• Engineering Geology
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NOLAN ASSOCIATES

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RE: Geologic and Seismologic Discussion
City of Santa Cruz General Plan Update

Dear Ms. Strelow:

At your request, we are providing a discussion of the geologic and seismologic setting and potential geologic and seismologic hazards in the City of Santa Cruz, California. This discussion is intended to support analysis and planning recommendations for the current General Plan Update for the City of Santa Cruz.

Our scope of services for this project included:

1. Review of pertinent geologic and seismologic literature and maps for the City of Santa Cruz and environs. Literature references are provided at the end of the text.
2. Updating of the City of Santa Cruz Liquefaction Hazards Map.
3. Synthesis of the acquired information and preparation of the following discussion of geology and seismology in the City of Santa Cruz.

GEOLOGIC SETTING

Physiographic Setting

The City of Santa Cruz lies on a narrow coastal plain at the mouth of the San Lorenzo River Valley on the northern shore of the Monterey Bay (Figure 1, Topographic Setting). The coastal plain is bounded landward by the Santa Cruz Mountains, rising to elevations over 2600 feet. The San Lorenzo River flows southward from the Santa Cruz Mountains and is the largest drainage in the region, with an area of about 106 square miles. The central district of the City of Santa Cruz is situated on flood plains within the San Lorenzo River valley. This river valley has been cut down 40 feet or more below the terrain to the east and west of the river. It is filled with young alluvial sediments deposited by the river over the last several thousand years. The flood plain slopes gently towards the river and gently downstream, towards the ocean.

Most of the City lies on a relatively flat topographic bench to the east and west of the San Lorenzo river valley. This bench was formed by marine wave erosion at a time when

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the land was lower relative to sea level than at present. The bench, referred to as a marine terrace, was preserved by gradual uplift of the region. This terrace is separated from successively higher (older) terraces by steep slopes that mark ancient sea cliffs. The older terraces ascend stair-step like up the mountain front bordering the City to the north.

The lowermost of these terraces forms a broad, gently seaward sloping surface that terminates in a sea cliff at the modern shoreline. This modern seacliff, or coastal bluff, is a result of wave erosion that is cutting a new marine terrace offshore. The upper west side of the City and the De La Veaga Golf Course are situated on an older, higher marine terrace. The marine terrace surfaces are cut by a series of south flowing seasonal streams that occupy smaller stream valleys.

Regional Geologic Setting

The City of Santa Cruz is situated on the southwestern slope of the central Santa Cruz Mountains, part of the Coast Ranges physiographic province of California. The northwest-southeast structural grain of the Coast Ranges is controlled by a complex of active faults within the San Andreas fault system (Figure 2, Regional Geologic Map, and Figure 3, Regional Seismicity Map). Southwest of the San Andreas fault in the Santa Cruz area, the Coast Ranges, including the Santa Cruz Mountains, are underlain by a large, northwest-trending, fault-bounded, elongate prism of granitic and metamorphic basement rocks (Figure 2). The granitic and metamorphic basement is Cretaceous in age, or older (See Table 1 for the Geologic Time Scale), and is overlain by a sequence of dominantly marine sedimentary rocks of Paleocene to Pliocene age and non-marine sediments of Pleistocene and Holocene age (Figure 2). The older sedimentary rocks are moderately to strongly deformed, with steep-limbed folds and several generations of faults associated with uplift of the Santa Cruz Mountains.

The region is tectonically active, that is, it is subject to forces causing the earth's crust to deform. The deformation can occur as movement on active faults, folding of layered rocks, or down warping or uplifting of portions of the crust. All these processes are active in the Santa Cruz area.

The Santa Cruz Mountains are cut by several active faults, of which the San Andreas is the most important (Figure 3). Along the coast, the ongoing tectonic activity is most evident in the gradual uplift of the coastline, as indicated by the series of uplifted marine terraces that sculpt the coastline. The Loma Prieta earthquake of 1989 and its aftershocks are recent reminders of the geologic unrest in the region.

Regional Seismic Setting

California's broad system of strike-slip faulting has a long and complex history. Locally, the San Andreas, Zayante-Vergeles and San Gregorio faults and the Monterey Bay-

Tularcitos fault zone are thought to present a significant seismic hazard to the City (Figure 3). These faults are associated with Holocene activity (movement in the last 11,000 years) and are therefore considered to be active. The most severe historical earthquakes to affect the project site are the 1906 San Francisco earthquake and the 1989 Loma Prieta earthquake, with Richter magnitudes of about 8.3 and 7.1, respectively.

Geologic Setting of the City of Santa Cruz

A geologic map of the City of Santa Cruz is depicted on Figure 4, Local Geologic Map. The geology of the City and surrounding area displays over 100 million years of geologic history, including collisions of crustal plates, multiple cycles of tectonic upheaval, and erosion of the land surface. These episodes of tectonic deformation are evident in the metamorphism and intrusion of older sedimentary rocks by plutonic igneous rocks, by folding and faulting of younger sedimentary layers, and by erosional remnants of once extensive geologic formations.

Geologic Units

Rock units in the City are separable into three major groups: granitic intrusive rocks of Late Cretaceous age (Table 1), pre-Cretaceous metasedimentary rocks, and sedimentary rocks of Tertiary and Quaternary age. The granitic intrusive rocks form the core of Ben Lomond Mountain and underlie the City at depth. These rocks formed from molten rock (magma) that melted its way upward from deep in the earth's crust and then cooled underground, forming granitic rock. The magma intruded older sedimentary rocks buried in the crust and metamorphosed them through heat and pressure into schist, quartzite, and marble. Some of the original sedimentary layering can still be seen in these metamorphosed rocks. The metamorphic and granitic rocks are observed cropping out along the northwestern margins of the City (Figure 4). These rocks have also been found underlying the City in deep borings.

The younger sedimentary rocks (Tertiary and Quaternary age) are draped over the the older granitic and metamorphic bedrock. The Tertiary rock units include the Santa Margarita Sandstone, the Santa Cruz Mudstone, and sandstones of the Purisima Formation (Figure 4). Surficial deposits of Quaternary age locally overly the Tertiary units. These units include marine terrace deposits, stream or river alluvium, and landslide deposits. The marine terrace deposits directly underly much of the City (Figure 4). These deposits generally range from a few feet thick to at most a few tens of feet thick. They consist of marine sands, including ancient beach sands, deposited while the marine terrace was being carved by the ocean, and colluvium deposited over the marine sands after the terrace was exposed by falling sea levels. Soil (residuum) derived from weathering of all the older geologic units is present in thicknesses up to a few feet throughout the area (Figure 4).

Table 1: Geologic Time Scale

GEOLOGIC TIME SCALE

EON	ERA	PERIOD		EPOCH	Age in millions of years before present
					Present
Phanerozoic	Cenozoic	Quaternary		Holocene	0.01
				Pleistocene	1.6
		Tertiary	Neogene	Pliocene	5.3
				Miocene	23.7
			Paleogene	Oligocene	36.6
				Eocene	57.8
				Paleocene	66.4
	Mesozoic	Cretaceous			144
		Jurassic			208
		Triassic			245
	Paleozoic	Permian			286
		Carboniferous	Pennsylvanian		320
			Mississippian		360
		Devonian			408
		Silurian			438
		Ordovician			505
		Cambrian			570
Precambrian	Proterozoic				2500
	Archean				3800
	Hadean				4550

Geologic Structure

The older igneous and metamorphic rocks are highly deformed, with many cross-cutting faults and folds. The tectonic forces responsible for the deformation seen in these rocks, however, have long since dissipated and the faults are no longer considered active. The sedimentary rocks overlying the granitic and metamorphic basement, principally the Santa Margarita Sandstone, the Santa Cruz Mudstone, and the Purisima Formation, are younger Tertiary age rocks and, locally, have experienced only gentle uplift and very mild folding. In most exposures, the layering in these rocks is near horizontal.

The only fault mapped within the boundaries of the City is the Ben Lomond fault. This fault trends southward from its intersection with the Zayante fault down the San Lorenzo Valley towards Santa Cruz (Figure 3). The fault has only been confidently mapped as far south as Felton, several miles north of Santa Cruz, but Stanley and McCaffrey (1983) extended the fault southward through the City into Monterey Bay, based largely on geophysical (indirect) evidence. Vertical movement on the fault, west side up, is thought to be responsible for uplift and tilting of the grantic rock mass that forms Ben Lomond Mountain. Most of the movement occurred on this fault prior to about six million years ago and it is not presently considered to be active (Stanley and McCaffrey, 1983; Cao et al., 2003).

Surface Processes

Surficial geologic processes in the area include weathering, erosion, and mass wasting (landsliding). Weathering of surficial materials and erosion by wind and water are the principal processes active in developing natural landscapes. When erosion leads to the development of steep slopes, landsliding may occur. In turn, landsliding breaks up the rock formations on the slope, leading to additional weathering and erosion. Landslides from the County of Santa Cruz landslide map occurring within the City are depicted on Figure 5, Landslide Map.

Karst Terrain

The northwest portion of the City is partially underlain by marble bedrock. Marble is distinct from other bedrock types in the area because it is soluble in water. Consequently, percolating ground water will gradually dissolve channels in the rock, resulting in underground conduits and caverns. Where these conduits or caverns intersect the ground surface, sinkholes result. Another aspect of areas underlain by marble is that the surface drainage system may be poorly developed or absent due to the capture of surface runoff by sinkholes. Where sinkholes intercept streams, they are known as swallow holes. A landscape that is dominated by features associated with soluble bedrock is known as karst terrain.

Karst terrain in the Santa Cruz area is of limited extent. Very large areas of the southeastern United States are underlain by karst terrain, and the sudden, spectacular collapse of large sinkholes is a potential hazard there. Most of the karst terrain in Santa Cruz lies on the University of California campus and in a few neighborhoods immediately south of the campus. Sinkholes associated with the karst terrain in the Santa Cruz area are not of great size, and they tend to develop gradually over time, rather than by sudden collapse. However, local sinkholes are often filled with fine grained sediment that has washed into the sinkhole from adjacent terrain. The sinkhole fill can prevent the sinkholes from being recognized. Soil settlement associated with filled sinkholes can damage buildings and other development. Mitigation of foundation problems associated with sinkholes has been an important focus for development on the UC campus.

Water flowing through the karst conduits in the marble emerges at the surface in form of springs where the downhill margins of marble outcrop are bounded by relatively impermeable rocks. The springs at Kalkar Quarry and the spring feeding Westlake are examples of such springs. Besides gradual settlement of sinkhole fill, there can also be problems associated with groundwater surfacing under buildings or roads in these areas, especially during the winter rains.

