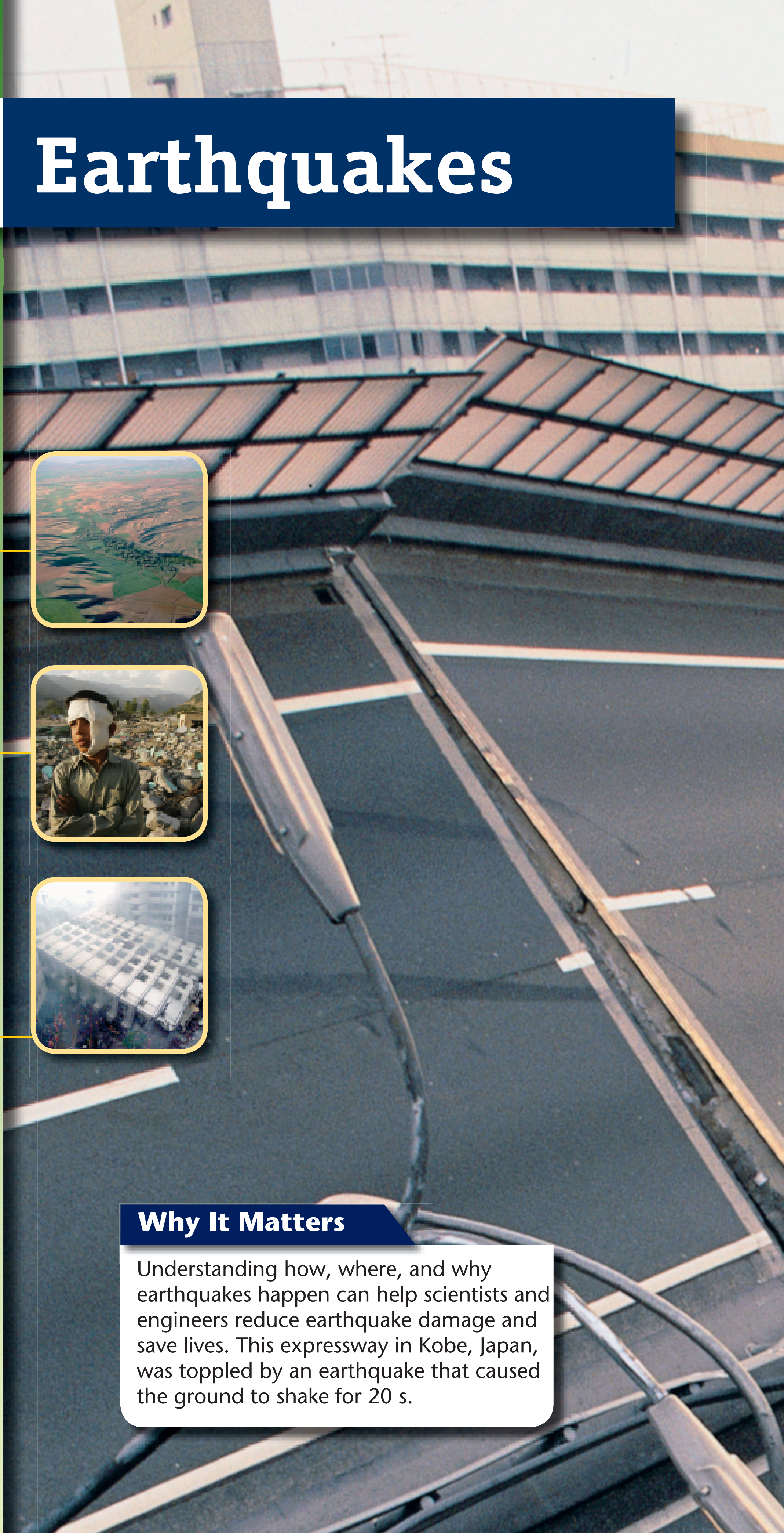
Chapter 12

Earthquakes



Chapter Outline

1 How and Where Earthquakes Happen

Why Earthquakes Happen

Seismic Waves and Earth's Interior

Earthquakes and Plate Tectonics

Fault Zones

2 Studying Earthquakes

Recording Earthquakes

Locating an Earthquake

Earthquake Measurement

3 Earthquakes and Society

Tsunamis

Destruction to Buildings and Property

Earthquake Safety

Earthquake Warnings and Forecasts

Why It Matters

Understanding how, where, and why earthquakes happen can help scientists and engineers reduce earthquake damage and save lives. This expressway in Kobe, Japan, was toppled by an earthquake that caused the ground to shake for 20 s.

Inquiry Lab

10 min

Modeling Earthquake Waves

Have two people stretch a spring toy along the floor. Hold one end of the spring still. Use push-pull motion at the other end to make a wave. Observe how the wave moves along the spring.

Shake one end of the spring from side to side to make a wave. Observe how this wave moves along the spring.

Draw a diagram showing characteristics of each wave.

Questions to Get You Started

1. Which wave moved parallel to the spring?
2. Which wave moved perpendicular to the spring?

READING TOOLBOX

These reading tools will help you learn the material in this chapter.

Word Parts

Root Words Many scientific words are made up of word parts derived from ancient or foreign languages. Understanding the meanings of these word parts can help you understand new scientific terms. Consider the term *seismic wave*. It contains the root word *seism-*, which comes from the Greek word *seismos*, meaning "earthquake."

Your Turn On a separate sheet of paper, start a table like the one below. As you read Section 2, find words that contain the root *seismo-* or *seism-* and make entries in the table for them.

Word or Term	Root	Definition
seismic wave	seism-	vibration that travels through Earth; often caused by an earthquake
seismology	seismo-	
seismograph		

Classification

Classifying Seismic Waves Classification is a tool for organizing objects and ideas by grouping them into categories. Groups are classified by defining characteristics. For example, the table below shows how seismic waves can be classified by their speed and type of movement they cause in Earth's crust.

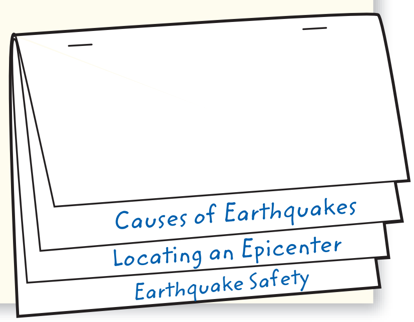
Your Turn As you read Section 1, make a table like the one below for the following classes of seismic waves: P waves, S waves, Love waves, and Rayleigh waves.

CLASS	DEFINING CHARACTERISTICS
P waves	a type of body wave; fastest seismic wave; causes particles to travel in a direction parallel to the direction of travel of the wave
S waves	

FoldNotes

Layered Book FoldNotes are a fun way to help you learn and remember ideas that you encounter as you read.

Your Turn Make a layered book, as described in **Appendix A.** Label the tabs of the layered book with "Causes of Earthquakes," "Locating an Epicenter," and "Earthquake Safety." Write notes on the appropriate layer as you read the chapter.



For more information on how to use these and other tools, see **Appendix A.**

SECTION 1

How and Where Earthquakes Happen

Key Ideas	Key Terms		Why It Matters
❯ Describe elastic rebound. ❯ Compare body waves and surface waves. ❯ Explain how the structure of Earth's interior affects seismic waves. ❯ Explain why earthquakes generally occur at plate boundaries.	**earthquake** **elastic rebound** **focus** **epicenter** **body wave**	**surface wave** **P wave** **S wave** **shadow zone** **fault zone**	Understanding earthquakes helps people limit the destruction and loss of life that earthquakes can cause. Studying earthquakes also helps scientists understand Earth's interior.

Earthquakes are one of the most destructive natural disasters. A single earthquake can kill many thousands of people and cause billions of dollars in damage. **Earthquakes** are defined as movements of the ground that are caused by a sudden release of energy when rocks along a fault move. Earthquakes usually occur when rocks under stress suddenly shift along a fault. A *fault* is a break in a body of rock along which one block slides relative to another.

Why Earthquakes Happen

The rocks along both sides of a fault are commonly pressed together tightly. Although the rocks may be under stress, friction prevents them from moving past each other. In this immobile state, a fault is said to be *locked*. Parts of a fault remain locked until the stress becomes so great that the rocks suddenly slip past each other. This slippage causes the trembling and vibrations of an earthquake.

