

BIG Idea Earthquakes are natural vibrations of the ground, some of which are caused by movement along fractures in Earth's crust.

19.1 Forces Within Earth

MAIN Idea Faults form when the forces acting on rock exceed the rock's strength.

19.2 Seismic Waves and Earth's Interior

MAIN Idea Seismic waves can be used to make images of the internal structure of Earth.

19.3 Measuring and Locating Earthquakes

MAIN Idea Scientists measure the strength and chart the location of earthquakes using seismic waves.

19.4 Earthquakes and Society

MAIN Idea The probability of an earthquake's occurrence is determined from the history of earthquakes and knowing where and how quickly strain accumulates.

GeoFacts

- Earth experiences 500,000 earthquakes each year.
- Most earthquakes are so small that they are not felt.
- Each year, Southern California has about 10,000 earthquakes.



Ruined house



Collapsed freeway



Structure inspector

Start-Up Activities

LAUNCH Lab

What can cause an earthquake?

When pieces of Earth's crust suddenly move relative to one another, earthquakes occur. This movement occurs along fractures in the crust that are called faults.



Procedure

1. Read and complete the lab safety form.
2. Slide the largest surfaces of two smooth **wooden blocks** against each other. Describe the movement.
3. Cut two pieces of coarse-grained **sandpaper** so that they are about 1 cm longer than the largest surface of each block.
4. Place the sandpaper, coarse side up, against the largest surface of each block. Wrap the paper over the edges of the blocks and secure it with **thumbtacks**.
5. Slide the sandpaper-covered sides of the blocks against each other. Describe the movement.

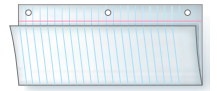
Analysis

1. **Compare** the two movements of the wooden blocks.
2. **Apply** Which parts of Earth are represented by the blocks?
3. **Infer** which of the two scenarios shows what happens during an earthquake.

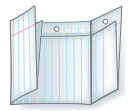
FOLDABLES™ Study Organizer

Types of Faults Make this Foldable to show the three basic types of faults.

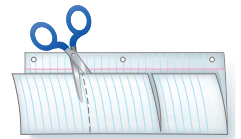
- ▶ **STEP 1** Fold a sheet of paper in half. Make the back edge about 2 cm longer than the front edge.



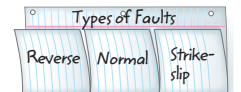
- ▶ **STEP 2** Fold into thirds.



- ▶ **STEP 3** Unfold and cut along the folds of the top flap to make three tabs.



- ▶ **STEP 4** Label the tabs *Reverse*, *Normal*, and *Strike-slip*.



FOLDABLES Use this Foldable with Section 19.1.

As you read this section, explain in your own words the characteristics associated with each type of fault.

Earth Science online

Visit glencoe.com to

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 - Interactive Time Lines
 - Interactive Figures
 - Interactive Tables
- ▶ access Web Links for more information, projects, and activities;
- ▶ review content with the Interactive Tutor and take Self-Check Quizzes.

Section 19.1

Objectives

- ▶ **Define** stress and strain as they apply to rocks.
- ▶ **Distinguish** among the three types of movement of faults.
- ▶ **Contrast** the three types of seismic waves.

Review Vocabulary

fracture: the texture or general appearance of the freshly broken surface of a mineral

New Vocabulary

stress
strain
elastic deformation
plastic deformation
fault
seismic wave
primary wave
secondary wave
focus
epicenter

Forces Within Earth

MAIN Idea Faults form when the forces acting on rock exceed the rock's strength.

Real-World Reading Link If you bend a paperclip, it takes on a new shape. If you bend a popsicle stick, it will eventually break. The same is true of rocks; when forces are applied to rocks, they either bend or break.

Stress and Strain

Most earthquakes are the result of movement of Earth's crust produced by plate tectonics. As a whole, tectonic plates tend to move gradually. Along the boundaries between two plates, rocks in the crust often resist movement. Over time, stress builds up. **Stress** is the total force acting on crustal rocks per unit of area. When stress overcomes the strength of the rocks involved, movement occurs along fractures in the rocks. The vibrations caused by this sudden movement are felt as an earthquake. The characteristics of earthquakes are determined by the orientation and magnitude of stress applied to rocks, and by the strength of the rocks involved.

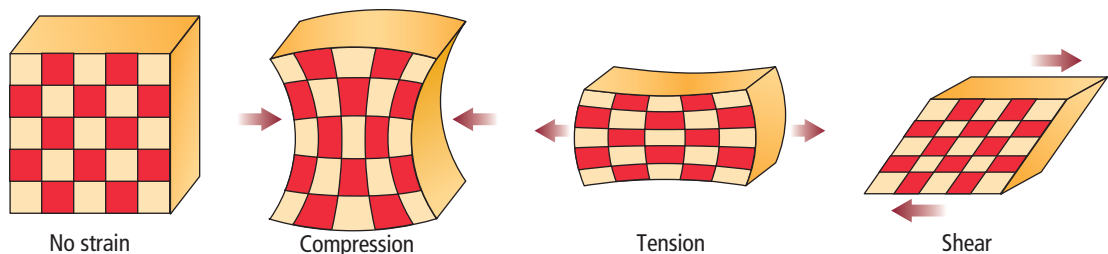
There are three kinds of stress that act on Earth's rocks: compression, tension, and shear. Compression is stress that decreases the volume of a material, tension is stress that pulls a material apart, and shear is stress that causes a material to twist. The deformation of materials in response to stress is called **strain**. **Figure 19.1** illustrates the strain caused by compression, tension, and shear.

Even though rocks can be twisted, squeezed, and stretched, they fracture when stress and strain reach a critical point. At these breaks rock can move, releasing the energy built up as a result of stress. Earthquakes are the result of this movement and release of energy. For example, the 2005 earthquake in Pakistan was caused by a release of built-up compression stress. When that energy was released as an earthquake, more than 75,000 people were killed and 3 million were made homeless.

■ **Figure 19.1** Compression causes a material to shorten. Tension causes a material to lengthen. Shear causes distortion of a material.

Concepts in Motion

Interactive Figure To see an animation of faults, visit glencoe.com.



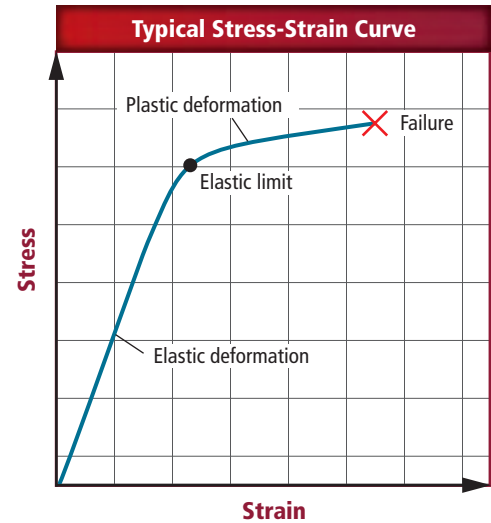
Laboratory experiments on rock samples show a distinct relationship between stress and strain. When the stress applied to a rock is plotted against strain, a stress-strain curve, like the one shown in **Figure 19.2**, is produced. A stress-strain curve usually has two segments—a straight segment and a curved segment. Each segment represents a different type of response to stress.

Elastic deformation The first segment of a stress-strain curve shows what happens under conditions in which stress is low. Under low stress, a material shows elastic deformation. **Elastic deformation** is caused when a material bends and stretches. This is the same type of deformation that happens from gently pulling on the ends of a rubber band. When the stress on the rubber band is released, it returns to its original size and shape. **Figure 19.2** illustrates that elastic deformation is proportional to stress. If the stress is reduced to zero, as the graph shows, the deformation of the rocks disappears.

Plastic deformation When stress builds up past a certain point, called the elastic limit, rocks undergo **plastic deformation**, shown by the second segment of the graph in **Figure 19.2**. Unlike elastic deformation, this type of strain produces permanent deformation, which means that the material stays deformed even when stress is reduced to zero. Even a rubber band undergoes plastic deformation when it is stretched beyond its elastic limit. At first the rubber band stretches, then it tears slightly, and finally, two pieces will snap apart. The tear in the rubber band is an example of permanent deformation. When stress increases to be greater than the strength of a rock, the rock ruptures. The point of rupture, called failure, is designated by the “X” on the graph in **Figure 19.2**.

 **Reading Check Differentiate** between elastic deformation and plastic deformation.

Most materials exhibit both elastic and plastic behavior, although to different degrees. Brittle materials, such as dry wood, glass, and certain plastics, fail before much plastic deformation occurs. Other materials, such as metals, rubber, and silicon putty, can undergo a great deal of deformation before failure occurs, or they might not fail at all. Temperature and pressure also influence deformation. As pressure increases, rocks require greater stress to reach the elastic limit. At high enough temperatures, solid rock can also deform, causing it to flow in a fluid-like manner. This flow reduces stress.



■ **Figure 19.2** A typical stress-strain curve has two parts. Elastic deformation occurs as a result of low stress. When the stress is removed, material returns to its original shape. Plastic deformation occurs under high stress. The deformation of the material is permanent. When plastic deformation is exceeded, an earthquake occurs.

Describe what happens to a material at the point on the graph at which elastic deformation changes into plastic deformation.

VOCABULARY

SCIENCE USAGE V. COMMON USAGE

Failure

Science usage: a collapsing, fracturing, or giving way under stress

Common usage: lack of satisfactory performance or effect



■ **Figure 19.3** A major fault passes through these rice fields on an island in Japan.

Identify the direction of movement that occurred along this fault.

FOLDABLES

Incorporate information from this section into your Foldable.

Faults

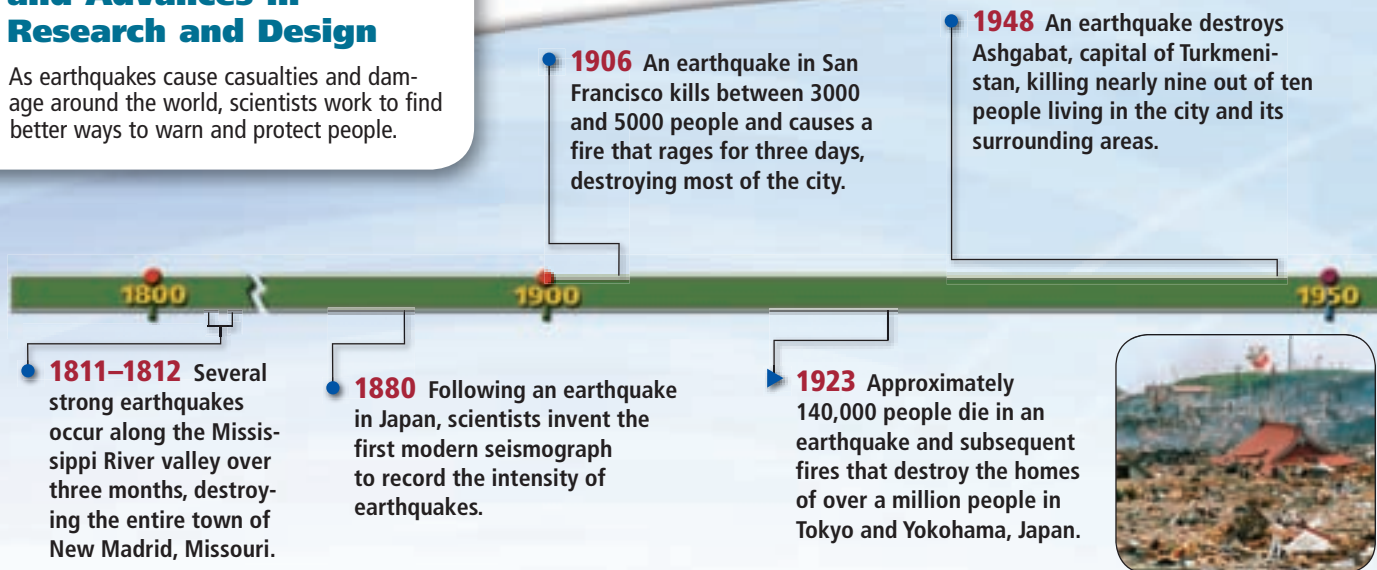
Crustal rocks fail when stresses exceed the strength of the rocks. The resulting movement occurs along a weak region in the crustal rock called a fault. A **fault** is any fracture or system of fractures along which Earth moves. **Figure 19.3** shows a fault. The surface along which the movement takes place is called the fault plane. The orientation of the fault plane can vary from nearly horizontal to almost vertical. The movement along a fault results in earthquakes. Several historic earthquakes are described in the time line in **Figure 19.4**.

