

LAB 5 ESCI 409 Geology and the Environment
EARTHQUAKES

The sudden slip of rock along a fault is the usual cause of an earthquake. Few of us have been around when an earthquake has occurred and therefore have never directly experienced earthquake waves. Two basic types of waves radiate from the point of initial slip of the fault. This point underground is called the *focus* or *hypocenter*. The point on the Earth's surface that is directly above the focus is called the *epicenter* (fig. 1).

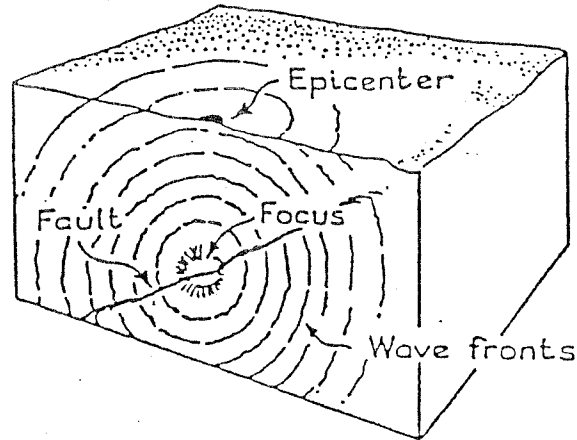
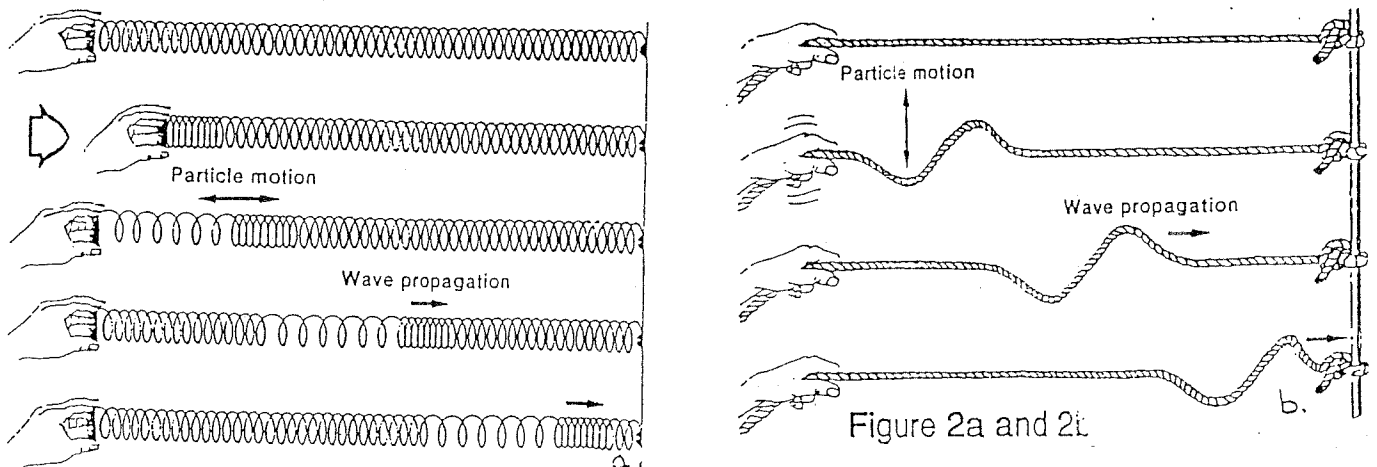


