid from a 10-meter digital elevation model of the land surface (U.S. Geological Survey, 1993) to yield a grid of ground-water *depth* values. Finally, we created a contour map based on the ground-water depth grid (Plate 1.2).

Historically high ground-water depths are less than 20 feet over much of the Ojai Valley (Plate 1.2). The large, young fan deposit of eastern Ojai Valley is characterized by ground water with depths generally greater than 40 feet. Depths greater than 40 feet also occur near valley margins. Depth to ground water within minor tributaries is unknown but probably generally less than 40 feet and probably only a few feet during prolonged winter storms.

Turner's ground-water investigation did not cover the Upper Ojai Valley. For that area, we were guided by data and analysis of shallow ground-water depths provided in a brief letter-report prepared for Atlantic Richfield Company (Latker, 1977). That report documents groundwater generally less than 20 feet deep throughout the axial part of the valley, and deepening to >40 feet along the valley margins (Plate 1.2).

Ground water in the alluvium of the southern border canyons was not evaluated in this study because data were not available. We infer, however, that the alluvium is very clayey, based on the mudstone-dominated lithology of the Tertiary rocks drained by these canyons. The fine-grained aspect of the alluvium minimizes the likelihood of liquefaction, and, thus, evaluating ground water in these areas was deemed not necessary.

PART II

LIQUEFACTION POTENTIAL

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

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

LIQUEFACTION SUSCEPTIBILITY

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

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

LIQUEFACTION OPPORTUNITY

Analysis of in-situ liquefaction potential requires assessment of liquefaction opportunity. Liquefaction opportunity is the estimation of the severity of expected future ground shaking over the region at a specific exceedance probability and exposure time (Real, 2002). 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 CGS's analysis of liquefaction potential is the magnitude that contributes most to the calculated PGA for an area.

For the Ojai Quadrangle, PGAs of 0.59 to 0.83 g, resulting from an earthquake of magnitude 6.8, 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 portion (section 3) of this report for further details.

Quantitative Liquefaction Analysis

CGS performs quantitative analysis of geotechnical data to evaluate liquefaction potential using the Seed-Idriss Simplified Procedure (Seed and Idriss, 1971; Seed and others, 1983; National Research Council, 1985; Seed and others, 1985; Seed and Harder, 1990; Youd and Idriss, 1997). Using the Seed-Idriss Simplified Procedure one can calculate soil resistance to liquefaction, expressed in terms of cyclic resistance ratio (CRR), based on SPT results, ground-water level, soil density, moisture content, soil type, and sample depth. CRR values are then compared to calculated earthquake-generated shear stresses expressed in terms of cyclic stress ratio (CSR). The Seed-Idriss Simplified Procedure requires normalizing earthquake loading relative to a M7.5 event for the liquefaction analysis. To accomplish this, CGS's analysis uses the Idriss magnitude-scaling factor (MSF) (Youd and Idriss, 1997). It is convenient to think in terms of a factor of safety (FS) relative to liquefaction, where: FS = (CRR / CSR) * MSF. FS, therefore, is a quantitative measure of liquefaction potential. CGS uses a factor of safety of 1.0 or less, where CSR equals or exceeds CRR, to indicate the presence of potentially liquefiable soil. While an FS of 1.0 is considered the "trigger" for liquefaction, for a site-specific analysis an FS of as much as 1.5 may be appropriate depending on the vulnerability of the site and related structures. The CGS liquefaction analysis program calculates an FS for each geotechnical sample for which blow counts were collected. Typically, multiple samples are collected for each borehole. The program also calculates an FS for each distinct lithologic layer with at least one penetration test within it, based on the minimum $(N1)_{60}$ value within that layer. For each borehole location, the minimum FS value among non-clay layers is used to characterize the liquefaction potential 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 20 geotechnical borehole logs reviewed in this study (Plate 1.2), 11 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 flagged 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 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 Ojai Quadrangle is summarized below.

Areas of Past Liquefaction

No historical occurrences of liquefaction or related ground failure within the Ojai Quadrangle have been reported.

Artificial Fills

In general, artificial fill areas large enough to show at the scale of mapping 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. However, no such applications of artificial fill are known to occur within the Ojai Quadrangle. Non-engineered fills are commonly loose and uncompacted, and the material varies in size and type. The few small patches of artificial fill that are otherwise adjacent to or contained by more extensive natural deposits that are included with a zone of required investigation for liquefaction hazard are incorporated within that zone. However, small, isolated patches of artificial fill do not form a sufficient basis for delineation of a zone of required investigation for liquefaction hazard.

Areas with Sufficient Existing Geotechnical Data

Borehole logs that include penetration test data and sufficiently detailed lithologic descriptions were used to evaluate liquefaction potential. However, with only 11 borehole logs within the Ojai Quadrangle that provide such data, the quantitative liquefaction analysis performed serves mainly to supplement and confirm the delineation of zones of required investigation developed pursuant to SMBG criterion #4 (see above). Thus there are no extensive areas within the Ojai Quadrangle where the primary basis for evaluation of the liquefaction potential was application of the Seed-Idriss Simplified

Procedure using sufficient geotechnical data. Nevertheless, in Holocene alluvial deposits that cover much of the Ojai valley, most of the borehole logs that were analyzed using the Seed-Idriss Simplified Procedure contain sediment layers that may liquefy under the expected earthquake loading. These areas containing saturated potentially liquefiable material are included in the zone. Several of the boreholes are located within older Quaternary deposits (for example, Qoa), where, as expected, application of the Seed-Idriss Simplified Procedure confirms that little if any potential for liquefaction exists within these older, denser deposits.

Areas with Insufficient Existing Geotechnical Data

As noted in the previous paragraph, the relatively few and sparsely distributed geotechnical boreholes reviewed during this evaluation provide mainly confirmatory evidence for the potential for liquefaction. The zones of required investigation for liquefaction hazard were primarily developed by application of SMBG criterion #4 (see above). All of the zones of required investigation for liquefaction hazard fall within valleys characterized by Holocene or active alluviation.

ACKNOWLEDGMENTS

The author would like to thank the managers and staff of the Ventura County Public Works Agency, for their generous assistance in accessing their borehole data. In particular, Jim O'Tousa, Laverne Hoffman, and Glen Luscombe of the Water Resources & Engineering Department, and Ray Gutierrez and Dave Salter of the Leaking Underground Fuel Tank Program, were all very helpful. We also extend thanks to Chris Hitchcock of William Lettis Associates for making digital versions (and revisions) of his Ventura County Quaternary mapping available to us. Thanks also to my CGS colleague Rick Wilson for his patient assistance in development of a ground-water map based on grids.

REFERENCES

American Society for Testing and Materials, 1999, Standard test method for penetration test and split-barrel sampling of soils, Test Method D1586-99, *in* Annual Book of ASTM Standards, v. 4.08.

Budiman, J.S. and Mohammadi, Jamshid, 1995, Effect of large inclusions on liquefaction of sands, *in* Evans, M.D. and Fragaszy, R.J., *editors*, Static and Dynamic properties of Gravelly Soils: American Society of Civil Engineers Geotechnical Special Publication no. 56, p. 48-63.

California Department of Conservation, Division of Mines and Geology, 1997, Guidelines for evaluating and mitigating seismic hazards in California, Special Publication 117, 74 p.

California Department of Conservation, Division of Mines and Geology, 2000, Recommended criteria for delineating seismic hazard zones in California, Special Publication 118, 12 p.

Cramer, C.H. and Petersen, M.D., 1996, Predominant seismic source distance and magnitude maps for Los Angeles, Orange, and Ventura counties, California: Bulletin of Seismological Society of America, v. 86, no. 5, p. 1,645-1,649.

Dibblee, T.W., Jr., 1987, Geologic map of the Ojai Quadrangle, Ventura County, California: Dibblee Foundation Map #DF-13, scale 1:24,000.

Evans, M.D. and Zhou, Shengping, 1995, Liquefaction behaviour of sand-gravel composites: American Society of Civil Engineers, Journal of Geotechnical Engineering, v. 121, no. 3, p. 287-298.

Harder, L.F. and Seed, H.B., 1986, Determination of penetration resistance for coarse-grained soils using the Becker hammer drill: University of California at Berkeley, College of Engineering, Earthquake Engineering Research Center, report no. UCB/EERC-86/06, 126 p.

Ishihara, Kenji, 1985, Stability of natural deposits during earthquakes, *in* Proceedings of the Eleventh International Conference on Soil Mechanics and Foundation Engineering, San Francisco, v. 1, p. 321-376.

Keller, E.A., Johnson, D.L., Clark, M.N. and Rockwell, T.K., 1981, Tectonic geomorphology and earthquake hazard, north flank, central Ventura Basin, California: U.S. Geological Survey Open-File Report 81-376, 167 p.

Latker, Mark, 1977, Reconnaissance ground water study, Upper Ojai Valley, Ventura County, California: unpublished letter-report to Atlantic Richfield in files of Don Sperling, Planning Division, County of Ventura, 7 p.

National Research Council, 1985, Liquefaction of soils during earthquakes: National Research Council Special Publication, Committee on Earthquake Engineering, National Academy Press, Washington, D.C., 240 p.

Petersen, M.D., Bryant, W.A., Cramer, C.H., Cao, Tianqing, Reichle, M.S., Frankel, A.D., Lienkaemper, J.J., McCrory, P.A. and Schwartz, D.P., 1996, Probabilistic seismic hazard assessment for the State of California: California Department of Conservation, Division of Mines and Geology, Open-File Report 96-08; also U.S. Geological Survey Open-File Report 96-706, 33 p.

Real, C.R., 2002, California's Seismic Hazards Mapping Act: Geoscience and Public Policy, *in* Babrowsky, P.T., *editor*, Geoenvironmental Mapping - Method, Theory and Practice: A.A. Balkema, Rotterdam, Netherlands, p. 93-120.

Rockwell, Thomas, 1988, Neotectonics of the San Cayetano Fault, Transverse Ranges, California: Geological Society of America Bulletin, v. 100, p. 500-513.

Seed, H.B. and Idriss, I.M., 1971, Simplified procedure for evaluating soil liquefaction potential: Journal of the Soil Mechanics and Foundations Division of ASCE, v. 97: SM9, p. 1,249-1,273.

Seed, H.B. and Idriss, I.M., 1982, Ground motions and soil liquefaction during earthquakes: Monograph Series, Earthquake Engineering Research Institute, Berkeley, California, 134 p.

Seed, H.B., Idriss, I.M., and Arango, Ignacio, 1983, Evaluation of liquefaction potential using field performance data: Journal of Geotechnical Engineering, v. 109, no. 3, p. 458-482.

Seed, H.B., Tokimatsu, Kohji, Harder, L.F., and Chung, R.M., 1985, Influence of SPT procedures in soil liquefaction resistance evaluations: Journal of Geotechnical Engineering, ASCE, v. 111, no. 12, p. 1,425-1,445.

Seed, R.B. and Harder, L.F., 1990, SPT-based analysis of cyclic pore pressure generation and undrained residual strength: Proceedings of the H. Bolton Seed Memorial Symposium, v. 2, p. 351-376.