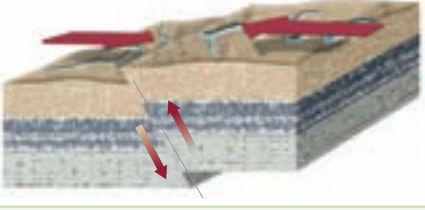
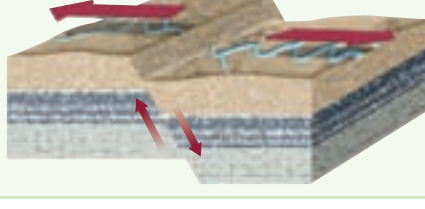
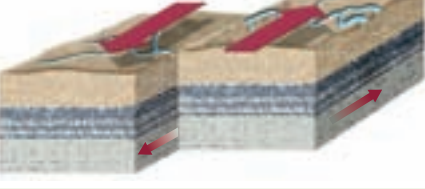
Reverse and normal faults Reverse faults form as a result of horizontal and vertical compression that squeezes rock and creates a shortening of the crust. This causes rock on one side of a reverse fault to be pushed up relative to the other side. Reverse faulting can be seen near convergent plate boundaries.

Movement along a normal fault is partly horizontal and partly vertical. The horizontal movement pulls rock apart and stretches the crust. Vertical movement occurs as the stretching causes rock on one side of the fault to move down relative to the other side. The Basin and Range province in the southwestern United States is characterized by normal faulting. The crust is being stretched apart in that area. Note in the diagrams shown in **Table 19.1** that the two areas separated by the reverse fault would be closer after the faulting than before, and that two areas at a normal fault would be farther apart after the faulting than before the faulting.

■ Figure 19.4 Major Earthquakes and Advances in Research and Design

As earthquakes cause casualties and damage around the world, scientists work to find better ways to warn and protect people.



| Table 19.1 | | Types of Faults |
|---------------|--|--|
| Type of Fault | Type of Movement | Example |
| Reverse | Compression causes horizontal and vertical movement. |  |
| Normal | Tension causes horizontal and vertical movement |  |
| Strike-slip | Shear causes horizontal movement. |  |

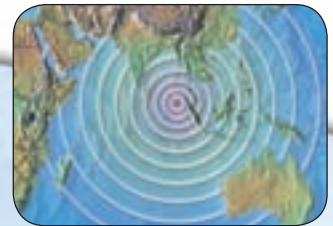
Strike-slip faults Strike-slip faults are caused by horizontal shear. As shown in **Table 19.1**, the movement at a strike-slip fault is mainly horizontal and in opposite directions, similar to the way cars move in opposite directions on either side of a freeway. The San Andreas Fault, which runs through California, is a strike-slip fault. Horizontal motion along the San Andreas and several other related faults is responsible for many of the state's earthquakes. The result of motion along strike-slip faults can easily be seen in the many offset features that were originally continuous across the fault.



1965 The United States, Japan, Chile, and Russia form the International Pacific Tsunami Warning System.

1982 New Zealand constructs the first building with seismic isolation, using lead-rubber bearings to prevent the building from swaying during an earthquake.

2004 A 9.0 earthquake in the Indian Ocean triggers the most deadly tsunami in history. The tsunami travels as far as the East African Coast.



1960

1960 In Chile, a 9.5 earthquake generates tsunamis that hit Hawaii, Japan, New Zealand, and Samoa. This is the largest earthquake recorded.

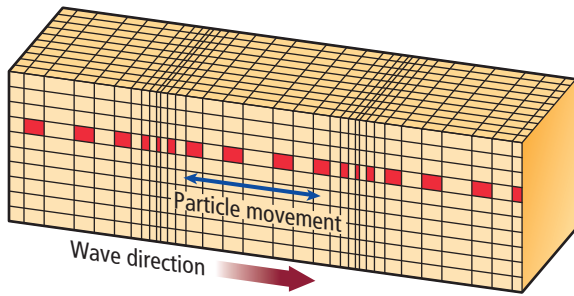
1972 The University of California, Berkeley creates the first modern shake table to test building designs.



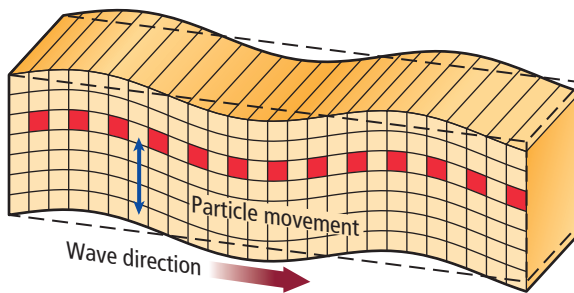
1980

2000

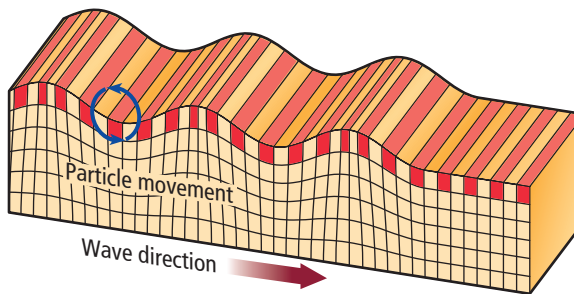
Interactive Figure To see an animation of seismic waves, visit glencoe.com.



P-wave movement



S-wave movement



Surface wave movement

■ **Figure 19.5** Seismic waves are characterized by the types of movement they cause. Rock particles move back and forth as a P-wave passes. Rock particles move at right angles to the direction of the S-wave. A surface wave causes rock particles to move both up and down and from side to side.

Earthquake Waves

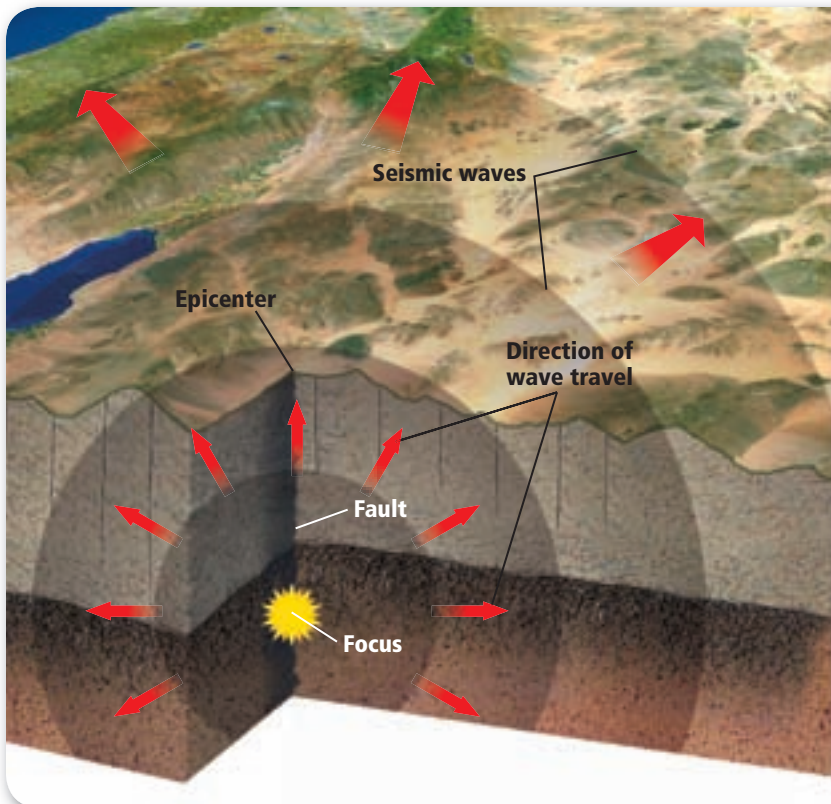
Most earthquakes are caused by movements along faults. Recall from the Launch Lab that some slippage along faults is relatively smooth. Other movements, modeled by the sandpaper-covered blocks, show that irregular surfaces in rocks can snag and lock. As stress continues to build in these rocks, they reach their elastic limit, undergo plastic deformation, then break, and the vibrations from the energy that is released produce an earthquake.

Types of seismic waves The vibrations of the ground during an earthquake are called **seismic waves**. Every earthquake generates three types of seismic waves: primary waves, secondary waves, and surface waves.

Primary waves Also referred to as P-waves, **primary waves** squeeze and push rocks in the direction along which the waves are traveling, as shown in **Figure 19.5**. Note how a volume of rock, which is represented by small red squares, changes length as a P-wave passes through it. The compressional movement of P-waves is similar to the movement along a loosely coiled wire. If the coil is tugged and released quickly, the vibration passes through the length of the coil parallel to the direction of the initial tug.

Secondary waves **Secondary waves**, called S-waves, are named with respect to their arrival times. They are slower than P-waves, so they are the second set of waves to be felt. S-waves have a motion that causes rocks to move at right angles in relation to the direction of the waves, as illustrated in **Figure 19.5**. The movement of S-waves is similar to the movement of a jump rope that is jerked up and down at one end. The waves travel vertically to the other end of the jump rope. Both P-waves and S-waves pass through Earth's interior. For this reason, they are also called body waves.

Surface waves The third and slowest type of waves are surface waves, which travel only along Earth's surface. Surface waves can cause the ground to move sideways and up and down like ocean waves, as shown in **Figure 19.5**. These waves usually cause the most destruction because they cause the most movement of the ground, and take the longest time to pass.



■ **Figure 19.6** The focus of an earthquake is the point of initial fault rupture. The surface point directly above the focus is the epicenter. **Infer** the point at which surface waves will cause the most damage.

Generation of seismic waves The first body waves generated by an earthquake spread out from the point of failure of crustal rocks. The point where the waves originate is the **focus** of the earthquake. The focus is usually several kilometers below Earth's surface. The point on Earth's surface directly above the focus is the **epicenter** (EH pih sen tur), shown in **Figure 19.6**. Surface waves originate from the epicenter and spread out.

Section 19.1 Assessment

Section Summary

- ▶ Stress is force per unit of area that acts on a material and strain is the deformation of a material in response to stress.
- ▶ Reverse, normal, and strike-slip are the major types of faults.
- ▶ The three types of seismic waves are P-waves, S-waves, and surface waves.

Understand Main Ideas

1. **MAIN Idea** Describe how the formation of a fault can result in an earthquake.
2. **Explain** why a stress-strain curve usually has two segments.
3. **Compare and contrast** the movement produced by each of the three types of faults.
4. **Draw** three diagrams to show how each type of seismic wave moves through rock. How do they differ?

Think Critically

5. **Relate** the movement produced by seismic waves to the observations a person would make of them as they traveled across Earth's surface.

WRITING in Earth Science

6. Relate the movement of seismic waves to movement of something you might see every day. Make a list and share it with your classmates.

Section 19.2

Objectives

- **Describe** how a seismometer works.
- **Explain** how seismic waves have been used to determine the structure and composition of Earth's interior.

Review Vocabulary

mantle: the part of Earth's interior beneath the lithosphere and above the central core

New Vocabulary

seismometer
seismogram

Seismic Waves and Earth's Interior

MAIN Idea Seismic waves can be used to make images of the internal structure of Earth.

Real-World Reading Link When you look in a mirror, you see yourself because light waves reflect off your face to the mirror and back to your eye. Similarly, seismic waves traveling through Earth reflect off structures inside Earth, which allows these structures to be imaged.

