EXERCISE 7

The Loma Prieta Earthquake of 1989

INTRODUCTION

As many people prepared to watch World Series baseball on October 17, 1989, the earth in the San Francisco Bay region shook from a major earthquake. The U.S. Geological Survey has named this earthquake after the small community of Loma Prieta near the epicenter. Although San Francisco and Oakland received the most media coverage for their damage, it is important to note that these large communities were about 100 km away from the epicenter. Closer communities, such as Watsonville and Santa Cruz, also suffered great damage and fatalities in the earthquake. This exercise looks at the regional geology of the San Andreas Fault and the geology of areas in San Francisco and Oakland that were damaged.

Damage that results from an earthquake is a result of many factors. Among these are

1. The geologic nature of the earthquake and the rocks between the focus and a site

  a. the type of fault movement: different earthquakes generate different frequencies

  b. the size of the earthquake: larger earthquakes will release more energy, and therefore cause more acceleration and have longer duration

  c. the distance from the source of the earthquake to a site: in general, sites closer to the focus fare worse

  d. characteristics of the rocks through which the seismic waves travel from the source to the site: some rocks transmit seismic energy better than others

2. The types and properties of the materials at the site determine the ground motions at the site

  a. soil thickness: shallow soils may not perform as well as deep, well-consolidated soils

  b. soil saturation: saturated soils will typically perform less well than dry soils

  c. soil grain size and sorting: well-sorted, fine-grained sands and coarse silts that are geologically young have the highest potential to liquefy (flow) if saturated; soils that liquify lose their ability to hold up structures such as buildings and bridges

  d. types and properties of the bedrock at the site: unweathered igneous and other massive rocks typically perform better than weak and fractured or jointed rocks

3. The nature of the building

  a. architectural simplicity of the building: seismic response of simple buildings is easier to predict and control than the response of complex buildings

  b. size and use of the building: a single family home will behave differently than a large commercial or industrial building

  c. type of construction: small wood structures will typically flex more and therefore perform better in earthquakes than brick or concrete block buildings

  d. type of seismic design considerations: is the building new or old, is it built to appropriate seismic standards or not?

The emphasis in this exercise is on the geology of the earthquake and the geologic reasons for building failures in different areas. The actual damage that occurred to specific buildings and other structures is not covered.

This exercise is divided into several parts. We first explore the nature of the San Andreas Fault, general seismic activity in the area, the specific sequence of Loma Prieta earthquakes, and seismic attenuation in this area. We will investigate the geology and hazards in the San Francisco Bay region in general, and focus in particular on the Marina district.

PART A. THE GEOLOGY AND SEISMIC ATTENUATION OF THE LOMA PRIETA EARTHQUAKE

Geology (7, Part A1)

Figure 7.1 shows and names many of the major faults in this area. Figure 7.2 shows the distribution of earthquakes along the San Andreas Fault before and immediately after the Loma Prieta earthquake. Figure 7.3 shows the distribution of the aftershocks of the Loma Prieta earthquake in map view and cross section. Use these figures to answer the following questions.

QUESTIONS (7, PART A1)

1. a. Describe the geographic orientation (compass direction) of the faults shown in Figure 7.1.

b. What is the large-scale geological process that is occurring in this part of California that accounts for fault orientation and motion?

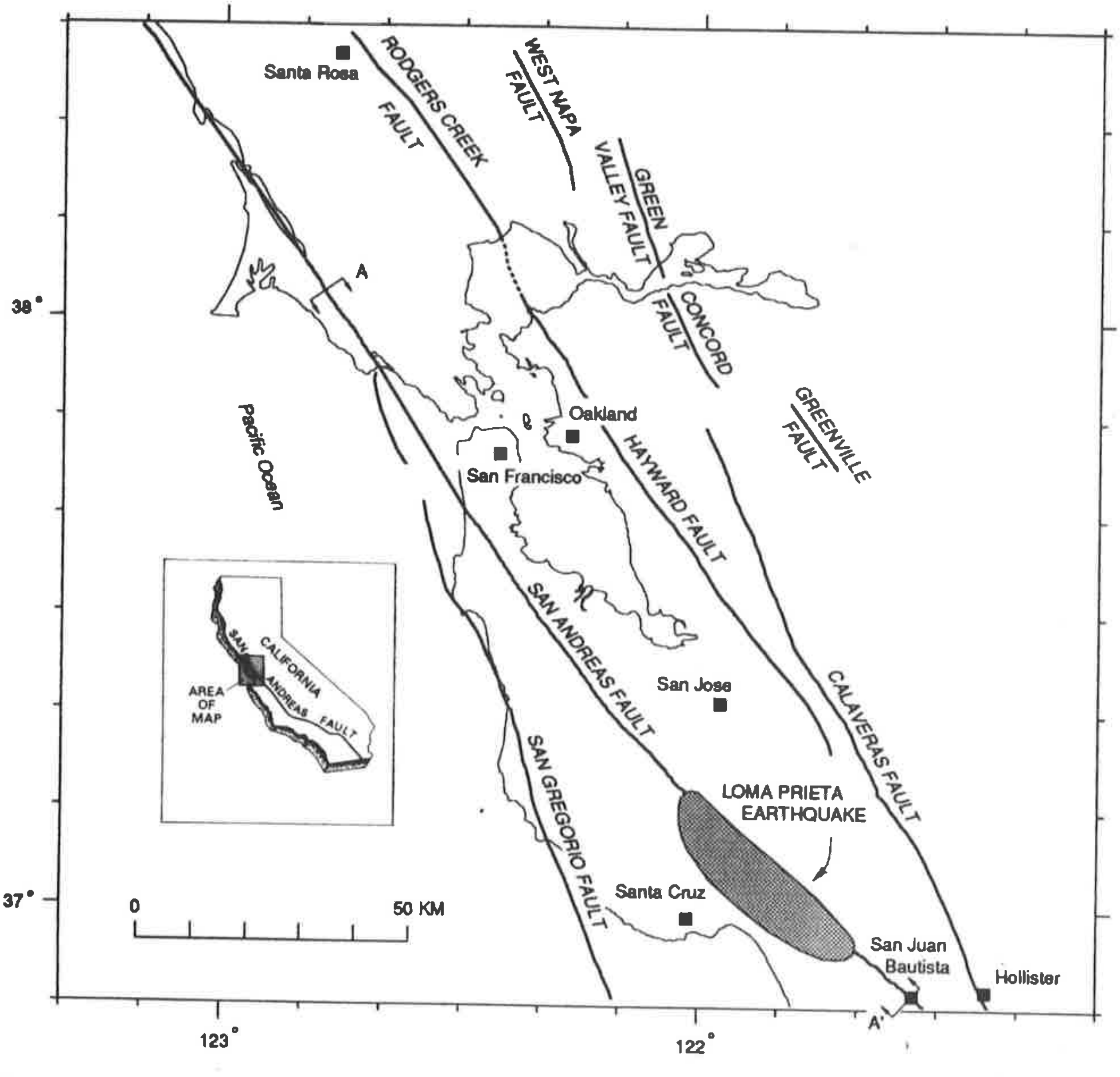

FIGURE 7.1 Major faults in the area of the Loma Prieta earthquake (Working Group, 1990).

