CHAPTER 7

Earthquakes

the BIG idea

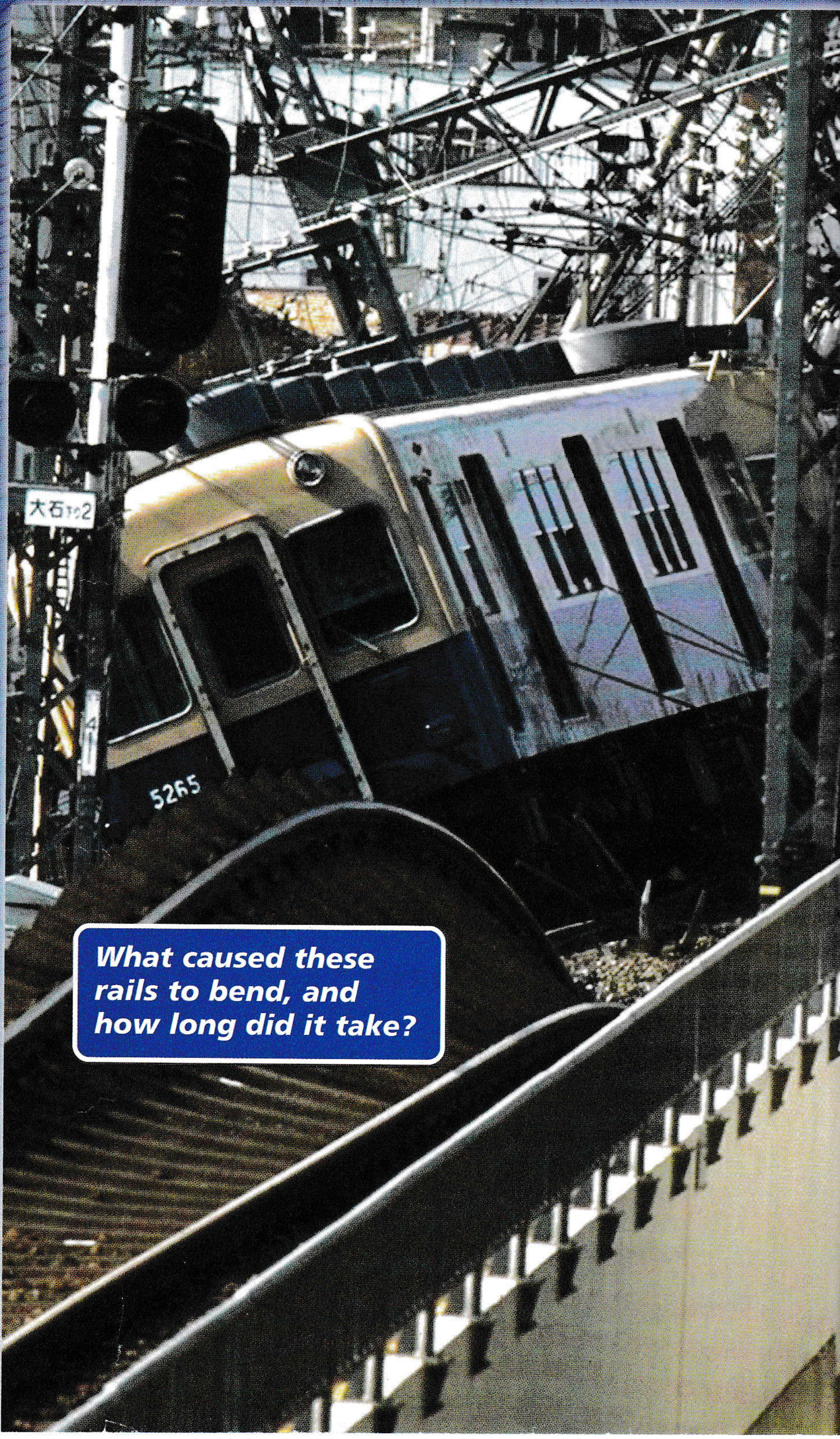
Earthquakes release stress that has built up in rocks.

Key Concepts

SECTION 1
Earthquakes occur along faults.
Learn how rocks move along different kinds of faults.