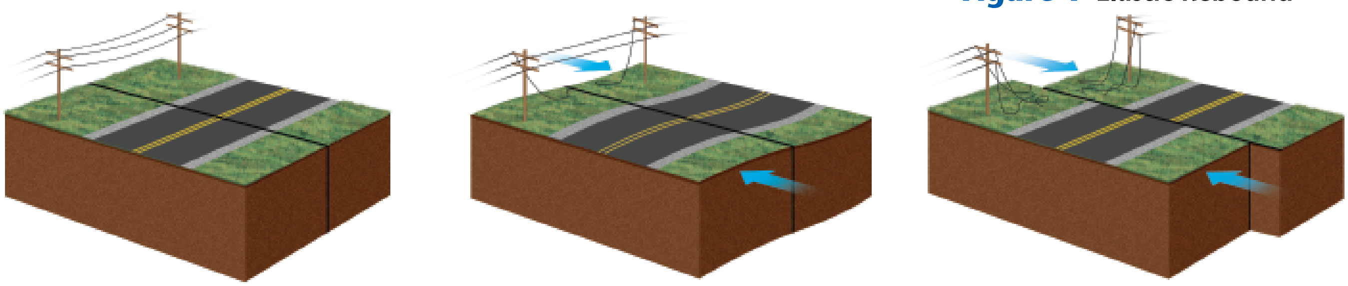
earthquake a movement or trembling of the ground that is caused by a sudden release of energy when rocks along a fault move

elastic rebound the sudden return of elastically deformed rock to its undeformed shape

Elastic Rebound

Earthquakes are a result of elastic rebound. **Elastic rebound** is the sudden return of elastically deformed rock to its undeformed shape. This process is shown in **Figure 1.**

Figure 1 Elastic Rebound



Two blocks of crust pressed against each other at a fault are under stress but do not move because friction holds them in place.

As stress builds up at the fault, the crust deforms. When rock is stressed past the point at which it can maintain integrity, it fractures.

When the rock fractures, it separates at the weakest point and snaps back, or *rebounds,* to its original shape, which causes an earthquake.

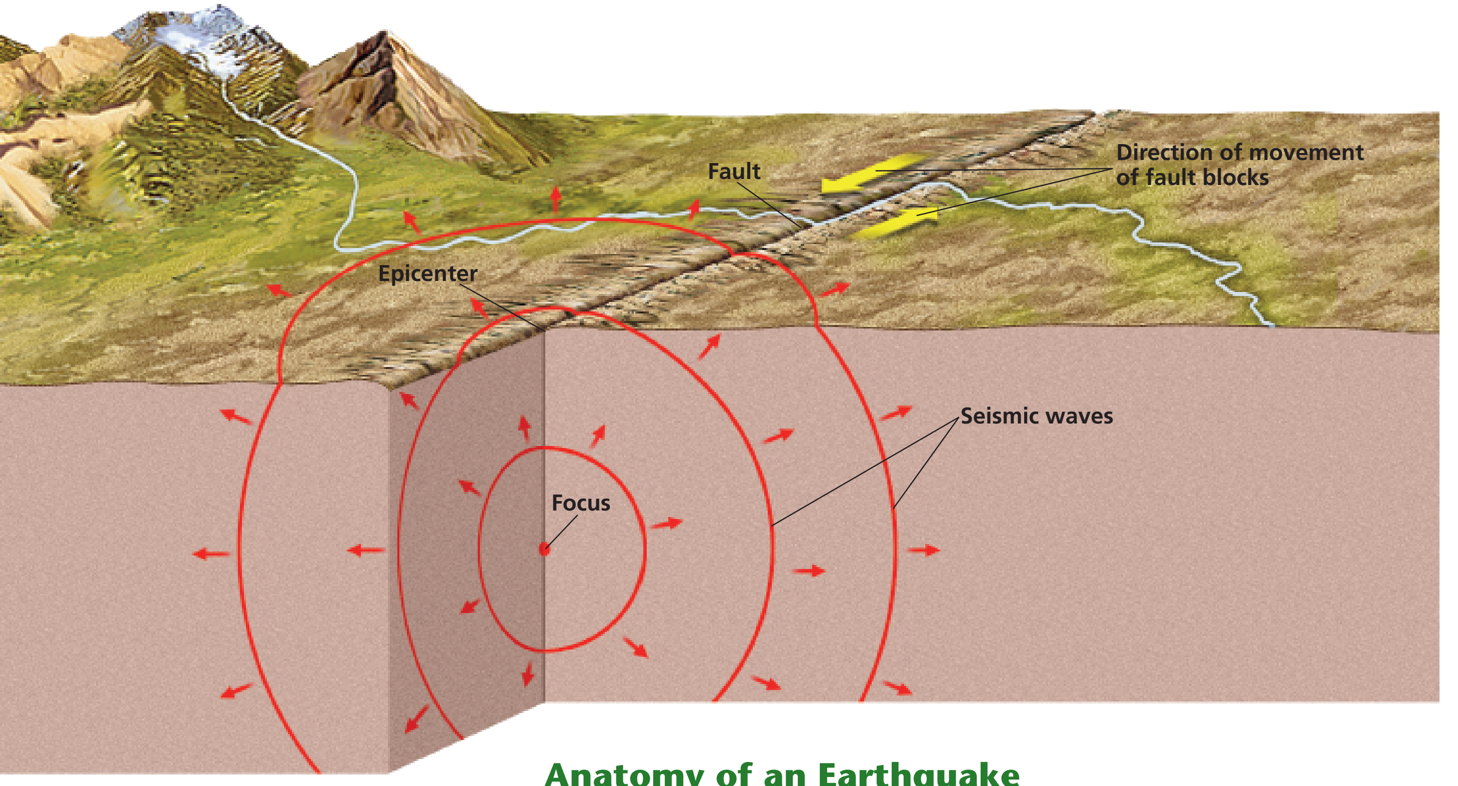


Figure 2 The epicenter of an earthquake is the point on the surface directly above the focus.

Anatomy of an Earthquake

The location within Earth along a fault at which the first motion of an earthquake occurs is called the **focus** (plural, *foci*). The point on Earth's surface directly above the focus is called the **epicenter** (EP i SENT uhr), as shown in **Figure 2.**

Although the focus depths of earthquakes vary, about 90% of continental earthquakes have shallow foci. Earthquakes that have shallow foci take place within 70 km of Earth's surface. Earthquakes that have intermediate foci take place at depths between 70 km and 300 km. Earthquakes that have deep foci take place at depths between 300 km and 650 km. Earthquakes that have deep foci usually occur in subduction zones and occur farther from the surface location of the plate boundary than shallower earthquakes do.

By the time the vibrations from an earthquake that has an intermediate or deep focus reach the surface, much of their energy has dissipated. For this reason, the earthquakes that cause the most damage usually have shallow foci.

focus the location within Earth along a fault at which the first motion of an earthquake occurs

epicenter the point on Earth's surface directly above an earthquake's starting point, or focus

body wave a seismic wave that travels through the body of a medium

surface wave a seismic wave that travels along the surface of a medium and that has a stronger effect near the surface of the medium than it has in the interior

Seismic Waves

As rocks along a fault slip into new positions, the rocks release energy in the form of vibrations called *seismic waves*. These waves travel outward in all directions from the focus through the surrounding rock. This wave action is similar to what happens when you drop a stone into a pool of still water and circular waves ripple outward from the center.

Earthquakes generally produce two main types of waves. **Body waves** are waves that travel through the body of a medium. **Surface waves** travel along the surface of a body rather than through the middle. Each type of wave travels at a different speed and causes different movements in Earth's crust.

Body Waves

Body waves can be placed into two main categories: P waves and S waves. **P waves,** also called *primary waves* or *compression waves,* are the fastest seismic waves and are always the first waves of an earthquake to be detected. P waves cause particles of rock to move in a back-and-forth direction that is parallel to the direction in which the waves are traveling, as shown in **Figure 3.** P waves can move through solids, liquids, and gases. The more rigid the material is, the faster the P waves travel through it.

S waves, also called *secondary waves* or *shear waves,* are the second-fastest seismic waves and arrive at detection sites after P waves. S waves cause particles of rock to move in a side-to-side direction that is perpendicular to the direction in which the waves are traveling. Unlike P waves, however, S waves can only travel through solid material.

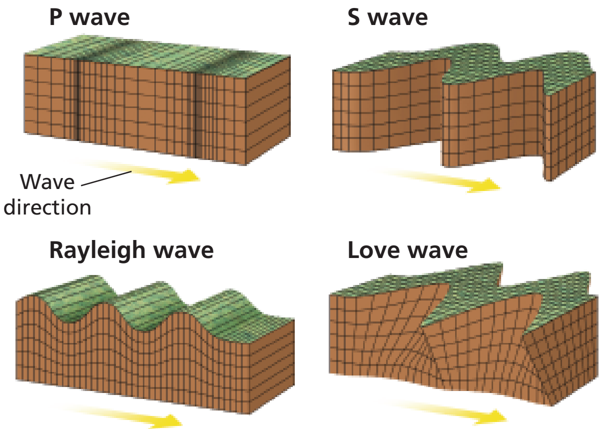


Figure 3 The different types of seismic waves cause different rock movements, which have different effects on Earth's crust.

Surface Waves

Surface waves form from motion along a shallow fault or from the conversion of energy when P waves and S waves reach Earth's surface. Although surface waves are the slowest-moving waves, they may cause the greatest damage during an earthquake. The two types of surface waves are Love waves and Rayleigh waves. *Love waves* cause rock to move side to side and perpendicular to the direction in which the waves are traveling. *Rayleigh waves* cause the ground to move with an elliptical, rolling motion.

Reading Check **Describe the two types of surface waves.**
(See Appendix G for answers to Reading Checks.)

P wave a primary wave, or compression wave; a seismic wave that causes particles of rock to move in a back-and-forth direction parallel to the direction in which the wave is traveling

S wave a secondary wave, or shear wave; a seismic wave that causes particles of rock to move in a side-to-side direction perpendicular to the direction in which the wave is traveling

Why It Matters

Do All Seismic Waves Come from Earthquakes?