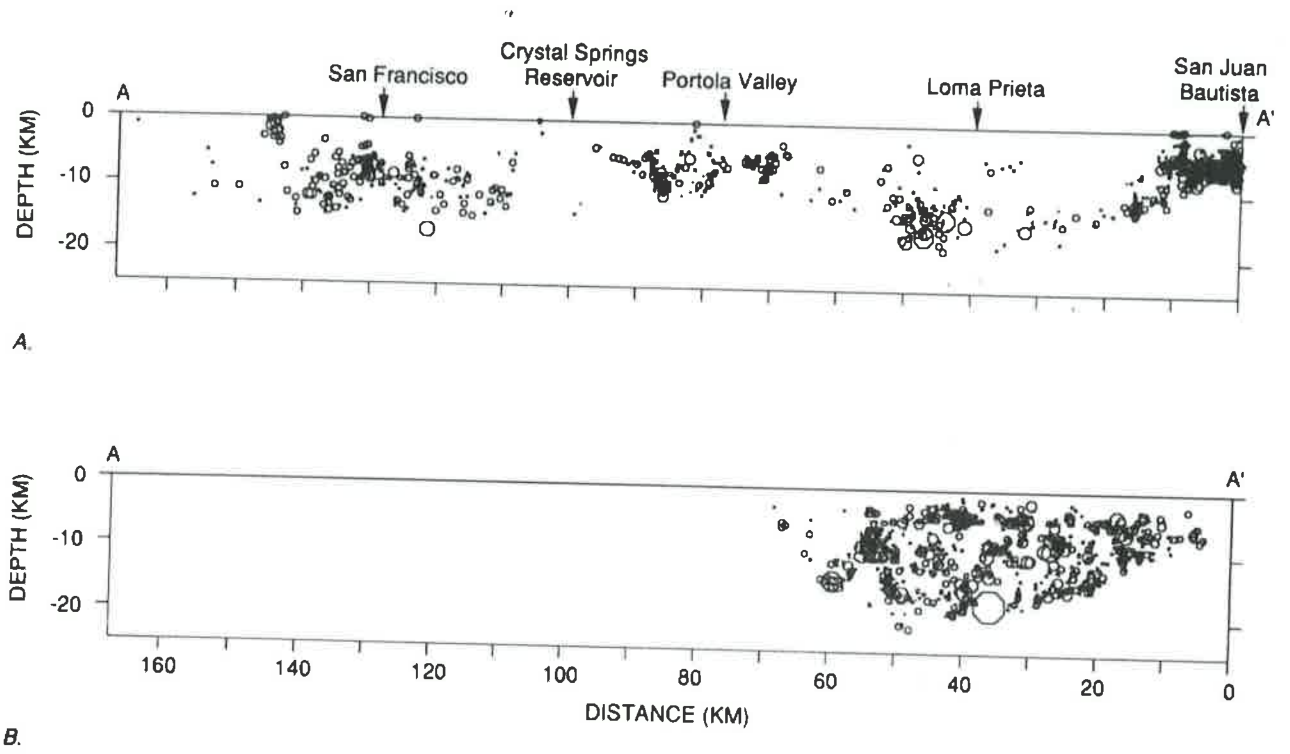

FIGURE 7.2 (a) Seismicity (1969–89) before the Loma Prieta earthquake along the San Andreas Fault. See Figure 7.1 for A-A'; size of symbols increases with increasing magnitude. (b) The Loma Prieta earthquake and its aftershocks (Working Group, 1990).