Smith, T.C., 1996, Preliminary maps of seismic hazard zones and draft guidelines for evaluating and mitigating seismic hazards: California Geology, v. 49, no. 6, p. 147-150.

Southern California Earthquake Center, 1999, Recommended procedures for implementation of DMG Special Publication 117 guidelines for analyzing and mitigating liquefaction in California: Southern California Earthquake Center, University of Southern California, 63 p.

Sy, Alex, Campanella, R.G. and Stewart, R.A., 1995, BPT-SPT correlations for evaluations of liquefaction resistance in gravelly soils, *in* Evans, M.D. and Fragaszy, R.J., *editors*, Static and Dynamic Properties of Gravelly Soils: American Society of Civil Engineers Geotechnical Special Publication no. 56, p. 1-19.

Tinsley, J.C., Youd, T.L., Perkins, D.M. and Chen, A.T.F., 1985, Evaluating liquefaction potential, *in* Ziony, J.I., *editor*, Evaluating earthquake hazards in the Los Angeles region — An earth science perspective: U.S. Geological Survey Professional Paper 1360, p. 263-316.

Turner, J.M., 1971, Ventura County Water Resources Management Study, Geohydrology of the Ventura River System; Ground Water Hydrology: Ventura County Department of Public Works Flood Control District, 31 p., 16 plates.

Ventura County Planning Department, 1974, Seismic Hazards Appendix of Seismic and Safety Elements of the General Plan of Ventura County.

William Lettis & Associates, 2001, Digital Quaternary geologic map of Ojai 7.5-minute Quadrangle, Ventura County, California: digitized at scale 1:24,000.

U.S. Geological Survey, 1993, Digital Elevation Models: National Mapping Program, Technical Instructions, Data Users Guide 5, 48 p.

Youd, T.L., 1973, Liquefaction, flow and associated ground failure: U.S. Geological Survey Circular 688, 12 p.

Youd, T.L., 1991, Mapping of earthquake-induced liquefaction for seismic zonation: Earthquake Engineering Research Institute, Proceedings, Fourth International Conference on Seismic Zonation, v. 1, p. 111-138.

Youd, T.L. and Idriss, I.M., 1997, *editors*, Proceedings of the NCEER workshop on evaluation of liquefaction resistance of soils: National Center for Earthquake Engineering Research Technical Report NCEER-97-0022, 276 p.

Youd, T.L. and Perkins, D.M., 1978, Mapping liquefaction-induced ground failure potential: Journal of Geotechnical Engineering, v. 104, p. 433-446.

SECTION 2
EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

Earthquake-Induced Landslide Zones in the Ojai 7.5-Minute Quadrangle, Ventura County, California

By
Rick I. Wilson and Pamela J. Irvine

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

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

This section of the evaluation report summarizes seismic hazard zone mapping for earthquake-induced landslides in the Ojai 7.5-minute Quadrangle. Section 1 (addressing liquefaction) and Section 3 (addressing earthquake shaking), complete the report, which is one of a series that summarizes the preparation of seismic hazard zone maps within the state (Smith, 1996). Additional information on seismic hazard zone mapping in California can be accessed on the California Geological Survey's Internet 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 Ojai Quadrangle.

METHODS SUMMARY

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

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

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

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

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

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

SCOPE AND LIMITATIONS

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

Earthquake-induced landslide zone maps are intended to prompt more detailed, site-specific geotechnical investigations as required by the Act. As such, these zone maps identify areas where the potential for earthquake-induced landslides is relatively high. Due to limitations in methodology, it should be noted that these zone maps do not necessarily capture all potential earthquake-induced landslide hazards. Earthquake-induced ground failures that are not addressed by this map include those associated with ridge-top spreading and shattered ridges. It should also be noted that no attempt has been made to map potential run-out areas of triggered landslides. It is possible that such run-out areas may extend beyond the zone boundaries. The potential for ground failure resulting from liquefaction-induced lateral spreading of alluvial materials, considered by some to be a form of landsliding, is not specifically addressed by the earthquake-induced landslide zone or this report. See Section 1, Liquefaction Evaluation Report for the Ojai 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 Ojai 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 Ojai Quadrangle covers approximately 62 square miles in southern Ventura County and includes portions of the City of Ojai along the western boundary and the unincorporated community of Summit near the eastern boundary. The City of Ojai is located about 12 miles north of the county seat at Ventura. Approximately 10 square miles in the northwestern and northeastern corners of the quadrangle were not evaluated for zoning because the land lies within Los Padres National Forest.

The northern third of the Ojai Quadrangle is dominated by steep mountainous terrain of the Santa Ynez-Topatopa Mountains. Ojai Valley lies along the southern edge of the mountain range. Numerous streams draining the southern slopes of the mountains have built large alluvial fans on the northeastern side of Ojai Valley. Drainage in Ojai Valley is toward the southwest via San Antonio Creek to the Ventura River. The central part of the map area is characterized by hilly and mountainous terrain of Black Mountain (Lion Mountain) and Sulphur Mountain, which nearly surround the gently sloping lowlands of Upper Ojai Valley on the northwest and south, respectively. Upper Ojai Valley drains in two directions – westward via Lion Creek to San Antonio Creek, and southeastward from Sisar Creek to Santa Paula Creek. The rugged southern slopes of Sulphur Mountain, which are cut by several wide, flat-bottomed canyons, occupy the southern part of the quadrangle. Drainage from Sulphur Canyon and Hammond Canyon on the west flows to the south-southwest via Canada Larga to the Ventura River. Drainage from Aliso Canyon and Wheeler Canyon on the east flows south to the Santa Clara River. Elevations range from about 700 feet above sea level in the valleys and canyons in the central and southern part of the quadrangle to 5526 feet in the northeast corner of the quadrangle.

State Highway 150 traverses the center of the Ojai Quadrangle and is the major east-west transportation route through the Upper Ojai and Ojai valleys. West of the map area, it connects with State Highway 33, which follows the Ventura River south to Ventura. East of the quadrangle, Highway 150 curves to the south and follows Santa Paula Creek to Santa Paula. Access to less developed areas is provided by fire roads, ranch roads, and oil field roads.

Residential development is concentrated in the valley areas with scattered development in the canyons, on the hillsides, and along Sulphur Mountain Road on the crest of Sulphur Mountain. Other land use in the area includes oil drilling and production in the Ojai Oil Field (Lion Mountain, Sisar Creek, North Sulphur Mountain, Sulphur Mountain, and

Sulphur Crest areas), cattle grazing, citrus and avocado orchards, parkland, campgrounds, golf courses, and several small reservoirs. The northern third of the quadrangle lies within Los Padres National Forest.

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 Ojai Quadrangle, a Level 2 digital elevation model (DEM) was obtained from the USGS (U.S. Geological Survey, 1993). This DEM, prepared from the 7.5-minute quadrangle topographic contours based on 1947 aerial photography, has a 10-meter horizontal resolution and a 7.5-meter vertical accuracy. There was no significant mass grading in the mapped area to warrant acquiring and using more up-to-date topography.

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 primary source of bedrock geologic mapping used in this slope stability evaluation was obtained from the Dibblee Geological Foundation (Dibblee, 1987) and then digitized by CGS staff for this study. Landslide deposits were deleted from the digital map so that the distribution of bedrock formations and the landslide inventory would exist on separate layers for the hazard analysis. CGS staff then merged the bedrock contacts on this map with a digital Quaternary geologic map prepared by William Lettis and Associates (2000). In the field, observations were made of exposures, aspects of weathering, and general surface expression of the geologic units. In addition, the relation of the various geologic units to development and abundance of landslides was noted. The lithology of the units described below is based on field observations and the following references: Dibblee (1966; 1987), Bush (1956), and Weber and others (1973).

Bedrock units in the Ojai Quadrangle range in age from early(?) Eocene to Pleistocene. A continuous sequence of Eocene clastic marine deposits is exposed in east-west-trending bands across the northern third of the quadrangle, forming the southern slopes of the Santa Ynez-Topatopa Mountains. The oldest geologic unit mapped in the Ojai Quadrangle is the early(?) to middle Eocene Juncal Formation, which crops out along the northern boundary of the quadrangle. The Juncal Formation primarily consists of olive gray to dark gray micaceous shale and siltstone (Tjsh) with thin interbeds of light gray to light brown arkosic sandstone. Sandstones (Tjss) of the Juncal Formation are generally hard, light gray, fine- to medium-grained, and form prominent ledges, dip slopes, and strike ridges.

The middle to late Eocene Matilija Sandstone conformably overlies the Juncal Formation and is composed of light brown to mottled pale green arkosic sandstone (Tma) that is well-indurated, fine- to medium-grained, and thick-bedded to massive with thin partings and interbeds of gray micaceous shale. A separately mapped micaceous shale and siltstone unit (Tmash) with interbedded sandstone is also included in the Matilija Sandstone. Conformably overlying the Matilija Sandstone is the late Eocene Cozy Dell Shale, which consists of dark gray, well-indurated, locally fissile, argillaceous to silty micaceous shale (Tcd) with minor interbedded sandstone, and separately mapped lenses of light-brown to gray-green arkosic sandstone with minor interbeds of micaceous shale (Tcdss).

The Cozy Dell Shale is conformably overlain by marine to transitional strata of the late Eocene Coldwater Sandstone, which form a prominent white ledge along the northern margin of Ojai Valley at the base of the Santa Ynez-Topatopa Mountains. The Coldwater Sandstone consists of hard, light brown and light gray to white, thick-bedded, well-indurated, fine- to coarse-grained, arkosic sandstone (Tcw) with minor interbeds of greenish gray siltstone and shale, and local oyster-shell beds. Also included in the Coldwater Sandstone is a separately mapped unit (Tcwsh) composed of greenish-gray siltstone and shale with interbeds of light brown sandstone.

Eocene marine strata are overlain by late Eocene to early Miocene non-marine to transgressive marine deposits of the Sespe Formation (Tsp), Vaqueros Sandstone (Tvq), and Rincon Shale (Tr). Sespe strata are exposed discontinuously along the base of the Santa Ynez-Topatopa Mountains and in the core of the Lion Mountain anticline that forms Black Mountain. The Sespe Formation consists of alluvial fan, floodplain, and deltaic deposits of maroon, red, and green silty shale and claystone interbedded with pale reddish gray, friable to poorly indurated sandstone and pebble-cobble conglomerate. Conformably overlying Sespe strata are the transitional to shallow marine deposits of the Vaqueros Sandstone, which are composed of light gray to light brown, massive to poorly bedded, fine-grained, locally calcareous sandstone. Limited exposures of Vaqueros Sandstone occur as narrow bands on the north side of Black Mountain and in Lion Canyon. The marine Rincon Shale conformably overlies the Vaqueros Sandstone and is exposed in the hills north of Upper Ojai Valley and on the northern slopes of Sulphur Mountain. Rincon Shale consists of blue-gray to brown, argillaceous clay shale and siltstone that is characterized by ellipsoidal and spheroidal fracturing and commonly contains light brown to orange dolomitic concretions.

