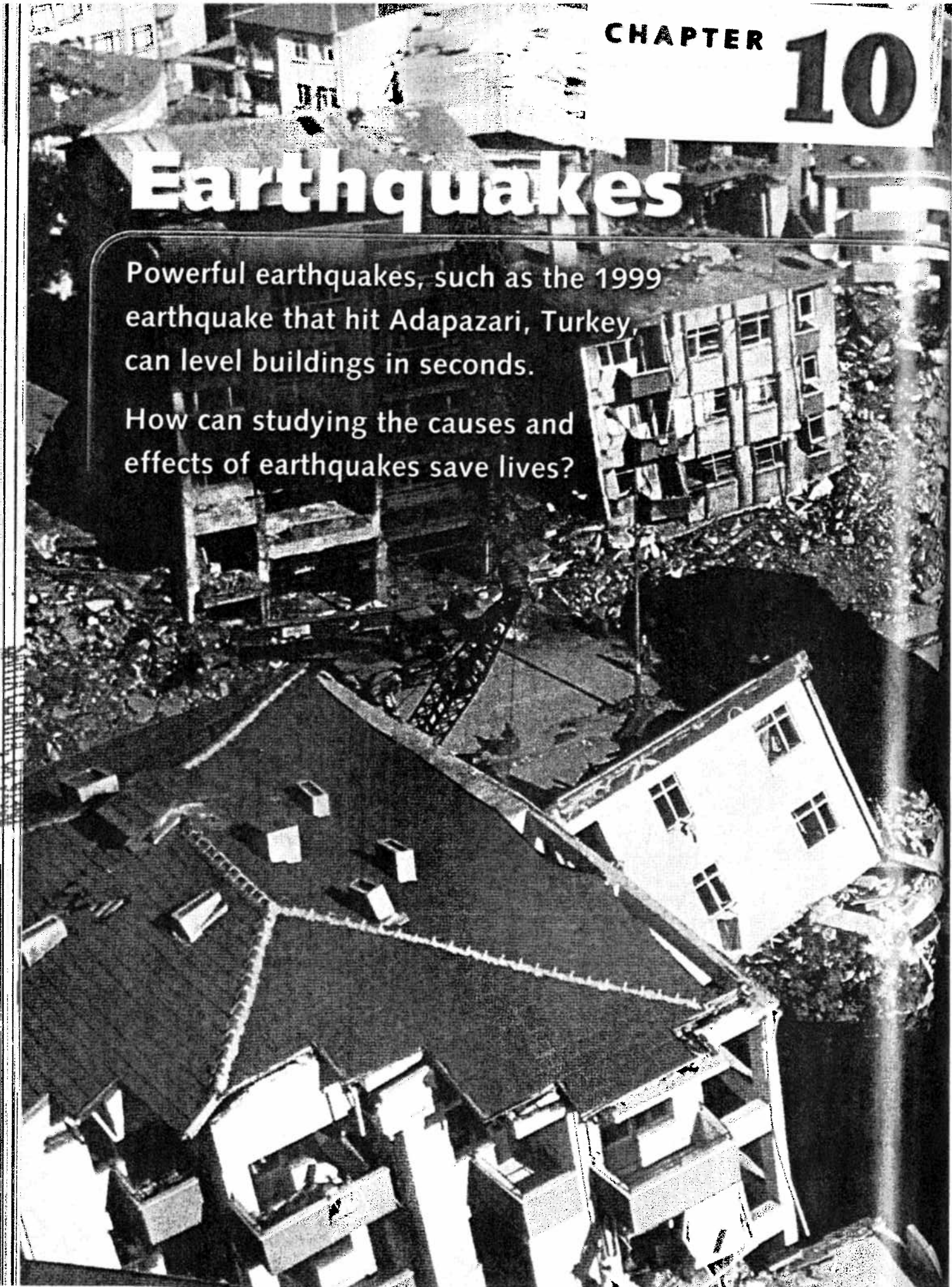


# Earthquakes

Powerful earthquakes, such as the 1999 earthquake that hit Adapazari, Turkey, can level buildings in seconds.

How can studying the causes and effects of earthquakes save lives?



# CHAPTER 10

## PREVIEW

► **FOCUS QUESTIONS** In this chapter you will study earthquakes and learn more about the key questions listed below.

Section 1 How and where do earthquakes occur?

Section 2 How do scientists locate and measure earthquakes?

Section 3 What types of damage do earthquakes cause, and how can people prepare for earthquakes?

Section 4 How do earthquakes help scientists understand Earth's interior?

► **REVIEW TOPICS** As you investigate earthquakes, you will need to use information from earlier chapters.

- mantle (p. 72)
- lithosphere (p. 73)
- plate tectonics (p. 172)
- transform boundary (p. 178)

## ► READING STRATEGY

### CONNECT

As you learned in Chapter 8, most earthquake activity takes place at or near plate boundaries. Before you read Chapter 10, review Chapter 8 and write down key information about each type of plate boundary in your science notebook.



### INTERNET RESOURCES

CLASSZONE.COM

At our Web site, you will find the following Internet support for this chapter.

#### DATA CENTER

#### EARTH NEWS

#### VISUALIZATIONS

- Earthquake Waves
- Effects of Earthquakes
- Earthquake Risk Map
- Movement of P and S waves

#### LOCAL RESOURCES

#### CAREERS

#### INVESTIGATIONS

- How Are Earthquakes Related to Plate Tectonics?
- Where Was That Earthquake?
- Which Fault Moved in the Northridge Earthquake?

# 10.1

## KEY IDEA

Most earthquakes result from the strain that builds up at plate boundaries.

## KEY VOCABULARY

- earthquake
- fault
- focus
- epicenter
- body waves
- P waves
- S waves
- surface waves

## How and Where Earthquakes Occur

More than 3 million earthquakes occur each year, or about one earthquake every ten seconds. Most of these are too small to be noticeable. Each year, however, a number of powerful earthquakes occur. Because such earthquakes are among the most destructive of natural disasters, it is important to understand how and where earthquakes occur in order to prevent the loss of lives and property.

## Causes of Earthquakes

An **earthquake** is a shaking of Earth's crust caused by a release of energy. Earthquakes can occur for many reasons. The ground may shake as a result of the eruption of a volcano, the collapse of a cavern, or even the impact of a meteor. The cause of most major earthquakes is the strain that builds up along faults at or near boundaries between lithospheric plates. A **fault** is a break in the lithosphere along which movement has occurred.

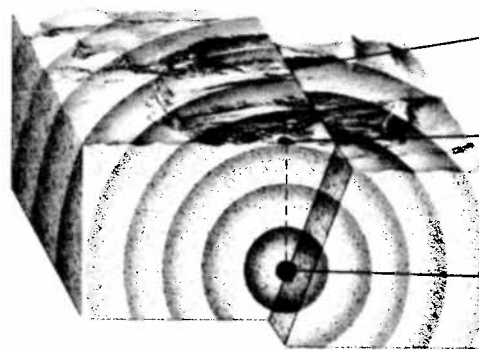
Most of the time, friction prevents the plates from moving, so strain builds up, causing the plates to deform, or change shape. Eventually, the strain becomes great enough to overcome the friction, and the plates move suddenly, causing an earthquake. The plates then snap back to the shapes they had before they were deformed, but at new locations relative to each other. This model of an earthquake is called the elastic-rebound theory.

The point at which the first movement occurs during an earthquake is called the **focus** of the earthquake. The focus is the point at which rock begins to move or break. It is where the earthquake originates and is usually many kilometers beneath the surface. The point on Earth's surface directly above the focus is the **epicenter** of the earthquake. News reports about earthquakes usually give the location of the epicenters.