REAL WORLD

Have you felt the ground shake as a large truck rumbles past? Seismic waves are produced not only by earthquakes but also by such events as explosions and even the movement of heavy equipment.

This meteorite impact in Peru produced measurable seismic waves.

Landslides produce seismic waves as large quantities of soil and rock suddenly collapse downhill.

Many seismic stations detected this explosion of a gas pipeline in New Mexico.

YOUR TURN

CRITICAL THINKING

What are some sources of seismic waves you may have felt?

Seismic Waves and Earth's Interior

Seismic waves are useful to scientists who are exploring Earth's interior. The composition of the material through which P waves and S waves travel affects the speed and direction of the waves. For example, P waves travel fastest through materials that are very rigid and are not easily compressed. By studying the speed and direction of seismic waves, scientists can learn more about the makeup and structure of Earth's interior.

SCILINKS
www.scilinks.org
Topic: Earthquakes
Code: **HQX0453**
Topic: Seismic Waves
Code: **HQX1371**

Earth's Internal Layers

In 1909, Andrija Mohorovičić (MOH hoh ROH vuh CHICH), a Croatian scientist, discovered that the speed of seismic waves increases abruptly at about a 30-km depth beneath the surface of continents. The location at which the speed of the waves increases marks the boundary between the crust and the mantle. The depth of this boundary varies from about 10 km below the oceans to about 30 km below continents. This increase in speed takes place because the mantle is denser than the crust. By studying the speed of seismic waves, scientists have been able to locate boundaries between other internal layers of Earth. The three main compositional layers of Earth are the *crust*, the *mantle*, and the *core*. Earth is also composed of five mechanical layers—the *lithosphere*, the *asthenosphere*, the *mesosphere*, the *outer core*, and the *inner core*.

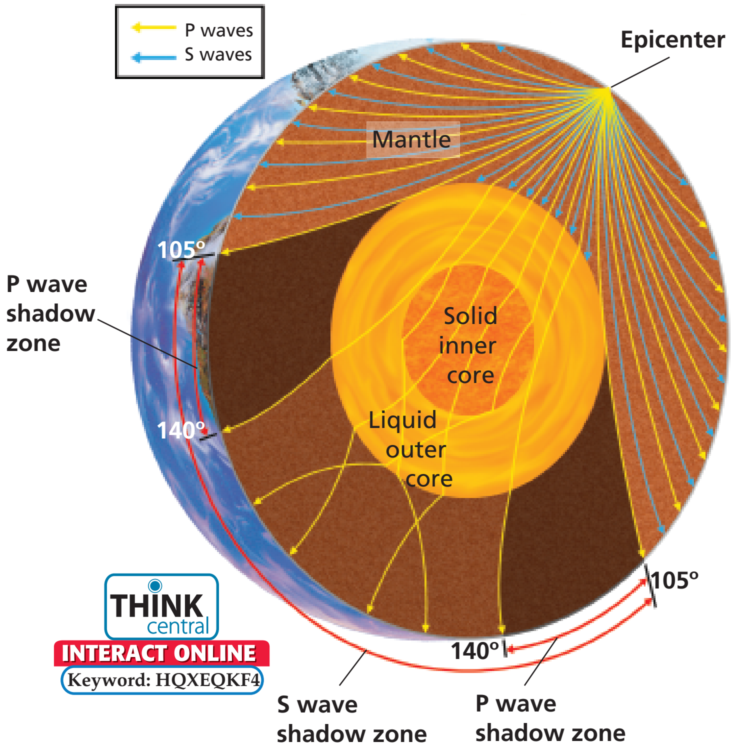
shadow zone an area on Earth's surface where no direct seismic waves from a particular earthquake can be detected

Shadow Zones

Recordings of seismic waves around the world reveal shadow zones. **Shadow zones** are locations on Earth's surface where no body waves from a particular earthquake can be detected. Shadow zones exist because the materials that make up Earth's interior are not uniform in rigidity. When seismic waves travel through materials of differing rigidities, the speed of the waves changes. The waves also bend and change direction as they pass through different materials.

As shown in **Figure 4,** a large S-wave shadow zone covers the side of Earth that is opposite an earthquake. S waves do not reach the S-wave shadow zone because they cannot pass through the liquid outer core. Although P waves can travel through all of the layers, the speed and direction of the waves change as the waves pass through each of Earth's layers. The waves bend in such a way that P-wave shadow zones form.

Figure 4 P waves and S waves behave differently as they pass through different structural layers of Earth.



THINK central
INTERACT ONLINE
Keyword: HQXEQKF4

Reading Check **What causes the speed of a seismic wave to change?**

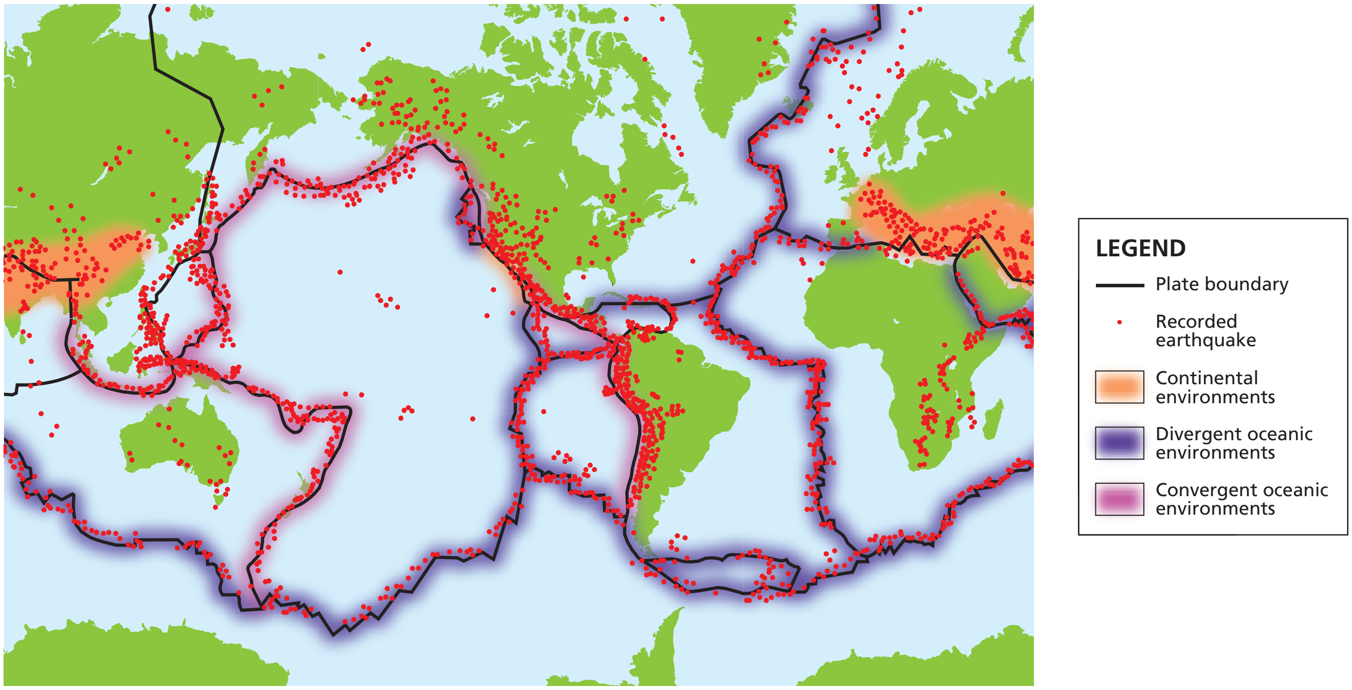


Figure 5 Earthquakes are the result of tectonic stresses in Earth's crust and occur in three main tectonic environments: mid-ocean ridges, subduction zones, and continental collisions.

Earthquakes and Plate Tectonics

Earthquakes are the result of stresses in Earth's lithosphere. Most earthquakes occur in three main tectonic environments, as shown in **Figure 5.** These environments are generally located at or near tectonic plate boundaries, where stress on the rock is greatest.

Convergent Oceanic Environments

At convergent plate boundaries, plates move toward each other and collide. The plate that is denser subducts, or sinks into the asthenosphere below the other plate. As the plates move, the overriding plate scrapes across the top of the subducting plate, and earthquakes occur. Convergent oceanic boundaries can occur between two oceanic plates or between one oceanic plate and one continental plate.

Divergent Oceanic Environments

At the divergent plate boundaries that make up the mid-ocean ridges, plates are moving away from each other. Earthquakes occur along mid-ocean ridges because oceanic lithosphere is pulling away from both sides of each ridge. This spreading motion causes earthquakes along the ocean ridges.

Continental Environments

Earthquakes also occur at locations where two continental plates converge, diverge, or move horizontally in opposite directions. As the continental plates interact, the rock surrounding the boundary experiences stress. The stress may cause mountains to form and also causes frequent earthquakes.

READING TOOLBOX

Classification
As you read about the three main tectonic environments in which earthquakes occur, make a table classifying the direction of movement of tectonic plates in each environment.