Rincon Shale is overlain by siliceous organic marine deposits of middle to late Miocene Monterey (Modelo) Formation and late Miocene Sisquoc Shale, which crop out along the crest, northern slopes, and uppermost southern slopes of Sulphur Mountain. Monterey Formation strata are divided into three members in the map area. These members include a lower shale unit (Tml) composed of soft, fissile to punky clay shale with interbeds of hard siliceous shale and thin limestone beds, an upper shale unit (Tm) consisting of thin-bedded, hard, platy to brittle siliceous shale, and a white-weathering diatomaceous shale (Tmd). The Sisquoc Shale (Tsq) consists of light-gray to gray-brown, silty shale or claystone that is locally siliceous and diatomaceous.

Sisquoc Shale is overlain by clastic marine deposits of the Pliocene Pico Formation (Tp), which are exposed on the southern slopes of Sulphur Mountain and in a fault-bounded sliver along the north side of Sulphur Mountain. The Pico Formation consists of blue-gray, massive to bedded siltstone and silty shale with minor light brown sandstone and pebbly sandstone. Upper Ojai Valley is underlain by non-marine Pleistocene Saugus Formation (Bush, 1956; Huftile, 1991a) and exposures of questionable Saugus Formation (QTs?) have been mapped along the Lion Fault at the southeast edge of Upper Ojai Valley. These outcrops consist of soft, massive, reddish yellow, medium-grained sandstone interbedded with boulder gravel and pebble conglomerate.

Quaternary surficial deposits cover the floor and margins of the Ojai and Upper Ojai valleys and extend up into the larger canyons that drain the Santa Ynez-Topatopa Mountains and Sulphur Mountain. These sediments consist of Pleistocene old alluvial-fan, alluvial-valley, pediment gravel, and stream-terrace deposits (Qof, Qoa, Qop, Qog, Qoat1, Qoat2), Pleistocene to Holocene young alluvial-fan, axial valley, and stream-terrace deposits (Qyf1, Qyf2, Qya1, Qya2, Qyat1, Qyat2), colluvium (Qc), and active and historical stream wash deposits (Qw). Pleistocene to Holocene landslide deposits are widespread in the southern half of the Ojai Quadrangle. Landslide deposits are not included in the bedrock/Quaternary geologic map, but are shown on a separate landslide inventory map (Plate 2.1). Artificial fill (af) also exists within the Ojai Quadrangle. A more detailed discussion of the Quaternary surficial deposits in the Ojai Quadrangle can be found in Section 1.

Structural Geology

The Ojai Quadrangle lies within the central Ventura Basin in the Transverse Ranges geomorphic province. Rocks in this region have been folded into a series of predominantly west-trending anticlines and synclines associated with thrust and reverse faults. This deformation was caused by regional north-south compression, which began during the late Pliocene and continues today (Yeats, 1989). Regional crustal shortening due to this compression is largely taken up by the San Cayetano Fault and associated folds in the eastern part of the quadrangle and by the Red Mountain Fault and associated folds west of the quadrangle. Between these two fault zones, in the Ojai Valley area, shortening is taken up on a blind thrust fault (Namson and Davis, 1988). The surface expression of the blind thrust is the south-dipping homocline south of Sulphur Mountain and the Lion Fault zone (Huftile, 1991b). The complex relationship between folding and faulting in the area is depicted in several cross sections (Huftile, 1991a and 1991b).

Major fold-related structures in the quadrangle include the Matilija Overturn, Ojai Syncline, Reeves Syncline, Lion Mountain Anticline, Big Canyon Syncline, Sulphur Mountain Anticlinorium, and Sulphur Mountain Homocline. The Matilija Overturn is the overturned south limb of an anticline in the Santa Ynez-Topatopa Mountains involving competent Eocene clastic marine rocks. Non-marine Sespe Formation and older marine rocks form the Ojai Syncline, which underlies Ojai Valley. The Reeves Syncline underlies the hills north of Upper Ojai Valley and involves the more ductile middle to late Miocene marine rocks. Sespe strata are exposed in the core of the Lion Mountain Anticline, which forms Black Mountain and continues to the east beneath Upper Ojai

Valley. The Big Canyon Syncline involves Miocene and younger rocks along the northeast side of Sulphur Mountain. In the eastern part of the map area, the relatively ductile Rincon Formation forms the subsurface core of the Sulphur Mountain Anticlinorium, which is complexly folded and has overturned limbs on both of its flanks. Late Miocene and Pliocene strata form the south-dipping Sulphur Mountain Homocline in the southern part of the quadrangle.

Thrust and reverse faults associated with folding in the Ojai Quadrangle include the San Cayetano, Santa Ana, Lion, Big Mountain, Sisar, and South Sulphur Mountain faults. The San Cayetano Fault is a major, active, north-dipping reverse fault, extending along the north flank of Ventura Basin from the east end of Ojai Valley to Piru. It displaces Tertiary and Quaternary rocks with as much as 9 kilometers of stratigraphic separation (Rockwell, 1988) and its surface trace in the Ojai Quadrangle is included in the Official Earthquake Zone prepared by CGS (DOC, 1986). The surface trace of the south-dipping (?) Santa Ana Fault has not been accurately located, but is tentatively mapped along the northern base of Black Mountain and is inferred to extend eastward under the San Cayetano Fault (Keller and others, 1982). The Lion, Big Mountain, and Sisar faults form a zone of south-dipping thrusts that extends across the Ojai Quadrangle along the north side of Sulphur Mountain. These faults formed as passive backthrusts above the main blind thrust fault (Huftile, 1991a). The South Sulphur Mountain Fault is a north-dipping reverse fault that forms a pop-up structure along the south side of the crest of Sulphur Mountain in the eastern part of the study area. Weber and others (1975) mapped the trace of the South Sulphur Mountain Fault across the entire quadrangle, but it is believed by others that it dies out to the west into tight recumbent folds (Keller and others, 1982).

Landslide Inventory

As a part of the geologic data compilation, an inventory of existing landslides in the Ojai Quadrangle was prepared by field reconnaissance, analysis of stereo-paired aerial photographs and a review of previously published landslide mapping (Morton, 1976; 1973). Additional landslide maps and reports that were reviewed during preparation of the landslide inventory are identified in the References section with an asterisk (*). A list of air photos that were examined for this study is included here under Air Photos in References. 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 abundant in the southern half of the Ojai Quadrangle where relatively weak, fine-grained sedimentary rocks have been deformed by folding and faulting. Landslides in the area range from minor surficial failures resulting from soil and rock creep, rock fall, earth and debris slumps, earth flows, and debris flows to large rotational and translation landslides, some of which are relatively old and deeply eroded.

Several large ancient rotational and translational landslide complexes have been mapped on the northern slopes of Sulphur Mountain involving Rincon Shale and the Monterey and Pico formations. In addition, there are numerous relatively young earth slides, debris slides, and earth flows mapped adjacent to and within the older bedrock slide complexes.

Numerous landslides occur on the south side of Sulphur Mountain on dip slopes and within the complexly folded shale of the Monterey Formation. Landslide identification is somewhat difficult in this area because some of the unusual topography and anomalous bedding attitudes may be the result of tight folding rather than mass movement.

Small-scale surficial ("thin-skin") failures including soil creep, earth slides, and earth flows are pervasive in the Pico Formation on the southern slopes of Sulphur Mountain. Relatively larger translational rock slides and earth slides are also common in the area. In many cases, the lower portions of these slide masses have yielded earth flows.

ENGINEERING GEOLOGY

Geologic Material Strength

To evaluate the stability of geologic materials under earthquake conditions, the geologic map units described above were ranked and grouped on the basis of their shear strength. Generally, the primary source for shear-strength measurements is geotechnical reports prepared by consultants on file with local government permitting departments. Shear-strength data for the units identified on the Ojai Quadrangle geologic map were obtained from the County of Ventura Public Works Agency and Earth Systems Consulting in Ventura (see Appendix A). The locations of rock and soil samples taken for shear testing within the Ojai Quadrangle are shown on Plate 2.1. Shear test information from the Matilija, Santa Paula Peak, and Santa Paula quadrangles were considered for several geologic formations for which little or no shear test information was available within the Ojai Quadrangle.

Shear strength data gathered from the above sources were compiled for each geologic map unit. Geologic units were grouped on the basis of average angle of internal friction (average phi) and lithologic character. Average (mean or median) phi values for each geologic map unit and corresponding strength group are summarized in Table 2.1. For most of the geologic strength groups (Table 2.2) in the map area, a single shear strength value was assigned and used in our slope stability analysis. A geologic material strength map was made based on the groupings presented in Table 2.1 and Table 2.2, and this map provides a spatial representation of material strength for use in the slope stability analysis. The phi value for Strength Group 1 is based on data from adjacent quadrangles and information given in Weber and others (1973) concerning relative strength and possible dip-slope conditions.

Several geologic map units were 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, were 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.

Formations that contain interbedded sandstone and shale were 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 (higher strength) dominates where bedding dips into a slope (favorable bedding) while fine-grained (lower strength) material 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 values to areas where potential adverse bedding conditions were identified. Where data were not available for certain formations to make a determination about adverse bedding conditions, other CGS geologists and references (Weber and others, 1973) were consulted. The favorable and adverse bedding shear strength parameters for the affected formations, are shown in Table 2.1 and 2.2.

Existing Landslides

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

The strength characteristics of existing landslides (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 Ojai Quadrangle, two direct shear tests of landslide slip surface materials were obtained, and the results are summarized in Table 2.1.

OJAI QUADRANGLE
SHEAR STRENGTH GROUPS

	Formation Name	Number Tests	Mean/Median Phi (deg)	Mean/Median Group Phi (deg)	Mean/Median Group C (psf)	No Data: Similar Lithology	Phi Values Used in Stability Analyses
GROUP 1						Tjsh(fbc)	38*
						Tjss(fbc)	
						Tma(fbc)	
						Tmash(fbc)	
GROUP 2	Tvq(fbc)	3	36/35	36/34	307/225		34**
	Qyf1	5	35/33				
GROUP 3	Tcw(fbc)	3	30/31	31/31	432/341	Tjsh(abc)	31
	Tcwsh(fbc)	2	33/33			Tjss(abc)	
	Tsp(fbc)	2	32/32			Tma(abc)	
	Tr	21	31/32			Tmash(abc)	
	Tm	9	31/32			Tcd(fbc)	
	Tml	16	30/31			Tcdss(fbc)	
	Qyf2	2	31/31			Tsq(fbc)	
	Qya2	7	31/29			QTs(fbc)	
	Qyat2	2	31/31			Qoat1, Qoat2	
	Qw	2	33/33			Qoa, Qog	
	af	6	30/31			Qya1, Qyat1, Qc	
GROUP 4	Tcw(abc)	1	25/25	27/28	387/403	Tcd(abc)	27
	Tsp(abc)	6	27/27			Tcdss(abc)	
	Tp	3	28/28			Tcwsh(abc)	
	Qof	4	26/29			Tvq(abc)	
						Tsq(abc), Tmd	
						QTs(abc), Qop	
GROUP 5	Qls	2	18/18	18/18	500/500	Qls	18

Formational Subunits on Map Combined in Analysis

*** = phi values selected based on data from surrounding quadrangles**
**** = phi value for median was selected because it better represents the units**

abc = adverse bedding condition, fine-grained material strength
fbc = favorable bedding condition, coarse-grained material strength

Table 2.1. Summary of the Shear Strength Statistics for the Ojai Quadrangle.