SEISMIC HAZARDS

Earthquakes are fact of life in a seismically active region such as Central California. Future earthquake shaking due to rupture of one of the local active faults is expected. Such shaking will likely be intense.

Historical earthquakes along the San Andreas fault and its branches have caused substantial seismic shaking in Santa Cruz County in historical time. The two largest historical earthquakes to affect the area were the moment magnitude (Mw) 7.9 San Francisco earthquake of 18 April 1906 and the Mw 6.9 Loma Prieta earthquake of 17 October 1989 (corresponding to *Richter* magnitudes of about 8.3 and 7.1). The San Francisco earthquake caused severe seismic shaking and structural damage to many buildings in the Santa Cruz Mountains. The Loma Prieta earthquake may have caused more intense seismic shaking than the 1906 event in localized areas of the Santa Cruz Mountains, although its regional effects were not as extensive. There were also major earthquakes in northern California along or near the San Andreas fault in 1838, 1865, and possibly 1890 (Sykes and Nishenko, 1984; WGONCEP, 1996).

A qualitative measure of earthquake shaking intensity is provided by the Modified Mercalli Intensity Scale (Table 2). The Mercalli Scale (and other, similar qualitative scales) provides a way to gauge earthquake shaking intensity based on verbal or published descriptions of earthquake damage. It was the principal means for measuring earthquake size before the advent of seismograph arrays in the early 20th Century.

Modified Mercalli Intensities of VIII (8) to IX (9) were measured in the City of Santa Cruz for the 1989 Loma Prieta and 1906 San Francisco earthquakes, respectively (Lawson et al., 1908; Stover et al. 1990). Similar shaking intensities are expected in future earthquakes

Seismic Shaking Hazard.

In addition to strong seismic shaking, seismic hazards include ground surface rupture due to faulting, soil liquefaction and related types of seismically induced ground failure, and tsunami. These hazards are discussed individually, below.

For the purpose of evaluating seismic shaking potential in the City, this discussion focuses on the San Andreas, Zayante-Vergeles, San Gregorio, and Monterey Bay-Tularcitos fault systems (Figure 3). These faults are considered active seismic sources by the State of California (Petersen et al., 1996; Cao et al., 2003). While other faults in this region may be active, their potential contribution to seismic hazards in the City is overshadowed by these

Table 2

Modified Mercalli Intensity Scale

The modified Mercalli scale measures the intensity of ground shaking as determined from observations of an earthquake's effect on people, structures, and the Earth's surface. This scale assigns to an earthquake event a Roman numeral from I to XII as follows:

I	Not felt by people, except rarely under especially favorable circumstances.
II	Felt indoors only by persons at rest, especially on upper floors. Some hanging objects may swing.
III	Felt indoors by several. Hanging objects may swing slightly. Vibration like passing of light trucks. Duration estimated. May not be recognized as an earthquake.
IV	Felt indoors by many, outdoors by few. Hanging objects swing. Vibration like passing of heavy trucks; or sensation of a jolt like a heavy ball striking the walls. Standing automobiles rock. Windows, dishes, doors rattle. Wooden walls and frame may creak.
V	Felt indoors and outdoors by nearly everyone; direction estimated. Sleepers wakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset; some dishes and glassware broken. Doors swing; shutters, pictures move. Pendulum clocks stop, start, change rate. Swaying of tall trees and poles sometimes noticed.
VI	Felt by all. Damage slight. Many frightened and run outdoors. Persons walk unsteadily. Windows, dishes, glassware broken. Knickknacks and books fall off shelves; pictures off walls. Furniture moved or overturned. Weak plaster and masonry cracked.
VII	Difficult to stand. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary buildings; considerable in badly designed or poorly built buildings. Noticed by drivers of automobiles. Hanging objects quiver. Furniture broken. Weak chimneys broken. Damage to masonry; fall of plaster, loose bricks, stones, tiles, and unbraced parapets. Small slides and caving in along sand or gravel banks. Large bells ring.
VIII	People frightened. Damage slight in specially designed structures; considerable in ordinary substantial buildings, partial collapse; great in poorly built structures. Steering of automobiles affected. Damage or partial collapse to some masonry and stucco. Failure of some chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed pilings broken off. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and on steep slopes.
IX	General panic. Damage considerable in specially designed structures; great in substantial buildings, with some collapse. General damage to foundations; frame structures, if not bolted, shifted off foundations and thrown out of plumb. Serious damage to reservoirs. Underground pipes broken. Conspicuous cracks in ground; liquefaction.
X	Most masonry and frame structures destroyed with their foundations. Some well-built wooden structures and bridges destroyed. Serious damage to dams, dikes, embankments. Landslides on river banks and steep slopes considerable. Water splashed onto banks of canals, rivers, lakes. Sand and mud shifted horizontally on beaches and flat land. Rails bent slightly.
XI	Few, if any masonry structures remain standing. Bridges destroyed. Broad fissures in ground; earth slumps and landslides widespread. Underground pipelines completely out of service. Rails bent greatly.
XII	Damage nearly total. Waves seen on ground surfaces. Large rock masses displaced. Lines of sight and level distorted. Objects thrown upward into the air.

four larger or closer faults. The distances between these faults and the City center are listed in Table 3. Also listed in Table 3 is the maximum expected earthquake size and the approximate time interval between major earthquakes on each fault. All of these faults are considered capable of magnitude (M) 6.5 or larger earthquakes. The faults are discussed individually in the following sections.

Table 3
Distances and Directions to Local Faults

Fault	Distance from site (miles)	Maximum Expected Earthquake Magnitude (Moment Magnitude)	Approximate Time Between Major Earthquakes (years)
San Gregorio	9.9	7.2	400
Zayante-Vergeles	7.9	7.9	8821
Monterey Bay-Tularcitos	6.5	6.5	2841
San Andreas	11.2	7.9	210

Faults

San Andreas Fault

The San Andreas fault is active and represents the major seismic hazard in northern California (Jennings, 1994). The main trace of the San Andreas fault trends northwest-southeast and extends over 700 miles from the Gulf of California through the Coast Ranges to Point Arena, where the fault passes offshore and merges with the Cascadia subduction zone.

Geologic evidence suggests that the San Andreas fault has experienced right-lateral, strike-slip movement throughout the latter portion of Cenozoic time (Table X1), with cumulative horizontal offset of hundreds of miles. Surface rupture during historical earthquakes, fault creep, and historical seismicity confirm that the San Andreas fault and its branches, the Hayward, Calaveras, and San Gregorio faults, are all active today.

Geologists have recognized that the San Andreas fault system can be divided into segments with "characteristic" earthquakes of different magnitudes and recurrence intervals (WGCEP, 1988 and 1990; WGONCEP, 1996). Two overlapping segments of the San Andreas fault system represent the greatest potential hazard to the City. The first segment is defined by the rupture that occurred from Mendocino to San Juan Bautista along the San Andreas fault during the great Mw 7.9 San Francisco earthquake of 1906. The

WGONCEP (1996) has hypothesized that this "1906 rupture" segment experiences earthquakes with comparable magnitudes about every 200 years.

The second segment is defined approximately by the rupture zone of the Mw 6.9 Loma Prieta earthquake. The WGONCEP (1996) has posited earthquakes of Mw 7.0 on this segment of the fault, with an independent segment recurrence interval of 138 years.

Zayante-Vergeles Fault

The Zayante fault lies southwest of the San Andreas fault and trends about 50 miles northwest from the Watsonville lowlands into the Santa Cruz Mountains (Figure 3). The postulated southern extension of the Zayante fault, known as the Vergeles fault, merges with the San Andreas fault south of San Juan Bautista.

The Zayante-Vergeles fault has a long, well-documented history of vertical movement (Clark and Reitman, 1973), probably accompanied by some right-lateral, strike-slip movement (Hall et al., 1974; Ross and Brabb, 1973). Stratigraphic and geomorphic evidence indicates that the Zayante-Vergeles fault has undergone late Pleistocene and Holocene movement and is potentially active (Coppersmith, 1979).

Some historical seismicity may be related to the Zayante-Vergeles fault (Griggs, 1973). The Zayante-Vergeles fault may have undergone sympathetic fault movement during the 1906 earthquake centered on the San Andreas fault, although this evidence is equivocal (Coppersmith, 1979). Gallardo et al. (1999) concluded that a magnitude 4.0 earthquake in 1998 in the Santa Cruz Mountains occurred on the Zayante fault.

In summary, the Zayante-Vergeles fault should be considered active for design purposes. Cao et al. (2003) concluded that the Zayante-Vergeles fault is capable of generating an Mw 6.8 earthquake, with a recurrence interval of almost 9,000 years.

San Gregorio Fault

The San Gregorio fault cuts the ocean floor seaward of Monterey Bay and skirts the Santa Cruz County coastline before coming on land at Point Año Nuevo. North of Año Nuevo it passes offshore, intersecting the coast again at Half Moon Bay (Figure 3). North of Half Moon Bay, the San Gregorio fault lies offshore until it connects with the San Andreas fault near Bolinas. Southward from Monterey Bay, the San Gregorio fault intersects the coast at Point Sur and eventually connects with the Hosgri fault in south-central California (Dickinson et al., 2005).

The onshore segments of the San Gregorio fault at Point Año Nuevo and at Half Moon Bay show evidence of late Pleistocene and Holocene displacement (Weber et al., 1995; Simpson et al., 1997). In addition to stratigraphic evidence for Holocene activity, the historical seismicity in the region is partially attributed to the San Gregorio fault. Due to inaccuracies of epicenter locations, the magnitude 6+ earthquakes of 1926, tentatively assigned to the Monterey Bay fault zone, may have actually occurred on the San Gregorio fault (Greene, 1977). Recent stratigraphic studies of the fault document 97 miles of horizontal offset on the fault (Dickinson et al., 2005).

Petersen et al. (1996) divided the San Gregorio fault into the “San Gregorio” and “San Gregorio, Sur Region” segments. The segmentation boundary is located west of Monterey Bay. Petersen et al. (1996) assigned the San Gregorio fault in the Santa Cruz County area a recurrence interval of 400 years. Cao et al. (2003) consider the fault capable of an Mw 7.2.

Monterey Bay-Tularcitos Fault Zone

The Monterey Bay-Tularcitos fault zone is based on a postulated connection between the Tularcitos fault, located on land near the Monterey Peninsula, and the offshore Monterey Bay fault zone (Figure 3). The Monterey Bay fault zone is 6 to 9 miles wide and about 25 miles long, consisting of many northwest-trending, en échelon faults identified during shipboard seismic reflection surveys (Greene, 1977).

