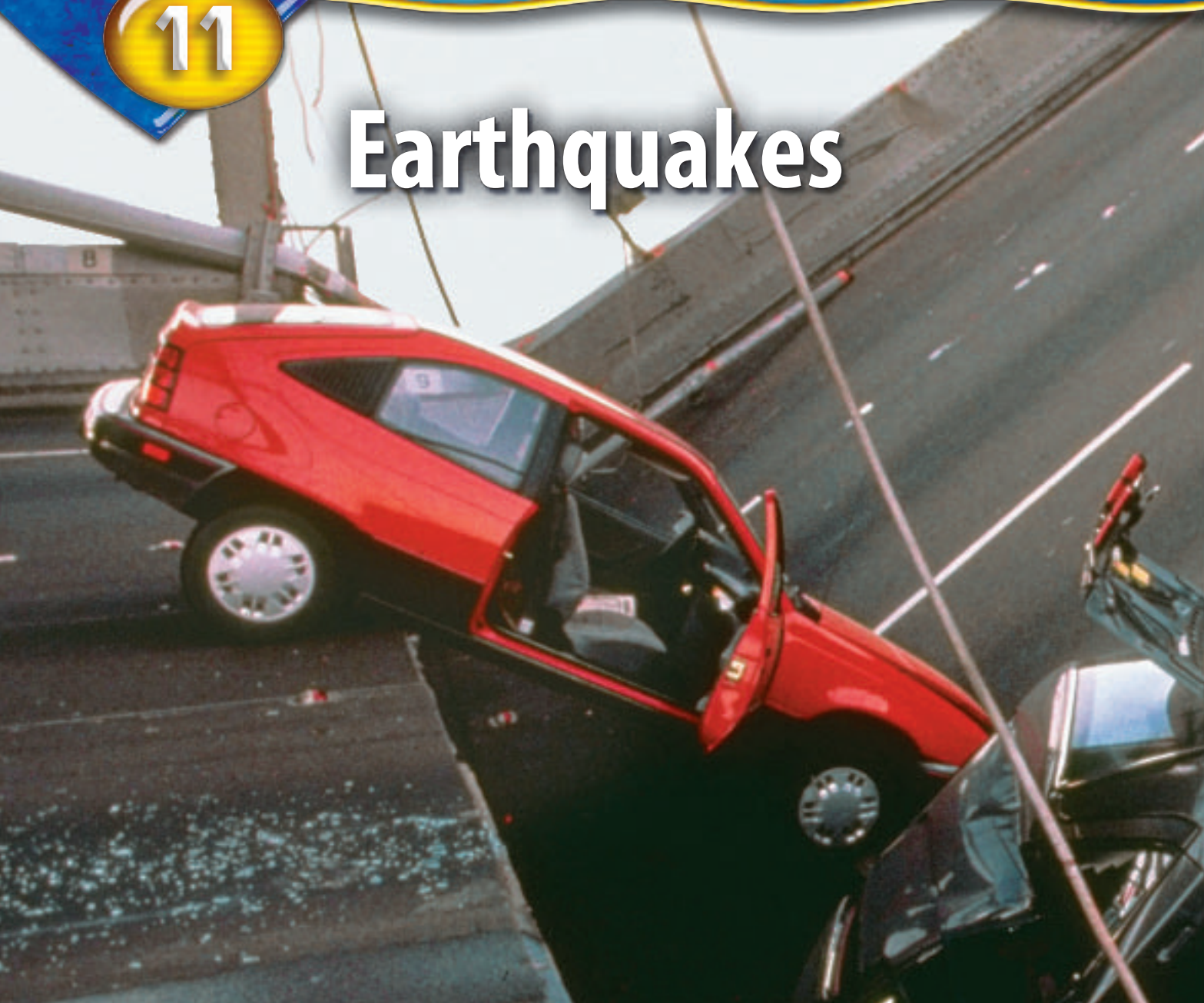




# Earthquakes



## chapter preview

### sections

- 1** Forces Inside Earth
- 2** Features of Earthquakes  
*Lab Epicenter Location*
- 3** People and Earthquakes  
*Lab Earthquake Depths*



**Virtual Lab** How do seismograph stations help determine an earthquake's epicenter?

## Was anyone hurt?



On October 17, 1989, the Loma Prieta earthquake rocked San Francisco, CA, leaving 62 dead and many more injured. Seismologists try to predict when and where earthquakes will occur so they can warn people of possible danger.

**Science Journal** Write *three* things that you would ask a scientist studying earthquakes.

# Start-Up Activities



## Why do earthquakes occur?

The bedrock beneath the soil can break to form cracks and move, forming faults. When blocks of bedrock move past each other along a fault, they cause the ground to shake. Why doesn't a block of bedrock move all the time, causing constant earthquakes? You'll find out during this activity.  

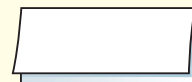
1. Tape a sheet of medium-grain sandpaper to the tabletop.
2. Tape a second sheet of sandpaper to the cover of a textbook.
3. Place the book on the table so that both sheets of sandpaper meet.
4. Tie two large, thick rubber bands together and loop one of the rubber bands around the edge of the book so that it is not touching the sandpaper.
5. Pull on the free rubber band until the book moves. Record your observations.
6. **Think Critically** Write a paragraph that describes how the book moved. Using this model, predict why blocks of bedrock don't move all the time.

## FOLDABLES™ Study Organizer

### Earthquakes and Earth's Crust

Make the following Foldable to help you understand the cause-and-effect relationship between earthquakes and movement in Earth's crust.

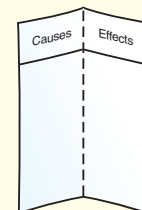
- STEP 1** Fold a sheet of paper in half lengthwise.



- STEP 2** Fold paper down 2.5 cm from the top. (Hint: From the tip of your index finger to your middle knuckle is about 2.5 cm.)



- STEP 3** Open and draw lines along the 2.5 cm fold. Label as shown.



**Read and Write** As you read the chapter, write the causes and effects of earthquakes on your Foldable.



Preview this chapter's content and activities at [earth.msscience.com](http://earth.msscience.com)

# Forces Inside Earth

## as you read

### What You'll Learn

- **Explain** how earthquakes result from the buildup of energy in rocks.
- **Describe** how compression, tension, and shear forces make rocks move along faults.
- **Distinguish** among normal, reverse, and strike-slip faults.

### Why It's Important

Earthquakes cause billions of dollars in property damage and kill an average of 10,000 people every year.

### Review Vocabulary

**plate:** a large section of Earth's crust and rigid upper mantle that moves around on the asthenosphere

### New Vocabulary

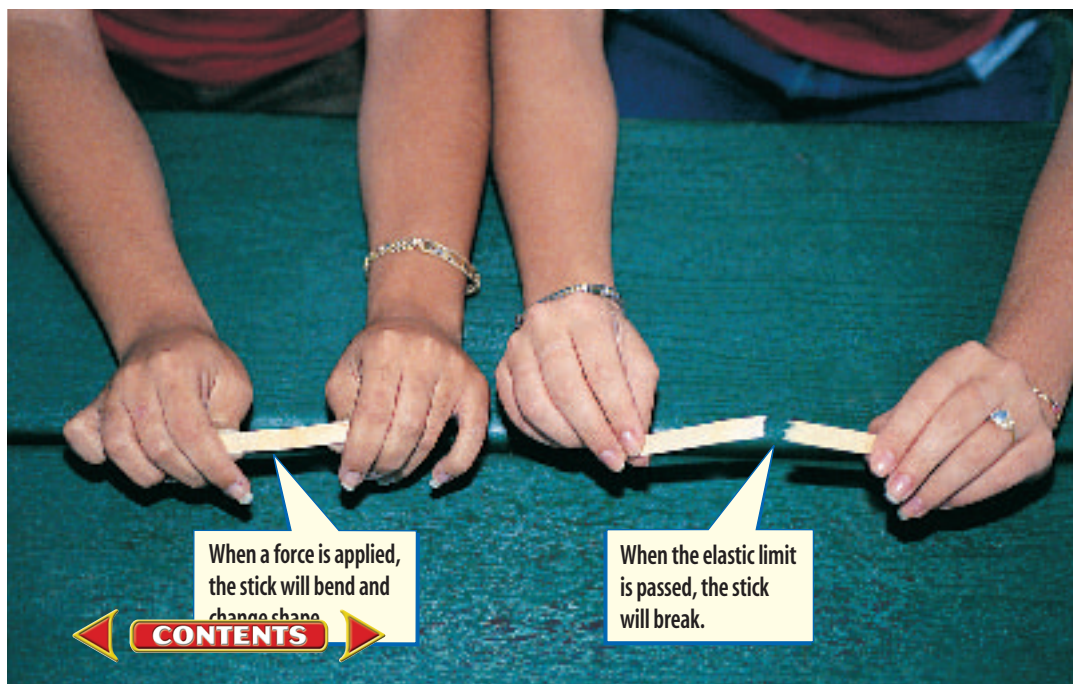
- fault
- reverse fault
- earthquake
- strike-slip fault
- normal fault

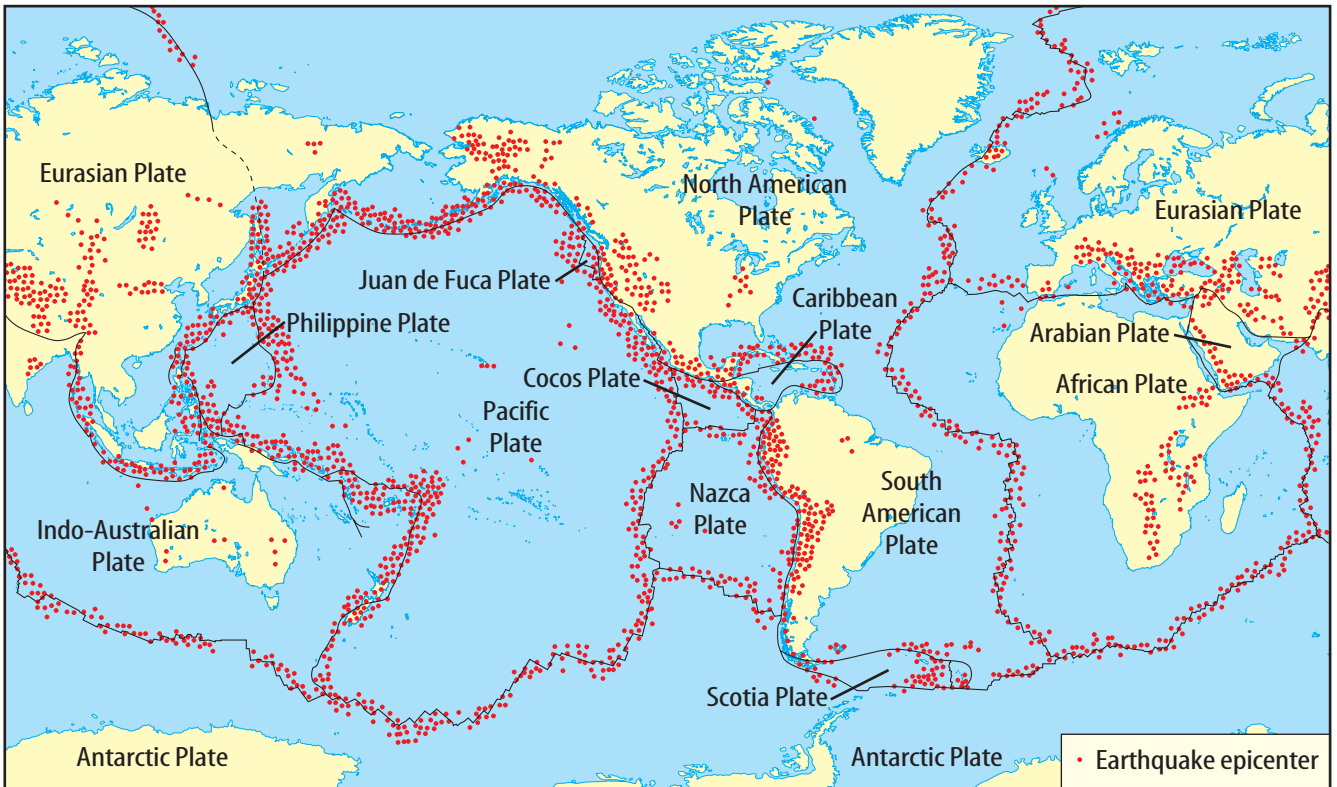
## Earthquake Causes

Recall the last time you used a rubber band. Rubber bands stretch when you pull them. Because they are elastic, they return to their original shape once the force is released. However, if you stretch a rubber band too far, it will break. A wooden craft stick behaves in a similar way. When a force is first applied to the stick, it will bend and change shape. The energy needed to bend the stick is stored inside the stick as potential energy. If the force keeping the stick bent is removed, the stick will return to its original shape, and the stored energy will be released as energy of motion.