SHEAR STRENGTH GROUPS FOR THE OJAI 7.5-MINUTE QUADRANGLE				
GROUP 1	GROUP 2	GROUP 3	GROUP 4	GROUP 5
Tjsh(fbc) Tjss(fbc) Tma(fbc) Tmash(fbc)	Tvq(fbc) Qyf1	Tjsh(abc) Tjss(abc) Tma(abc) Tmash(abc) Tcd(fbc) Tcdss(fbc) Tcw(fbc) Tcwsh(fbc) Tsp(fbc), Tr Tsq(fbc), Tm Tml, QTs(fbc) Qoat1, Qoat2 Qoa, Qog, Qyf2 Qya1, Qya2 Qyat1, Qyat2 Qw, af	Tcd(abc) Tcdss(abc) Tcw(abc) Tcwsh(abc) Tsp(abc) Tvq(abc) Tmd, Tsq(abc) Tp, QTs(abc) Qop, Qof	Qls

Table 2.2. Summary of Shear Strength Groups for the Ojai 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 Ojai Quadrangle, selection of a strong motion record was based on an estimation of probabilistic ground motion parameters for modal magnitude, modal distance, and peak ground acceleration (PGA). The parameters were estimated from maps prepared by CGS for a 10% probability of being exceeded in 50 years (Petersen and others, 1996). The parameters used in the record selection are:

Modal Magnitude:	6.8 to 6.9
Modal Distance:	3.6 km to 7.5 km
PGA:	0.66 g to 0.99 g

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

Displacement Calculation

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

The amount of displacement predicted by the Newmark analysis provides an indication of the relative amount of damage that could be caused by earthquake-induced landsliding. Displacements of 30, 15 and 5 cm were used as criteria for rating levels of earthquake-induced landslide hazard potential based on the work of Youd (1980), Wilson and Keefer (1983), and a CGS pilot study for earthquake-induced landslides (McCrink and Real, 1996; McCrink, 2001). Applied to the curve in Figure 2.1, these displacements correspond to yield accelerations of 0.086, 0.133, and 0.234 g. Because these yield acceleration values are derived from the design strong-motion record, they represent the ground shaking opportunity thresholds that are significant in the Ojai Quadrangle.

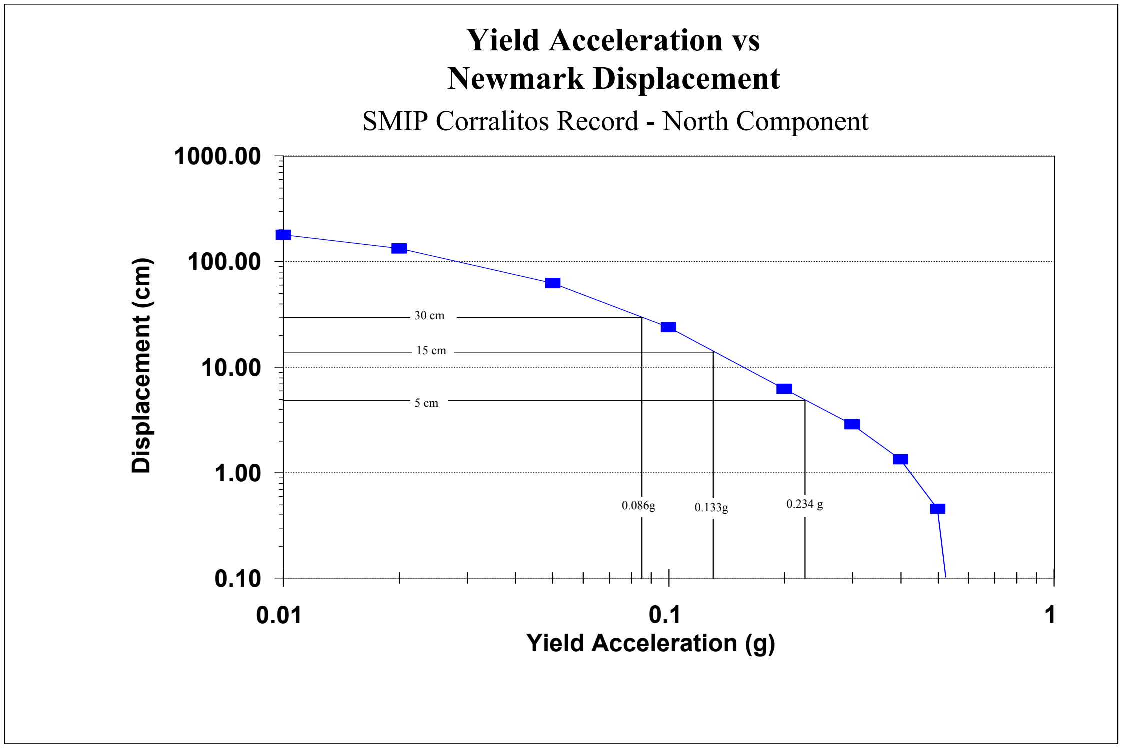


Figure 2.1. Yield Acceleration vs. Newmark Displacement for the 1989 Loma Prieta Earthquake Corralitos Record. Record from California Strong Motion Instrumentation Program (CSMIP) Station 57007.

Slope Stability Analysis

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

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

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

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

1. If the calculated yield acceleration was less than 0.086g, Newmark displacement greater than 30 cm is indicated, and a HIGH hazard potential was assigned (H on Table 2.3)

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

OJAI QUADRANGLE HAZARD POTENTIAL MATRIX

Geologic Material Group	MEAN PHI	SLOPE CATEGORY (% SLOPE)										
		I	II	III	IV	V	VI	VII	VII	IX	X	XI
		0-18	19-24	25-26	27-36	37-42	43-46	47-52	53-57	58-62	63-69	>69
1	**38**	VL	VL	VL	VL	VL	VL	VL	L	L	M	H
2	**34**	VL	VL	VL	VL	VL	L	L	M	H	H	H
3	**31**	VL	VL	VL	VL	L	L	M	H	H	H	H
4	**27**	VL	VL	VL	L	M	H	H	H	H	H	H
5	**18**	L	M	H	H	H	H	H	H	H	H	H

Table 2.3. Hazard Potential Matrix for Earthquake-Induced Landslides in the Ojai Quadrangle. Shaded area indicates hazard potential levels included within the 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 CGS (McCrink and Real, 1996; McCrink, 2001), it has been concluded that earthquake-induced landslide hazard zones should encompass all areas that have a High, Moderate or Low level of hazard potential (see Table 2.3). This would include all areas where the analyses indicate earthquake displacements of 5 centimeters or greater. Areas with a Very Low hazard potential, indicating less than 5 centimeters displacement, are excluded from the zone.

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

1. Geologic Strength Group 5 is included for all slope gradient categories. (Note: Geologic Strength Group 5 includes all mappable landslides with a definite or probable confidence rating).

2. Geologic Strength Group 4 is included for all slopes steeper than 26 percent.

3. Geologic Strength Group 3 is included for all slopes steeper than 36 percent.

4. Geologic Strength Group 2 is included for all slopes steeper than 42 percent.

5. Geologic Strength Group 1 is included for all slopes greater than 52 percent.

This results in approximately 56 percent of the area mapped in the quadrangle lying within the earthquake-induced landslide hazard zone for the Ojai Quadrangle.

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: 1) the Ventura County Public Works Agency with the assistance of LaVonne Driver, Larry Cardozo, and James O'Tousa; 2) the Ventura County Resource Management Agency with the assistance of Julie Ward; and 3) Earth Systems Southern California in Ventura with the assistance of Patrick Boales, Richard Beard, and Todd Tranby. Additional information about specific landslides in the area was also provided by James O'Tousa. Pam Gallo (Park Operations Supervisor, Ventura County Parks Department) provided access to Sulphur Mountain Road for field reconnaissance. Stephen Mulqueen (DOGGR) provided assistance in the field and information to access oil field properties. At CGS, Ellen Sander, Ian Penney, and Bryan Caldwell digitized borehole locations and entered shear test data into the database. Terilee McGuire, Lee Wallinder, and Bob Moscovitz provided GIS support. Barbara Wanish and Ross Martin prepared the final landslide hazard zone maps and the graphic displays for this report.

REFERENCES

*Advanced Geotechnical Services, Inc.(ags), 1998, Summary of geologic conditions – existing agricultural reservoir, Upper Ojai, California: unpublished consultant report dated March 11, 1998.

Brabb, E.E., 1983, Map showing direction and amount of bedding dip of sedimentary rocks in San Mateo County, California: U.S. Geological Survey Miscellaneous Investigations Series Map I-1257C, 1 sheet, scale 1:62,500.

*Buena Engineers, 1989, Geotechnical report for the Caliva property, Sulphur Mountain, Ventura County, California: unpublished consultant report dated March, 1989.

Bush, G. L., 1956, Geology of Upper Ojai Valley: unpublished MA thesis, University of California, Los Angeles, 60 p.

California Department of Conservation, Division of Mines and Geology, 1986, Official Map of Earthquake Fault Zones, Ojai Quadrangle, scale 1:24,000.

California Department of Conservation, Division of Mines and Geology, 1997, Guidelines for evaluating and mitigating seismic hazards in California: California Department of Conservation, Division of Mines and Geology, Special Publication 117, 74 p.

California Department of Conservation, Division of Mines and Geology, 2000, Recommended criteria for delineating seismic hazard zones: California Department of Conservation, Division of Mines and Geology, Special Publication 118, 12 p.

*Dial Services, 1989, Geotechnical study and effluent disposal evaluation for proposed agricultural building, Sulphur Mountain Road, upper Ojai area of County of Ventura, California: unpublished consultant report dated December 18, 1989.

Dibblee, T.W., Jr., 1966, Geology of the central Santa Ynez Mountains, Santa Barbara County, California: California Division of Mines and Geology Bulletin 186, 99 p.

Dibblee, T.W., Jr., 1987, Geologic map of the Ojai Quadrangle, Ventura County, California: Dibblee Geological Foundation Map DF-13, scale 1:24000.

*Gold Coast GeoServices, Inc., 1995, Geological/geotechnical engineering report, proposed single family residence and horse barn, 7287 Ojai Road, Upper Ojai Valley, County of Ventura: unpublished consultant report dated April 18, 1995 and response to Ventura County comments dated July 10, 1995.

Horn, B.K.P., 1981, Hill shading and the reflectance map: Proceedings of the IEEE, v. 69, no. 1, p. 14-47.

Huftile, Gary J., 1991a, Thin-skinned tectonics of the Upper Ojai Valley and Sulphur Mountain area, Ventura Basin, California: American Association of Petroleum Geologists Bulletin, v. 75, No. 8, p.1353-1373.