Figure 1

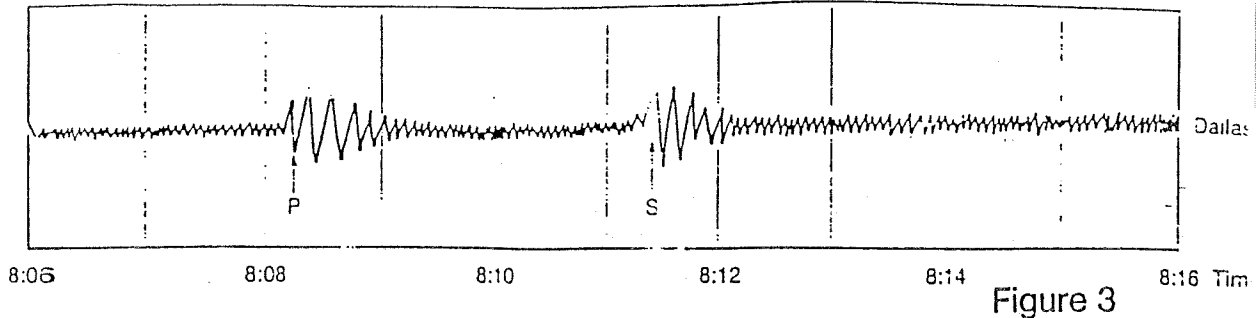
Wave motion is a means of transmitting energy from one place to another without transmitting matter itself. The first waves to arrive at the Earth's surface are P waves (Primary or compressional waves). Rock vibrates parallel to the direction of wave propagation, that is in the same direction as the waves are moving (fig. 2A). Their speed depends on the type of rock through which the waves are passing. The next waves to arrive are S waves (Secondary or shear waves). These waves are transverse waves and rock vibrates in the vertical plane perpendicular to the direction of propagation (fig. 2B). These waves have a slower velocity than P waves. They both pass easily through solid rock, but only P waves can pass through a fluid. Surface waves are slower still and propagate along the surface as their name implies. They are transverse waves called the Love and Rayleigh waves.



Seismometers detect ground motion and record the seismic waves (P, S, and surface waves) on seismographs. The records (old analog seismograms can be viewed in

the foyer) are now largely replaced by digital recordings (see <http://quake.bc.edu:8000/drums.htm> and <http://earthquake.usgs.gov/eqcenter/top10.php> for seismograms in "real time"

Fig. 3 represents a typical record that illustrates the arrival of P, S and surface waves.



If the velocity of the seismic waves and the time of arrival of P and S at a given recording station the epicenter can be located.

Background: On January 19, 1982 at 12:14 AM a magnitude 4.5 earthquake was felt over a 127,000 km² area of New England including parts of CT, ME, MA, NH, VT, RI, and Canada. Following the main quake, two aftershocks were felt at 12:31 and 12:55 AM. Maximum ground shaking of Intensity VI cracked chimneys, plaster, and concrete floors in MA, NH, and VT. Other reported damage includes: broken glassware, overturned small objects, fallen hanging pictures, and merchandise thrown from store shelves.

The location of the epicenter can be determined from data from seismic stations in New England (see <http://www.bc.edu/research/westonobservatory>) for more recent events.

Table 1

Seismic Station	Location	Time between P- and S-wave arrival
WNH	Whiteface Mountain, NH	5.0 sec
ONH	Oak Hill, NH	4.0
PNH	Pitcher Mountain, NH	7.5
DNH	Durham, NH	9.0
WFN	Westford, MA	12.5
GLO	Gloucester, MA	15.0
DUX	Duxbury, MA	21.5
UXB	Uxbridge, MA	20.0
COD	South Dennis, MA	29.0

The bedrock in the New England area (Fig. 4) consists primarily of crystalline igneous and metamorphic rocks. P-wave velocity through such rock is approximately 6 km/sec and S-wave propagates with an approximate velocity of 3.5 km/sec. A time-distance graph was plotted where the slopes are equal to the velocities of the P and S waves.

Problem 1. Determine from the time-distance graph the distance from each station listed in Table 1. Using a compass, plot these distances on Figure 4 to locate the epicenter where the circles intersect. What is the nearest town? Carefully examine the 1997 Geologic Map of New Hampshire.. What rock types and/or structure (fault?) occurs at or near this locality. Check <http://quake.bc.edu:8000/index.htm> for additional information quakes in New England.

Economic repercussions...