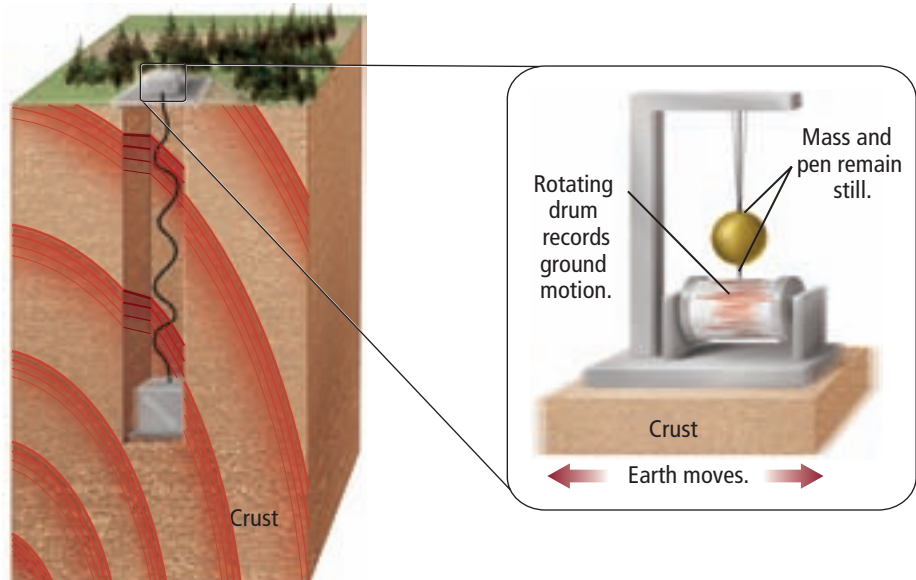
Seismometers and Seismograms

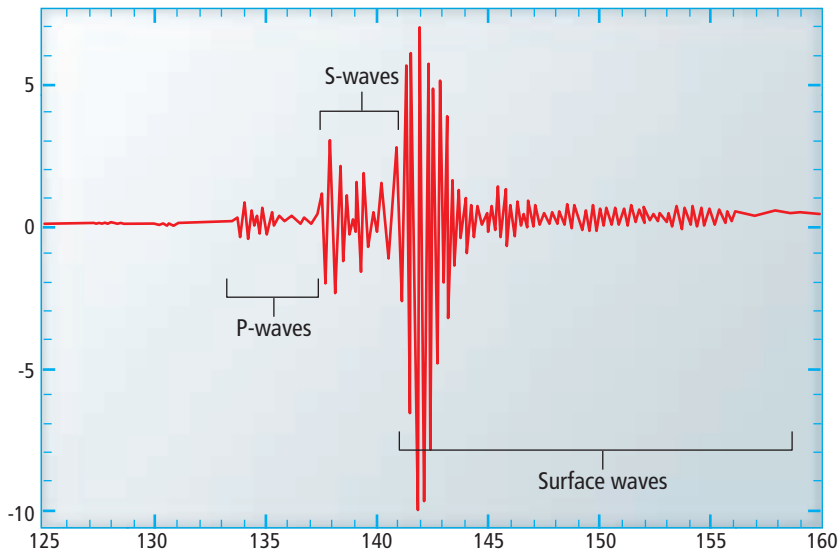
Most of the vibrations caused by seismic waves cannot be felt at great distances from an earthquake's epicenter, but they can be detected by sensitive instruments called **seismometers** (size MAH muh turz). Some seismometers consist of a rotating drum covered with a sheet of paper, a pen or other such recording tool, and a mass, such as a pendulum. Seismometers vary in design, but all include a frame that is anchored to the ground and a mass that is suspended from a spring or wire, as shown in **Figure 19.7**. During an earthquake, the mass and the pen attached to it tend to stay at rest due to inertia, while the ground beneath shakes. The motion of the mass in relation to the frame is then registered on the paper with the recording tool, or is directly recorded onto a computer disk. The record produced by a seismometer is called a **seismogram** (SIZE muh gram). A portion of one is shown in **Figure 19.8**.

Concepts in Motion

Interactive Figure To see an animation of seismometers, visit glencoe.com.

■ **Figure 19.7** The frame of a seismometer is anchored to the ground. When an earthquake occurs, the frame moves but the hanging mass and attached pen do not. The mass and pen record the relative movement as the recording device moves under them.





■ **Figure 19.8** Seismograms provide a record of the seismic waves that pass a certain point.

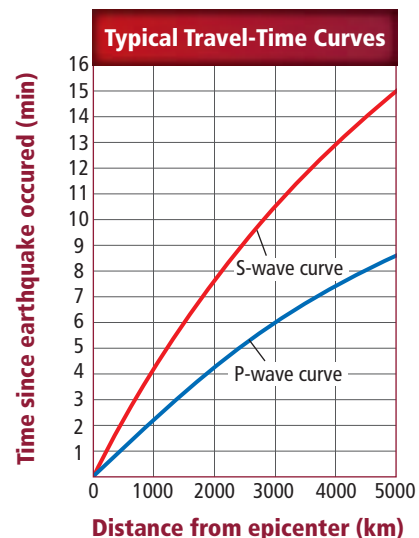
Travel-time curves Seismic waves that travel from the focus of an earthquake are recorded by seismometers housed in distant facilities. Over many years, the arrival times of seismic waves from countless earthquakes at seismic facilities around the world have been collected. Using these data, seismologists have been able to construct global travel-time curves for the arrival of P-waves and S-waves of earthquakes, as shown in **Figure 19.9**. These curves provide the average travel times of all P- and S-waves, from wherever an earthquake occurs on Earth.

✓ **Reading Check Summarize** how seismograms are used to construct global travel-time curves.

Distance from the epicenter Note that in **Figure 19.9**, as in **Figure 19.8**, the P-waves arrive first, then the S-waves, and the surface waves arrive last. With increasing travel distance from the epicenter, the time separation between the curves for the P-waves and S-waves increases. This means that waves recorded on seismograms from more distant facilities are farther apart than waves recorded on seismograms at stations closer to the epicenter. This separation of seismic waves on seismograms can be used to determine the distance from the epicenter of an earthquake to the seismic facility that recorded the seismogram. This method of precisely locating an earthquake's epicenter will be discussed in Section 19.3.

■ **Figure 19.9** Travel-time curves show how long it takes for P-waves and S-waves to reach seismic stations located at different distances from an earthquake's epicenter.

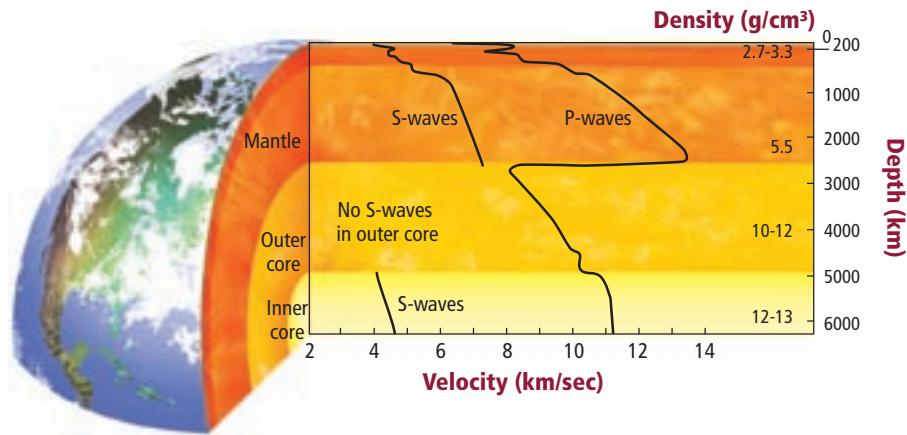
Determine how long it takes P-waves to travel to a seismogram 2000 km away. How long does it take for S-waves to travel the same distance?



■ **Figure 19.10** Earth's layers are each composed of different materials. By knowing the behavior of seismic waves through different kinds of rock, scientists have determined the composition of layers all the way to Earth's inner core.

Concepts In Motion

Interactive Figure To see an animation of P-waves and S-waves, visit glencoe.com.



Clues to Earth's Interior

The seismic waves that shake the ground during an earthquake also travel through Earth's interior. This provides information that has enabled scientists to construct models of Earth's internal structure. Therefore, even though seismic waves can wreak havoc on the surface, they are invaluable for their contribution to scientists' understanding of Earth's interior.

Earth's internal structure Seismic waves change speed and direction when they encounter different materials. Note in **Figure 19.10** that as P-waves and S-waves initially travel through the mantle, they follow fairly direct paths. When P-waves strike the core, they are refracted, which means they bend. Seismic waves also reflect off of major boundaries inside Earth. By recording the travel-time curves and path of each wave, seismologists learn about differences in density and composition within Earth.

What happens to the S-waves generated by an earthquake? To answer this question, seismologists first determined that the back-and-forth motion of S-waves does not travel through liquid. Then, seismologists noticed that S-waves do not travel through Earth's center. This observation led to the discovery that Earth's core must be at least partly liquid. The data collected for the paths and travel times of the waves inside Earth led to the current understanding that Earth has an outer core that is liquid and an inner core that is solid.

Earth's composition **Figure 19.11** shows that seismic waves change their paths as they encounter boundaries between zones of different materials. They also change their speed. By comparing the speed of seismic waves with measurements made on different rock types, scientists have determined the thickness and composition of Earth's different regions. As a result, scientists have determined that the upper mantle is peridotite, which is made mostly of the mineral olivine. The outer core is mostly liquid iron and nickel. The inner core is mostly solid iron and nickel.

VOCABULARY

ACADEMIC VOCABULARY

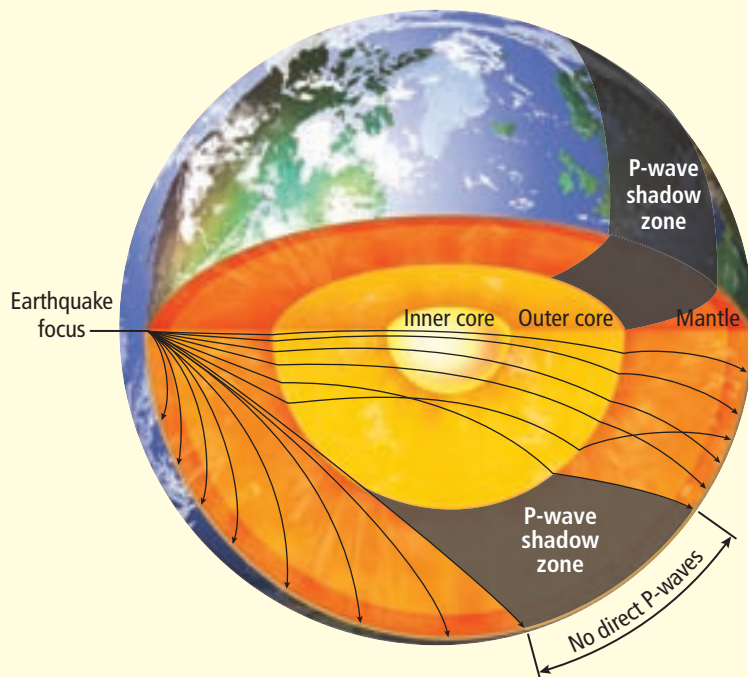
Encounter

to come upon or experience, especially unexpectedly

We had never encountered such a violent storm.

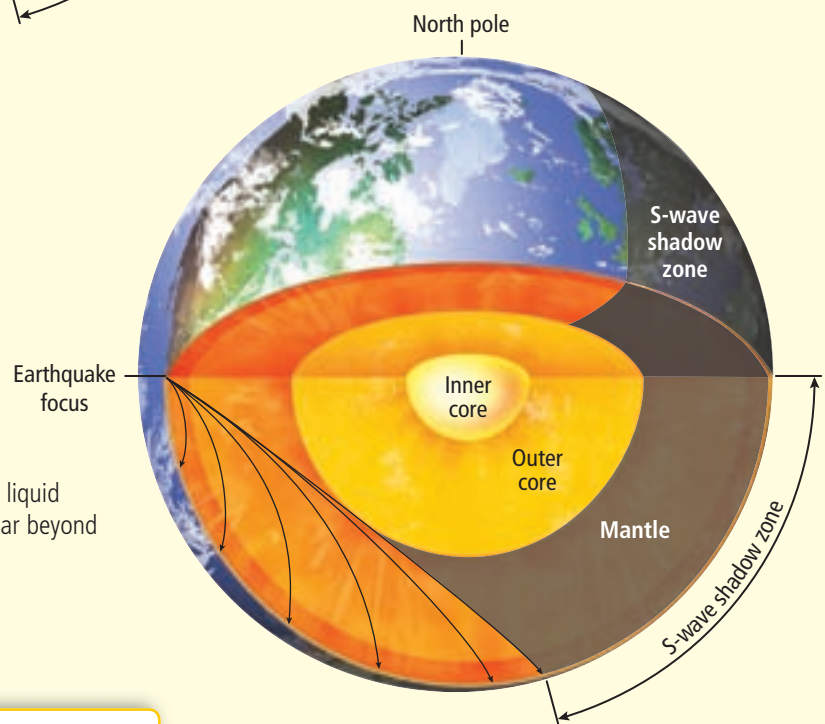
Visualizing Seismic Waves

Figure 19.11 The travel times and behavior of seismic waves provide a detailed picture of Earth's internal structure. These waves also provide clues about the composition of the various parts of Earth.