Huftile, Gary J., 1991b, Displacement transfer between the Red Mountain and San Cayetano faults *in* Active folding and reverse faulting in the western Transverse Ranges, southern California: Field Trip Guidebook to Accompany the 1991 Geological Society of America Annual Meeting, San Diego, California, October 20 to 24, 63 p.

Jibson, R.W., 1993, Predicting earthquake-induced landslide displacements using Newmark's sliding block analysis: Transportation Research Board, National Research Council, Transportation Research Record 1411, 17 p.

Keefer, D.K., 1984, Landslides caused by earthquakes: Geological Society of America Bulletin, v. 95, no. 4, p. 406-421.

Keller, E.A., Johnson, D.L., Clark, M.N. and Rockwell, T.K., 1982, Tectonic geomorphology and earthquake hazard north flank, central Ventura Basin, California: U. S. Geological Survey Open-File Report 81-376, 178 p., Plate 1 geologic map, scale 1:24,000.

McCrink, T.P. and Real, C.R., 1996, Evaluation of the Newmark method for mapping earthquake-induced landslide hazards in the Laurel 7-1/2 minute Quadrangle, Santa Cruz County, California: California Division of Mines and Geology Final Technical Report for U.S. Geological Survey Contract 143-93-G-2334, U.S. Geological Survey, Reston, Virginia, 31 p.

McCrink, T.P., 2001, Mapping earthquake-induced landslide hazards in Santa Cruz County *in* Ferriz, H. and Anderson, R., *editors*, Engineering geology practice in northern California: California Geological Survey Bulletin 210 / Association of Engineering Geologists Special Publication 12, p.77-94.

Morton, D.M., 1973, Reconnaissance photo-interpretation map of major landslides, southern Ventura County, California: California Division of Mines and Geology Preliminary Report 14, Plate 5, scale 1:48,000.

Morton, D.M., 1976, Reconnaissance surficial geologic map of the Ojai 7.5' Quadrangle, Ventura County, California: U.S. Geological Survey Open-File Report 76-212, scale 1:24,000.

Namson, J. and Davis, T., 1988, Structural transect of the western Transverse Ranges, California: Implications for lithospheric kinematics and seismic risk evaluation: Geology, v. 16, p. 675-679.

Newmark, N.M., 1965, Effects of earthquakes on dams and embankments: Geotechnique, v. 15, no. 2, p. 139-160.

*Pacific Materials Laboratory, Inc., 1989, Geotechnical exploration, proposed single family residence, Sulphur Mountain Road, Santa Paula, California: unpublished consultant report dated September 14, 1989, Enclosure A - Geologic map, scale 1 inch = 100 feet.

Petersen, M.D., Bryant, W.A., Cramer, C.H., Cao. T., Reichle, M.S., Frankel, A.D., Lienkaemper, J.J., McCrory, P.A. and Schwartz, D.P., 1996, Probabilistic seismic hazard assessment for the State of California: California Department of Conservation, Division of Mines and Geology, Open-File Report 96-08; also U.S. Geological Survey Open-File Report 96-706, 33 p.

Rockwell, T.K., 1988, Neotectonics of the San Cayetano fault, Transverse Ranges, California: Geological Society of America Bulletin, v. 100, p.500-513.

Shakal, A., Huang, M., Reichle, M., Ventura, C., Cao, T., Sherburne, R., Savage, M., Darragh, R. and Peterson, C., 1989, CSMIP strong-motion records from the Santa Cruz Mountains (Loma Prieta), California earthquake of 17 October 1989: California

Department of Conservation, Division of Mines and Geology, Office of Strong Motion Studies Report OSMS 89-06, 196 p.

Smith, T.C., 1996, Preliminary maps of seismic hazard zones and draft guidelines for evaluating and mitigating seismic hazards: California Geology, v. 49, no. 6, p. 147-150.

Southern California Earthquake Center, 2002, Recommended procedures for implementation of DMG Special Publication 117 guidelines for analyzing and mitigating landslide hazards in California: Southern California Earthquake Center, University of Southern California, 108 p.

U.S. Geological Survey, 1993, Digital Elevation Models: National Mapping Program, Technical Instructions, Data Users Guide 5, 48 p.

Weber, F.H., Jr., Cleveland, G.B., Kahle, J.E., Kiessling, E.W., Miller, R.V., Mills, M.F. and Morton, D.M., 1973, Geology and mineral resources of southern Ventura County, California: California Division of Mines and Geology Preliminary Report 14,102 p., Plate 1 geologic map of southern Ventura County, California, scale 1:48,000.

Weber, F.H.,Jr., Kiessling, E.W., Sprotte, E.C., Johnson, J.A., Sherburne, R.W. and Cleveland, G.B., 1975, Seismic hazards study of Ventura County, California: California Division of Mines and Geology Open-File Report 76-05, Plates 5A and 5B, scale 1:48,000.

*Westland Geological Services, Inc., 1989, Geological investigation – suspected landslide, 9950 Sulphur Mountain Road, Upper Ojai Valley, County of Ventura: unpublished consultant report dated July 17, 1989, Plate 1 – Geologic Map, scale 1 inch = 40 feet.

William Lettis and Associates, 2000, Preliminary digital geologic map of the Ojai 7.5-minute Quadrangle, California; digitized at scale of 1:24000.

Wilson, R.C. and Keefer, D.K., 1983, Dynamic analysis of a slope failure from the 1979 Coyote Lake, California, earthquake: Bulletin of the Seismological Society of America, v. 73, p. 863-877.

Yeats, R.S., 1989, Oak Ridge Fault, Ventura Basin, California, slip rates and late Quatenary history: U.S. Geological Survey Open-File Report 89-343, 30 p., 6 plates.

Youd, T.L., 1980, Ground failure displacement and earthquake damage to buildings: American Society of Civil Engineers Conference on Civil Engineering and Nuclear Power, 2d, Knoxville, Tennessee, 1980, v. 2, p. 7-6-2 to 7-6-26.

AIR PHOTOS

I.K. Curtis Services, Inc., Ventura County Photos, April 2, 2000, Frames 661-664, 676-680, 719-723; Color, Vertical, scale 1: 42,000.

NASA (National Aeronautics and Space Administration) 04689; Flight 94-002-02; January 22, 1994; Frames 633-640; Black and White; Vertical; scale 1:15,000.

PACWAS (Pacific Western Aerial Surveys); Flight PW VEN6; November 22, 1988; Frames 281-285, 249-254, and 216-220; Color; Vertical; scale 1: 24,000.

USDA (U.S. Department of Agriculture); Flight AXI; 1953; Frames 4K 7-14 and 47-54, 7K 18-20, 7K 68-72, 7K 74-79, 9K 80-84 and 121-124, and 11K 33-35; Black and White; Vertical; scale 1:20,000.

USGS (U.S. Geological Survey) Area A; July 8, 1998; Frames 2A-12 to 2A-16, 3A-10 to 3A-15, 4A-9 to 4A-15; Color; Vertical; scale 1:24,000.

APPENDIX A
SOURCES OF GEOLOGIC MATERIAL STRENGTH DATA

SOURCE	NUMBER OF TESTS SELECTED
County of Ventura, Public Works Department	**71**
Earth Systems Consulting	**25**
Total Number of Shear Tests	**96**

SECTION 3
GROUND SHAKING EVALUATION REPORT

Potential Ground Shaking in the Ojai 7.5-Minute Quadrangle, Ventura County, California

By

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

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

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 hazards zone mapping in California is on CGS's Internet web page:
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 [California Geological Survey], and the U.S. Geological Survey (Petersen and others, 1996). That report documents an extensive 3-year effort to obtain consensus within the scientific community regarding fault parameters that characterize the seismic hazard in California. Fault sources included in the model were evaluated for long-term slip rate, maximum earthquake magnitude, and rupture geometry. These fault parameters, along with historical seismicity, were used to estimate return times of moderate to large earthquakes that contribute to the hazard.

The ground shaking levels are estimated for each of the sources included in the seismic source model using attenuation relations that relate earthquake shaking with magnitude, distance from the earthquake, and type of fault rupture (strike-slip, reverse, normal, or subduction). The published hazard evaluation of Petersen and others (1996) only considers uniform firm-rock site conditions. In this report, however, we extend the hazard analysis to include the hazard of exceeding peak horizontal ground acceleration (PGA) at 10% 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.

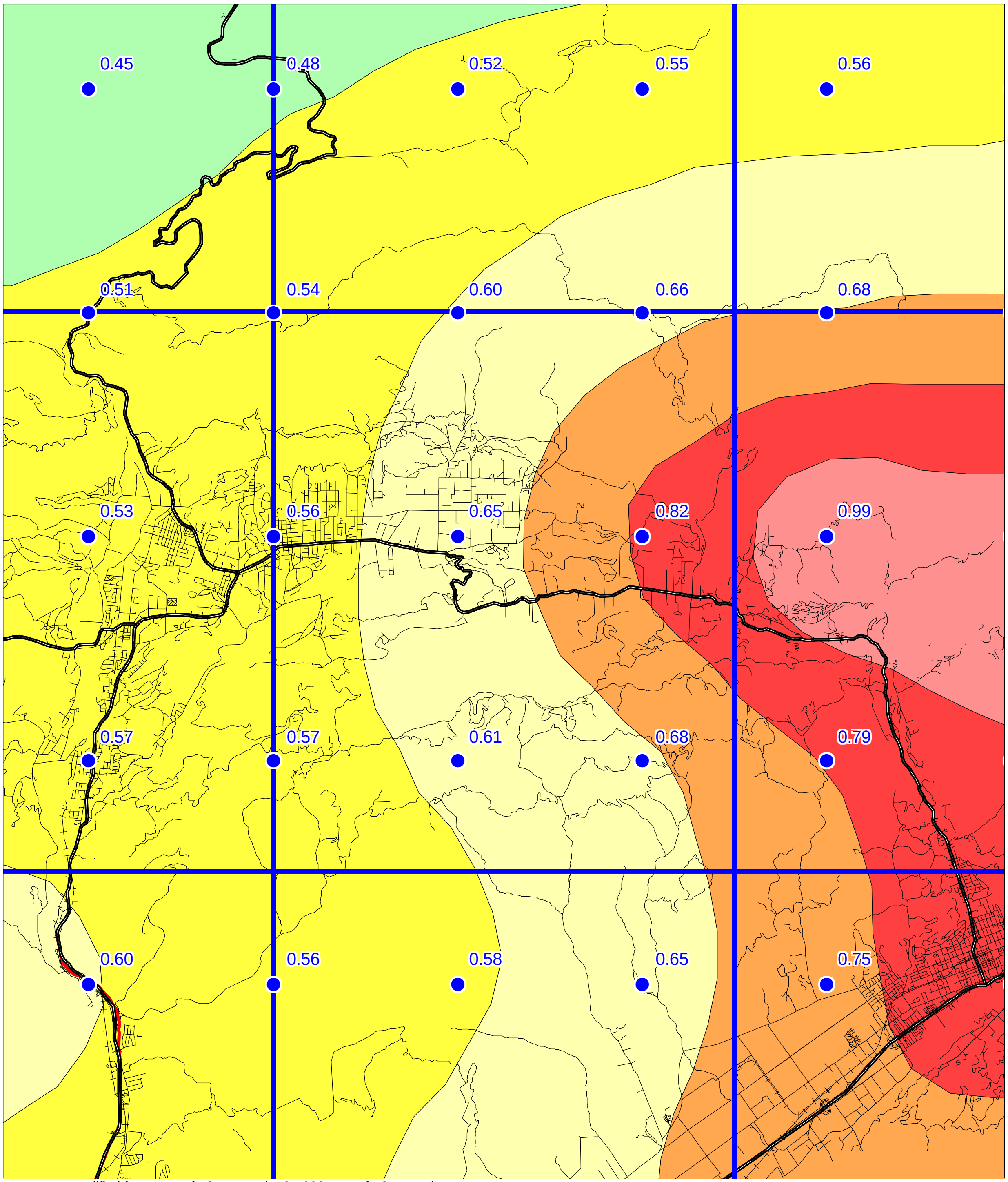
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10% probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively. 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