The size of an earthquake is usually measured in several ways. Intensity is a qualitative measure of damage based on observations from those affected by the quake. Table 2 summarizes damage characteristics of the Modified Mercalli Intensity Scale. Magnitude is a more quantitative measure of earthquake energy release: The Richter Scale estimates the local magnitude (ML) from the log of maximum ground motion at a distance of 100 km from the epicenter. This is the number often reported on the news. The Richter scale has more recently been replaced by the Movement Magnitude (MW), which quantitatively relates the area of the rupture and the amount of fault offset. The numbers are broadly comparable.

***Background:** On October 17, 1989 at 5:04 PM a magnitude 7.1 earthquake struck the San Francisco area. The earthquake was felt over an area of 400,000 square miles, caused 62 deaths, and over 3,700 injuries, and caused over \$6 billion in property damage. The earthquake resulted from movement along segment of the San Andreas fault system. The main quake was followed by numerous aftershocks, which continued for at least 2 years.*

Following the earthquake, the USGS sent out questionnaires to the residents of the area requesting information about the earthquake and its effects. Table 3 lists typical responses to this survey.

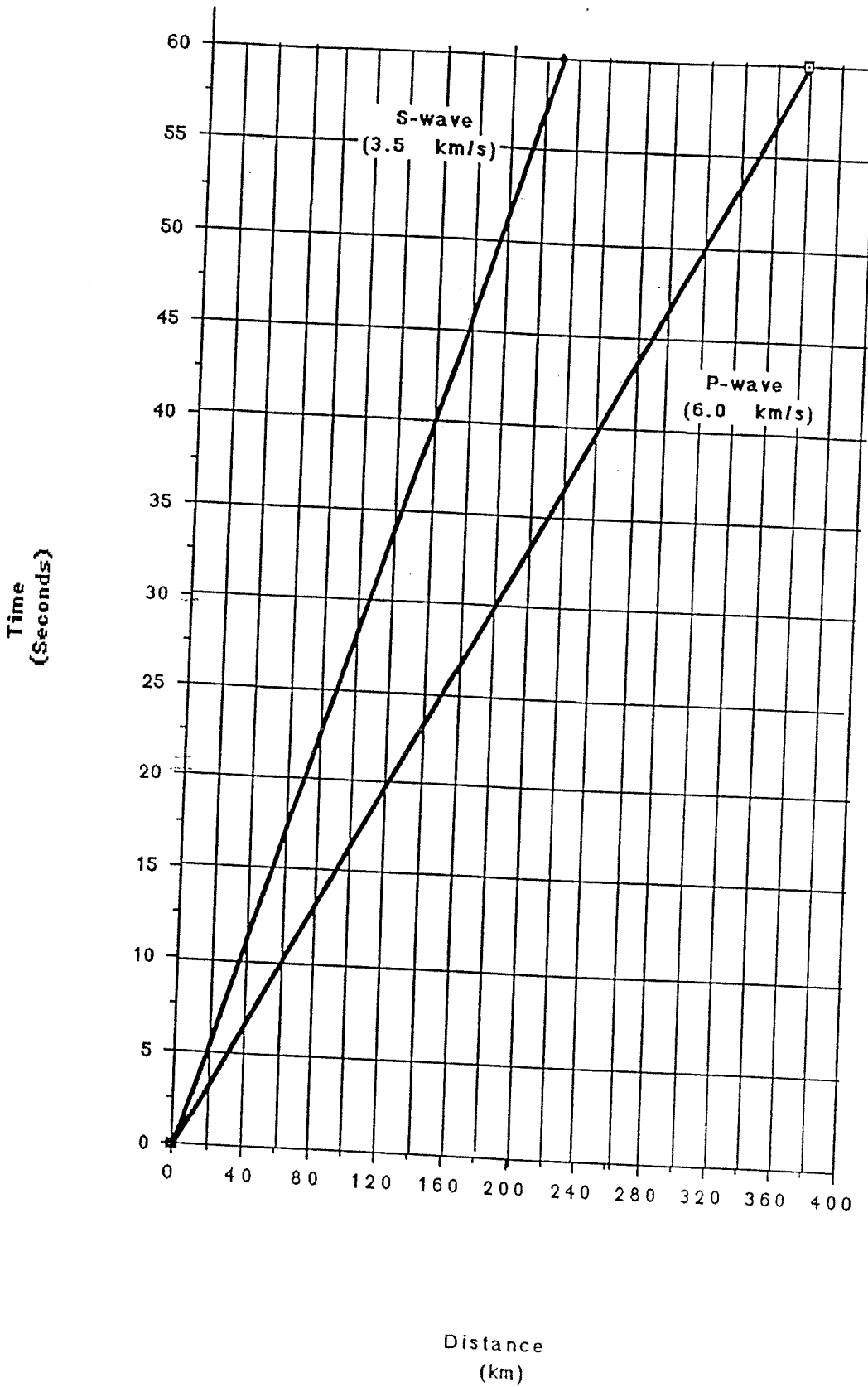
Problem 2.