**EARTHQUAKE** These rows of lettuce were displaced by an earthquake in California in 1979.

### Focus and Epicenter of an Earthquake



**FAULT** Most earthquakes originate at faults along plate boundaries.

**EPICENTER** The epicenter is the point on Earth's surface directly above the focus.

**FOCUS** Energy is released at the focus and travels away from it in all directions.

The depth at which an earthquake originates depends upon the type of plate boundary involved. At divergent boundaries, such as the Mid-Atlantic Ridge, earthquakes tend to occur within 30 kilometers of the surface. Earthquakes also tend to occur at shallow depths along transform boundaries. At subduction boundaries, however, where plates plunge beneath other plates, the focus of an earthquake can be located as far as

700 kilometers beneath the surface. The depth of an earthquake's focus can affect the amount of damage the earthquake causes.

## Body Waves

The energy released in an earthquake travels in waves. Waves that travel from the focus of an earthquake through Earth are called **body waves** because they travel through the material of Earth's body. Every earthquake produces two different types of body waves, called P waves and S waves.

The body waves known as compressional waves, primary waves, or **P waves** squeeze and stretch rock materials as they pass through Earth. P waves can travel through any material—solid rock, magma, ocean water, even air.

The body waves called shear waves, secondary waves, or **S waves** cause particles of rock material to move at right angles to the direction in which the waves are traveling. S waves can travel through solid material, but not through liquids or gases.

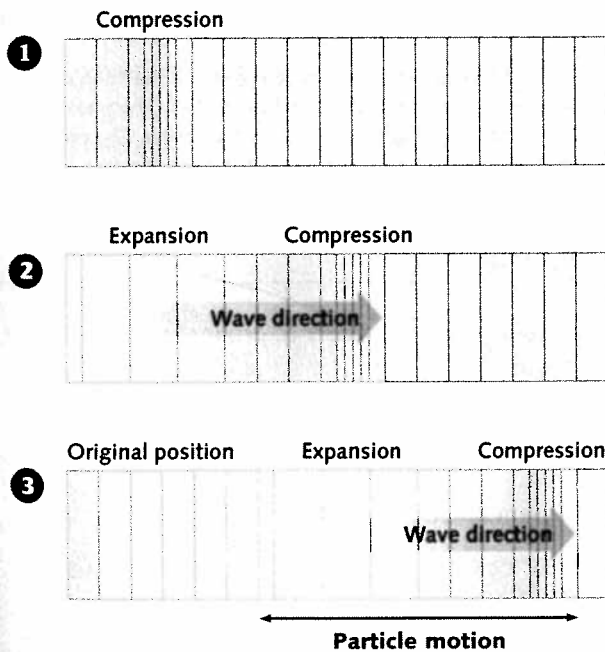
### How Are Earthquakes Related to Plate Tectonics?

Plot earthquakes on a world map. Analyze their location and depths at various plate boundaries.

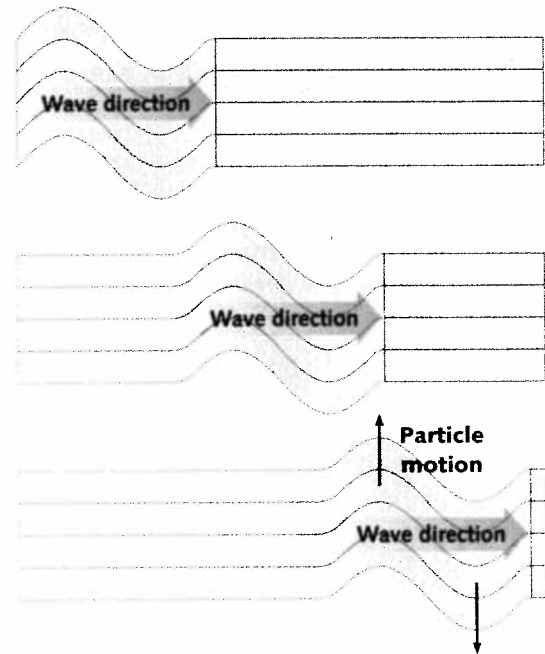
Keycode: ES1001

### Modeling P Waves and S Waves

**P WAVE** As a P wave travels through rock, the rock particles are (1) compressed and (2) expanded before returning to their (3) original positions.



**S WAVE** As an S wave travels through rock, the rock particles move at right angles to the direction in which the wave is traveling.



The rate at which P waves and S waves move depends upon the type and density of the material through which they travel. The velocity of these waves is greater through material that is rigid and dense than it is through material that is less rigid and less dense. Through all types of solid material, S waves usually travel at a little more than half the speed of P waves.

## Surface Waves

As their name implies, **surface waves** are earthquake waves that travel along Earth's surface. When P waves and S waves reach Earth's surface, they produce surface waves. The two types of surface waves are Love waves and Rayleigh waves.

Love waves cause particles of material to move from side to side, in a direction perpendicular to the waves' direction of travel. Rayleigh waves travel more slowly than Love waves and cause particles of material to move in elliptical patterns. The Rayleigh wave pattern is similar to the movement of particles in the ripples that appear on the surface of a lake into which a pebble has been tossed.

Even though surface waves travel more slowly than either P waves or S waves, they are often perceptible far from the epicenter of the earthquake and can cause considerable damage.



Observe animations of earthquake waves.

Keycode: ES1002



**EARTHQUAKE DAMAGE** Surface waves can cause damage far from an earthquake's epicenter, as demonstrated by an earthquake that struck India in 2001. The photograph at the left is from the town of Bhubaneswar, about 20 kilometers from the epicenter. The photograph at the right is from the city of Ahmedabad, about 253 kilometers from the epicenter.

### 10.1 Section Review

- 1 Explain where earthquakes are most likely to originate and why they originate in these places.
- 2 Describe the difference between the focus of an earthquake and the epicenter of an earthquake.
- 3 Draw and label a diagram illustrating two types of surface waves.
- 4 **CRITICAL THINKING** Compare and contrast body waves and surface waves. Explain how the depth of an earthquake's focus might determine the extent of the damage it causes.
- 5 **MATHEMATICS** Suppose an earthquake's P waves travel at an average speed of 6 kilometers per second, and its S waves travel at an average speed of 3.4 kilometers per second. How long will it take the P waves to reach a recording station that is 60 kilometers from the focus? How long after the P waves will the S waves reach the same station?

# Locating and Measuring Earthquakes

An instrument called a **seismograph** detects and records waves produced by earthquakes that may have originated hundreds, even thousands, of kilometers away. Scientists use data from seismographs to locate earthquakes' epicenters and to measure their magnitudes. There are more than 10,000 seismograph stations around the world.

## Seismographs

Because earthquakes produce different types of wave motions, there are different types of seismographs. Some record side-to-side motions. Others record up-and-down motions. A modern seismograph station usually has three seismographs. One records up-and-down motions, another records side-to-side motions in a north-south direction, and a third records side-to-side motions in an east-west direction.

In one common type of seismograph, a heavy weight is attached to a base anchored in bedrock. The weight is attached in such a way that it stays almost perfectly still, even when the bedrock and the base are being shaken by an earthquake.

A record sheet called a **seismogram** is placed on a drum attached to the base. The drum is turned slowly by a clock. Attached to the heavy weight is a pen, with its point resting on the drum. As long as the bedrock is not moving, the pen makes a straight line on the seismogram. When the bedrock shakes, the drum shakes as well. The pen does not shake because it is attached to the heavy weight. As you might expect, when the pen is stationary and the drum moves, the pen produces a zigzag trace. The distance the pen departs from the center line is related to the amount of energy released in the earthquake. To assess how powerful an earthquake is, scientists must determine the distance of its epicenter from the seismograph station.

