CHAPTER 1: SEISMIC HAZARDS

1.1 Introduction

While Glendale is at risk from many natural and man-made hazards, an earthquake is the event with the greatest potential for far-reaching loss of life or property, and economic damage. This is true for most of southern California, since damaging earthquakes are frequent, affect widespread areas, trigger many secondary effects, and can overwhelm the ability of local jurisdictions to respond. Earthquake-triggered geologic effects include ground shaking, surface fault rupture, landslides, liquefaction, subsidence, and seiches, all of which are discussed below. Earthquakes can also cause human-made hazards such as urban fires, dam failures, and toxic chemical releases. These man-made hazards are also discussed in this document.

In California, recent earthquakes in or near urban environments have caused relatively few casualties. This is due more to luck than design. For example, when a portion of the Nimitz Freeway in Oakland collapsed at rush hour during the 1989, MW 7.1 Loma Prieta earthquake, it was uncommonly empty because so many were watching the World Series. The 1994, MW 6.7 Northridge earthquake occurred before dawn, when most people were home safely in bed. Despite such good luck, California's urban earthquakes have resulted in significant losses. The moderate-sized Northridge earthquake caused 54 deaths and nearly $30 billion in damage. Glendale is at risk from earthquakes that could release more than 10 times the seismic energy of the Northridge earthquake.

Although it is not possible to prevent earthquakes, their destructive effects can be minimized. Comprehensive hazard mitigation programs that include the identification and mapping of hazards, prudent planning, public education, emergency exercises, enforcement of building codes, and expedient retrofitting and rehabilitation of weak structures can significantly reduce the scope of an earthquake's effects and avoid disaster. Local government, emergency relief organizations, and residents must take action to develop and implement policies and programs to reduce the effects of earthquakes.

1.2 Earthquake and Mitigation Basics

1.2.1 Definitions

The outer 10 - 70 kilometers of the Earth consist of enormous blocks of moving rock, called **plates**. There are about a dozen major plates, which slowly collide, separate, and grind past each other. In the uppermost plates, friction locks the plate edges together, while movement continues at depth. Consequently, the near-surface rocks bend and deform near plate boundaries, storing strain energy. Eventually, the frictional forces are overcome and the locked portions of the plates move. The stored strain energy is released in waves.

By definition, the break or fracture between moving blocks of rock is called a **fault**, and such differential movement produces a **fault rupture**. The place where the fault first ruptures is called the **focus** (or **hypocenter**). The released energy waves radiate out in all directions from the rupture surface, making the earth vibrate and shake as the waves travel through. This shaking is what we feel in an **earthquake**.

Although faults exist everywhere, most earthquakes occur on or near plate boundaries. Thus, southern California has many earthquakes, because it straddles the boundary between the North American and Pacific plates, and fault rupture accommodates their motion. The Pacific Plate is moving northwesterly, relative to the North American Plate, at about 50 mm/yr. This is about the rate at which fingernails grow, and seems unimpressive. However, it is enough to accumulate enormous amounts of strain energy over dozens to thousands of years. Despite being locked in place most of the time, in another 15 million years (a short time in the context of the Earth's history), due to plate movements, Glendale will be hundreds of kilometers north of San Francisco.

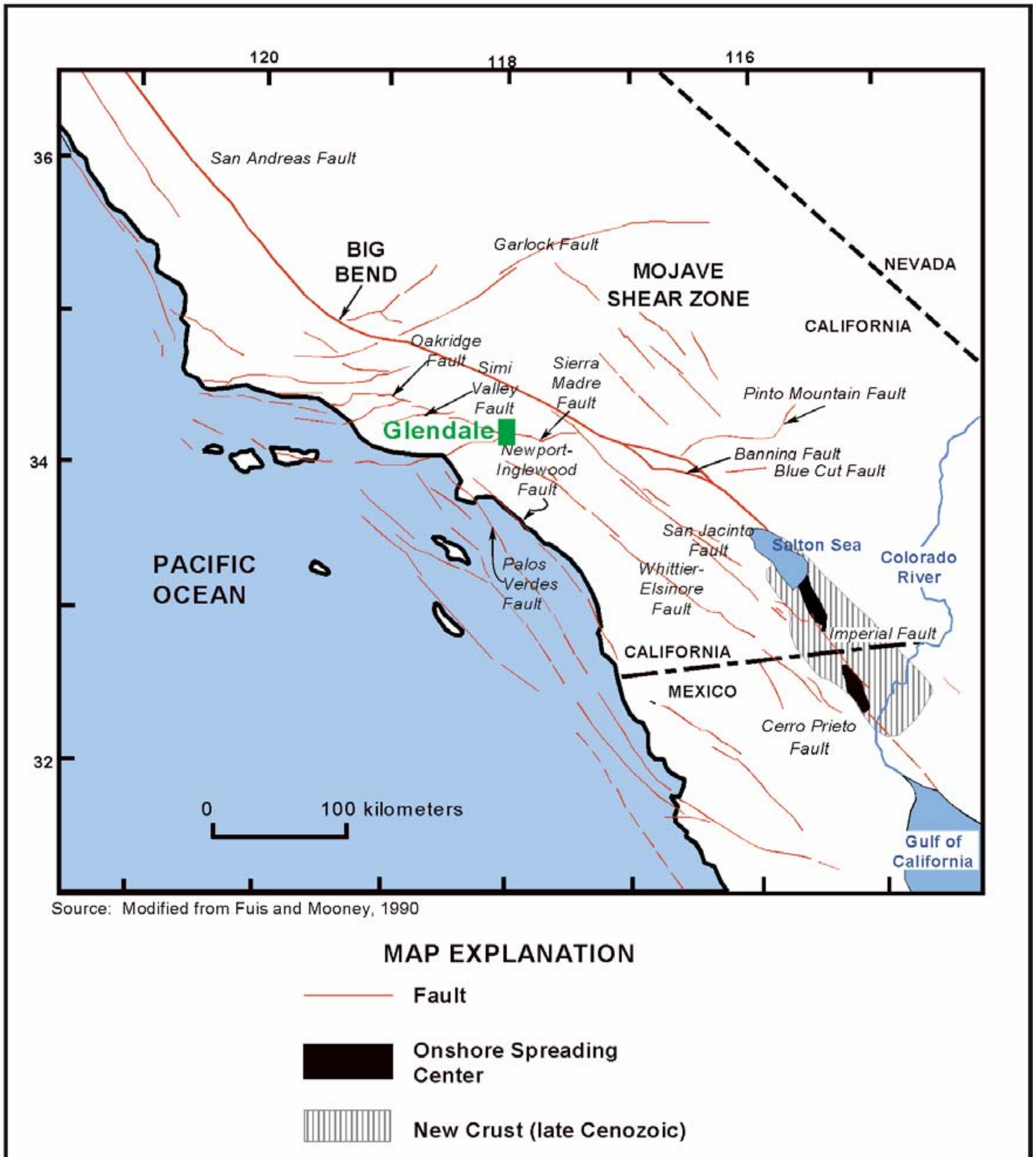
Although the San Andreas fault marks the actual separation between the Pacific and North American plates, only about 70 percent of the plate motion occurs on the San Andreas fault itself. The rest is distributed among other faults of the San Andreas system, including the San Jacinto, Whittier-Elsinore, Newport-Inglewood, Palos Verdes, plus several offshore faults; and among faults of the Eastern Mojave Shear Zone, a series of faults east of the San Andreas, responsible for the 1992, MW 7.3 Landers and 1999 MW 7.1 Hector Mine earthquakes (Figures 1-1 and 1-2). (MW stands for moment magnitude, a measure of earthquake energy release, discussed below.) Thus, the zone of plate-boundary earthquakes and ground deformation covers an area that stretches from the Pacific Ocean to Nevada.

Because the Pacific and North American plates are sliding past each other, with relative motions to the northwest and southeast, respectively, all of the faults mentioned above are aligned northwest-southeast, and are **strike-slip faults**. On average, strike-slip faults are nearly vertical breaks in the rock, and when a strike-slip fault ruptures, the rocks on either side of the fault slide horizontally past each other.

However, there is a kink in the San Andreas fault, commonly referred to as the "Big Bend". The northwest corner of the Big Bend is located about 75 miles northeast of Glendale (Figure 1-1). Near the Big Bend, the two plates do not slide past each other. Instead, they collide, causing localized compression, resulting in folding and **thrust faulting**. Thrust faults meet the surface of the Earth at a low angle, dipping 25 – 35 degrees from the horizontal. Thrusts are a type of **dip-slip fault**, where rocks on opposite sides of the fault move up or down relative to each other. When a thrust fault ruptures, the top block of rock moves up and over the rock on the other side of the fault.

In southern California, ruptures along thrust faults have built the Transverse Ranges geologic province, a region with an east-west trend to its landforms and underlying geologic structures. This orientation is anomalous, virtually unique in the western United States, and a direct consequence of the plates colliding at the Big Bend. Many of southern California's most recent damaging earthquakes have occurred on thrust faults that are uplifting the Transverse Ranges, including the 1971 MW 6.7 San Fernando, the 1987 MW 5.9 Whittier Narrows, the 1991 MW 5.8 Sierra Madre, and the 1994 MW 6.7 Northridge earthquakes. Thrust faults can be particularly hazardous because many are **blind thrust faults**, that is, they do not extend to the surface of the Earth. These faults are extremely difficult to detect before they rupture. Some of the most recent earthquakes, like the 1987 Whittier Narrows earthquake, and the 1994 Northridge earthquake, occurred on blind thrust faults.

The City of Glendale is situated in the Transverse Ranges Province, an area that is exposed to risk from multiple earthquake fault zones. The highest risks originate from the Sierra Madre (dip-slip, reverse) fault zone, the Verdugo (dip-slip, reverse) fault zone, the Hollywood (predominantly strike-slip, left lateral) fault, the Elysian Park (blind thrust) fault zone, and the Raymond (predominantly strike-slip, left lateral) fault zone. Each one of these faults will be discussed in more detail in Section 1-5.



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Regional Fault Map

Figure 1-1

1.2.2 Evaluating Earthquake Hazard Potential

When comparing the sizes of earthquakes, the most meaningful feature is the amount of energy released. Thus scientists most often consider **seismic moment**, a measure of the energy released when a fault ruptures. We are more familiar, however, with scales of magnitude, which measure amplitude of ground motion. Magnitude scales are logarithmic. Each one-point increase in **magnitude** represents a ten-fold increase in amplitude of the waves as measured at a specific location, and a 32-fold increase in energy. That is, a magnitude 7 earthquake produces 100 times (10 x 10) the ground motion amplitude of a magnitude 5 earthquake. Similarly, a magnitude 7 earthquake releases approximately 1,000 times more energy (32 x 32) than a magnitude 5 earthquake. Recently, scientists have developed the **moment magnitude (Mw)** scale to relate energy release to magnitude.

An early measure of earthquake size still used today is the seismic **intensity scale**, which is a qualitative assessment of an earthquake's effects at a given location. Although it has limited scientific application, intensity is still widely used because it is intuitively clear and quick to determine. The most commonly used measure of seismic intensity is called the Modified Mercalli Intensity (MMI) scale, which has 12 damage levels (Table 1.1).

A given earthquake will have one moment and, in principle, one magnitude, although there are several methods of calculating magnitude, which give slightly different results. However, one earthquake will produce many intensities because intensity effects vary with the location and perceptions of the observer.

Few faults are simple, planar breaks in the Earth. They more often consist of smaller **strands**, with a similar orientation and sense of movement. A strand is mappable as a single, fairly continuous feature at a scale of about 1:24,000. Sometimes geologists group strands into **segments**, which are believed capable of rupturing together during a single earthquake. The more extensive the fault, the bigger the earthquake it can produce. Therefore, multi-strand fault ruptures produce larger earthquakes.

The bigger and closer the earthquake, the greater the likelihood of damage. Thus fault dimensions and proximity are key parameters in any hazard assessment. In addition, it is important to know a fault's style of movement (i.e. is it dip-slip or strike-slip, discussed above), the age of its most recent activity, its total displacement, and its slip rate (all discussed below). These values indicate how often a fault produces damaging earthquakes, and how big an earthquake should be expected the next time the fault ruptures.

Total displacement is the length, measured in kilometers (km), of the total movement that has occurred along the fault over as long a time as the geologic record reveals. It is usually estimated by measuring distances between geologic features that have been split apart and separated (**offset**) by the cumulative movement of the fault over many earthquakes. **Slip rate** is a speed, expressed in millimeters per year (mm/yr). Slip rate is estimated by measuring an amount of offset accrued during a known amount of time, obtained by dating the ages of geologic features. Slip rate data also are used to estimate a fault's **earthquake recurrence interval**. Sometimes referred to as "repeat time" or "return interval", the recurrence interval represents the average amount of time that elapses between major earthquakes on a fault. The most specific way to derive recurrence interval is to excavate a trench across a fault to obtain **paleoseismic** evidence of earthquakes that have occurred during prehistoric time.