OJAI 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

FIRM ROCK CONDITIONS



Base map modified from MapInfo StreetWorks © 1998 MapInfo Corporation

0 1.5 3
Miles

Department of Conservation
Division of Mines and Geology

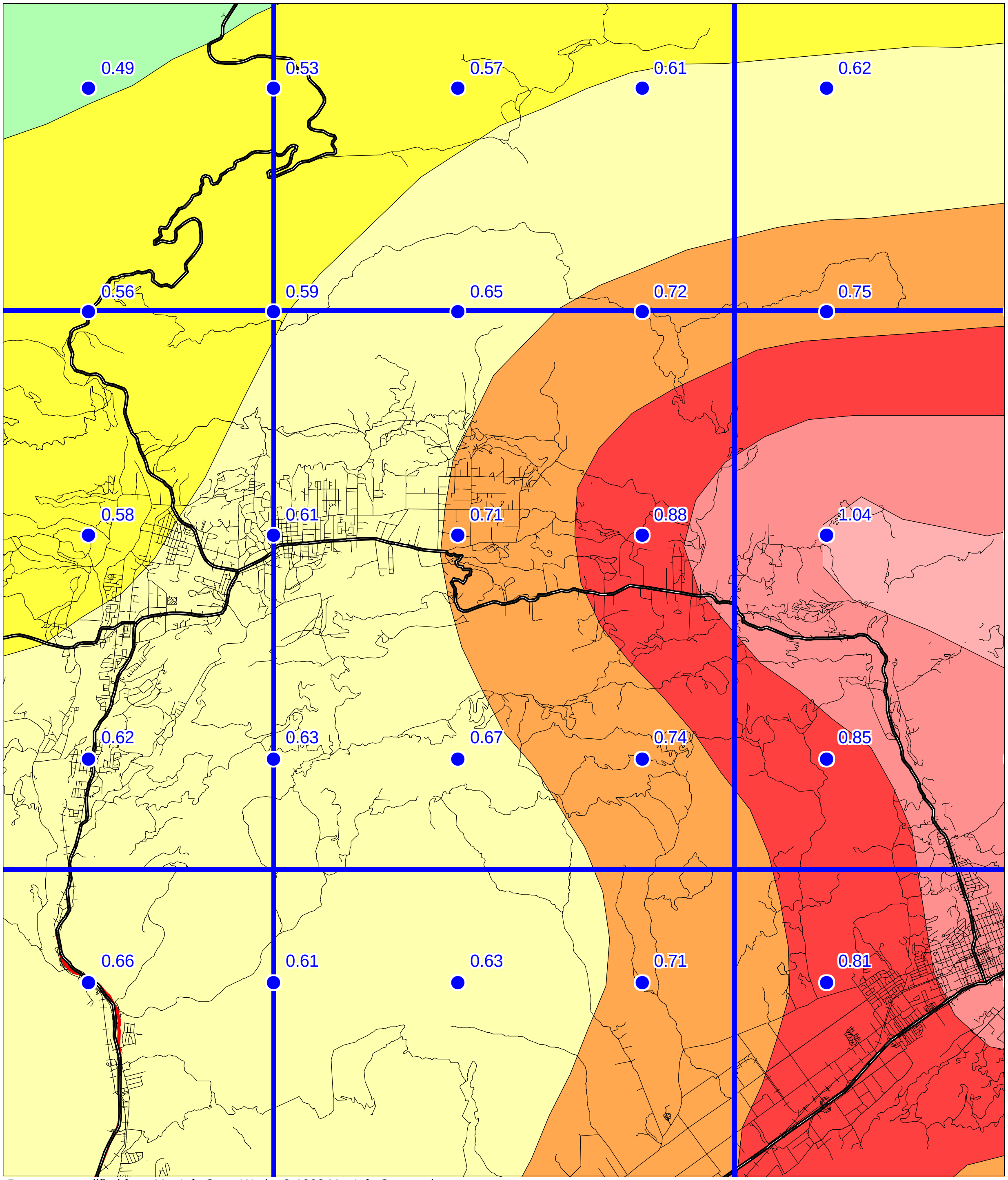
Figure 3.1

OJAI 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

SOFT ROCK CONDITIONS



Base map modified from MapInfo StreetWorks © 1998 MapInfo Corporation

0 1.5 3
Miles

Department of Conservation
Division of Mines and Geology

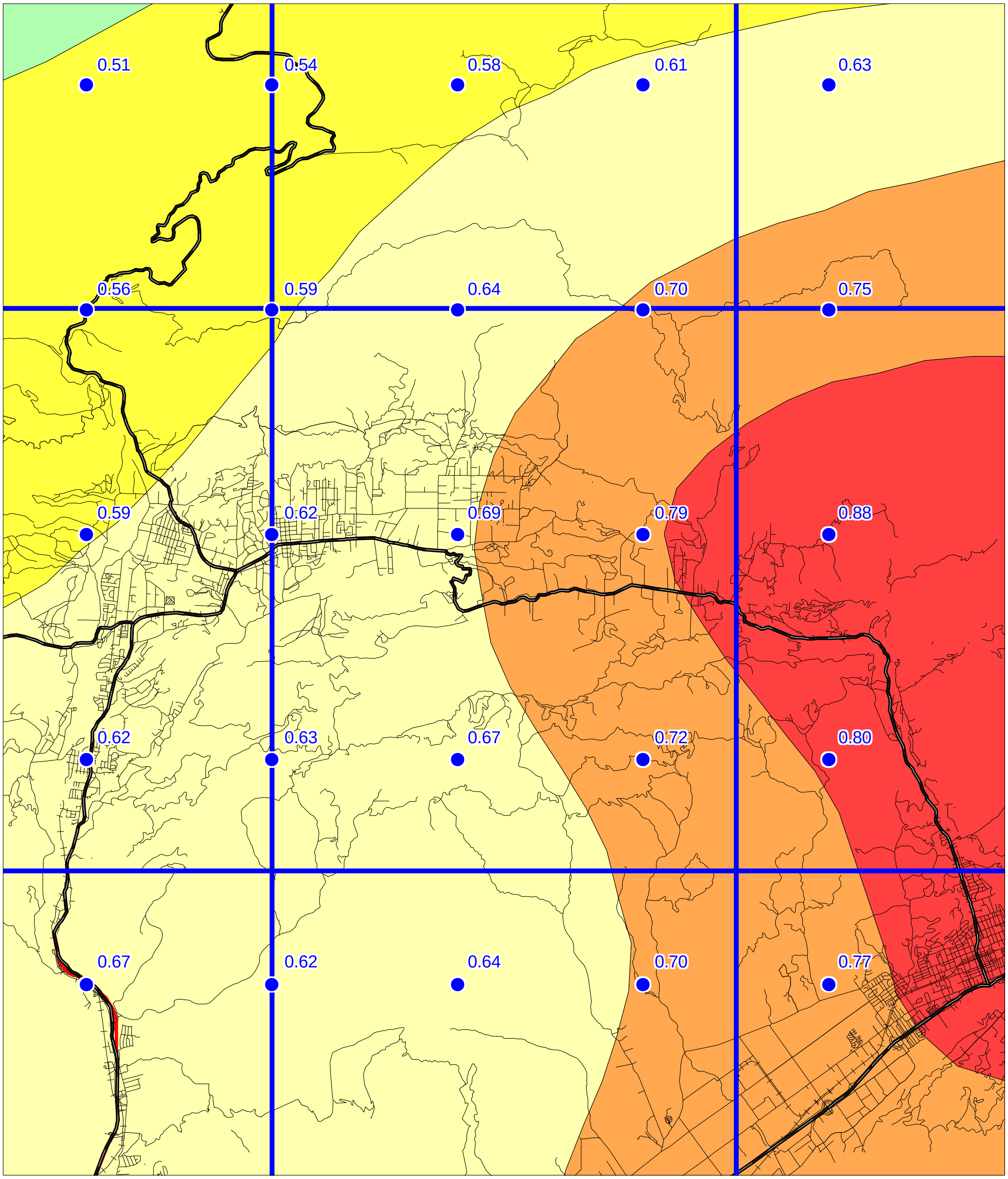
Figure 3.2

OJAI 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 1.5 3

Miles

Department of Conservation
Division of Mines and Geology

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.

