EXERCISE 6

Earthquake Epicenters, Intensities, Risks, Faults, Nonstructural Hazards and Preparation

INTRODUCTION

Zachary Grey, writing in 1750, said "An earthquake is a vehement shake or agitation of some considerable place or part of the Earth, from natural causes, attended with a huge noise, like thunder; and frequently with an eruption of water, fire, smoke or wind. They are looked upon to be the greatest and most formidable phenomena of nature." Although our present understanding of earthquakes is much more refined, they are still considered to be formidable phenomena. An earthquake is the ground shaking caused by elastic waves propagating in the Earth generated by a sudden release of stored strain energy. The sudden release of stored strain energy is the result of an abrupt slip of rock masses along a break in the Earth called a *fault*. Most fault slip occurs below the Earth's surface without leaving any surface evidence. The place where this slippage occurs is known as the *hypocenter* or *focus* of the earthquake, and the point on the surface vertically above the focus is the *epicenter*.

In this exercise we review earthquake wave types, locate an earthquake epicenter, determine earthquake intensities, assess seismic risk, examine fault types, and study fault zone characteristics.

Earthquake Waves

The energy released at the focus of an earthquake sets up several types of vibrations or waves that are transmitted through the Earth in all directions. Some waves travel through the Earth to the surface and are known as body waves. Others travel along the Earth's surface and are known as surface waves (Figure 6.1).

One type of body wave is a compressional wave in which the particles of rock vibrate back and forth in the direction of wave travel; the motion is similar to that of sound waves that alternately compress and dilate the medium—solid, liquid, or gas—through which they travel. Compressional waves are also called longitudinal or *primary* waves (P waves); the latter name is given because these waves appear first on seismograms (Figure 6.2) that record earthquake waves. Another type of wave is the shear or transverse wave, in which the particles vibrate at right angles to the direction of wave progress, in the same manner as a wave moving along a stretched string that is plucked. Because these waves are the second waves to appear on the seismogram, they are called *secondary* waves (S waves).

After the body waves, another class of seismic waves, the surface waves, arrive. They have frequencies of less than 1 cycle per second and often approximate the natural frequency of vibration in tall buildings. Surface waves in general decrease in amplitude more slowly than body waves. The surface waves consist of *Love* waves (horizontal lateral vibrations perpendicular to direction of transmission; they travel forwards but shake sideways) and *Rayleigh* waves (rotational displacement of particles to produce a wavy or undulating surface; they travel up and down in small circles).

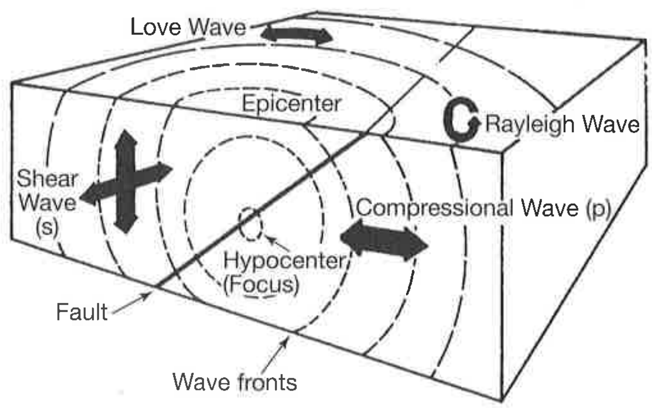

FIGURE 6.1 Diagram of directions of vibrations of body (P and S) and surface (Love and Rayleigh) waves (Hays, 1981).

PART A. EPICENTER, INTENSITY, AND SEISMIC RISK

Epicenter (6, Part A1)

After an earthquake, seismologists are faced with the task of finding when and where the shaking began. They do this by examining the *seismograms* from several seismograph stations. Because the P and S waves travel at different rates, the difference in arrival times varies from station to station depending on the distance from the source.

The average travel times of P and S waves compiled from many earthquake records are used to make travel-time graphs and tables showing the time required for waves to travel various distances from a hypocenter. These records show that P waves travel more rapidly than S waves. Therefore, travel-time curves will show P and S waves as separate curves. Surface waves travel at about 90 percent of the velocity of S waves because the surface waves are traveling through lower velocity materials located at the Earth's surface.

If arrival times are available from several seismograph stations, the distances given by the travel-time curves may be used to determine the earthquake's location. The distance provides the radius of a circle about the seismograph station. The *epicenter* is located somewhere on that circle. With at least three stations, the location of the epicenter may be determined as the point where the three circles intersect.

We can also arrive at the distance to the epicenter by using simple subtraction and a proportional relationship. Because of their different velocities, there is a time lag between arrival of the first P and first S wave at a seismograph station. The time lag (time of S minus time of P) can be determined from seismograms. This time lag can be used to compute the distance to the epicenter, provided the average velocity of each wave type is known. In the first part of the exercise, we will use seismograms from four different stations to locate the epicenter and time of an earthquake.

QUESTIONS (6, PART A1)

Epicenter

1. In Figure 6.2, use the time scale to determine the lag in arrival time between the P and S waves at four stations: St. Louis, Missouri (SLM); Bloomington, Indiana (BLO); Minneapolis, Minnesota (MNM); and Bowling Green, Ohio (BGO). The first major impulse on the left in the seismogram indicates the arrival of the first P wave at the station, the second impulse, the arrival of the first S wave. The lag time, T, is given by the difference between S and P times. Enter the lag time value for each station below:

SLM: _______ sec	BLO: _______ sec
MNM: _______ sec	BGO: _______ sec

2. To determine the distance from the earthquake to each seismograph station we must first determine the time lag between P and S wave arrivals at a given distance from an earthquake, say 100 km, knowing the average velocities of the P and S waves. If the average velocity of the P wave is 6.1 km/sec and the average velocity of the S wave is 4.1 km/sec, what is the time required for each wave to travel 100 km? (It may help to think of this problem like a very fast driving trip: if you want to go 100 km, and you drive at a rate of 6.1 km/sec, how long, in seconds, will it take you to get to your destination?)

P waves (6.1 km/sec) travel 100 km in _____ seconds.
S waves (4.1 km/sec) travel 100 km in _____ seconds.
Thus the time lag between the arrival of P and S waves at a distance 100 km from the hypocenter (T_{100}) is _____ seconds.

3. Remembering that for longer distances there is a proportionally longer lag time, we can construct a simple equation to calculate the unknown distance x to each station:

$$\frac{x}{T_x} = \frac{100\text{km}}{T_{100}}$$

where x = unknown distance in km; Tx = lag time for distance x; T_{100} = lag time at 100 km

Since values for Tx are known from Question 1 and the value of T_{100} is known from Question 2, the equation can be solved for x for each station. More than one station is needed to determine the epicenter since the information from one station can only give the distance to the earthquake and not the direction. The minimum number of stations needed to locate an epicenter is three.

Using the data from Figure 6.2 and the equation above, determine the distance to the earthquake epicenter from each station and enter below.

SLM: ______________________	km
MNM: ______________________	km
BLO: ______________________	km
BGO: ______________________	km