The fault zone projects toward the coastline in the vicinity of Seaside and Ford Ord. At this point, a principal offshore fault trace in the heart of the Monterey Bay fault zone is tentatively correlated by Greene (1977) with the Navy Fault, a postulated westward extension of the Tularcitos fault. It should be emphasized that this correlation between onshore and offshore portions of the Monterey Bay-Tularcitos fault zone is only tentative; no concrete geologic evidence for connecting the Navy and Tularcitos faults under the Carmel Valley alluvium has been observed, nor has a direct connection between these two faults and any offshore trace been found.

Outcrop evidence indicates a variety of strike-slip and dip-slip movements associated with the onshore and offshore traces. Earthquake studies suggest the Monterey Bay-Tularcitos fault zone is predominantly right-lateral, strike-slip in character (Greene, 1977). Both offshore and onshore fault traces in this zone have displaced Quaternary age rock layers and, therefore, are considered potentially active. One offshore trace, which aligns with the trend of the Navy fault, has displaced Holocene beds and is therefore considered active (Greene, 1977).

Seismically, the Monterey Bay-Tularcitos fault zone may be historically active. The largest historical earthquakes tentatively located in the Monterey Bay-Tularcitos fault zone are two events, estimated at 6.2 on the Richter Scale, in October 1926 (Greene, 1977). Because of possible inaccuracies in locating the epicenters of these earthquakes, it is possible that these earthquakes actually occurred on the nearby San Gregorio fault (Greene, 1977).

Another earthquake in April 1890 might be attributed to the Monterey Bay-Tularcitos fault zone (Burkland and Associates, 1975); this earthquake had an estimated Modified Mercalli Intensity of VII (Table X2) for northern Monterey County.

The WGONCEP (1996) has assigned an expected earthquake of Mw 7.1 to the Monterey Bay-Tularcitos fault zone, with an effective recurrence interval of 2,600 years, based on Holocene offsets noted on an offshore strand of the fault. Cao et al. (2003) chose a 7.3 expected earthquake magnitude, but with a recurrence interval of 2,841 years. Their expected earthquake is based on a composite slip rate of 0.5 millimeters per year (after Rosenberg and Clark, 1994).

Estimates of Seismic Shaking Intensity

The principal factors which affect the severity of seismic shaking in a given area are the magnitude of the earthquake and the distance from the earthquake source to the location of interest. All of the listed faults, because of the size and proximity to the City, are significant potential sources of strong seismic shaking. Another factor which affects the intensity of shaking is the type of geologic materials underlying the site. Certain types of earth materials can amplify or dampen shaking.

The intensity of seismic ground motions are commonly expressed as horizontal ground acceleration in units of “g”, where one g equivalent to the acceleration produced by earth’s gravity. Acceleration is a measure of how rapidly a point on the ground speeds up and slows down as the seismic wave passes.

There are two methods for estimating the intensity of seismic ground motions that may be expected at a site: "deterministic" and "probabilistic". A deterministic approach estimates the magnitude of the most severe shaking that can reasonaby expected at a particular site, without regard for the likelihood that such shaking will occur. In this type of analysis, the largest earthquake thought credible on each fault is assumed to occur on the portion of the fault nearest the site.

A probabilistic analysis considers the likelihood that a certain earthquake will occur and includes other uncertainties, such as epicentral location, as part of the overall probability. The advantage of a probabilistic analysis over a deterministic analysis is that the probabilistic estimate specifies the intensity of ground motion that is likely to occur during the design life of a project, rather than the greatest intensity that is ever likely to occur. Using probabilistic ground motions, a building may be designed for the a shaking intensity that has a reasonable likleyhood of occurring during the building lifetime, rather than a maximum value that has very little likelihood of occurring. In most cases, the probabilistically predicted ground motion is lower than the deterministic ground motion. However, in Santa Cruz County, the San Andreas fault produces large earthquakes so often that the deterministic and probabilistic ground motion values tend to be very similar.

Ground motion probabilities are commonly expressed as the probability of exceedance in a given time period. In the past, ground motion with a probability of exceedance of 10% in 50 years has been considered appropriate for design for most residential and commercial development. This probability level means that there is only a 10% chance that the specified ground motion will be exceeded in a 50 year period. For more critical structures, such as hospitals, a much lower probability level (higher ground motion) is specified for design.

Probabilistic Ground Motion

The U.S. Geological Survey and the California Division of Mines and Geology have prepared a probabilistic seismic hazard assessment for the state of California (Petersen et al., 1996). The investigative team identified the principal active faults in the state and estimated the magnitudes and frequencies for earthquakes likely to be produced by these faults. Probabilistic ground motions with 10% in 50 years and 2% in 50 years probability of exceedance are summarized in Table 4. These numbers can be compared to ground accelerations measured during the Loma Prieta earthquake, Table 5

Table 4: Predicted Seismic Ground Motions in Soft Rock	
Probability	Mean Peak Horizontal Ground Acceleration, City Center (g)
10% probability of exceedance in 50 years	0.41
2% probability of exceedance in 50 years	0.63

Table 5: Seismic Ground Motions Measured during the Loma Prieta Earthquake		
Measurement Site	Peak Ground Acceleration	Earth Material at Measurement Site
Corralitos	0.64	Landslide deposits
Capitola	0.54	Alluvium
UCSC	0.47	Marble

Ground Shaking Amplification

The expected ground motion values listed in Table 4 are based on average (soft rock) site conditions; actual ground motions during an earthquake may vary due to differences in the way portions of the earth's crust transmit seismic energy or because of unique site conditions, such as soil type, bedrock type, and topography. Sites underlain by very hard bedrock tend to produce the least damaging effects on buildings, other factors being equal, while relatively soft alluvial deposits can increase the amplitude of ground shaking that affects buildings. Site topography can also affect the severity of ground shaking. Ground accelerations at the crests of narrow, steep-sided ridges can be several times as intense as in adjacent valleys (Hartzell et al., 1994).

The central district of Santa Cruz is situated on young alluvial deposits of the San Lorenzo River (Qal, Figure 4). This type of earth material will amplify the effects of seismic shaking on buildings. Other portions of Santa Cruz are primarily underlain by sandstone and shale that can be categorized as soft rock. The impact of seismic shaking in these areas will be lower. Seismic shaking is expected to have the least impact on portions of the City underlain by granitic or metamorphic rocks such as marble (Figure 4).

Ground Surface Rupture Due to Faulting

Earthquakes are caused by slippage along faults, or cracks, in the earth's crust. Where the fault intersects the ground surface, this slippage causes offset of the ground surface that can damage or destroy structures placed over the fault. The only suspected fault trace crossing throught the City is the southern extension of the Ben Lomond fault proposed by Stanley and McCaffrey (1983). This fault is not considered to be active and therefore any risk of ground surface rupture across the fault trace must be considered low. Ground surface rupture due to faulting is therefore not considered a significant risk in the City of Santa Cruz.

Seismically Induced Ground Failure

This section describes several types of ground failure that may accompany seismic shaking. These ground failure types include liquefaction and its related hazards of lurch cracking and lateral spreading, differential settlement, off-fault ground cracking, and landsliding. These particular hazards are discussed in the following sections.

Liquefaction, Lurch Cracking, and Lateral Spreading

Liquefaction occurs in loose, cohesionless, granular materials that are saturated with ground water. The effects of seismic shaking can cause this type of sediment to loose strength and flow like a liquid. Liquefaction related ground deformation includes lurch cracking, fissuring, and lateral spreading.

Lurch cracking and fissuring occurs where a liquefied layer at depth is overlain by a surficial layer of relatively brittle, non-liquefied soil. In this situation, the surface layer may crack into individual blocks that can tip or rotate relative to each other. The resulting surface deformation can damage or destroy overlying buildings.

Lateral spreading occurs most often on level terraces or flood plains bounded on one side by a steep stream or river bank. When the sediments adjacent to the river liquefy, they flow into the stream or river channel. Lurch cracking and lateral spreading are potential hazards in areas susceptible to liquefaction.

There are four factors that help geologists and engineers estimate that likelihood that liquefaction will occur in a given area: 1) age of the underlying geologic materials, 2) type of geologic deposit, 3) depth to ground water, and 4) potential intensity and duration of seismic shaking

1. Age Geologic deposits tend to consolidate (become denser) with time. The densification is due to the gradual settling in natural deposits over time, especially where the weight of new deposits compacts earlier, underlying sediments. Also, there are changes that can take place over time that add cohesion or cementation to the sediments and make them more resistant to liquefaction.

2. Type of deposit The most easily liquefied sediments are well sorted (of uniform grain size), with clean, fine-grained sands and silts being the most susceptible. Sand (or gravel) that is mixed with significant amounts of clay and silt ("mud") is less likely to liquefy. Some types of geologic deposits naturally tend to be better sorted than others. Sediments deposited by rivers or streams are usually well sorted by the flowing water and are the type of deposits most frequently associated with liquefaction.

3. Depth to ground water The depth to ground water is an important factor because the deeper the layer of concern, the more weight it has pressing down on it by overlying deposits and the less likely it is to liquefy. Although researchers have reported evidence for liquefaction of sediments at depths of 100 feet or more, for practical purposes, liquefaction is generally not considered a hazard for sediments below a depth of about 50 feet. Sediments nearer the surface are more easily liquefied, all other factors being equal, and the effects are more likely to impact the ground surface. Since sediments cannot liquefy unless they are fully saturated, the shallower the water table, the higher the liquefaction hazard.

4. Seismic shaking intensity and duration In order for sediments to liquefy, they must be subjected to strong seismic shaking long enough in duration to raise pore water pressures (pore water refers to the ground water filling the spaces between individual sediment grains). Once the pore water pressure exceeds the weight of the overlying soil, the deposit will behave as a liquid. Because of the high regional seismic potential, ground shaking sufficient to liquefy susceptible deposits is expected to occur throughout the planning area.

Once a susceptibility to liquefaction is identified in an area, the risk posed to buildings and other structures by liquefaction depends strongly on the thickness and depth of the liquefiable layer. If the liquefiable layer is only six inches thick and is buried by 40 feet of non-liquefiable sediment, the actual hazard posed to a building at the surface may be relatively small. On the other hand, a 20-foot thick liquefiable layer buried by five feet of dry soil would be very likely to cause damage.

There is evidence for liquefaction in Santa Cruz during both the 1906 San Francisco and 1989 Loma Prieta earthquakes (Lawson, 1908; Youd and Hoose, 1978; Kropp and Thomas, 1991). A previous evaluation of liquefaction hazard was prepared for Santa Cruz County by Dupre (1975).

For liquefaction hazard studies intended to address specific sites, liquefaction susceptibility is determined based on empirical relationships developed from the study of historical liquefaction events. These relationships use data obtained from exploratory borings or other types of field investigations on the site under investigation, including estimated or laboratory-determined in-place densities, grain size observations, and water table information. However, the effort required to perform this type of liquefaction susceptibility analysis for a large area, such as the City of Santa Cruz, is beyond the scope of this evalution.