Table 1-1: Abridged Modified Mercalli Intensity Scale

Intensity Value and Description		Average Peak Velocity (cm/sec)	Average Peak Acceleration (g = gravity)
I.	Not felt except by a very few under especially favorable circumstances (I Rossi-Forel scale). Damage potential: None.	<0.1	<0.0017
II.	Felt only by a few persons at rest, especially on upper floors of high-rise buildings. Delicately suspended objects may swing. (I to II Rossi-Forel scale). Damage potential: None.	0.1 – 1.1	0.0017 – 0.014
III.	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing automobiles may rock slightly. Vibration like passing of truck. Duration estimated. (III Rossi-Forel scale). Damage potential: None.		
IV.	During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like a heavy truck striking building. Standing automobiles rocked noticeably. (IV to V Rossi-Forel scale). Damage potential: None. Perceived shaking: Light.	1.1 – 3.4	0.014 - 0.039
V.	Felt by nearly everyone; many awakened. Some dishes, windows, and so on broken; cracked plaster in a few places; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop. (V to VI Rossi-Forel scale). Damage potential: Very light. Perceived shaking: Moderate.	3.4 – 8.1	0.039-0.092
VI.	Felt by all; many frightened and run outdoors. Some heavy furniture moved, few instances of fallen plaster and damaged chimneys. Damage slight. (VI to VII Rossi-Forel scale). Damage potential: Light. Perceived shaking: Strong.	8.1 - 16	0.092 -0.18
VII.	Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving cars. (VIII Rossi-Forel scale). Damage potential: Moderate. Perceived shaking: Very strong.	16 - 31	0.18 - 0.34
VIII.	Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, and walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving cars disturbed. (VIII+ to IX Rossi-Forel scale). Damage potential: Moderate to heavy. Perceived shaking: Severe.	31 - 60	0.34 - 0.65
IX.	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken. (IX+ Rossi-Forel scale). Damage potential: Heavy. Perceived shaking: Violent.	60 - 116	0.65 – 1.24
X.	Some well-built wooden structures destroyed; most masonry and frame structures destroyed; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed, slopped over banks. (X Rossi-Forel scale). Damage potential: Very heavy. Perceived shaking: Extreme.	> 116	> 1.24
XI.	Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.		
XII.	Damage total. Waves seen on ground surface. Lines of sight and level distorted. Objects thrown into air.		

Modified from Bolt (1999); Wald et al. (1999).

Paleoseismic studies show that faults with higher slip rates often have shorter recurrence intervals between major earthquakes. This makes sense. A high slip rate indicates rocks that, at depth, are moving relatively quickly. Thus the locked, surficial rocks are storing more strain energy, so the forces of friction will be exceeded more often, releasing the strain energy in more frequent, large earthquakes.

Faults have formed over millions of years, usually in response to regional stresses. Shifts in these stress regimes do occur over millennia. As a result, some faults change in character. For example, a thrust fault in a compressional environment may become a strike-slip fault in a transpressive (oblique compressional) environment. Other faults may be abandoned altogether. Consequently, the State of California, under the guidelines of the Alquist-Priolo Earthquake Fault Zoning Act of 1972 (Hart and Bryant, 1999), classifies faults according to the following criteria:

Active: faults showing proven displacement of the ground surface within about the last 11,000 years (within the Holocene Epoch), that are thought capable of producing earthquakes;

Potentially Active: faults showing evidence of movement within the last 1.6 million years, but that have not been shown conclusively whether or not they have moved in the last 11,000 years; and

Not active: faults that have conclusively NOT moved in the last 11,000 years.

These definitions are used primarily for residential subdivisions. Other definitions of activity are used by other agencies or organizations, depending on the type of facility being planned or developed. For example, longer periods of inactivity may be required for dams or nuclear power plants. An important subset of active faults are those with historical earthquakes. In California, that means faults that have ruptured since 1769, when the Spanish first arrived in the area.

The underlying assumption in this classification system is that if a fault has not ruptured in the last 11,000 years, it is not likely to be the source of a damaging earthquake in the future. In reality, however, most potentially active faults have been insufficiently studied to determine their hazard level. Also, although simple in theory, the evidence necessary to determine whether a fault has or has not moved during the last 11,000 years can be difficult to obtain. For example, some faults leave no discernable evidence of their earthquakes, while other faults stop rupturing for millennia, and then are "reactivated" as the tectonic environment changes.

1.2.3 Causes of Earthquake Damage

Causes of earthquake damage can be categorized into three general areas: strong shaking, various types of ground failure that are a result of shaking, and ground displacement along the rupturing fault. The State definition of an active fault is designed to gauge the surface rupture potential of a fault, and is used to prevent development from being sited directly on an active fault. This helps to reduce damage from the third category. Below, the three categories are discussed in order of their likelihood to occur extensively:

1) **Strong Ground Shaking** causes the vast majority of earthquake damage. Horizontal ground **acceleration** is frequently responsible for widespread damage to structures, so it is commonly estimated, as a percentage of **g**, the acceleration of gravity. Full characterization of shaking potential, though, requires estimates of peak (maximum) ground displacement and velocity, the duration of strong shaking, and the periods (lengths) of waves that will control each of these factors at a given location. We look to the recorded effects of damaging earthquakes worldwide to understand what might happen in similar environments here in the future. In general, the degree of shaking can depend upon:

- **Source effects**. These include earthquake size, location, and distance, as discussed above. In addition, the exact way that rocks move along the fault can influence shaking. For example, the 1995, MW 6.9, Kobe, Japan earthquake was not much bigger than the 1994, MW 6.7 Northridge, California earthquake, but Kobe caused much worse damage. During the Kobe earthquake, the fault's orientation and movement directed seismic waves into the city. During the Northridge earthquake, the fault's motion directed waves away from populous areas.

- **Path effects**. Seismic waves change direction as they travel through the Earth's contrasting layers, just as light bounces (reflects) and bends (refracts) as it moves from air to water. Sometimes seismic energy gets focussed into one location and causes damage in unexpected areas. Focussing of 1989's MW 7.1 Loma Prieta earthquake waves caused damage in San Francisco's Marina district, some 100 km distant from the rupturing fault.

- **Site effects**. Seismic waves slow down in the loose sediments and weathered rock at the Earth's surface. As they slow, their energy converts from speed to amplitude, which heightens shaking. This is like the behavior of ocean waves - as the waves slow down near shore, their crests grow higher. In addition, seismic waves can get trapped at the surface and reverberate (resonate). Whether resonance will occur depends on the period (the length) of the incoming waves. Waves, soils and buildings all have resonant periods. When these coincide, tremendous damage can occur.

We keep talking about periods. What do we mean? Waves repeat their motions with varying frequencies. Slow-to-repeat waves are called long-period waves. Quick-to-repeat waves are called short-period waves. Long-period seismic waves, which are created by large earthquakes, are most likely to reverberate and cause damage in long-period structures, like bridges and high-rises. ("Long-period structures" are those that respond to long-period waves.) Shorter-period seismic waves, which tend to die out quickly, will most often cause damage fairly near the fault, and they will cause most damage in shorter-period structures such as one- to three-story buildings. Very short-period waves are most likely to cause near-fault, interior damage, such as to equipment.

2) **Liquefaction and Slope Failure** are very destructive secondary effects of strong seismic shaking.

- **Liquefaction** typically occurs within the upper 50 feet of the surface, when saturated, loose, fine- to medium-grained soils (sand and silt) are present. Earthquake shaking suddenly increases pressure in the water that fills the pores between soil grains, causing the soil to lose strength and behave as a liquid. This process can be observed at the beach by standing on the wet sand near the surf zone. Standing still, the sand will support your weight. However, when you tap the sand with your feet, water comes to the surface, the sand liquefies, and your feet sink.

When soils liquefy, the structures built on them can sink, tilt, and suffer significant structural damage. Liquefaction-related effects include loss of bearing strength, ground oscillations, lateral spreading and flow failures or slumping. The excess water pressure is relieved by the ejection of material upward through fissures and cracks. A water-soil slurry bubbles onto the ground surface, resulting in features called "sand boils", "sand blows" or "sand volcanoes". Site-specific geotechnical studies are the only practical, reliable way to determine the liquefaction potential of a site.

- **Landslides and Rockfall (Mass Wasting).** Gravity inexorably pulls hillsides down and earthquake shaking enhances this on-going process. Slope stability depends on many factors and their interrelationships. Rock type and pore water pressure are arguably the most important factors, as well as slope steepness due to natural or human-made undercutting. Where slopes have failed before, they may fail again. Thus, it is essential to map existing landslides and soil slumps. Furthermore, because there are predictable relationships between local geology and the likelihood that mass wasting will occur, field investigations can be used to identify failure-prone slopes before an earthquake occurs. This, combined with GIS-based analyses of slope gradient, land use, and bedrock or soil materials can be used to identify high-risk areas where mitigation measures would be most effective.

3) **Primary Ground Rupture Due to Fault Movement** typically results in a relatively small percentage of the total damage in an earthquake, yet being too close to a rupturing fault can result in extensive damage. It is difficult to safely reduce the effects of this hazard through building and foundation design. Therefore, the primary mitigation measure is to avoid active faults by setting structures back from the fault zone. Application of this measure is subject to requirements of the Alquist-Priolo Earthquake Fault Zoning Act and guidelines prepared by the California Geological Survey – previously known as the California Division of Mines and Geology (CDMG Note 49). The final approval of a fault setback lies with the local reviewing agency.

Earthquake damage also depends on the characteristics of human-made structures. The interaction of ground motion with the built environment is complex. Governing factors include a structure's height, construction, and stiffness, which determine the structure's resonant period; the underlying soil's strength and resonant period; and the periods of the incoming seismic waves. Other factors include architectural design, condition, and age of the structure.

1.2.4 Choosing Earthquakes for Planning and Design

It is often useful to create a **deterministic** or **design earthquake scenario** to study the effects of a particular earthquake on a building or a community. Often, such scenarios consider the largest earthquake that is believed possible to occur on a fault or fault segment, referred to as the **maximum magnitude earthquake** (**Mmax**). Other scenarios consider the **maximum probable earthquake (MPE)** or **design basis earthquake (DBE)** (1997 Uniform Building Code - UBC), the earthquake with a statistical return period of 475 years (with ground motion that has a 10 percent probability of being exceeded in 50 years). For public schools, hospitals, and other critical facilities, the California Building Code (1998) defines the **Upper Bound Earthquake** (UBE), which has a statistical return period of 949 years and a ground motion with a 10 percent probability of being exceeded in 100 years. As the descriptions above suggest, which earthquake scenario is most appropriate depends on the application, such as the planned use, lifetime or importance of a facility. The more critical the structure, the longer the time period used between earthquakes and the larger the design earthquake should be.

Geologists, seismologists, engineers, emergency response personnel and urban planners typically use maximum magnitude and maximum probable earthquakes to evaluate seismic hazard. The assumption is that if we plan for the worst-case scenario, we establish safety margins. Then smaller earthquakes, that are more likely to occur, can be dealt with effectively.

Seismic design parameters define what kinds of earthquake effects a structure must be able to withstand. These include peak ground acceleration, duration of strong shaking, and the periods of incoming strong motion waves.

As is true for most earthquake-prone regions, many potential earthquake sources pose a threat to Glendale. Thus it is also important to consider the overall likelihood of damage from a plausible suite of earthquakes. This approach is called **probabilistic seismic hazard analysis (PSHA)**, and typically considers the likelihood of exceeding a certain level of damaging ground motion that could be produced by any or all faults within a 100-km radius of the project site, or in this case, the City. PSHA is utilized by the U.S. Geological Survey to produce national seismic hazard maps that are used by the Uniform Building Code (ICBO, 1997).

Regardless of which fault causes a damaging earthquake, there will always be **aftershocks**. By definition, these are smaller earthquakes that happen close to the **mainshock** (the biggest earthquake of the sequence) in time and space. These smaller earthquakes occur as the Earth adjusts to the regional stress changes created by the mainshock. The bigger the mainshock, the greater the number of aftershocks, the larger the aftershocks will be, and the wider the area in which they might occur.

On average, the largest aftershock will be 1.2 magnitude units less than the mainshock. Thus, a MW 6.9 earthquake will tend to produce aftershocks up to Mw 5.7 in size. This is an average, and there are many cases where the biggest aftershock is larger than the average predicts. The key point is this: any major earthquake will produce aftershocks large enough to cause additional damage, especially to already-weakened structures. Consequently, post-disaster response planning must take damaging aftershocks into account.

1.3 Laws To Mitigate Earthquake Hazard

1.3.1 Alquist-Priolo Earthquake Fault Zoning Act

The Alquist-Priolo Special Studies Zones Act was signed into law in 1972 (in 1994 it was renamed the Alquist-Priolo Earthquake Fault Zoning Act). The primary purpose of the Act is to mitigate the hazard of fault rupture by prohibiting the location of structures for human occupancy across the trace of an active fault (Hart and Bryant, 1999). This State law was passed in direct response to the 1971 San Fernando earthquake, which was associated with extensive surface fault ruptures that damaged numerous homes, commercial buildings and other structures. Surface rupture is the most easily avoided seismic hazard.