Figure 6 A series of parallel transform faults, seen in the center of this photo, make up part of the North Anatolian fault zone in Turkey.

Fault Zones

At some plate boundaries, there are regions of numerous, closely spaced faults called **fault zones.** Fault zones form at plate boundaries because of the intense stress that results when the plates separate, collide, subduct, or slide past each other. One such fault zone is the North Anatolian fault zone, shown in **Figure 6,** which extends almost the entire length of the country of Turkey. Where the edge of the Arabian plate pushes against the Eurasian plate, the small Turkish microplate is squeezed westward. When enough stress builds up, movement occurs along one or more of the individual faults in the fault zone and sometimes causes major earthquakes.

fault zone a region of numerous, closely spaced faults

Earthquakes Away from Plate Boundaries

Not all earthquakes result from movement along plate boundaries. A widely felt series of earthquakes occurred in the United States far from any active plate boundary. Instead, these earthquakes occurred in the middle of the continent, near New Madrid, Missouri, in 1811 and 1812. The vibrations from the earthquakes that rocked New Madrid were so strong that they caused damage as far away as South Carolina.

It was not until the late 1970s that studies of the Mississippi River region revealed an ancient fault zone deep within Earth's crust. This zone is thought to be part of a major fault zone in the North American plate. Scientists have determined that the fault formed at least 600 million years ago and that it was later buried under many layers of sediment and rock.

Academic Vocabulary

series (SEER eeze) a number of related events or objects coming one after another in succession

Section 1 Review

Key Ideas

1. **Describe** elastic rebound.
2. **Explain** the difference between the epicenter and the focus of an earthquake.
3. **Compare** body waves and surface waves.
4. **Explain** how seismic waves help scientists learn about Earth's interior.
5. **Explain** how the structure of Earth's interior affects seismic wave speed and direction.
6. **Explain** why earthquakes generally take place at plate boundaries.
7. **Describe** a fault zone, and explain how earthquakes occur along fault zones.

Critical Thinking

8. **Applying Ideas** In earthquakes that cause the most damage, at what depth would movement along a fault most likely occur?
9. **Identifying Patterns** If a seismologic station measures P waves but no S waves from an earthquake, what can you conclude about the earthquake's location?
10. **Making Inferences** If an earthquake occurs in the center of Brazil, what can you infer about the geology of that area?

Concept Mapping

11. Use the following terms to create a concept map: *earthquake, seismic wave, body wave, surface wave, P wave, S wave, Rayleigh wave,* and *Love wave.*

SECTION 2

Studying Earthquakes

Key Ideas	Key Terms	Why It Matters
❯ Describe the instrument used to measure and record earthquakes. ❯ Summarize the method scientists use to locate an epicenter. ❯ Describe the scales used to measure the magnitude and intensity of earthquakes.	**seismograph** **seismogram** **magnitude** **intensity**	Determining an earthquake's location and intensity allows aid to be sent quickly after a significant earthquake occurs.

The study of earthquakes and seismic waves is called *seismology*. Many scientists study earthquakes because earthquakes are the best tool available for investigating Earth's internal structure and dynamics. These scientists have developed special sensing equipment to record, locate, and measure earthquakes.

Recording Earthquakes

Vibrations in the ground can be detected and recorded by using an instrument called a **seismograph** (SIEZ MUH graf), such as the one shown in **Figure 1.** A modern three-component seismograph consists of three sensing devices. One device records the vertical motion of the ground. The other two devices record horizontal motion—one for east-west motion and the other for north-south motion. Seismographs record motion by tracing wave-shaped lines on paper or by translating the motion into electronic signals. The electronic signals can be recorded on magnetic tape or can be loaded directly into a computer that analyzes seismic waves. A tracing of earthquake motion that is recorded by a seismograph is called a **seismogram.**

seismograph an instrument that records vibrations in the ground

seismogram a tracing of earthquake motion that is recorded by a seismograph

Because P waves are the fastest-moving seismic waves, they are the first waves to be recorded by a seismograph. S waves travel much slower than P waves. Therefore, S waves are the second waves to be recorded by a seismograph. Surface waves are the slowest-moving waves and are the last waves to be recorded by a seismograph.

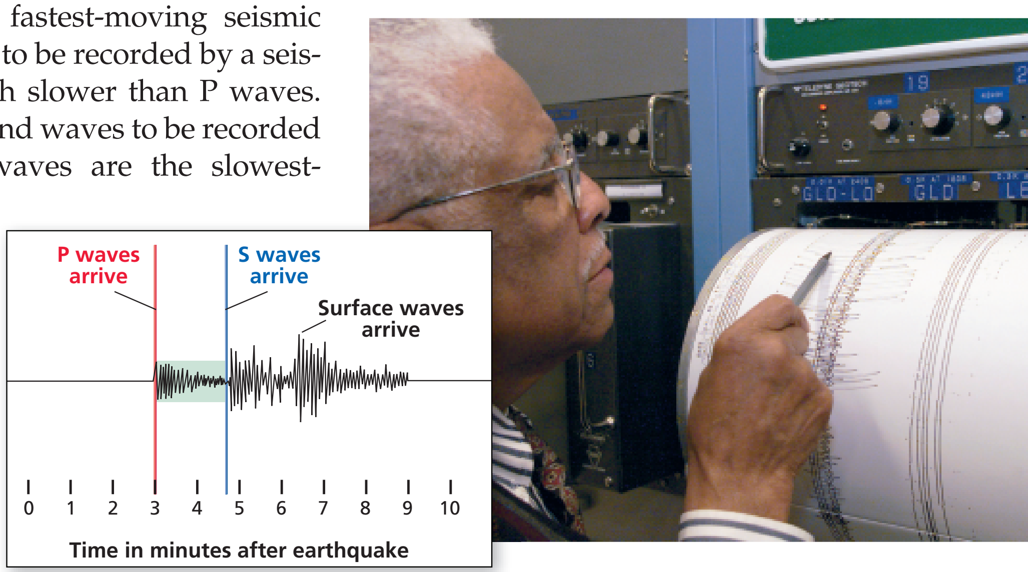


Figure 1 A seismograph station has banks of seismographs to record earthquakes. Each type of seismic wave leaves a unique "signature" on a seismogram (inset).

Locating an Earthquake

Academic Vocabulary

analyze (AN uh LIEZ) study in detail

To determine the distance to an epicenter, scientists analyze the arrival times of the P waves and the S waves. The longer the lag time between the arrival of the P waves and the arrival of the S waves is, the farther away the earthquake occurred. Scientists use computers to calculate how far an earthquake is from a given seismograph station. Before computers were widely available, scientists consulted a lag-time graph. This graph translates the difference in arrival times of the P waves and S waves into distance from the epicenter to each station. The start time of the earthquake can also be determined by using this graph.

To locate the epicenter of an earthquake, scientists use computers to perform complex triangulations based on information from several seismograph stations. An earlier technique was simpler but less precise. On a map, scientists drew circles around at least three seismograph stations that recorded vibrations from the earthquake. The radius of each circle represented the distance from that station to the earthquake's epicenter. The point at which all of the circles intersected indicated the location of the epicenter of the earthquake.

SCILINKS.
www.scilinks.org
Topic: Earthquake Measurement
Code: **HQX0452**

Quick Lab: Seismographic Record

20 min

Procedure

1. Line a shoe box with a plastic bag. Fill the box to the rim with sand. Put on the lid.
2. Mark an X near the center of the lid.
3. Fasten a felt-tip pen to the lid of the box with a tight rubber band so that the pen extends slightly beyond the edge of the box.
4. Have a partner hold a pad of paper so that the paper touches the pen.
5. Hold a ball over the X at a height of 30 cm. As your partner slowly moves the paper horizontally past the pen, drop the ball on the X.
6. Label the resulting line with the type of material in the box.
7. Replace about 2/3 of the sand with crumpled newspaper. Put on the lid, and fasten the pen to the lid with the rubber band.
8. Repeat steps 4–6.

Analysis

1. What do the lines on the paper represent?
2. What do the sand and newspaper represent?
3. Compare the lines made in steps 4–6 with those made in step 8. Which material vibrated more when the ball was dropped on it? Explain why one material might vibrate more than the other.
4. How might different types of crustal material affect seismic waves that pass through it?
5. How might the distance of the epicenter of an earthquake from a seismograph affect the reading of a seismograph?

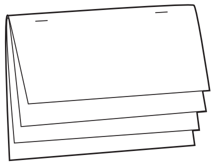
Figure 2 The 2005 earthquake in northern Pakistan had a moment magnitude of 7.6, killed more than 86,000 people, and left about 3 million people homeless.

Earthquake Measurement

Scientists who study earthquakes are interested in the amount of energy released by an earthquake. Scientists also study the amount of damage done by the earthquake. These properties are studied by measuring magnitude and intensity.

READING TOOLBOX

Layered Book
Make a layered book, and label the tabs with "Richter Scale," "Moment Magnitude Scale," and "Modified Mercalli Intensity Scale." Write notes on the appropriate tab as you read this section.