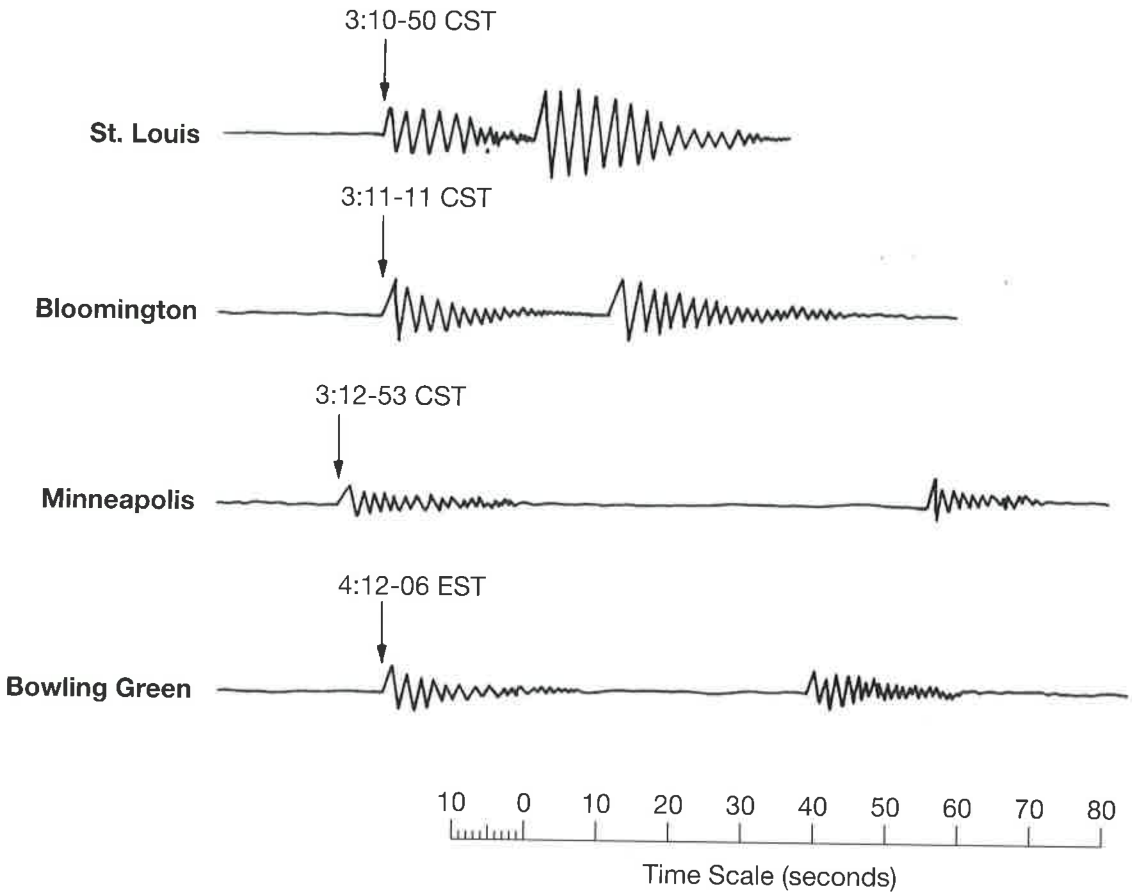

FIGURE 6.2 Partial seismograms for an earthquake. The P wave arrived at the St. Louis seismograph at 10 minutes and 50 seconds after 3:00 P.M. CST. The second disturbance on the seismogram represents the arrival of the S waves.

4. a. The epicenter of the earthquake can be pinpointed by drawing compass arcs from three of the stations with radii corresponding to the distances calculated in Question 3. The intersection of these radii marks the epicenter. Do this in Figure 6.3.

b. Where is the epicenter? (Give location within a state.)

c. Label it on the map (Figure 6.3).

d. At what time did the earthquake occur? (Refer to Figure 6.2.)

Intensity (6, Part A2)

The *intensity* of an earthquake at a site is based on the observations of individuals during and after the earthquake. It represents the severity of the shaking, as perceived by those who experienced it. It is also based on observations of damage to structures, movement of furniture, and changes in the Earth's surface as a result of geologic processes during the earthquake. The Modified Mercalli Intensity Scale is commonly used to quantify intensity descriptions. It ranges from I to XII (Table 6.1).

An *isoseismal* map shows the distribution of seismic intensities associated with an earthquake. The greatest impact of an earthquake is usually in the epicentral region, with lower intensities occurring in nearly concentric zones outward from this region. The quality of construction and variation of geologic conditions affect the distribution of intensity.

Seismic risk maps have been based on the distribution and intensities of past earthquakes or on the probability of future earthquake occurrences (of a given ground motion in a given time period). In this exercise the first type of map is adequate for our examination of seismic risk in middle North America; however, maps based on the probabilistic approach may be needed in other investigations. The latter maps do not express intensity. Rather, they show probability of occurrence of ground shaking that has a 10 percent probability of being exceeded in 50 years.

Note that we also use the term *magnitude* to describe an earthquake. The magnitude of an earthquake is a measure of the amplitude of an earthquake wave on a seismograph (Bolt, 1988). The Richter magnitude scale is a commonly used standardized system of amplitude measurement, and allows for comparison of different

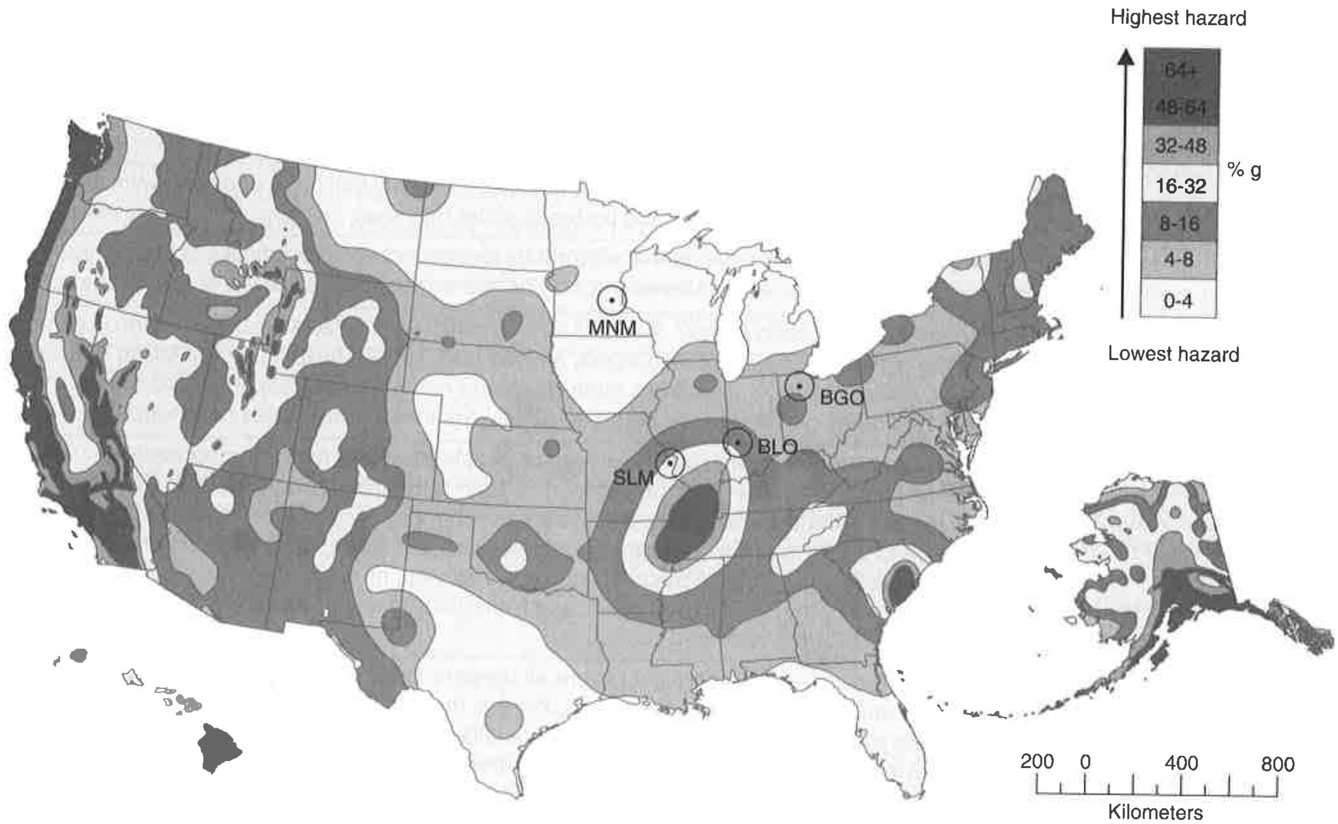

FIGURE 6.3 Seismic acceleration, expressed as a percent of gravity, that can be expected during a 50 year period. Higher numbers indicate greater potential for shaking (From Peterson and others, 2008).

earthquakes around the world. The Richter scale is a logarithmic scale, which means that each increase in number, for example from M5 to M6, represents a 10-fold increase in amplitude (and about a 30-fold increase in actual energy released by the earthquake).