The Act requires the State Geologist (Chief of the California Geological Survey) to delineate "Earthquake Fault Zones" along faults that are "sufficiently active" and "well defined." These faults show evidence of Holocene surface displacement along one or more or their segments (sufficiently active) and are clearly detectable by a trained geologist as a physical feature at or just below the ground surface (well defined). The boundary of an "Earthquake Fault Zone" is generally about 500 feet from major active faults, and 200 to 300 feet from well-defined minor faults. The Act dictates that cities and counties withhold development permits for sites within an Earthquake Fault Zone within their jurisdiction until geologic investigations demonstrate that the sites are not threatened by surface displacements from future faulting (Hart and Bryant, 1999).

The Alquist-Priolo maps are distributed to all affected cities and counties for their use in planning and controlling new or renewed construction. Local agencies must regulate most development projects within the zones. Projects include all land divisions and most structures for human occupancy. State law exempts single-family wood-frame and steel-frame dwellings which are less than three stories and are not part of a development of four units or more. However, local agencies can be more restrictive than State law requires. Alquist-Priolo Earthquake Fault Zone mapping has been completed by the State Geologist for the northwestern Glendale area, in the Sunland and Burbank Quadrangles (CDMG, 1979a; 1979b).

1.3.2 Seismic Hazards Mapping Act

The Alquist-Priolo Earthquake Fault Zoning Act only addresses the hazard of surface fault rupture and is not directed toward other earthquake hazards. Recognizing this, in 1990, the State passed the Seismic Hazards Mapping Act (SHMA), which addresses non-surface fault rupture earthquake hazards, including strong ground shaking, liquefaction and seismically induced landslides. The California Geological Survey (CGS) is the principal State agency charged with implementing the Act. Pursuant to the SHMA, the CGS is directed to provide local governments with seismic hazard zone maps that identify areas susceptible to amplified shaking, liquefaction, earthquake-induced landslides, and other ground failures. The goal is to minimize loss of life and property by identifying and mitigating seismic hazards. The seismic hazard zones delineated by the CGS are referred to as "zones of required investigation." Site-specific geological hazard investigations are required by the SHMA when construction projects fall within these areas.

The CGS, pursuant to the 1990 SHMA, has been releasing seismic hazards maps since 1997. In the Glendale area, the CGS has mapped the Sunland, Burbank, Pasadena, Hollywood and Los Angeles quadrangles. These maps indicate that liquefaction and earthquake-induced landslides are hazards present locally in the Glendale area.

1.3.3 Real Estate Disclosure Requirements

Since June 1, 1998, the **Natural Hazards Disclosure Act** has required that sellers of real property and their agents provide prospective buyers with a "Natural Hazard Disclosure Statement" when the property being sold lies within one or more State-mapped hazard areas. If a property is located in a Seismic Hazard Zone as shown on a map issued by the State Geologist, the seller or the seller's agent must disclose this fact to potential buyers. The law specifies two ways in which this disclosure can be made. One is to use the new Natural Hazards Disclosure Statement as provided in Section 1102.6c of the California Civil Code. The other way is to use the Local Option Real Estate Disclosure Statement as provided in Section 1102.6a of the California Civil Code. The Local Option Real Estate Disclosure

Statement can be substituted for the Natural Hazards Disclosure Statement only if the Local Option Statement contains substantially the same information and substantially the same warning as the Natural Hazards Disclosure Statement.

California State law also requires that when houses built before 1960 are sold, the seller must give the buyer a completed earthquake hazards disclosure report, and a copy of the booklet entitled "The Homeowner's Guide to Earthquake Safety." This publication was written and adopted by the California Seismic Safety Commission. The most recent edition of this booklet is available from the web at www.seismic.ca.gov/. The booklet contains a sample of a residential earthquake hazards report that buyers are required to fill in, and it provides specific information on common structural weaknesses that can fail, damaging homes during earthquakes. The booklet further describes specific actions that can be taken by homeowners to strengthen their home.

The Alquist-Priolo Earthquake Fault Zoning Act and the Seismic Hazards Mapping Act also require that real estate agents, or sellers of real estate acting without an agent, disclose to prospective buyers that the property is located in an Earthquake Fault or Seismic Hazard Zone.

1.3.4 California Environmental Quality Act

The California Environmental Quality Act (CEQA) was passed in 1970 to insure that local governmental agencies consider and review the environmental impacts of development projects within their jurisdictions. CEQA requires that an Environmental Impact Report (EIR) be prepared for projects that may have significant effects on the environment. EIRs are required to identify geologic and seismic hazards, and to recommend potential mitigation measures, thus giving the local agency the authority to regulate private development projects in the early stages of planning.

1.3.5 Uniform Building Code and California Building Code

The City of Glendale has been enforcing building code provisions since 1920, when it passed Ordinance 411 regulating garages, filling stations, gasoline pumps and buggies. In 1922, it expanded its regulations to address the State Tenement House Act and other matters dealing with buildings. Ordinance 522 established the term "Superintendent of Buildings", the forerunner of the Building Official, as the overseer of enforcement of the regulations governing the construction of buildings on private property in the City of Glendale. Since then, Glendale has regularly updated its building code regulations to protect the safety of the community.

The International Conference of Building Officials (ICBO) was formed in 1922 to develop a uniform set of building regulations; this led to the publication of the first Uniform Building Code (UBC) in 1927. In keeping with the intent of providing a safe building environment for our community, the technical provisions of the City's building codes have been updated on a regular basis as new editions of the UBC have been published. In addition to updating the regulations concerning fire and life, this has also kept Glendale current with the latest provisions for the seismic design of buildings.

Recognizing that many building code provisions are not affected by local conditions, like exiting from a building, and to facilitate the concept that industries working in California should have some uniformity in building code provisions throughout the State, in 1980 the legislature amended the State's Health and Safety Code to require local jurisdictions to adopt the latest edition of the Uniform Building Code (UBC). The law states that every local agency, City and County, enforcing building regulations must adopt the provisions of the California Building Code (CBC) within 180 days of its publication. The publication date of the CBC is established by the California Building Standards Commission and the code is known as Title 24 of the California Code of Regulations. Based upon the publication cycle of the UBC, the CBC has been updated and republished every three years since the initial action by the legislature.

To further the concept of uniformity in building design, in 1994 ICBO joined with the two other national building code publishers, the Building Officials and Code Administrators International, Inc. (BOCA) and the Southern Building Code Congress International, Inc. (SBCCI), to form a single organization, the International Code Council, (ICC). In 2000, the group published the first International Building Code (IBC) as well as an entire family of codes, (i.e. building, mechanical, plumbing and fire) that were coordinated with each other. As a result, the last (and final) version of the UBC was issued in 1997.

Since the formation of the ICC and the publication of the IBC, the California legislature has not addressed the matter of updating the CBC with a building code other than the UBC. Therefore, even though the seismic design provisions have not been brought up to the current standards of the IBC, the Building Standards Commission has chosen to continue to adopt the old 1997 UBC for the CBC through the 2004 cycle.

In addition to adopting the provisions of the CBC, local jurisdiction may adopt more restrictive amendments provided that they are based upon local geographic, topographic or climatic conditions. The City of Glendale, along with 55 other local jurisdictions, have worked together to make our local amendments consistent with the rest of southern California. Currently, Glendale's Building and Safety staff are very active in the code development process and all regional activities to improve the technical provisions of the building code and the understanding of the purpose of the building codes by the public. They participate in the Los Angeles Regional Uniform Code Program, (LARUCP), and promote the adoption of uniform amendments to the CBC by other local jurisdictions.

1.3.6 Unreinforced Masonry Law

Enacted in 1986, the Unreinforced Masonry Law (Section 8875 et seq of the California Government Code) required all cities and counties in Seismic Zone 4 (zones near historically active faults) to identify hazardous unreinforced masonry (URM) buildings in their jurisdictions, establish a URM loss reduction program, and report their progress to the State by 1990. The owners of such buildings were to be notified of the potential earthquake hazard these buildings pose. The loss reduction program to be implemented, however, was left to each local jurisdiction, although the law recommends that local governments adopt mandatory strengthening programs by ordinance and that they establish seismic retrofit standards. Some jurisdictions did implement mandatory retrofit programs, while others established voluntary programs. A few cities only notified the building owners, but did not adopt any type of strengthening program.

The Glendale area lies entirely within Seismic Zone 4. Therefore, and in compliance with the Unreinforced Masonry Law, Glendale issued Chapter 58 of the City Code – Earthquake Hazard Reduction in Existing Buildings. The provisions of Chapter 58 apply to all URM buildings constructed before June 7, 1938, or buildings for which a building permit was issued prior to June 7, 1938. The Code requires all URMs, except for detached one- or two-family dwellings and apartment houses with less than 5 dwelling units, to be identified and catalogued. Owners of applicable URMs are then to retain a civil or structural engineer or architect licensed in California to conduct a structural analysis of the building to determine whether the structure meets the minimum earthquake standards specified in the City Code. If the building does not meet the minimum requirements, the owner is to either retrofit or demolish the building. The Code establishes time limits to comply with these requirements depending on the use of the building; essential and high-risk structures are to be surveyed and retrofitted more quickly than other types of buildings.

1.4 Notable Historic Earthquakes in the Glendale Region

Figure 1-2 shows the approximate epicenters of earthquakes that have resulted in significant ground shaking in the Los Angeles basin, including Glendale. The most significant of these events are summarized below. Plate 1-1 shows the historical seismicity in the immediate vicinity of Glendale. The map shows that small earthquakes, of magnitude between 1 and 3, have occurred historically in the area, but that no moderate to large earthquakes have occurred beneath Glendale in historical times.

1.4.1 Long Beach Earthquake of 1933

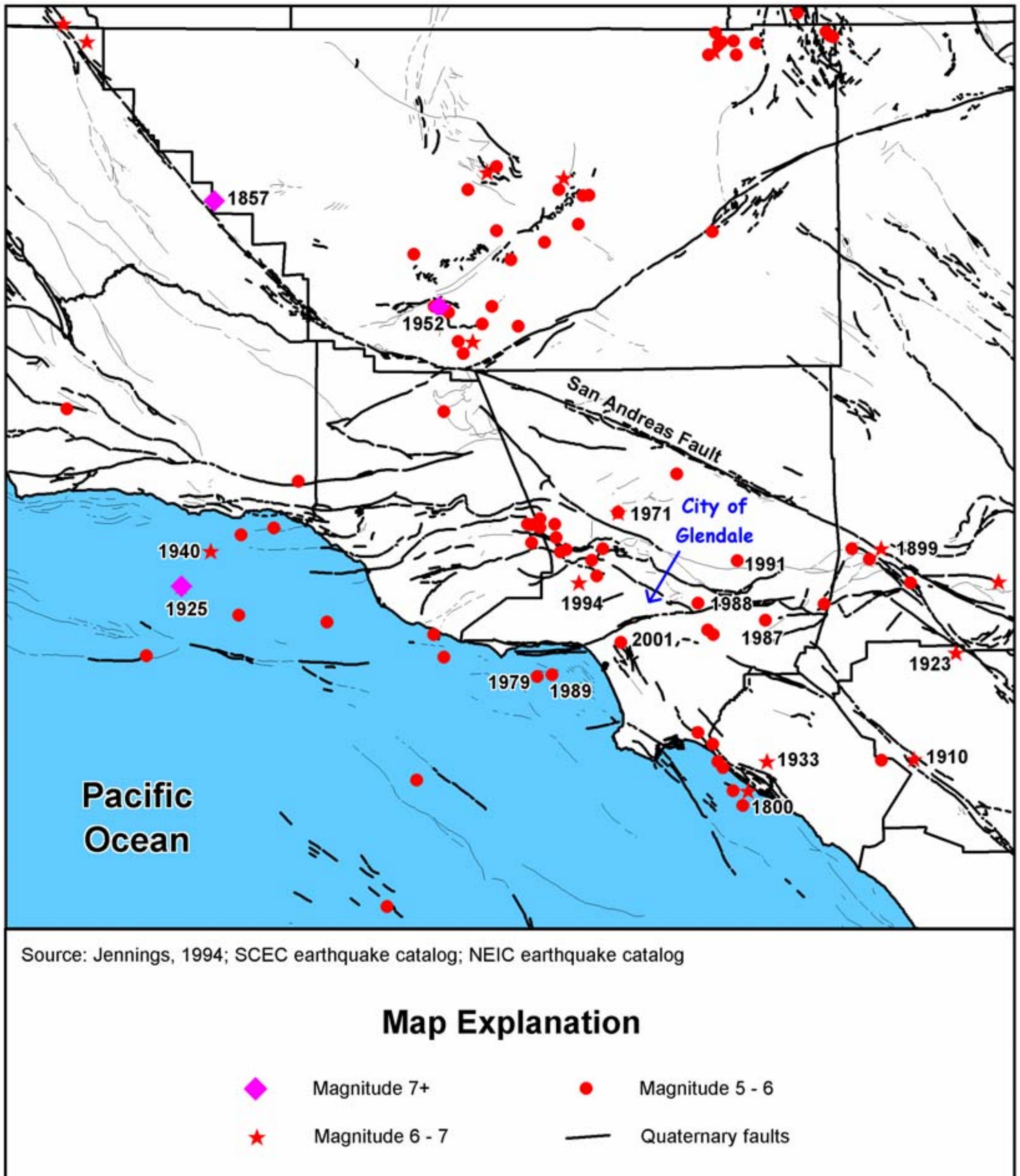
This Mw 6.4 earthquake occurred on March 10, 1933, at 5:54 in the afternoon. The location of the earthquake's epicenter has been re-evaluated, and determined to have occurred approximately 3 miles south of present-day Huntington Beach. However, it caused extensive damage in Long Beach, hence its name. The earthquake occurred on the Newport-Inglewood fault, a right-lateral strike slip fault that extends across the western portion of the Los Angeles basin (see Figure 1-1). The Newport-Inglewood fault did not rupture the surface during this earthquake, but substantial liquefaction-induced damage was reported. The earthquake caused 120 deaths, and over $50 million in property damage (Wood, 1933).