Magnitude

The measure of the strength of an earthquake is called **magnitude.** Magnitude is determined by measuring the amount of ground motion caused by an earthquake. Seismologists express magnitude by using a magnitude scale, such as the Richter scale or the moment magnitude scale.

magnitude a measure of the strength of an earthquake

The *Richter scale* measures the ground motion from an earthquake to find the earthquake's strength. While the Richter scale was widely used for most of the 20th century, scientists now prefer the moment magnitude scale. *Moment magnitude* is a measurement of earthquake strength based on the size of the area of the fault that moves, the average distance that the fault blocks move, and the rigidity of the rocks in the fault zone. Although the moment magnitude and the Richter scales provide similar values for small earthquakes, the moment magnitude scale is more accurate for large earthquakes, such as the one shown in **Figure 2.**

The moment magnitude of an earthquake is expressed by a number. The larger the number, the stronger the earthquake. The largest earthquake that has been recorded (in Chile) registered a moment magnitude of 9.5. The earthquake in China in 2008 had a moment magnitude of 7.9 and devastated the country just before it hosted the Olympic Games that year. Earthquakes that have moment magnitudes of less than 2.5 usually are not felt by people.

Reading Check **What is the difference between the Richter scale and the moment magnitude scale?**

Math Skills

Magnitudes On both the moment magnitude scale and the Richter scale, the energy of an earthquake increases by a factor of about 30 for each increment on the scale. Thus, a magnitude 4 earthquake releases 30 times as much energy as a magnitude 3 earthquake does. How much more energy does a magnitude 6 earthquake release than a magnitude 3 earthquake does?

Table 1 Modified Mercalli Intensity Scale

Intensity	Description
I	is not felt except by very few under especially favorable conditions
II	is felt by only few people at rest; delicately suspended items may swing
III	is felt by most people indoors; vibration is similar to the passing of a large truck
IV	is felt by many people; dishes and windows rattle; sensation is similar to a building being struck
V	is felt by nearly everyone; some objects are broken; unstable objects are overturned
VI	is felt by all people; some heavy objects are moved; causes very slight damage to structures
VII	causes slight to moderate damage to ordinary buildings; some chimneys are broken
VIII	causes considerable damage (including partial collapse) to ordinary buildings
IX	causes considerable damage (including partial collapse) to earthquake-resistant buildings
X	destroys some to most structures, including foundations; rails are bent
XI	causes few structures, if any, to remain standing; bridges are destroyed and rails are bent
XII	causes total destruction; distorts lines of sight; objects are thrown into the air

Intensity

intensity in Earth science, the amount of damage caused by an earthquake

Before the development of magnitude scales, the size of an earthquake was determined based on the earthquake's effects. A measure of the effects of an earthquake is the earthquake's **intensity.** The modified *Mercalli scale,* shown in **Table 1,** expresses intensity in Roman numerals from I to XII and provides a description of the effects of each earthquake intensity. The highest-intensity earthquake is designated by Roman numeral XII and is described as total destruction. The intensity of an earthquake depends on the earthquake's magnitude, the distance between the epicenter and the affected area, the local geology, the earthquake's duration, and human infrastructure.

Section 2 Review

Key Ideas

1. **Describe** the instrument that is used to record seismic waves.
2. **Compare** a seismograph and a seismogram.
3. **Summarize** the method that scientists used to identify the location of an earthquake before computers became widely used.
4. **Describe** the scales that scientists use to measure the magnitude of an earthquake.
5. **Explain** the difference between magnitude and intensity of an earthquake.

Critical Thinking

6. **Analyzing Methods** Explain why it would be difficult for scientists to locate the epicenter of an earthquake if they have seismic wave information from only two locations.
7. **Evaluating Data** Explain why an earthquake with a moderate magnitude might have a high intensity.

Concept Mapping

8. Use the following terms to create a concept map: *seismograph, seismogram, epicenter, P wave, S wave, magnitude,* and *intensity.*

SECTION 3

Earthquakes and Society

Key Ideas	Key Terms	Why It Matters
❯ Discuss the relationship between tsunamis and earthquakes. ❯ Describe two possible effects of a major earthquake on buildings. ❯ List three safety techniques to prevent injury caused by earthquake activity. ❯ Identify four methods scientists use to forecast earthquake risks.	**tsunami** **seismic gap**	Knowing where powerful earthquakes are likely to occur and preparing for them in advance can save many lives, perhaps your own. Several safety rules should be followed by those living in areas prone to earthquakes.

Movement of the ground during an earthquake seldom directly causes many deaths or injuries. Instead, most injuries result from the collapse of buildings and other structures or from falling objects and flying glass. Other dangers include landslides, fires, explosions caused by broken electric and gas lines, and floodwaters released from collapsing dams.

Tsunamis

An earthquake whose epicenter is on the ocean floor may cause a giant ocean wave called a **tsunami** (tsoo NAH mee), which may cause serious destruction if it crashes into land. A tsunami may begin to form when a sudden drop or rise in the ocean floor occurs because of faulting associated with undersea earthquakes. The drop or rise of the ocean floor causes a large mass of sea water to also drop or rise suddenly. This movement sets into motion a series of long, low waves that increase in height as they near the shore. These waves are tsunamis.

tsunami a giant ocean wave that forms after a volcanic eruption, submarine earthquake, or landslide

Destruction to Buildings and Property

Most buildings are not designed to withstand the swaying motion caused by earthquakes. Buildings whose walls are weak may collapse completely. Very tall buildings may sway so violently that they tip over and fall onto lower neighboring structures, as shown in **Figure 1.**

The type of ground beneath a building can affect the way in which the building responds to seismic waves. During an earthquake, the loose soil and rock can vibrate like jelly. Buildings constructed on top of this kind of ground experience exaggerated motion and sway violently.

Figure 1 Rescue workers surround a building that toppled in Taipei, Taiwan, during the earthquake of 1999.

Figure 2 In Tokyo, Japan—an area that has a high earthquake-hazard level—earthquake safety materials are available at disaster control centers.

Quick Lab 10 min

Earthquake-Safe Buildings

Procedure

1. On a tabletop, build a structure by stacking **building blocks** on top of each other.
2. Pound gently on the side of the table. Record what happens to the structure.
3. Using **rubber bands,** wrap sets of three blocks together. Build a second structure by using these blocks.
4. Repeat step 2.

Analysis

1. Which of your structures was more resistant to damage caused by the "earthquake"?
2. How could this model relate to building real structures, such as elevated highways?

Academic Vocabulary

instruction (in STRUHK shun) information given; a direction

Earthquake Safety

A destructive earthquake may take place in any region of the United States. However, destructive earthquakes are more likely to occur in certain geographic areas, such as California or Alaska. People who live near active faults should be ready to follow a few simple earthquake safety rules. These safety rules may help prevent death, injury, and property damage.

Before an Earthquake

Before an earthquake occurs, be prepared. Keep on hand a supply of canned food, bottled water, flashlights, batteries, and a portable radio. Some safety materials are shown in **Figure 2.** Plan what you will do if an earthquake strikes while you are at home, at school, or in a car. Discuss these plans with your family. Learn how to turn off the gas, water, and electricity in your home.

During an Earthquake

When an earthquake occurs, stay calm. During the few seconds between tremors, you can move to a safer position. If you are indoors, protect yourself from falling debris by standing in a doorway or crouching under a desk or table. Stay away from windows, heavy furniture, and other objects that might topple over. If you are in school, follow the instructions given by your teacher or principal. If you are in a car, stop in a place that is away from tall buildings, tunnels, power lines, or bridges. Then, remain in the car until the tremors cease.

After an Earthquake

After an earthquake, be cautious. Check for fire and other hazards. Always wear shoes when walking near broken glass, and avoid downed power lines and objects touched by downed wires.

Earthquake Warnings and Forecasts

Humans have long sought methods by which to predict earthquakes. Accurate earthquake predictions could help prevent injuries and deaths that result from earthquakes.

Today, scientists study past earthquakes to predict where future earthquakes are most likely to occur. Using records of past earthquakes, scientists can make approximate forecasts of future earthquake risks. However, there is currently no reliable way of predicting exactly when or where an earthquake will occur. Even the best forecasts may be off by several years.

To make forecasts that are more accurate, scientists are trying to detect changes in Earth's crust that can signal an earthquake. Faults near many population centers have been located and mapped. Instruments placed along these faults measure small changes in rock movement around the faults and can detect an increase in stress. Currently, however, these methods cannot provide reliable or accurate predictions of earthquakes.