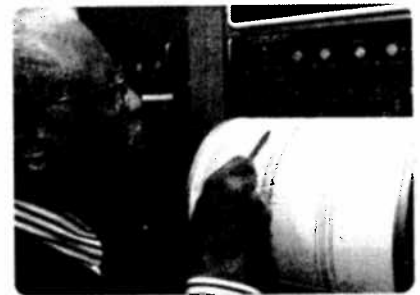
# 10.2

## KEY IDEA

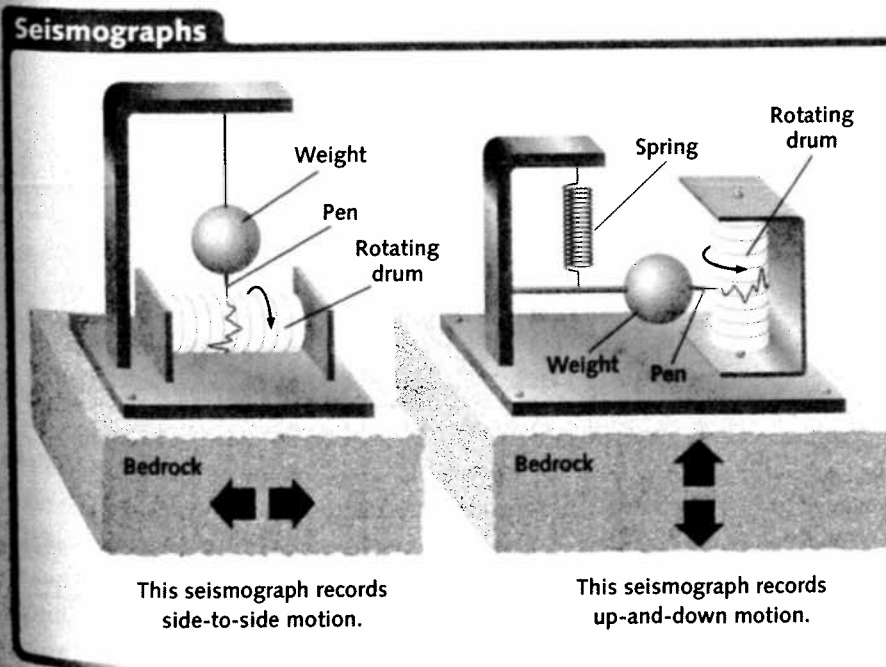
A seismograph is used to determine the magnitude of an earthquake and the location of its epicenter.

## KEY VOCABULARY

- seismograph
- seismogram
- magnitude



**SEISMOGRAM** A seismologist at the National Earthquake Information Center studies a seismogram. Note that *seismogram* refers to the record of an earthquake, while *seismograph* refers to the instrument that records it.



## Interpreting a Seismogram

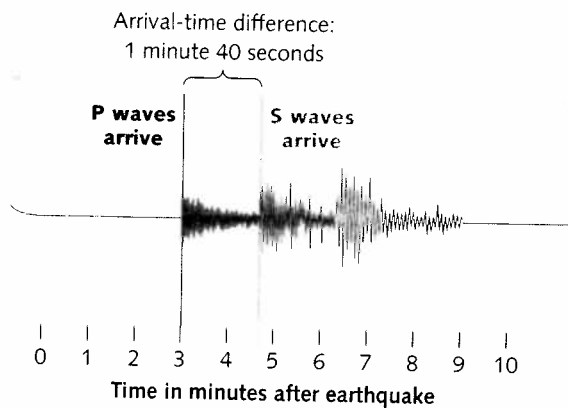
Because P waves travel faster than S waves, the P waves produced by an earthquake always arrive at a seismograph station before the S waves. The first major zigzag on the seismogram marks the arrival of the P waves at the station. As the seismogram below shows, the slower S waves arrive next, producing a different pattern. The seismogram indicates the arrival time of each type of wave.

As the P waves and S waves travel through the ground, the slower S waves lag progressively farther behind. Thus, the farther a seismograph station is from the epicenter, the greater the difference in the arrival times of the P and S waves. Suppose, for example, that a seismograph station in Berkeley, California, records an arrival-time difference of 1 minute 40 seconds between the P waves and the S waves from a given earthquake. (See the seismogram below.) For the same earthquake, a station in St. Louis, Missouri, records a difference of 2 minutes 45 seconds. From this information, you can determine that the St. Louis station is farther from the earthquake's epicenter.

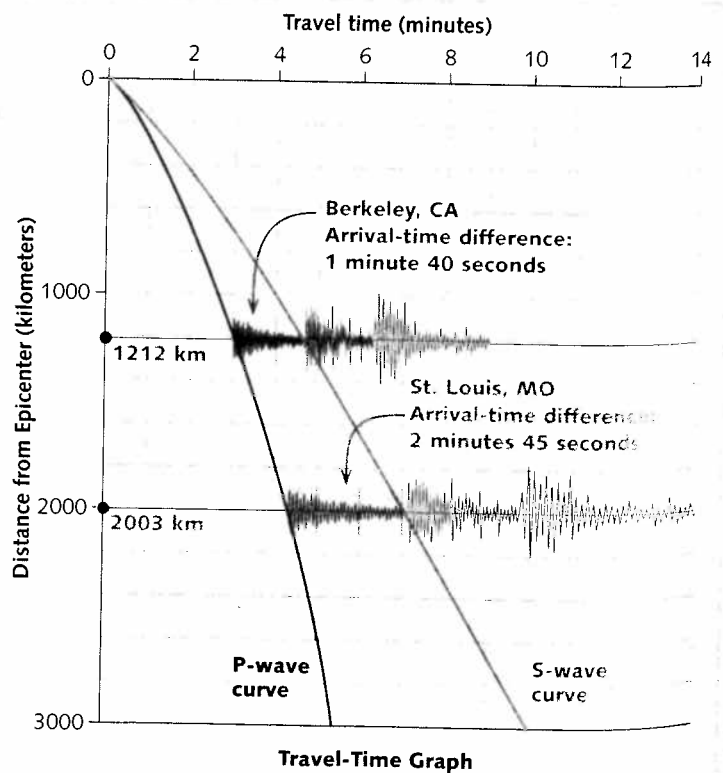
A travel-time graph, such as the one below, shows the relationship between P-wave and S-wave arrival times and the distance from an earthquake's epicenter. Given the difference in arrival times between the first P waves and the first S waves, you can determine the distance to the epicenter. The graph shows that the distance from the Berkeley station to the epicenter is 1212 kilometers; from the St. Louis station, the distance is 2003 kilometers.

### Interpreting a Travel-Time Graph

This seismogram was recorded at Berkeley, California.



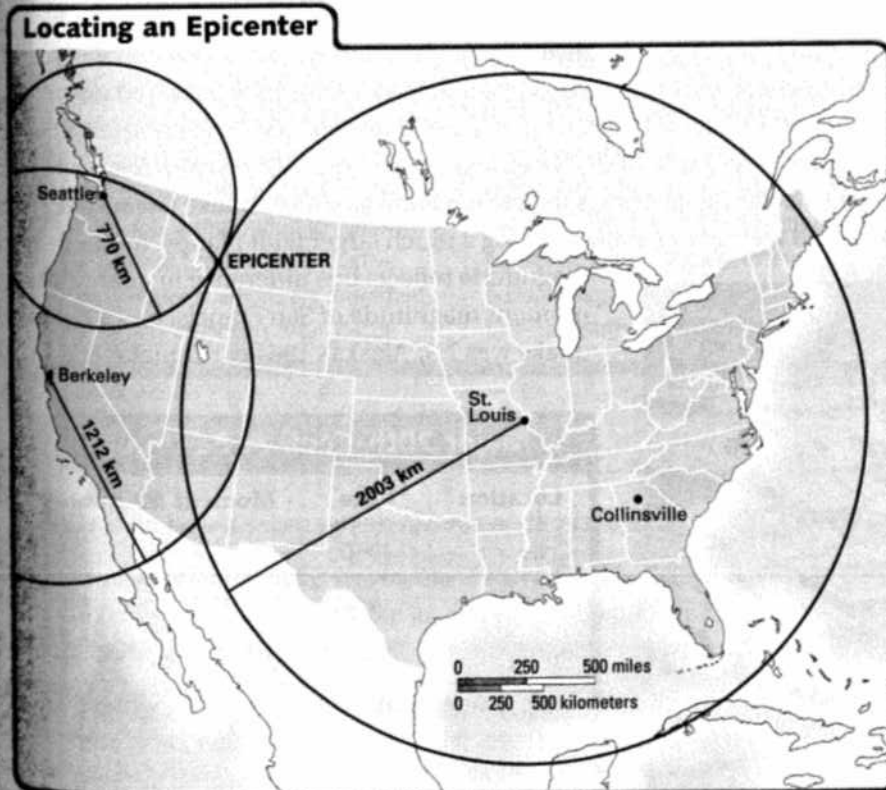
The red curve on the graph at the right shows the times at which an earthquake's first P wave reaches locations at various distances from the epicenter. The blue curve gives the same information about the first S wave. Two seismograms, each showing data from a different seismograph, are superimposed on the graph.