SECTION 2
Earthquakes release energy.
Learn how energy from an earthquake is used to determine its location and size.

SECTION 3
Earthquake damage can be reduced.
Learn how structures are built to better withstand earthquakes.

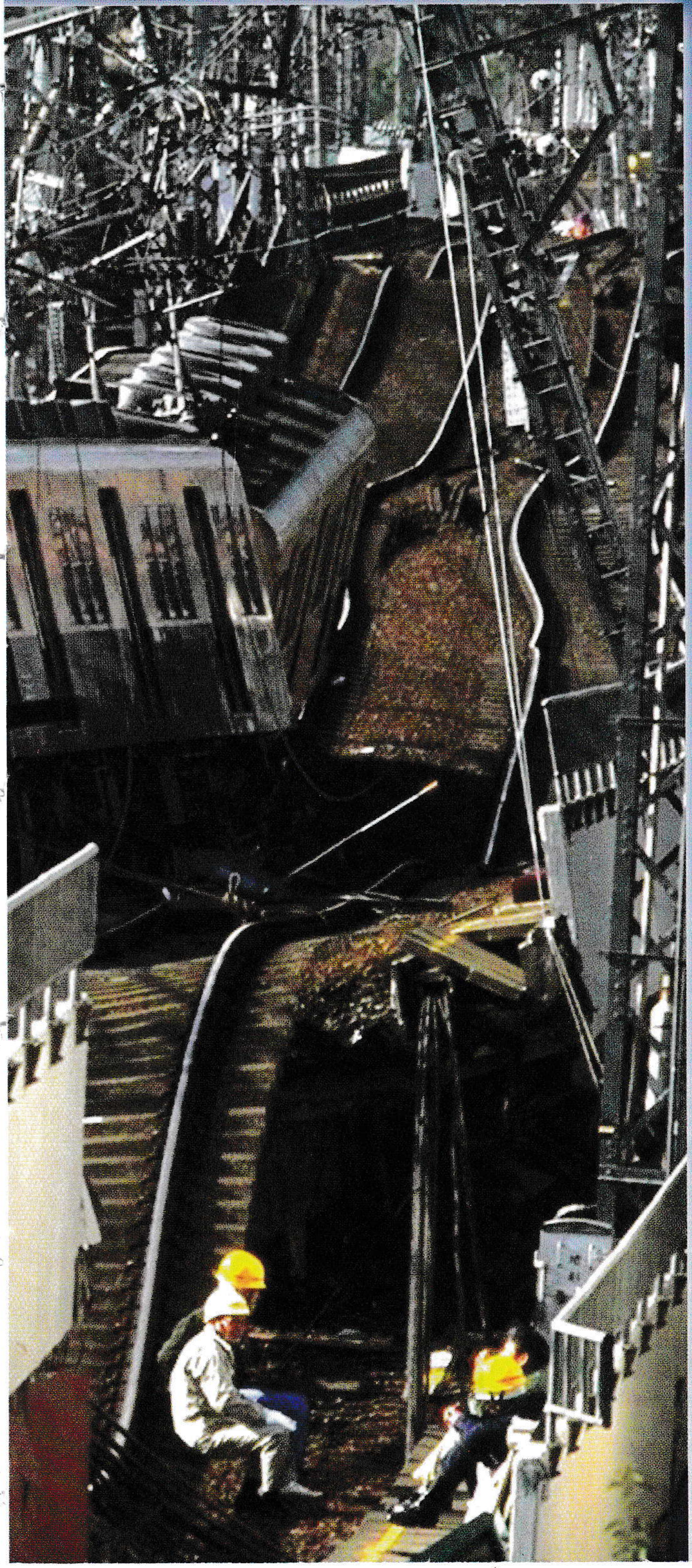


What caused these rails to bend, and how long did it take?

Internet Preview

CLASSZONE.COM

Chapter 7 online resources: Content Review, two Visualizations, three Resource Centers, Math Tutorial, Test Practice



EXPLORE the BIG idea

Can You Bend Energy?