READING TOOLBOX

Root Words
Explain how you can use the meaning of the root word *seism-* to understand the term *seismic gap.*

seismic gap an area along a fault where relatively few earthquakes have occurred recently but where strong earthquakes are known to have occurred in the past

Seismic Gaps

Scientists have identified zones of low earthquake activity, or seismic gaps, along some faults. A **seismic gap** is an area along a fault where relatively few earthquakes have occurred recently but where strong earthquakes occurred in the past. Some scientists think that seismic gaps are likely locations of future earthquakes. Several gaps that exist along the San Andreas Fault zone may be sites of major earthquakes in the future. A couple of seismic gaps in California are illustrated in **Figure 3.**

Reading Check **Why do scientists think that seismic gaps are areas where future earthquakes are likely to occur?**

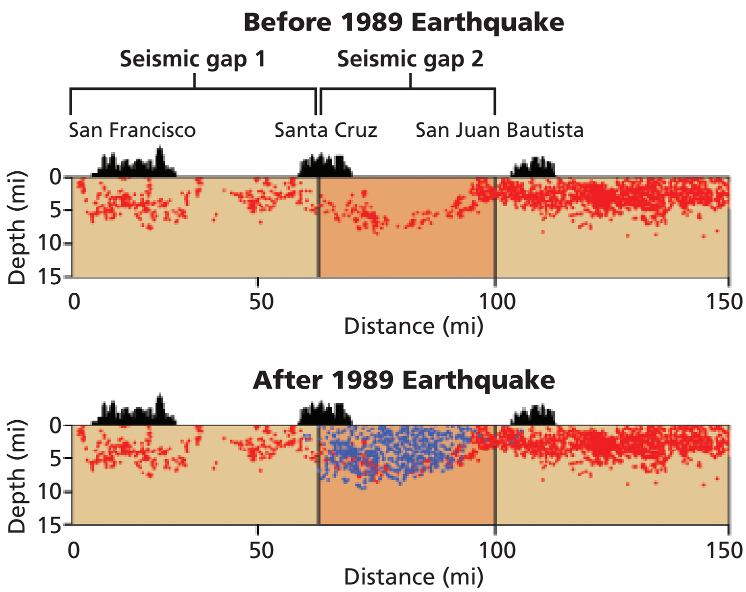


Figure 3 Each red dot in the cross sections of the San Andreas Fault represents an earthquake or aftershock before the 1989 Loma Prieta earthquake. Note how seismic gap 2 was filled by the 1989 earthquake and its aftershocks, which are represented by the blue dots.

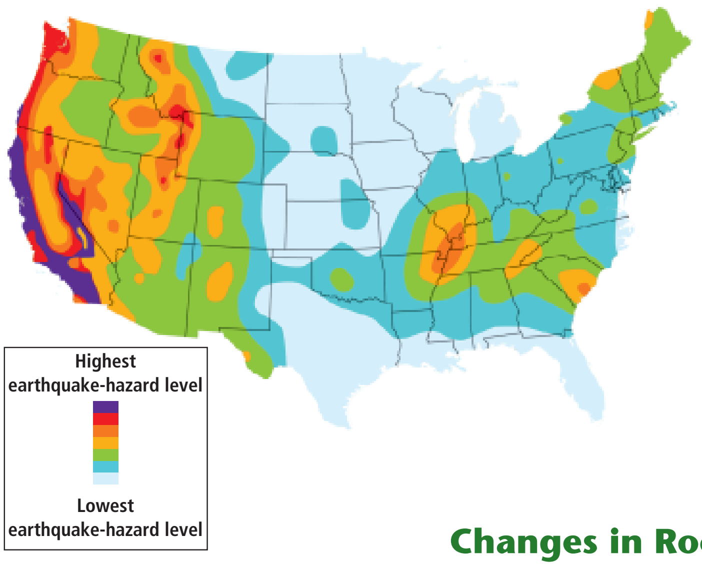


Figure 4 California, which has experienced severe earthquakes recently, has the highest earthquake-hazard level in the contiguous United States.

Foreshocks

Some earthquakes are preceded by little earthquakes called *foreshocks*. Foreshocks can precede an earthquake by a few seconds or a few weeks. In 1975, geophysicists in China recorded foreshocks near the city of Haicheng, which had a history of earthquakes. The city was evacuated the day before a major earthquake. The earthquake caused widespread destruction, but few lives were lost thanks to the warning. However, the Haicheng earthquake is the only example of a successful prediction made by using this method.

Changes in Rocks

Scientists use a variety of sensors to detect slight tilting of the ground and to identify the strain and cracks in rocks caused by the stress that builds up in fault zones. When cracks in rocks are filled with water, the magnetic and electrical properties of the rocks may change. Scientists also monitor natural gas seepage from rocks that are strained or fractured from seismic activity. Scientists hope that they will one day be able to use these signals to predict earthquakes.

SCILINKS.
www.scilinks.org
Topic: Earthquakes and Society
Code: **HQX0455**

Reliability of Earthquake Forecasts

Unfortunately, not all earthquakes have foreshocks or other precursors. Earthquake prediction is mostly unreliable. However, scientists have been able to determine areas that have a high earthquake-hazard level, as shown in **Figure 4.** Scientists continue to study seismic activity so that they may one day make accurate forecasts and save more lives.

Section 3 Review

Key Ideas

1. **Discuss** the relationship between tsunamis and earthquakes.
2. **Describe** two possible effects of a major earthquake on buildings.
3. **List** three safety rules to follow when an earthquake strikes.
4. **Describe** how identifying seismic gaps may help scientists predict earthquakes.
5. **Identify** changes in rocks that may signal earthquakes.

Critical Thinking

6. **Applying Concepts** What type of building construction and location regulations should be included in the building code of a city that is located near an active fault?
7. **Applying Concepts** You are a scientist assigned to study an area that has a high earthquake-hazard level. Describe a program that you could set up to predict potential earthquakes.

Concept Mapping

8. Use the following terms to create a concept map: *earthquake, earthquake-hazard level, damage, tsunami, safety,* and *prediction.*

Why It Matters

HISTORY IN SCIENCE

Detecting Earthquakes

The first known seismic wave detector was invented in China by Zhang Heng in 132 A.D. During an earthquake, a pendulum inside a large urn would move, causing one of eight dragons to drop a ball into the mouth of a frog below. The first "modern" seismograph was installed by Luigi Palmieri on Mount Vesuvius, Italy, in 1856. Today, the Global Seismographic Network has seismic detection stations around the world. Rapid detection of earthquakes allows tsunami warnings to be issued and aid efforts to be started quickly.

The direction of ground movement determined which dragon released its ball into the frog's mouth.

1. Palmieri's electromagnetic seismograph could measure both horizontal and vertical ground motions as well as duration and magnitude. **2.** This Global Seismographic Network station in Antarctica is part of the worldwide monitoring network. **3.** Early warning systems that alert commuter transit systems to slow down or stop at the first signs of shaking could help to save lives.

YOUR TURN

CRITICAL THINKING

What is the relationship between detecting earthquakes and quickly issuing tsunami warnings?

Skills Practice Lab

45 min

What You'll Do

- **Analyze** P waves and S waves to determine the distance from a city to the epicenter of an earthquake.
- **Determine** the location of an earthquake epicenter by using the distance from three different cities to the epicenter.

What You'll Need

calculator
drawing compass
ruler

Finding an Epicenter

An earthquake releases energy that travels through Earth in all directions. This energy is in the form of waves. Two kinds of seismic waves are P waves and S waves. P waves travel faster than S waves and are the first to be recorded at a seismograph station. The S waves arrive after the P waves. The time difference between the arrival of the P waves and the arrival of the S waves increases as the waves travel farther from their origin. This difference in arrival time, called *lag time*, can be used to find the distance to the epicenter of the earthquake. Once the distance from three different locations is determined, scientists can find the approximate location of the epicenter.

Procedure

1. The average speed of P waves is 6.1 km/s. The average speed of S waves is 4.1 km/s. Calculate the lag time between the arrival of P waves and S waves over a distance of 100 km.
2. The graph below shows seismic records made in three cities following an earthquake. The records begin at the left. The arrows indicate the arrival of the P waves. The beginning of the next wave on each record indicates the arrival of the S wave. Use the time scale to find the lag time between the P waves and the S waves for each city. Draw a table similar to **Table 1.**
3. Record the lag time for each city in your table.
4. Use the lag times found in step 2 and the lag time per 100 km found in step 1 to calculate the distance from each city to the epicenter of the earthquake by using the equation below.

$$\textit{distance} = \frac{\textit{measured lag time (s)} \times 100 \text{ km}}{\textit{lag time for 100 km}}$$

Seismograms

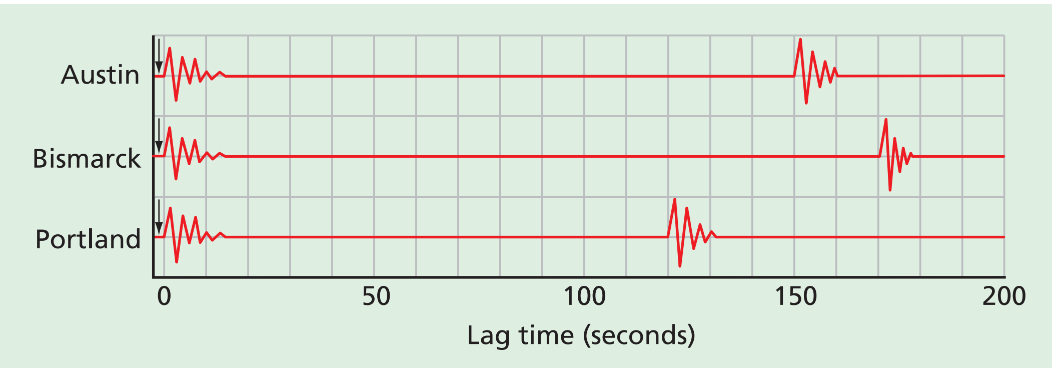


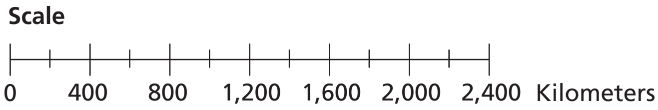
Table 1

City	Lag time (seconds)	Distance from city to epicenter
Austin		
Bismarck		
Portland		

5. Record the distances in your table.

6. Copy the map below, which shows the location of the three cities. Using the map scale on your copy of the map, adjust the compass so that the radius of the circle with Austin at the center represents the distance calculation for Austin from step 4. Put the point of the compass on Austin. Draw a circle on your copy of the map.