## Locating the Epicenter

Although a seismogram tells scientists the distance between the seismograph station and the earthquake's epicenter; it does not actually give scientists enough information to locate the epicenter. For example, the information from the St. Louis station indicates that an earthquake is located somewhere within a 2003 kilometers radius of St. Louis. (See map below. That makes a very large circle of territory, with St. Louis at its center.) Because the direction from any single station to the epicenter is unknown, scientists need to know the distances from at least three different stations in order to plot an epicenter's location.

Think again about the earthquake with an epicenter 2003 kilometers from St. Louis and 1212 kilometers from Berkeley. Suppose a third station in Seattle, Washington, finds that the distance to the same earthquake's epicenter is only 770 kilometers. To locate the epicenter, one can draw three circles on a map. The center of the first circle is St. Louis; the radius of that circle is 2003 kilometers. Berkeley is at the center of a second circle, with a radius of 1212 kilometers. Seattle is at the center of the third circle, with a radius of 770 kilometers. The point where all three circles meet is the location of the earthquake's epicenter.



In the United States, some 2500 seismograph stations work together to collect earthquake data. Computer technology enables scientists at these stations to analyze and share data about recent earthquake activity quickly. In some areas, such as central California, it takes scientists only about a minute to determine the location of an earthquake and to relay that information to the public.

10-Minute

Mini LAB

### Interpreting a Travel-Time Graph

#### Procedure

- 1 Use the travel-time graph on page 218. Suppose a station in Collinsville, Georgia, records data from the same earthquake. The difference between the P-wave and S-wave arrival times at this station is 3 minutes 45 seconds. Estimate the distance of the Collinsville station from the epicenter.
- 2 Use the map below to check your answer.

#### Analysis

Suppose a seismograph station in Chapel Hill, North Carolina, records data from the same earthquake. Chapel Hill is 3006 kilometers from the epicenter. Predict the difference in P and S wave arrival times at this station. Explain how you determined these arrival times.

**i** INVESTIGATIONS  
CLASSZONE.COM

#### Where Was That Earthquake?

Read seismograms and use the information to locate the epicenter of an earthquake.

Keycode: ES1003

## Measuring an Earthquake's Magnitude

In addition to using seismograms to locate the epicenters of earthquakes, scientists use them to collect other data. For example, seismograms can be used to determine the strength, or **magnitude** (MAG-nih-TOOD), of an earthquake. Magnitude is a measure of the amount of energy released in an earthquake.

One widely used scale of earthquake magnitude was developed by Charles F. Richter (RIHK-tuhr) in 1935. Each increase of one whole number in Richter magnitude represents a 31-fold increase in energy. For example, a magnitude-6 earthquake is about 31 times more powerful than a magnitude-5 earthquake. A magnitude-7 earthquake is about 31 times more powerful than a magnitude-6 earthquake, or about  $31 \times 31$  times more powerful than a magnitude-5 earthquake.

In the years since its introduction, the Richter scale has been shown to have limitations. For example, it does not indicate accurately the amounts of energy released in very large earthquakes. Another measure that scientists now use to describe earthquakes' power is called moment magnitude. Whereas Richter magnitude measures the intensity of ground movements, moment magnitude indicates the energy released at an earthquake's source.

Although not as easy to measure as Richter magnitude, moment magnitude more accurately indicates the total energy involved in an earthquake. For example, the 1906 San Francisco earthquake had an estimated Richter magnitude of 8.3, and the 1964 Alaskan earthquake had a Richter magnitude of 8.5. The Alaskan earthquake, however, released at least twice as much energy as the San Francisco earthquake because it involved greater movements along a much larger fault plane—moment

magnitude reflects this difference in energy. The moment magnitude of San Francisco's 1906 earthquake was 7.9; Alaska's 1964 earthquake, 9.2!



**ALASKA, 1964** The earthquake that struck along the coast of Prince William Sound in 1964 caused massive displacements along faults.

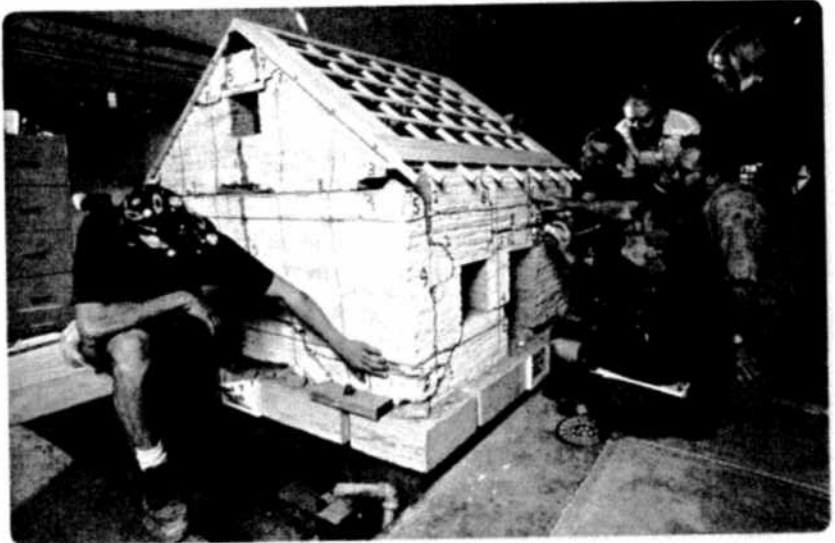
### Major 20th-Century Earthquakes

Location	Date	Moment Magnitude
Chile	1960	9.5
Alaska	1964	9.2
Russia	1952	9.0
Ecuador	1906	8.8
Alaska	1957	8.8
Kuril Islands	1958	8.7
Alaska	1965	8.7
India	1950	8.6
Chile	1922	8.5
Indonesia	1938	8.5

## Earthquake Engineer

**W**hen an earthquake strikes, earthquake engineers find out how well they have done their jobs. Together with teams of architects and other engineers, earthquake engineers design buildings that can withstand earthquakes. They use 3-D computer modeling to evaluate how a building and the ground beneath it will act during a quake. Based on their findings they recommend suitable building materials and construction techniques. Earthquake engineers also evaluate older structures and find ways to reinforce them so that the structures will meet current building standards in earthquake-prone areas.

Most earthquake engineers have advanced degrees in civil or structural engineering. Core studies include math, physics, geology, and chemistry. On the job, a disposition for teamwork and a knack for designing creative, cost-effective solutions are important. Earthquake engineers often divide



**SCALE MODEL** Earthquake engineers use a scale model to test the effects of earthquake tremors on a bracing system.

their time between analyzing data at the office and solving problems at building sites. The job is challenging but rewarding, especially when a building stands up to the ultimate test—an earthquake. ■



Find out more about a career in structural engineering.  
Keycode: ES1004

### 10.2 Section Review

- 1 Explain how a seismograph records earthquake data.
- 2 How is the fact that P waves travel more quickly than S waves used to determine the distance of an earthquake's epicenter from a seismograph station?
- 3 Explain what is meant by *magnitude* with regard to an earthquake, and name two different scales that are used to measure an earthquake's magnitude.
- 4 **CRITICAL THINKING** Suppose one earthquake has a Richter magnitude of 3. A second earthquake has a Richter magnitude of 7. How many times more powerful is the magnitude-7 earthquake than the magnitude-3 earthquake? Explain how you got your answer.
- 5 **PAIRED ACTIVITY** Work with a partner to prepare a presentation on how to locate the epicenter of an earthquake.

# 10.3

## KEY IDEAS

The amount of damage an earthquake causes depends on its magnitude and where it occurs. Safe building practices can limit loss of life and damage to property.