P-waves in the outer core are refracted. This generates a P-wave shadow zone on Earth's surface where no direct P-waves appear on seismograms. Other P-waves are reflected and refracted by the inner core. These can be detected by seismometers on the other side of the shadow zone.

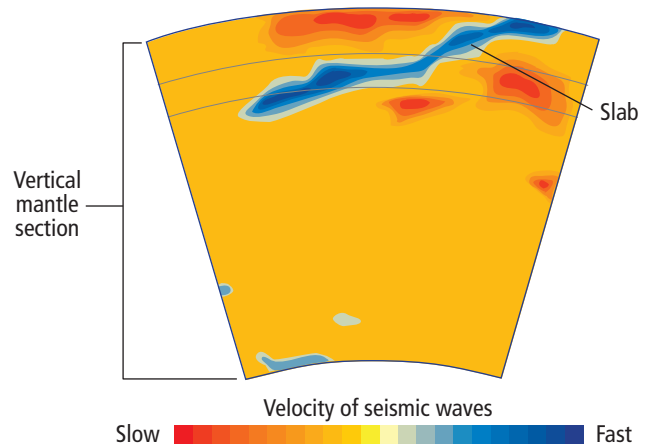
S-waves cannot travel through the liquid outer core and thus do not reappear beyond the S-wave shadow zone.



CONCEPTS IN MOTION To explore more about seismic waves, visit glencoe.com.



■ **Figure 19.12** Images like this one from Japan are generated by capturing the path of seismic waves through Earth's interior. Areas of red indicate seismic waves that are traveling more slowly than average and areas of blue indicate seismic waves that are traveling faster than average.



Imaging Earth's interior Seismic wave speed and Earth's density vary with factors other than depth. Recall from Chapter 17 that cold slabs sink back into Earth at subduction zones, and recall from Chapter 18 that mantle plumes are regions where hot mantle material is rising. Because the speed of seismic waves depends on temperature and composition, it is possible to use seismic waves to create images of structures such as slabs and plumes. In general, the speed of seismic waves decreases as temperature increases. Thus, waves travel more slowly in hotter areas and more quickly in cooler regions. Using measurements made at seismometers around the world and waves recorded from many thousands of earthquakes, Earth's internal structure can be visualized, and features such as slabs can be located in images like the one in **Figure 19.12**. These images are similar to CT scans, except that the images are made using seismic waves instead of X rays.

Section 19.2 Assessment

Section Summary

- ▶ Seismometers are devices that record seismic wave activity on a seismogram.
- ▶ Travel times for P-waves and S-waves enable scientists to pinpoint the location of earthquakes.
- ▶ P-waves and S-waves change speed and direction when they encounter different materials.
- ▶ Analysis of seismic waves provides a detailed picture of the composition of Earth's interior.

Understand Main Ideas

1. **MAIN Idea** **Explain** how P-waves and S-waves are used to determine the properties of Earth's core.
2. **Draw** a diagram of a seismometer showing how the movement of Earth is translated into a seismogram.
3. **Describe** how seismic travel-time curves are used to study earthquakes.
4. **Differentiate** between the speed of waves through hot and cold material.

Think Critically

5. **Infer** Using the seismogram in **Figure 19.8**, suggest why surface waves cause so much damage even though they are the last to arrive at a seismic station.

WRITING in Earth Science

6. Write a newspaper article reporting on the ways scientists have determined the composition of Earth.

Section 19.3

Objectives

- ▶ **Compare and contrast** earthquake magnitude and intensity and the scales used to measure each.
- ▶ **Explain** why data from at least three seismic stations are needed to locate an earthquake's epicenter.
- ▶ **Describe** Earth's seismic belts.

Review Vocabulary

plot: to mark or note on a map or chart

New Vocabulary

Richter scale
magnitude
amplitude
moment magnitude scale
modified Mercalli scale

Measuring and Locating Earthquakes

MAIN Idea Scientists measure the strength and chart the location of earthquakes using seismic waves.

Real-World Reading Link When someone speaks to you from nearby, you can hear them clearly. However, the sound gets fainter as they get farther away. Similarly, the energy of seismic waves gets weaker the farther away you are from the source of an earthquake.

Earthquake Magnitude and Intensity

More than 1 million earthquakes are felt each year, but news accounts report on only the largest ones. Scientists have developed several methods for describing the size of an earthquake.

Richter scale The **Richter scale**, devised by a geologist named Charles Richter, is a numerical rating system that measures the energy of the largest seismic waves, called the **magnitude**, that are produced during an earthquake. The numbers in the Richter scale are determined by the height, called the **amplitude**, of the largest seismic wave. Each successive number represents an increase in amplitude of a factor of 10. For example, the seismic waves of a magnitude-8 earthquake on the Richter scale are ten times larger than those of a magnitude-7 earthquake. The differences in the amounts of energy released by earthquakes are even greater than the differences between the amplitudes of their waves. Each increase in magnitude corresponds to about a 32-fold increase in seismic energy. Thus, an earthquake of magnitude-8 releases about 32 times the energy of a magnitude-7 earthquake. The damage shown in **Figure 19.13** was caused by an earthquake measuring 7.6 on the Richter scale.

■ **Figure 19.13** The damage shown here was caused by a magnitude-7.6 earthquake that struck Pakistan in December 2005.





■ **Figure 19.14** The modified Mercalli scale measures damage done by an earthquake. An earthquake strong enough to knock groceries off the store's shelves would probably be rated V using the modified Mercalli scale.

Moment magnitude scale While the Richter scale is often used to describe the magnitude of an earthquake, most earthquake scientists, called seismologists, use a scale called the moment magnitude scale. The **moment magnitude scale** is a rating scale that measures the energy released by an earthquake, taking into account the size of the fault rupture, the amount of movement along the fault, and the rocks' stiffness. Most often, when you hear about an earthquake on the news, the number given is from the moment magnitude scale.

Modified Mercalli scale Another way to describe earthquakes is with respect to the amount of damage they cause. This measure, called the intensity of an earthquake, is determined using the **modified Mercalli scale**, which rates the types of damage and other effects of an earthquake as noted by observers during and after its occurrence. This scale uses the Roman numerals I to XII to designate the degree of intensity. Specific effects or damage correspond to specific numerals; the worse the damage, the higher the numeral. A simplified version of the modified Mercalli scale is shown in **Table 19.2**. You can use the information given in this scale to rate the intensity of the earthquakes such as the one that caused the damage shown in **Figure 19.14**.

Table 19.2

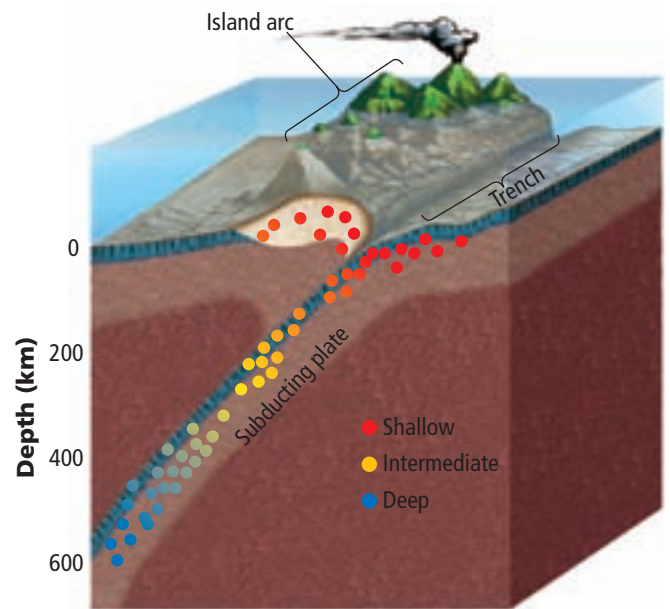
Modified Mercalli Scale

| | |
|------|--|
| I | Not felt except under unusual conditions |
| II | Felt only by a few persons; suspended objects might swing. |
| III | Quite noticeable indoors; vibrations are like the passing of a truck. |
| IV | Felt indoors by many, outdoors by few; dishes and windows rattle; standing cars rock noticeably. |
| V | Felt by nearly everyone; some dishes and windows break and some plaster cracks. |
| VI | Felt by all; furniture moves; some plaster falls and some chimneys are damaged. |
| VII | Everybody runs outdoors; some chimneys break; damage is slight in well-built structures but considerable in weak structures. |
| VIII | Chimneys, smokestacks, and walls fall; heavy furniture is overturned; partial collapse of ordinary buildings occurs. |
| IX | Great general damage occurs; buildings shift off foundations; ground cracks; underground pipes break. |
| X | Most ordinary structures are destroyed; rails are bent; landslides are common. |
| XI | Few structures remain standing; bridges are destroyed; railroad ties are greatly bent; broad fissures form in the ground. |
| XII | Damage is total; objects are thrown upward into the air. |

Earthquake intensity The intensity of an earthquake depends primarily on the amplitude of the surface waves generated. Like body waves, surface waves gradually decrease in size with increasing distance from the focus of an earthquake. Because of this, the intensity also decreases as the distance from an earthquake's epicenter increases. Maximum intensity values are observed in the region near the epicenter; Mercalli values decrease to I at distances far from the epicenter.

In the MiniLab, you will use the modified Mercalli scale values to make a seismic-intensity map. These maps are a visual demonstration of an earthquake's intensity. Contour lines join points that experienced the same intensity. They demonstrate how the maximum intensity is usually found near the earthquake's epicenter.

Depth of focus As you learned earlier in this section, earthquake intensity and magnitude reflect the size of the seismic waves generated by the earthquake. Another factor that determines the intensity of an earthquake is the depth of its focus. As shown in **Figure 19.15**, earthquakes can be classified as shallow, intermediate, or deep, depending on the location of the focus. Catastrophic earthquakes with high intensity values are almost always shallow-focus events.



■ **Figure 19.15** Earthquakes are classified as shallow, intermediate, or deep, depending on the location of the focus. Shallow-focus earthquakes are the most damaging.

MiniLab

Make a Map

How is a seismic-intensity map made? Seismic-intensity data plotted on contour maps give scientists a visual picture of an epicenter's location and the earthquake's intensity.

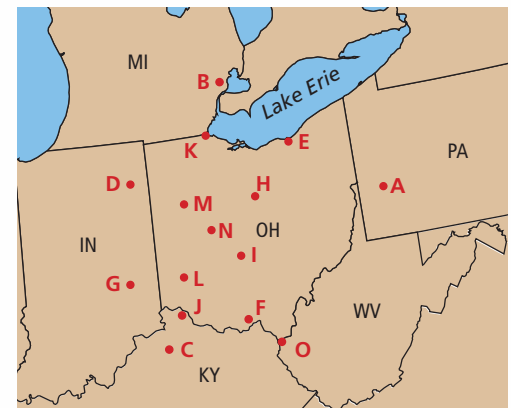
Procedure

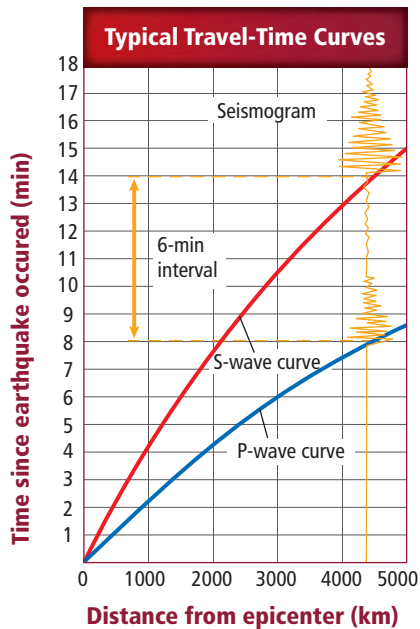
1. Read and complete the lab safety form.
2. Trace the map onto **paper**. Mark the locations indicated by the letters on the map.
3. Plot these Mercalli intensity values on the map next to the correct letter: A, I; B, III; C, II; D, III; E, IV; F, IV; G, IV; H, V; I, V; J, V; K, VI; L, VIII; M, VII; N, VIII; O, III.
4. Draw contours on the map to connect the intensity values.