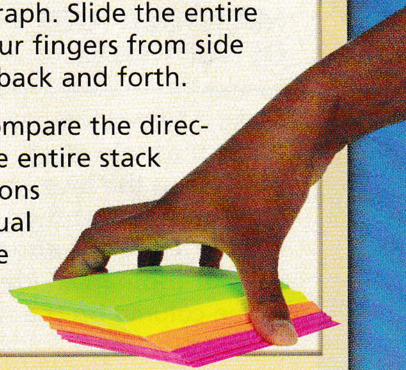
Put a clear glass filled with water on a table. Holding a flashlight at an angle to the glass, shine light through the water so that an oval of light forms on the table.

Observe and Think Did the light, which is a form of energy, travel in a straight line through the layers of air and water? Do you think other forms of energy travel in straight lines through layers inside Earth?

How Can Something Move Forward, Yet Sideways?

Put a stack of cards on a table and hold them as shown in the photograph. Slide the entire stack forward, tilting your fingers from side to side to fan the cards back and forth.

Observe and Think Compare the direction of movement of the entire stack of cards with the directions of movement of individual cards. How might this be similar to how energy can travel in waves?



Internet Activity: Earthquakes

Go to **ClassZone.com** to see maps of recent earthquakes around the world, in the United States, and in your own area.

Observe and Think Where and when did the largest earthquakes occur?

NSTA scilinks.org SCILINKS

Earthquakes **Code: MDL053**

CHAPTER 7

Getting Ready to Learn

CONCEPT REVIEW

- Earth's lithosphere is broken into tectonic plates.
- Tectonic plates pull apart, push together, and scrape past one another.
- Major geologic events occur along tectonic plate boundaries.

VOCABULARY REVIEW

lithosphere p. 187
tectonic plate p. 188
mid-ocean ridge p. 192
subduction p. 206

CONTENT REVIEW
CLASSZONE.COM
Review concepts and vocabulary.

TAKING NOTES

MAIN IDEA AND DETAIL NOTES

Make a two-column chart. Write the main ideas, such as those in the blue headings, in the column on the left. Write details about each of those main ideas in the column on the right.

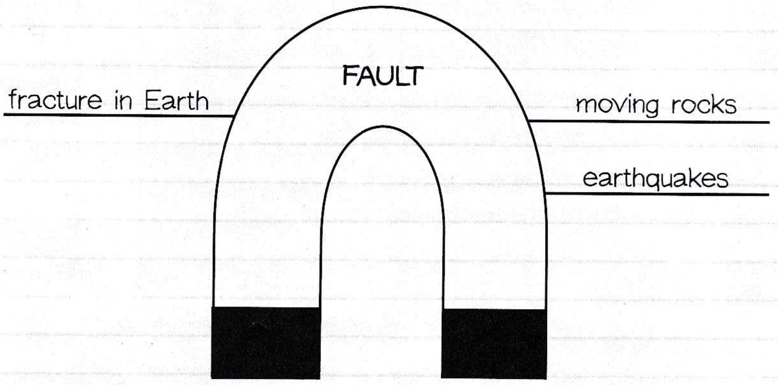
VOCABULARY STRATEGY

For each vocabulary term, make a **magnet word** diagram. Write other terms or ideas related to that term around it.

See the Note-Taking Handbook on pages R45–R51.

SCIENCE NOTEBOOK

MAIN IDEAS	DETAIL NOTES
1. Rocks move along faults.	1. Blocks of rock can move past one another slowly and constantly. 1. Blocks of rock can get stuck and then break free, causing earthquakes.
2. Most faults are located along tectonic plate boundaries.	2. 2. 2.



KEY CONCEPT

7.1 Earthquakes occur along faults.

BEFORE, you learned

- The crust and uppermost mantle make up the lithosphere
- The lithosphere is cold and rigid
- Tectonic plates move over hotter, weaker rock in the asthenosphere

NOW, you will learn

- Why earthquakes occur
- Where most earthquakes occur
- How rocks move during earthquakes

VOCABULARY

fault p. 221
stress p. 221
earthquake p. 221

EXPLORE Pressure

How does pressure affect a solid material?

PROCEDURE

1. Hold a wooden craft stick at each end.
2. Bend the stick very slowly. Continue to put pressure on the stick until it breaks.

MATERIALS

wooden craft stick

WHAT DO YOU THINK?

- How did the stick change before it broke?
- How might rocks react to pressure?