QUESTIONS (6, PART A2)

1. Following are some historical descriptions of earthquakes (a–d). Such statements, made to scientists or reporters or recorded in diaries or on survey forms distributed by government agencies, allow scientists to determine the intensity of an earthquake. Using the Modified Mercalli Intensity Scale (Table 6.1), assign each of the quakes an intensity number. Pick the lowest number exhibiting the characteristics given. The first quotation describes the observations of an eyewitness to a California earthquake around 1913. The second, third, and part of the fourth descriptions are from data gathered by the U.S. Coast and Geodetic Survey after the Daly City, California, earthquake of 1957 (Richter magnitude 5.3).

a. "There was a keen frost, and when we reached the water-hole a thin film of ice was seen upon the water. I dismounted and led my horse by the bridle, and walked to the edge of the water. Just as I reached it, the ground seemed to be violently swayed from east to west. The water splashed up to my knees; the trees whipped about and limbs fell on and all around me. I was affected by a fearful nausea, my horse snorted and in terror struggled violently to get away from me, but I hung to him, having as great a fear as he had himself. The lake commenced to roar like the ocean in a storm, and, staggering and bewildered, I vaulted into the saddle and my terrified horse started, as eager as I was to get out of the vicinity." (Eisman, 1972)

Intensity:

b. "The shock seemed to be a sort of gentle swaying back and forth, causing hanging fixtures to swing, but doing no damage." (Iacopi, 1971)

Intensity:

c. "The earthquake was very intense . . . a heavy oak china cabinet and massive table moved 2 to 3 inches away from original positions; kitchen stove moved 2 inches; furnace in basement moved two inches off base and water heater tilted off base." (Iacopi, 1971)

Intensity:

TABLE 6.1 Modified Mercalli Intensity Scale of 1931.

Intensity	Description of Effects
I	Not felt by people, except under especially favorable circumstances. Sometimes birds and animals are disturbed. Trees, structures, liquids, and bodies of water may sway gently, and doors may swing slowly.
II	Felt indoors by a few people, especially on upper floors of multistory buildings. Birds and animals are disturbed, and trees, structures, liquids, and bodies of water may sway. Hanging objects may swing.
III	Felt indoors, usually as a rapid vibration that may not be recognized as an earthquake at first, similar to that of a light truck passing nearby. Movements may be appreciable on upper levels of tall structures.
IV	Felt indoors by many, outdoors by few. Awakens a few individuals. Characterized by vibration like that due to passing of heavy or heavily loaded trucks, a heavy body striking building, or the falling of heavy objects inside. Dishes, windows, and doors rattle. Walls and house frames creak. Hanging objects often swing. Liquids in open vessels are disturbed slightly. Stationary automobiles rock noticeably.
V	Felt indoors by practically everyone, outdoors by most people. Awakens many or most sleepers. Frightens a few people; some persons run outdoors. Buildings tremble throughout. Dishes and glassware break to some extent. Windows crack in some cases, but not generally. Vases and small or unstable objects overturn in many instances. Hanging objects and doors swing generally. Pictures knock against walls, or swing out of place. Pendulum clocks stop, or run fast or slow. Doors and shutters open or close abruptly. Small objects move, and furnishings may shift to a slight extent. Small amounts of liquids spill from well-filled containers.
VI	Felt by everyone, indoors and outdoors. Awakens all sleepers. Frightens many people; there is general excitement, and some persons run outdoors. Persons move unsteadily. Trees and bushes shake slightly to moderately. Liquids are set in strong motion. Plaster cracks or falls in small amounts. Many dishes and glasses, and a few windows, break. Books and pictures fall. Furniture may overturn or heavy furnishings move.
VII	Frightens everyone. There is general alarm, and everyone runs outdoors. People find it difficult to stand. Persons driving cars notice shaking. Trees and bushes shake moderately to strongly. Waves form on ponds, lakes, and streams. Suspended objects quiver. Damage is negligible in buildings of good design and construction; slight to moderate in well-built ordinary buildings; considerable in poorly built or badly designed buildings. Plaster and some stucco fall. Many windows and some furniture break. Loosened brickwork and tiles shake down. Weak chimneys break at the roofline. Cornices fall from towers and high buildings. Bricks and stones are dislodged. Heavy furniture overturns.
VIII	There is general fright, and alarm approaches panic. Persons driving cars are disturbed. Trees shake strongly, and branches and trunks break off. Sand and mud erupt in small amounts. Flow of springs and wells is changed. Damage slight in brick structures built especially to withstand earthquakes; considerable in ordinary substantial buildings, with some partial collapse; heavy in some wooden houses, with some tumbling down. Walls fall. Solid stone walls crack and break seriously. Chimneys twist and fall. Very heavy furniture moves conspicuously or overturns.
IX	There is general panic. Ground cracks conspicuously. Damage is considerable in masonry structures built especially to withstand earthquakes; great in other masonry buildings, with some collapsing in large part. Some wood frame houses built especially to withstand earthquakes are thrown out of plumb, others are shifted wholly off foundations. Reservoirs are seriously damaged, and underground pipes sometimes break.
X	Most masonry and frame structures and their foundations are destroyed. Ground, especially where loose and wet, cracks up to widths of several inches. Landsliding is considerable from riverbanks and steep coasts. Sand and mud shift horizontally on beaches and flat land. Water level changes in wells. Water is thrown on banks of canals, lakes, rivers, etc. Dams, dikes, and embankments are seriously damaged. Well-built wooden structures and bridges are severely damaged, and some collapse. Railroad rails bend slightly. Pipelines tear apart or are crushed endwise. Open cracks in cement pavements and asphalt road surfaces.
XI	Few if any masonry structures remain standing. Broad fissures, earth slumps, and land slips develop in soft wet ground. Water charged with sand and mud is ejected in large amounts. Sea waves of significant magnitude may develop. Damage is severe to wood frame structures, especially near shock centers, great to dams, dikes, and embankments, even at long distances. Supporting piers or pillars of large, well-built bridges are wrecked. Railroad rails bend greatly and some thrust endwise. Pipelines are put out of service.

TABLE 6.1 Modified Mercalli Intensity Scale of 1931. (Continued)

Intensity	Description of Effects
XII	Damage is nearly total. Practically all works of construction are damaged greatly or destroyed. Disturbances in the ground are great and varied, and numerous shearing cracks develop. Landslides, rockfalls, and slumps in riverbanks are numerous and extensive. Large rock masses are wrenched loose and torn off. Fault slips develop in firm rock, and horizontal and vertical offset displacements are notable. Water channels, both surface and underground, are disturbed and modified greatly. Lakes are dammed, new waterfalls are produced, rivers are deflected, etc. Surface waves are seen on ground surfaces. Lines of sight and level are distorted. Objects are thrown upward into the air.

(Modified from Cluff and Bolt, 1969, p. 9)

d. "It was as if giant hands took the house and shook it ... the pea soup jumped out of the pot and the grandfather clock was silenced." (modified from Iacopi, 1971)

Intensity:

2. Not all earthquakes occur in areas where high levels of risk have been identified. On July 27, 1980, an earthquake of Richter magnitude 5.1 shook Kentucky, Ohio, and adjacent states. The earthquake epicenter was determined to be at latitude 38.2° N, longitude 83.9° W, near Sharpsburg, Kentucky (approximately 30 miles southwest of the Ohio River town of Maysville, Kentucky). It had a focal depth of 13 km. Damage to structures along the Ohio River in Maysville, Kentucky, and in the Ohio communities of Aberdeen, Manchester, Ripley, and West Union, consisted of chimneys being knocked down, cracks in plaster and concrete blocks, and merchandise being toppled from store shelves. In Cincinnati a cornice reportedly fell from city hall.

a. Based on the reported damage, what was the intensity of this earthquake along the Ohio River?

b. Locate the earthquake epicenter with an X on Figure 6.3.

Isoseismal Maps (6, Part AB)

Large earthquakes have the potential for significant damage. This damage varies with the geologic nature of the earthquake and the rocks between the focus and the site, types and properties of the materials at a site, and the nature of the buildings. In this part of the exercise we use data from 1949 and 1965 earthquakes in western Washington to construct isoseismal maps.

QUESTIONS (6, PART A3)

1. The intensity of an earthquake is a measure of the impact of seismic shaking on the ground, structures, and people. It is described on a scale of I to XII (in Roman numerals), where I is only rarely felt and XII is total destruction. Use the Modified Mercalli Intensity Scale (Table 6.1) and the descriptions of site damage for the April 13, 1949, earthquake (Table 6.2) to determine the intensity at each site. Record the intensity and the primary evidence used in determining the intensity for each site, beside the names of the sites in Table 6.3. Several intensities, with evidence, are given.