Consequently, for this area-wide study, we have relied on a ranking of mapped geologic units by liquefaction susceptibility according to age and type of deposit. This ranking draws on historical occurrences of liquefaction and previous liquefaction hazard studies. Potential liquefaction hazard zones are depicted on Liquefaction Susceptibility Map, Figure 6. Susceptibility areas are divided into areas “A” and “B”. Both areas are underlain by soils considered to be liquefiable, but the “B” areas are anticipated to have greater depth to groundwater, and therefore, a lesser susceptibility to liquefaction.

This map is intended as a planning tool to identify areas where more in-depth analysis of liquefaction potential may be required. Not all of the liquefaction hazard zones showed evidence of liquefaction during the 1906 or 1989 earthquakes. Nevertheless, ground water levels fluctuate over time and different earthquakes can produce different effects.

Seismically Induced Differential Settlement

Seismically induced differential settlement may occur anywhere that soils are in a loose state. In the planning area, soils subject to this hazard will probably be limited to areas of improperly compacted artificial fill or areas of the most recently deposited sediments on the banks of the San Lorenzo River. In general, areas of natural soils that are potentially susceptible to differential settlement will be included in areas that are potentially liquefiable, as these soils are usually the type of soils that would liquefy if they were saturated. In our opinion, areas of loose soil that could be subject to seismically induced differential settlement are of limited extent in the study area. We have not attempted to map areas subject to this potential hazard. This hazard can generally be mitigated by appropriate site-specific geotechnical investigations and proper foundation design. Any site screened for liquefaction hazard should also be evaluated for differential settlement potential.

Off-Fault Ground Cracking

During the 1989 earthquake, numerous ground cracks opened up along the crests and flanks of ridges. The ground cracks ranged from fractions of an inch to many feet wide and up to one-quarter mile long. Where the ground cracks crossed under buildings, the buildings were often severely damaged.

These ground cracks are considered to be co-seismic ground surface rupture; that is, they occur in response to severe ground shaking, but are not caused directly by offset of a fault. Ground cracking can also occur due to liquefaction, but such cracks are generally grouped with lurch cracking and are not included in this category. The co-seismic ground cracks may occur for a variety of reasons, but they are generally associated with steep topography, particularly ridge crests. With the exception of the crest of coastal bluffs, the topography within the City is generally not conducive to formation of co-seismic ground cracks and this hazard is therefore considered to be low throughout the City. Ground cracking is expected to occur in zones up to 50 feet wide landward from the crest of coastal bluffs, or anywhere there is a high, vertical or near-vertical cliff face.

Seismically Induced Landsliding

Seismically induced landsliding results when earthquake shaking adds extra stress to an already marginally stable slope. Landsliding that occurred in the Santa Cruz region as a result of the 1989 Loma Prieta earthquake included: 1) reactivation of existing landslides, including several very large, ancient landslide complexes that had previously been thought to be stable; 2) shallow slumps, calving, and toppling of natural cliffs and stream banks; and 3) slumping of steep cut slopes and embankments associated with grading for roads and development

Movement of the large, ancient landslides that took place during the 1989 earthquake involved incremental movements on the order of a few inches to a few feet. These landslides tended to move while the strong shaking was occurring, and then came to rest as soon as the shaking diminished. Because of the size and limited displacement of these landslides, damage to homes sited on the landslides was often remarkably light, except where the homes spanned the cracks around the landslide margins.

The other types of landsliding that occurred during the Loma Prieta earthquake were generally localized, affecting single homes or blocking roadways with loose soil and rock debris. There were extensive, but very shallow failures of sea cliffs around Monterey Bay and on very steep to vertical banks along creeks and rivers. There were also a number of landslides, mostly from cut slopes, that closed roads in the Santa Cruz Mountains, including State Highway 17. In most cases, the landslides were cleared within a few days, although permanent repair of the roadways took longer.

In terms of hazards posed to public safety, landslide hazards associated with the seismic shaking are similar to those occurring under static (non-seismic) conditions. Additional discussion of landslide hazard is provided below.

Tsunami Hazard

Tsunamis are giant ocean waves generated when uplift or down-dropping movement occurs over a broad area of the ocean floor. The movement displaces the overlying water column, causing waves to radiate outward from the area of disturbance. Ocean floor displacement may occur due to movement on submarine faults during large earthquakes, submarine landslides, or violent volcanic eruptions. Tsunamis are a potential hazard posed to the City of Santa Cruz.

An earthquake anywhere in the Pacific can cause tsunamis around the entire Pacific basin. Since the Pacific Rim is highly seismically active, tsunamis are not uncommon. Historically, this portion of the California coast has not been subject to very damaging tsunamis. Of the 19 tsunami events recorded at the mouth of San Francisco Bay since 1868, none have exceeded 3.9 feet (1.2 meters) in height (Griggs and Gilchrist, 1983). The tsunami from the 1964 Alaskan earthquake was 9.8 feet (3 meters) high at Half Moon Bay, 40 miles south of San Francisco and 9 feet (2.7 meters) at Moss Landing and Monterey harbor (Burkland and Associates, 1975).

Tsunamis can also be generated locally, by movement on an offshore fault or by landsliding along the banks of the Monterey submarine canyon. The San Gregorio fault and the Monterey Bay fault zone are both considered active and capable of large earthquakes. However, these faults are not likely to produce large vertical offsets of the sea floor and therefore are probably not likely to generate significant tsunami. Submarine landslides in the Monterey submarine canyon, however, are a more likely local source of tsunami. Many large landslides have been mapped along the flanks of the canyon. Ward and Day (2005) modeled a landslide generated tsunami in the Monterey Bay. Their model predicted about 23 feet (7 meters) of runup along the Monterey Bay coastline. A particular hazard with a locally generated tsunami is that there is little warning time before the wave impacts the shoreline; a landslide generated tsunami in the Monterey Bay could strike the coast line in as little as 10 minutes from the time it was generated.

The US Army Corps of Engineers has looked at potential earthquake sources around the Pacific and modeled expected tsunami impacts on the coast of the Monterey Bay (US Army Corps of Engineers, 1975). Their study estimated that a tsunami wave with a probability of occurrence of one every 100 years would be about 5.9 feet high. A tsunami with a probability of occurrence of one every 500 years is expected to be 11.5 feet high.

The Army Corps of Engineers study only considered distant earthquake sources, and did not look at other potential sources of Tsunami. Consequently, their study probably underestimates tsunami hazard. Tsunami hazard prediction is an area that has been attracting more attention since the December 2004 Indian Ocean earthquake and tsunami that that killed over 200,000 people. There are many new studies under way. Tsunami prediction and hazard analysis is expected to improve markedly in the coming years.

NON-SEISMIC GEOLOGIC HAZARDS

Geologic hazards that are not seismically induced include landslides, slope instability, and cliff retreat.

Slope Instability and Landslides

Landslides are the rapid downward or outward movement of rock, earth or artificial fill on a slope. Factors causing landsliding include rock strength, the orientation of rock structure such as layering or fractures in the slope, erosion, weathering, high rainfall, steepness of slopes, and human activities such as the removal of vegetation and inappropriate grading.

Although landsliding is mostly a natural process that accompanies erosional downcutting and oversteepening of slopes, road building or other types of earth-moving can result in steep cut slopes and loose fill soils, both of which can be prone to landsliding. Roads can also collect naturally dispersed runoff and concentrate it into a rapidly flowing stream that can trigger erosion or landsliding.

A portion of the Santa Cruz County landslide map that covers the City is reproduced on Figure 5. This map should not be considered a complete catalogue of all existing landslides, especially where smaller landslides are concerned, but it shows in a general way the distribution of landslides in the City. The City is not as susceptible to landslides as are steeper areas of Santa Cruz County.

Because landslide hazard is associated primarily with steep slopes, landslide hazards in the City are confined to a few particular locations: 1) along the modern sea cliffs bounding the City to the south, 2) along the steeper banks of the San Lorenzo river valley and along the banks of smaller stream drainages, and 3) along the steep risers separating successively older marine terraces. In general, landsliding can be considered a potentially significant hazard where slopes exceed a gradient of about 50% (about 26½º). Slope instability can sometimes occur on less than 50% slopes, but the risk is typically much lower. Figure 7, Slope Map, shows slopes of 30% to 50% and slopes over 50%.

Coastal Bluff Retreat

The City of Santa Cruz is bounded to the south by the Pacific Ocean. Landward erosion by wind and wave action over time has created coastal bluffs along most of the City's coastline.

The term bluff retreat is commonly used to describe the horizontal (landward) erosion of the shoreline along the coastline.

Coastal erosion includes both bluff erosion and beach erosion; wind, waves, and long-shore currents are the driving forces behind coastal erosion. Winter storm waves are larger, steeper and contain more energy, and typically move significant amounts of sand from the beaches to offshore bars, creating steep, narrow beaches. In the summer, lower, less energetic waves allow return of the sand, making for wider beaches. During the winter months when beaches are narrow, or absent altogether, the storm waves attack the cliffs and bluffs more frequently.

Bluff retreat is usually expressed in terms of a uniform rate, such as feet per year or cubic yards of eroded sediment per linear foot of shoreline per year. However, bluff retreat is mostly the result of specific events associated with major coastal storms, earthquakes, or landslides; many years worth of retreat at a particular point may occur during the course of one particularly intense winter storm or may be due to a single landslide event. Therefore, it is important to bear in mind that average retreat rates calculated over many decades may be accurate, but actual retreat events may be much larger than average retreat rates would predict, although infrequent.

Bluff retreat rates are calculated by comparing older survey information along the coast that shows where the bluff was in the past with modern survey data. Bluff retreat rates are also commonly calculated by comparing older aerial photographs of the coast line with new ones. Aerial photography along the California coastline dates back to the late 1920's, so we currently have about 80 years of photographic documentation of the coastline in the Santa Cruz area.

Human activities, such as construction of shore protection structures and dredging may also impact retreat rates. Another factor that is having an impact on the rate of bluff retreat is gradual sea level rise due to global warming. The precise impact of observed sea level rise on bluff retreat rates is not known with precision, and uncertainty in the rate of future sea level rise compounds the difficulty in predicting the impacts of sea level rise.

Retreat rates are influenced by the orientation of the cliff relative to the prevailing storm wave direction, coastline geometry, rock type, and beach width and persistence. A number of studies have been done of coastal retreat rates in the Santa Cruz area including area-wide studies (Griggs and Johnson, 1979; Moore et al., 1999) and site specific studies for individual coastal development projects. Moore et al. (1999) measured average retreat rates of 2.75 to 5.9 inches per year for the portion of the shoreline they studied, although they found retreat rates exceeded 23 inches per year for specific locations.