Analysis

1. **Determine** the maximum intensity value.
2. **Find** the location of the maximum intensity value.
3. **Estimate** the earthquake's epicenter.

Intensity Values of an Earthquake





■ **Figure 19.16** This travel-time curve also shows seismographic data for an earthquake event.

■ **Figure 19.17** To locate the epicenter of an earthquake, scientists identify the seismic stations on a map, and draw a circle with the radius of distance to the epicenter from each station. The point where all the circles intersect is the epicenter.

Identify the epicenter of this earthquake.



Deep-focus earthquakes generally produce smaller vibrations at the epicenter than those produced by shallow-focus earthquakes. For example, a shallow-focus, moderate earthquake that measures a magnitude-6 on the Richter scale can generate a greater maximum intensity than a deep-focus earthquake of magnitude-8. Because the modified Mercalli scale is based on intensity rather than magnitude, it is a better measure of an earthquake's effect on people.

Locating an Earthquake


The location of an earthquake's epicenter and the time of the earthquake's occurrence are usually not known at first. However, the epicenter's location, as well as the time of occurrence, can be determined using seismograms and travel-time curves.

Distance to an earthquake Just as a person riding a bike will travel faster than a person who is walking, P-waves reach a seismograph station before the S-waves. Consider the effect of the distance traveled on the time it takes for both waves to arrive. Like the bicyclist and the walker, the gap in their arrival times will be greater when the distance traveled is longer. **Figure 19.16** shows the same travel-time curve graph shown in **Figure 19.9** of Section 19.2, but this time it is joined with the seismogram from a specific earthquake. The seismometer recorded the time that elapsed between the arrival of the first P-waves and first S-waves. Seismologists determine the distance to an earthquake's epicenter by measuring the separation on any seismogram and identifying that same separation time on the travel-time graph. The separation time for the earthquake shown in **Figure 19.16** is 6 min. Based on travel times of seismic waves, the distance between the earthquake's epicenter and the seismic station that recorded the waves can only be 4500 km. This is because the known travel time over that distance is 8 min for P-waves and 14 min for S-waves. Farther from the epicenter, the gap between the travel times for both waves increases.

✓ **Reading Check Apply** If the gap between P- and S-waves is 2 min, what can you infer about the distance from the epicenter to the seismometer?

Seismologists analyze data from many seismograms to locate the epicenter. Calculating the distance between an earthquake's epicenter and a seismic station provides enough information to determine that the epicenter was a certain distance in any direction from the seismic station. This can be represented by a circle around the seismic station with a radius equal to the distance to the epicenter. Consider the effect of adding data from a second seismic station. The two circles will overlap at two points. When data from a third seismic station is added, the rings will overlap only at one point—the epicenter, as shown in **Figure 19.17**.

Time of an earthquake The gap in the arrival times of different seismic waves on a seismogram provides information about the distance to the epicenter. Seismologists can also use the seismogram to gain information about the exact time that the earthquake occurred at the focus. The time can be determined by using a table similar to the travel-time graph shown in **Figure 19.9**. The exact arrival times of the P-waves and S-waves at a seismic station are recorded on the seismogram. Seismologists read the travel time of either wave to the epicenter from that station using graphs similar to the one shown in **Figure 19.9**. For example, consider a seismogram that registered the arrival of P-waves at exactly 10:00 A.M. If the P-waves traveled 4500 km, and took 8 min according to the appropriate travel-time curve, then it can be determined that the earthquake occurred at the focus at 9:52 A.M.

 **Reading Check List** the information contained in a seismogram.

Seismic Belts

Over the years, seismologists have collected and plotted the locations of numerous earthquake epicenters. The global distribution of these epicenters reveals a noteworthy pattern. Earthquake locations are not randomly distributed. The majority of the world's earthquakes occur along narrow seismic belts that separate large regions with little or no seismic activity.

DATA ANALYSIS LAB

Based on Real Data*

Interpret the Data

How can you find an earthquake's epicenter?

To pinpoint the epicenter, analyze the P-wave and S-wave data recorded at seismic stations.

Analysis

1. Obtain a map of the western hemisphere from your teacher and mark the seismic stations listed in the table.
2. For each station, calculate and record the arrival time differences by subtracting the P-wave arrival time from the S-wave arrival times.
3. Use the arrival time differences and the travel-time curve (**Figure 19.9**) to find the distance between the epicenter and each seismic station. Record the distances.
4. Draw a circle around each station. Use the distance from the epicenter as the radius for each circle. Repeat for each seismic station.
5. Identify the epicenter of the earthquake.

Data and Observations

| Seismic Station | P-wave Arrival Time (PST) | S-wave Arrival Time (PST) | Arrival Time Difference (min) | Distance from Epicenter (km) |
|-------------------|---------------------------|---------------------------|-------------------------------|------------------------------|
| Newcomb, NY | 8:39:02 | 8:44:02 | | |
| Idaho Springs, CO | 8:35:22 | 8:37:57 | | |
| Darwin, CA | 8:35:38 | 8:38:17 | | |

Think Critically

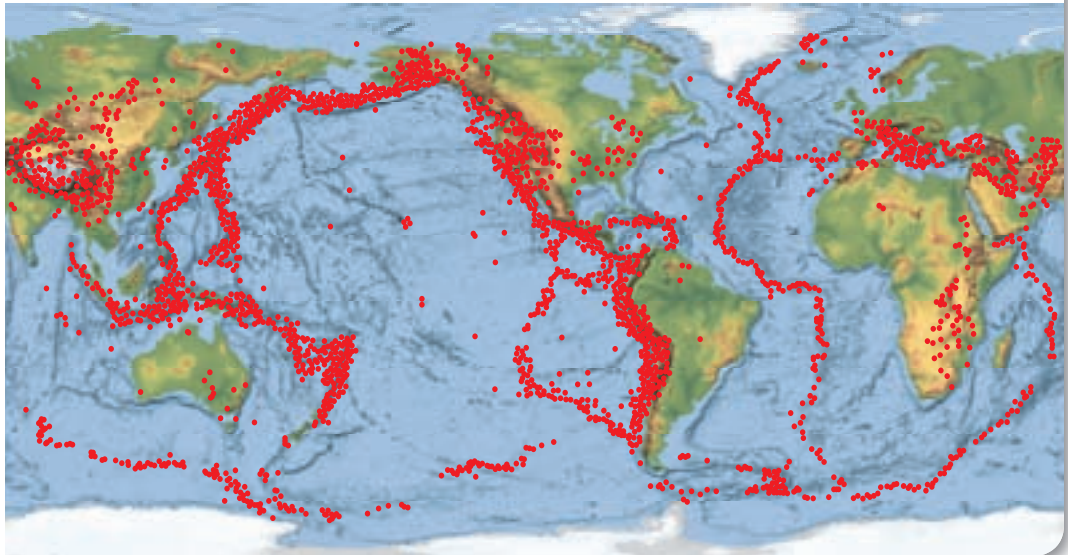
6. **Explain** why you need to find the difference in time of arrival between P- and S-waves for each seismic station.
7. **Identify** sources of error in determining an earthquake's epicenter.
8. **Explain** why data from more seismic stations would be useful for finding the epicenter.

*Data obtained from: Significant earthquakes of the world. 2006. *USGS Earthquake Center*.

■ **Figure 19.18**

Notice the pattern of global epicenter locations on the map.

Identify Based on this map, do you live near an epicenter?



Global Earthquake Epicenter Locations

As shown in **Figure 19.18**, earthquakes occur in narrow bands. The location of most earthquakes corresponds closely with tectonic plate boundaries. In fact, almost 80 percent of all earthquakes occur on the Circum-Pacific Belt and about 15 percent on the Mediterranean-Asian Belt across southern Europe and Asia. These belts are subduction zones, where tectonic plates are colliding, and one plate is forced to sink beneath another. Most of the remaining earthquakes occur in narrow bands along the crests of ocean ridges, where tectonic plates are diverging.

Section 19.3 Assessment

Section Summary

- ▶ Earthquake magnitude is a measure of the energy released during an earthquake and can be measured on the Richter scale.
- ▶ Intensity is a measure of the damage caused by an earthquake and is measured with the modified Mercalli scale.
- ▶ Data from at least three seismic stations are needed to locate an earthquake's epicenter.
- ▶ Most earthquakes occur in seismic belts, which are areas associated with plate boundaries.

Understand Main Ideas

1. **MAIN Idea** **Summarize** the ways that scientists can use seismic waves to measure and locate earthquakes.
2. **Compare and contrast** earthquake magnitude and intensity and the scales used to measure each.
3. **Explain** why data from at least three seismic stations makes it possible to locate an earthquake's epicenter.
4. **Describe** how the boundaries between Earth's tectonic plates compare with the location of most of the earthquakes shown in the map in **Figure 19.18**.

Think Critically

5. **Formulate** a reason why a magnitude-3 earthquake can possibly cause more damage than a magnitude-6 earthquake.

MATH in Earth Science

6. Calculate how much more energy a magnitude-9 earthquake releases compared to that of a magnitude-7 earthquake.

Section 19.4

Objectives

- **Discuss** factors that affect the amount of damage caused by an earthquake.
- **Explain** some of the factors considered in earthquake-probability studies.
- **Identify** how different types of structures are affected by earthquakes.

Review Vocabulary

geology: study of materials that make up Earth and the processes that form and change these materials

New Vocabulary

soil liquefaction
tsunami
seismic gap

Earthquakes and Society

MAIN Idea The probability of an earthquake's occurrence is determined from the history of earthquakes and knowing where and how quickly strain accumulates.

Real-World Reading Link If, in your city, it rains an average of 11 days every July, how can you predict the weather in your city for July 4 ten years from now? You could estimate that there is a 11/31 chance that it will rain. In the same way, the probability of an earthquake's occurrence can be estimated from the history of earthquakes in the region.

Earthquake Hazards

Earthquakes are known to occur frequently along plate boundaries. An earthquake of magnitude-5 can be catastrophic in one region, but relatively harmless in another. There are many factors that determine the severity of damage produced by an earthquake. These factors are called earthquake hazards. Identifying earthquake hazards in an area can sometimes help to prevent some of the damage and loss of life. For example, the design of certain buildings can affect earthquake damage. As you can see in **Figure 19.19**, the most severe damage occurs to unreinforced buildings made of brittle building materials such as concrete. Wooden structures, on the other hand, are more resilient and generally sustain less damage.

■ **Figure 19.19** Concrete buildings are often brittle and can be easily damaged in an earthquake. The building on the left shifted on its foundation after an earthquake and is held up by a single piece of wood.



■ **Figure 19.20** One type of damage caused by earthquakes is called pancaking because shaking causes a building's supporting walls to collapse and the upper floors to fall one on top of the other like a stack of pancakes.



Structural failure In many earthquake-prone areas, buildings are destroyed as the ground beneath them shakes. In some cases, the supporting walls of the ground floor fail and cause the upper floors, which initially remain intact, to fall and collapse as they hit the ground or lower floors. The resulting debris resembles a stack of pancakes; thus, the process is called pancaking. This type of structural failure, shown in **Figure 19.20**, was a tragic consequence of the earthquake in Islamabad, Pakistan, in 2005.

✓ **Reading Check Explain** what happens when a building pancakes.

Another type of structural failure is related to the height of a building. During the 1985 Mexico City earthquake, for example, most buildings between five and 15 stories tall collapsed or were otherwise completely destroyed, as shown in **Figure 19.21**. Similar structures that were either shorter or taller, however, sustained only minor damage. The shaking caused by the earthquake had the same frequency of vibration as the natural sway of the intermediate buildings. This caused those buildings to sway the most violently during the earthquake. The ground vibrations, however, were too rapid to affect taller buildings, whose frequency of vibration was longer than those of the earthquake, and too slow to affect shorter buildings, whose frequency of vibration was shorter.