2. Place the intensity values from Table 6.3 on the map of Washington (Figure 6.4). Then draw boundaries between these intensities to produce an isoseismal map.

3. What was the maximum intensity from the 1949 earthquake?

4. Where does the epicenter for the 1949 earthquake appear to have been?

5. What observation in Table 6.2 was the most interesting or surprising to you? Why?

6. Using intensity numbers from the April 29, 1965, western Washington earthquake shown in Table 6.4, enter the intensity values on the map of Washington (Figure 6.5).

7. Draw the approximate boundaries of the intensity zones as determined by the values you entered for each locality. Part of one boundary is given for you in Figure 6.5.

TABLE 6.2 Impact of the 1949 Earthquake in Western Washington at Various Sites.

Aberdeen	One death. Scores of chimneys tumbled at roof level. Broken dishes and windows.
Bellingham	Hanging objects swung. Swaying of buildings. Pendulum clocks stopped or ran fast or slow.
Bremerton	One death. Considerable falls of plaster. Elevator counterweights pulled out of guides. Swaying of buildings. Trees shaken moderately to strongly.
Buckley	Part of high school building fell. Most chimneys in town toppled at roofline. Cracked plaster and ground.
Centralia	One death; 10 persons hospitalized. Very heavy damage. Collapse of building walls and many chimneys. Water mains broken; Water and sand spouted from ground. Violent swaying of buildings and trees. Many objects moved, including pianos. Objects fell from shelves. Pendulums swinging east–west stopped. Many persons panic-stricken. Four miles southwest of town, water spouted 18 in. high in middle of field, leaving a very fine sand formation around each hole (1–3 in. in diameter). Gas or air boiling up through river.
Cle Elum	Pendulum clocks stopped. Small objects and furnishings shifted. Trees and bushes shaken moderately.
Eatonville	Chimneys toppled. Plaster fell in large pieces in schoolhouse. People had difficulty in maintaining balance.
Hyak	Few windows broke. Trees and bushes shaken moderately. Furnishings shifted.
Longview	Two minor injuries. Gable of community church fell. Water main broke, beams cracked in school. Extensive but scattered damage to business buildings, industrial properties, and residences. Considerable damage to irrigation ditches. Landslides on cuts along highway. Objects fell in all directions. Some heavy furniture overturned. Glass figurine on mantle thrown 12 ft.
Olympia	Two deaths; many persons injured. Conspicuous cracks in ground and damage in masonry structures. Capitol buildings damaged. Nearly all large buildings had cracked or fallen walls and plaster. Two large smokestacks and many chimneys fell. Streets damaged extensively; many water and gas mains broken. Portion of a sandy spit in Puget Sound disappeared during the earthquake.
Port Townsend	Pendulum clocks facing northeast stopped. Hanging objects swung. Slight damage in poorly built buildings. Subterranean sounds heard. Bells rang in a small church.
Puyallup	Many injured. High school stage collapsed. Nearly every house chimney toppled at roof line. Several houses were jarred off foundations. Minor landslides blocked roads. Water mains broke. Multiple-story brick buildings most severely damaged. Some basement floors raised several feet, driving supports through floor above. Plaster badly damaged. Water spouted in fields, bringing up sand.
Randle	Twisting and falling of chimneys; about one-fourth of all chimneys fell. Damage considerable. Water spilled from containers and tanks. Plaster and walls fell; dishes and windows broke. Lights went out.
Satsop	Cracked ground. Pendulum clocks stopped. Trees and bushes shaken strongly. Furnishings overturned.
Seattle	One death; many seriously injured with scores reporting shock, bruises, and cuts. Many houses on filled ground demolished; many old buildings on soft ground damaged considerably. Collapse of top of one radio tower and one wooden water tank with damage to many tanks on weak buildings. Many chimneys toppled. Heavy damage to docks (fractures in decayed pilings). Several bridges damaged; many water mains in soft ground broken. Telephone and power service interrupted. Large cracks in filled ground; some cracking of pavement. Water spouted 6 ft or more from ground cracks. At the federal office building, bookcases thrown face down. Very heavy furniture overturned. Plaster badly cracked and broken with pieces 1–3 ft square thrown from walls. Pictures on north–south walls canted; those on east–west walls—little cant. Some doors did not fit after shock. Many old brick buildings partially destroyed.
Snoqualmie	Most damage confined to brick chimneys, windows, and plaster. Overturned vases and floor lamps. Coffee shaken out of cups. Rockslides on Mt. Si. Trees and bushes shaken strongly.
Tacoma	One death. Many buildings damaged and parts fell. Many chimneys toppled. Several houses slid into Puget Sound. One smokestack fell. One 23-ton cable saddle was thrown from the top of tower at Tacoma Narrows Bridge, causing considerable loss. Railroad bridges thrown out of line. Tremendous rockslide, a half-mile section of a 300-ft cliff, into Puget Sound. Considerable damage to brick; plaster, windows, walls, and ground cracked.

(Modified from Murphy and Ulrich, 1951)

TABLE 6.3 Intensities from the April 13, 1949, Earthquake

Location (symbol)	Intensity	Primary Evidence for 1949 Earthquake
Aberdeen (Ab)		
Bellingham (Be)		
Bremerton (Br)		
Buckley (Bu)	VIII	Walls and chimneys fall; cracked ground
Centralia (Ce)	VIII–IX	Sand and mud eruption: pipes break; damage considerable
Cle Elum (Cl)		
Eatonville (Ea)	VII	Plaster falls in large pieces; difficulty maintaining balance
Hyak (Hy)	VI	Trees/bushes shake moderately; few windows break
Longview (Lo)	IX	
Olympia (Ol)		
Port Townsend (Po)		
Puyallup (Pu)		
Randle (Ra)	VIII	Twisted and fallen chimneys; walls fall
Satsop (Sa)		
Seattle (Se)		
Snoqualmie (Sn)	VII	Damaged chimneys/windows; trees/bushes shaken strongly
Tacoma (Ta)		