SOILS

Soil Conditions and Constraints

Soils develop as a result of physical and chemical weathering of geologic materials at the earth's surface combined with biologic mixing due to plants and animals. Based on the Soil Conservation Service Soil Survey for Santa Cruz County (SCS, 1980), there are 57 soil types within the City. Figure 8, Soils Map, lists the soil types found in the City and provides the percentage of the City's area covered by each type. The variety of soils reflects a diversity in parent geologic material, climate, topography, and biologic environment.

The many soil types within the City are broadly separable into three principal units: 1) soils developed on marine terraces and alluvial flats along streams, 2) soils on hills and mountains developed under forest canopy, and 3), soils on hills and mountains developed under brush vegetation. The soils developed on marine terraces and stream-side alluvial flats that underlie much of the City include the Watsonville, Watsonville-Tierra, Elkhorn, Pinto, Baywood, Cropley, Danville, and Soquel soil series (Figure 8). These soils cover the largest area out of the three principal units, amounting to 69% of the City area. The Watsonville Series is notable because it underlies broad areas of the City. It is generally poorly drained and causes ponding and shallow ground water problems. The soils formed under forest canopy include the Ben Lomond, Lompico, and Nisene-Aptos series (Figure 8). These soils occur in the forested uplands north of the city. About 15.4% of the City lies on this map unit. The soils developed on brush covered slopes occur primarily along the foot of Ben Lomond Moutain, between the coastal plains and the forested uplands. These soils include the Aptos, Los Osos, and Bonny Doon series (Figue X7) They occur mostly in small areas on west side of Santa Cruz, covering about 8.9% of the City. Because of their occurrence on steeper slopes, the soils developed on hills and mountains will be more susceptible to erosion hazard.

Some soils may place constraints on development unless specific measures are implemented to mitigate poor soil conditions Typical constraints that may affect development include expansive soils, low density soils prone to settlement, low permeability soils than can cause ponding and poor drainage, and soils with high erosion potential.

Expansive soils shrink and swell depending on moisture level as the clay minerals in these soils expand and contract. Soils with moderate or high shrink-swell potential are a common cause of foundation deterioration, pavement damage, cracking of concrete slabs, and shifting of underground utilities as they expand and contract with seasonal variations in soil moisture. These soils are undesirable for use as engineered fill or subgrade directly underneath foundations or pavement, and must be replaced with non-expansive engineered fill or require treatment to mitigate their expansion. Although shrink-swell tendency presents a potentially serious hazard to development, it can be mitigated by a variety of standard engineering measures.

The impact of potentially weak or soft soils on development is generally manifested in two ways: as problems associated with low shear strength, affecting primary bearing capacity and slope stability; and as problems associated with loss of strength due to cyclic loading during seismic activity, affecting the potential for liquefaction, lateral spreading and seismically induced differential settlements. Soils with low strengths may fail on steep cut or fill slopes or natural slopes inclined at gradients of 30% or greater, and they may settle under the weight of new buildings. As with expansive soils, the hazards associated with weak soils can be mitigated with a series of standard engineering measures. Risks associated with low strength soils or expansive soils can be mitigated with appropriately scoped geotechnical investigations.

Erosion

Soil erosion potential is the susceptibility of the soil to erosion by water or wind. The risk of erosion depends upon the type of soil, slope of the land, slope length, rainfall amount and intensity, and vegetation cover. Removal of vegetation and the disturbance of the ground by mechanical grading or cattle grazing accelerate the erosion process. Impervious surfaces from urban development (roads and buildings) can collect rainwater from large areas and concentrate the runoff on small areas, causing gullying and other problems. The result may include not only the loss of valuable soils but also sedimentation of stream beds, habitat degradation, landslides and increased downstream flooding potential.

In general, erosion potential increases with the steepness of slope, but it is also affected by soil texture. Finer grained soils with strong cohesion tend to resist erosion better than loose, sandy soils. The National Resource Conservation Service soil mapping program (SCS, 1980) provides a ranking of erosion potential by soil type. These erosion hazard rankings were developed principally to address soil loss due to agriculture, and do not necessarily provide a useful measure of erosion potential with regard to urban planning and development.

The principal risk associated with erosion in an urban or semi-urban setting is due to *accelerated erosion*, that is erosion which has been caused directly or indirectly by human activities or land management. Accelerated erosion is caused principally by grading for roads and other development and by land clearing, Both these processes remove vegetative cover that protects soils from erosion and they change natural drainage patterns in a way that can concentrate runoff, increasing its erosive potential. Consequently, erosion hazards can be best mitigated by proper planning and implementation of erosion

control measures on a site-specific basis during construction, and by implementation of permanent, fail-safe drainage systems post-construction.
[FROM 1990-2005 GP]

This concludes our discussion. Please contact me if you have any questions.

Sincerely,
Nolan Associates

Jeffrey M. Nolan
Principal
CEG #2247
CHG #946

Attachments:

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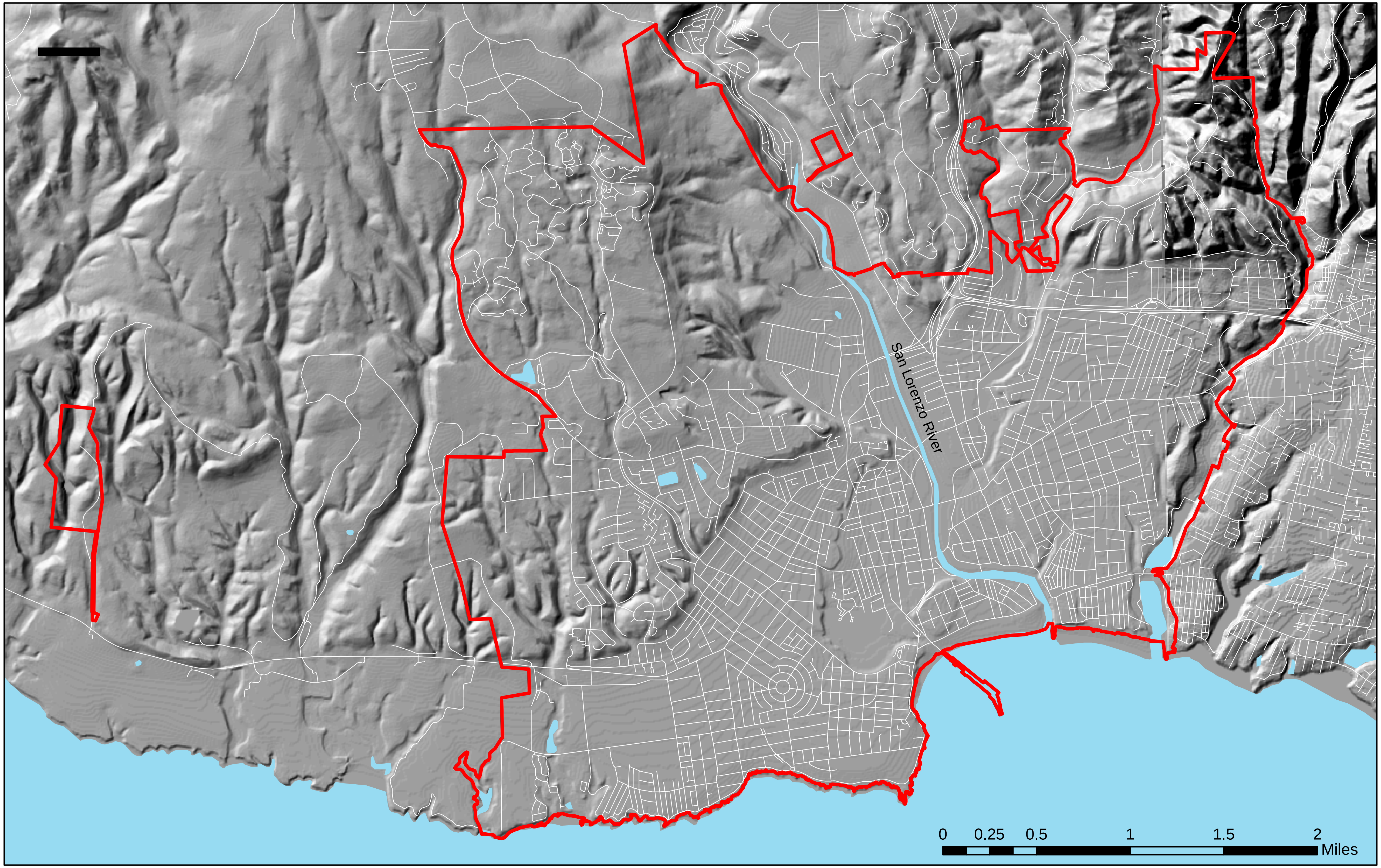
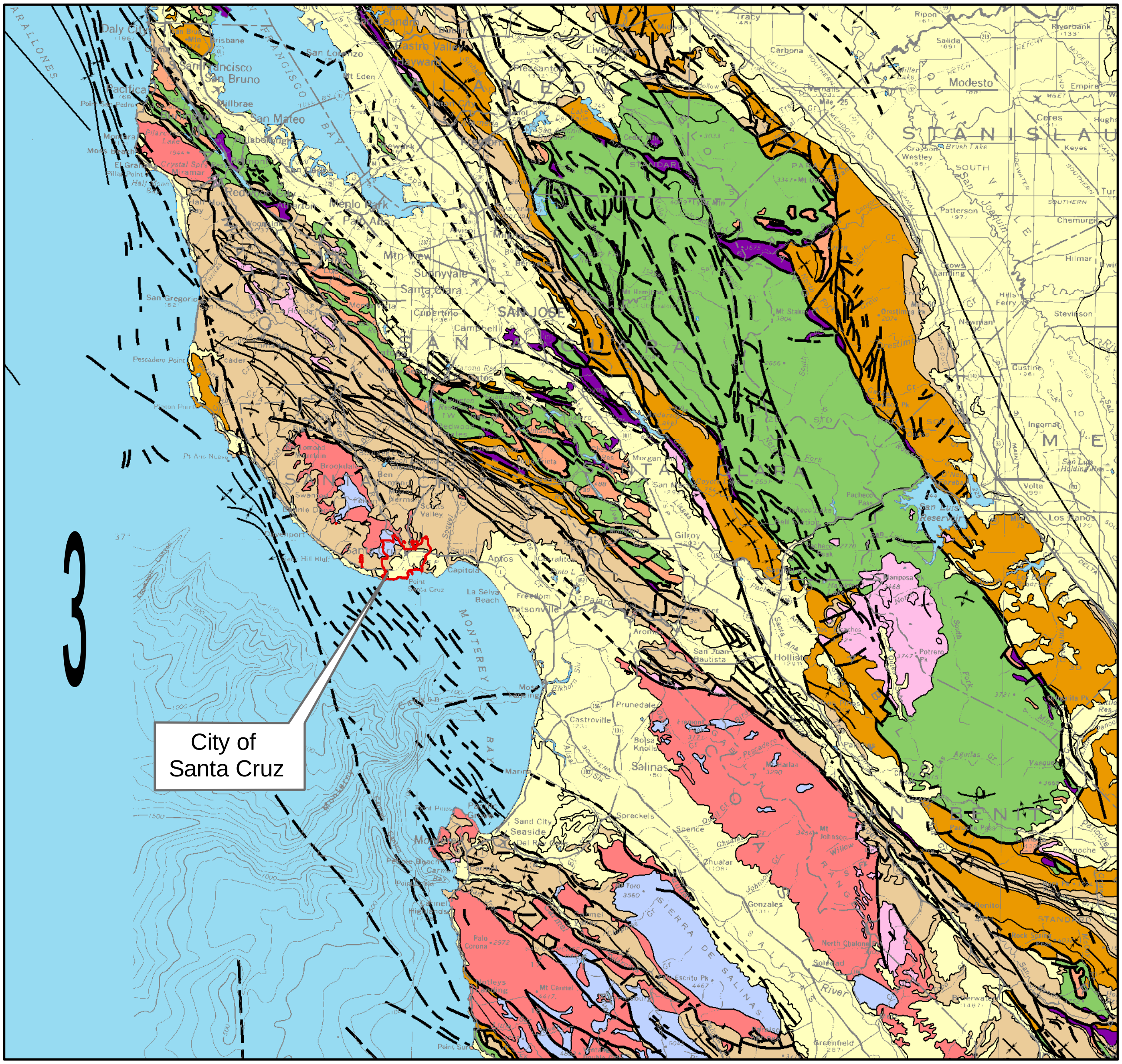