■ **Figure 19.21** Many medium-sized buildings were damaged or destroyed during the 1985 Mexico City earthquake because they vibrated with the same frequency as the seismic waves.





■ **Figure 19.22** Soil liquefaction happens when seismic vibrations cause poorly consolidated soil to liquefy and behave like quicksand. The buildings pictured here were built on this type of soil and an earthquake caused the buildings to sink into the ground.

Land and soil failure In addition to their effects on structures made by humans, earthquakes can wreak havoc on Earth's landscape. In sloping areas, earthquakes can trigger massive landslides. For example, most of the estimated 30,000 deaths caused by the magnitude-7.8 earthquake that struck in Peru in 1970 resulted from a landslide that buried several towns. In areas with sand that is nearly saturated with water, seismic vibrations can cause the ground to behave like a liquid in a phenomenon called **soil liquefaction** (lih kwuh FAK shun). It can generate landslides even in areas of low relief. It can cause trees and houses to fall over or to sink into the ground and underground pipes and tanks to rise to the surface. **Figure 19.22** shows tilted buildings that resulted when the soil under them liquefied during an earthquake.

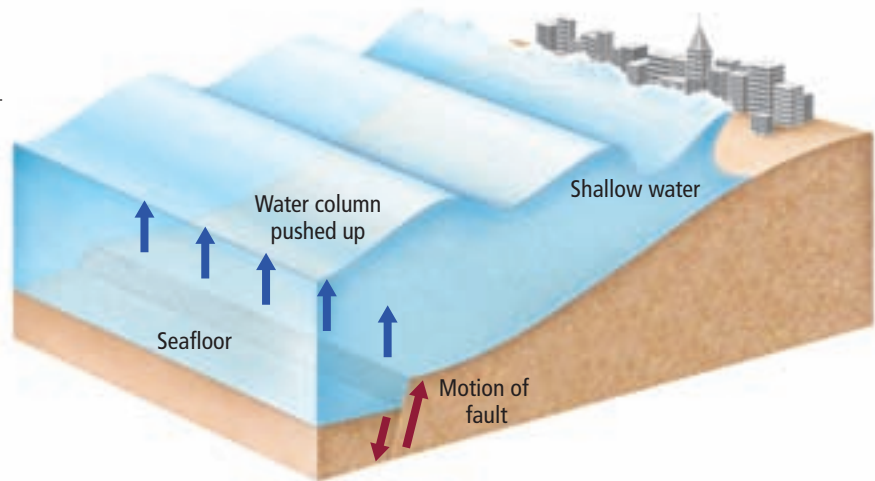
✓ **Reading Check Summarize** how solid ground can take the properties of a liquid.

In addition to determining landslide risks, the type of ground material can also affect the severity of an earthquake in an area. Seismic waves are amplified in some hard materials, such as granite. They are muted in more resistant materials, such as soft, unconsolidated sediments. The severe damage to structures in Mexico City during the 1985 earthquake is attributed to the soft sediments on which the city is built. The thickness of the sediments caused them to resonate with the same frequency as that of the surface waves generated by the earthquake. This produced reverberations that greatly enhanced the ground motion and the resulting damage.

■ **Figure 19.23** A tsunami is generated when an underwater fault displaces a column of water.

Concepts in Motion

Interactive Figure To see an animation of a tsunami, visit glencoe.com.



VOCABULARY

SCIENCE USAGE V. COMMON USAGE

Column

Science usage: a hypothetical cylinder of water that goes from the surface to the bottom of a body of water

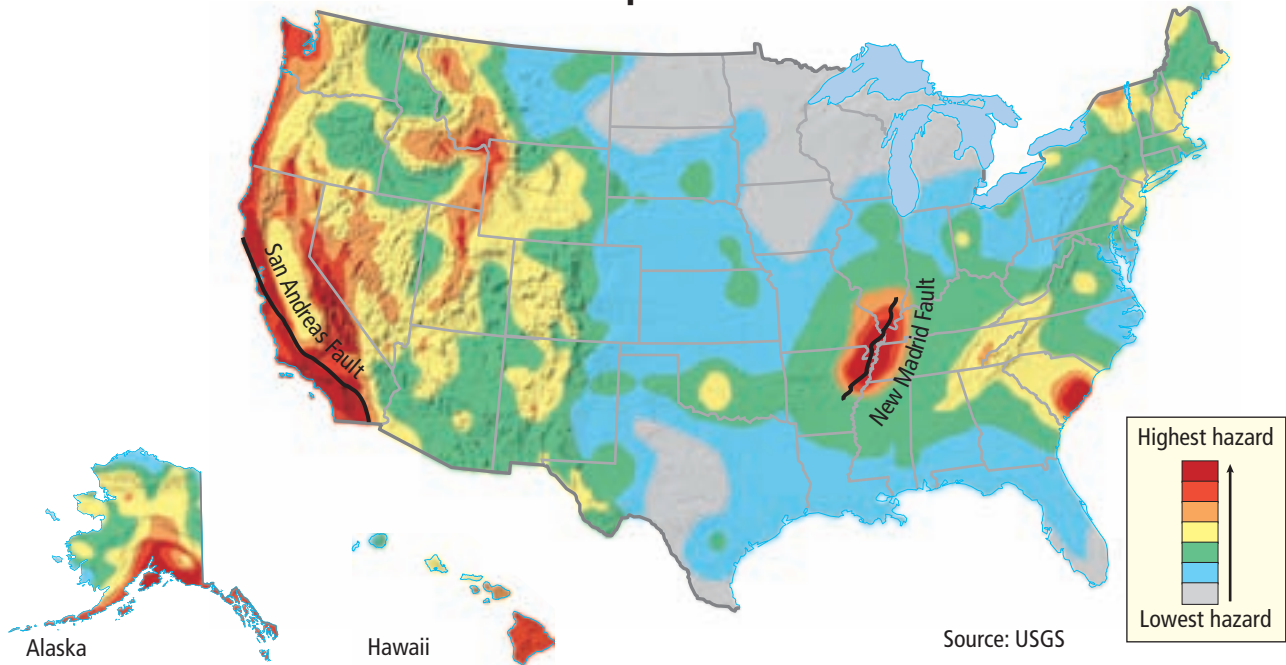
Common usage: a vertical arrangement of items

Tsunami Another type of earthquake hazard is a **tsunami** (soo NAH mee)—a large ocean wave generated by vertical motions of the seafloor during an earthquake. These motions displace the entire column of water overlying the fault, creating bulges and depressions in the water, as shown in **Figure 19.23**. The disturbance then spreads out from the epicenter in the form of extremely long waves. While these waves are in the open ocean, their height is generally less than 1 m. When the waves enter shallow water, however, they can form huge breakers with heights occasionally exceeding 30 m. These enormous wave heights, together with open-ocean speeds between 500 and 800 km/h, make tsunamis dangerous threats to coastal areas both near to and far from an earthquake's epicenter. The Indian Ocean tsunami of December 26, 2004, originated with a magnitude-9.0 earthquake in the ocean about 160 km west of Sumatra. The 30-m-tall tsunami radiated across the Indian Ocean and struck the coasts of Indonesia, Sri Lanka, India, Thailand, Somalia, and several other nations. The death toll from the tsunami exceeded 225,000, making it one of the most devastating natural disasters in modern history. The aftermath of that catastrophic event is shown in **Figure 19.24**.

■ **Figure 19.24** The destruction from the December 26, 2004, tsunami in the Indian Ocean, was not isolated to the shoreline. As seen here, areas inland were devastated by the tsunami, which took at least 225,000 lives.




U.S. Earthquake Hazard



Earthquake Forecasting


To minimize the damage and deaths caused by earthquakes, seismologists are searching for ways to forecast these events. There is currently no completely reliable way to forecast the exact time and location of the next earthquake. Instead, earthquake forecasting is based on calculating the probability of an earthquake. The probability of an earthquake's occurrence is based on two factors: the history of earthquakes in an area and the rate at which strain builds up in the rocks.

 **Reading Check** Identify the two factors seismologists use to determine the probability of an earthquake occurring in a certain area.

Seismic risk Recall that most earthquakes occur in long, narrow bands called seismic belts. The probability of future earthquakes is much greater in these belts than elsewhere on Earth. The pattern of earthquakes in the past is usually a reliable indicator of future earthquakes in a given area. Seismometers and sedimentary rocks can be used to determine the frequency of large earthquakes. The history of an area's seismic activity by can be used to generate seismic-risk maps. A seismic-risk map of the United States is shown in **Figure 19.25**. In addition to Alaska, Hawaii, and some western states, there are several regions of relatively high seismic risk in the central and eastern United States. These regions have experienced some of the most intense earthquakes in the past and probably will experience significant seismic activity in the future.

■ **Figure 19.25** Areas of high seismic risk in the United States include Alaska, Hawaii, and some of the western states.

Locate the areas of highest seismic risk on the map. Locate your own state. What is the seismic risk of your area?

 **NATIONAL GEOGRAPHIC** To read about the challenges of earthquake forecasting, go to the [National Geographic Expedition](#) on page 916.



■ **Figure 19.26** This drill platform was used to drill a hole 2.3 km deep in Parkfield, California. Once completed, the hole was rigged with instruments to record data during major and minor tremors. The goal of the project was to better understand how earthquakes work and what triggers them. This information could help scientists predict when earthquakes will occur.

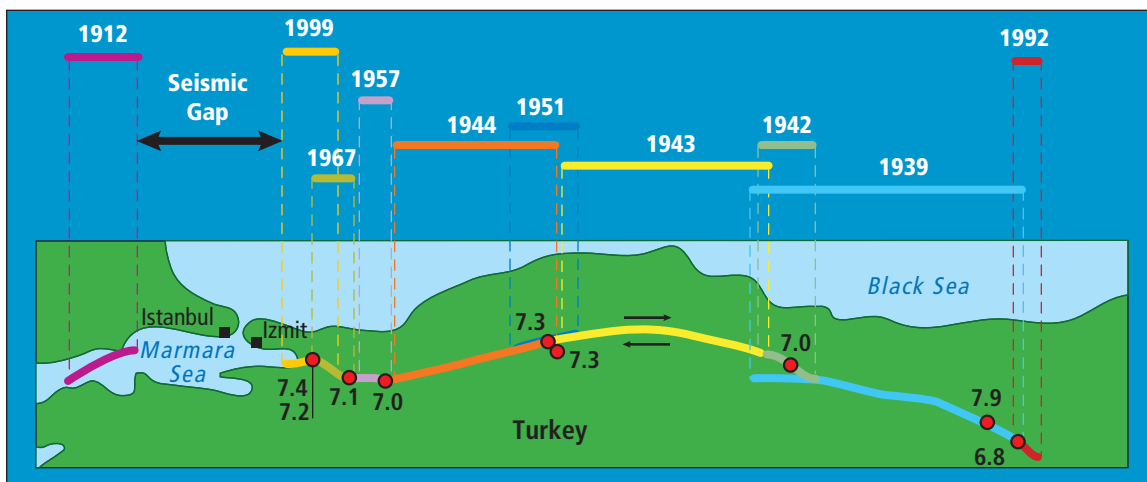
Recurrence rates Earthquake-recurrence rates along a fault can indicate whether the fault ruptures at regular intervals to generate similar earthquakes. The earthquake-recurrence rate along a section of the San Andreas fault at Parkfield, California, for example, shows that a sequence of earthquakes of approximately magnitude-6 shook the area about every 22 years from 1857 until 1966. In 1987 seismologists forecasted a 90-percent probability that a major earthquake would rock the area within the next few decades. Several kinds of instruments, including the drill shown in **Figure 19.26**, were installed around Parkfield in an attempt to measure the earthquake as it occurred. In September, 2004, a magnitude-6 earthquake struck. Extensive data was collected before and after the 2004 earthquake. The information obtained will be invaluable for predicting and preparing for future recurrent earthquakes around the world.