Most of the damaged buildings were of unreinforced masonry, and many school buildings were destroyed. Fortunately, children were not present in the classrooms at that time, otherwise, the death toll would have been much higher. This earthquake led to the passage of the Field Act, which gave the Division of the State Architect authority and responsibility for approving design and supervising construction of public schools. Building codes were also improved.

1.4.2 San Fernando (Sylmar) Earthquake of 1971

This Mw 6.6 earthquake occurred on the San Fernando fault zone, the western-most segment of the Sierra Madre fault, on February 9, 1971, at 6:00 in the morning. The surface rupture caused by this earthquake was nearly 12 miles long, and occurred in the Sylmar-San Fernando area, just a few miles northwest of Glendale. The maximum slip measured at the surface was nearly 6 feet.

The earthquake caused over $500 million in property damage and 65 deaths. Most of the deaths occurred when the Veteran's Administration Hospital collapsed. Several other hospitals, including the Olive View Community Hospital in Sylmar suffered severe damage. Newly constructed freeway overpasses also collapsed, in damage scenes similar to those which occurred 23 years later in the 1994 Northridge earthquake. Loss of life could have been much greater had the earthquake struck at a busier time of day. Thirty-one buildings in Glendale were so severely damaged that they had to be demolished, and approximately 3,250 masonry chimneys in the City collapsed. The total building loss in Glendale as a result of this earthquake was estimated at more than $2 million (Oakeshott, 1975).



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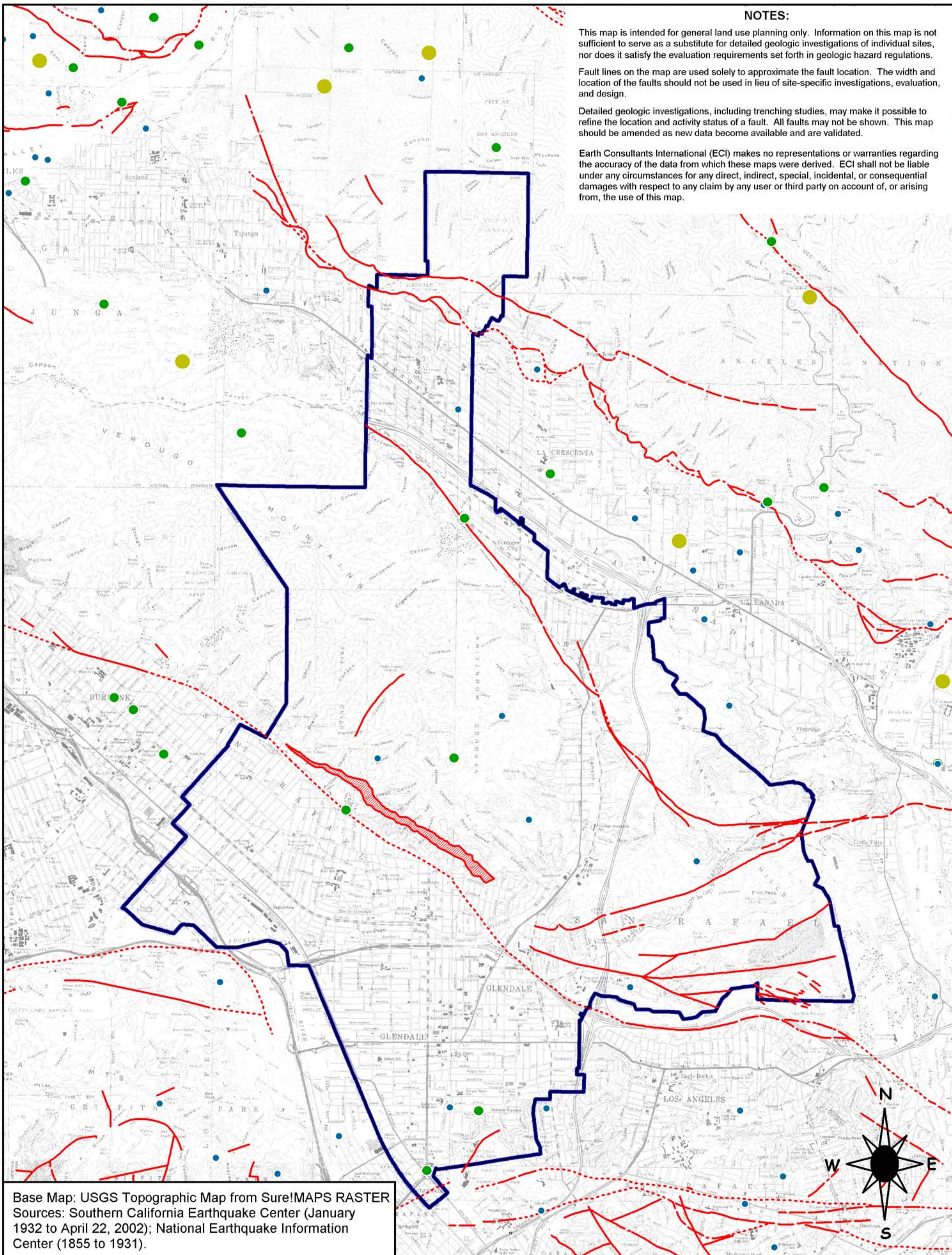
Regional Seismicity Map

Figure 1-2



NOTES:

This map is intended for general land use planning only. Information on this map is not sufficient to serve as a substitute for detailed geologic investigations of individual sites, nor does it satisfy the evaluation requirements set forth in geologic hazard regulations.

Fault lines on the map are used solely to approximate the fault location. The width and location of the faults should not be used in lieu of site-specific investigations, evaluation, and design.

Detailed geologic investigations, including trenching studies, may make it possible to refine the location and activity status of a fault. All faults may not be shown. This map should be amended as new data become available and are validated.

Earth Consultants International (ECI) makes no representations or warranties regarding the accuracy of the data from which these maps were derived. ECI shall not be liable under any circumstances for any direct, indirect, special, incidental, or consequential damages with respect to any claim by any user or third party on account of, or arising from, the use of this map.

Base Map: USGS Topographic Map from Sure!MAPS RASTER
Sources: Southern California Earthquake Center (January 1932 to April 22, 2002); National Earthquake Information Center (1855 to 1931).

Scale: 1:60,000

1000 0 1000 2000 3000 Meters

5000 0 5000 10000 15000 Feet

Explanation

Earthquake Magnitude

- 3 to 4
- 2 to 3
- 1 to 2

Fault, solid where location known, dashed where approximate, dotted where inferred; hatchured where defined as a zone, (for more information refer to Plate 1-2).

Glendale City Limit

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Historical Seismicity Map (1855-2002)

Glendale, California

Plate 1-1

As with the Long Beach earthquake, legislation was passed in response to the damage caused by the 1971 earthquake. In this case, the building codes were strengthened and the Alquist Priolo Special Studies (now Earthquake Fault) Zone) Act was passed in 1972.

1.4.3 Malibu Earthquake of 1979

This earthquake occurred on January 1, 1979 at 3:15 in the afternoon. The epicenter of the ML5.2 earthquake was approximately 8 miles south of Malibu, and 23 miles west of Los Angeles. Although it caused only minor damage in the areas closest to its epicenter, the earthquake was felt as far away as Kings, Kern and San Diego counties.

1.4.4 Whittier Narrows Earthquake of 1987

The Whittier Narrows earthquake occurred on October 1, 1987, at 7:42 in the morning, with its epicenter located approximately 12 miles southwest of Glendale (Hauksson and Jones, 1989). The ML 5.9 earthquake occurred on a previously unknown, north-dipping concealed thrust fault (blind thrust) now called the Puente Hills fault (Shaw, and Shearer, 1999). The earthquake caused eight fatalities, over 900 injured, and $358 million in property damage. Severe damage was confined mainly to communities east of Los Angeles and near the epicenter. Areas with high concentrations of URMs, such as the “Uptown” district of Whittier, the old downtown section of Alhambra, and the “Old Town” section of Pasadena, were severely impacted. Several tilt-up buildings partially collapsed, including tilt-up buildings built after 1971, that were built to improved building standards but were of irregular configuration, revealing seismic vulnerabilities not previously recognized. Residences that sustained damage usually were constructed of masonry, were not fully anchored to foundations, or were houses built over garages with large door openings. Many chimneys collapsed and in some cases, fell through roofs. Wood-frame residences, in contrast, sustained relatively little damage, and no severe structural damage to high-rise structures in downtown Los Angeles was reported.

1.4.5 Pasadena Earthquake of 1988

The Pasadena earthquake occurred at 3:38 in the morning on December 3, 1988, directly underneath the city of Pasadena. The ML5.0 earthquake occurred on the Raymond fault (Hauksson and Jones, 1991), and helped determine that the Raymond fault is a left-lateral strike-slip fault (prior to this earthquake, the geological community was divided on this issue – the fault forms a well-defined scarp that many attributed to reverse faulting). This earthquake was also notable because it was followed by an unusually small number of aftershocks, and these were of small size (the largest was only a magnitude 2.4).

1.4.6 Malibu Earthquake of 1989

This ML5.0 earthquake occurred on January 18, 1989 at 10:53 in the evening. The earthquake’s epicenter was about 10 miles south of Malibu. As a result of this earthquake, several people were injured, shelved items fell in local stores, and some windows were broken. Hardest hit was the coastal region encompassing Malibu, Santa Monica, and Redondo Beach, though damage was low even in that area. Slight damage was also reported in Los Angeles, Hollywood, Monterey Park, and Lancaster.

1.4.7 Sierra Madre Earthquake of 1991

The Sierra Madre earthquake occurred on June 28, 1991 at 7:43 in the morning approximately 18 miles northeast of Glendale. The Mw 5.8 earthquake probably occurred on the Clamshell-Sawpit Canyon fault, an offshoot of the Sierra Madre fault zone in the San Gabriel Mountains (Haukson, 1994). Because of its depth and moderate size, it caused no surface rupture, but it did trigger rockslides that blocked some of the local mountain roads. Roughly $40 million in property damage occurred in the San Gabriel Valley; URM buildings were hardest hit, and many brick chimneys collapsed. Two deaths resulted from this earthquake -- one person was killed in Arcadia, and one person in Pasadena died from a heart attack. In all, at least 100 others were injured, though the injuries were mostly minor.

1.4.8 Landers and Big Bear Earthquakes of 1992

On the morning of June 28, 1992, most people in southern California were awakened at 4:57 by the largest earthquake to strike California in 40 years. Named "Landers" after a small desert community near its epicenter, the earthquake had a magnitude of 7.3. More than 50 miles of surface rupture associated with five or more faults occurred as a result of this earthquake. The average right-lateral strike-slip displacement was about 10 to 15 feet, but a maximum of 18 feet of slip was observed. Centered in the Mojave Desert, approximately 120 miles from Los Angeles, the earthquake caused relatively little damage for its size (Brewer, 1992). It released about four times as much energy as the very destructive Loma Prieta earthquake of 1989, but fortunately, it did not claim as many lives (one child died when a chimney collapsed). The power of the earthquake was illustrated by the length of the ground rupture it left behind. The earthquake ruptured 5 separate faults: Johnson Valley, Landers, Homestead Valley, Emerson, and Camp Rock faults (Sieh et al., 1993). Nearby faults also experienced triggered slip and minor surface rupture. There are no Modified Mercalli Intensity (MMI) reports for this earthquake in the Glendale area, but in Pasadena three individuals reported MMIs of IV, and in Burbank, MMIs of IV to V were reported (see Table 1-1) (http://pasadena.wr.usgs.gov/shake/ca/).