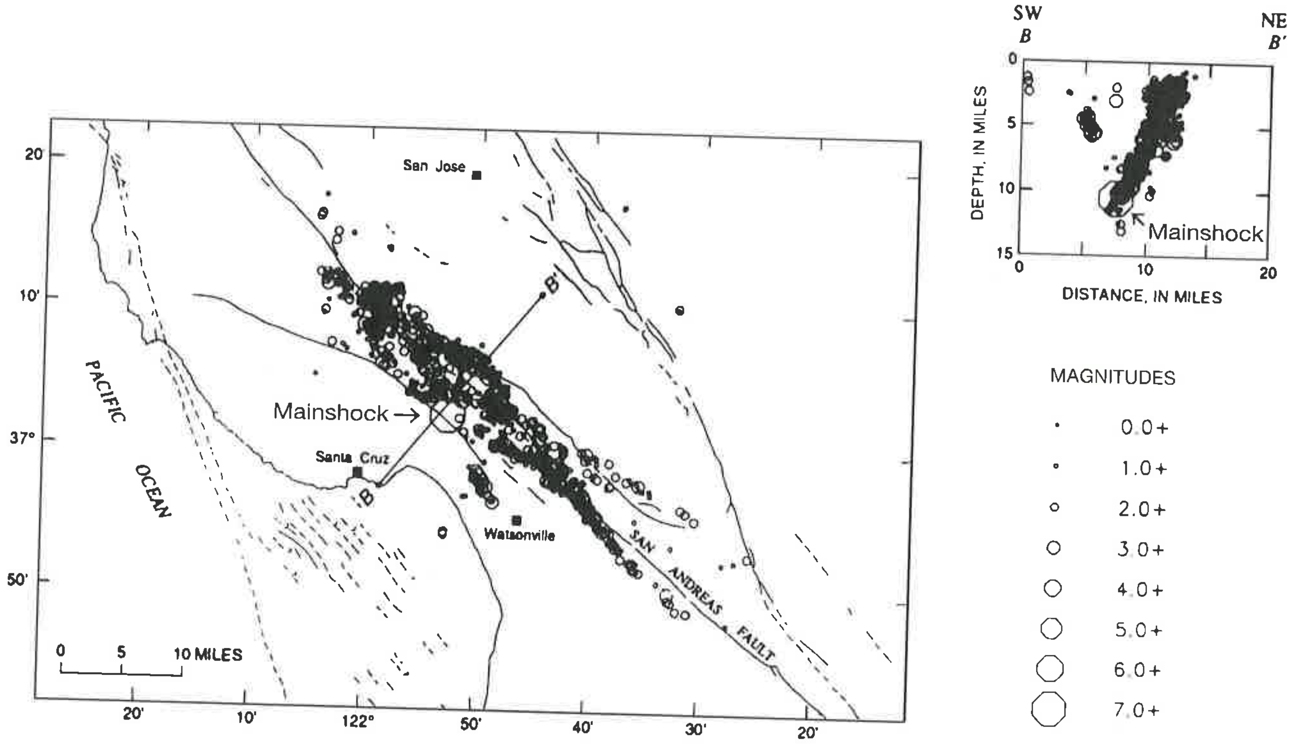

FIGURE 7.3 Map and cross-section (B-B') views of the distribution of earthquakes related to the Loma Prieta earthquake. Solid and dashed lines represent faults (except coast) (Pflaker and Galloway, 1989).

2. One theory for the prediction of earthquakes suggests that new events will fill in gaps where earthquakes have not been recently recorded. The gaps are presumed to be zones where stress is accumulating, which will be released in a future earthquake. In areas along faults with frequent earthquakes, stress is released in each event.

a. Describe the differences in locations of epicenters for earthquakes that occurred before the Loma Prieta earthquake (Figure 7.2a) and the main shock and aftershocks (Figure 7.2b and shaded zone in Figure 7.1).

b. Do the Loma Prieta earthquake and its aftershocks fit the pattern of new events filling gaps? Explain.

3. Figure 7.3 shows a map and an insert with a cross-section view along line B-B′; of the Loma Prieta earthquake and its aftershocks.

a. Looking at the map view, would you infer that all of the earthquakes occurred along the San Andreas Fault?

b. Compare the map view with the cross-section view. What would you infer from the cross-section view about the number of faults?

c. What is the evidence for your inferences?

Seismic Attenuation and Acceleration (7, Part A2)

Attenuation is the decrease in the amplitude of seismic waves as distance from the source increases. In general, there is a geometric decrease in amplitude with distance. Selected conditions, however, tend to cause local variations in amplitude such that sites distant from the epicenter will show an amplification of ground motion.

Seismologists use sophisticated instruments to measure many different components of the earthquake waves that travel within and along the surface of the Earth. These components include acceleration, velocity, and total displacement at a site. For example, in automobiles acceleration is how fast the vehicle starts from a stop (the faster it starts, the more you are pushed back in your seat), velocity is how fast it is going (has it reached 25 mph?), and displacement is how far it has gone (has it moved a mile?). These are practical measurements for an earthquake because the damage a building sustains can be related to how quickly it is hit by the shock waves, how fast it moves, or how far it moves.

Accelerographs, which measure acceleration of the ground, record data that is typically presented as a percentage of the force of gravity (g). Buildings are designed to withstand the vertical force of gravity (1 g = 980 cm/sec/sec); that is, they are designed to stand up under gravitational forces. They are not, however, necessarily designed to be moved sideways, and earthquakes generate strong sideways forces against a building.

Figure 7.4 is a map showing the horizontal acceleration from the Loma Prieta earthquake as recorded at many sites in western California.

QUESTIONS (7, PART A2)

1. Describe the general relationship between the recorded acceleration at different sites and the epicentral area, which is indicated by shading.

2. a. Draw a contour line around the sites with 20% g in Figure 7.4. 20% g is a value for moderate damage.

b. What is the general shape of the contour?

c. How does its shape compare with the orientation of the faults that are shown in Figure 7.1?

3. What geological factors contribute to the difficulties in drawing the irregular 20% g isoseismal line?

4. From the data presented in Figure 7.4, summarize the role of distance from the epicenter in attenuating earthquake waves.

5. Compare the data shown in Figure 7.5, which is an isoseismal map showing areas of similar damage to structures as measured by the Modified Mercalli Intensity scale, with the acceleration numbers shown in Figure 7.4. Describe the correlation between acceleration and seismic impacts as recorded on the Mercalli scale.

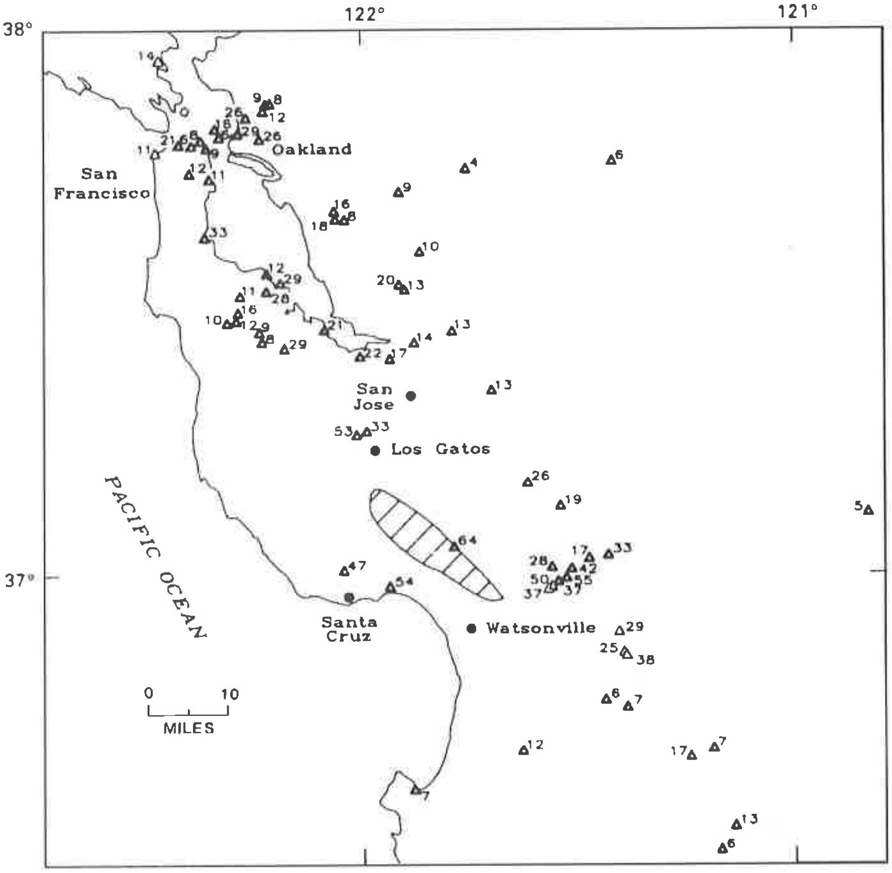

FIGURE 7.4 Horizontal acceleration as a percent of gravity (980 cm/sec/sec) at measured sites for the Loma Prieta earthquake. The lined region is the epicentral area (Pflaker and Galloway, 1989).