Legend

Santa Cruz City Limit

Topography from U.S. Geological Survey Laurel, Soquel, Santa Cruz, and Felton 7.5' digital elevation models (10m)

Topographic Setting
FIGURE 1



Reference: Jennings, 1977, Geologic Map of California
Digital Data: Saucedo et al., 2000, GIS Data for the Geologic Map of California

Legend

Geologic Units

- Quaternary Deposits
- Quaternary Volcanics
- Tertiary Sedimentary Rocks
- Tertiary Volcanic Rocks
- Pre-Tertiary Sedimentary Rocks
- Pre-Tertiary Volcanic Rocks
- Grantic Intrusive Rocks
- Franciscan Complex
- Ultramafic Rocks
- Pre-Tertiary Metamorphic Rock
- Pre-Cambrian Metamorphic and Igneous Rocks

Symbols

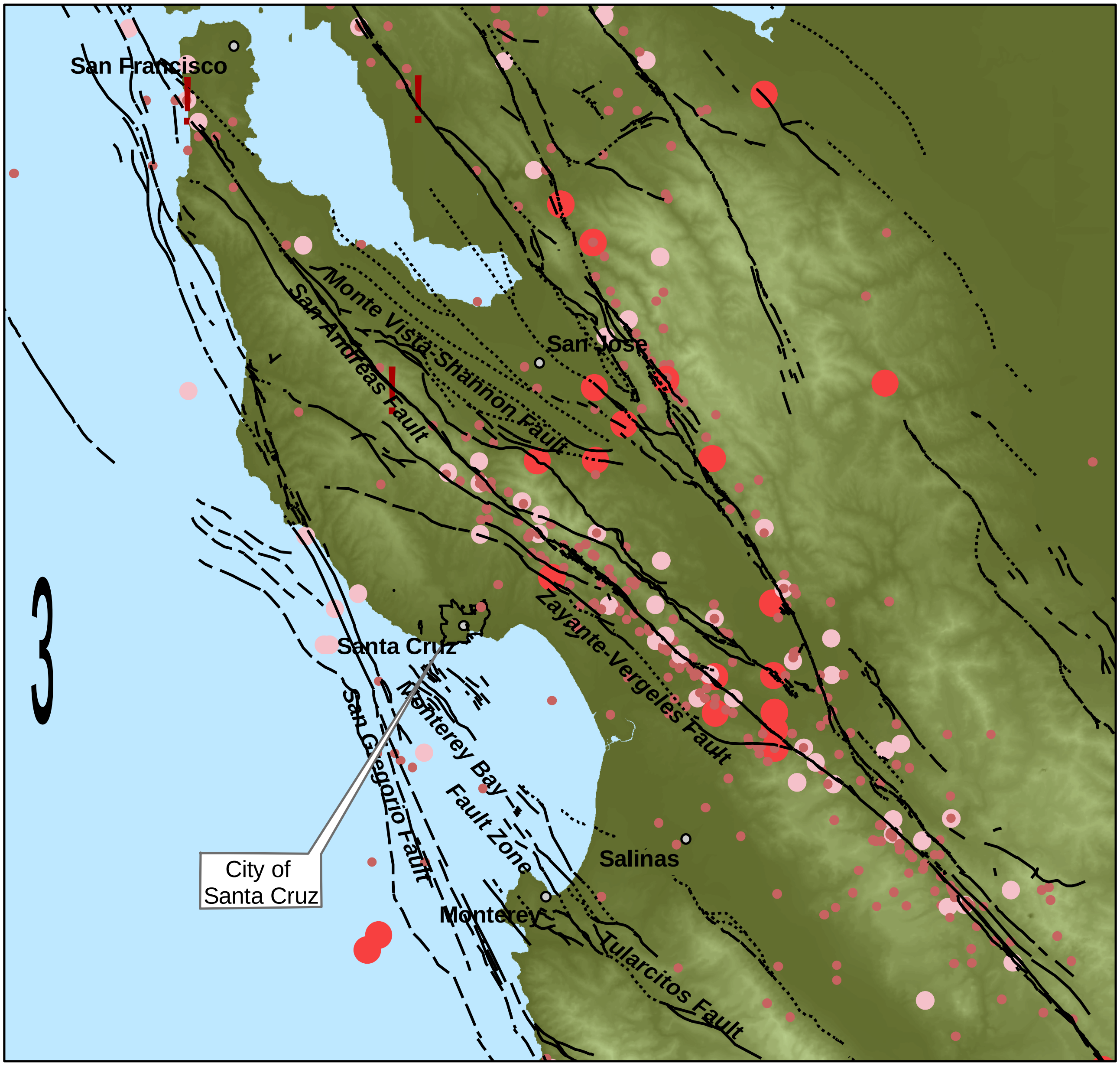
- contact
- fault, certain
- fault, approximate
- fault, concealed or inferred
- anticline
- monocline
- syncline

SCALE

10 0 10 20 Miles

Regional Geologic Map

FIGURE 2



Seismicity Information: CGS, 2000, Magnitude 4 and greater earthquakes
Fault Information: Bryant, 2005, Quaternary fault digital database

EXPLANATION

Quaternary (Active/Potentially Active) Faults

- certain
- approximate
- concealed

Earthquake Magnitude

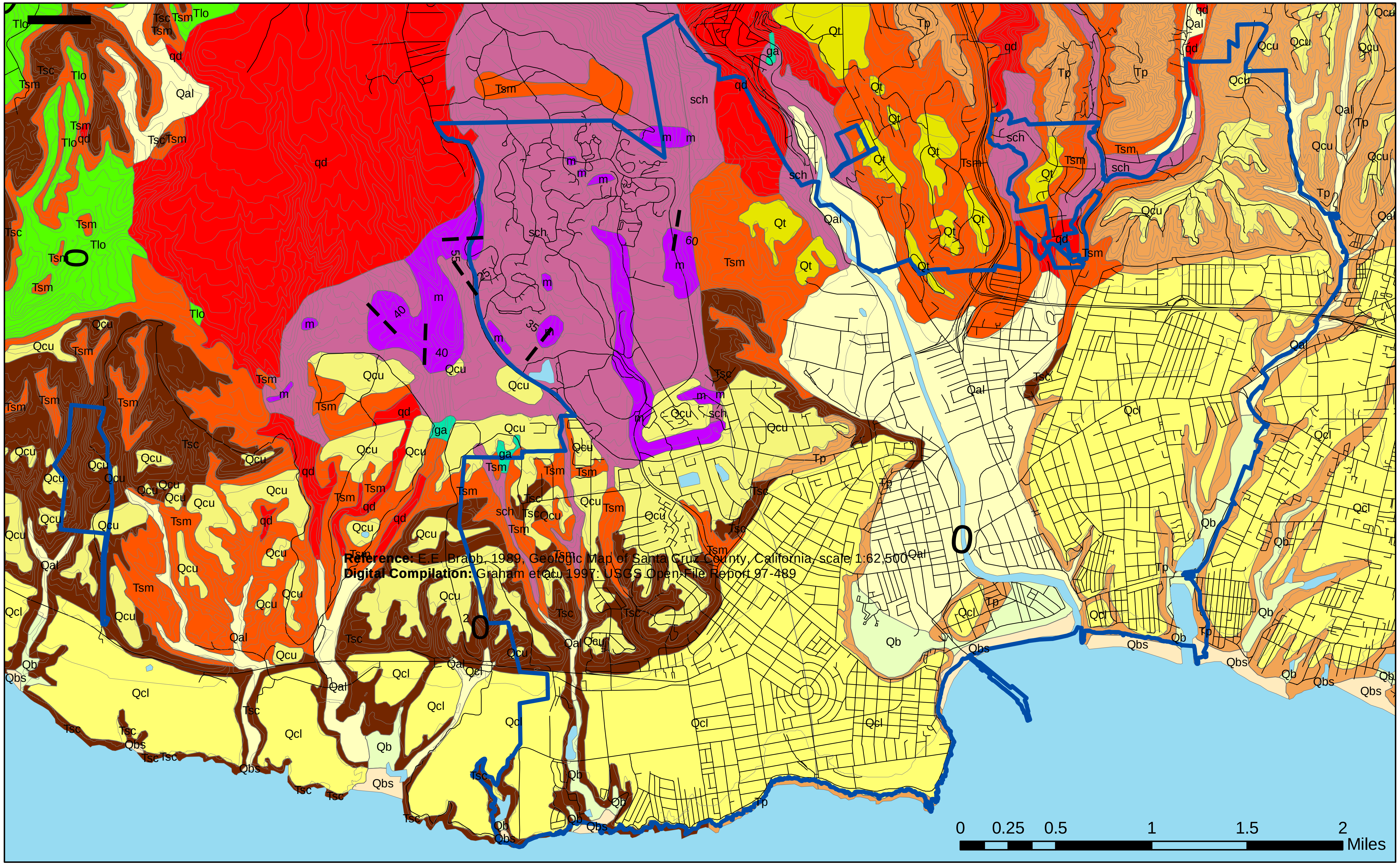
- 4.0 to 4.99
- 5.0 to 5.99
- 6.0 to 6.99
- 7.0 +