Rocks move along faults.

Sometimes when you pull on a drawer, it opens smoothly. At other times, the drawer sticks shut. If you pull hard enough, the drawer suddenly flies open. Rocks along faults behave in a similar way. A **fault** is a fracture, or break, in Earth's lithosphere, along which blocks of rock move past each other.

VOCABULARY
Add magnet word diagrams for *fault, stress,* and *earthquake* to your notebook.

Along some parts of a fault, the rock on either side may slide along slowly and constantly. Along other parts of the fault, the rocks may stick, or lock together. The rocks bend as stress is put on them. **Stress** is the force exerted when an object presses on, pulls on, or pushes against another object. As stress increases, the rocks break free. A sudden release of stress in the lithosphere causes an earthquake. An **earthquake** is a shaking of the ground caused by the sudden movement of large blocks of rock along a fault.

Most faults are located along tectonic plate boundaries, so most earthquakes occur in these areas. However, the blocks of rock that move during an earthquake are much smaller than a tectonic plate. A plate boundary can be many thousands of kilometers long. During even a very powerful earthquake, blocks of rock might move only a few meters past each other along a distance of several hundred kilometers. The strength of an earthquake depends in part on

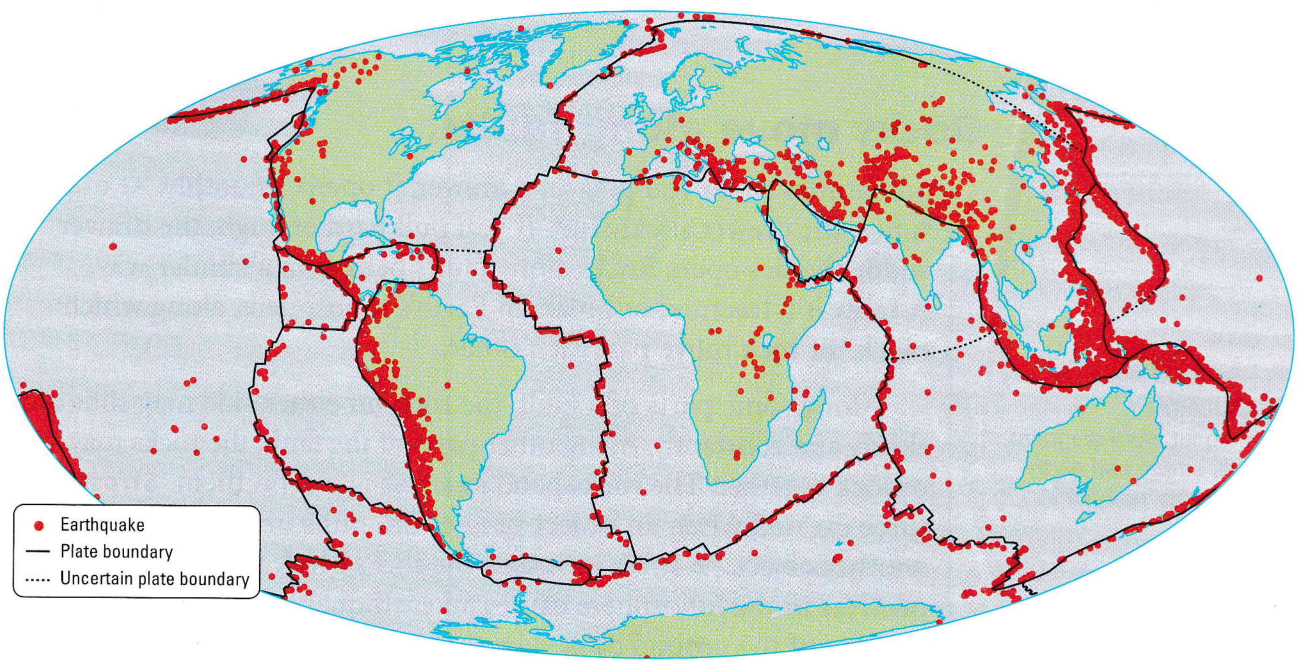
- how much stress builds up before the rocks move
- the distance the rocks move along the fault

About 80 percent of all earthquakes occur in a belt around the edges of the Pacific Ocean. In the United States, the best-known fault in this belt is the San Andreas (san an-DRAY-uhs) Fault in California. It forms part of the boundary between the North American Plate and the Pacific Plate. Unlike many other faults, parts of the San Andreas Fault can be seen on the surface of the ground.