7. Repeat step 6 for Bismarck and for Portland. The epicenter of the earthquake is located near the point at which the three circles intersect.



THINK central
INTERACT ONLINE
Keyword: HQXEQKL3

Analysis

1. **Evaluating Data** Describe how to locate an earthquake's epicenter. The epicenter that you found is closest to which city?

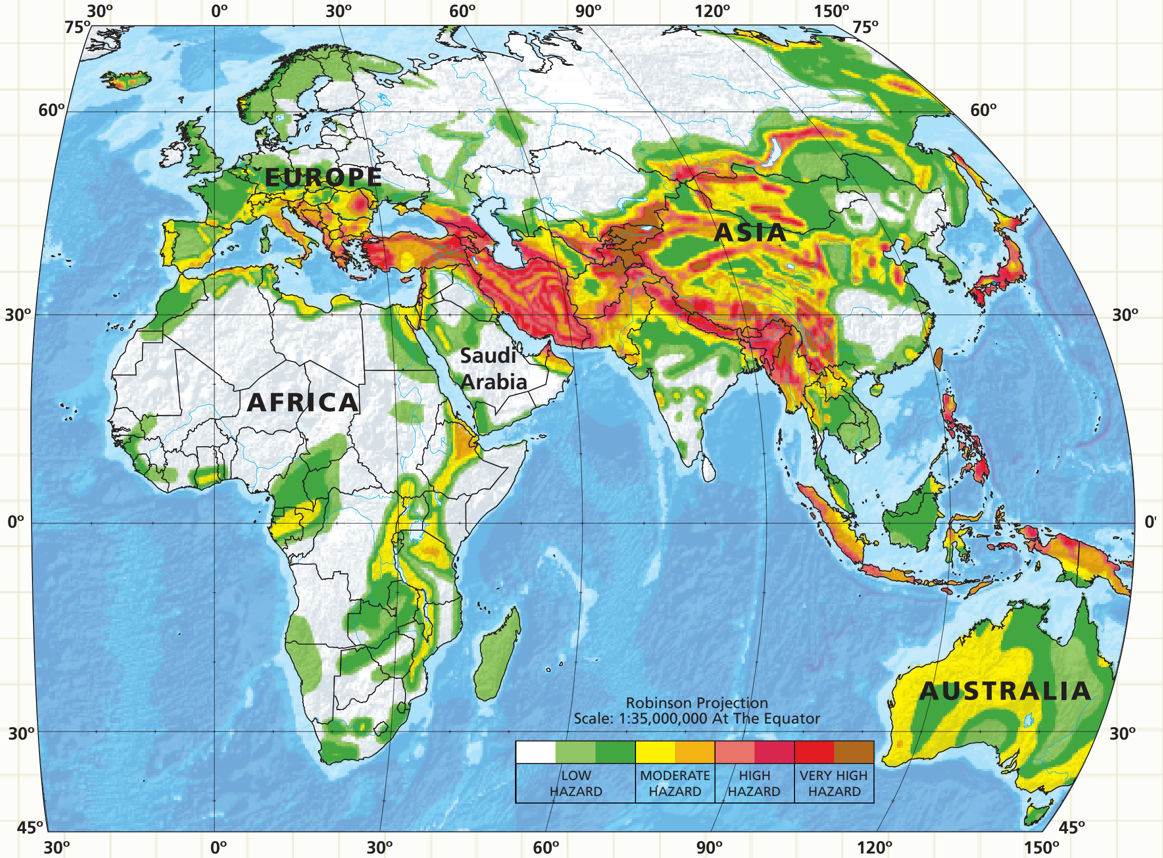
2. **Analyzing Processes** Why must measurements from three locations be used to find the epicenter of an earthquake?

Extension

Evaluating Data Research earthquakes in the United States. What is the probability of a major earthquake occurring in the area where you live? If an earthquake did occur in your area, what would most likely cause the earthquake?

MAPS in Action

Earthquake Hazard Map



Map Skills Activity

This map shows the earthquake-hazard levels for Europe, Asia, Africa, and Australia. Use the map to answer the questions below.

1. **Using a Key** Which areas of the map have a very high earthquake-hazard level?
2. **Using a Key** Which areas of the map have very low earthquake-hazard levels?
3. **Inferring Relationships** Most earthquakes take place near tectonic plate boundaries. Based on the hazard levels, describe the areas of the map where you think tectonic plate boundaries are located.
4. **Analyzing Relationships** In Asia, just below 60° north latitude, there are areas that have high earthquake-hazard levels but no plate boundaries. Explain why these areas might experience earthquakes.
5. **Forming a Hypothesis** There is a tectonic plate boundary between Africa and Saudi Arabia. However, the earthquake-hazard level in that region is low. Explain the low earthquake-hazard level.
6. **Analyzing Relationships** A divergent plate boundary began to tear apart the continent of Africa about 30 million years ago. Where on the continent of Africa would you expect to find landforms created by this boundary? Explain your answer.

Chapter 12 Summary

THINK central
SUPER SUMMARY
Keyword: HQXEQKS

Key Ideas | **Key Terms**

Section 1

How and Where Earthquakes Happen

- In the process of elastic rebound, stress builds in rocks along a fault until they break and spring back to their original shape.
- The two major types of seismic waves are body waves, which travel through a medium, and surface waves, which travel along the surface of a medium.
- Different seismic waves act differently depending on the material of Earth's interior through which they pass.
- Most earthquakes occur near tectonic plate boundaries, because stress on rock is highest in these areas.

Key Terms

earthquake, p. 319
elastic rebound, p. 319
focus, p. 320
epicenter, p. 320
body wave, p. 320
surface wave, p. 320
P wave, p. 321
S wave, p. 321
shadow zone, p. 322
fault zone, p. 324

Section 2

Studying Earthquakes

- Seismographs are instruments that record earthquake vibrations.
- The difference in the times that P waves and S waves take to arrive at a seismograph station helps scientists locate the epicenter of an earthquake.
- Earthquake magnitude scales describe the strength of an earthquake. Intensity is a measure of the effects of an earthquake.

Key Terms

seismograph, p. 325
seismogram, p. 325
magnitude, p. 327
intensity, p. 328

Section 3

Earthquakes and Society

- Tsunamis often are caused by ocean-floor earthquakes.
- During a major earthquake, buildings can sway violently or collapse.
- Earthquake safety techniques include developing a safety plan before an earthquake, moving to a safer location during an earthquake, and avoiding downed power lines after an earthquake.
- Seismic gaps, tilting ground, foreshocks, and variations in rock properties are some of the changes in Earth's crust that scientists use when trying to predict earthquakes.

Key Terms

tsunami, p. 329
seismic gap, p. 331

Chapter 12 Review

1. Layered Book Make a layered book, and label the tabs with "Seismic Gaps," "Changes in Rocks," and "Earthquake Hazard Levels." Write notes on the appropriate tab to summarize your understanding of earthquake prediction.

READING TOOLBOX

USING KEY TERMS

Use each of the following terms in a separate sentence.

2. *elastic rebound*

3. *fault zone*

4. *seismic gap*

For each pair of terms, explain how the meanings of the terms differ.

5. *focus* and *epicenter*

6. *body wave* and *surface wave*

7. *P wave* and *S wave*

8. *seismograph* and *seismogram*

9. *intensity* and *magnitude*

UNDERSTANDING KEY IDEAS

10. Vibrations in Earth that are caused by the sudden movement of rock are called
a. epicenters.
b. earthquakes.
c. faults.
d. tsunamis.

11. In the process of elastic rebound, as rock becomes stressed, it first
a. deforms.
b. melts.
c. breaks.
d. shrinks.

12. Earthquakes that cause severe damage are likely to have what characteristic?
a. a deep focus
b. an intermediate focus
c. a shallow focus
d. a deep epicenter

13. Most earthquakes occur
a. in mountains.
b. along major rivers.
c. at plate boundaries.
d. in the middle of tectonic plates.

14. P waves travel
a. only through solids.
b. only through liquids and gases.
c. through solids, liquids, and gases.
d. only through liquids.

15. S waves cannot pass through
a. solids.
b. the mantle.
c. Earth's outer core.
d. the asthenosphere.

16. Most injuries during earthquakes are caused by
a. the collapse of buildings.
b. cracks in Earth's surface.
c. the vibration of S waves.
d. the vibration of P waves.