## KEY TERMS

- liquefaction
- aftershock
- tsunami
- seismic gap

## VOCABULARY STRATEGY

The words *liquid*, *liquefy*, and *liquefaction* are closely related. *Liquefaction* comes from a Latin word that means "to make liquid."

## Earthquake Hazards

In January 1995, the city of Kobe, Japan, was rocked by an earthquake with a moment magnitude of 6.9. More than 5000 people were killed, and over 180,000 buildings were badly damaged or destroyed. The Kobe earthquake highlights the vulnerability of people living near Earth's major plate boundaries. By studying the causes and effects of such devastating earthquakes, scientists hope to minimize loss of life in the future.

## Damage from Earthquakes

In an earthquake, ground shaking and foundation failure may cause buildings to collapse. Aftershocks, fire, and tsunamis may cause additional damage.

## Ground Shaking and Foundation Failure

Ground shaking is produced by the waves set in motion by an earthquake's sudden release of energy. The ground vibrates in much the same way that a bell vibrates when struck. Some of these vibrations are up-and-down, but the largest vibrations at Earth's surface are side-to-side motions. Most buildings can withstand fairly violent up-and-down shaking; however, few buildings can survive side-to-side shaking, and as a result many buildings collapse.

As a result of severe ground shaking, soils under buildings may settle or even liquefy. **Liquefaction** occurs when loose soil temporarily takes on some of the properties of a liquid. A building located on soil that settles is no longer safely supported and may collapse. During the 1906 San Francisco earthquake, buildings located on solid rock experienced little damage, while buildings located on bog muds or soft landfill suffered severe damage or collapsed because of foundation failure.

Other earthquakes have caused foundation failure. San Francisco's Marina District sits on landfill that was used to extend the city into San Francisco Bay. In the 1989 Loma Prieta earthquake, this landfill liquefied,

**EARTHQUAKE DAMAGE** This building in San Francisco's Marina District collapsed during the 1989 Loma Prieta earthquake.



shaking buildings off their foundations. In Mexico City, buildings located on unstable lake sediments collapsed during a 1985 earthquake. Liquefaction of sediments also caused great destruction in the 1964 Alaskan earthquake and in a 1999 earthquake that devastated many areas in Turkey.

## Aftershocks and Fire

Even after earthquake waves subside, danger remains. Aftershocks and fires can cause damage to buildings and other structures and can harm people.

A large earthquake may be followed by a series of smaller ones originating close to the focus of the large earthquake. These smaller earthquakes are called **aftershocks**. After a large earthquake the number of aftershocks can be as great as 1000 per day, though the frequency usually diminishes quickly over time. Aftershocks can cause damage to buildings and other structures, especially ones already weakened by ground shaking.

Whenever a large earthquake affects a heavily populated area, there is a danger of fire. In January 1994, an earthquake with a moment magnitude of 6.7 struck Northridge, California, just outside Los Angeles. One of the most damaging effects of this earthquake was the rupturing of gas lines by ground movement. When gas from these lines ignited, towering flames shot up through cracks in the roadways, kindling many large fires.

Fires that broke out after the 1906 San Francisco earthquake raged uncontrolled, largely because the city was not adequately prepared to handle such a calamity. These fires destroyed about 3000 buildings and burned about 11 square kilometers of the city.

## Tsunamis

Underwater earthquakes and landslides sometimes cause huge ocean waves called **tsunamis** (tsu-NAH-meez). A tsunami can travel very quickly across large expanses of water. Its speed depends on the depth of the water. The average depth of the ocean is about 4500 meters. In water that deep, a tsunami's speed is about 750 kilometers per hour. When a tsunami reaches shallower water near a shoreline, however, it slows down and increases dramatically in height.

In 1946, a large earthquake in the Aleutian Islands of Alaska produced one of the largest tsunamis ever recorded. Almost five hours after the earthquake occurred, the tsunami reached the Hawaiian Islands—about 4000 kilometers from the earthquake's epicenter. When it crashed into shore, it caused tremendous damage and destruction, killing 159 people.

In response to this devastating tsunami, officials created a tsunami warning system for regions in the Pacific Ocean. Scientists now carefully monitor seismic activity to identify earthquakes large enough to cause tsunamis. They try to detect tsunamis by monitoring wave activity at various stations throughout the Pacific.



**FIRE** Many fires broke out after the Northridge, California, earthquake in 1994.



Observe video taken during an earthquake.

Keycode: ES1005

## SAFETY TIPS

### EARTHQUAKES

**Before an earthquake**, check your house for potential hazards, such as large, heavy objects that could fall and injure people. Keep disaster supplies readily available.

**During an earthquake**, take cover under a piece of heavy furniture if you are inside. If you are outside, move into the open, away from buildings, lights, and electrical wires.

**After an earthquake**, stay out of damaged buildings and away from downed electrical wires. If you are inside and hear a hissing noise or smell gas, get out of the building immediately, then call for help.



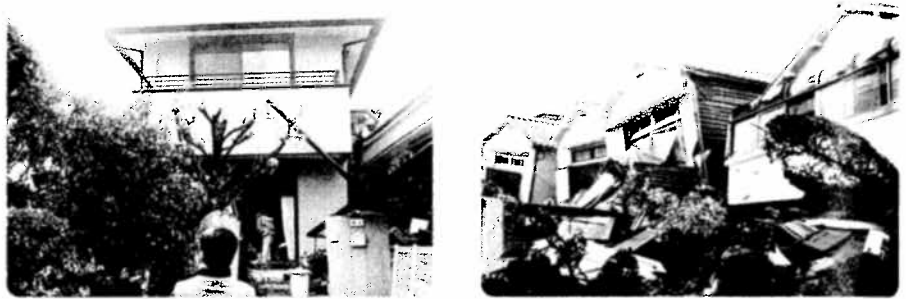
Learn more about earthquake safety.

Keycode: ES1006

## Preventing Earthquake Damage

Most large cities in earthquake-prone areas have building codes intended to prevent structural collapse during an earthquake. These codes are usually developed by scientists and engineers who study how buildings and other structures respond to earthquakes.

For example, in 1981, Japan adopted a revised building code for concrete-frame buildings. After the 1995 Kobe earthquake, engineers discovered that most of the concrete-frame buildings constructed after the new code was adopted had only light damage. Older concrete buildings had suffered far greater damage.



**KOBE EARTHQUAKE, 1995** The photograph on the left shows the undamaged roof of a house. The photograph to the right, taken in the same neighborhood, shows that houses with heavy tile roofs collapsed.

Engineers may try to determine why some structures successfully withstand an earthquake while others collapse. Monitoring equipment installed in and around structures can provide precise records of how different parts of the structures have responded to ground shaking. Over time, the knowledge gained by analyzing such records can help engineers develop better designs for buildings, bridges, and other structures.

## Earthquake Risk

Where in the United States is the risk of earthquakes the greatest? Almost everyone thinks regions lying near plate boundaries, such as California or Alaska, are at greatest risk. But many other areas of the United States are at risk as well. Three of the most powerful earthquakes in U.S. history did not occur anywhere near a plate boundary. They originated near the Mississippi River town of New Madrid, Missouri.

The three earthquakes that struck New Madrid during the winter of 1811 and 1812 were felt throughout most of the northeastern United States. The earthquake activity at New Madrid did not end in 1812. Today the New Madrid region is the most seismically active region east of the Rocky Mountains in the United States.