**Fault Formation** There is a limit to how far a wooden craft stick can bend. This is called its elastic limit. Once its elastic limit is passed, the stick remains bent or breaks, as shown in **Figure 1**. Rocks behave in a similar way. Up to a point, applied forces cause rocks to bend and stretch, undergoing what is called elastic deformation. Once the elastic limit is passed, the rocks may break. When rocks break, they move along surfaces called **faults**. A tremendous amount of force is required to overcome the strength of rocks and to cause movement along a fault. Rock along one side of a fault can move up, down, or sideways in relation to rock along the other side of the fault.

**Figure 1** The bending and breaking of wooden craft sticks are similar to how rocks bend and break.





**What causes faults?** What produces the forces that cause rocks to break and faults to form? The surface of Earth is in constant motion because of forces inside the planet. These forces cause sections of Earth's surface, called plates, to move. This movement puts stress on the rocks near the plate edges. To relieve this stress, the rocks tend to bend, compress, or stretch. If the force is great enough, the rocks will break. An **earthquake** is the vibrations produced by the breaking of rock. **Figure 2** shows how the locations of earthquakes outline the plates that make up Earth's surface.



*Why do most earthquakes occur near plate boundaries?*

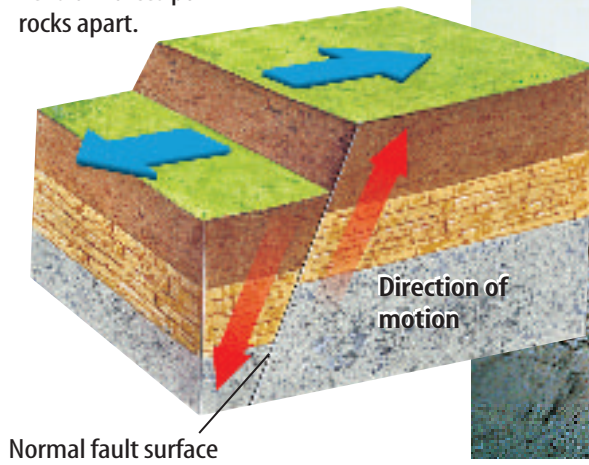
**How Earthquakes Occur** As rocks move past each other along a fault, their rough surfaces catch, temporarily halting movement along the fault. However, forces keep driving the rocks to move. This action builds up stress at the points where the rocks are stuck. The stress causes the rocks to bend and change shape. When the rocks are stressed beyond their elastic limit, they can break, move along the fault, and return to their original shapes. An earthquake results. Earthquakes range from unnoticeable vibrations to devastating waves of energy. Regardless of their intensity, most earthquakes result from rocks moving over, under, or past each other along fault surfaces.

**Figure 2** The dots represent the epicenters of major earthquakes over a ten-year period. Note that most earthquakes occur near plate boundaries.

**Form a hypothesis** to explain why earthquakes rarely occur in the middle of a plate.



Tension forces pull rocks apart.



**Figure 3** Rock above the normal fault surface moves downward in relation to rock below the fault surface. This normal fault formed near Kanab, Utah.

## Types of Faults



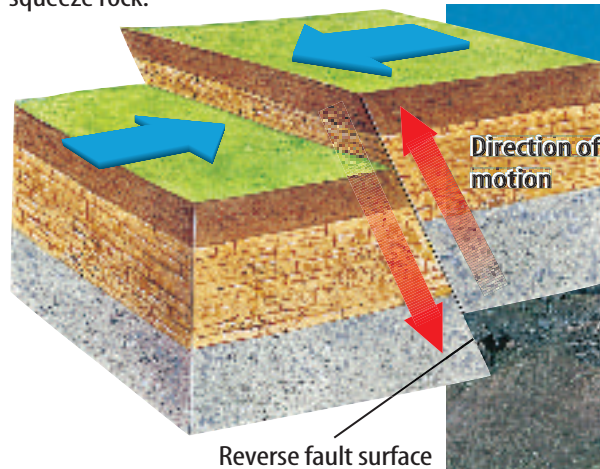
Three types of forces—tension, compression, and shear—act on rocks. Tension is the force that pulls rocks apart, and compression is the force that squeezes rocks together. Shear is the force that causes rocks on either side of a fault to slide past each other.

**Normal Faults** Tensional forces inside Earth cause rocks to be pulled apart. When rocks are stretched by these forces, a normal fault can form. Along a **normal fault**, rock above the fault surface moves downward in relation to rock below the fault surface. The motion along a normal fault is shown in **Figure 3**. Notice the normal fault shown in the photograph above.

**Figure 4** The rock above the reverse fault surface moves upward in relation to the rock below the fault surface.

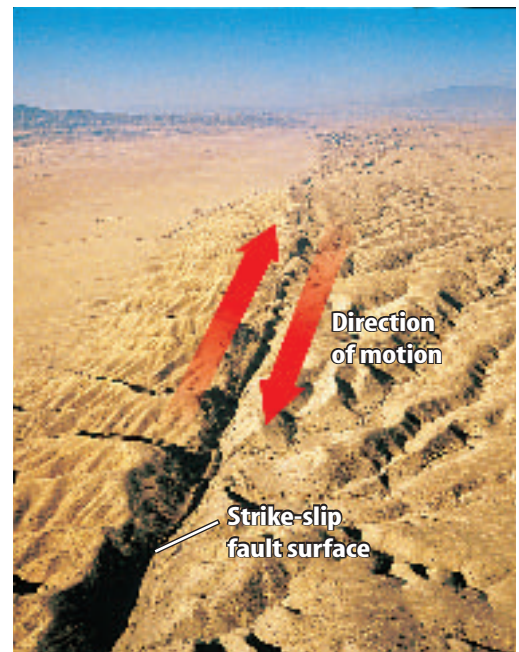
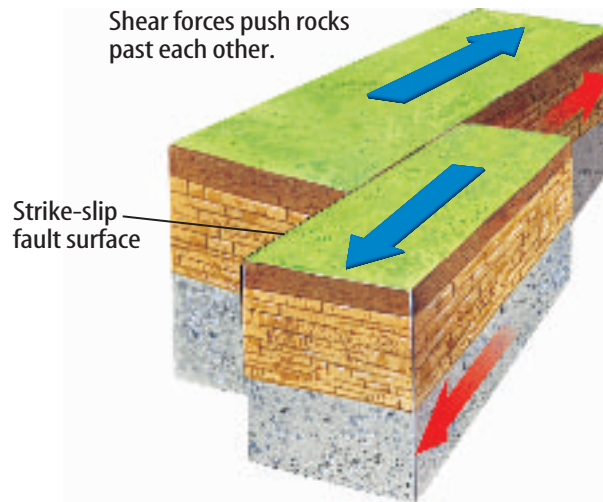
**Reverse Faults** Reverse faults result from compression forces that squeeze rock. **Figure 4** shows the motion along a reverse fault. If rock breaks from forces pushing from opposite directions, rock above a **reverse fault** surface is forced up and over the rock below the fault surface. The photo below shows a large reverse fault in California.

Compression forces squeeze rock.





**Figure 5** Shear forces push on rock in opposite—but not directly opposite—horizontal directions. When they are strong enough, these forces split rock and create strike-slip faults.



**Strike-Slip Faults** At a **strike-slip fault**, shown in **Figure 5**, rocks on either side of the fault are moving past each other without much upward or downward movement. The photo above shows the largest fault in California—the San Andreas Fault—which stretches more than 1,100 km through the state. The San Andreas Fault is the boundary between two of Earth’s plates that are moving sideways past each other.

**Reading Check** *What is a strike-slip fault?*

## section 1 review

### Summary

#### Earthquake Causes

- Faults form when stressed rocks break along surfaces.
- Stresses on rock are created by plate movements.
- When rocks break along a fault, vibrations are created. This is an earthquake.

#### Types of Faults

- Normal faults can form when rocks undergo tension.
- Compression forces produce reverse faults.
- Strike-slip faults result when rocks move past each other without much upward or downward movement.

### Self Check

1. **Infer** The Himalaya in Tibet formed when two of Earth’s plates collided. What types of faults would you expect to find in these mountains? Why?
2. **State** In what direction do rocks move above a normal fault surface? What force causes this?
3. **Describe** how compression forces make rocks move along a reverse fault.
4. **Think Critically** Why is it easier to predict where an earthquake will occur than it is to predict when it will occur?

### Applying Skills

5. **Infer** Why do the chances of an earthquake increase rather than decrease as time passes since the last earthquake?

# Features of Earthquakes

## as you read

### What You'll Learn

- **Explain** how earthquake energy travels in seismic waves.
- **Distinguish** among primary, secondary, and surface waves.
- **Describe** the structure of Earth's interior.

### Why It's Important

Seismic waves are responsible for most damage caused by earthquakes.

### Review Vocabulary

**wave:** rhythmic movement that carries energy through matter and space

### New Vocabulary

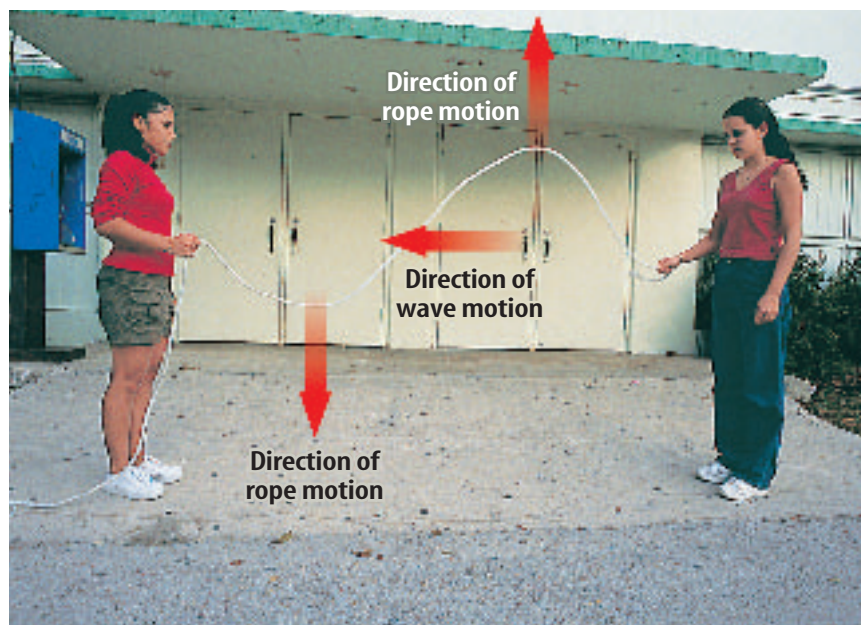
- seismic wave
- surface wave
- focus
- epicenter
- primary wave
- seismograph
- secondary wave

**Figure 6** Some seismic waves are similar to the wave that is traveling through the rope. Note that the rope moves perpendicular to the wave direction.