PART B. GEOLOGY AND SEISMIC IMPACTS: SAN FRANCISCO BAY AND MARINA DISTRICT

San Francisco Bay Region (7, Part B1)

Figures 7.6 (geologic map), 7.7 (maximum predicted intensity), and 7.8 (1906 apparent intensity) show different factors of the geology and the expected and actual impacts of earthquakes in the San Francisco Bay region. The regional setting for these maps is shown on Figure 2.17, the satellite image on the back cover of this book.

QUESTIONS (7, PART B1)

Read and compare the maps in Figures 7.6, 7.7, and 7.8 to answer the following questions.

1. a. What two geologic units in San Francisco and Oakland have the maximum predicted intensities for earthquakes?

b. What are the geologic conditions that have lead these areas to have high predicted maximum intensities?

2. Compare Figure 7.6 with Figure 7.8.

a. What geologic conditions (materials and setting) led to the maximum intensities during the 1906 earthquake?

b. What geologic conditions led to the minimum intensities during the 1906 earthquake?

3. a. Using data from all three maps, determine typical geologic conditions that are likely to create areas with maximum seismic impacts. Explain these conditions below.

b. Using data from all three maps, determine typical geologic conditions that are likely to create areas with minimum seismic impacts. Explain these conditions below.

The Marina District (7, Part B2)

Impressive photographs and videos were made of damage from the Loma Prieta earthquake in the Marina District in northern San Francisco. This was an area of extensive collapsed and damaged buildings

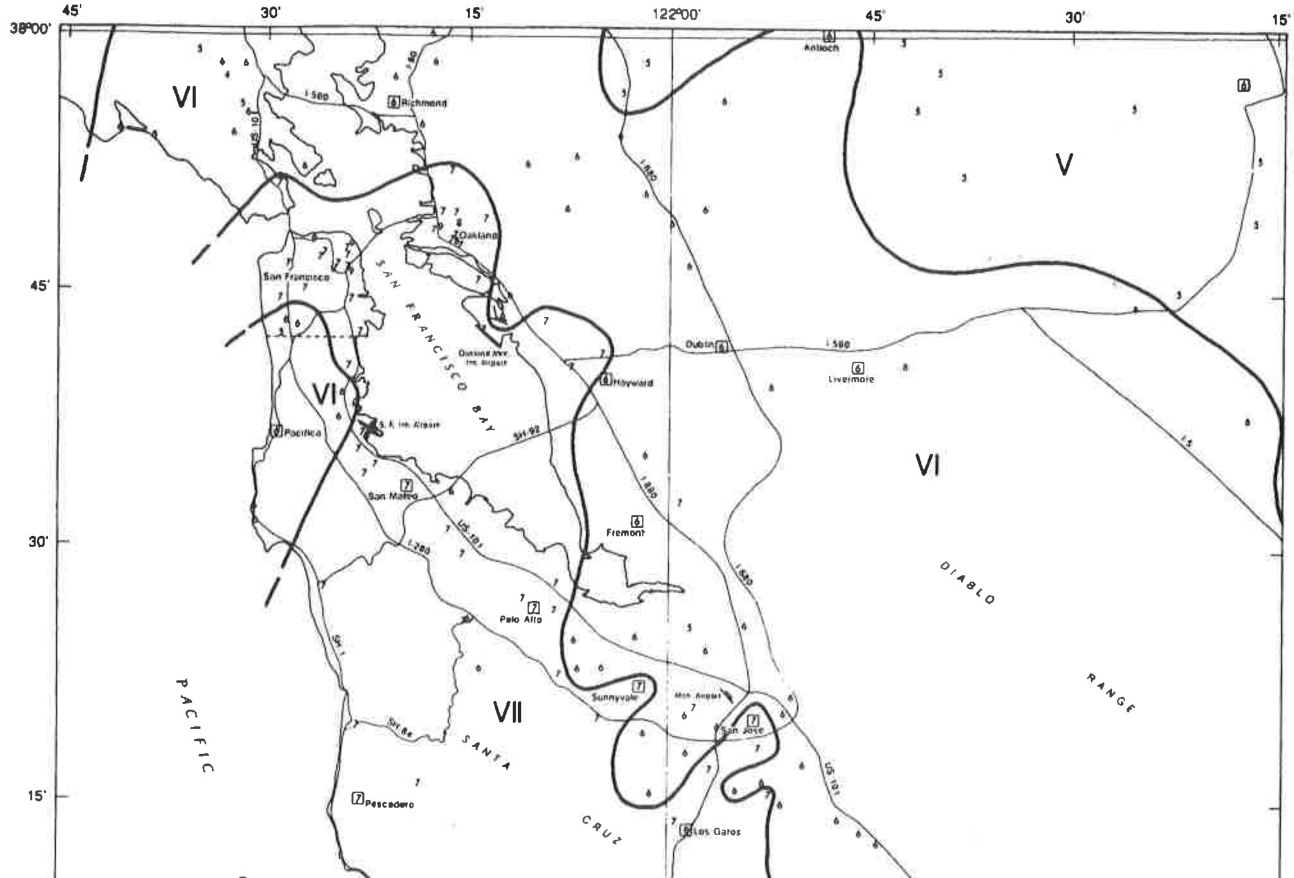

FIGURE 7.5 Isoseismal map of impacts from the Loma Prieta earthquake (Stover et al., 1990).

and dramatic fires. Although much of the problem with building collapse in this area was due to the structural style of the buildings, local geology also played an important role.

Figure 7.9 is a map of the Marina District, showing in detail the dates when artificial fill was placed in San Francisco Bay (this area is shown only as Qm on the larger geologic map and is located just west of Fort Mason; see map labels). Use this figure, and Figures 7.10 (types of fills) and 7.11 (location of sand boils) to answer the following questions. Figure 7.12 shows changes in seismic response at three temporary seismograph stations. You may also wish to refer to earlier figures in this exercise.