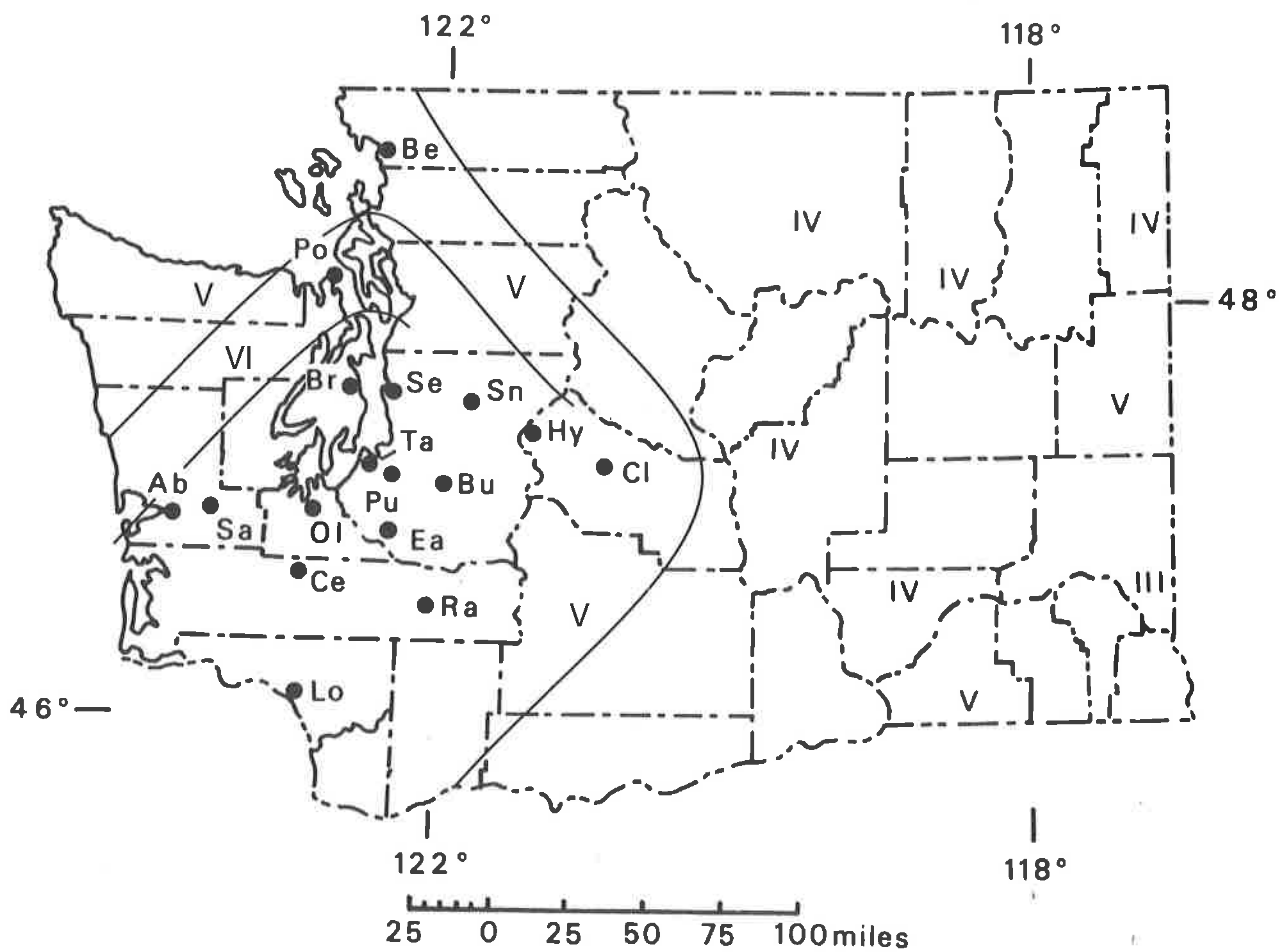

FIGURE 6.4 Index map of Washington showing locations of the sites listed in Table 6.3. Modified Mercalli Intensities for April 13, 1949, earthquake are given for eastern Washington. Some boundaries of intensity zones shown. Completed map is an isoseismal map.

TABLE 6.4 Locations and Intensity Data for the April 29, 1965, Western Washington Earthquake

Location	Intensity	Location	Intensity
Aberdeen (Ab)	V	Longview (Lo)	V
Arlington (Ar)	VI	Olympia (Ol)	VI
Bellingham (Be)	V	Port Angeles (Pa)	V
Bremerton (Br)	VI	Port Townsend (Po)	V
Buckley (Bu)	VI	Puyallup (Pu)	VII
Centralia (Ce)	VI	Randle (Ra)	V
Cle Elum (Cl)	V	Satsop (Sa)	VI
Concrete (Co)	VI	Seattle (Se)	VII
Eatonville (Ea)	VI	Snoqualmie (Sn)	VII
Forks (Fo)	IV	Tacoma (Ta)	VII
Hyak (Hy)	VI	Vancouver (Va)	V

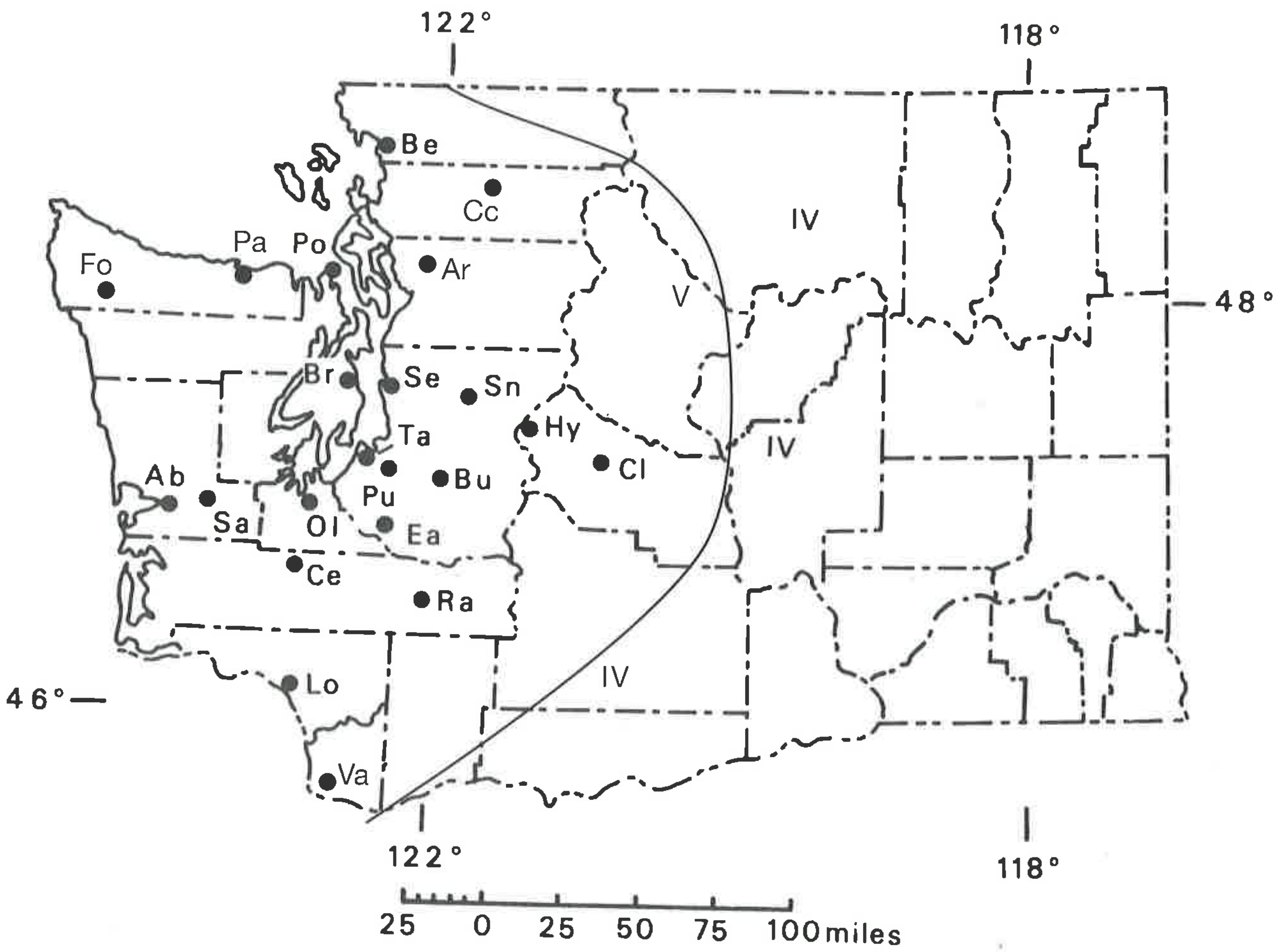

FIGURE 6.5 Index map of State of Washington showing the sites of intensity data from the 1965 western Washington earthquake.

8. a. What was the maximum intensity for the 1965 earthquake?

b. Where does the epicenter for the 1965 earthquake appear to have been?

9. On the Web you will find additional information on these two earthquakes (and others) at http://earthquake.usgs.gov/eqcenter/dyfi.php. Complete the following blanks for these two western Washington earthquakes.

a.	**1949 Earthquake**	**1965 Earthquake**
Date		
Maximum Intensity		
Name (Earthquake)		
Magnitude		
Number of Reports		

b. You might still be curious about earthquake intensities. Below write a question for your TA or instructor about some aspect of the exercise that you don't understand.

Note: If you experience an earthquake you can report what you saw/felt during the earthquake and what damage you noted. It is useful to write your account of the event as soon as you are safe and can make notes. Then use those notes when completing the form at http://pasadena.wr.usgs.gov/shake/pnw/html/unknown_form.html.

Earthquake Shaking Hazard Maps (6, Part A4)

National maps of earthquake shaking hazards provide information that helps to save lives and property by providing data for building codes. Buildings designed to withstand severe shaking are less likely to injure occupants. These hazard maps are also used by insurance companies, FEMA (for support of earthquake preparedness), EPA (for landfill design), and engineers (for landslide potential).

The map shows the hazard by zones (or in some maps contour peak values) of the levels of horizontal shaking. The higher the number the stronger is the shaking. The number is % g or percent of acceleration due to gravity (in this case as horizontal acceleration). Acceleration is chosen, because building codes prescribe how much horizontal force a building should be able to withstand during an earthquake. 10% g is the approximate threshold for damage to older (pre-1965) structures. Additional information on these maps is available from Frankel et al. (1997) and from the USGS (Fact Sheet 183-96).