17. Which of the following is not a method used to forecast earthquake risks?
a. identifying seismic gaps
b. determining moment magnitude
c. recording foreshocks
d. detecting changes in rock

SHORT ANSWER

18. How do seismic waves help scientists understand Earth's interior?

19. Why is the S-wave shadow zone larger than the P-wave shadow zones are?

20. How do scientists determine the location of an earthquake's epicenter?

21. Why do scientists prefer the moment magnitude scale to the Richter scale?

22. How might tall buildings respond during a major earthquake?

23. What should you do if you are in a car when an earthquake happens?

24. List three changes in rock that may one day be used to help forecast earthquakes.

CRITICAL THINKING

25. Understanding Relationships Why might surface waves cause the greatest damage during an earthquake?

26. Determining Cause and Effect Two cities are struck by the same earthquake. The cities are the same size, are built on the same type of ground, and have the same types of buildings. The city in which the earthquake produces a maximum intensity of VI on the Mercalli scale suffers $1 million in damage. The city in which the earthquake produces a maximum intensity of VIII on the Mercalli scale suffers $50 million in damage. What might account for this great difference in the costs of the damage?

27. Recognizing Relationships Would an earthquake in the Rocky Mountains in Colorado be likely to cause a tsunami? Explain your answer.

CONCEPT MAPPING

28. Use the following terms to create a concept map: *earthquake, elastic rebound, surface wave, body wave, seismic wave, tsunami, seismograph, magnitude, intensity, moment magnitude scale,* and *Richter scale.*

MATH SKILLS

Math Skills

29. Making Calculations If a P wave traveled 6.1 km/s, how long would the P wave take to travel 800 km?

30. Using Equations An earthquake with a magnitude of 3 releases 30 times more energy than does an earthquake with a magnitude of 2. How much more energy does an earthquake with a magnitude of 8 release than an earthquake with a magnitude of 6 does?

31. Making Calculations Of the approximately 420,000 earthquakes recorded each year, about 140 have a magnitude greater than 6. What percentage of all earthquakes have a magnitude greater than 6?

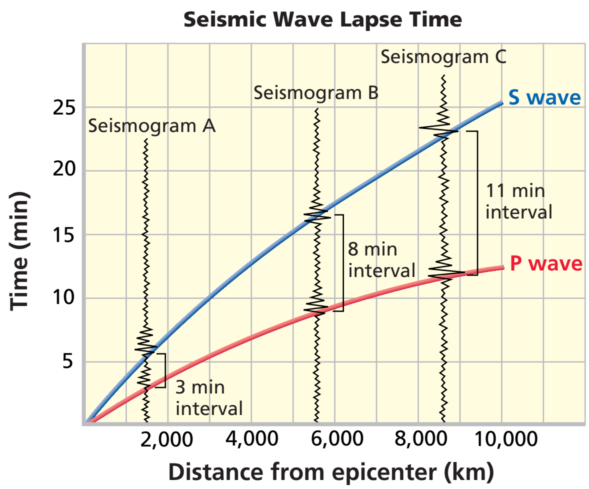
WRITING SKILLS

32. Writing from Research Find out how and why the worldwide network of seismograph stations was formed. Also, find out how all the stations in the network work together. Prepare a report about your findings.

33. Communicating Main Ideas Find out which earthquake registered the highest intensity in history. Write a brief report that describes the effects of this earthquake.

INTERPRETING GRAPHICS

The graph below shows three seismograms from a single earthquake. Use the graph to answer the questions that follow.



34. How far from the epicenter is seismograph B?

35. How far from the epicenter is seismograph C?

36. Which seismograph is farthest from the epicenter?

37. Why is there an 8 min interval between P waves and S waves in seismogram B but an 11 min interval between P waves and S waves in seismogram C?

Chapter 12 Standardized Test Prep

Understanding Concepts

Directions (1–5): For each question, write on a separate sheet of paper the letter of the correct answer.

1. Energy waves that produce an earthquake begin at what location on or within Earth?
- **A.** the epicenter
- **B.** the seismic gap
- **C.** the focus
- **D.** the shadow zone

2. The fastest-moving seismic waves produced by an earthquake are called
- **F.** P waves.
- **G.** S waves.
- **H.** Rayleigh waves.
- **I.** surface waves.

3. The magnitude of an earthquake can be expressed numerically by using
- **A.** only the Richter scale.
- **B.** only the Mercalli scale.
- **C.** both the Mercalli scale and the moment magnitude scale.
- **D.** both the Richter scale and the moment magnitude scale.

4. Most earthquake-related injuries are caused by
- **F.** tsunamis.
- **G.** collapsing buildings.
- **H.** rolling ground movements.
- **I.** sudden cracks in the ground.

5. Which of the following is least likely to cause deaths during an earthquake?
- **A.** floodwaters from collapsing dams
- **B.** falling objects and flying glass
- **C.** actual ground movement
- **D.** fires from broken electric and gas lines

Directions (6–8): For each question, write a short response.

6. What is the name of the instrument that is used to detect and record seismic waves?

7. What is the term for waves that move through a medium instead of along its surface?

8. How can the type of ground beneath a building affect the building's response to seismic waves?

Reading Skills

Directions (9–11): Read the passage below. Then, answer the questions.

The Loma Prieta Earthquake

At 5:04 P.M. on October 17, 1989, life in California's San Francisco Bay Area seemed relatively normal. While more than 62,000 excited fans filled Candlestick Park to watch the third game of baseball's World Series, other people were still rushing home from a long day's work or picking their children up from extracurricular activites. By 5:05 P.M., the situation had changed drastically. The area was rocked by the Loma Prieta earthquake, which was 6.9 on the moment magnitude scale. The earthquake lasted 20 seconds and caused 62 deaths, 3,757 injuries, and the destruction of more than 1,000 homes and businesses. By midnight, the city was fighting more than 20 large structural fires resulting from the earthquake. People suffered injuries from collapses in weakened structures for days following the initial earthquake. Considering that the earthquake was of such a high magnitude and that it happened during the busy rush hour, it is amazing that more people were not injured or killed.

9. What type of waves are the most likely to have caused the damage described during the Loma Prieta earthquake?
- **F.** P waves
- **G.** S waves
- **H.** body waves
- **I.** surface waves

10. Which of the following statements can be inferred from the information in the passage?
- **A.** *Loma Prieta* is the Spanish term for "deadly earthquake."
- **B.** The damage caused by the earthquake continued even after the waves had passed.
- **C.** There were fewer people injured in this earthquake than in most earthquakes.
- **D.** The Loma Prieta earthquake has the highest magnitude of any earthquake ever recorded.

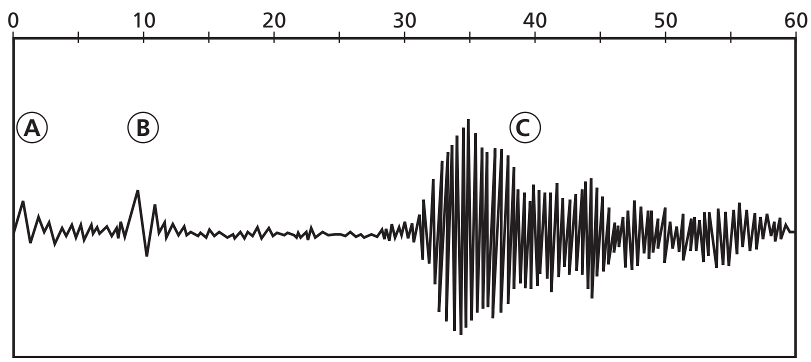
11. The 6.9 rating of the Loma Prieta earthquake is a rating on what measurement scale?

Interpreting Graphics

Directions (12–14): For each question below, record the correct answer on a separate sheet of paper.

The diagram below shows a recording of data by a seismograph. Use this diagram to answer questions 12 and 13.

Reading a Seismogram



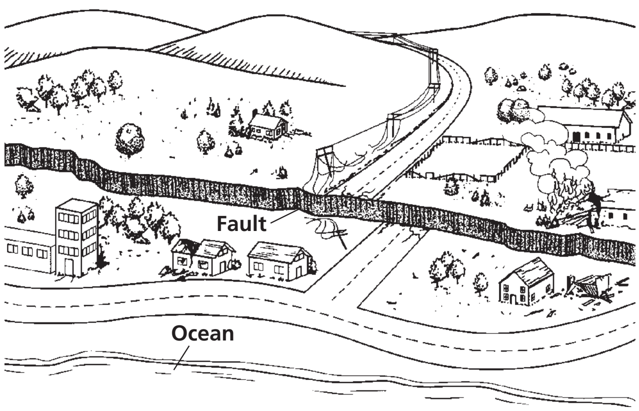
12. What type of seismic waves are indicated by the points on the seismogram marked by the letter A?

F. Love waves
G. Rayleigh waves
H. P waves
I. S waves

13. What type of seismic waves are indicated by the point on the seismogram marked by the letter C? How are these waves connected to the smaller waves that preceded them?

The illustration below shows the damage caused by an earthquake. Objects shown in this illustration are not drawn to scale. Use this illustration to answer question 14.

Earthquake Damage



14. What safety hazards can you identify in this scene? What safety advice would you give to someone approaching this scene? How should people prepare for dealing with such post-earthquake safety hazards?

Test Tip

Always read the full question to make sure you understand what is being asked before you look at the answer choices.