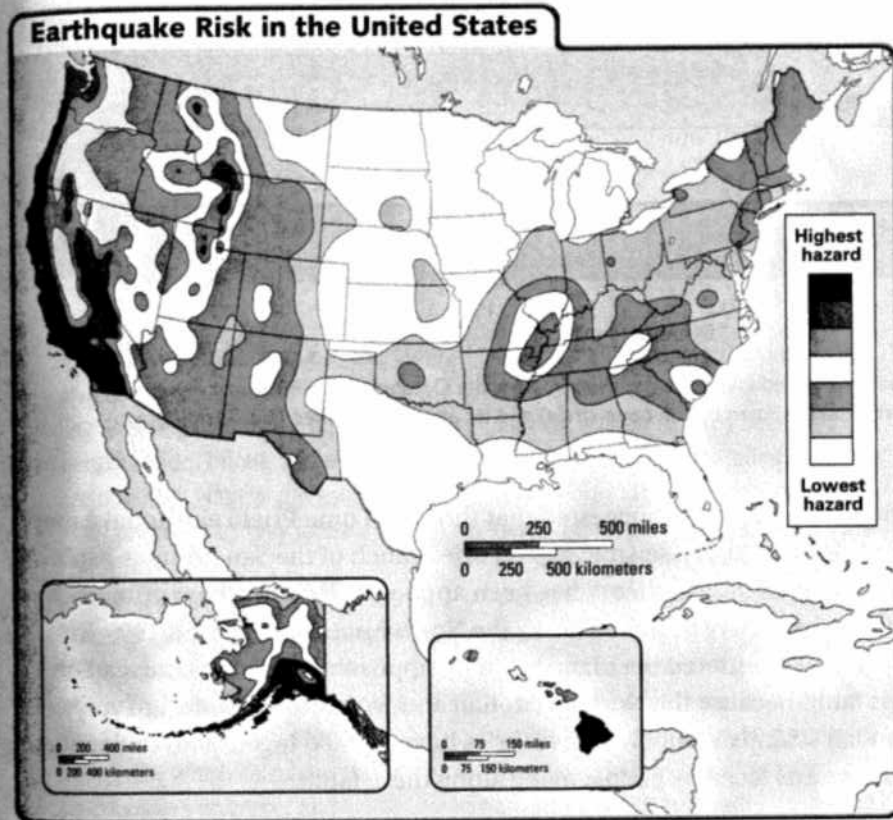
If New Madrid is not on a plate boundary, why is there so much seismic activity there? The activity is caused by many faults buried deep beneath sediments deposited by the Mississippi, Missouri, and Ohio rivers and beneath the thick layers of sedimentary rock that underlie these sediments.

The New Madrid faults are significant because of the size of the area that could be affected by a major earthquake there and because that area is relatively unprepared for such a large earthquake.

The map below shows that some regions in the United States have a much higher risk of experiencing a damaging earthquake than others.

Examine a map showing earthquake risks.

Keycode: ES1007



## Predicting Earthquakes

To be most effective, an earthquake prediction must correctly forecast three things—where an earthquake will occur, when it will occur, and what its magnitude will be.

Many prediction efforts are based on an assumption that earthquakes are periodic events. By studying past earthquake activity, scientists may be able to predict the probability that an earthquake will affect a particular region over the next few years or even decades. Such long-term predictions are useful. They can, for example, help city officials assess the costs and benefits of adopting stricter building codes. Officials in an area where there is a high probability of an earthquake occurring in the next decade might want to make sure that appropriate emergency services are in place.

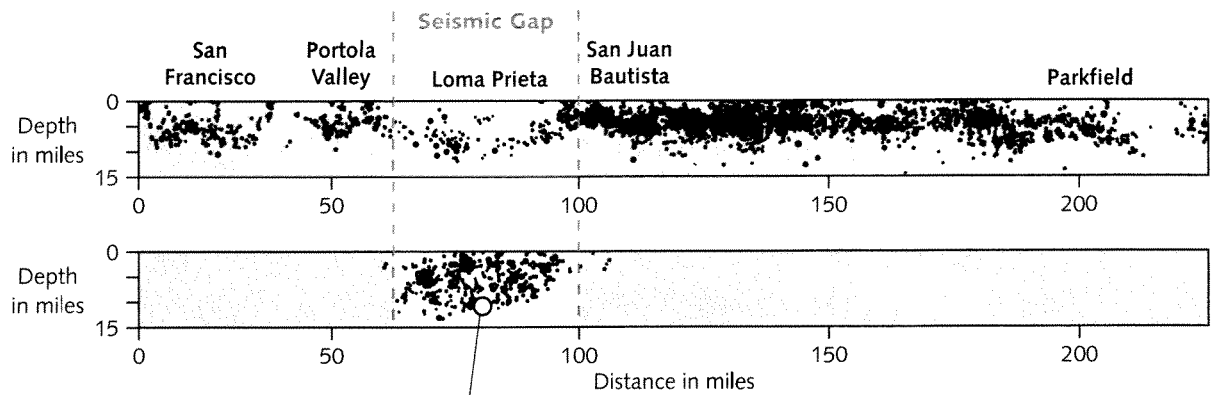
Geologists use data from past earthquakes to evaluate activity along faults. By plotting earthquake foci along a fault, they can identify areas where the fault has not moved over a period. Such areas are called **seismic gaps**. Seismic gaps may be places where stress is building up. Scientists may hypothesize that these locations will be sites of earthquake activity in the future.

### VOCABULARY STRATEGY

The word *focus* comes from the Latin word for "hearth." In many Latin-derived words, including *focus*, *-us* indicates the singular form, and *-i* indicates the plural form, as in *foci*.

## The Loma Prieta Seismic Gap

The top band in the diagram shows the depths of earthquake foci along a cross section of the San Andreas fault from January 1969 through July 1989. Notice that there are fewer data points in the seismic gap—the blue area.



The lower band in the diagram shows how the October 17, 1989, Loma Prieta earthquake (shown by the open circle) and its aftershocks filled in a seismic gap.

Some scientists have suggested that the 1989 Loma Prieta earthquake may have originated in a seismic gap on one branch of the San Andreas Fault.

The seismic-gap theory has been applied in Turkey, where numerous earthquakes have occurred along the North Anatolian Fault. In 1999, an earthquake centered near Izmit, Turkey, appeared to fill a seismic gap on this fault. Because the North Anatolian and San Andreas faults are very similar, scientists from both countries have worked together to understand the hazards faced by people living along these faults.

### 10.3 Section Review

- 1 Describe how ground shaking and liquefaction can cause buildings to collapse.
- 2 How can studying the effects of earthquakes help engineers improve the safety of buildings and other structures?
- 3 Describe a seismic gap and explain why it may be a site of future earthquake activity.
- 4 **CRITICAL THINKING** Local planning organizations often decide whether residential developments can be built within their cities or towns. How would the type of soil in an area near a fault affect the area's suitability for development of high-rise residences?
- 5 **SOCIAL STUDIES** Most earthquake predictions are long-term. They may state the probability that an earthquake will happen in the next few years or the next few decades. Work with others to develop a list of the benefits of long-term earthquake predictions. Explain why it would be valuable to find ways to improve short-term predictions.

## Earthquakes: Technology to the Rescue

On October 17, 1989, millions of TV viewers waited eagerly for a World Series game to begin in San Francisco. Suddenly, the announcer said, "We're having an earth . . .," and the picture and sound from the ballpark were cut off. Few people had trouble guessing how the announcer had finished his sentence.

What are some of the emergency situations people face after an earthquake? How can technology help communities respond quickly to these emergencies?

**E**arthquakes as strong as the 1989 Loma Prieta quake can cripple a city. Buildings crumble, trapping people inside. Phone and electric lines are downed. Natural gas escaping from broken lines may ignite and cause fires.

One technology that helps people respond quickly to these emergencies is the seismographic network. During an earthquake, remote seismographs send information to a central computer, which calculates the earthquake's epicenter and magnitude. Within minutes, scientists and emergency managers get this information on pagers. The scientists feed the information into a computer that relates it to local geological

conditions. The computer produces a color-coded map showing where shaking is likely to have been strongest. (A map created after the 1994 Northridge earthquake is shown below.) Emergency managers use the map to determine where building damage and human injuries may be the most serious. Rescue crews are then sent to those areas.

