CHAPTER 19

Earthquakes

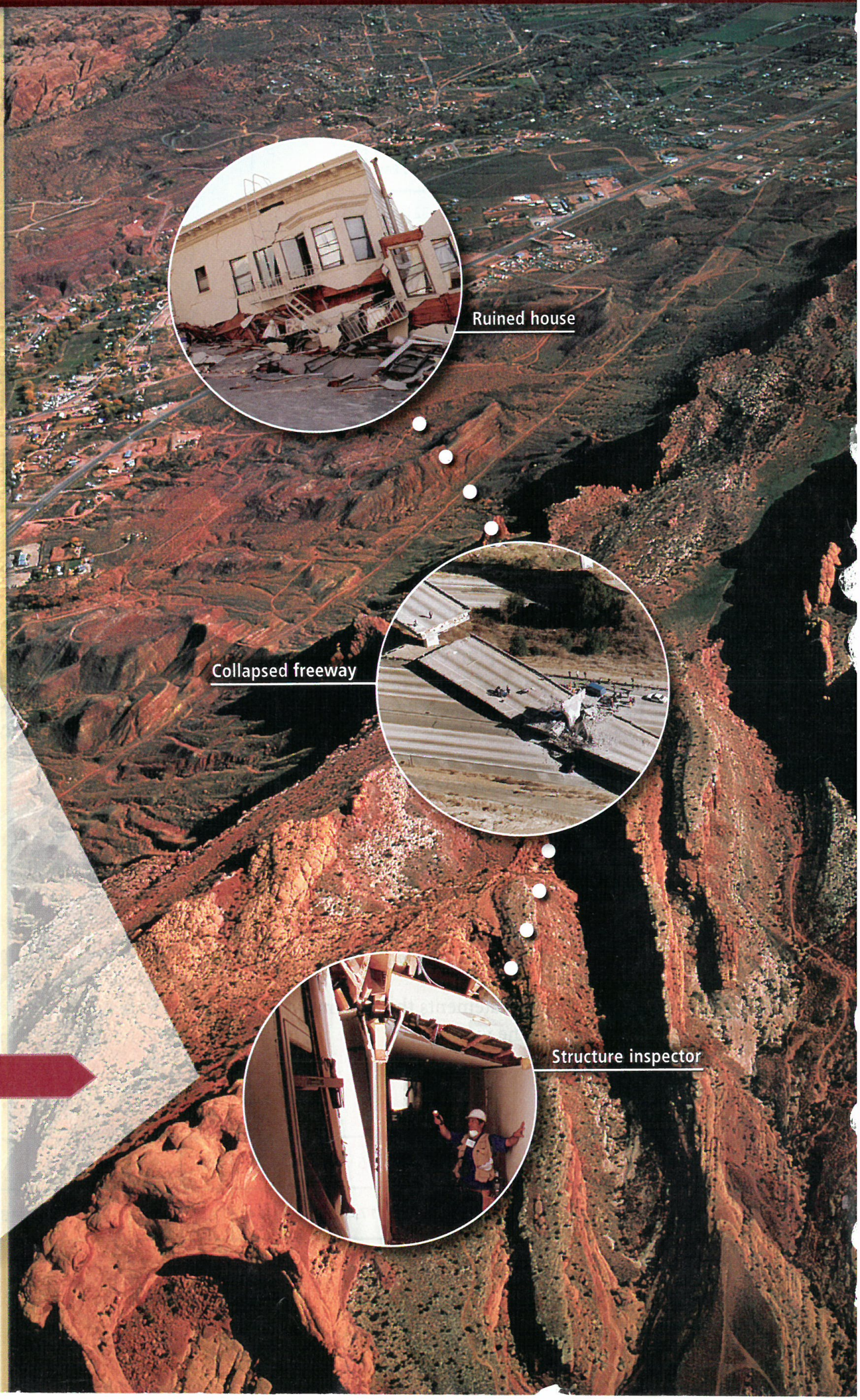
BIG Idea Earthquakes are natural vibrations of the ground, some of which are caused by movement along fractures in Earth's crust.

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.

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.

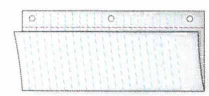
Analysis

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.