## Seismic Waves

When two people hold opposite ends of a rope and shake one end, as shown in **Figure 6**, they send energy through the rope in the form of waves. Like the waves that travel through the rope, **seismic (SIZE mihk) waves** generated by an earthquake travel through Earth. During a strong earthquake, the ground moves forward and backward, heaves up and down, and shifts from side to side. The surface of the ground can ripple like waves do in water. Imagine trying to stand on ground that had waves traveling through it. This is what you might experience during a strong earthquake.

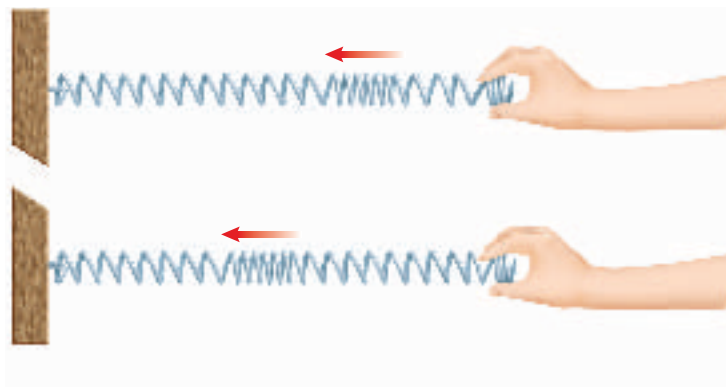
**Origin of Seismic Waves** You learned earlier that rocks move past each other along faults, creating stress at points where the rocks' irregular surfaces catch each other. The stress continues to build up until the elastic limit is exceeded and energy is released in the form of seismic waves. The point where this energy release first occurs is the **focus** (plural, *foci*) of the earthquake. The foci of most earthquakes are within 65 km of Earth's surface. A few have been recorded as deep as 700 km. Seismic waves are produced and travel outward from the earthquake focus.





**Primary Waves** When earthquakes occur, three different types of seismic waves are produced. All of the waves are generated at the same time, but each behaves differently within Earth.

**Primary waves** (P-waves) cause particles in rocks to move back and forth in the same direction that the wave is traveling. If you squeeze one end of a coiled spring and then release it, you cause it to compress and then stretch as the wave travels through the spring, as shown in **Figure 7**. Particles in rocks also compress and then stretch apart, transmitting primary waves through the rock.



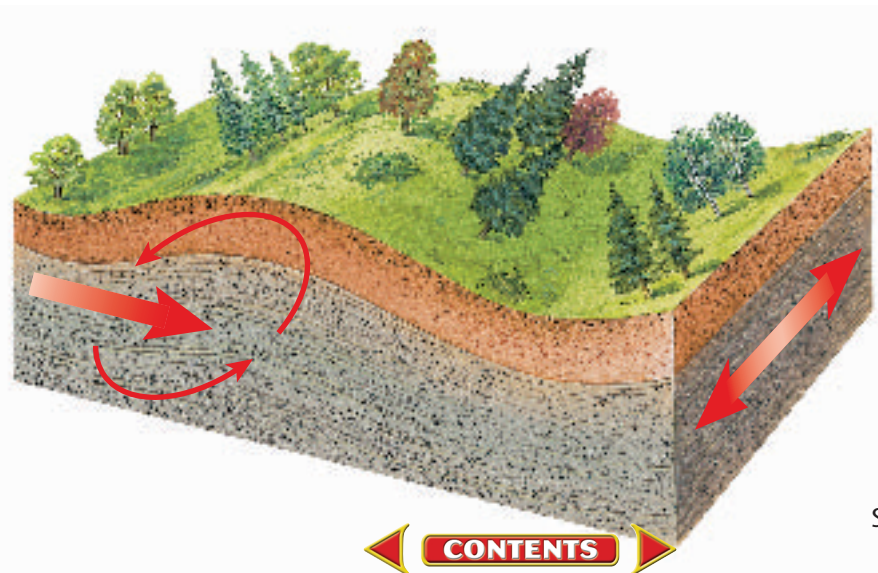
**Figure 7** Primary waves move through Earth the same way that a wave travels through a coiled spring.

**Secondary and Surface Waves** **Secondary waves** (S-waves) move through Earth by causing particles in rocks to move at right angles to the direction of wave travel. The wave traveling through the rope shown in **Figure 6** is an example of a secondary wave.

Surface waves cause most of the destruction resulting from earthquakes. **Surface waves** move rock particles in a backward, rolling motion and a side-to-side, swaying motion, as shown in **Figure 8**. Many buildings are unable to withstand intense shaking because they are made with stiff materials. The buildings fall apart when surface waves cause different parts of the building to move in different directions.

**Reading Check** Why do surface waves damage buildings?

Surface waves are produced when earthquake energy reaches the surface of Earth. Surface waves travel outward from the epicenter. The earthquake **epicenter** (EH pih sen tur) is the point on Earth's surface directly above the earthquake focus. Find the focus and epicenter in **Figure 9**.



**Figure 8** Surface waves move rock particles in a backward, rolling motion and a side-to-side, swaying motion.

**Compare and contrast** surface waves and secondary waves.

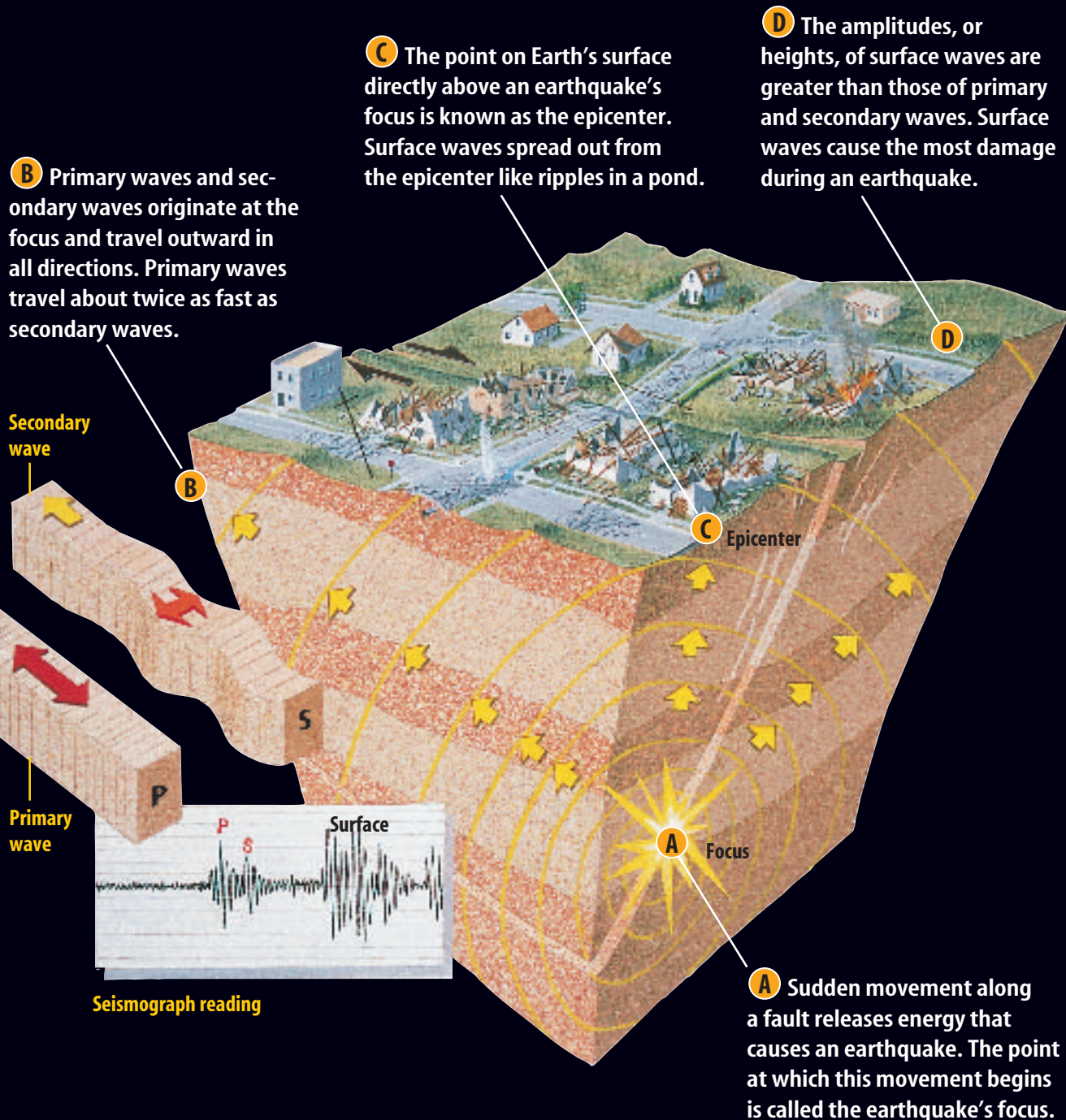
**INTEGRATE**  
Physics

**Sound Waves** When sound is produced, waves move through air or some other material. Research sound waves to find out which type of seismic wave they are similar to.



**Figure 9**

**A**s the plates that form Earth's lithosphere move, great stress is placed on rocks. They bend, stretch, and compress. Occasionally, rocks break, producing earthquakes that generate seismic waves. As shown here, different kinds of seismic waves—each with distinctive characteristics—move outward from the focus of the earthquake.





## Locating an Epicenter

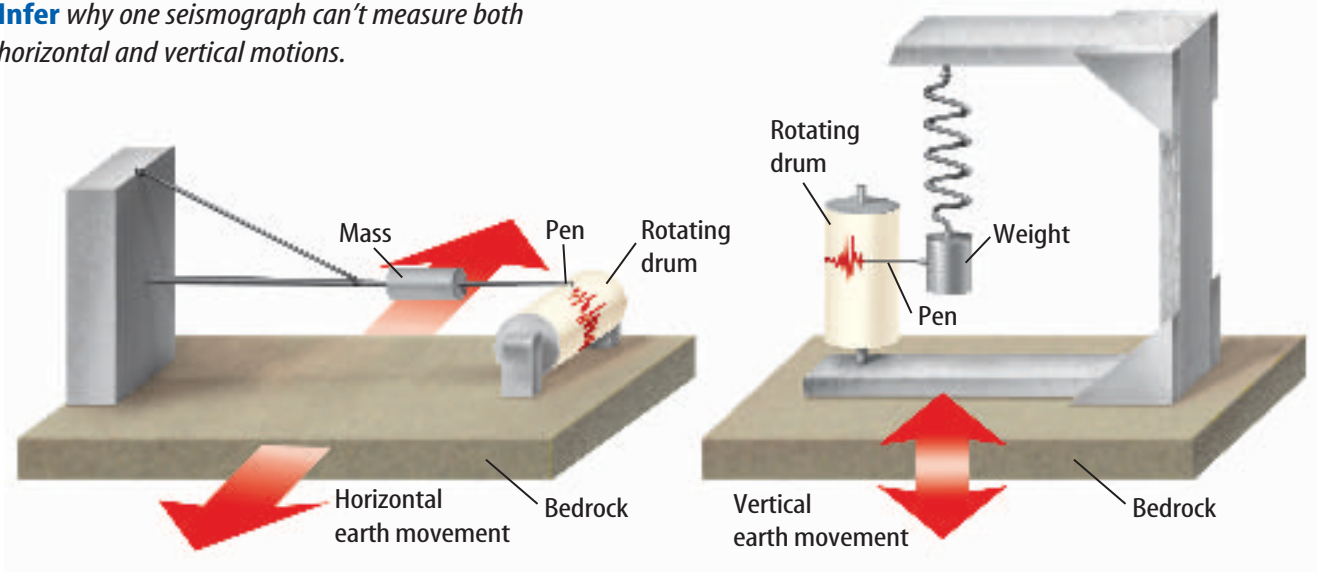
Different seismic waves travel through Earth at different speeds. Primary waves are the fastest, secondary waves are slower, and surface waves are the slowest. Can you think of a way this information could be used to determine how far away an earthquake epicenter is? Think of the last time you saw two people running in a race. You probably noticed that the faster person got further ahead as the race continued. Like runners in a race, seismic waves travel at different speeds.