The magnitude 6.4 Big Bear earthquake struck little more than 3 hours after the Landers earthquake on June 28, 1992 at 8:05:30 A.M. PDT. This earthquake is technically considered an aftershock of the Landers earthquake (indeed, the largest aftershock), although the Big Bear earthquake occurred over 20 miles west of the Landers rupture, on a fault with a different orientation and sense of slip than those involved in the main shock. From its aftershock, the causative fault was determined to be a northeast-trending left-lateral fault. This orientation and slip are considered "conjugate" to the faults that slipped in the Landers rupture. The Big Bear earthquake did not break the ground surface, and, in fact, no surface trace of a fault with the proper orientation has been found in the area. The Big Bear earthquake caused a substantial amount of damage in the Big Bear area, but fortunately, it claimed no lives. However, landslides triggered by the quake blocked roads in the mountainous areas, aggravating the clean-up and rebuilding process (SCEC-DC, 2001).

1.4.9 Northridge Earthquake of 1994

The Northridge Earthquake of January 17, 1994 woke up most of southern California at 4:30 in the morning. The earthquake's epicenter was located 20 miles to the west-northwest of downtown Los Angeles, on a previously unknown blind thrust fault now called the Northridge (or Pico) Thrust. Although moderate in size, this earthquake produced the strongest ground motions ever instrumentally recorded in North America. The Mw 6.7 earthquake is one of the most expensive natural disasters to have impacted the United States. Damage was widespread, sections of major freeways collapsed, parking structures and office buildings collapsed, and numerous apartment buildings suffered irreparable damage. Damage to wood-frame apartment houses was very widespread in the San Fernando Valley and Santa Monica areas, especially to structures with "soft" first floor or lower-level parking garages. The high accelerations, both vertical and horizontal, lifted structures off of their foundations and/or shifted walls laterally. The death toll was 57, and more than 1,500 people were seriously injured.

In the Glendale area, this earthquake caused predominantly Modified Mercalli intensities of VII (44 individuals reported MMIs of VII and one individual reported MMIs of VIII) (http://pasadena.wr.usgs.gov/shake/ca/). High-profile damage in Glendale includes the following cases: A section of the third level above grade in the Glendale City Center parking structure collapsed, sections of the Glendale Galleria parking structure settled 4 to 8 inches due to damage to pedestals, and the Glendale Fashion Center had damage to exterior columns.

Despite the losses, gains made through earthquake hazard mitigation efforts of the last two decades were obvious. Retrofits of masonry building helped reduce the loss of life, hospitals suffered less structural damage than in 1971 San Fernando earthquake, and emergency response was exemplary. Extensive documentation regarding this earthquake and its effects on the built environment is available on the world wide web. Additional information can be found at the following web sites as well as others:
http://geohazards.cr.usgs.gov/northridge/
www.eqe.com/publications/northridge/northridge.html.

1.4.10 West Hollywood Earthquake of 2001

A M4.2 earthquake occurred in West Hollywood at 4:59 in the afternoon on September 9, 2001. This earthquake was widely felt throughout the Los Angeles Basin and in parts of San Fernando Valley. No significant damage was reported. This is the largest earthquake to occur in the Los Angeles basin since the 1994 Northridge earthquake and its aftershocks. The earthquake's epicenter was located near the intersection of the Newport-Inglewood and Hollywood faults. The focal mechanism showed horizontal strike-slip motion on a north-northwest striking plane, suggesting that this event may be associated with the north end of the Newport-Inglewood fault (Hauksson, Hutton and Jones, 2001; at http://Pasadena.wr.usgs.gov/eqinthenews/ci09703873/index.html). This earthquake caused MMIs in Glendale of between III and IV (http://pasadena.wr.usgs.gov/shake/ca/).

1.5 Potential Sources of Seismic Ground Shaking

Seismic shaking is the geologic hazard that has the greatest potential to severely impact Glendale given the City's proximity to several active seismic sources (faults). As discussed in Section 1.4 above, some of these faults caused moderate-sized earthquakes in the last century; but, given their length, are thought capable of generating even larger earthquakes in the future that would cause strong ground shaking in Glendale and nearby communities.

To give the City a better understanding of the hazard posed by these faults, we performed a deterministic seismic hazard analysis using software that is an industry standard [EQFAULT, by Blake (2000a)], to estimate the Peak Horizontal Ground Accelerations (PHGA) that can be expected at Glendale's City Center due to earthquakes occurring on any of the known active or potentially active faults within 100 km (62 miles) from the City. We also conducted probabilistic seismic hazard analyses using FRISKSP (Blake, 2000b) to estimate the median PHGA at twelve different sites throughout the City. The difference between these two approaches is that, while a deterministic hazard assessment addresses individual sources or scenario events, probabilistic assessments combine all seismic sources and consider the likelihood (or probability) of each source to generate an earthquake. In a probabilistic analysis, a mathematical equation is used to estimate the combined risk posed by all known faults within 100 km, and for each fault, a suite of possible damaging earthquakes is considered, each weighed according to its likelihood of occurring in any particular year.

To conduct these seismic shaking analyses, we used the same fault database (including fault locations and earthquake magnitudes of the maximum magnitude and maximum probable earthquakes for each fault) used by the CGS and USGS for the National Seismic Hazard Maps (Peterson and others, 1996). The PHGA estimates obtained from these analyses provide a general indication of relative earthquake risk in Glendale. However, studies that better constrain the distance from a given site to the various faults in the region, and that consider the near-surface soil types should be conducted for site-specific projects.

Those faults that, based on the ground shaking analyses described above, can cause peak horizontal ground accelerations of about 0.1g or greater (Modified Mercalli Intensities greater than VII) in the Glendale area are listed in Table 1-2. For a map showing most of these faults, refer to Figure 1-3. Those faults included in Table 1-2 that have the greatest impact on the Glendale area, or that are thought to have a higher probability of causing an earthquake, are described in more detail in the following pages.

Table 1-2 shows:

- The closest approximate distance, in miles and in kilometers, between Glendale's City Hall and each of the main faults considered in the deterministic and probabilistic analyses;
- the maximum magnitude earthquake (Mmax) each fault is estimated capable of generating;
- the intensity of ground motion, expressed as a fraction of the acceleration of gravity (g), that could be experienced in the Glendale area if the Mmax occurs on one of these faults; and
- the Modified Mercalli seismic Intensity (MMI) values estimated to be felt in the City as a result of the Mmax on each one of these faults.

In general, peak ground accelerations and seismic intensity values decrease with increasing distance away from the causative fault. However, local site conditions, such as the top of ridges, can amplify the seismic waves generated by an earthquake, resulting in localized higher accelerations than those listed here. The strong ground motion values presented here should therefore be considered as average values; higher values may occur locally in response to site-specific conditions.

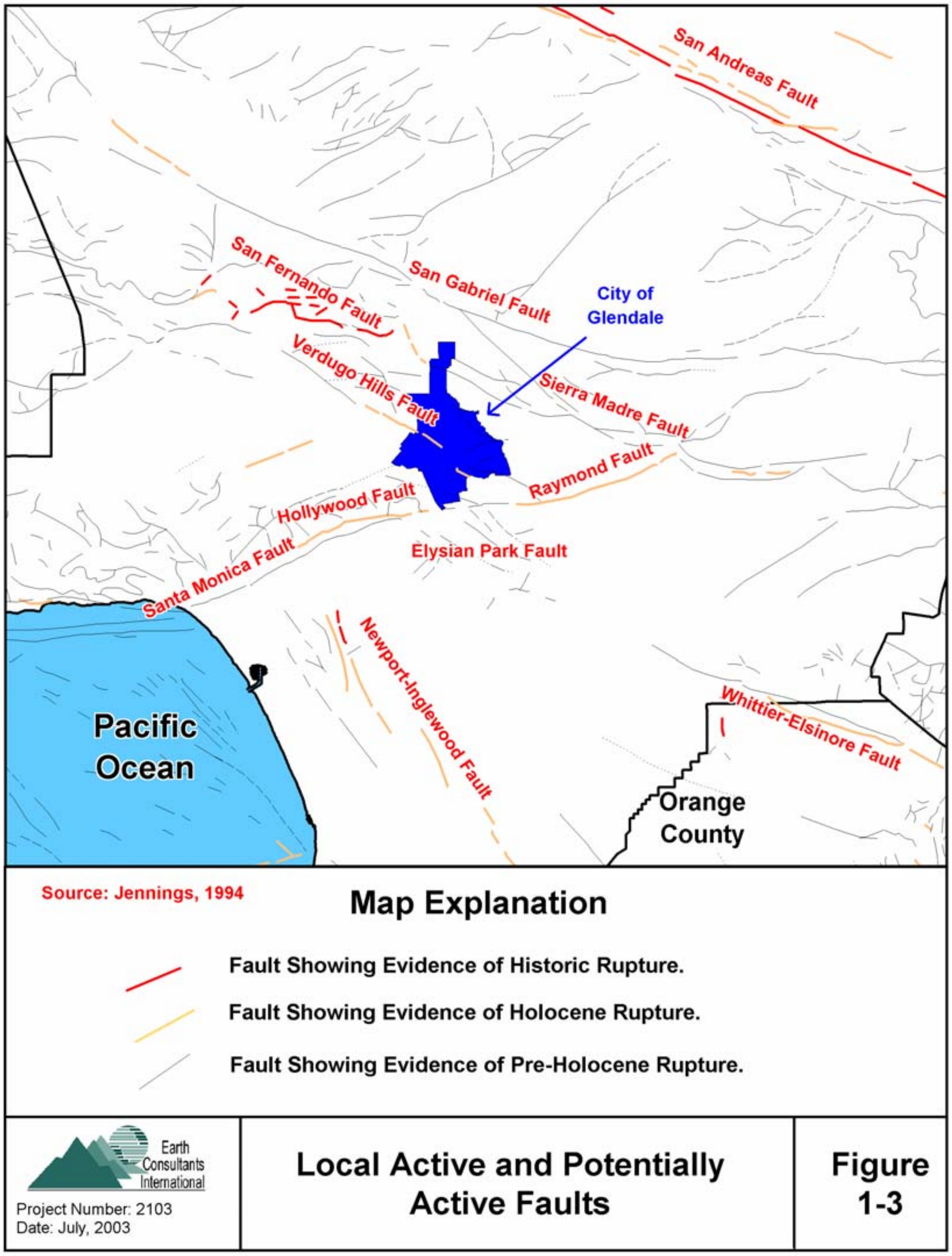
The probabilistic seismic analyses performed for this study indicate that the Glendale area has a 10 percent chance of experiencing ground accelerations greater than 55 to 70 percent the force of gravity (0.55g to 0.70g) in 50 years. These probabilistic ground motion values for the City of Glendale are in the high to very high range for southern California, and are the result of the City's proximity to major fault systems with high earthquake recurrence rates.

Table 1-2
Estimated Horizontal Peak Ground Accelerations and Seismic Intensities in the Glendale Area

Fault Name	Distance to Glendale (mi)	Distance to Glendale (km)	Magnitude of Mmax *	PGA (g) from Mmax	MMI from Mmax
Verdugo	<1	<1	6.7	0.61	X
Hollywood	<2	~1	6.4	0.55	X
Raymond	<2	~1	6.5	0.55	X
Sierra Madre	5	9	7.0	0.46+	X
Elysian Park Thrust	6	10	6.7	0.38	IX
Sierra Madre (San Fernando)	9	15	6.7	0.28	IX
Santa Monica	10	16	6.6	0.25	IX
Newport-Inglewood	11	17	6.9	0.24	IX
Compton Thrust	12	19	6.8	0.25	IX
San Gabriel	12	19	7.0	0.23	IX
East Oak Ridge (Northridge)	12	20	6.9	0.26	IX
Clamshell-Sawpit	13	21	6.5	0.20	VIII
Malibu Coast	17	28	6.7	0.18	VIII
Whittier	17	28	6.8	0.16	VIII
Santa Susana	19	30	6.5	0.16	VIII
San Jose	21	33	6.5	0.14	VIII
Palos Verdes	21	34	7.1	0.16	VIII
Holser	24	39	6.5	0.13	VIII
Cucamonga	27	43	7.0	0.15	VIII
Chino-Central Avenue	27	44	6.7	0.13	VIII
Anacapa Dume	28	45	7.3	0.17	VIII
San Andreas (1857 Rupture)	29	46	7.8	0.18	VIII
San Andreas - Mojave	29	46	7.1	0.12	VII
Oakridge (Onshore)	31	49	6.9	0.13	VIII
Simi-Santa Rosa	33	53	6.7	0.11	VII
San Cayetano	36	57	6.8	0.11	VII

* The Mmax reported herein are based on the fault parameters published by the CGS (CDMG, 1996). However, as described further below, in the text, recent paleoseismic studies suggest that some of these faults, like the Sierra Madre fault, can generate even larger earthquakes than those listed above. These PGAs were calculated using Blake's (2000a) deterministic analysis software. In general, areas closer to a given fault will generally experience higher accelerations than areas farther away, therefore the northern portion of the City, next to the Sierra Madre fault, would experience higher accelerations than those reported herein.

Abbreviations used in Table 1-2:
mi – miles; **km** – kilometers; Mmax – maximum magnitude earthquake; **PGA** – peak ground acceleration as a percentage of g, the acceleration of gravity; **MMI** – Modified Mercalli Intensity.