- A. Compare the effects of the earthquake (Table 3) to the Modified Mercalli Scale (Table 2) and assign an intensity value for each location of Table 3.
- B. Plot the intensity values on Figure 5 and contour the data to produce an ISOSEIMAL MAP. Compare your map with the Shake Maps on www.iris.edu of a recent quake in CA.
- C. Based on the distribution of damage, show the approximate location of the epicenter for the earthquake.
- D. Discuss the reasons for high amounts of damage in San Francisco and Oakland. Why is this damage concentrated so far away from the epicenter?

References:

- Plafker, G. and Galloway, JP (eds), 1989, Lessons learned from the Loma Prieta, California earthquake of October 17, 1989: USGS Circular 1045, 48p.
Stover, CW, 1985, United States Earthquakes 1982: USGS Bulletin, p.57-62.

TRAVEL TIME CURVE



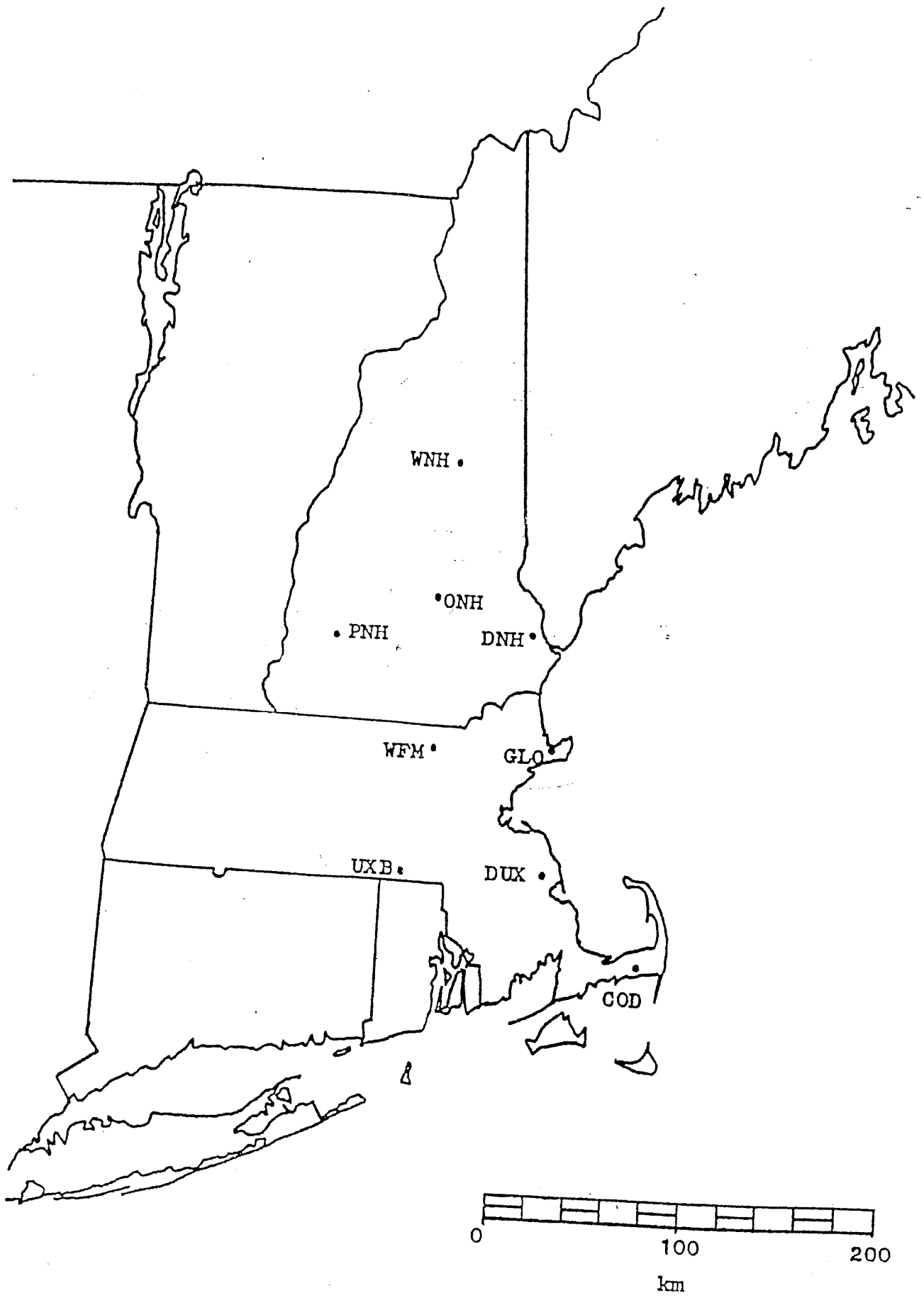


FIGURE 1: Locating Earthquake Epicenter

Table 2. Modified Mercalli intensity scale

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

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

Table 3

<u>Location</u>	<u>Intensity Value</u>	<u>Effects of Earthquake</u>
Mill Valley -		Felt by everyone. Dishes and books knocked from shelves. Some cracked plaster walls.
Berkeley -		Some people who were standing fell down. Much of the plaster walls and some masonry structures damaged.
Oakland -		General panic. Concrete bridges collapsed. Many houses shifted off foundations. Gas leaks reported.
Brentwood -		Many frightened people ran outdoors. Tall trees swayed. Some furniture moved around.
Vernalis -		Some windows broken. Pictures fell off walls. Dishes and glassware broken.
Livermore -		Felt by everyone. People reported that it was not easy to walk. Slight damage to some buildings.
Hayward -		Bookcases fell. Everyone felt earthquake. Many people were frightened.