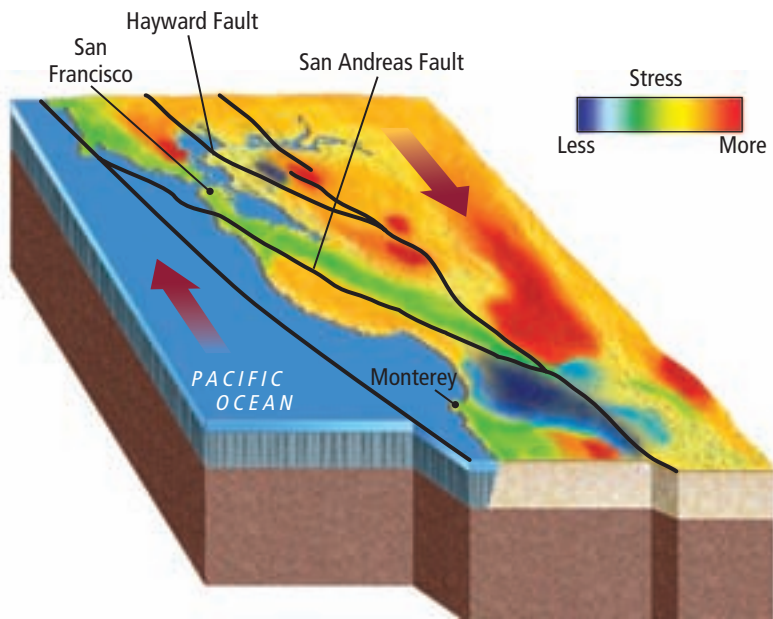


Reading Check Infer the significance of studying recurrence rates of earthquakes.

Seismic gaps Probability forecasts are also based on the location of seismic gaps. **Seismic gaps** are sections located along faults that are known to be active, but which have not experienced significant earthquakes for a long period of time. A seismic gap in the San Andreas Fault cuts through San Francisco. This section of the fault has not ruptured since the devastating earthquake that struck the city in 1906. Because of this inactivity, seismologists currently forecast that there is a 67-percent probability that the San Francisco area will experience a magnitude-7 or higher earthquake within the next 30 years. **Figure 19.27** shows the seismic-gap map for a fault that passes through an area of Turkey. Like the San Andreas Fault in California, there is a long history of earthquakes along the major fault shown below.

■ **Figure 19.27** Earthquakes in 1912 and 1999 happened on either side of Istanbul, a city of 18 million people. The earthquakes around the city leave a seismic gap that indicates that an earthquake is likely to occur in that area.





■ **Figure 19.28** Stress-accumulation maps help scientists determine the probability of an earthquake in any particular place.

Explain Why does stress build up in the areas indicated?

Stress accumulation The rate at which stress builds up in rocks is another factor seismologists use to determine the earthquake probability along a section of a fault. Eventually this stress is released, generating an earthquake. Scientists use satellite-based technology such as GPS to measure the stress that accumulates along a fault. The stress accumulated in a particular part of a fault, together with the amount of stress released during the last earthquake in a particular part of the fault, can be used to develop images like **Figure 19.28**. Another factor is how much time has passed since an earthquake has struck that section of the fault.

Section 19.4 Assessment

Section Summary

- ▶ Earthquake forecasting is based on seismic history and measurements of accumulated strain.
- ▶ Earthquakes cause damage by creating vibrations that can shake Earth.
- ▶ Earthquakes can cause structural collapse, landslides, soil liquefaction, and tsunamis.
- ▶ Seismic gaps are sections along an active fault that have not experienced significant earthquakes for a long period of time.

Understand Main Ideas

1. **MAIN Idea** List some examples of how scientists determine the probability of an earthquake occurring.
2. **Summarize** the effects of the different types of hazards caused by earthquakes.
3. **Draw** before-and-after pictures of what can happen when an earthquake ruptures along a fault.
4. **Summarize** the events that lead to a tsunami.

Think Critically

5. **Assess** where an earthquake is most likely to occur: In the same place that a magnitude-7.5 earthquake occurred 20 years ago or at a location between areas that had earthquakes 20 and 60 years ago, respectively.

WRITING in Earth Science

6. Imagine you are on an international aid committee. Write a report suggesting ways to identify areas that are vulnerable to earthquakes.

Earth Science & Society

Learning from the Past

At 5:15 on a Wednesday morning, most people were still sleeping when an earthquake struck California. The city of San Francisco was the hardest hit. It shook violently for an entire minute, toppling many buildings. In the days that followed, fire devastated entire neighborhoods.

The earthquake leveled the city Modern geologists calculate that the earthquake of April 18, 1906, had an approximate magnitude of 7.9. The total damage to San Francisco involved 490 city blocks—25,000 buildings were destroyed, 250,000 people were left homeless, and approximately 3000 were killed. Streets sank 1 m, bridges collapsed, and people were trapped under buildings.

Fires caused by broken gas lines spread through the city for three days. The efforts of the firefighters were futile, because the city's water supply had been destroyed. Contaminated drinking water put the survivors' health at risk. The food supply became limited, disease spread, and looting was rampant.

Scientists analyze the earthquake The 1906 San Francisco earthquake had monumental effect on human life and on the area. Before 1906, scientists knew very little about earthquakes and their effects. This earthquake is considered to be the beginning of modern seismology in the United States.

A theory is proposed At the time of the earthquake, the theory of plate tectonics was not yet understood, so the vast movements of land puzzled scientists. Geologists analyzed the displacement of the crust and the energy released in the movement. They proposed the elastic-rebound theory, which is still used today. They theorized that tensions had been gradually building up in the Earth's crust north and south of San Francisco, along a line now known as the San Andreas Fault.



Beitmann/CORBIS

The San Francisco city hall was destroyed during the 1906 earthquake.

The tension accumulated until portions of the crust reached a limit. Like a rubber band that had been stretched too far, portions of the crust snapped. This sudden release of stored energy was the cause of the 1906 earthquake.

Preparing for the future Geologists know that tensions in the crust along the Hayward Fault, the part of the San Andreas Fault where the San Francisco earthquake is thought have occurred, continue to build as they did before the 1906 earthquake. However, in the past century, scientists and society have worked to prepare for future earthquakes, to predict where they are likely to occur, and to design buildings that can withstand their impacts.

WRITING in Earth Science

Earthquake Expedition Create a presentation or Web site that compares and contrasts the 1906 San Francisco earthquake with the 1989 Loma Pieta earthquake. For more information on these earthquakes, visit glencoe.com.

GEO LAB

RELATE EPICENTERS AND PLATE TECTONICS

Background: The separation of P-waves and S-waves on a seismogram allows you to estimate the distance between the seismic station that recorded the data and the epicenter of that earthquake. If the distance to the epicenter, called epicentral distance, from three or more seismic stations is known, then the exact location of the earthquake's epicenter can be determined. By locating the epicenter on a map of tectonic plate boundaries, you can determine the type of plate movement that caused the earthquake.

Question: How do seismologists locate the epicenter of an earthquake?

Materials

U.S. map

Figure 17.16 and Figure 19.9

calculator

drafting compass

metric ruler

Procedure

Determine the epicenter location and the time of occurrence of an actual earthquake, using the travel times of P- and S-waves recorded at three seismic stations.

1. Read and complete the lab safety form.
2. The table gives data from three seismic stations. Use the travel-time curves in **Figure 19.9** and the P-S separation times to determine the distances from the epicenter to each seismic station. Enter these distances in the table row *Distance from epicenter*.
3. Obtain a map of North America from your teacher. Accurately mark the three seismic station locations.
4. Use the map scale to determine the distance in cm represented by the *Distance from epicenter* calculated in Step 2. Enter these distances in the table row *Map distance*.
5. Use the number calculated in *Map distance* to set the compass point to a spacing that represents the distance from the first seismic station to the epicenter.

| Seismic Data | | | |
|------------------------------|--------------|-------------|---------------|
| Seismic station | Berkeley, CA | Boulder, CO | Knoxville, TN |
| P-S separation (min) | 3.9 | 3.6 | 4.6 |
| Distance from epicenter (km) | | | |
| Map distance (cm) | | | |

6. Place the compass point on the seismic station location and draw a circle.
7. Repeat for the other two seismic stations.
8. Mark the point of intersection of the three circles. This is the epicenter of the earthquake.

Analyze and Conclude

1. **Interpret Data** Where is this epicenter located?
2. **Describe** In which major seismic belt did this earthquake occur?
3. **Interpret Data** Use **Figure 17.16** to determine which plates forms the boundary associated with this earthquake.
4. **Conclude** Describe how tectonic motions caused this earthquake.

WRITING in Earth Science

Imagine You are a reporter for the newspaper based near the epicenter of this earthquake. Write an article explaining how geologic processes resulted in this earthquake. Describe whether the earthquake should have been a surprise to the residents, given its location in relation to plate boundaries.



BIG Idea Earthquakes are natural vibrations of the ground, some of which are caused by movement along fractures in Earth's crust.

Vocabulary

Key Concepts

Section 19.1 Forces Within Earth

- elastic deformation (p. 529)
- epicenter (p. 533)
- fault (p. 530)
- focus (p. 533)
- plastic deformation (p. 529)
- primary wave (p. 532)
- secondary wave (p. 532)
- seismic wave (p. 532)
- strain (p. 528)
- stress (p. 528)

- MAIN Idea** Faults form when the forces acting on rock exceed the rock's strength.
- Stress is force per unit of area that acts on a material and strain is the deformation of a material in response to stress.
 - Reverse, normal, and strike-slip are the major types of faults.
 - The three types of seismic waves are P-waves, S-waves, and surface waves.

Section 19.2 Seismic Waves and Earth's Interior

- seismogram (p. 534)
- seismometer (p. 534)

- MAIN Idea** Seismic waves can be used to make images of the internal structure of Earth.
- Seismometers are devices that record seismic wave activity on a seismogram.
 - Travel times for P-waves and S-waves enable scientists to pinpoint the location of earthquakes.
 - P-waves and S-waves change speed and direction when they encounter different materials.
 - Analysis of seismic waves provides a detailed picture of the composition of Earth's interior.

Section 19.3 Measuring and Locating Earthquakes

- amplitude (p. 539)
- magnitude (p. 539)
- modified Mercalli scale (p. 540)
- moment magnitude scale (p. 540)
- Richter scale (p. 539)

- MAIN Idea** Scientists measure the strength and chart the location of earthquakes using seismic waves.
- Earthquake magnitude is a measure of the energy released during an earthquake and can be measured on the Richter scale.
 - Intensity is a measure of the damage caused by an earthquake and is measured with the modified Mercalli scale.
 - Data from at least three seismic stations are needed to locate an earthquake's epicenter.
 - Most earthquakes occur in seismic belts, which are areas associated with plate boundaries.

Section 19.4 Earthquakes and Society

- seismic gap (p. 550)
- soil liquefaction (p. 547)
- tsunami (p. 548)

- MAIN Idea** The probability of an earthquake's occurrence is determined from the history of earthquakes and knowing where and how quickly strain accumulates.
- Earthquake forecasting is based on seismic history and measurements of accumulated strain.
 - Earthquakes cause damage by creating vibrations that can shake Earth.
 - Earthquakes can cause structural collapse, landslides, soil liquefaction, and tsunamis.
 - Seismic gaps are sections along an active fault that have not experienced significant earthquakes for a long period of time.

Vocabulary Review

Complete the sentences below with the correct vocabulary term from the Study Guide.

- _____ is the deformation caused by stress.
- _____ deformation causes a material to bend and stretch.
- The amount of energy released and the amplitude of seismic waves are measured by the scale known as the _____.
- _____ happens when seismic vibrations cause subsurface materials to liquefy and behave like quicksand.
- A travel-time curve shows the relationship between the travel time of a given type of wave and _____.
- The type of seismic wave that does not pass through the outer core is called a(n) _____.

The sentences below are incorrect. Make each sentence correct by replacing the italicized word with a vocabulary term from the Study Guide.

- A *fault plane* is a region where earthquakes are expected but none has occurred for a long time.
- The damage caused by earthquakes is described by the *moment magnitude* scale.
- An underwater earthquake causes the movement of a column of water, resulting in a *seismic wave*.
- The recording made by a seismometer is called a *stress-strain curve*.