San Andreas Fault
San Fernando Fault
San Gabriel Fault
City of
Glendale
Verdugo Hills Fault
Sierra Madre Fault
Raymond Fault
Hollywood Fault
Elysian Park Fault
Santa Monica Fault
Newport-Inglewood Fault
Whittier-Elsinore Fault
Pacific
Ocean
Orange
County
Source: Jennings, 1994
Map Explanation
Fault Showing Evidence of Historic Rupture.
Fault Showing Evidence of Holocene Rupture.
Fault Showing Evidence of Pre-Holocene Rupture.
Earth
Consultants
International
Project Number: 2103
Date: July, 2003
Local Active and Potentially
Active Faults
Figure
1-3

1.5.1 San Andreas Fault Zone

As discussed previously, the San Andreas fault is the principal boundary between the Pacific and North American plates, and as such, it is considered the "Master Fault" because it has frequent (geologically speaking), large, earthquakes, and it controls the seismic hazard in southern California. The fault extends over 750 miles (1,200 kilometers), from near Cape Mendocino in northern California to the Salton Sea region in southern California. At its closest approach, the San Andreas fault is approximately 24 miles (38 km) north of Glendale.

Large faults, such as the San Andreas fault, are generally divided into segments in order to evaluate their future earthquake potential. The segments are generally defined at discontinuities along the fault that may affect the rupture length. In central and southern California, the San Andreas fault zone is divided into five segments named, from north to south, the Cholame, Carrizo, Mojave, San Bernardino Mountains, and Coachella Valley segments (Working Group on California Earthquake Probabilities - WGCEP, 1995). Each segment is assumed to have a characteristic slip rate (rate of movement averaged over time), recurrence interval (time between moderate to large earthquakes), and displacement (amount of offset during an earthquake). While this methodology has some value in predicting earthquakes, historical records and studies of prehistoric earthquakes show that it is possible for more than one segment to rupture during a large quake or for ruptures to overlap into adjacent segments.

The last major earthquake on the southern portion of the San Andreas fault was the 1857 Fort Tejon (Mw 7.8) event. This is the largest earthquake reported in California. The 1857 surface rupture broke the Cholame, Carrizo, and Mojave segments, resulting in displacements of as much as 27 feet (9 meters) along the rupture zone. Peak ground accelerations in the Glendale area as a result of the 1857 earthquake are estimated to have been as high as 0.18g. Rupture of these fault segments as a group, during a single earthquake, is thought to occur with a recurrence interval of between 104 and 296 years.

The closest segment of the San Andreas fault to Glendale is the Mojave segment, located approximately 29 miles to the northeast of the City Center area. This segment is 83 miles (133 km) long, extending from approximately Three Points southward to just northwest of Cajon Creek, at the southern limit of the 1857 rupture (WGCEP, 1995). Using a slip rate of 30±8 millimeters per year (mm/yr) and a characteristic displacement of 4.5±1.5 meters (m), the Working Group on California Earthquake Probabilities (WGCEP, 1995) derived a recurrence interval of 150 years for this segment. The Mojave segment is estimated to be capable of producing a magnitude 7.1 earthquake, which could result in peak ground accelerations in the Glendale area of about 0.13g. The WGCEP (1995) calculated that this segment has a 26 percent probability of rupturing sometime between 1994 and 2024.

The next closest segment of the San Andreas fault to the City of Glendale is the Carrizo segment, located approximately 41 miles from downtown. This fault segment, which is about 75 miles (121 km) long, also ruptured during the 1857 earthquake. Slip on this segment of the San Andreas fault was greater than on either of the two other segments, averaging 6 to 7 m, and locally displaying offsets of as much as 8 to 10 m. Several paleoseismological studies have been conducted on this segment of the San Andreas fault. This would suggest that this segment is well understood, but the data are often conflicting or inconclusive. Past earthquakes have been resolved in some trench exposures but not in others only a few miles away, and the slip estimates for past earthquakes as determined from these exposures also vary. To account for and resolve these discrepancies, the 1995 WGCEP used a slip rate of

34±3 mm/yr, and a slip per event of 7±4 m. The error bars on the slip-per-event data reflect the varying measurements that have been made along the fault length for the 1857 event. These values resolve into a recurrence interval of 206 (+149, -125 years). This segment is thought capable of producing a magnitude 7.2 earthquake, which could result in peak ground accelerations in the Glendale area of about 0.10g. The WGCEP (1995) also calculated an 18 percent probability that this fault segment will generate an earthquake sometime between 1994 and 2024.

The San Bernardino Mountains segment, located about 43 miles from downtown Glendale, is approximately 49 miles (78 km) long, and extends from Cajon Creek to the San Gorgonio Pass. This segment is a structurally complex zone that is poorly understood, and for which there are scant data on fault behavior. Using a slip rate of 24±5 mm/yr and a characteristic displacement of 3.5±1.0 m, the WGCEP (1995) derived a recurrence interval on this fault of 146 years. This fault segment is estimated capable of producing a magnitude 7.3 earthquake, which could result in peak ground accelerations in Glendale of about 0.1g. If this fault segment ruptures together with the Mojave and Coachella Valley segments, higher ground motions would be expected. In 1994, the WGCEP (1995) calculated that this fault segment had a 28 percent probability of rupturing sometime in the next 30 years. Since the fault has not ruptured yet, the probability that it will before the year 2024 has increased.

1.5.2 Verdugo Fault

The Verdugo fault is a 13 to 19-mile (21 to 30 km) long, southeast-striking fault that that extends along the northeastern edge of the San Fernando Valley, and at or near the southern flank of the Verdugo Mountains, through the cities of Glendale and Burbank. Weber et al. (1980) first reported southwest-facing scarps 2 to 3 meters high in the alluvial fan deposits in the Burbank and west Glendale areas, and other subsurface features indicative of faulting. Weber et al. (1980) relied on these scarps, on offset alluvial deposits at two localities, and on a subsurface groundwater cascade beneath Verdugo Wash to suggest that movement on this fault is youthful, but no age estimates were provided. Weber et al. (1980) further suggested that this fault is a shallow, north-dipping reverse fault responsible for uplift of the Verdugo Mountains, and proposed that the fault zone is approximately 1 km wide. For nearly 20 years since Weber et al.'s (1980) report, the Verdugo fault was not studied, but in the last few years, recognizing the potential threat that this fault poses to the Los Angeles metropolitan region, several researchers have started to investigate this fault.

Some researchers have relied on deep subsurface data, primarily oil well records and geophysical data to review the subsurface geology of the San Fernando Valley area, including the characteristics of the Verdugo fault (Tsutsumi and Yeats, 1999; Langenheim et al., 2000; Pujol et al., 2001). Results of these studies suggest that the Verdugo fault changes in character from a reverse fault adjacent to the Pacoima Hills, near its northwestern terminus, to a normal fault at the southwest edge of the Verdugo Mountains. To the north, the Verdugo fault appears to merge with both the Mission Hills and Northridge Hills faults. To the south, the fault is on trend with the Eagle Rock fault, but it is still unclear whether these faults are connected. Vertical separation on the Verdugo fault is at least 1,000 meters (3,300 feet), based on the structural relief between the valley floor and the crest of the Verdugo Mountains and other indicators (Tsutsumi and Yeats, 1999). Even though some of the data suggest that the Verdugo fault is a reverse fault, there are several researchers who now propose that the Verdugo fault is a left-lateral strike-slip fault (Walls et al., 1998; Dolan, personal communication, 2002).

Other investigators have taken a more direct, hands-on approach to study this fault, but finding locations suitable for trenching has been difficult in the extensively developed San Fernando Valley. Dolan and Tucker (1999) tried to better define the location and recency of activity of the Verdugo fault by conducting geological and geophysical studies across the inferred trace of the fault in Brand Park. They used closely spaced boreholes drilled in a line perpendicular to the trend of the fault, and ground penetrating radar to look for stratigraphic anomalies that could be suggestive of faulting. They identified one possible anomaly that could be the Verdugo fault and excavated a trench across the suspect area. However, the sediments exposed in the trench were too friable to maintain the trench open long enough to conduct their study. Dolan and Tucker believe that they did locate a fault, but they are uncertain about whether or not the fault is a recent strand of the Verdugo fault. Realizing that the Brand Park site may not yield any additional, useful information, Dolan and Tucker (1999) shifted their attention to another potential trenching site, at Palm Park in Burbank. Unfortunately, their studies at Palm Park were equally unsuccessful at locating and characterizing this fault (Dolan, personal communication, 2002).

Slip rate on the Verdugo fault is poorly constrained, and currently estimated at about 0.5 mm/yr (CDMG, 1996). The fault's recurrence interval is unknown; however, the fault's southern segment is thought to have ruptured during the Holocene, and the fault is therefore considered active (Jennings, 1994). Based on its length, the Verdugo fault is thought capable of generating magnitude 6.0 to 6.8 earthquakes. A magnitude 6.7 earthquake on this fault would generate peak ground accelerations in the Glendale area of about 0.6g to 0.7g. Higher accelerations can be expected locally. Given the high accelerations that this fault is estimated capable of generating in Glendale, an earthquake scenario on this fault was modeled for loss estimation using HAZUS (see Section 1.9, below).

1.5.3 Hollywood Fault

The Hollywood fault is the eastern 9-mile (14 km) long segment of the Santa Monica – Hollywood fault system that forms the southern margin of the Santa Monica Mountains (locally known as the Hollywood Hills). It has also been considered the westward extension of the Raymond fault (see Section 1.5.4 below). From east to west, the fault traverses the Hollywood section of Los Angeles, and the cities of West Hollywood and Beverly Hills. Its eastern end is mapped immediately south of Glendale's southern boundary (see Plate 1-2). Movement on the Hollywood fault over geologic time is thought responsible for the growth of the Hollywood Hills, which is why earlier researchers characterized this fault as a northward-dipping reverse fault. However, recent studies by Dolan et al. (1997, 2000a) and Tsutsumi et al. (2001) show that the Hollywood fault is primarily a left-lateral strike-slip fault. A lateral component of movement on this fault is consistent with its linear trace and steep, 80- to 90-degree dips (reverse faults typically have irregular, arcuate traces and shallow dips).

The Santa Monica – Hollywood fault system has not produced any damaging historical earthquakes, and it has had only relatively minor microseismic activity. Subsurface studies by Dolan et al. (2000a) suggest that the Hollywood fault moves infrequently. The most recent surface-rupturing earthquake on this fault appears to have occurred 7,000 to 9,500 years ago, and another earthquake appears to have occurred in the last 10,000 to 22,000 years (Dolan et al., 2000a). These data suggest that the fault either has a slow rate of slip (of between 0.33 and 0.75 mm/yr), or that it breaks in large-magnitude events. Interestingly, the recent past history of earthquakes on the Hollywood fault is remarkably similar to that of the Sierra Madre fault. Paleoseismologists are currently researching the possibility that earthquakes on the Sierra Madre fault trigger rupture of the Santa Monica – Hollywood fault system. If this is the case, then large earthquakes in the Los Angeles region may cluster in time, releasing a significant amount of strain over a geologically short time period, followed by lengthy periods of seismic quiescence.

Based on its length, the Hollywood fault is thought capable of generating a Mw ~6.4 to 6.6 earthquake. A conservative magnitude 6.4 earthquake on the Hollywood fault is thought capable of generating peak ground accelerations of about 0.55g in Glendale, near City Hall. Even higher accelerations, of as much as 0.7g can be expected along the southernmost portion of the City, near the eastern end of the fault.

1.5.4 Raymond Fault

The Raymond (or Raymond Hills) fault is a left-lateral, strike-slip fault about 13 miles (20 km) long that extends across the San Gabriel Valley, along the eastern and southern margins of Pasadena, and through the northern reaches of Arcadia, San Marino and South Pasadena. The westernmost portion of the Raymond fault is mapped just south of the City of Glendale (see Plate 1-2). The fault produces a very obvious south-facing scarp along much of its length, which led many geologists to favor reverse-slip as the predominant sense of fault motion. However, left-deflected channels, shutter-ridges, sag ponds, and pressure ridges indicate that the Raymond fault is predominantly a left-lateral strike-slip fault. This sense of motion is confirmed by the seismological record, especially by the mainshock and aftershock sequence to the 1988 Pasadena earthquake of local magnitude (ML) 5.0 that probably occurred on this fault (Jones et al., 1990; Hauksson and Jones, 1991). Investigators have suggested that the Raymond fault transfers slip southward from the Sierra Madre fault zone to other fault systems (Walls et al., 1998).

The Raymond fault was recently trenched in San Marino, at the Los Angeles Arboretum in Arcadia (Weaver and Dolan, 2000), and in eastern Pasadena (Dolan et al., 2000b) where significant data on the recent history of this fault were collected. These studies indicate that the most recent surface-rupturing earthquake on this fault occurred 1,000 to 2,000 years ago, and that between three and five earthquakes occurred on this fault between 41,500 and 31,500 years ago. This suggests that the fault either breaks in cluster earthquakes, or that several more surface-rupturing earthquakes have occurred on this fault that were not detected in the trenches. Proposed slip rates on the fault vary from a minimum of 1.5 mm/yr (Weaver and Dolan, 2000) to 4 (+1, -0.5) mm/yr (Marin et al., 2000; Dolan et al., in review). Weaver and Dolan (2000) also suggest an average recurrence interval for this fault of about 3,000 years.