SCALE

10 0 10 20 Miles

Regional Seismicity Map

FIGURE 3

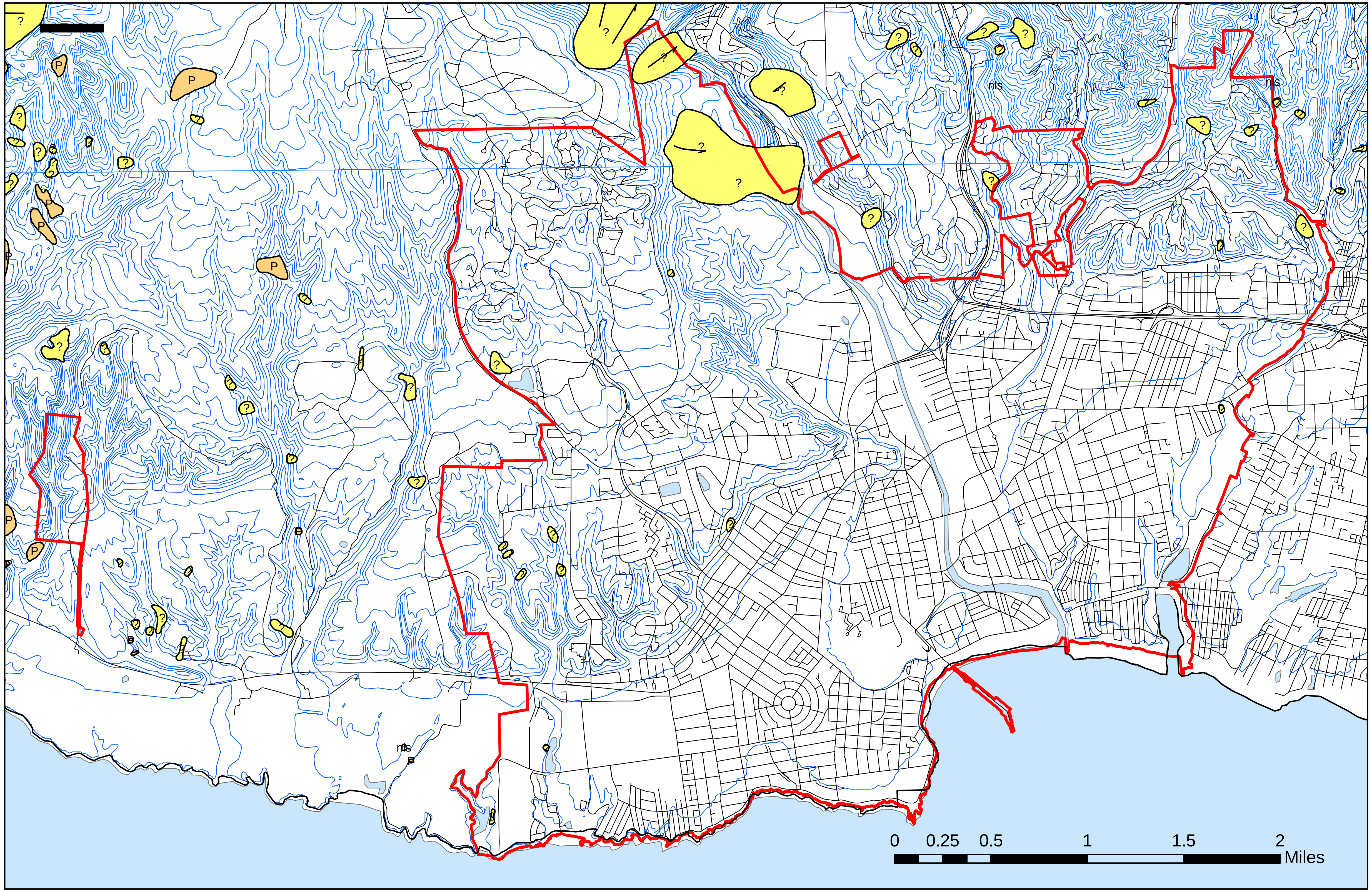


Reference: Graham, et al., 1997, Geologic Map of Santa Cruz County, California. A digital compilation. U.S. Geological Survey Open File Report 97-489. 1:62,500

Legend

- Qal: Alluvial deposits
- Qb: Basin deposits
- Qbs: Beach sand
- Qt: Terrace deposits
- Qcl: Lowest emergent coastal terrace deposit
- Qcu: Coastal terrace deposits
- Tp: Purisima Formation
- Tsc: Santa Cruz Mudstone
- Tsm: Santa Margarita Sandstone
- Tlo: Lompico Sandstone
- Tl:Locatelli Formation
- ga: Granite and adamellite
- hcg: Hornblende-cummingtonight gabbro
- qd: Quartz diorite
- m: Marble
- sch: Schist
- bedding, certain
- bedding, approximate
- bedding, vertical
- bedding, horizontal
- bedding, overturned
- foliation
- Santa Cruz City Limit

Local Geologic Map
FIGURE 4



Legend

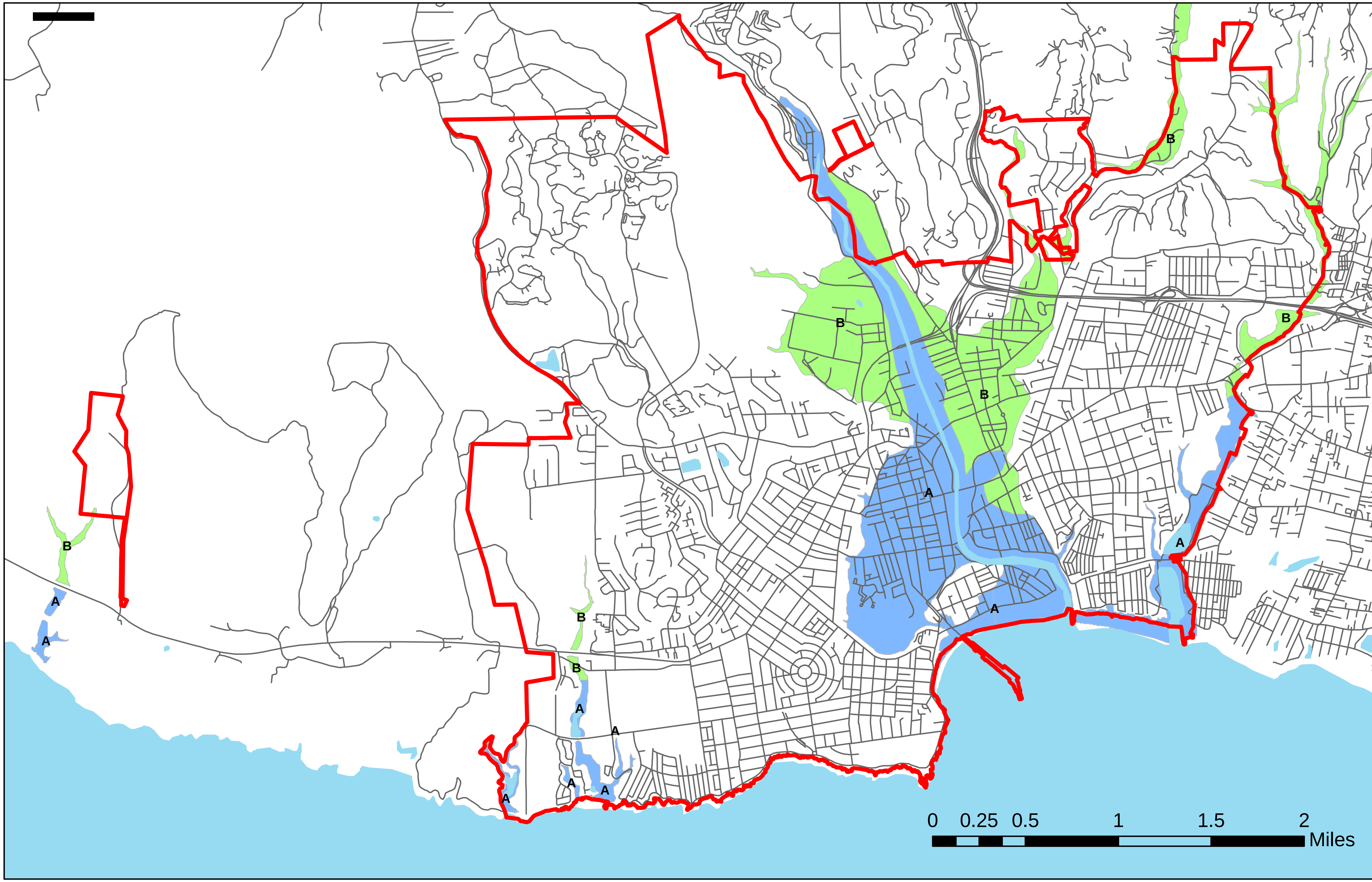
Landslide deposits

- DR: Definite recent landslide
- D: Definite landslide
- P: Probable landslide
- ?: Questionable landslide

Santa Cruz City Limit

Reference: Landslide mapping by Cooper-Clark and Associates, 1975, Preliminary map of landslide deposits in Santa Cruz County, California. 1:24,000.
Digital compilation: Roberts et al., 1998