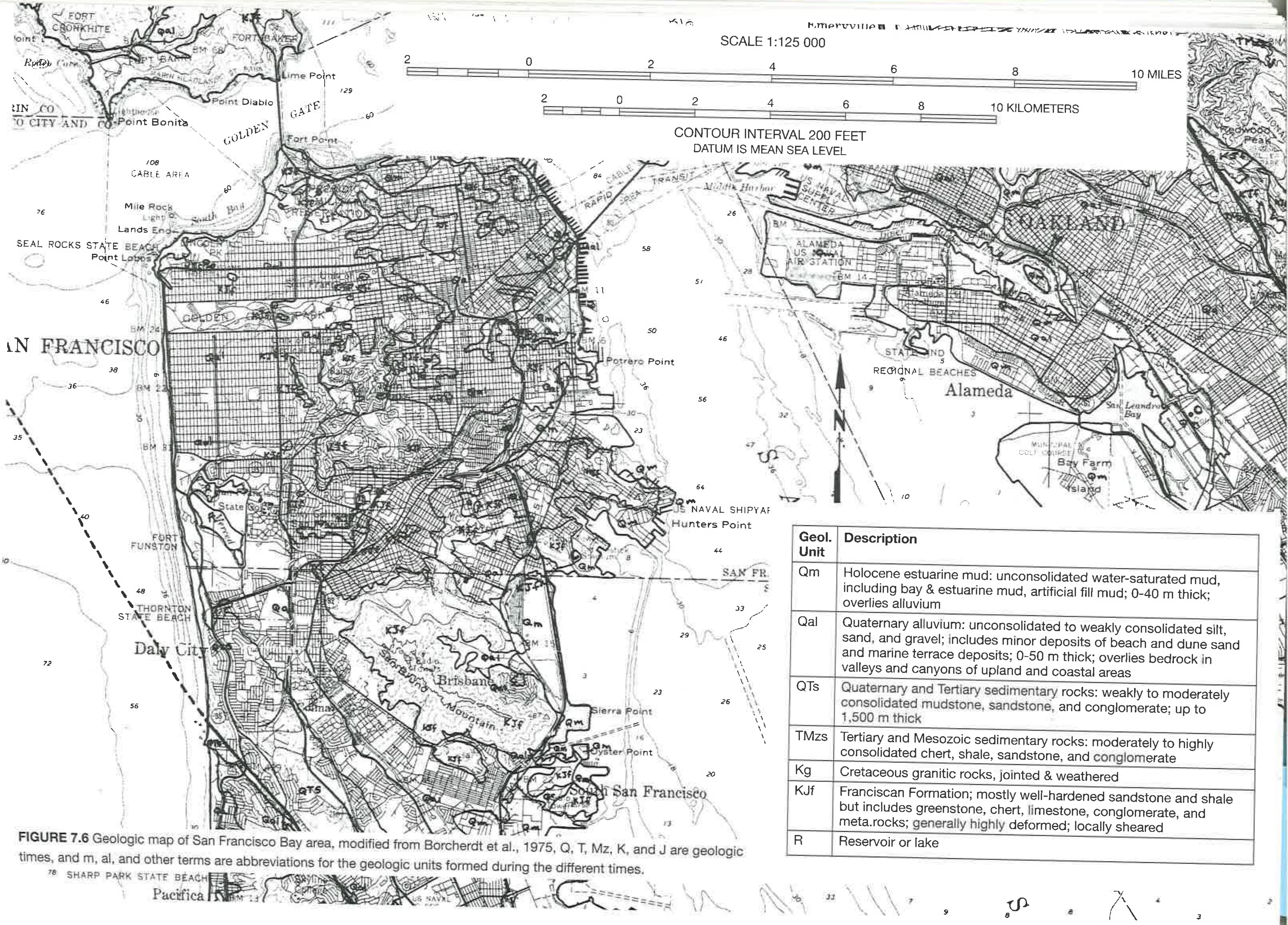

FIGURE 7.6 Geologic map of San Francisco Bay area, modified from Borcherdt et al., 1975, Q, T, Mz, K, and J are geologic times, and m, al, and other terms are abbreviations for the geologic units formed during the different times.

Geol. Unit	Description
Qm	Holocene estuarine mud: unconsolidated water-saturated mud, including bay & estuarine mud, artificial fill mud; 0-40 m thick; overlies alluvium
Qal	Quaternary alluvium: unconsolidated to weakly consolidated silt, sand, and gravel; includes minor deposits of beach and dune sand and marine terrace deposits; 0-50 m thick; overlies bedrock in valleys and canyons of upland and coastal areas
QTs	Quaternary and Tertiary sedimentary rocks: weakly to moderately consolidated mudstone, sandstone, and conglomerate; up to 1,500 m thick
TMzs	Tertiary and Mesozoic sedimentary rocks: moderately to highly consolidated chert, shale, sandstone, and conglomerate
Kg	Cretaceous granitic rocks, jointed & weathered
KJf	Franciscan Formation; mostly well-hardened sandstone and shale but includes greenstone, chert, limestone, conglomerate, and meta.rocks; generally highly deformed; locally sheared
R	Reservoir or lake