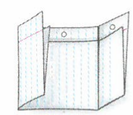
FOLDABLES™ Study Organizer

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

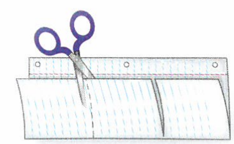
STEP 1 Fold a sheet of paper in half. Make the back edge about 2 cm longer than the front edge.



STEP 2 Fold into thirds.

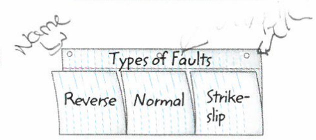


STEP 3 Unfold and cut along the folds of the top flap to make three tabs.



Pen

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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- **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

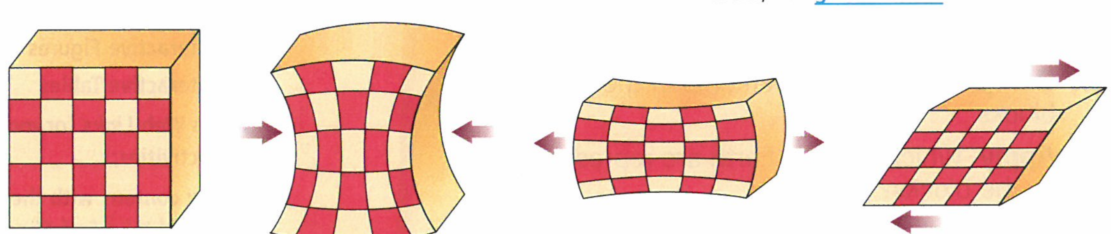
Most earthquakes are the result of movement of Earth's crust produced by plate tectonics. As a whole, tectonic plates tend to move gradually. Along the boundaries between two plates, rocks in the crust often resist movement. Over time, stress builds up. **Stress** is the total force acting on crustal 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 is compressed, bent, or stretched. 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 the result of stress and strain. If the stress is reduced to zero, as the graph shows, the deformation of the rock 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 fluidlike manner. This flow reduces stress.

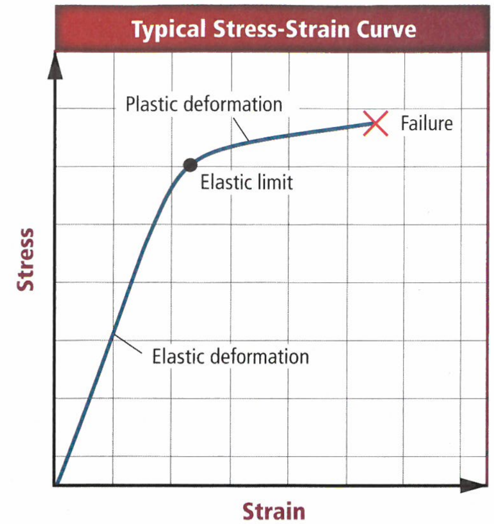


Figure 19.2 A typical stress-strain curve has two parts. Elastic deformation occurs as a result of low stress. When the stress is removed, material returns to its original shape. Plastic deformation occurs under high stress. The deformation of the material is permanent. When plastic deformation is exceeded,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

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 places 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.

FOLDABLES
Incorporate information from this section into your Foldable.

■ **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.

1800 — 1900 — 1950

1811–1812 Several strong earthquakes occur along the Mississippi River valley over three months, destroying the entire town of New Madrid, Missouri.

1880 Following an earthquake in Japan, scientists invent the first modern seismograph to record the intensity of earthquakes.

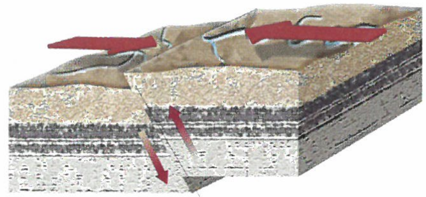
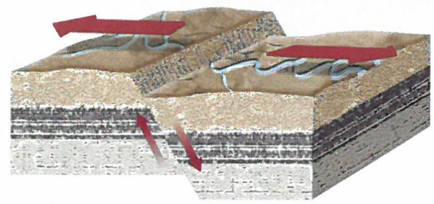
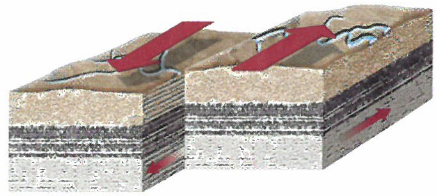
1906 An earthquake in San Francisco kills between 3000 and 5000 people and causes a fire that rages for three days, destroying most of the city.