Emergency managers also rely on simple radio technology to protect rescue workers from dangerous aftershocks. Because radio waves travel more quickly than seismic waves, radios can be used to give rescue workers advance warning of potential shaking. The benefits of such an emergency warning system



**PAGERS** Soon after an earthquake occurs, scientists and others receive critical data on pagers.

were apparent after the Loma Prieta earthquake. The warning came just in time when workers clearing wreckage from a collapsed freeway were told that they had 25 seconds to move to safety before an aftershock would rumble through the area. ■

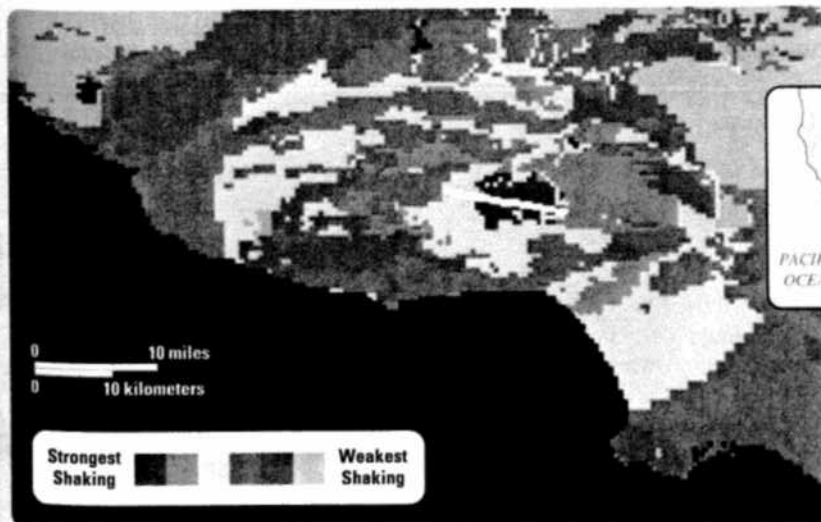
### Extension

#### RESEARCH ACTIVITY

Research the supplies that should be included in an earthquake disaster kit. Create an emergency supply kit.



Learn more about the impact of earthquakes in populated areas.  
Keycode: ES1008



**ANALYZING** Emergency officials used this computer-generated map to make important decisions about how to provide emergency relief after the 1994 Northridge earthquake. The white line represents the fault along which the earthquake occurred.

# 10.4

## KEY IDEA

Scientists use data from seismic waves to learn about the structure of Earth's interior.

## Studying Earth's Interior

By studying earthquakes, scientists have learned about the structure of Earth's interior. Seismologists have observed that the velocities of both P waves and S waves increase when the waves travel through more dense material, and decrease when the waves travel through material that is less dense. In addition, evidence shows that S waves cannot travel through liquids. Knowledge about P-wave and S-wave velocities through materials of different densities has made it possible for geologists to infer the depths and characteristics of Earth's layers.

For example, scientists observe a sharp change in velocities at a depth of 2900 kilometers, at the core-mantle boundary. P waves are greatly slowed at this boundary, and S waves are stopped. Because S waves cannot travel through liquids, scientists conclude that the material directly below 2900 kilometers, the outer core, must be liquid. P-wave velocity increases again at a depth of about 5200 kilometers. This increase in speed suggests that the inner core, like the mantle, is solid.

## The Shadow Zone

Even though an earthquake's waves travel in all directions from its focus, not all seismograph stations can receive information from the earthquake. Seismograph stations in what is called the earthquake's shadow zone cannot detect P waves or S waves from the earthquake. The shadow zone is a wide belt around the side of Earth opposite the focus of the earthquake.

Why does the shadow zone exist? The diagram below shows that P waves passing through the mantle are refracted (bent) in smooth arcs back to the surface. When P waves travel deep enough to enter the outer core, however, they are refracted again as they enter the outer core and yet again when they re-enter the mantle. As a result, seismograph stations that are between the earthquake's epicenter and the shadow zone receive both

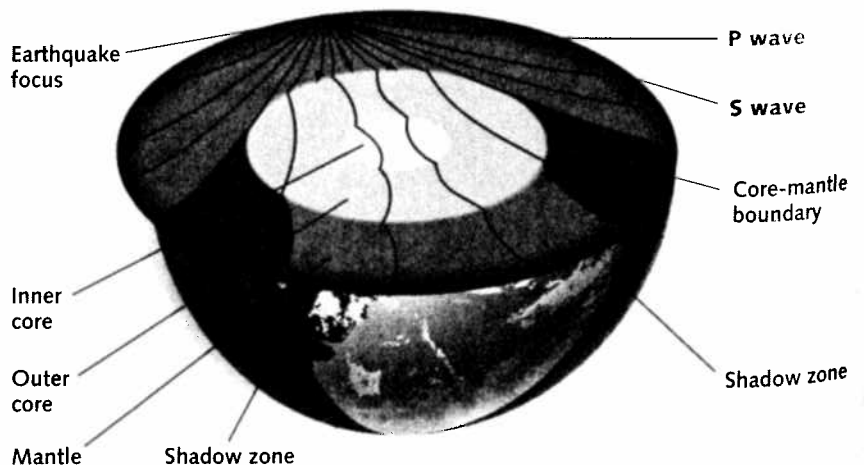
### VISUALIZATIONS CLASSZONE.COM

Examine P and S waves moving through Earth's interior.

Keycode: ES1009

### P and S Waves Inside Earth

Because P waves are refracted and S waves cannot travel through the liquid outer core, seismograph stations in the shadow zone do not receive any waves from the earthquake.



P waves and S waves. Stations within the shadow zone receive neither P waves nor S waves. This is because P waves have been refracted away and S waves cannot pass through the liquid outer core. Stations that are beyond the shadow zone on the opposite side of Earth receive only P waves because the liquid outer core stops the S waves.

## The Moho

An abrupt change in the velocities of P waves and S waves occurs at the boundary between the crust and the mantle. In 1909, Croatian seismologist Andrija Mohorovičić (ahn-DREE-yah maw-HAWR-aw-VEE-cheech) discovered this fact while studying seismograms of minor earthquakes. Several seismograms showed two distinct groups of P waves and S waves. One of the groups had traveled at an average velocity of 6.75 kilometers per second, but the other had sped up to 8 kilometers per second. He reasoned that the second group had gone through denser material below the crust. He calculated the depth of the denser material to be about 50 kilometers. The boundary he discovered is named the *Mohorovičić discontinuity*, or *Moho* for short. This boundary is where the dense rock of the mantle meets the less dense rock of the crust. Additional study has revealed that the Moho is located about 32 kilometers under the continents and between 5 and 10 kilometers under the oceans.

## The Transition Zone

Abrupt changes in P-wave and S-wave velocities occur when the waves pass across boundaries between rocks of different compositions. Yet experiments have shown that between depths of 400 and 670 kilometers, seismic-wave velocities increase more quickly than expected. These depths mark a region in the middle of the mantle called the transition zone. The transition zone separates the upper mantle from the denser lower mantle.

If the mantle is made up of the same kind of material throughout, what could cause the P-wave and S-wave velocities to change in the middle of the mantle? The answer to this question has to do with the fact that the material deeper within the mantle is under greater pressure from the overlying material. This increase in pressure compresses the material in the lower mantle. As a result, the material is more dense, and P waves and S waves travel more quickly through it.

### 10.4 Section Review

- 1 How was the Moho discovered?
- 2 **CRITICAL THINKING** Explain why the shadow zone of an earthquake in Japan would be different from the shadow zone of an earthquake in California.
- 3 **APPLICATION** Petroleum geologists can use seismic waves to locate oil beneath Earth's surface. Oil is usually trapped in porous rock that lies beneath a layer of denser rock. Predict how the speed of a seismic wave would change as it traveled through these layers.

### Scientific Thinking

#### COMMUNICATE

In 1691, astronomer Sir Edmund Halley proposed that Earth was hollow, with another sphere inside it that was illuminated and inhabited. Authors such as Jules Verne and Edgar Rice Burroughs later wrote fiction that was inspired by Halley's idea. Draw a diagram or write a description to explain how data from seismic waves disproves Halley's hypothesis.

## "Earthquake Engineering"

## SKILLS AND OBJECTIVES

- **Design** a model of an earthquake resistant building.
- **Record** a procedure for repeatability.
- **Build** the design.
- **Test** the model using an earthquake simulation device.
- **Improve** the design based on initial trials.