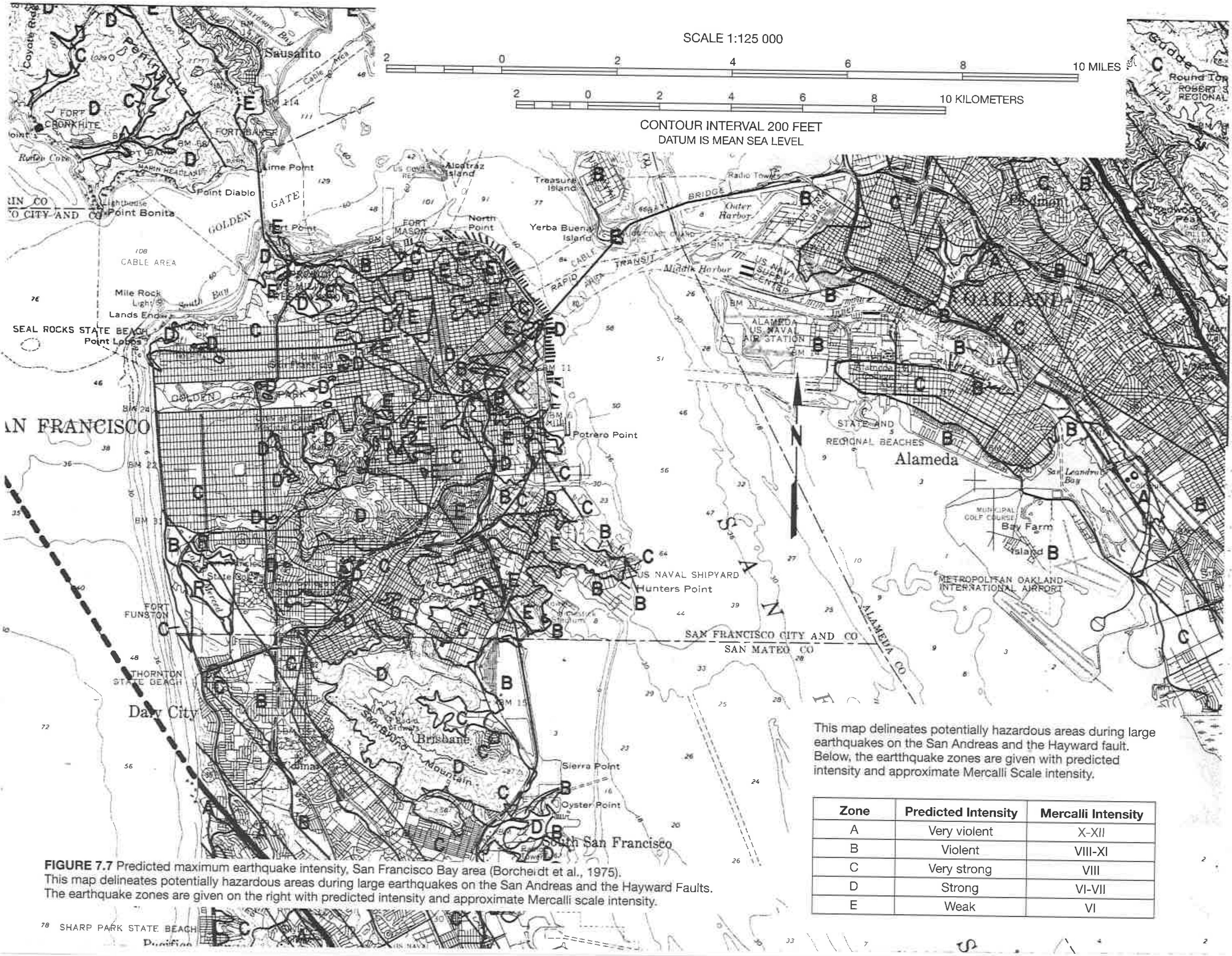

FIGURE 7.7 Predicted maximum earthquake intensity, San Francisco Bay area (Borcheidt et al., 1975). This map delineates potentially hazardous areas during large earthquakes on the San Andreas and the Hayward Faults. The earthquake zones are given on the right with predicted intensity and approximate Mercalli scale intensity.

This map delineates potentially hazardous areas during large earthquakes on the San Andreas and the Hayward fault. Below, the eartthquake zones are given with predicted intensity and approximate Mercalli Scale intensity.

Zone	Predicted Intensity	Mercalli Intensity
A	Very violent	X-XII
B	Violent	VIII-XI
C	Very strong	VIII
D	Strong	VI-VII
E	Weak	VI

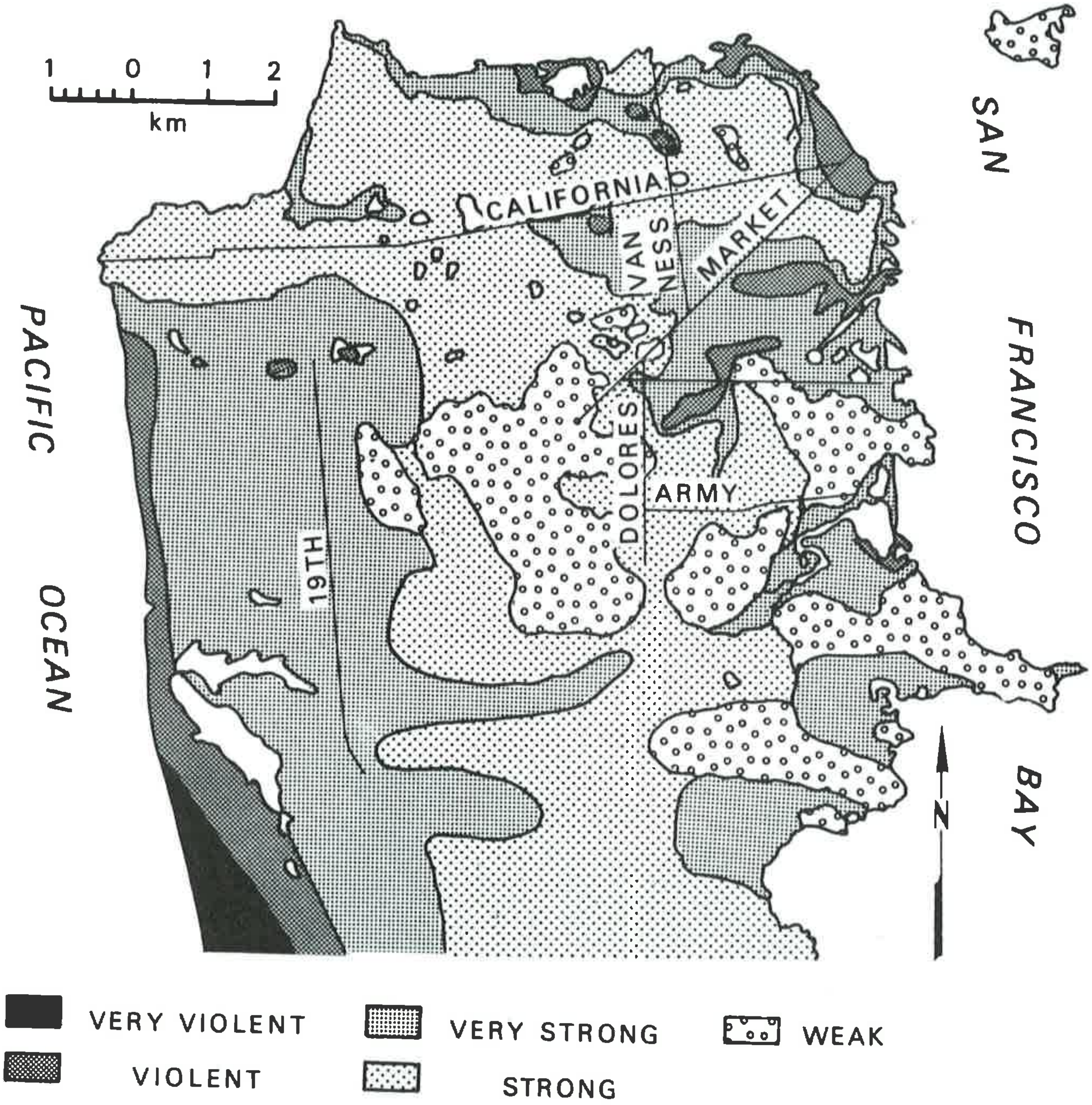

FIGURE 7.8 Apparent intensities of the 1906 San Francisco earthquake.
(After Wood, 1908; in Borcherdt et al., 1975)

QUESTIONS (7, PART B2)

1. What are the ages of fills in the Marina District (Figure 7.9)? Was any fill emplaced in the last 50 years? How well engineered for seismic response do you think the fill is? Explain your answer.