1923 Approximately 140,000 people die in an earthquake and subsequent fires that destroy the homes of over a million people in Tokyo and Yokohama, Japan.

1948 An earthquake destroys Ashgabat, capital of Turkmenistan, killing nearly nine out of ten people living in the city and its surrounding areas.

Concepts In Motion
Interactive Table To explore more about faults, visit glencoe.com.

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.

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

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

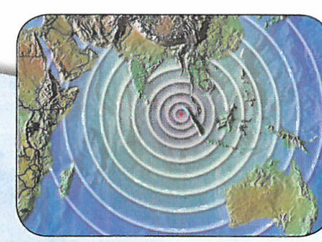
1972 The University of California, Berkeley creates the first modern shake table to test building designs.

1980

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

2000

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.



Concepts In Motion
Interactive Time Line To learn more about these discoveries and others, visit glencoe.com. Earth Science Online

Concepts In Motion

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

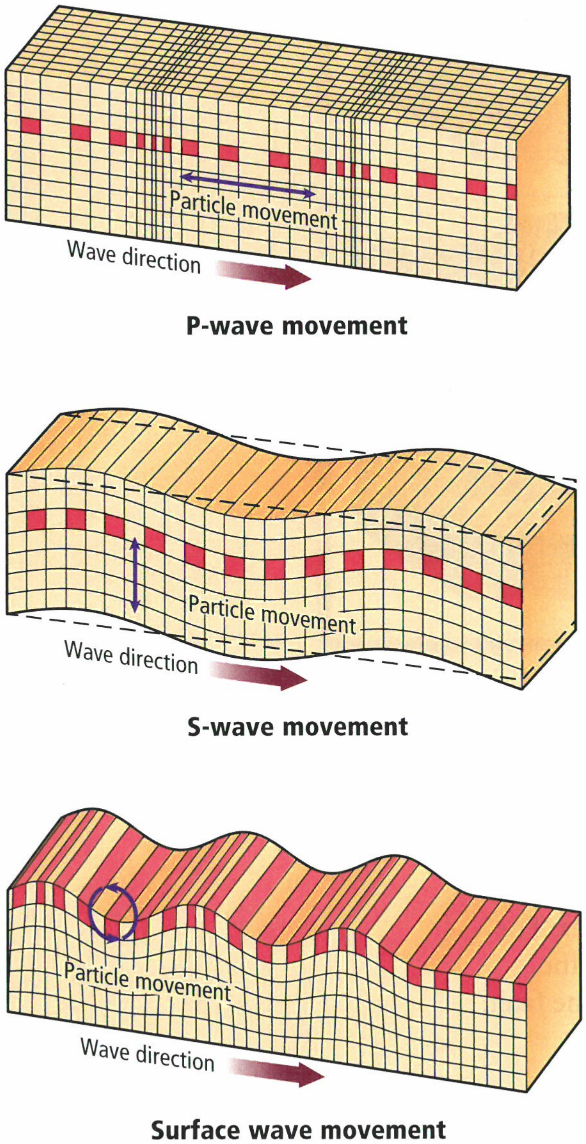


Figure 19.5 Seismic waves are characterized by the types of movement they cause. Rock particles move back and forth as a P-wave passes. Rock particles move at right angles to the direction of the S-wave. A surface wave causes rock particles to move both up and down and from side to side.

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 undergo elastic deformation. Beyond the elastic limit, they bend or stretch. Before that limit, an earthquake occurs when they slip or crumble.