Figure 6.3 is a ground-shaking hazard map that shows a 10 percent probability of exceeding a given value in a 50-year period (Peterson and others, 2008). That is, over the next 50 years there is a 1 in 10 chance that the acceleration given for any area will be exceeded. Use information in Figure 6.3 to help answer the following questions.

QUESTIONS (6, PART A4)

1. Which areas of the country have the lowest hazard from earthquake shaking (where 4% g, or less, peak acceleration is expected)?

2. If damage to older (pre-1965) structures can be expected with horizontal accelerations of 10% g or more, which areas of your home state are:

a. at some risk?

b. at greatest risk?

c. what is your home state?

3. What three or four regions of the country have the highest accelerations?

4. What geologic processes, other than shaking and fault displacement, could produce a hazard in an earthquake? List two.

5. The geologic material on which a building rests plays a role in the type of shaking that occurs during an earthquake. Weak materials amplify the shaking. Which of the following foundation materials would most likely result in less shaking and a safer building? (circle one)

artificial fill, poorly consolidated sediments, marine clays, unweathered bedrock

6. If the Internet is available, now or after class, determine and list (places and magnitudes) where the largest two earthquakes have occurred in the last 2 weeks. Also list what processes, other than shaking, contributed to the loss of structures and life. A possible source to begin the search is: http://earthquake.usgs.gov/recenteqs/

7. The Mississippi Valley is indicated as a high-risk area because of earthquake activity that is associated with stress within the continental lithospheric plate. Consider the types of plate margins in the plate tectonics model to answer the following questions. (See a geology text for basic details on plate margins.)

a. What is the tectonic explanation for the major shaking hazard in southern California?

b. What is the tectonic explanation for the major shaking hazard around Seattle?

PART B. FAULTS AND FAULT DETECTION

Earthquakes are related to movements along fault zones. Diagrams of several types of faults are shown in Figure 6.6. If necessary, the review questions in this portion of the exercise may be answered with the aid of a standard introductory geology textbook.

Fault zones can be recognized on aerial photographs, satellite and LIDAR images, geologic maps, and topographic maps, as well as by field observations. Features that might indicate a fault zone area are (1) scarps (cliff or break in slope) formed by horizontal or vertical movement; (2) steep mountain fronts; (3) offset streams and ridges; (4) sag ponds and lakes; (5) lineaments of vegetation; (6) valleys in fault zones; (7) changes in rock type, structure, moisture, and vegetation and (8) faceted spurs. These features are shown in Figure 6.7, which depicts a strike-slip fault (largely horizontal displacement). Normal faults also can have distinct features, which are illustrated in Figure 6.8.

QUESTIONS (6, PART B)

Fault Diagrams

1. The freshly exposed cliff of bedrock or regolith along a fault line is known as a fault ______________.

2. Following an earthquake, the horizontal distance between two utility poles on opposite sides of a fault trace (not a strike-slip fault) had increased. Are the regolith (soils) and bedrock in this area in a region of compression (squeezing together) or tension (pulling apart)? Explain your reasoning.

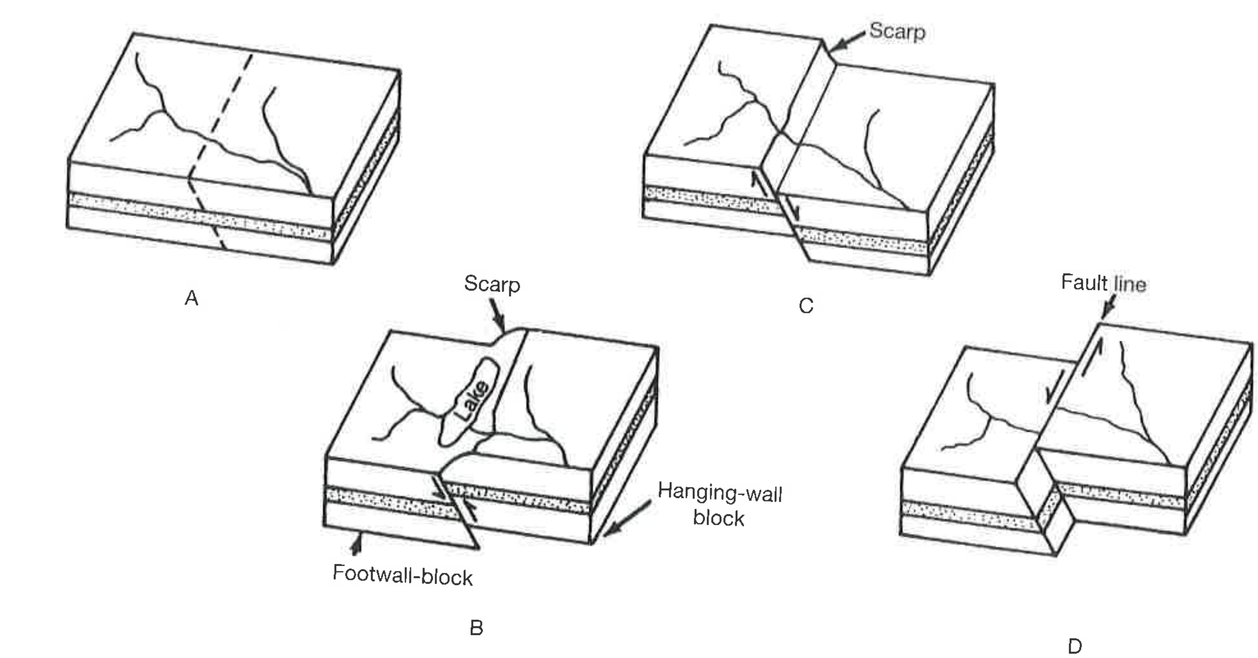

FIGURE 6.6 Types of fault movement: (a) block before movement; (b) reverse fault, or thrust fault, in which the hanging-wall block has moved up relative to the footwall block; (c) normal fault, in which the hanging-wall block has moved down relative to the footwall block; (d) strike-slip fault, in which the blocks on either side of the fault have moved sideways past each other. Arrows indicate relative motion of the blocks.

(Modified in part from McKenzie, Pettyjohn, and Utgard, 1975)

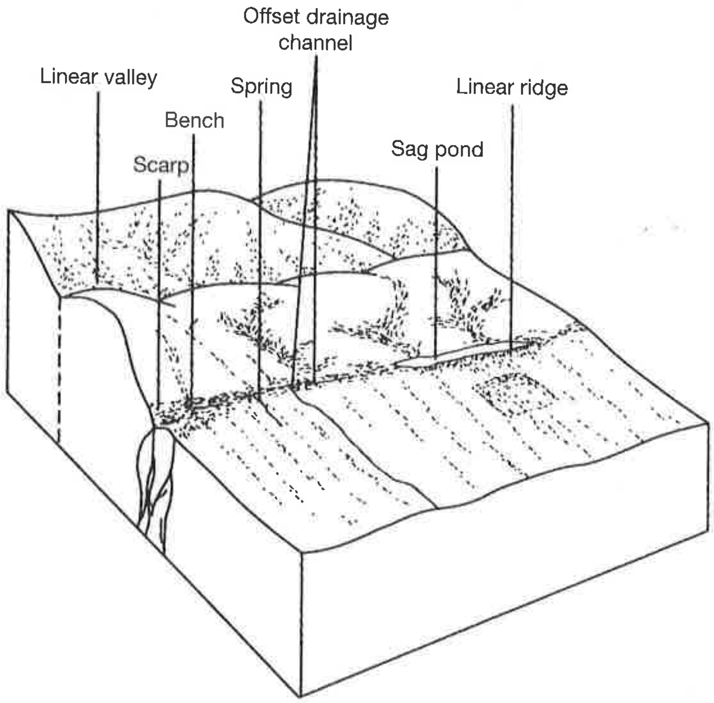

FIGURE 6.7 Distinctive landforms and drainage patterns aligned along a strike-slip fault are visible evidence that fault movement is recent enough to have interrupted the more gradual processes of erosion and deposition. (Brown and Kockelman, 1983)

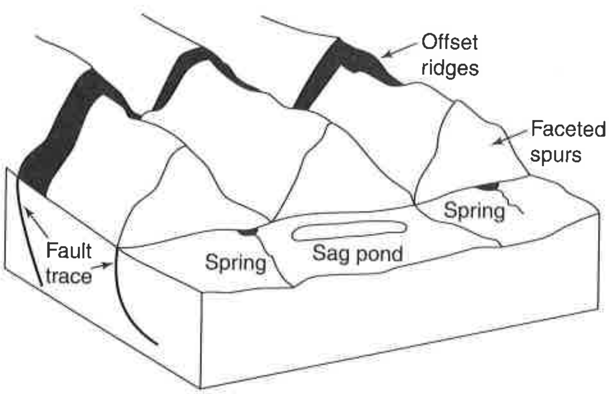

FIGURE 6.8 Typical geologic features found associated with a normal fault in mountainous terrain.