Scientists have learned how to use the different speeds of seismic waves to determine the distance to an earthquake epicenter. When an epicenter is far from a location, the primary wave has more time to put distance between it and the secondary and surface waves, just like the fastest runner in a race.

**Measuring Seismic Waves** Seismic waves from earthquakes are measured with an instrument known as a **seismograph**. Seismographs register the waves and record the time that each arrived. Seismographs consist of a rotating drum of paper and a pendulum with an attached pen. When seismic waves reach the seismograph, the drum vibrates but the pendulum remains at rest. The stationary pen traces a record of the vibrations on the moving drum of paper. The paper record of the seismic event is called a seismogram. **Figure 10** shows two types of seismographs that measure either vertical or horizontal ground movement, depending on the orientation of the drum.

**Figure 10** Seismographs differ according to whether they are intended to measure horizontal or vertical seismic motions.

**Infer** why one seismograph can't measure both horizontal and vertical motions.



### Topic: Earthquake Data

Visit [earth.msscience.com](http://earth.msscience.com) for Web links to the National Earthquake Information Center and the World Data Center for Seismology.

**Activity** List the locations and distances of each reference that seismograph stations used to determine the epicenter of the most recent earthquake.



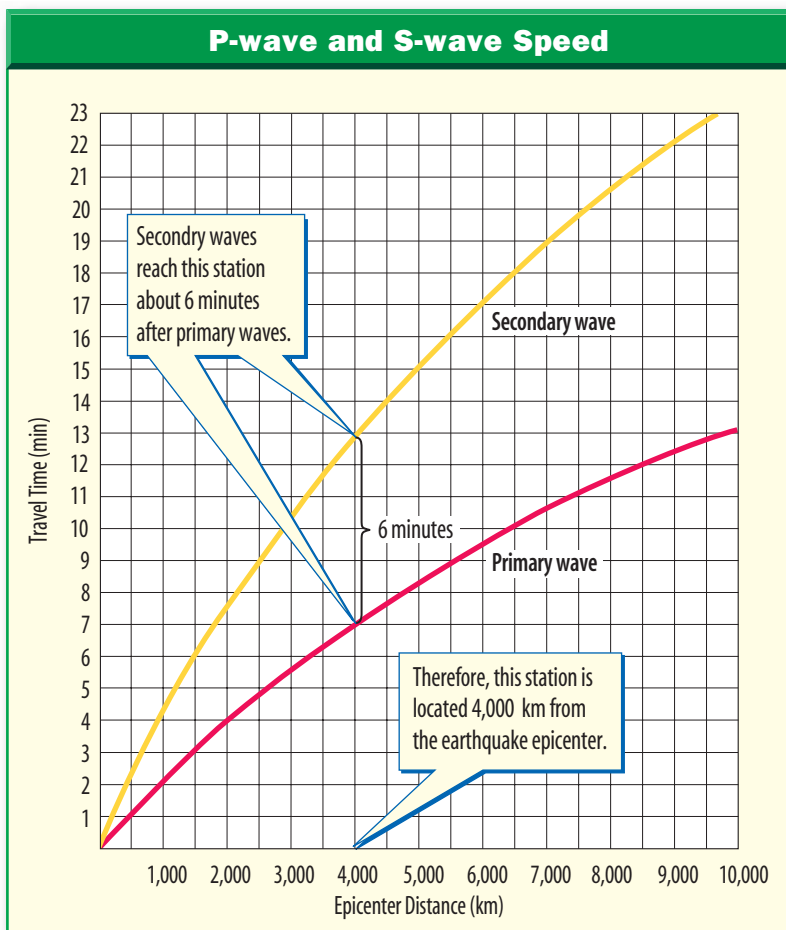
**Seismograph Stations** Each type of seismic wave reaches a seismograph station at a different time based on its speed. Primary waves arrive first at seismograph stations, and secondary waves, which travel slower, arrive second. Because surface waves travel slowest, they arrive at seismograph stations last. This difference in arrival times is used to calculate the distance from the seismograph station to the earthquake epicenter, as shown in **Figure 11**. If a seismograph station is located 4,000 km from an earthquake epicenter, primary waves will reach the station about 6 minutes before secondary waves.

**Figure 11** Primary waves arrive at a seismograph station before secondary waves do.

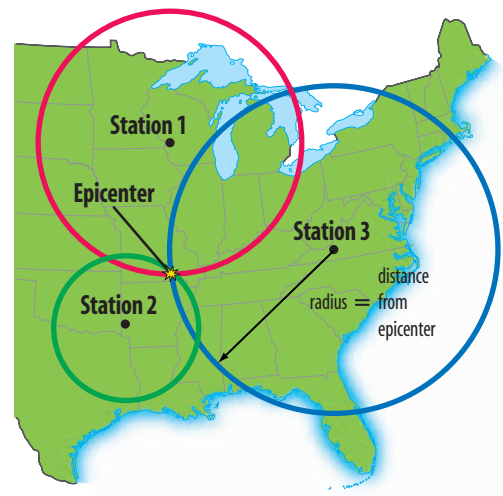
**Use Graphs** If primary waves reach a seismograph station two minutes before secondary waves, how far is the station from the epicenter?

If seismic waves reach three or more seismograph stations, the location of the epicenter can be determined. To locate an epicenter, scientists draw circles around each station on a map. The radius of each circle equals that station's distance from the earthquake epicenter. The point where all three circles intersect, shown in **Figure 12**, is the location of the earthquake epicenter.

Seismologists usually describe earthquakes based on their distances from the seismograph. Local events occur less than 100 km away. Regional events occur 100 km to 1,400 km away. Teleseismic events are those that occur at distances greater than 1,400 km.



**Figure 12** The radius of each circle is equal to the distance from the epicenter to each seismograph station. The intersection of the three circles is the location of the epicenter.





## Basic Structure of Earth

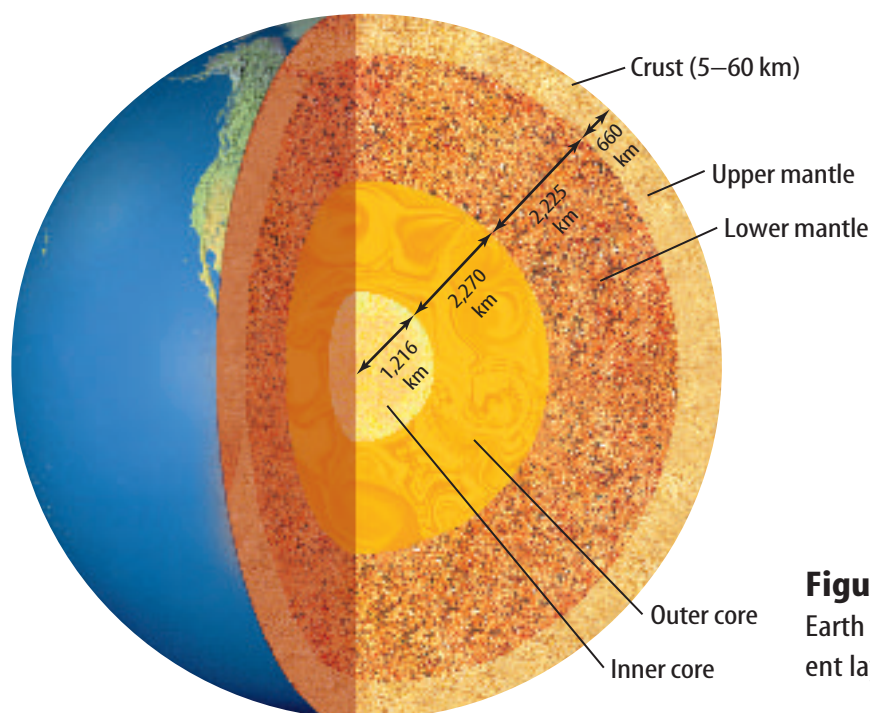
**Figure 13** shows Earth's internal structure. At the very center of Earth is a solid, dense inner core made mostly of iron with smaller amounts of nickel, oxygen, silicon, and sulfur. Pressure from the layers above causes the inner core to be solid. Above the solid inner core lies the liquid outer core, which also is made mainly of iron.

**Reading Check** How do the inner and outer cores differ?

Earth's mantle is the largest layer, lying directly above the outer core. It is made mostly of silicon, oxygen, magnesium, and iron. The mantle often is divided into an upper part and a lower part based on changing seismic wave speeds. A portion of the upper mantle, called the asthenosphere (as THE nuh sfih), consists of weak rock that can flow slowly.

**Earth's Crust** The outermost layer of Earth is the crust. Together, the crust and a part of the mantle just beneath it make up Earth's lithosphere (LIH thuh sfih). The lithosphere is broken into a number of plates that move over the asthenosphere beneath it.

The thickness of Earth's crust varies. It is more than 60 km thick in some mountainous regions and less than 5 km thick under some parts of the oceans. Compared to the mantle, the crust contains more silicon and aluminum and less magnesium and iron. Earth's crust generally is less dense than the mantle beneath it.



**Figure 13** The internal structure of Earth shows that it is made of different layers.

## Mini LAB

### Interpreting Seismic Wave Data

#### Procedure

Copy the table below into your Science Journal. Use the graph in **Figure 11** to determine the difference in arrival times for primary and secondary waves at the distances listed in the data table below. Two examples are provided for you.

#### Wave Data

Distance (km)	Difference in Arrival Time
1,500	2 min, 50 s
2,250	Do not write in this book.
2,750	Do not write in this book.
3,000	Do not write in this book.
4,000	5 min, 55 s
7,000	
9,000	


#### Analysis

1. What happens to the difference in arrival times as the distance from the earthquake increases?
2. If the difference in arrival times at a seismograph station is 6 min, 30 s, how far away is the epicenter?