2. a. What is the relationship between the age and kinds of fills?

b. How do you interpret the term *hydraulic?*

c. What is the natural coastal landform that existed at "A" (Figure 7.9) prior to 1912?

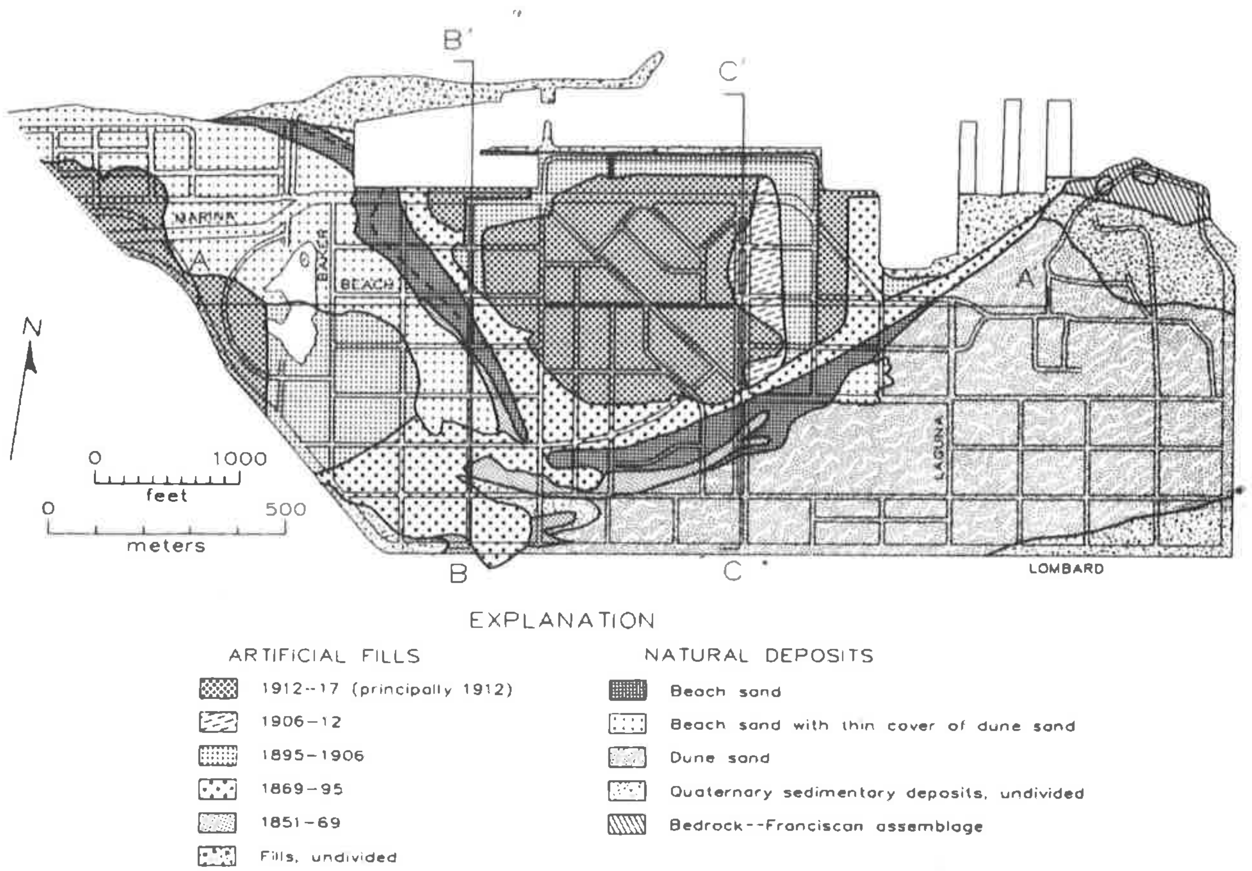

FIGURE 7.9 Dates of artificial fills and types of natural deposits, Marina District, San Francisco (Bonilla, 1992).