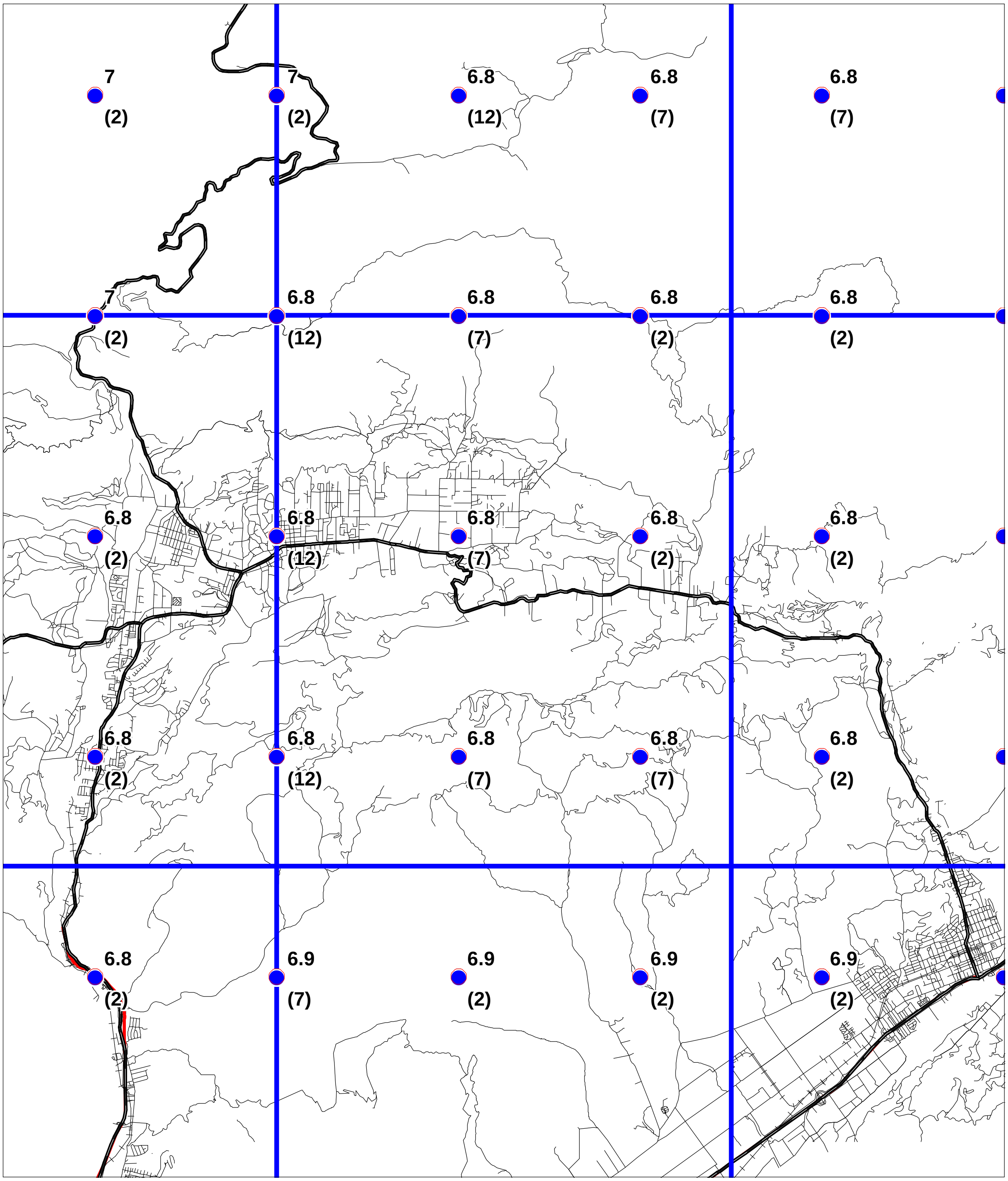
Figure 3.5 shows the magnitude-weighted alluvial PGA based on Idriss’ weighting function (Youd and Idriss, 1997). It is important to note that the values obtained from this map are pseudo-accelerations and should be used in the formula for factor of safety without any magnitude-scaling (a factor of 1)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

OJAI 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 1.5 3
Miles

Department of Conservation
Division of Mines and Geology

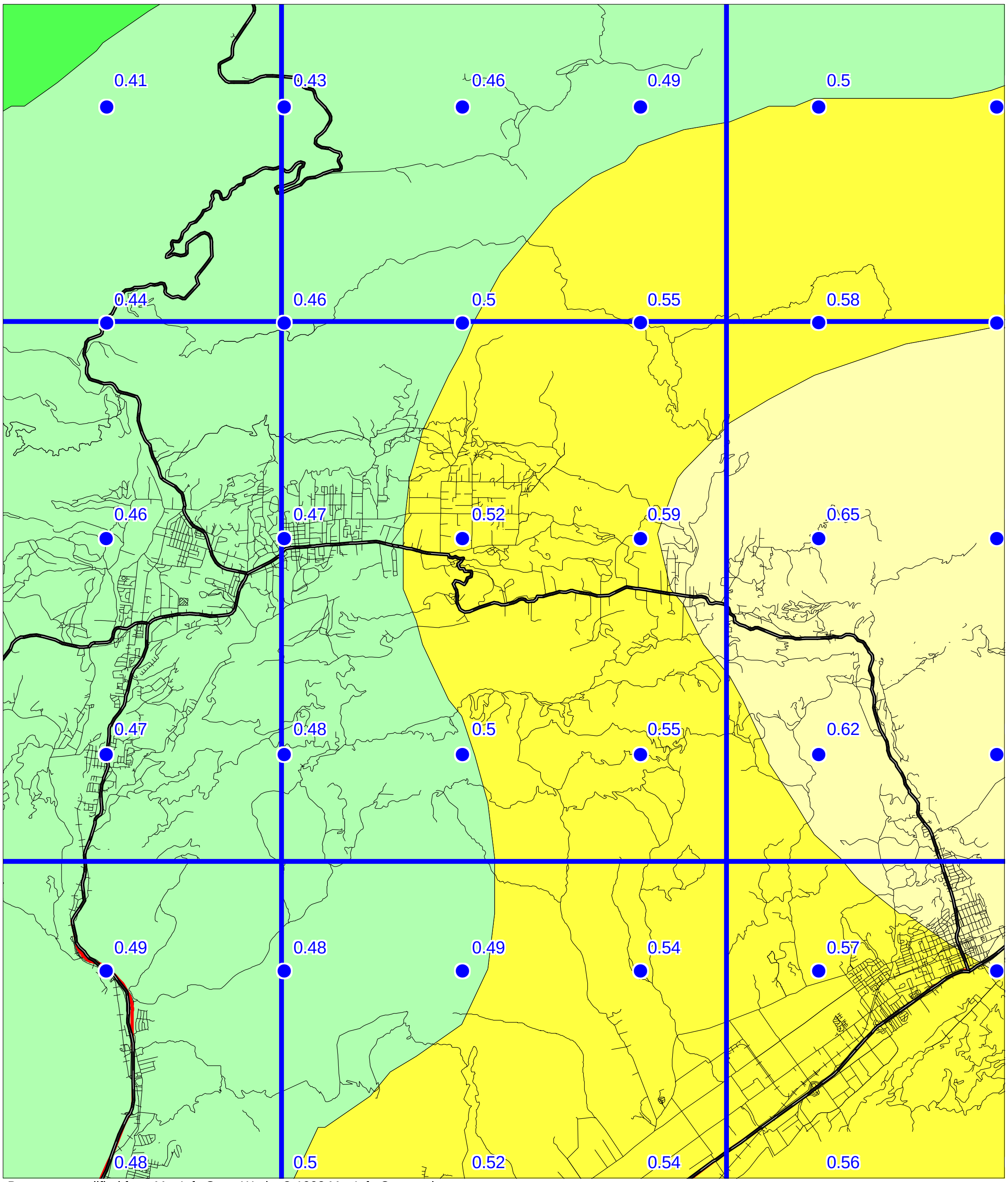
Figure 3.4

OJAI 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.

REFERENCES

Boore, D.M., Joyner, W.B. and Fumal, T.E., 1997, Empirical near-source attenuation relationships for horizontal and vertical components of peak ground acceleration, peak ground velocity, and pseudo-absolute acceleration response spectra: Seismological Research Letters, v. 68, p. 154-179.

California Department of Conservation, Division of Mines and Geology, 1997, Guidelines for evaluating and mitigating seismic hazards in California: Special Publication 117, 74 p.

Campbell, K.W., 1997, Attenuation relationships for shallow crustal earthquakes based on California strong motion data: Seismological Research Letters, v. 68, p. 180-189.

Cramer, C.H. and Petersen, M.D., 1996, Predominant seismic source distance and magnitude maps for Los Angeles, Orange and Ventura counties, California: Bulletin of the Seismological Society of America, v. 85, no. 5, p. 1645-1649.

Cramer, C.H., Petersen, M.D. and Reichle, M.S., 1996, A Monte Carlo approach in estimating uncertainty for a seismic hazard assessment of Los Angeles, Ventura, and Orange counties, California: Bulletin of the Seismological Society of America, v. 86, p. 1681-1691.

International Conference of Building Officials (ICBO), 1997, Uniform Building Code: v. 2, Structural engineering and installation standards, 492 p.

Jennings, C.W., *compiler*, 1994, Fault activity map of California and adjacent areas: California Department of Conservation, Division of Mines and Geology, California Geologic Data Map Series, map no. 8.

Petersen, M.D., Bryant, W.A., Cramer, C.H., Cao, T., Reichle, M.S., Frankel, A.D., Lienkaemper, J.J., McCrory, P.A. and Schwartz, D.P., 1996, Probabilistic seismic hazard assessment for the State of California: California Department of Conservation, Division of Mines and Geology Open-File Report 96-08; also U.S. Geological Survey Open-File Report 96-706, 33 p.

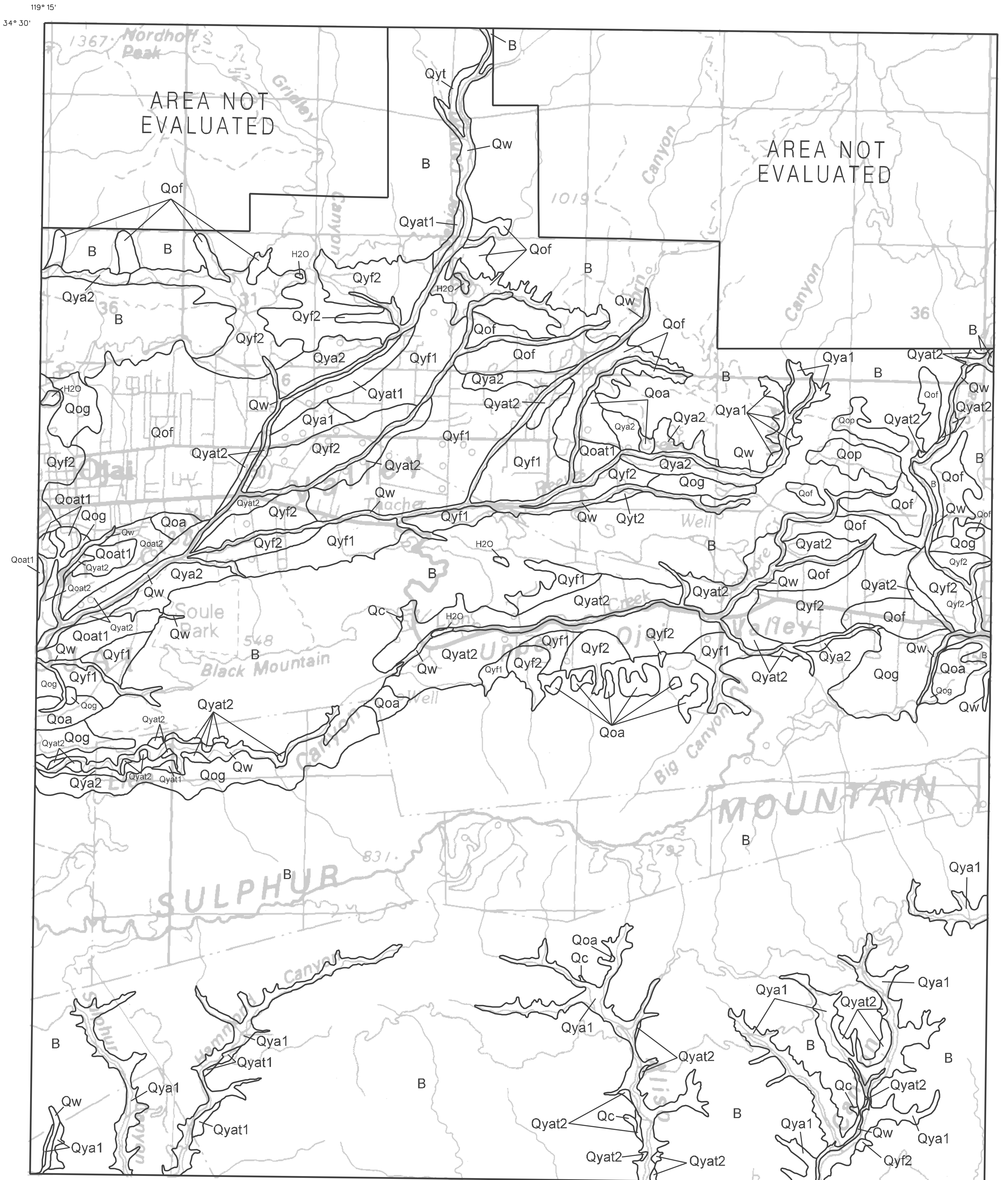
Real, C.R., Petersen, M.D., McCrink, T.P. and Cramer, C.H., 2000, Seismic Hazard Deaggregation in zoning earthquake-induced ground failures in southern California: Proceedings of the Sixth International Conference on Seismic Zonation, November 12-15, Palm Springs, California, EERI, Oakland, CA.