Fremont -		Doors reported to swing open and closed. Weak plaster and masonry cracked. Not felt in moving cars.
San Francisco -		Many wood frame buildings fell as foundations collapsed. Water and sand observed bubbling from large cracks in ground. Gas leaks caused fires and water pipe breaks made fighting fires difficult.
Pacifica -		Many frightened. Felt by everyone. Knicknacks fell from shelves. Pictures fell off walls.
Monterey -		Furniture overturned. Windows broken. Many people ran outdoors.
Half Moon Bay -		Felt by everyone including people in moving cars. Some chimneys broken. Masonry walls damaged.
San Mateo -		Poorly constructed buildings destroyed. Some people fell down. Church bells rang.
San Jose -		Hanging lights swayed. Bookshelves in public library broken. Weak chimneys broken.
Los Altos -		Small landslides started along stream and highway embankments. Top of church steeple collapsed.
Los Gatos -		Some masonry structures collapsed. Branches broken from large trees. Most people frightened.

- Boulder Creek - Some houses shifted off foundations. Some drivers lost control of vehicles. Grave stones toppled.
- Santa Cruz - Water wells dried up. Some masonry buildings collapsed. Water supply tank collapsed.
- Watsonville - Cracks opened in ground in wet areas. Well built structures damaged slightly. People frightened.
- Gilroy - Noticed by people in moving cars. Older stone walls fell over. Plaster fell from walls.
- Hollister - Swimming pools cracked. People fell down. Little damage in well built structures.
- Salinas - Considerable damage in poorly constructed buildings. Street lights quivered and swayed.
- Monterey - Felt by all. Damage slight. Furniture moved around rooms especially on upper floors.
- Gonzales - Water splashed out of swimming pools. Dishes and glassware broken. Tall trees swayed.