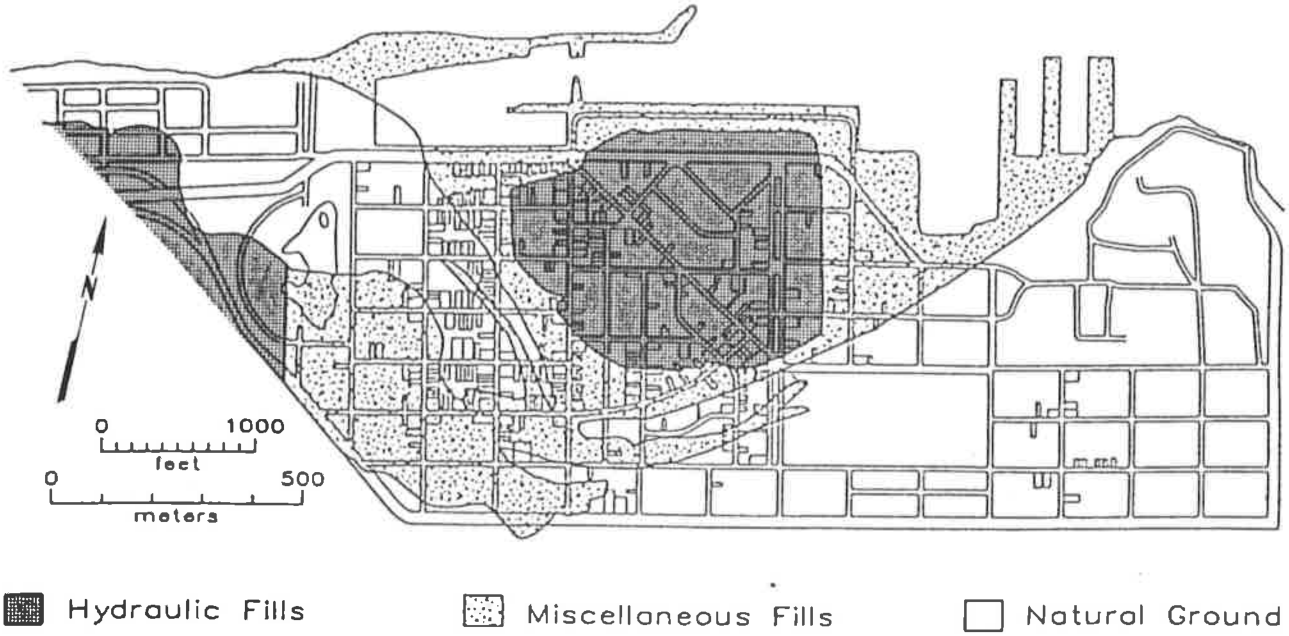

FIGURE 7.10 Types of artificial fills, Marina District, San Francisco (Seekings et al., 1990).

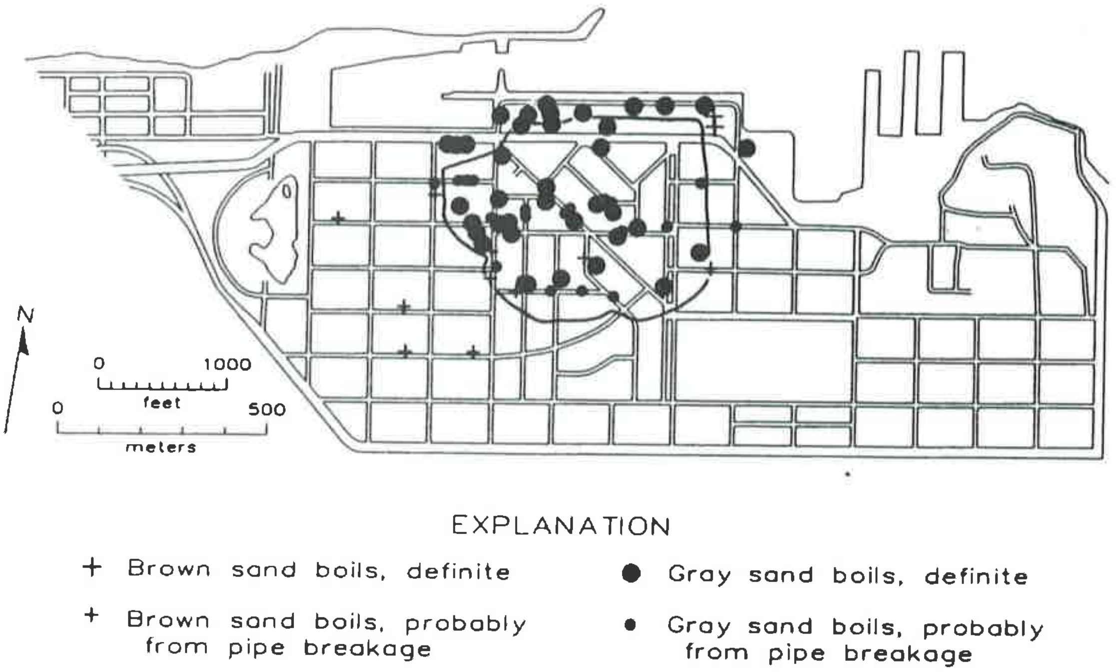

FIGURE 7.11 Locations of sand boils, Marina District, San Francisco (Bennett, 1990).

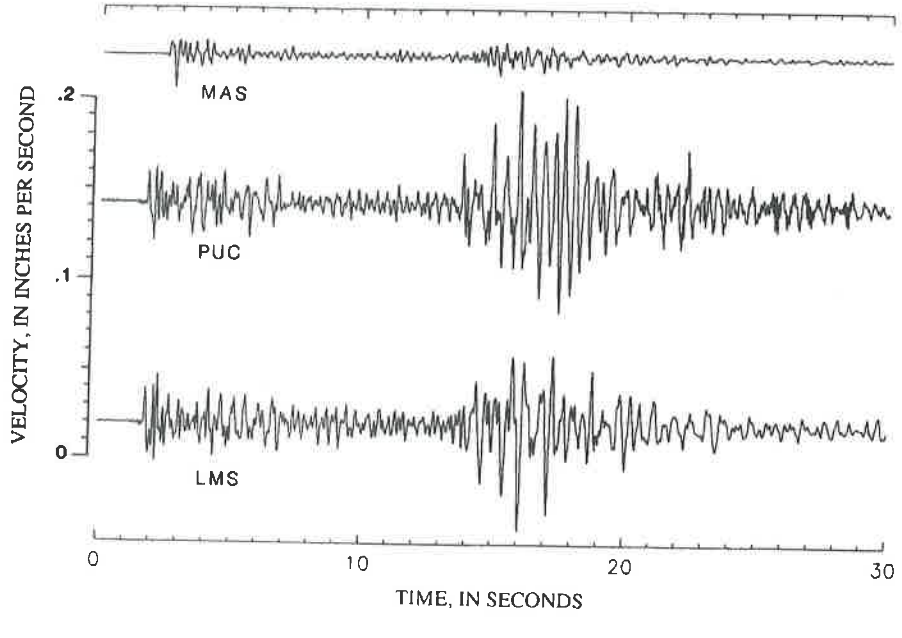

FIGURE 7.12 Vertical velocities at three seismic stations in and near the Marina district, from a magnitude 4.6 aftershock to the Loma Prieta earthquake. MAS is a site on bedrock. PUC is located on natural sand deposits and LMS is located on fill (Pflaker and Galloway, 1989).

3. Sand boils are sites of liquefaction (where the ground changes from behaving as a solid to behaving as a fluid, like quicksand, when shaken). Use Figure 7.11 and explain the relationship of sand boils to areas of fill. Why does this relationship exist?

4. Figure 7.12 presents three seismic responses. The larger squiggles on the figure represent greater velocities when the sites were shaken. What is the relationship of velocity to types of geologic deposit? If you wanted to build near the Marina district, but yet be relatively safe from earthquake damage (assuming that you were building an appropriate, seismic-resistant structure), where would be a safer place to build? Mark the site on Figure 7.9, and explain your choice.

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