Sadigh, K., Chang, C.-Y., Egan, J.A., Makdisi, F. and Youngs, R.R., 1997, SEA96- A new predictive relation for earthquake ground motions in extensional tectonic regimes: Seismological Research Letters, v. 68, p. 190-198.

Wilson, R.C. and Keefer, D.K., 1983, Dynamic analysis of a slope failure from the 1979 Coyote Lake, California, Earthquake: Bulletin of the Seismological Society of America, v. 73, p. 863-877.

Youd, T.L. and Idriss I.M., 1997, Proceedings of the NCEER workshop on evaluation of liquefaction resistance of soils: Technical Report NCEER-97-0022, 40 p.

Youngs, R.R., Chiou, S.-J., Silva, W.J. and Humphrey, J.R., 1997, Stochastic point-source modeling of ground motions in the Cascadia Region: Seismological Research Letters, v. 68, p. 74-85.



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

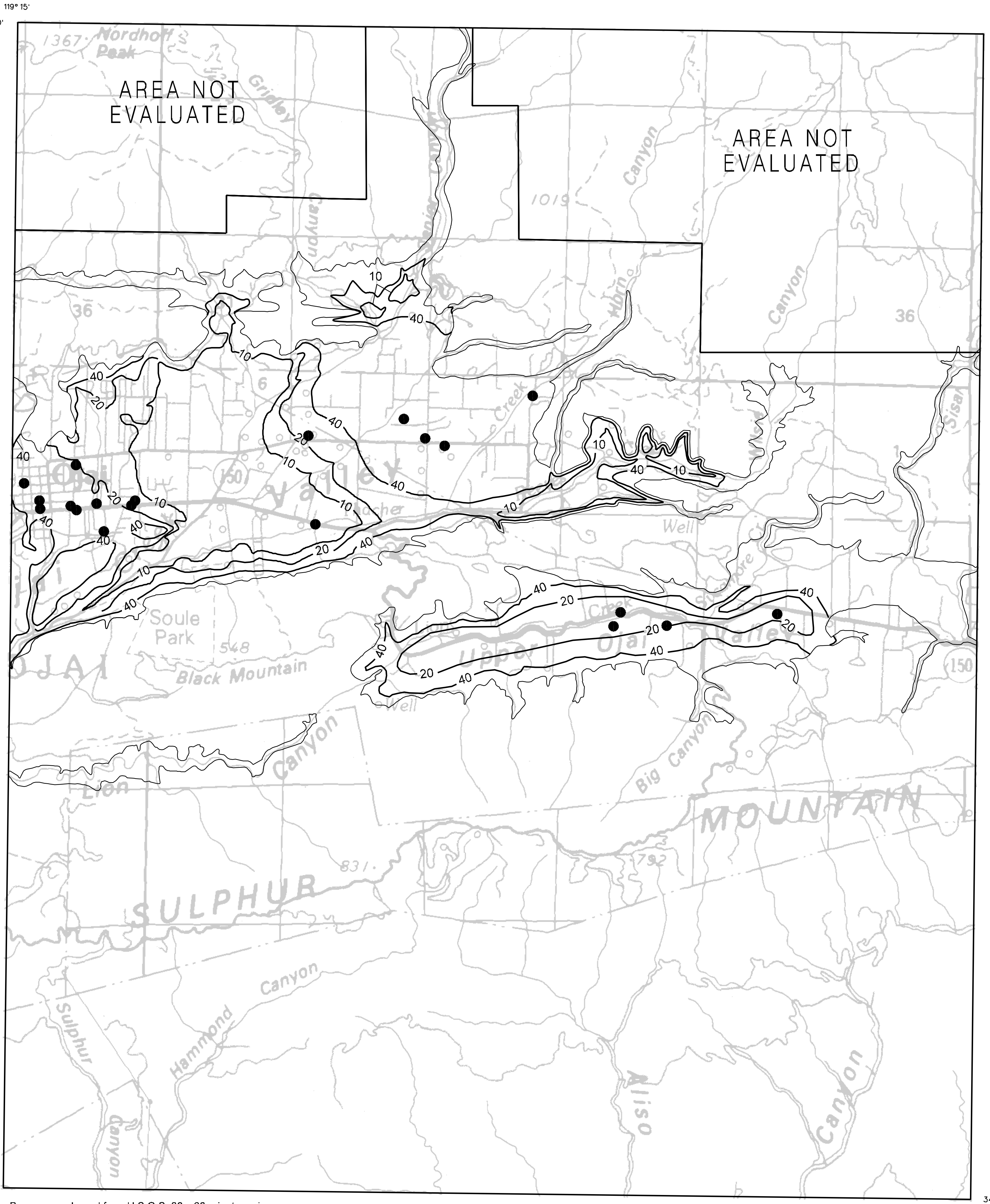
OJAI QUADRANGLE

SCALE

B = Pre-Quaternary bedrock.

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

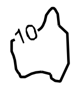
Plate 1.1 Quaternary Geologic Map of the Ojai 7.5-minute Quadrangle, California.



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

OJAI QUADRANGLE

SCALE



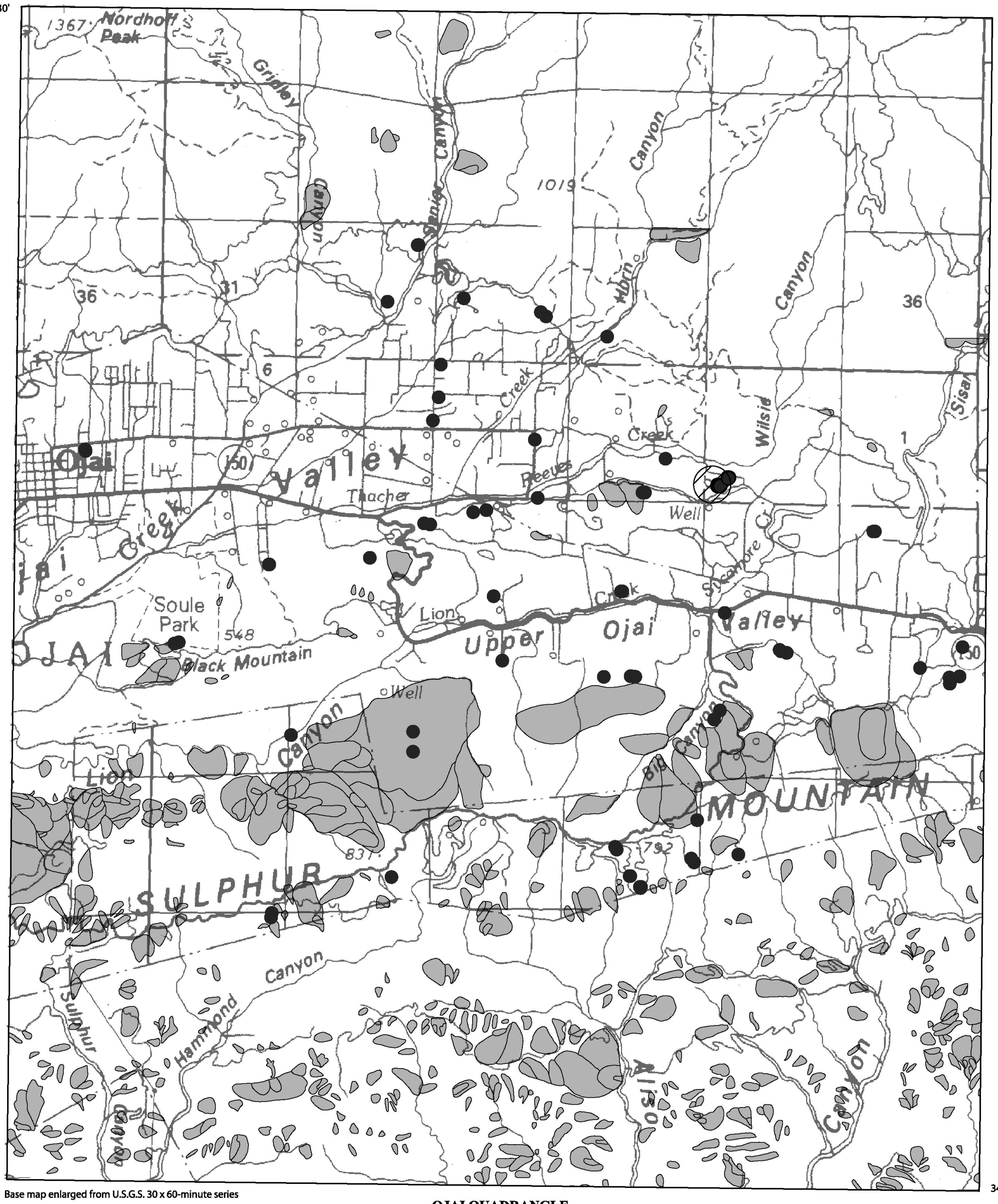
Countoured ground-water depth, in feet, Spring 1969; modified from Turner, 1971, Plates 6A & 6B;

Upper Ojai Valley contours modified from Latker, 1977

● Geotechnical borehole used in liquefaction evaluation

Plate 1.2 Estimated depth to historically high ground water within alluviated valleys, and locations of boreholes of the evaluated part of the Ojai 7.5-minute Quadrangle (modified from Turner, 1971 and Latker, 1977)

119°15'
34°30'



34°22'30"
119°07'30"

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

OJAI QUADRANGLE

SCALE

1 .5 0 1 MILE
1000 0 2000 4000 6000 FEET
1 .5 0 1 KILOMETER

N

○ Shear test sample location — Landslide — Tract report with multiple shear tests

Plate 2.1 Landslide inventory and shear test sample locations, Ojai 7.5-minute Quadrangle, California.