Landslide Map
FIGURE 5



Legend

Hazard Level

A High Liquefaction Hazard

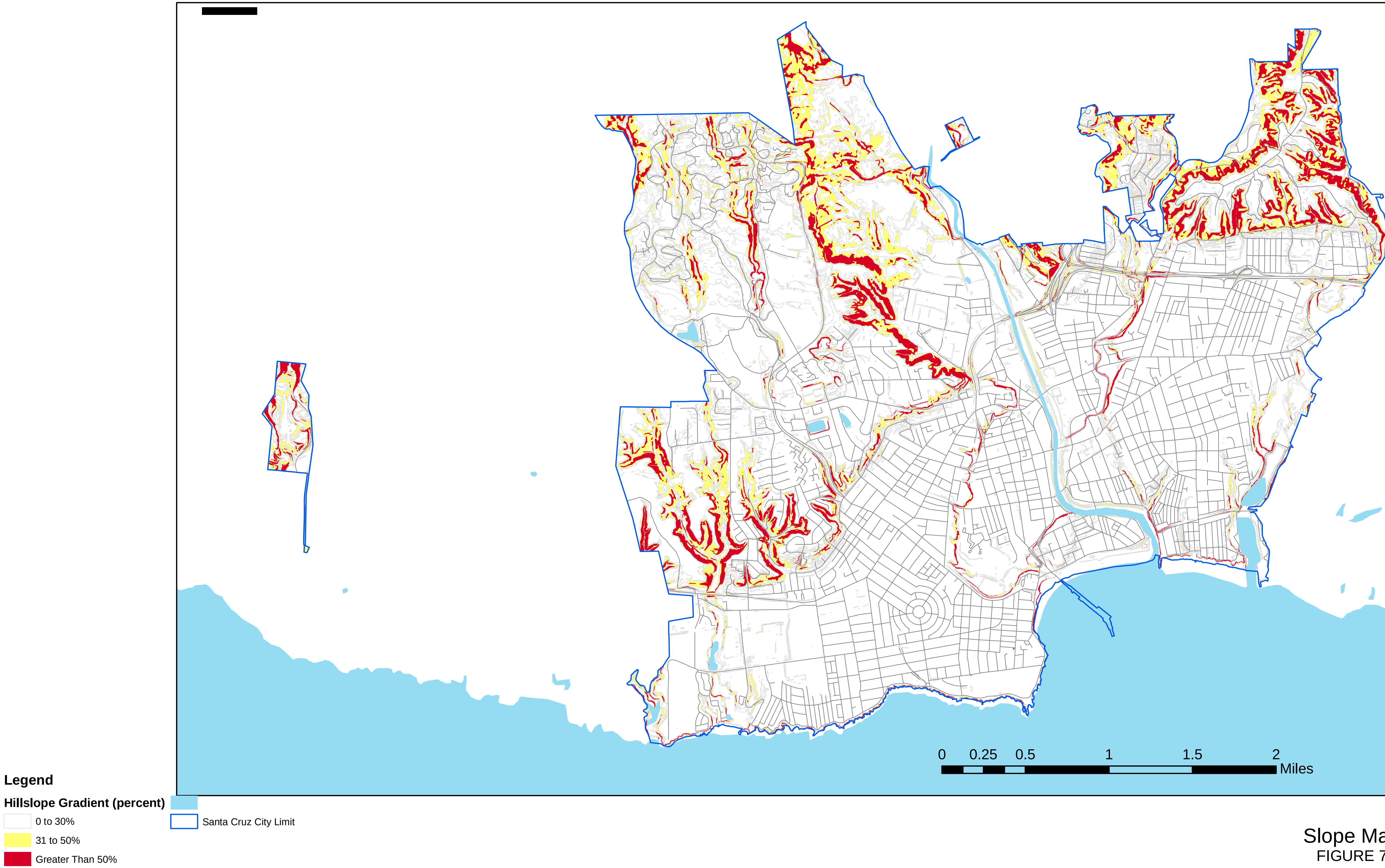
B Moderate Liquefaction Hazard

Santa Cruz City Limit

Reference: Nolan Associates, 2009

Liquefaction Hazard Map

FIGURE 6

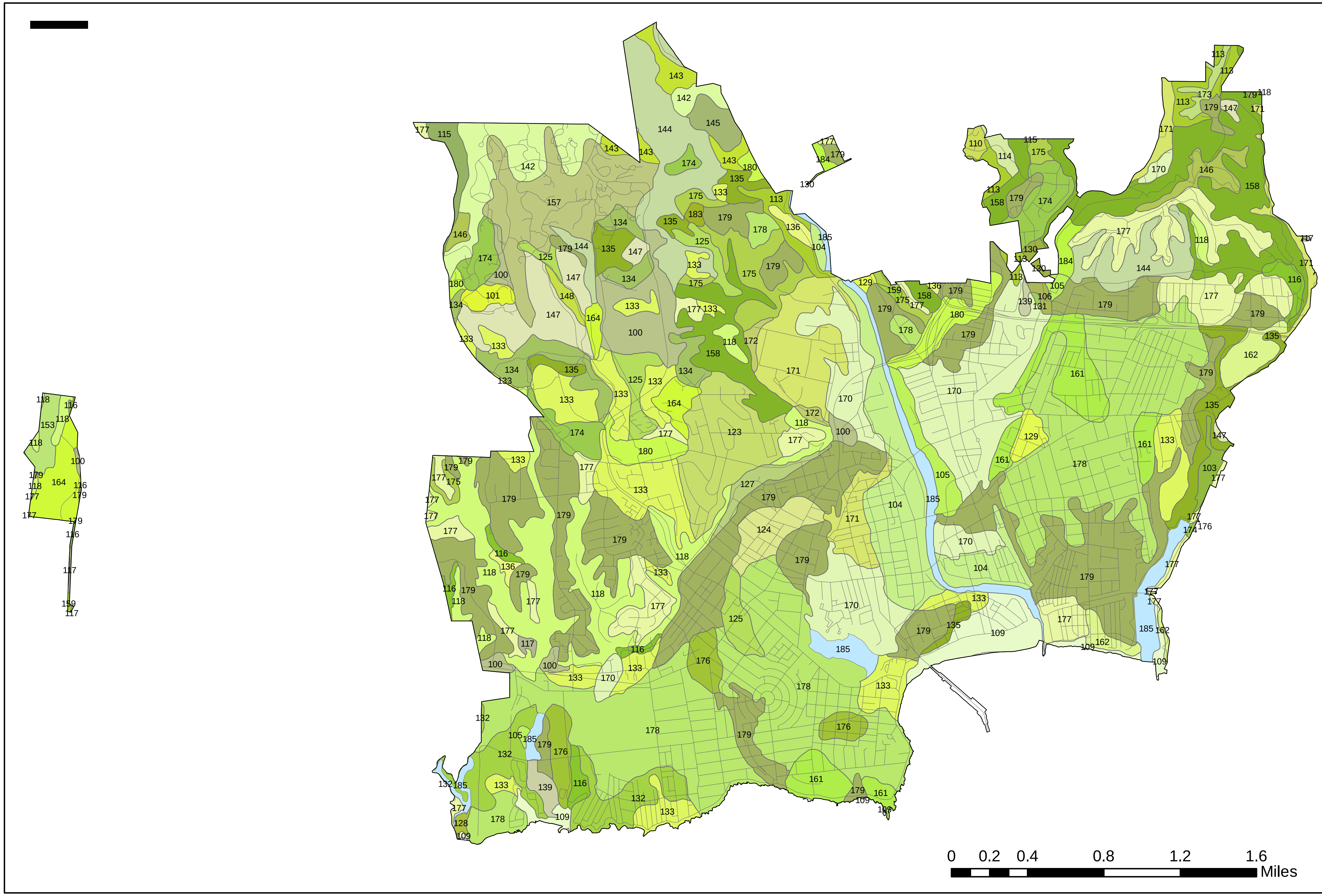


Slope Map
FIGURE 7

Legend

Soil Type

- 100: Aptos loam, warm, 15 to 30 percent slopes
- 101: Aptos loam, warm, 30 to 50 percent slopes
- 103: Aquents, flooded
- 104: Baywood loamy sand, 0 to 2 percent slopes
- 105: Baywood loamy sand, 2 to 15 percent slopes
- 106: Baywood loamy sand, 15 to 30 percent slopes
- 109: Beachs
- 110: Ben Lomond sandy loam, 5 to 15 percent slopes
- 112: Ben Lomond sandy loam, 50 to 75 percent slopes
- 113: Ben Lomond-Catelli-Sur complex, 30 to 75 percent slopes
- 114: Ben Lomond-Felton complex, 30 to 50 percent slopes
- 115: Ben Lomond-Felton complex, 50 to 75 percent slopes
- 116: Bonnydoon loam, 5 to 30 percent slopes
- 117: Bonnydoon loam, 30 to 50 percent slopes
- 118: Bonnydoon-Rock outcrop complex, 50 to 85 percent slopes
- 123: Cropley silty clay, 2 to 9 percent slopes
- 124: Danville loam, 0 to 2 percent slopes
- 125: Danville loam, 2 to 9 percent slopes
- 127: Diablo clay, 15 to 30 percent slopes
- 128: Dune land
- 129: Elder sandy loam, 0 to 2 percent slopes
- 130: Elder sandy loam, 2 to 9 percent slopes
- 131: Elder sandy loam, 9 to 15 percent slopes
- 132: Elkhorn sandy loam, 0 to 2 percent slopes
- 133: Elkhorn sandy loam, 2 to 9 percent slopes
- 134: Elkhorn sandy loam, 9 to 15 percent slopes
- 135: Elkhorn sandy loam, 15 to 30 percent slopes
- 136: Elkhorn-Pfeiffer complex, 30 to 50 percent slopes
- 139: Fluvaquentic Haploxerolls-Aquic Xerofluvents complex
- 142: Lompico-Felton complex, 5 to 30 percent slopes
- 143: Lompico-Felton complex, 30 to 50 percent slopes
- 144: Lompico-Felton complex, 50 to 75 percent slopes
- 145: Lompico variant loam, 5 to 30 percent slopes
- 146: Los Osos loam, 5 to 15 percent slopes
- 147 Los Osos loam, 15 to 30 percent slopes:
- 148: Los Osos loam, 30 to 50 percent slopes
- 153: Maymen-Rock outcrop complex, 50 to 75 percent slopes
- 157: Nisene-Aptos complex, 30 to 50 percent slopes
- 158: Nisene-Aptos complex, 50 to 75 percent slopes
- 159: Pfeiffer gravelly sandy loam, 15 to 30 percent slopes
- 161: Pinto loam, 0 to 2 percent slopes
- 162: Pinto loam, 2 to 9 percent slopes
- 164: Pits-Dumps complex
- 170: Soquel loam, 0 to 2 percent slopes
- 171: Soquel loam, 2 to 9 percent slopes
- 172: Soquel loam, 9 to 15 percent slopes
- 173: Sur-Catelli complex, 50 to 75 percent slopes
- 174: Tierra-Watsonville complex, 15 to 30 percent slopes
- 175: Tierra-Watsonville complex, 30 to 50 percent slopes
- 176: Watsonville loam, 0 to 2 percent slopes
- 177: Watsonville loam, 2 to 15 percent slopes
- 178: Watsonville loam, thick surface, 0 to 2 percent slopes
- 179: Watsonville loam, thick surface, 2 to 15 percent slopes
- 180: Watsonville loam, thick surface, 15 to 30 percent slopes
- 183: Zayante coarse sand, 30 to 50 percent slopes
- 184: Zayante-Rock outcrop complex, 15 to 75 percent slopes
- 185: Water
- Santa Cruz City Limit



Soils Map
FIGURE 8