A small percentage of earthquakes occur along faults within plates. As you read in Chapter 6, a tectonic plate is rigid. Therefore, stress along a plate's boundary can cause rocks to break and move along weak areas toward the middle of the plate.

Where Earthquakes Occur

This map shows the locations of moderate to intense earthquakes from 1993 through 2002.



READING VISUALS Why do most earthquakes in North America and South America occur near the continents' western coasts?

All earthquakes occur in the lithosphere. To understand why, you might compare a tectonic plate to a piece of cold, hard caramel. Like cold caramel, the plate is rigid and brittle. The rocks can break and move suddenly, causing an earthquake. Now compare the asthenosphere below the plate to warm, soft caramel. In the asthenosphere, hot rock bends and flows rather than breaks. A few earthquakes occur far below the normal depth of the lithosphere only because tectonic plates sinking in subduction zones are still cold enough to break.

CHECK YOUR READING Why don't earthquakes occur in the asthenosphere?

Faults are classified by how rocks move.

MAIN IDEA AND DETAILS Record information about each type of fault in your notebook.

The blocks of rock along different types of faults move in different directions, depending on the kinds of stress they are under. Scientists classify a fault according to the way the rocks on one side move with respect to the rocks on the other side.

The three main types of faults are normal faults, reverse faults, and strike-slip faults. More than one type of fault may be present along the same plate boundary. However, the type of fault that is most common along a boundary depends on whether plates are pulling apart, pushing together, or scraping past one another at that boundary.

INVESTIGATE Faults

How can rocks move along faults?

SKILL FOCUS
Modeling

MATERIALS
- 2 triangular blocks of wood
- masking tape
- marker

TIME
15 minutes

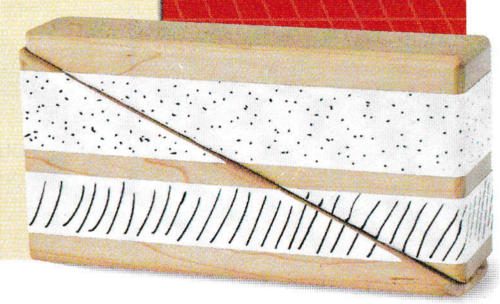
PROCEDURE

1. Place one triangular block of wood against the other to form a rectangle.
2. Put two pieces of masking tape across both blocks. Draw a different pattern on each piece of tape. Break the tape where it crosses the blocks.
3. Keep the blocks in contact and slide one block along the other.
4. Repeat step 3 until you find three different ways the blocks can move relative to each other. Draw diagrams showing how the blocks moved. Include the tape patterns.

WHAT DO YOU THINK?

- How can you use the tape patterns to find the relative directions in which the blocks were moved?
- In each case, what sort of stress (such as pulling) did you put on the blocks?

CHALLENGE Compare the ways you moved the blocks with the ways tectonic plates move at their boundaries.



READING TIP

The word *plane* comes from the Latin word *planum,* which means "flat surface."

The illustrations on this page and page 225 show that a fault forms a plane that extends both horizontally and vertically. Blocks of rock move along the fault plane during an earthquake. Along a normal or reverse fault, the movement of the blocks is mainly vertical—the blocks move up or down. Along a strike-slip fault, the movement is horizontal—the blocks move sideways.