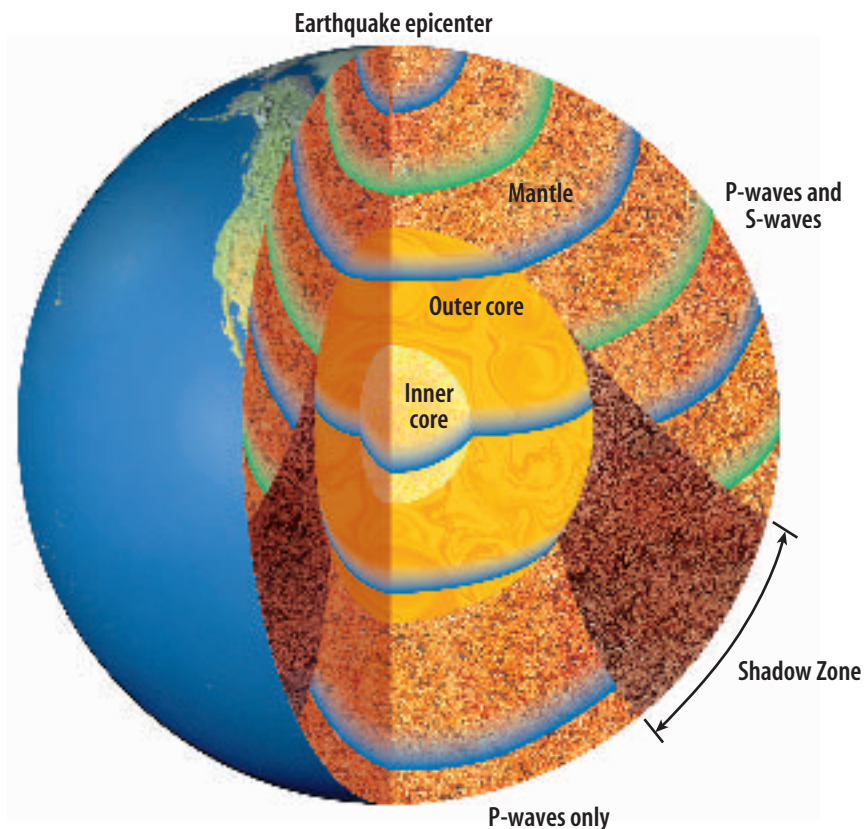


**Mapping Earth's Internal Structure** As shown in **Figure 14**, the speeds and paths of seismic waves change as they travel through materials with different densities. By studying seismic waves that have traveled through Earth, scientists have identified different layers with different densities. In general, the densities increase with depth as pressures increase. Studying seismic waves has allowed scientists to map Earth's internal structure without being there.

Early in the twentieth century, scientists discovered that large areas of Earth don't receive seismic waves from an earthquake. In the area on Earth between  $105^\circ$  and  $140^\circ$  from the earthquake focus, no waves are detected. This area, called the shadow zone, is shown in **Figure 14**. Secondary waves are not transmitted through a liquid, so they stop when they hit the liquid outer core. Primary waves are slowed and bent but not stopped by the liquid outer core. Because of this, scientists concluded that the outer core and mantle are made of different materials. Primary waves speed up again as they travel through the solid inner core. The bending of primary waves and the stopping of secondary waves create the shadow zone.

 **Reading Check** *Why do seismic waves change speed as they travel through Earth?*

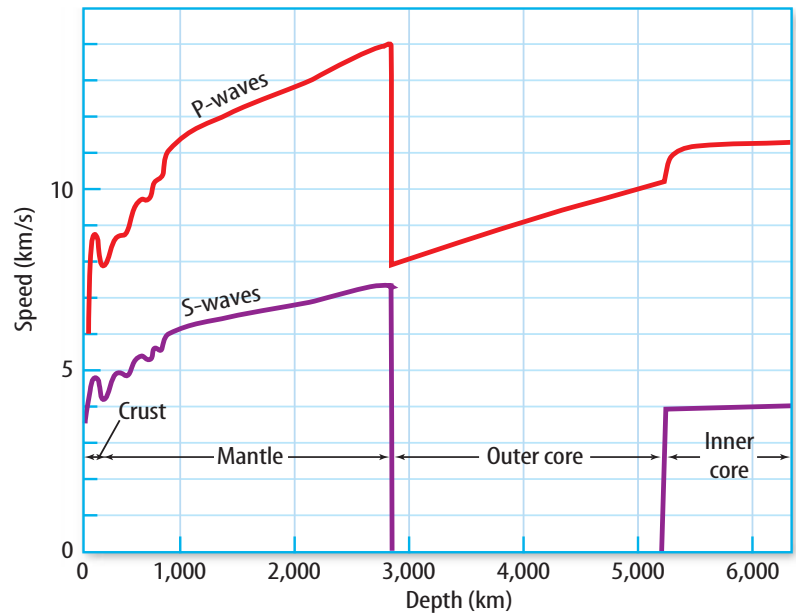
**Figure 14** Seismic waves bend and change speed as the density of rock changes. Primary waves bend when they contact the outer core, and secondary waves are stopped completely. This creates a shadow zone where no seismic waves are received.



**Layer Boundaries** Figure 15 shows how seismic waves change speed as they pass through layers of Earth. Seismic waves speed up when they pass through the bottom of the crust and enter the upper mantle, shown on the far left of the graph. This boundary between the crust and upper mantle is called the Mohorovicic discontinuity (moh huh ROH vee chihch • dis kahn tuh NEW uh tee), or Moho.

The mantle is divided into layers based on changes in seismic wave speeds. For example, primary and secondary waves slow down again when they reach the asthenosphere. Then they generally speed up as they move through a more solid region of the mantle below the asthenosphere.

The core is divided into two layers based on how seismic waves travel through it. Secondary waves do not travel through the liquid core, as you can see in the graph. Primary waves slow down when they reach the outer core, but they speed up again upon reaching the solid inner core.



**Figure 15** Changes in the speeds of seismic waves allowed scientists to detect boundaries between Earth's layers. S waves in the inner core form when P waves strike its surface.

## section 2 review

### Summary

#### Seismic Waves

- Stress builds up at the points where the surfaces of the fault touch.
- When the elastic limit of the rock is exceeded, it moves, producing seismic waves.
- There are three types of seismic waves—primary, secondary, and surface.

#### Locating an Epicenter

- A seismograph measures seismic waves.
- Three seismograph stations are needed to determine the location of an epicenter.

#### Basic Structure of Earth

- The inner core, the outer core, the lower mantle, the upper mantle, and the crust make up Earth.

### Self Check

1. **Compare and contrast** the movement of rocks by primary waves, secondary waves, and surface waves.
2. **Explain** why surface waves cause the most damage to property.
3. **Describe** what makes up most of Earth's inner core.
4. **Explain** why three seismograph stations are needed to determine the location of an epicenter.
5. **Think Critically** Why do some seismograph stations receive both primary and secondary waves from an earthquake but other stations don't?

### Applying Skills

6. **Simple Equations** Primary waves travel about 6 km/s through Earth's crust. The distance from Los Angeles to Phoenix is about 600 km. How long would it take primary waves to travel between the two cities?

## Epicenter Location

In this lab you can plot the distance of seismograph stations from the epicenters of earthquakes and determine the location of earthquake epicenters.

### Real-World Question

How can plotting the distance of several seismograph stations from an earthquake epicenter allow you to determine the locations of the epicenter?

#### Goals

- **Plot** the distances from several seismograph stations based on primary and secondary wave arrival times.
- **Interpret** the location of earthquake epicenters from these plots.

#### Materials

string      globe  
metric ruler      chalk

### Procedure

1. Determine the difference in arrival time between the primary and secondary waves at each station for each earthquake listed in the table.
2. After you determine the arrival time differences for each seismograph station, use the graph in **Figure 11** to determine the distance in kilometers of each seismograph from the epicenter of each earthquake. Record these data in a data table. For example, the difference in arrival times in Paris for earthquake B is 9 min, 30 s. On the graph, the primary and secondary waves are separated along the vertical axis by 9 min, 30 s at a distance of 8,975 km.

### Earthquake Data

Location of Seismograph	Wave	Wave Arrival Times	
		Earthquake A	Earthquake B
New York, New York	P	2:24:05 P.M.	1:19:42 P.M.
	S	2:29:15 P.M.	1:25:27 P.M.
Seattle, Washington	P	2:24:40 P.M.	1:14:37 P.M.
	S	2:30:10 P.M.	1:16:57 P.M.
Rio de Janeiro, Brazil	P	2:29:10 P.M.	—
	S	2:37:50 P.M.	—
Paris, France	P	2:30:30 P.M.	1:24:57 P.M.
	S	2:40:10 P.M.	1:34:27 P.M.
Tokyo, Japan	P	—	1:24:27 P.M.
	S	—	1:33:27 P.M.

3. Using the string, measure the circumference of the globe. Determine a scale of centimeters of string to kilometers on Earth's surface. (Earth's circumference is 40,000 km. )
4. For each earthquake, place one end of the string at each seismic station location on the globe. Use the chalk to draw a circle with a radius equal to the distance to the earthquake's epicenter.
5. **Identify** the epicenter for each earthquake.

### Conclude and Apply

1. How is the distance of a seismograph from the earthquake related to the arrival times of the waves?
2. **Identify** the location of the epicenter for each earthquake.
3. How many stations were needed to locate each epicenter accurately?
4. **Explain** why some seismographs didn't receive seismic waves from some quakes.

# People and Earthquakes

## Earthquake Activity

Imagine waking up in the middle of the night with your bed shaking, windows shattering, and furniture crashing together. That's what many people in Northridge, California, experienced at 4:30 A.M. on January 17, 1994. The ground beneath Northridge shook violently—it was an earthquake.

Although the earthquake lasted only 15 s, it killed 51 people, injured more than 9,000 people, and caused \$44 billion in damage. More than 22,000 people were left homeless. **Figure 16** shows some of the damage caused by the Northridge earthquake and a seismogram made by that quake.

Earthquakes are natural geological events that provide information about Earth. Unfortunately, they also cause billions of dollars in property damage and kill an average of 10,000 people every year. With so many lives lost and such destruction, it is important for scientists to learn as much as possible about earthquakes to try to reduce their impact on society.

**Figure 16** The 1994 Northridge, California, earthquake was a costly disaster. Several major highways were damaged and 51 lives were lost.



### as you read

#### What You'll Learn

- **Explain** where most earthquakes in the United States occur.
- **Describe** how scientists measure earthquakes.
- **List** ways to make your classroom and home more earthquake-safe.

#### Why It's Important

Earthquake preparation can save lives and reduce damage.



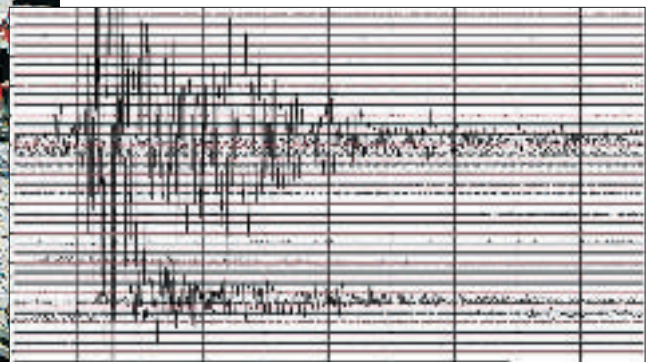
#### Review Vocabulary

**crest:** the highest point of a wave

#### New Vocabulary

- magnitude
- liquefaction
- tsunami

Seismogram of the Northridge earthquake







**Figure 17** The 1999 earthquake in Turkey released about 32 times more energy than the 1994 Northridge earthquake did.

**Studying Earthquakes** Scientists who study earthquakes and seismic waves are seismologists. As you learned earlier, the instrument that is used to record primary, secondary, and surface waves from earthquakes all over the world is called a seismograph. Seismologists can use records from seismographs, called seismograms, to learn more than just where the epicenter of an earthquake is located.