A conservative magnitude 6.5 earthquake on the Raymond fault would generate peak ground accelerations in the Glendale area of about 0.55g. However, the paleoseismic data suggest that this fault is capable of generating larger earthquakes, in the 7.0 magnitude range (Dolan et al., 2000b). If this is the case, stronger ground shaking as a result of an earthquake on this fault could be experienced in Glendale.

1.5.5 Sierra Madre Fault

The Sierra Madre fault zone is a north-dipping reverse fault zone approximately 47 miles (75 km) long that extends along the southern flank of the San Gabriel Mountains from San Fernando to San Antonio Canyon, where it continues southeastward as the Cucamonga fault. The Sierra Madre fault has been divided into five segments, and each segment seems to have a different rate of activity.

The northwestern-most segment of the Sierra Madre fault (the San Fernando segment) ruptured in 1971, causing the Mw 6.7 San Fernando (or Sylmar) earthquake. As a result of this earthquake, the Sierra Madre fault has been known to be active. In the 1980s, Crook and others (1987) studied the Transverse Ranges using general geologic and geomorphic mapping, coupled with a few trenching locations, and suggested that the segments of the Sierra Madre fault east of the San Fernando segment have not generated major earthquakes in several thousands of years, and possibly as long as 11,000 years. By California's definitions of active faulting, most of the Sierra Madre fault would therefore be classified as not active. Then, in the mid 1990s, Rubin et al. (1998) trenched a section of the Sierra Madre fault in Altadena, at the Loma Alta Park, and determined that this segment has ruptured at least twice in the last 15,000 years, causing magnitude 7.2 to 7.6 earthquakes. This suggests that the Los Angeles area is susceptible to infrequent, but large near-field earthquakes on the Sierra Madre fault. Rubin et al.'s (1998) trenching data show that during the last earthquake, this fault trace shifted as much as 13 feet (4 meters) at the surface, and that total displacement in the last two events adds to more than 34 feet (10.5 meters)!

Although the fault seems to slip at a rate of only between 0.5 and 1 mm/yr (Walls et al., 1998), over time, it can accumulate a significant amount of strain. The paleoseismic data obtained at the Loma Alta Park site were insufficient to estimate the recurrence interval and the age of the last surface-rupturing event on this segment of the fault. However, Tucker and Dolan (2001) trenched the east Sierra Madre fault at Horsethief Canyon and obtained data consistent with Rubin et al.'s (1998) findings. At Horsethief Canyon, the Sierra Madre fault last ruptured about 8,000 to 9,000 years ago. Using a slip rate of 0.6 mm/yr and a slip per event of 5 meters, resolves into a recurrence interval of about 8,000 years. If the last event occurred more than 8,000 years ago, it is possible that these segments of the Sierra Madre fault are near the end of their cycle, and therefore likely to generate an earthquake in the not too distant future.

Given the data presented above, and since the Sierra Madre fault extends across the northern reaches of the Glendale area, this fault poses a significant hazard to the City. The deterministic analysis for the Glendale City Center area estimates peak ground accelerations of about 0.46g, based on a magnitude 7.0 earthquake on the segment of the Sierra Madre fault that extends through the City of Glendale. A larger earthquake on this fault, of magnitude between 7.2 and 7.6, could generate significantly stronger peak ground accelerations, especially in the northern portion of the City. Specific losses in Glendale as a result of an earthquake on the Sierra Madre fault are discussed in detail in Section 1.9, below. If the San Fernando segment of the Sierra Madre fault ruptured, causing a magnitude 6.7 earthquake, peak ground accelerations of about 0.28g are anticipated in the southern portion of Glendale, near City Hall. As before, stronger ground accelerations would be expected in the northern reaches of the City, closer to the fault.

1.5.6 Elysian Park Fault

The Whittier Narrows earthquake of October 1, 1987 occurred on a previously unknown blind thrust fault underneath the eastern part of the Los Angeles basin. Davis et al. (1989) used oil field data to construct cross-sections showing the subsurface geology of the basin, and concluded that the Whittier Narrows earthquake occurred on a thrust ramp they called the Elysian Park thrust fault. They modeled the Elysian Park as a shallow-angle, reverse-motion fault 6 to 10 miles below the ground surface generally located between the Whittier fault to the southeast, and the Hollywood fault to the west-northwest. Although blind thrusts do not extend to the Earth's surface, they are typically expressed at the surface by a series of hills or mountains. Davis et al. (1989) indicated that the Elysian Park thrust ramp is expressed at the surface by the Santa Monica Mountains, and the Elysian, Repetto, Montebello and Puente Hills.

Davis et al. (1989) estimated a long-term slip rate on the Elysian Park of between 2.5 and 5.2 mm/yr. Dolan et al. (1995) used a different approach to estimate a slip rate on the Elysian Park fault of about 1.7 mm/yr with a recurrence interval of about 1,475 years. Then, in 1996, Shaw and Suppe re-interpreted the subsurface geology of the Los Angeles basin, proposed a new model for what they call the Elysian Park trend, and estimated a slip rate on the thrust ramp beneath the Elysian Park trend of 1.7±0.4 mm/yr. More recently, Shaw and Shearer (1999) relocated the main shock and aftershocks of the 1987 Whittier Narrows earthquake, and showed that the earthquake sequence occurred on an east-west trending buried thrust they called the Puente Hills thrust (rather than the northwest-trending Elysian Park thrust).

Given the enormous amount of research currently underway to better characterize the blind thrust faults that underlie the Los Angeles basin, the Elysian Park thrust fault will most likely undergo additional significant re-interpretations. In fact, Shaw and Shearer (1999) suggest that the Elysian Park thrust fault is no longer active. However, since this statement is under consideration, and the Elysian Park thrust is still part of the active fault database for southern California (CGS, previously CDMG, 1996), we have considered this fault as a potential seismic source in Glendale. If this fault caused a magnitude 6.7 earthquake, it is estimated that Glendale would experience peak ground accelerations of about 0.38g.

1.6 Potential Sources of Fault Rupture

1.6.1 Primary Fault Rupture

Primary fault rupture refers to fissuring and offset of the ground surface along a rupturing fault during an earthquake. Primary ground rupture typically results in a relatively small percentage of the total damage in an earthquake, but being too close to a rupturing fault can cause severe damage to structures. As discussed previously, development constraints within active fault zones were implemented in 1972 with passage of the California Alquist-Priolo Earthquake Fault Zoning Act. The Alquist-Priolo Act prohibits the construction of new habitable structures astride an active fault and requires special geologic studies to locate, and evaluate whether a fault has ruptured the ground surface in the last about 11,000 years. If an active fault is encountered, structural setbacks from the fault are defined.

In the Glendale vicinity, the CGS has identified the Rowley fault (a section of the Sierra Madre fault) and the Raymond fault as sufficiently active and well defined to require zoning under the guidelines of the Alquist-Priolo Earthquake Fault Zoning Act. The Alquist-Priolo zones designated by the CGS for these faults are shown on Plate 1-2. Only the Rowley fault zone extends into the City of Glendale proper, so the Raymond fault is not discussed further below. Other faults that have been mapped in Glendale but have not been zoned by the California Geological Survey are discussed in more detail below.

The **Rowley fault** is the first segment of the **Sierra Madre fault** to the east of the fault traces that ruptured the ground surface during the 1971 Sylmar earthquake (see Plate 1-2; the Lakeview fault is the easternmost fault that ruptured the surface in 1971. The Sunland fault to the north did not break, but extensive landsliding occurred in the Sunland fault area in response to movement on the Lakeview fault). Where the Rowley fault has been mapped in

NOTES:

This map is intended for general land use planning only. Information on this map is not sufficient to serve as a substitute for detailed geologic investigations of individual sites, nor does it satisfy the evaluation requirements set forth in geologic hazard regulations.

Fault lines on the map are used solely to approximate the fault location. The width and location of the faults should not be used in lieu of site-specific investigations, evaluation, and design.

Detailed geologic investigations, including trenching studies, may make it possible to refine the location and activity status of a fault. All faults may not be shown. This map should be amended as new data become available and are validated.

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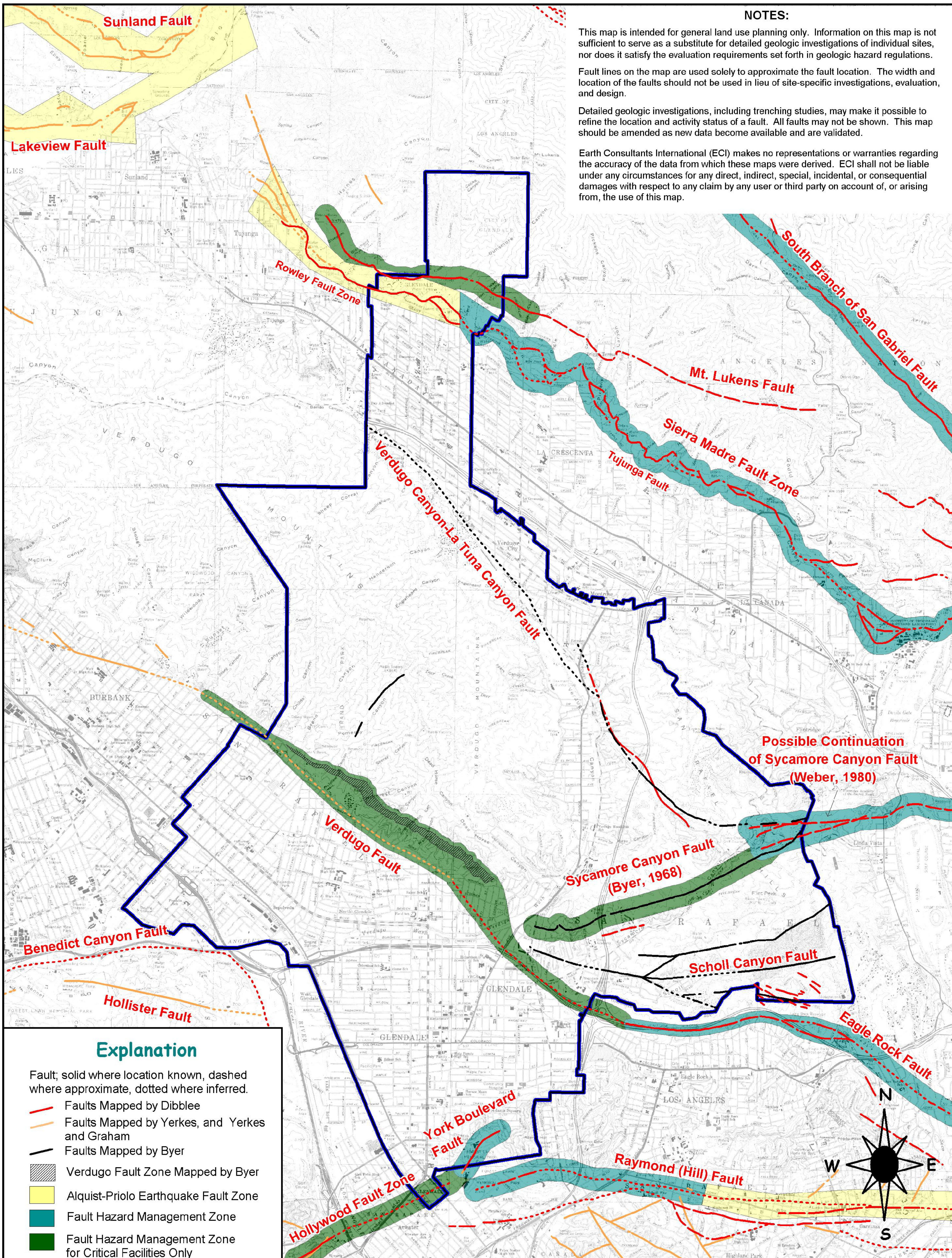

Scale: 1:60,000

1000 0 1000 2000 3000 Meters

5000 0 5000 10000 15000 Feet

Glendale City Limit

Base Map: USGS Topographic Map from Sure!MAPS RASTER
Sources: Weber, 1980; Dibblee, 1989a, 1989b, 1991a, 1991b, 2002; Rubin, 1992; Yerkes, 1997; Yerkes and Graham, 1997; Byer, 1968.

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Fault Map

Glendale, California

Plate 1-2

the town of Tujunga, it consists of at least three fault planes in a zone of brecciated granodiorite that is thrust over very coarse conglomerate and basalt flows. In Glendale, the Rowley fault has been mapped as a single strand that bifurcates at its eastern end, near Ward Canyon (see Plate 1-2). The fault has been well located as evidenced by a single solid line on the map. Farther to the east, the fault is not as well defined and is therefore not currently zoned under the Alquist-Priolo Act criteria.