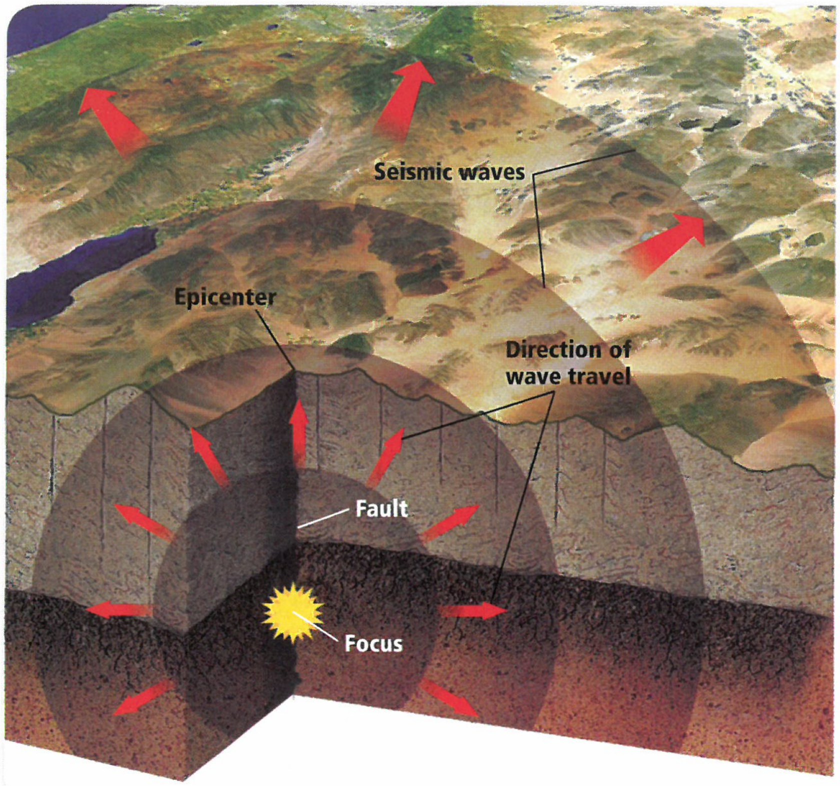
Types of seismic waves

The vibrations of the ground produced 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.

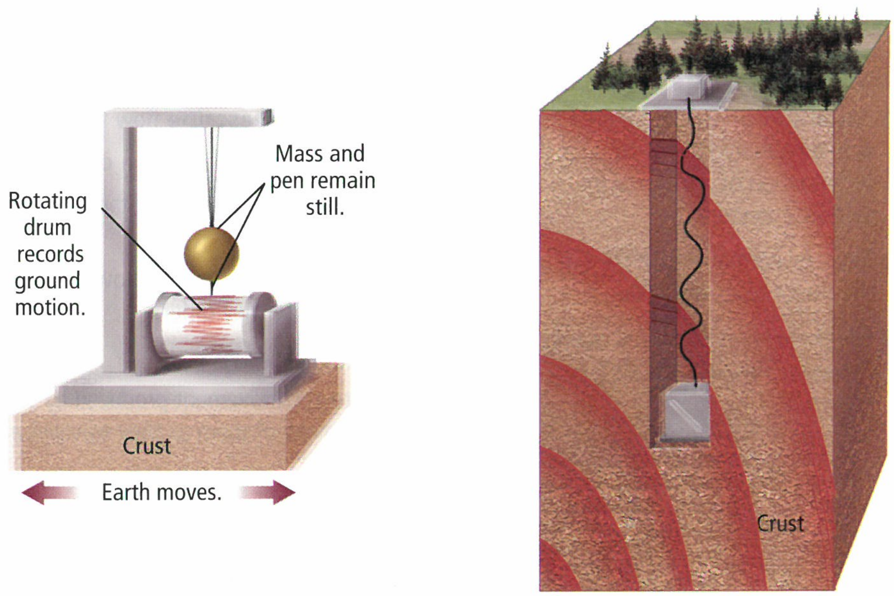
Real-World Reading Link When you look in a mirror, you see yourself because light waves reflect off your face to the mirror and back to your eye. Similarly, seismic waves traveling through Earth reflect off structures inside Earth, which allows these structures to be imaged.

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.



Historic

Modern

■ **Figure 19.7** The frame of a historic 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. Compare this to a modern sensor and transmitter.