**Measuring Earthquake Magnitude** The height of the lines traced on the paper of a seismograph is a measure of the energy that is released, or the **magnitude**, of the earthquake. The Richter magnitude scale is used to describe the strength of an earthquake and is based on the height of the lines on the seismogram. The Richter scale has no upper limit. However, scientists think that a value of about 9.5 would be the maximum strength an earthquake could register. For each increase of 1.0 on the Richter scale, the height of the line on a seismogram is ten times greater. However, about 32 times as much energy is released for every increase of 1.0 on the scale. For example, an earthquake with a magnitude of 8.5 releases about 32 times more energy than an earthquake with a magnitude of 7.5.

**Table 1 Large-Magnitude Earthquakes**

Year	Location	Magnitude	Deaths
1556	Shensi, China	?	830,000
1886	Charleston, SC	?	60
1906	San Francisco, CA	8.3	700 to 800
1923	Tokyo, Japan	9.2	143,000
1960	Chile	9.5	490 to 2,290
1975	Laoning Province, China	7.5	few
1976	Tangshan, China	8.2	242,000
1990	Iran	7.7	50,000
1994	Northridge, CA	6.8	51
2001	India	7.7	>20,000
2003	Bam, Iran	6.6	30,000

**Past Earthquakes** Damage from the 7.8-magnitude earthquake in Turkey in 1999 is shown in **Figure 17**. **Table 1** is a list of some large-magnitude earthquakes that have occurred around the world and the damage they have caused. Most of the earthquakes you hear about are large ones that cause great damage. However, of all the earthquakes detected throughout the world each year, most have magnitudes too low to be felt by humans. Scientists record thousands of earthquakes every day with magnitudes of less than 3.0. Each year, about 55,000 earthquakes are felt but cause little or no damage. These minor earthquakes have magnitudes that range from approximately 3.0 to 4.9 on the Richter scale.



**Describing Earthquake Intensity** Earthquakes also can be described by the amount of damage they cause. The modified Mercalli intensity scale describes the intensity of an earthquake using the amount of structural and geologic damage in a specific location. The amount of damage done depends on the strength of the earthquake, the nature of surface material, the design of structures, and the distance from the epicenter.

Under ideal conditions, only a few people would feel an intensity-I earthquake, and it would cause no damage. An intensity-IV earthquake would be felt by everyone indoors during the day but would be felt by only a few people outdoors. Pictures might fall off walls and books might fall from shelves. However, an intensity-IX earthquake would cause considerable damage to buildings and would cause cracks in the ground. An intensity-XII earthquake would cause total destruction of buildings, and objects such as cars would be thrown upward into the air. The 1994 6.8-magnitude earthquake in Northridge, California, was listed at an intensity of IX because of the damage it caused.

**Liquefaction** Have you ever tried to drink a thick milkshake from a cup? Sometimes the milkshake is so thick that it won't flow. How do you make the milkshake flow? You shake it. Something similar can happen to very wet soil during an earthquake. Wet soil can be strong most of the time, but the shaking from an earthquake can cause it to act more like a liquid. This is called **liquefaction**. When liquefaction occurs in soil under buildings, the buildings can sink into the soil and collapse, as shown in **Figure 18**. People living in earthquake regions should avoid building on loose soils.



**Magnetism** In 1975, Chinese scientists successfully predicted an earthquake by measuring a slow tilt of Earth's surface and small changes in Earth's magnetism. Many lives were saved as a result of this prediction. Research the jobs that seismologists do and the types of organizations that they work for. Find out why most earthquakes have not been predicted.

**Figure 18** San Francisco's Marina district suffered extensive damage from liquefaction in the 1989 Loma Prieta earthquake because it is built on a landfilled marsh.



**Topic: Tsunamis**

Visit [earth.msscience.com](http://earth.msscience.com) for Web links to information about tsunamis.

**Activity** Make a table that displays the location, date, earthquake magnitude, and maximum runup of the five most recent tsunamis.

**Tsunamis** Most earthquake damage occurs when surface waves cause buildings, bridges, and roads to collapse. People living near the seashore, however, have another problem. An earthquake under the ocean causes a sudden movement of the ocean floor. The movement pushes against the water, causing a powerful wave that can travel thousands of kilometers in all directions.

Ocean waves caused by earthquakes are called seismic sea waves, or **tsunamis** (soo NAH meez). Far from shore, a wave caused by an earthquake is so long that a large ship might ride over it without anyone noticing. But when one of these waves breaks on a shore, as shown in **Figure 19**, it forms a towering crest that can reach 30 m in height.

**Tsunami Warnings** Just before a tsunami crashes onto shore, the water along a shoreline might move rapidly toward the sea, exposing a large portion of land that normally is underwater. This should be taken as a warning sign that a tsunami could strike soon. You should head for higher ground immediately.

Because of the number of earthquakes that occur around the Pacific Ocean, the threat of tsunamis is constant. To protect lives and property, a warning system has been set up in coastal areas and for the Pacific Islands to alert people if a tsunami is likely to occur. The Pacific Tsunami Warning Center, located near Hilo, Hawaii, provides warning information including predicted tsunami arrival times at coastal areas.

However, even tsunami warnings can't prevent all loss of life. In the 1960 tsunami that struck Hawaii, 61 people died when they ignored the warning to move away from coastal areas.

**Figure 19** A tsunami begins over the earthquake focus.

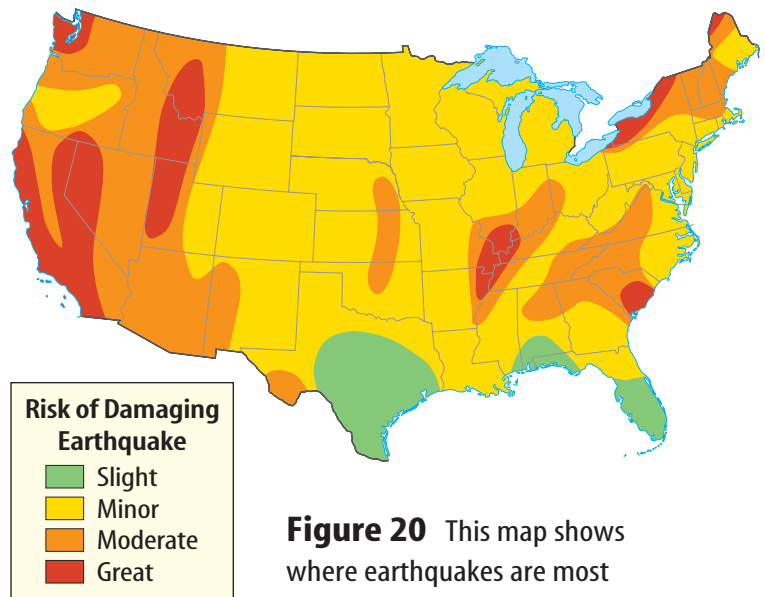
**Infer** what might happen to towns located near the shore.





## Earthquake Safety

Although earthquakes cannot be predicted reliably, **Figure 20** shows where earthquakes are most likely to occur in the United States. Knowing where earthquakes are likely to occur helps in long-term planning. Cities can take action to reduce damage and loss of life. Many buildings withstood the 1989 Loma Prieta earthquake because they were built with the expectation that such an earthquake would occur someday.



**Figure 20** This map shows where earthquakes are most likely to cause severe damage.

### Applying Math Find a Ratio

**EARTHQUAKE ENERGY** An increase of one magnitude on the Richter scale for an earthquake means that 32 times more energy is released. How many times greater is the energy released by a magnitude-6 earthquake than the energy released by a magnitude-3 earthquake?

#### Solution

- This is what you know:*
  - magnitude-6 earthquake, magnitude-3 earthquake
  - energy increases 32 times per magnitude number
- This is what you need to find out:* How many times greater is the energy of the larger earthquake than the energy of the smaller earthquake?
- This is the procedure you need to use:*
  - Find the difference in magnitudes:  $6 - 3 = 3$ .
  - This is the number of times 32 is multiplied times itself.  $32 \times 32 \times 32 = 32,768$ .
  - The magnitude-6 earthquake releases 32,768 times more energy than the magnitude-3 earthquake.
- Check your answer:* Count how many times you need to divide 32,768 by 32 to obtain 1. You should get 3.

#### Practice Problems

- How many times greater is the energy released by a magnitude-7 earthquake than the energy released by a magnitude-2 earthquake?
- How many times greater is the energy released by a magnitude-5 earthquake than the energy released by a magnitude-3 earthquake?



For more practice, visit [earth.msscience.com/math\\_practice](http://earth.msscience.com/math_practice)



## Mini LAB

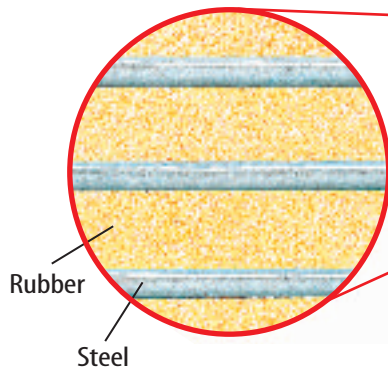
### Modeling Seismic-Safe Structures

#### Procedure

1. On a **tabletop**, build a structure out of **building blocks** by simply placing one block on top of another.
2. Build a second structure by wrapping sections of three blocks together with **rubber bands**. Then, wrap larger rubber bands around the entire completed structure.
3. Set the second structure on the tabletop next to the first one and pound on the side of the table with a slow, steady rhythm.

#### Analysis

1. Which of your two structures was better able to withstand the “earthquake” caused by pounding on the table?
2. How might the idea of wrapping the blocks with rubber bands be used in construction of supports for elevated highways?



**Quake-Resistant Structures** During earthquakes, buildings, bridges, and highways can be damaged or destroyed. Most loss of life during an earthquake occurs when people are trapped in or on these crumbling structures. What can be done to reduce loss of life?

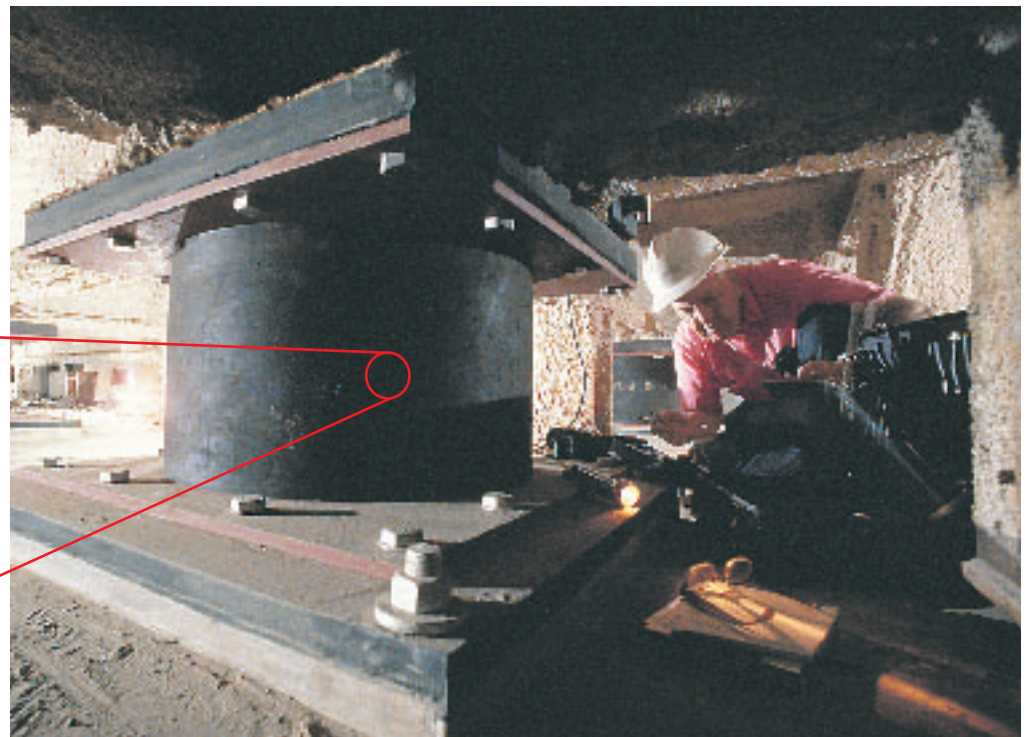
Seismic-safe structures stand up to vibrations that occur during an earthquake. **Figure 21** shows how buildings can be built to resist earthquake damage. Today in California, some new buildings are supported by flexible, circular moorings placed under the buildings. The moorings are made of steel plates filled with alternating layers of rubber and steel. The rubber acts like a cushion to absorb earthquake waves. Tests have shown that buildings supported in this way should be able to withstand an earthquake measuring up to 8.3 on the Richter scale without major damage.