## MATERIALS

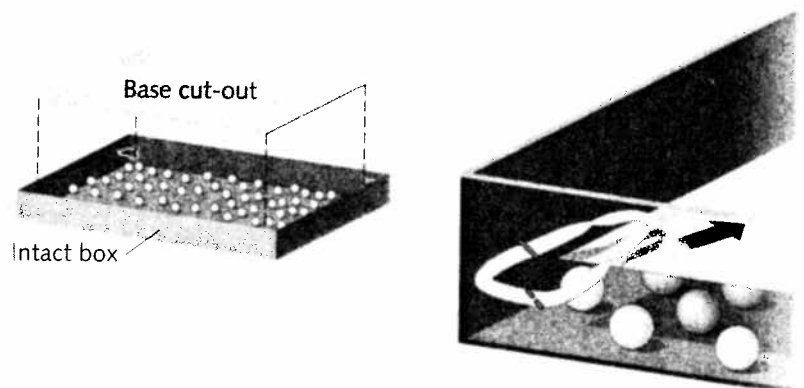
- 40 coffee stirrers (per model)
- 40 mini-marshmallows (per model)
- metric ruler
- 2 identical shallow cardboard boxes
- scissors
- 10–20 marbles
- 4 small rubber bands
- stapler

Earthquakes can occur even in areas where they are not fairly common. Sometimes the loss of lives and homes in such areas is greater than in high-risk areas due to a lack of earthquake preparedness. A building's design determines how well the structure withstands earthquake stress. In this activity, you will design, build and test an earthquake resistant structure.

## Procedure

## Part A: Build an Earthquake Platform

- 1 Using the scissors, cut the bottom of one of the boxes so that the piece will fit inside the other box with a 2-cm clearance on all sides.
- 2 Staple a rubber band to each inside corner of the intact box.
- 3 Fill the intact box with the marbles. Place the cardboard base cut-out on top of the marbles.



- 4 Staple the free end of each corner rubber band to the corresponding corner edge of the base cut-out, making sure that each rubber band connection is taut.
- 5 To simulate a model "earthquake," gently pull one side of the cut-out (the earthquake platform) to the edge of the outside box and let go.

## Part B: Design and Build an Earthquake-Resistant Structure

- 6 Design an earthquake-resistant structure to be made of marshmallows and stirrers, that will most optimally resist collapse on the earthquake platform. The structure should be at least 50 cm tall. Record the procedure for assembling your design; make diagrams as necessary.

The building instructions should be detailed enough so that another person can accurately build your structure.

- 8 Build your structure using the available materials.
- 9 Design a procedure to test your model. Record the testing procedure, outlining the duration of shaking time and number of trials. Also detail the criteria by which you will judge the quality of your model.
- 10 Test the quality of your design by placing it on the earthquake platform. Be sure to follow your testing procedure. Use a chart such as the one shown below to record your results and observations.

Trial Number	Model Number	Shake Duration	Observations After the Simulation

- 11 Use what you have learned from your testing to design several more structures. Record or diagram the assembly instructions for each.
- 12 Build and test the additional structures.

## Analysis and Conclusions

1. Which of your designs holds up to the "earthquake" test the best? What aspects of its structure do you think help it resist the earthquake stress? Do you know of any buildings that have a similar structure?
2. What type of earthquake motion does the "earthquake" tray simulate? How could you simulate other earthquake motions?
3. Based on your models, hypothesize how the duration or strength of the shaking affects structural damage.
4. When designing earthquake resistant buildings structural engineers focus on shock absorption. In what way, if any, does your building model provide shock absorption?
5. Besides the architectural design, what other factors do you think affect the ability of a building to resist damage during an earthquake?



Learn more about creating earthquake resistant structures.

Keycode: ES1011

# CHAPTER 10

## REVIEW

### Summary of Key Ideas

**10.1** An earthquake is a shaking of Earth's crust caused by a release of energy. Most earthquakes are caused by strain that builds up along faults at or near boundaries between lithospheric plates. Earthquakes produce body waves and surface waves.

**10.2** A seismograph detects and records earthquake waves. Scientists use seismograph data to locate an earthquake's epicenter and determine its magnitude. The Richter scale and moment magnitude are two measures of magnitude.

**10.3** Earthquake hazards include ground shaking and liquefaction, aftershocks, fires, and tsunamis. Damage and loss of life can be minimized through use of building codes. Long-term predictions about earthquakes help people decide how and where to implement building codes and emergency services.

**10.4** Scientists use earthquake data and knowledge about earthquake waves to make inferences about Earth's interior.

### KEY VOCABULARY

aftershock (p. 223)	P waves (p. 215)
body waves (p. 215)	S waves (p. 215)
earthquake (p. 214)	seismic gap (p. 225)
epicenter (p. 214)	seismogram (p. 217)
fault (p. 214)	seismograph (p. 217)
focus (p. 214)	surface waves (p. 216)
liquefaction (p. 222)	tsunami (p. 223)
magnitude (p. 220)	

### Vocabulary Review

Write the term from the key vocabulary list that best completes the sentence.

1. Smaller earthquakes called \_\_\_\_\_ may follow a large earthquake.
2. The Richter scale is used to describe the strength, or \_\_\_\_\_, of an earthquake.
3. An underwater earthquake may generate a large ocean wave called a \_\_\_\_\_.

Explain the difference between the terms in each pair.

4. epicenter, focus
5. body waves, surface waves
6. seismograph, seismogram

### Concept Review

7. According to the elastic-rebound theory, what is a cause for earthquakes along plate boundaries?
8. At what type of plate boundary do very deep earthquakes tend to occur?
9. What information about an earthquake can scientists obtain from seismograms?
10. Compare the strengths of an earthquake whose Richter magnitude is 5 and an earthquake whose Richter magnitude is 7.
11. What is liquefaction and how does it occur?
12. What data do scientists need to determine whether a seismic gap may exist along a fault?
13. How is the shadow zone of an earthquake related to the focus of the earthquake?
14. **Graphic Organizer** Use the following terms to complete the flow chart: *surface waves*, *foundation failure*, *liquefaction*.

? → ? → ?

## Critical Thinking

15. **Compare** In what way is the time difference between the arrival of P waves and S waves at a seismograph station like the time difference between a lightning flash and thunder?
16. **Predict** The diagram on page 226 shows the Loma Prieta seismic gap. Identify another seismic gap on the diagram. What predictions might scientists make for the region where this seismic gap is located?
17. **Analyze** Use the travel-time graph on page 218. Determine the distance to the epicenter if difference in the arrival times of the P waves and the S waves is 2 minutes and 30 seconds.
18. **Infer** Rocks of the eastern United States are cooler and more dense than rocks near the West Coast. The cooler rocks transmit seismic waves better. How might these facts explain why the New Madrid earthquakes affected such a large region?

## Interpreting Data

The drawings at the right are seismogram tracings made at three seismograph stations for the same earthquake. The arrival times of the P waves and S waves are indicated on each tracing.

19. Which wave arrived at each seismograph station first? Why?
20. How long after the earthquake did the P wave arrive at station A? Give your answer to the nearest minute.
21. How long after the earthquake did the S wave arrive at station B? Give your answer to the nearest minute.
22. What is the difference between the arrival times of the P waves and the S waves at station C?
23. Station B was located nearest to the earthquake's epicenter, while station A was farthest away. Cite three types of evidence from the tracings to support this statement.

## Internet Extension



**Which Fault Moved in the Northridge Earthquake?**  
Use epicenter location information and a shaking intensity map to pinpoint the fault that moved in this 1994 California earthquake.

Keycode: ES1010

## Writing About the Earth System

**SCIENCE NOTEBOOK** During the last ice age, massive ice sheets covered the northern regions of North America. Some scientists have hypothesized that the New Madrid earthquakes are related to the melting of those ice sheets. When the ice melted, a great weight was removed from the continent. As a result, the continent may still be rebounding. Earthquakes occur from time to time as the land adjusts to the removal of the ice. According to this hypothesis, which of Earth's spheres are interacting? What other spheres are affected by their interaction?

Seismogram Tracings