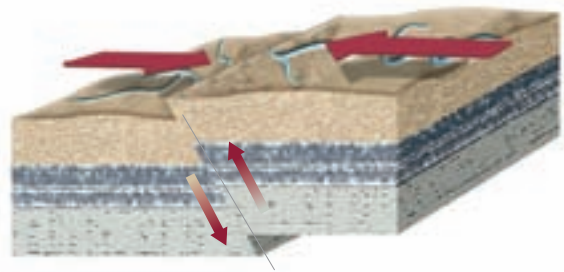
Distinguish between the vocabulary terms in each pair.

- epicenter, focus
- stress, strain
- plastic deformation, elastic deformation
- secondary wave, surface wave
- Richter scale, moment magnitude scale
- amplitude, magnitude

Understand Key Concepts

- What is stress?
 - speed seismic waves travel
 - point at which rocks fail and generate an earthquake
 - force per unit area
 - measure of the deformation of rocks

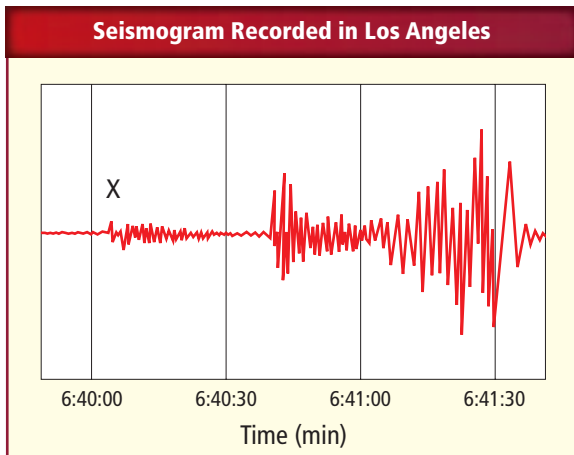
Use the diagram below to answer Questions 18–20.



- Which type of fault is shown?
 - reverse
 - normal
 - shear
 - strike-slip
- Which type of force caused this fault to form?
 - compression
 - tension
 - shear
 - divergent
- In which direction is the movement in this type of fault?
 - horizontal
 - horizontal and vertical
 - side-to-side
 - vertical
- What happens to a rock that undergoes elastic deformation once the stress is removed?
 - It returns to its original shape.
 - It breaks to generate an earthquake.
 - It undergoes plastic deformation.
 - It does not change shape.

22. Which type of geologic material is most prone to liquefaction?
- granite
 - metamorphic rock
 - soil and loose sediment
 - lava flows

Use the figure below to answer Questions 23–25.



23. Which type of wave is labeled “X”?
- P-wave
 - S-wave
 - surface wave
 - shear wave
24. At what time did the surface waves arrive at this station?
- 6:40:00
 - 6:40:05
 - 6:40:33
 - 6:41:10
25. What can the difference in travel times between P- and S-waves be used to determine?
- how far away the earthquake was
 - the type of fault
 - the depth of the earthquake
 - whether the core is liquid
26. Which seismic hazard is a form of structural failure?
- tsunami
 - pancaking
 - soil liquefaction
 - seismic gap

Constructed Response

Use the figure below to answer Questions 27–29.

| Some Earthquakes in Recent History | | |
|------------------------------------|------|-------------------|
| Location | Year | Richter Magnitude |
| Chile | 1960 | 8.5 |
| California | 1906 | 7.9 |
| Alaska | 1964 | 8.6 |
| Colombia | 1994 | 6.8 |
| Taiwan | 1999 | 7.6 |

27. **Calculate** How much more energy was released by the Chilean earthquake than the Taiwan earthquake?
28. **Approximate** How much larger was the amplitude of the waves generated by the Alaskan earthquake than the Taiwan earthquake?
29. **Classify** the earthquake locations with the type of plate boundary, and suggest how the tectonic processes were probably related.
30. **Name** five states with high seismic risk.
31. **Compare and contrast** a tsunami and a surface wave.
32. **Explain** why scientists need measurements from more than two seismometers to determine the exact location of an earthquake. Make a diagram similar to **Figure 19.14** to support your answer.
33. **Describe** three different ways earthquakes can cause damage or cause harm to people.

Think Critically

34. **Summarize** the factors considered when assessing seismic risk.
35. **Evaluate** how earthquake intensity is related to the type of fault.
36. **Draw** the basic components of a seismogram.

Use the figure below to answer Questions 37 and 38.



37. **Appraise** the specific type of earthquake damage shown, and propose the possible causes.
38. **Infer** the intensity of the earthquake that caused this damage, using the modified Mercalli scale.
39. **Explain** why there are three different ways to measure the size of earthquakes.
40. **Critique** this statement: If a certain area has not had an earthquake for over a hundred years, it is not likely to ever occur.
41. **Design** a house that would be structurally sound in an earthquake. Label the features, and explain how they would help sustain earthquake damage.
42. **Suggest** cost-effective ways of saving lives in an earthquake in the United States. How might your strategy be different in California and Florida?

Concept Mapping

43. Use the following terms to complete the concept map: *reverse faults, tension, types of stress, strike-slip faults, compression, shear, causes, and normal faults.*

Challenge Question

44. **Explain** why most earthquakes are shallow. Use the concept of plastic deformation and brittle deformation and your knowledge about the temperature of Earth's interior.

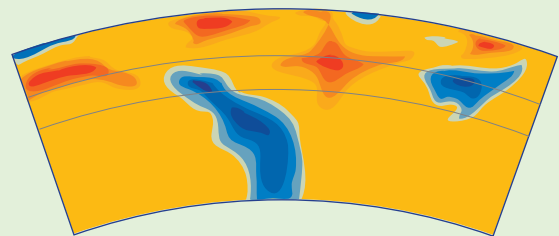
Additional Assessment

45. **WRITING in Earth Science** Imagine you live along an active fault. Write a disaster plan for your school giving guidelines on what to do before, during, and after an earthquake. Include a list of disaster kit supplies.

DBQ Document-Based Questions

Data obtained from: Fukao Y., S. Widiyantoro, and M. Obayashi. 2001. Stagnant slabs in the upper and lower mantle transition region. *Reviews of Geophysics* 39 (3): 291–323.

The figure below shows a cross section of Earth extending from the surface to the boundary between the core and the mantle. The colors show how the speed of seismic waves differs from the expected value for waves at that depth. This cross section is taken across the subduction zone off the west coast of South America. West is left, and east is right.



Velocity of seismic waves
Slow Fast

46. What properties of subsurface material could cause seismic waves to move quickly through the blue areas and more slowly through the red areas?
47. Thinking about plate tectonics, what portion of the diagram could represent a subducting plate with molten rock rising from the subduction zone to form volcanoes?

Cumulative Review

48. What is the most common extrusive igneous rock? (**Chapter 5**)
49. Describe three processes that affect the salinity of the oceans. (**Chapter 15**)

Standardized Test Practice

Multiple Choice

- Why is only 61 percent of the northern hemisphere covered with water?
 - Most landmasses are in the northern hemisphere.
 - Most landmasses are in the southern hemisphere.
 - The northern hemisphere is colder thus allowing less water to flow there.
 - Gravity causes more water to settle in the southern hemisphere.

Use the table below to answer Questions 2 and 3.

| Some Earthquakes in Recent History | | |
|------------------------------------|------|-------------------|
| Location | Year | Richter Magnitude |
| Chile | 1960 | 8.5 |
| California | 1906 | 7.9 |
| Alaska | 1964 | 8.6 |
| Colombia | 1994 | 6.8 |
| Taiwan | 1999 | 7.6 |

- Approximately how much more energy was released by the earthquake in Chile than the earthquake in Taiwan?
 - 2 times as much
 - 10 times as much
 - 32 times as much
 - 1000 times as much
- Approximately how much larger was the amplitude of the waves generated by the earthquake in Alaska than the earthquake in Taiwan?
 - 2 times as large
 - 10 times as large
 - 100 times as large
 - 1000 times as large
- Who were the first people to propose the idea that Earth's landmasses at one time were all connected?
 - explorers
 - mathematicians
 - scientists
 - mapmakers
- Which does NOT have any effect on Earth's tides?
 - Earth
 - the Moon
 - the Sun
 - the atmosphere
- What is formed as turbidity currents drop sediment?
 - continental rise
 - continental slope
 - abyssal plains
 - deep-sea trenches

Use the maps below to answer Questions 7 and 8.



Ocean currents

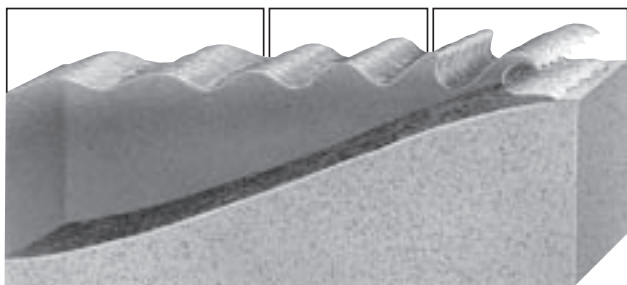


Wind currents

- What can be concluded by comparing the maps?
 - Surface wind currents flow mostly to the east, and surface ocean currents flow mostly to the west.
 - Surface wind currents flow mostly to the west, and surface ocean currents flow mostly to the east.
 - The direction of surface ocean currents is opposite the direction of surface wind currents.
 - The direction of surface ocean currents is related to the direction of surface wind currents.
- The Coriolis effect is the rightward curvature of winds in the northern hemisphere and the leftward curvature of winds in the southern hemisphere. What causes the Coriolis effect?
 - the intersection of warm and cool ocean currents
 - the revolution of Earth around the Sun
 - the rotation of Earth on its axis
 - the seasonal changes in global temperature
- Most sedimentary rocks are formed by
 - uplifting and melting
 - compaction and cementation
 - eruption of volcanoes
 - changes deep within Earth
- Which type of volcano is potentially the most dangerous to humans and the environment?
 - shield volcano
 - composite volcano
 - cinder cone volcano
 - compact volcano

Short Answer

Use the illustration below to answer Questions 11 and 12.



11. Describe the changes that occur as waves move closer to shore.
12. Contrast water movement and energy movement in an ocean wave.
13. What does the location of mountains on the sea-floor that are not near any active volcanism suggest?
14. How does convection in the mantle cause plate motions?
15. Describe tephra and its two possible sources.
16. How are the continental shelves, covered with water after the last ice age, now benefiting humans?

Reading for Comprehension

Earthquake Detection

The belief that animals can detect incoming earthquakes has been around for centuries. In 373 B.C., historians recorded that animals, including rats, snakes, and weasels, deserted the Greek city of Helice just days before an earthquake devastated the place. Similar accounts have surfaced across the centuries since.

Catfish moving violently, chickens that stop laying eggs, and bees leaving their hive in a panic have been reported. But precisely what animals sense is a mystery. One theory is that wild and domestic creatures can feel Earth vibrate before humans can. Other ideas suggest that they detect electric changes in the air or gas released from Earth. Earthquakes are a sudden phenomenon. Seismologists have no way of knowing exactly when or where the next one will hit. An estimated 500,000 detectable earthquakes occur in the world each year. Of those, 100,000 can be felt by humans, and 100 cause damage. Researchers have long studied animals in hopes of discovering what they hear or feel before an earthquake in order to use that sense as a prediction tool. American seismologists are skeptical. Even though there have been documented cases of strange animal behavior prior to earthquakes, according to the USGS, a reproducible connection between a specific behavior and the occurrence of an earthquake has never been made.

Article obtained from: Mott, M. Can animals sense earthquakes? *National Geographic News*. November 11, 2003.

17. What can be inferred from this passage?
 - A. Animals can predict earthquakes because they can feel the vibrations before humans.
 - B. Animals cannot predict earthquakes.
 - C. Further study and research is needed before it can be confirmed or denied that animals can predict earthquakes.
 - D. Animals have been predicting earthquakes for centuries.
18. Which was NOT an animal behavior cited as proof that animals can predict earthquakes?
 - A. catfish moving violently
 - B. chickens laying eggs
 - C. bees leaving their hives
 - D. snakes deserting a city

NEED EXTRA HELP?

| If You Missed Question . . . | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|------------------------------|------|------|------|------|------|------|------|------|-----|------|------|------|------|------|------|------|
| Review Section . . . | 15.1 | 19.3 | 19.3 | 17.1 | 15.2 | 16.2 | 15.3 | 12.2 | 6.1 | 18.3 | 15.3 | 15.3 | 16.2 | 17.4 | 18.2 | 16.2 |