In older buildings, workers often install steel rods to reinforce building walls. Such measures protect buildings in areas that are likely to experience earthquakes.

 **Reading Check** *What are seismic-safe structures?*

**Figure 21** The rubber portions of this building’s moorings absorb most of the wave motion of an earthquake. The building itself only sways gently.

**Infer** *what purpose the rubber serves.*





**Before an Earthquake** To make your home as earthquake-safe as possible, certain steps can be taken. To reduce the danger of injuries from falling objects, move heavy objects from high shelves to lower shelves. Learn how to turn off the gas, water, and electricity in your home. To reduce the chance of fire from broken gas lines, make sure that water heaters and other gas appliances are held securely in place as shown in **Figure 22**. A newer method that is being used to minimize the danger of fire involves placing sensors on gas lines. The sensors automatically shut off the gas when earthquake vibrations are detected.

**During an Earthquake** If you're indoors, move away from windows and any objects that could fall on you. Seek shelter in a doorway or under a sturdy table or desk. If you're outdoors, stay in the open—away from power lines or anything that might fall. Stay away from chimneys or other parts of buildings that could fall on you.

**After an Earthquake** If water and gas lines are damaged, the valves should be shut off by an adult. If you smell gas, leave the building immediately and call authorities from a phone away from the leak area. Stay away from damaged buildings. Be careful around broken glass and rubble, and wear boots or sturdy shoes to keep from cutting your feet. Finally, stay away from beaches. Tsunamis sometimes hit after the ground has stopped shaking.



**Figure 22** Sturdy metal straps on this gas water heater help reduce the danger of fires from broken gas lines during an earthquake.

## section 3 review

### Summary

#### Earthquake Activity

- The height of the lines traced on a seismogram can be used to determine an earthquake's magnitude.
- The intensity of an earthquake is determined by examining the amount of damage caused by the earthquake.

#### Earthquake Safety

- Knowing where large earthquakes are likely to occur helps people plan how to reduce damage.
- If you're ever in an earthquake, move away from windows or any object that might fall on you. Seek shelter in a doorway or under a sturdy table or desk.

### Self Check

1. **Explain** how you can determine if you live in an area where an earthquake is likely to occur.
2. **Compare and contrast** the Richter and the Mercalli scales.
3. **Explain** what causes a tsunami.
4. **Describe** three ways an earthquake causes damage.
5. **Think Critically** How are shock absorbers on a car similar to the circular moorings used in modern earthquake-safe buildings? How do they absorb shock?

### Applying Skills

6. **Infer** Seismographs around the world record the occurrence of thousands of earthquakes every day. Why are so few earthquakes in the news?

## Earthquake Depths

### Goals

- **Observe** any connection between earthquake-focus depth and epicenter location using the data provided on the next page.
- **Describe** any observed relationship between earthquake-focus depth and the movement of plates at Earth's surface.

### Materials

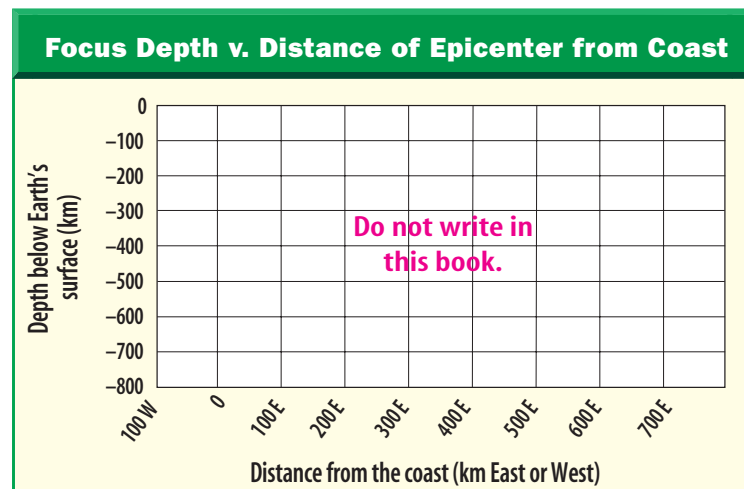
graph paper  
pencil

### Real-World Question

You learned in this chapter that Earth's crust is broken into sections called plates. Stresses caused by movement of plates generate energy within rocks that must be released. When this release is sudden and rocks break, an earthquake occurs. Can a study of the foci of earthquakes tell you about plate movement in a particular region?

### Analyze Your Data

1. Use graph paper and the data table on the right to make a graph plotting the depths of earthquake foci and the distances from the coast of a continent for each earthquake epicenter.
2. Use the graph below as a reference to draw your own graph. Place *Distance from the coast* and units on the x-axis. Begin labeling at the far left with 100 km west. To the right of it should be 0 km, then 100 km east, 200 km east, 300 km east, and so on through 700 km east. What point on your graph represents the coast?
3. Label the y-axis *Depth below Earth's surface*. Label the top of the graph 0 km to represent Earth's surface. Label the bottom of the y-axis -800 km.
4. **Plot** the focus depths against the distance and direction from the coast for each earthquake in the table below.



## Using Scientific Methods

### Conclude and Apply

- Describe** any observed relationship between the location of earthquake epicenters and the depth of foci.
- Explain** why none of the plotted earthquakes occurred below 700 km.
- Based on your graph, form a hypothesis to explain what is happening to the plates at Earth's surface in the vicinity of the plotted earthquake foci. In what direction are the plates moving relative to each other?
- Infer** what process is causing the earthquakes you plotted on your graph.
- Infer** whether these earthquakes are occurring along the eastern side of a continent or along the western side of a continent.
- Draw and label** a cross section of the Earth beneath this coast. Label the eastern plate, the western plate, and use arrows to show the directions the plates are moving.
- Form a hypothesis** to predict which continent these data might apply to. Apply what you have learned in this lab and the information in **Figure 2**. Explain your answer.



### Focus and Epicenter Data

Earthquake	Focus Depth (km)	Distance of Epicenter from Coast (km)
A	-55	0
B	-295	100 east
C	-390	455 east
D	-60	75 east
E	-130	255 east
F	-195	65 east
G	-695	400 east
H	-20	40 west
I	-505	695 east
J	-520	390 east
K	-385	335 east
L	-45	95 east
M	-305	495 east
N	-480	285 east
O	-665	545 east
P	-85	90 west
Q	-525	205 east
R	-85	25 west
S	-445	595 east
T	-635	665 east
U	-55	95 west
V	-70	100 west

### Communicating Your Data

**Compare** your graph with those of other members of your class. For more help, refer to the **Science Skill Handbook**.



## Moving Earth!

### Did you know...

... **Tsunamis can travel as fast as commercial jets and can reach heights of 30 m.** A wave that tall would knock over this lighthouse. Since 1945, more people have been killed by tsunamis than by the ground shaking from earthquakes.



### ... The most powerful earthquake

to hit the United States in recorded history shook Alaska in 1964. At 8.5 on the Richter scale, the quake shook all of Alaska for nearly 5 min, which is a long time for an earthquake. Nearly 320 km of roads near Anchorage suffered damage, and almost half of the 204 bridges had to be rebuilt.

#### Applying Math

How many 3.0-magnitude earthquakes would it take to equal the energy released by one 8.0-magnitude earthquake?

### ... Snakes can sense the vibrations

made by a small rodent up to 23 m away. Does this mean that they can detect vibrations prior to major earthquakes? Unusual animal behavior was observed just before a 1969 earthquake in China—an event that was successfully predicted.



### Write About It

Visit [earth.msscience.com/science\\_stats](http://earth.msscience.com/science_stats) to research the history and effects of earthquakes in the United States. In a paragraph, describe how the San Francisco earthquake of 1906 affected earthquake research.

Reviewing Main Ideas

**Section 1 Forces Inside Earth**

1. Plate movements can cause rocks to bend and stretch. Rocks can break if the forces on them are beyond their elastic limit.
2. Earthquakes are vibrations produced when rocks break along a fault.
3. Normal faults form when rocks are under tension. Reverse faults form under compression and shearing forces produce strike-slip faults.

**Section 2 Features of Earthquakes**

1. Primary waves stretch and compress rock particles. Secondary waves move particles at right angles to the direction of wave travel.

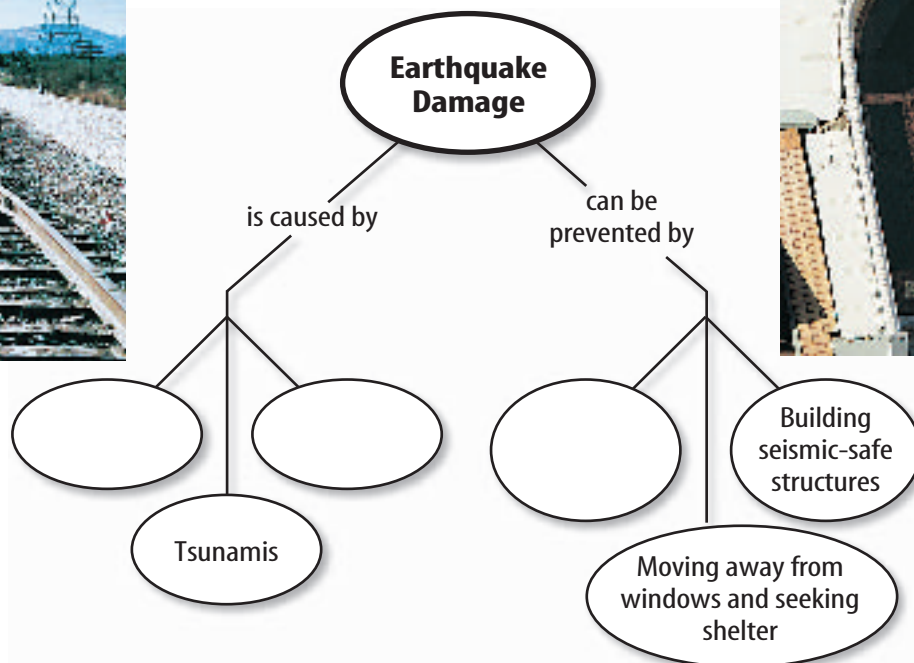
2. Surface waves move rock particles in a backward, rolling motion and a side-to-side swaying motion.
3. Earthquake epicenters are located by recording seismic waves.
4. The boundaries between Earth's internal layers are determined by observing the speeds and paths of seismic waves.