3. Sketch two utility poles on Figure 6.6a, placing one on each side of the fault. Use fault diagrams Figure 6.6b and c, and determine if the relative motion of the fault blocks in Question 2 indicates that it is a normal fault or reverse fault. Explain your reasoning.

San Andreas Fault

Study Figure 6.9, which is a photo of the San Andreas Fault, and then answer the questions below. It will help to review Figure 6.7.

4. What geological features can be used to identify the location of the fault? Outline the fault zone in Figure 6.9.

5. Does the fault zone consist of a single fracture or several parallel fractures? What is your evidence?

6. In addition to faults, what other natural or human-made features can create straight lines in topography? Are any of these features present in this photograph?

7. Indicate the direction of movement along the fault by drawing arrows on either side of the fault in Figure 6.9.

FIGURE 6.9 Aerial photograph of the San Andreas Fault in the Carrizo Plain at Wallace Creek, California. The fault runs horizontally across the middle of the photograph; the horizontal white line in the lower part of the photograph is a road. Agricultural features on the photo include fences and crop harvest patterns (Wallace, 1990).

Figure 2.17, on the back cover of this book, is a satellite image of the San Francisco Bay area. The yellow dots on this image are earthquake epicenters. Use this figure to answer the following questions.

8. Which features of strike-slip faults shown of Figure 6.7 can be seen easily on the satellite image? Why are some features easier than other features to see on the image?

9. How do the locations of earthquake epicenters help you determine geographic features that are related to faults?

10. Mark on the back cover (Figure 2.17) or on a tracing such as Figure 2.18, the traces of several major faults in this area.

Study the radar image of southern California in Figure 6.10. This image was made from an airplane that bounced radar waves off the earth. The radar is able to penetrate vegetation and clouds, so the image is very clear. The surface of the land is shown as if the sun lighted it, with bright slopes facing the sun and dark areas of shadow. Of course, in a radar image it is not sunlight but is the location of the airplane sending out the radar that creates the bright and shadow areas.

Different geologic and land use patterns are distinctive on the image. Areas with large shadows indicate high topography (mountains). Linear alignments of valleys, rivers, lakes, or mountains may indicate a fault zone. Flat, dark areas may be lakes, reservoirs, or the ocean. Mottled gray patterns, with very small rectangles, are urban areas, broken into blocks and dissected by rivers and freeways. Larger rectangular patterns can represent agricultural fields. Rivers often have winding patterns through mountain, agricultural, and urban areas.

11. What evidence of faults do you see on the radar image?

12. Draw on the image all the fault traces you can find.

13. Use the Web, or material provided by the instructor, to label faults including the Elsinore and San Andreas on Figure 6.10.

14. Find and label an example of the following: agriculture pattern (A), urban region (U), major highway (H), lake (L), and river (R).

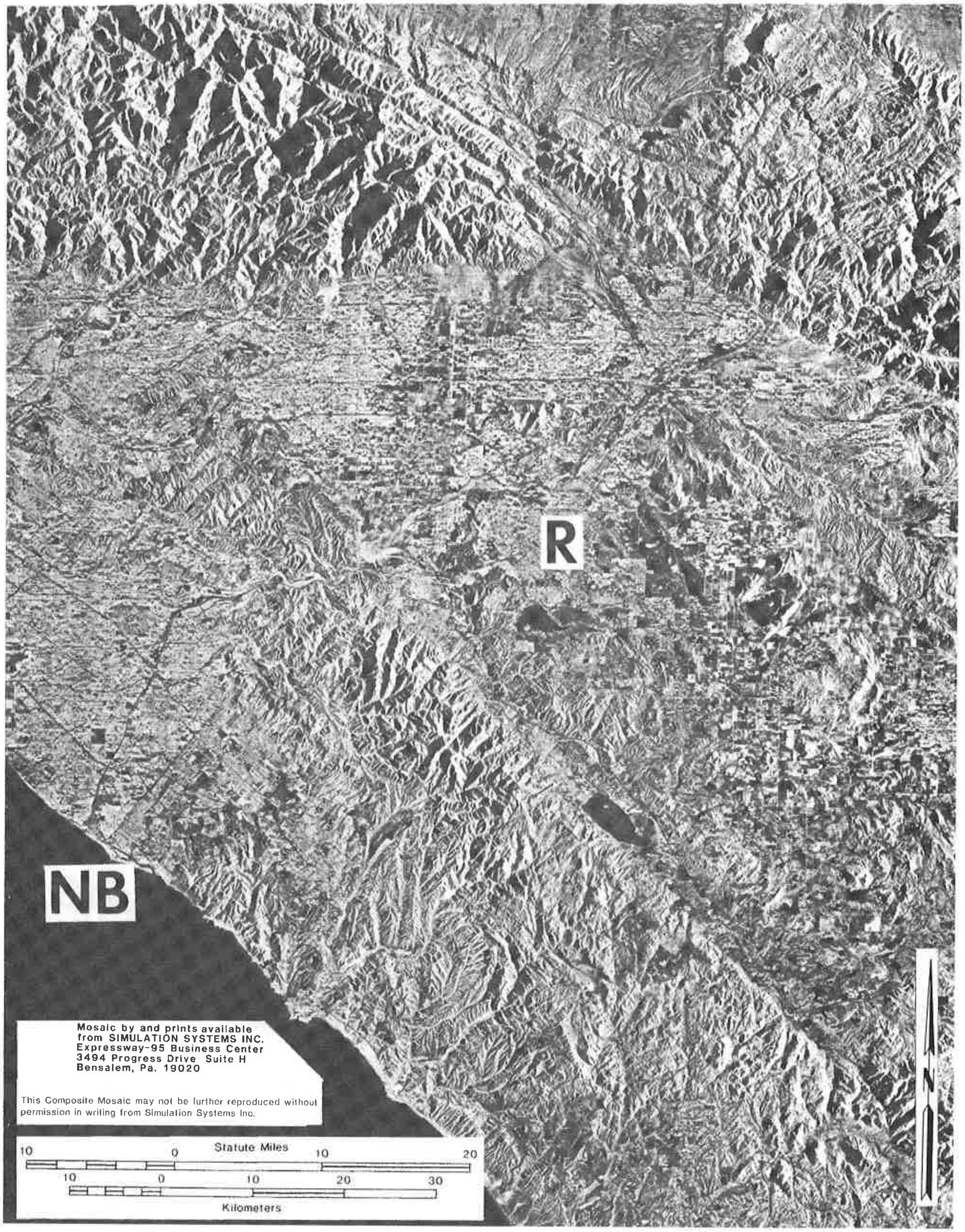

FIGURE 6.10 Radar image of southern California. R = Riverside, NB = Newport Beach.

(Courtesy of and copyrighted by Simulation Systems, Inc.)

Wasatch Fault

15. Study the map of the Draper, Utah, quadrangle (Figure 6.11 in the colored plates section of this book) and mark on the map the location of the Wasatch Fault along the mountain front. (Hint: Refer to Figure 6.8 for features found along normal faults, and begin your identification at Beaver Ponds Springs.)

Figure 2.16, also in the colored plates section at the back of the book, is a color stereo photograph of this area. Locate Beaver Ponds Springs on the photograph, and extend the fault based on topographic features.

Faults can also be seen on color oblique photographs. Use Figure 6.12 and identify on it the fault scarp and extend trace of the fault both north and south.