Geologic studies conducted soon after the 1971 earthquake suggested that the last rupture on the San Fernando segment of the Sierra Madre fault prior to 1971 had occurred less than 200 years before (Bonilla, 1973). However, a more recent trenching study in the immediate vicinity of Bonilla's trench suggests that this fault has only broken twice in the last 3,500 to 4,000 years, including the 1971 rupture (Fumal et al., 1995), which suggests this fault has a recurrence interval of about 2,000 years rather than 200 years. Nevertheless, the San Fernando segment appears to be more active than other segments of the Sierra Madre fault, as first suggested by Crook et al. (1987), who proposed that the rest of the fault zone has not moved in many thousands of years, possibly since before the Holocene. Relatively recent trenching studies by Rubin et al. (1998) in Altadena, approximately 6 miles to the southeast of Glendale, have shown that the segment of the Sierra Madre fault through Altadena, and possibly through Glendale, has a long recurrence interval, but that it has moved in the Holocene and is therefore active. The segment of fault that Rubin et al. (1998) trenched has ruptured the ground surface twice in the last about 15,000 years, with the most recent earthquake having occurred probably 8,000 to 9,000 years ago. Other studies farther to the southeast, at Horsethief Canyon in the San Dimas area, also showed that this section of the Sierra Madre fault has not broken in the last 8,000 years, but that the fault has slipped as much as 46 feet (14 m) between 8,000 and 24,000 years ago (Tucker and Dolan, 2001). These two studies suggest that the central segments of the Sierra Madre fault, between the San Fernando segment on the north and the Cucamonga fault on the south, ruptures at the same time in infrequent but large magnitude (M>7) events.

Based on the data presented above, the section of the Rowley fault not currently zoned by the State should nevertheless be considered active. A fault hazard management zone that includes and extends beyond the inferred traces of the fault is proposed, as shown on Plate 1-2. Geologic studies similar in scope to those required by the CGS in Alquist-Priolo Earthquake Fault Zones should be conducted if new development or redevelopment is proposed in the fault hazard management zone. As detailed geological investigations are conducted, the location and activity status (some of the splays may be proven to have not moved within the last 11,000 years) of the faults shown on Plate 1-2 may be refined or modified. The map should be amended as new data become available and are validated.

The **Mt. Lukens fault** is a west- to northwest-trending thrust fault that extends across the south flank of the San Gabriel Mountains, between Haynes Canyon on the northwest, and the Los Angeles Crest Highway on the southeast. In the Glendale area, the fault is mapped about 1,500 feet to the north of the Sierra Madre fault. Because of its closeness to the Sierra Madre fault, Smith (1978) previously mapped this fault as part of the Sierra Madre fault system. The fault was mapped more recently by Crook et al. (1987), and Dibblee (1991a, 1991b, 2002). Although the Mt. Lukens thrust fault appears to be a separate fault system, in the Glendale area this fault is so close to the Sierra Madre fault that if the Sierra Madre fault ruptured, it could trigger co-seismic movement on the Mt. Lukens thrust fault. Therefore, a fault hazard management zone for critical facilities is herein proposed for the Mt. Lukens fault.

The **Verdugo Canyon – La Tuna Canyon fault** is oriented in a northwesterly direction through Glendale, where it inferred at the base of the northeast flank of the Verdugo Mountains, but changes to a more westerly orientation in the La Tuna Canyon, where the fault reportedly controls the location of the drainage. This fault was proposed by geologists from the Metropolitan Water District (as mentioned in Envicom, 1975), who indicated that the fault is north-dipping in the La Tuna Canyon, and south-dipping farther east. The fault was also inferred under the Verdugo Wash, where a deep, northwest-trending depression in the basement rocks has been reported (California State Water Rights Board, 1962 as discussed in Envicom, 1975). The sections of the fault described above are not recognized by Dibblee (1991a, 1991b) in his geologic maps of the area, but farther to the east, in the San Rafael Hills, Dibblee maps a fault that is consistent with Byer's (1968) mapping. Farther to the east, the fault appears to swing to the east, where it may join the Sycamore Canyon fault (see Plate 1-2). There are no data available to suggest that this fault is active; Envicom (1975) indicate that the fault is not a barrier to groundwater flow in the Verdugo Wash area, and should therefore be considered inactive.

The **Sycamore Canyon fault** zone consists of a series of discontinuous faults that trend northeasterly in the vicinity of Sycamore Canyon, in the western part of the San Rafael Hills. Byer (1968) extended this fault zone westward across and along the north side of Sycamore Canyon, but more recent geologic maps of the area (Dibblee, 1989b) do not show this trace (see Plate 1-2). Although the presence of sheared clays along a portion of the fault, in the eastern San Rafael Hills, has contributed to some slope instability problems, Weber (1980) reported that no evidence that the fault zone is active has been found. Weber (1980) also suggested that topographic lineaments observed in the northeastern San Rafael Hills (within Pasadena) might be an extension of the Sycamore Canyon fault. This connection has not been proven out by field evidence. However, Weber's (1980) lineaments coincide with lineaments in the younger alluvial fan deposits in the Pasadena area mapped by Rubin (1992) that may be the surface expression of the most recently active traces of the Sierra Madre fault. Therefore, in the Pasadena area, the Sycamore Canyon fault has been zoned, with geological studies required in this zone if the proposed development is a critical facility. A similar approach is recommended for the southwest-trending section of the Sycamore Canyon fault that extends through the San Rafael Hills in the Glendale area. Even if the fault is not active, the sheared clays that have been reported along the fault zone may be highly expansive. If a structure is built across the surface trace of these clays, and these clays swell when wetted, the structure could experience some structural damage (see Section 2.4.3). Engineered mitigation measures such as deep removals along the clay zone and replacement with non-expansive materials may be warranted.

The **Verdugo fault** strikes southeasterly across the southern edge of the Verdugo Mountains, through the central portion of Glendale, and across the foot of the San Rafael Hills, where it seems to merge with the Eagle Rock fault. The Verdugo fault separates the plutonic and metamorphic rocks that crop out in the Verdugo Mountains from the alluvial fan deposits to the southwest. The fault is probably coincident with the sharp break in slope along the southwestern edge of the Verdudo Mountains, where many of the alluvial fans that emanate from the mountains merge together to form the gently southwest-facing alluvial surface between the mountains and the Los Angeles River. In older aerial photographs of the area, Dolan and Tucker (1999) interpreted several small scarps that could represent the last surface rupturing event on this fault, but these scarps have all been obliterated by development. In fact, the inferred trace of the Verdugo fault is covered with buildings and roads along almost its entire length, which makes it difficult to find suitable field study areas where the fault can be exposed and studied.

To date, there has been only one study in Glendale that attempted to locate and date the most recent surface rupturing events on this fault. This study, conducted in Brand Park (Dolan and Tucker, 1999) may have constrained the location of the fault zone in the area, but the actual fault trace could not be identified due to the discontinuous nature of the alluvial fan deposits that they encountered, and because the trench excavated was too unstable to be entered safely. Dolan and Tucker (1999) proposed that the trace of the Verdugo fault in this area is approximately 300 feet (90 m) farther to the north of where it is inferred by Dibblee (1991), extending in a southeasterly direction through the area between the Tea House and the Dr.'s House at Brand Park. Unfortunately, Dolan and Tucker (1999) could not confirm the fault location elsewhere due to landscaping and previous ground surface modifications at the park (for parking lots and playing fields) that precluded the possibility of excavating another trench.

Previous investigators (Byer, 1968) also identified a wide zone of faulting farther to the north that consists of laterally discontinuous fault planes that generally dip to the northeast. Locally, they observed minor shearing of the terrace deposits, which suggested to them relatively youthful movement on the fault. This zone of faulting is identified in Plate 1-2 with cross-hatchures. This zone of faulting may not be the most recent fault trace, but there are insufficient data to determine whether or not these faults are active. Therefore, this fault zone should be investigated in the future if development is proposed in the area..

Although the most recently active traces of the Verdugo fault are not well located, most investigators agree that the Verdugo fault is active and therefore has the potential to generate future surface-rupturing earthquakes. Earlier investigators suggested that this fault is primarily a thrust fault, responsible for uplift of the Verdugo Mountains (R.T. Frankian & Associates, 1968; Weber et al., 1980; Weber, 1980), but more recently, it is thought that the fault displays primarily left-lateral strike-slip movement (Walls et al., 1998; Dolan, personal communication, 2002). A fault hazard management zone that includes the inferred trace of the fault as mapped by Dibblee (1991), but is wider to the north, to include the break in slope and the zone of faulting mapped by Byer (1968) is proposed. As with the fault hazard management zone for the Rowley fault, geological studies should be conducted for sites within the Verdugo fault hazard management zone if new development or significant redevelopment is proposed.

The **Eagle Rock fault** crosses the southwestern part of Pasadena and the northernmost portion of Los Angeles, including along a 2-mile stretch of the Ventura (134) Freeway, where it separates crystalline bedrock on the north from sedimentary rock on the south (see Plates 1-2 and 2-1). The portion of the Eagle Rock fault east of the San Rafael Hills was originally termed the "San Rafael fault" by Weber (1980), who suggested the fault was active in late Quaternary time. This conclusion was based on the presence of linear topographic features across the Pleistocene alluvial fan surface east of the San Rafael Hills. Farther to the southeast, the fault appears to join the Raymond fault, however the exact location of the eastern terminus of the Eagle Rock fault is not well defined, and its geomorphology in this area is much more subdued than that of the Raymond fault. Consequently, Weaver and Dolan (2000) concluded that a connection with the Raymond fault could not be established with certainty. To the west, the Eagle Rock fault lies on trend with the Verdugo fault, although in the subsurface, based on gravity data, Weber (1980) suggests that there may be a step or bend between the two fault zones. Although very little is known about the Eagle Rock fault, given that it appears to be related to active faults in the area, such as the Verdugo fault, it should be considered potentially active, subject to further study. For example, although the Eagle Rock fault may not be capable of generating an earthquake, it may break co-seismically with movement on the Verdugo fault. A fault hazard management zone for this fault has been recommended in the Pasadena area, similar to that for the Sierra Madre and Verdugo faults (Plate 1-2). Extension of this zone between Pasadena and Glendale is recommended, but the limits of this zone are predominantly outside the City of Glendale.

The **Scholl Canyon faults** were mapped by Byer (1968), and Envicom (1975) suggested that this fault zone connects the Verdugo fault in the west to the Eagle Rock fault in the east. However, more recent mapping by Dibblee (1989b) does not even show these faults, and there are no data data available to indicate that these fault traces, if even present, are active.

The **York Boulevard fault** is a short, northeast trending fault first mapped by Lamar (1970), and more recently by Dibblee (1989a, 1989b) in the Adams Hill area of southern Glendale. According to Lamar (1970) the fault does not offset older, Pleistocene-age deposits, and is therefore not active. However, the York Boulevard fault does appear to separate the Raymond fault from the Hollywood fault, in an area where according to Weber (1980) there is step or bend in the fault zones at depth. Alternatively, the York Boulevard fault may be the eastern extension of the Hollywood fault. Based on these relationships, and given that both the Raymond and Hollywood faults are active, Envicom (1975) suggested that the York Boulevard fault may be active also. Given its length, the York Boulevard fault is not likely to generate an earthquake, but it may move co-seismically with an earthquake on the Hollywood fault. Therefore, a hazard management zone for this fault is proposed, where geological studies to locate and characterize the fault would be required prior to development of a critical facility.

The eastern terminus of the **Hollywood fault** has been mapped along the southwesternmost corner of the City of Glendale (see Plate 1-2). This fault has been shown to be active in the Los Angeles and West Hollywood areas, where recently obtained data indicate that this fault breaks in infrequent, but large magnitude earthquakes. In the West Hollywood area, the inferred location of the fault along Sunset Boulevard has been proven to be incorrect; the fault is farther south, in the valley. However, in the Los Angeles area, the fault does appear to be at the mountain front. The fault has been well located in the Hollywood Hills, just to the west of Glendale, by Yerkes (1967) and Dibblee (1991b), but as it extends across the Los Angeles River and into the Glendale area, its location is less well defined. Given that this fault is considered active, the inferred location of the fault in Glendale is herein included in a fault hazard management zone. Because of its location in the floodplain of the Los Angeles River, where shallow ground water and deep Holocene sediments are anticipated, geologic studies to locate this fault may prove to be difficult and expensive, requiring the use of deep boreholes rather than trenching.

A few other minor, **unnamed faults** have been mapped both in the San Rafael Hills and in the Verdugo Mountains (see Plate 1-2). These faults appear to be confined to the older bedrock units, with no impact on the younger terrace and alluvial deposits, and are therefore not considered active. Fault hazard management zones for these faults are not considered warranted, however, geologists studying these areas should continue to look for evidence of Holocene movement on these faults. As new data are developed and verified by third-party reviewers, Plate 1-2 should be amended to reflect any changes in the location, recency of activity and need for future studies on these faults.