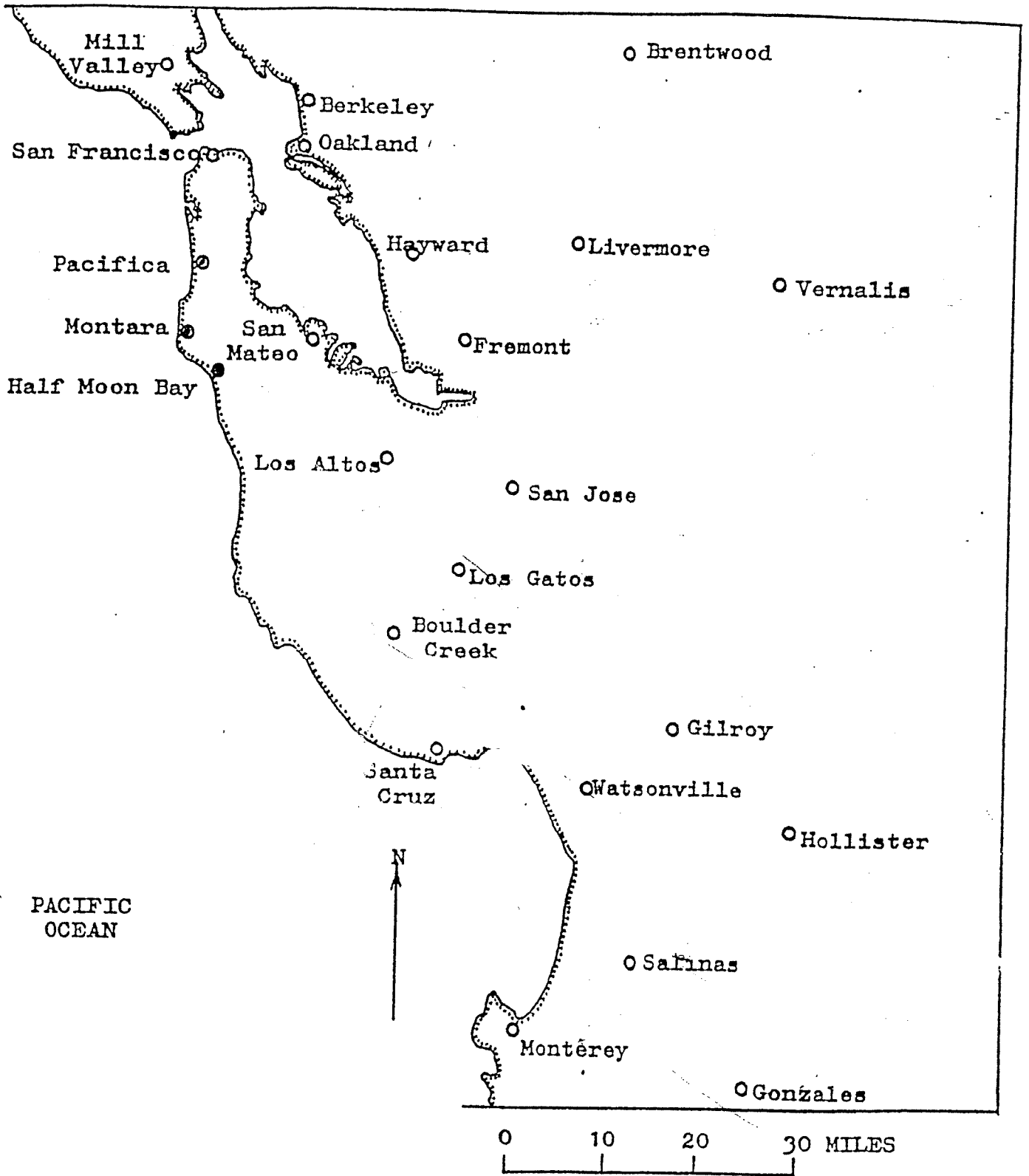


FIGURE 2: Mapping Earthquake Damage