16. Using information on normal faults from Figures 6.6, 6.7, and 6.8, review the photographs of the site (Figures 2.16 and 6.12) and the map (Figure 6.11), and describe the location and appearance of at least one of each of the following features of a normal fault:

spring

sag pond

fault scarp

faceted spur

FIGURE 6.12 Salt Lake City oblique photo, Little Cottonwood Canyon. North to left. (U.S. Department of Agriculture, Soil Conservation Service, Salt Lake City, UT).

17. In the San Andreas Fault example (questions 4 and 5 above), lateral stream offset was an important clue to movement along the fault. Follow the traces of streams in Figure 6.11 as they flow west from the mountains to the valley. Is there any offset of streams where they cross the fault(s)? Why or why not?

18. Can you tell from the map (Figure 6.11) which side of the fault has moved up and which side has moved down? Describe your evidence. What additional kinds of information might be helpful in determining the movement along the fault?

Faults in Forests (Bainbridge Island, Washington)

Urban areas and thick forests are two environments in which it can be difficult to locate active or potentially active faults. In urban areas, faults may only be exposed in excavations for construction, or detectable if there is offset of roads or structures. In forested areas, virtual deforestation provided by LIDAR can allow the identification of faults. The example below is from such a forested area.

19. Look at the aerial photograph in Figure 6.13. Identify on this figure any linear zones you see that might be faults, being careful to avoid roads and property lines that are marked by cut forests.

20. Figure 6.14 is a LIDAR image of the same area, processed to remove the forest from the image. Mark on this figure any traces of faults that you see. Compare the trace of the fault with the drawings in Figures 6.7 and 6.8. What are the surface features that you see along the fault? What kind of fault movement and offset is most likely here? (Circle One) Normal, Reverse, Strike slip?

PART C. RECOGNITION OF NONSTRUCTURAL HAZARDS

This exercise looks at the recognition of nonstructural earthquake hazards and approaches the question, how safe are we in our daily lives? Recognition of nonstructural hazards, however, is something that everyone should know to be able to lead safer lives in earthquake country.

The structure of a building consists of those parts that help it stand up and withstand the forces of weight, wind, and earthquakes that may impact it. Everything else in a building is nonstructural. Structural failure can cause partial or total collapse of a building and injury or death to occupants and those near a building. Nonstructural hazards can be caused by things the occupants of a building do, such as hanging plants or positioning bookshelves, or they may arise from the failure of the integral components of buildings such as water pipes, ventilation systems, and electrical systems. Nonstructural hazards may also be external, such as decorative trim that can fall off a building (Figure 6.15) or glass that can break out of windows. In summary, nonstructural hazards include building furniture, utility systems, and internal and external trim and decoration. The behavior of these items in an earthquake can cause damage, destruction, and injury, even if the building remains standing during and after an earthquake.

According to the U.S. Geological Survey, falling objects and toppling materials present the greatest hazards in earthquakes. Falling objects account for about two-thirds of the casualties from earthquakes. Also, replacement of these materials and loss of building use can be very expensive.

In this exercise you will draw a careful sketch of a room (or other indoor site) and complete a checklist to identify and comment on the hazards you find.

QUESTIONS (6, PART C)

1. Select a site that you frequently use. Make a sketch of this room on the graph paper provided in Figure 6.16. The choice of site is up to you. It could be a dorm room, a bedroom at home, a place where you work, a place where you study, or some other room or facility. You may do a map view or an elevation, but there is no need to do both. Identify and label the nonstructural hazards that you find. Include a scale on your drawing.

2. The list in Table 6.5 identifies some of the nonstructural hazards that you may encounter in your search. This list is not intended to be comprehensive; there are undoubtedly some missing hazards. Space is left at the bottom of the list for you to add other hazards that you discover.

Identify the room and building in the table title. Then identify all hazards in the room that you select. In the space provided, make brief comments about the specific nature of each hazard and your vulnerability (such as "Textbooks in environmental geology may fall off shelf and hit me"). Remember, in analyzing earthquake hazards you need to imagine what would happen to the objects around you if they were suddenly launched horizontally.

PART D. EARTHQUAKE PREPARATION AND HAZARD REDUCTION

This exercise explores specific coping techniques to reduce earthquake hazards and improve safety during and after an earthquake. Consider situations in which electric power and water supplies are not available; ATMs, credit cards and other sources of money are not

FIGURE 6.13 Aerial photograph of a portion of Bainbridge Island, WA. (USGS)

functioning; and the only transportation is by foot or bicycle. By imagining the conditions in a disaster, seeking information from various sources on preparation and coping, and preparing for the disaster, you and your family, friends, and coworkers or students can minimize losses. And remember, many of the preparations for an earthquake can be transferred to other types of natural and human-induced disasters. Even if you do not live in an earthquake hazard area, an earthquake could occur when you are traveling. It makes sense to understand the nature of disasters and to prepare for them.

Use a separate sheet of paper for answers to Questions 1 and 2.

1. Assume that you have three different amounts to spend on earthquake preparation for you or your family: $25, $100, and $200. Develop specific earthquake safety strategies for each amount. Explain what you would buy, how you would store it, and how you would cope with safety and survival issues in and after an earthquake. Are there simple lifestyle changes before the earthquake that would also help you? You may find it helpful to use your textbook or other sources from a library to do research on earthquake hazard reduction.

2. Imagine that an earthquake occurs while you are in a class. What would you want from your educational institution immediately? What would you want over the next few days? How soon would you want to be back in class? Develop a separate list of items that you believe your educational institution should be ready to provide or situations that it should be prepared to deal with after an earthquake. Divide your list into two sections, with the first section itemizing needs during the first 72 hours, and the second section listing longer-term considerations. Who do you contact at your school to determine which preparations on your list have been made and which are still needed?

FIGURE 6.14 LIDAR image of part of Bainbridge Island, WA. (Image courtesy of Puget Sound Lidar Consortium)

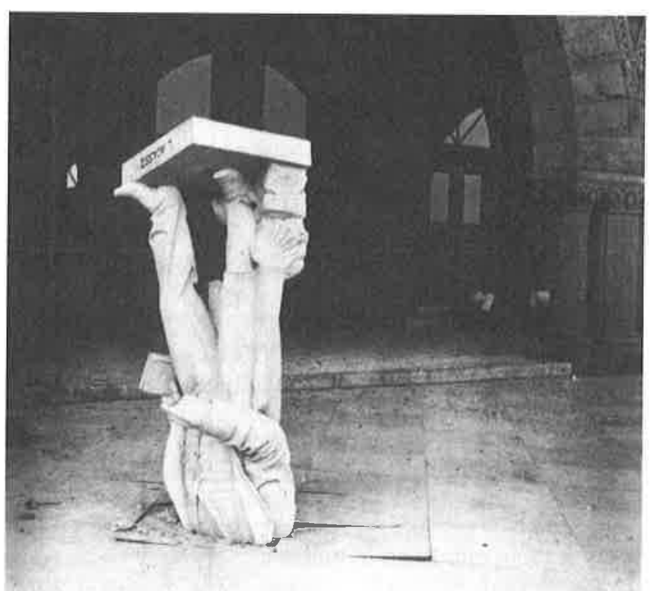

FIGURE 6.15 The statue of Louis Aggasiz at Stanford University after the 1906 earthquake illustrates what can happen when large unsecured objects fall.

(W.C. Mendenhall, USGS).

FIGURE 6.16 Sketch of ____________ (your caption)

TABLE 6.5 List of Possible Hazards in ________________.

Type of Hazard	Nature and Effect of Hazard	Possible Methods to Reduce Hazard
Windows: may implode in large pieces; consider proximity to furniture, especially beds		
Bookcases: may topple if not secured		
Books: may fall out of bookshelves		
Furniture: may slide across room; if tall and narrow, such as files, may tip over		
Cabinets: doors may open and contents may fall out if unsecured		
Storage items on desks, shelves, or other surfaces: may fly or fall if unsecured; special hazards if toxic or flammable		
Fixtures: heavy objects may fall if unsecured or poorly secured		
Hanging objects: if unsecured, plants, pictures, mirrors may fall		
Lights: can swing, shatter, and fall		
Exits: consider conditions that would block room exits, such as toppled furniture		
Lifelines: problems in room if adjacent to lifelines, such as water pipes, break		
Other items:		