**Section 3 People and Earthquakes**

1. A seismograph measures the magnitude of an earthquake.
2. The magnitude of an earthquake is related to the energy released by the earthquake.

Visualizing Main Ideas

Copy and complete the following concept map on earthquake damage.



## Using Vocabulary

earthquake p. 301	reverse fault p. 302
epicenter p. 305	secondary wave p. 305
fault p. 300	seismic wave p. 304
focus p. 304	seismograph p. 307
liquefaction p. 315	strike-slip fault p. 303
magnitude p. 314	surface wave p. 305
normal fault p. 302	tsunami p. 316
primary wave p. 305	

Fill in the blanks with the correct words.

- \_\_\_\_\_ causes most of the damage in earthquakes because of the side to side swaying motion that many buildings are unable to withstand.
- At a(n) \_\_\_\_\_, rocks move past each other without much upward or downward movement.
- The point on Earth's surface directly above the earthquake focus is the \_\_\_\_\_.
- The measure of the energy released during an earthquake is its \_\_\_\_\_.
- An earthquake under the ocean can cause a(n) \_\_\_\_\_ that travels thousands of kilometers.

## Checking Concepts

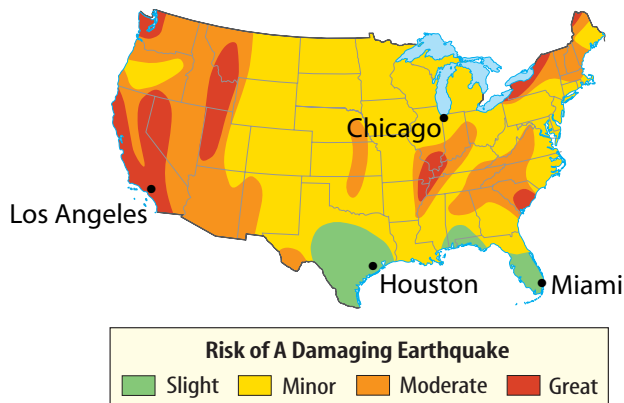
Choose the word or phrase that best answers the question.

- Earthquakes can occur when which of the following is passed?
 

A) tension limit	C) elastic limit
B) seismic unit	D) shear limit
- When the rock above the fault surface moves down relative to the rock below the fault surface, what kind of fault forms?
 

A) normal	C) reverse
B) strike-slip	D) shear

Use the illustration below to answer question 8.



- Using the figure above, which city should be most prepared for an earthquake?
 

A) Miami, FL	C) Chicago, IL
B) Houston, TX	D) Los Angeles, CA
- From which of the following do primary and secondary waves move outward?
 

A) epicenter	C) Moho
B) focus	D) tsunami
- What kind of earthquake waves stretch and compress rocks?
 

A) surface	C) secondary
B) primary	D) shear
- What are the slowest seismic waves?
 

A) surface	C) secondary
B) primary	D) pressure
- What is the fewest number of seismograph stations that are needed to locate the epicenter of an earthquake?
 

A) two	C) four
B) three	D) five
- What happens to primary waves when they pass from liquids into solids?
 

A) slow down	C) stay the same
B) speed up	D) stop
- What part of a seismograph does not move during an earthquake?
 

A) sheet of paper	C) drum
B) fixed frame	D) pendulum

**Thinking Critically**

15. **Infer** The 1960 earthquake in the Pacific Ocean off the coast of Chile caused damage and loss of life in Chile, Hawaii, Japan, and other areas along the Pacific Ocean border. How could this earthquake do so much damage to areas thousands of kilometers from its epicenter?
16. **Explain** why a person who is standing outside in an open field is relatively safe during a strong earthquake.
17. **Describe** how a part of the seismograph remains at rest during an earthquake.
18. **Explain** why it is incorrect to call a tsunami a tidal wave.
19. **Predict** which is likely to be more stable during an earthquake—a single-story wood-frame house or a brick building. Explain.
20. **Measure in SI** Use an atlas and a metric ruler to answer the following question. Primary waves travel at about 6 km/s in continental crust. How long would it take a primary wave to travel from San Francisco, California, to Reno, Nevada?

Use the table below to answer question 21.

Seismograph Station Data			
Station	Latitude	Longitude	Distance from Earthquake
1	45° N	120° W	1,300 km
2	35° N	105° W	1,200 km
3	40° N	115° W	790 km

21. **Use Tables** Use a map of the United States that has a distance scale, a compass for drawing circles, and the table above to determine the location of the earthquake epicenter.

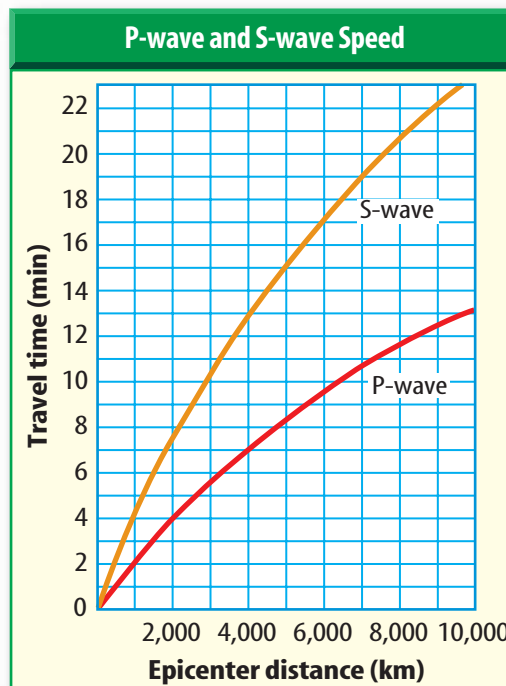
**Performance Activities**

22. **Model** Use layers of different colors of clay to illustrate the three different kinds of faults. Label each model, explaining the forces involved and the rock movement.

**Applying Math**

23. **Earthquake Magnitude** An increase of one on the Richter scale corresponds to an increase of 10 in the size of the largest wave on a seismogram. How many times larger is the largest wave of a Richter magnitude-6 earthquake than a Richter magnitude-3 earthquake?
24. **Tsunami Speed** An underwater earthquake produces a tsunami 1,500 km away from Hawaii. If the tsunami travels at 600 km/h, how long will it take to reach Hawaii?

Use the graph below to answer question 25.



25. **Earthquake Waves** The graph above shows a P-wave and an S-wave plotted on a time-distance graph. According to the graph, which wave moves at the greater speed?

## Part 1 Multiple Choice

Record your answers on the answer sheet provided by your teacher or on a sheet of paper.

Use the photo below to answer question 1.



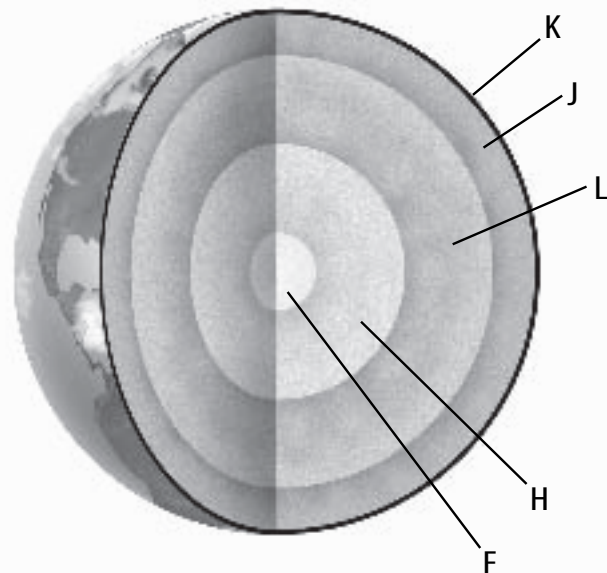
- The instrument above records seismic waves from an earthquake. Which of the following is the name of this instrument?
  - seismogram
  - seismograph
  - tiltmeter
  - strainmeter
- Which of the following terms is used to indicate the region where no earthquake waves reach Earth's surface?
  - light zone
  - waveless zone
  - shadow zone
  - seismic zone
- Which is used to measure magnitude?
  - Richter scale
  - Mercalli scale
  - shadow zone
  - seismic gap
- What is earthquake intensity?
  - a measure of energy released
  - a measure of seismic risk
  - a measure of damage done
  - a measure of an earthquake's focus

## Test-Taking Tip

**Eliminate Incorrect Answers** If you don't know the answer to a multiple choice question, try to eliminate as many incorrect answers as possible.

- Which of the following describes liquefaction?
  - the stopping of S-waves by Earth's molten outer core
  - ice melting during an earthquake to cause flooding
  - seismic waves shaking sediment, causing it to become more liquid like
  - rivers diverted by the motion of earthquake flooding
- Which of the following describes the motion of secondary waves?
  - a backward rolling and a side-to-side swaying motion
  - a back-and-forth motion that is parallel to the direction of travel
  - vibration in directions that are perpendicular to the direction of wave travel
  - a forward rolling motion

Use the illustration below to answer question 7.



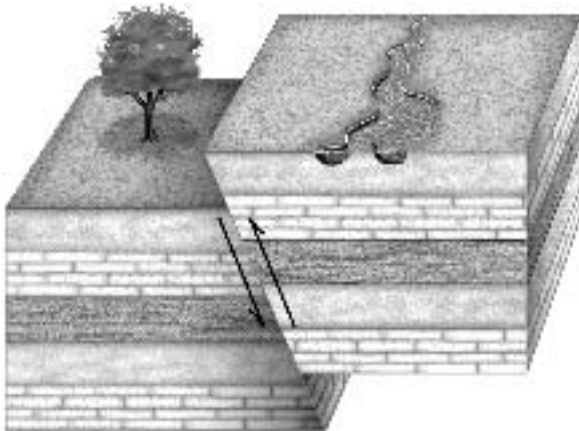
- Which letter corresponds to the lower mantle?
  - F
  - H
  - L
  - J

## Part 2 Short Response/Grid In

Record your answers on the answer sheet provided by your teacher or on a sheet of paper.

- Explain how earthquakes occur. Include a description of how energy builds up in rocks and is later released.

Use the illustration below to answer questions 9–10.



- What type of fault is shown?
- What type of force caused this fault to form?
- Where is the fault plane?
- Explain why most earthquakes occur along plate boundaries.
- An earthquake that occurred in San Fernando, California, in 1971 caused \$500 million in damage. An earthquake that occurred in Whittier, California, in 1987 caused \$358 million in damage. How much more damage was caused by the San Fernando earthquake?
- What factors affect damage done by an earthquake?
- Explain the relationship between world-wide earthquake distribution and tectonic boundaries.

## Part 3 Open Ended

Record your answers on a sheet of paper.

- The three types of faults are normal faults, reverse faults, and strike-slip faults. Draw each type of fault including arrows that show which way the rocks move.
- Describe how a person should prepare for an earthquake and how a person should react if an earthquake occurs.

Use the map below to answer question 18.



- The map above shows three circles drawn around three different seismograph stations. The circles have radii equal to the distance between the seismograph station and the earthquake's epicenter. Which labeled point on the map represents the earthquake's epicenter? How do you know?
- Compare and contrast the three types of seismic waves.
- Draw three diagrams to show how each type of seismic wave moves through rocks.
- Describe what happens to S-waves when they contact Earth's outer core. Describe what happens to P-waves when they reach Earth's outer core. What is the *shadow zone*?