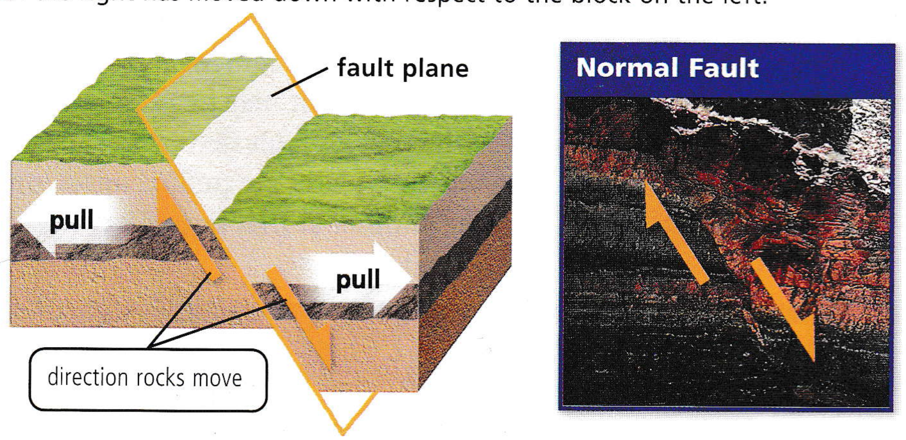
Normal Faults

Along a normal fault, the block of rock above the fault plane slides down relative to the other block. Stress that pulls rocks apart causes normal faults. Earthquakes along normal faults are common near boundaries where tectonic plates are moving apart, such as in the Great Rift Valley of Africa.

READING TIP

Compare the directions of the arrows in the diagrams with the directions of the arrows on the photographs.

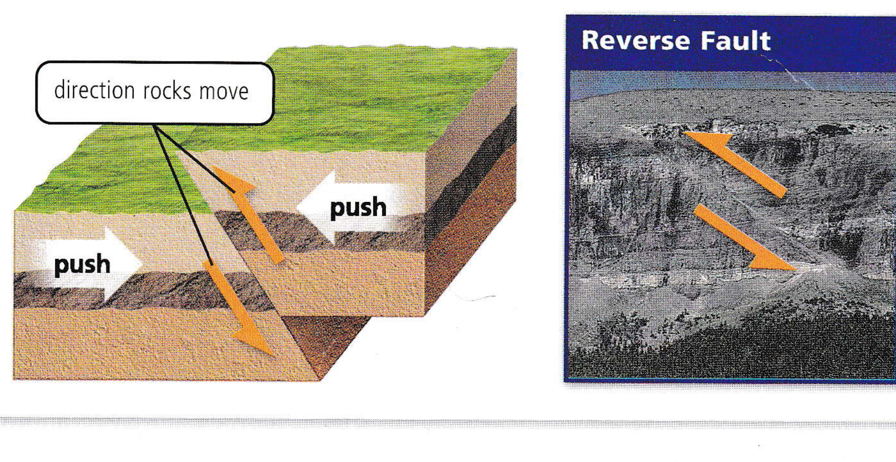
As rocks are pulled apart (white arrows), normal faults form. The block on the right has moved down with respect to the block on the left.



Reverse Faults

Along a reverse fault, the block of rock above the fault plane moves up relative to the other block. Stress that presses rocks together causes reverse faults. These faults can occur near collision-zone boundaries

As rocks are pushed together (white arrows), reverse faults form. The block on the right has moved up with respect to the block on the left.



between plates. The Himalaya Mountains, which rise in the area where the Indian Plate is pushing into the Eurasian Plate, have many earthquakes along reverse faults.

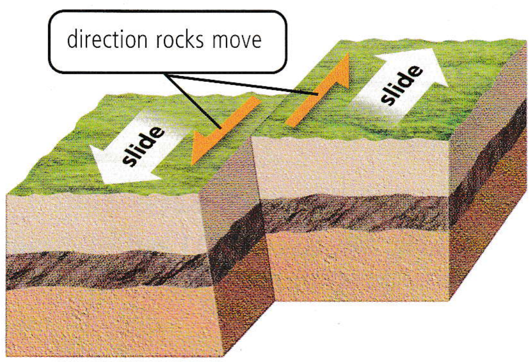
CHECK YOUR READING What type of stress produces reverse faults?

Strike-Slip Faults

Along a strike-slip fault, blocks of rock move sideways on either side of the fault plane. Stresses that push blocks of rock horizontally cause earthquakes along strike-slip faults. These faults can occur where plates scrape past each other. The San Andreas Fault is a strike-slip fault.

VISUALIZATION CLASSZONE.COM
Explore animations showing fault motion.

As rocks are pushed horizontally in opposite directions, strike-slip faults form. The block on the right has moved to the right with respect to the block on the left.



Over time, movement of rocks along normal and reverse faults can push up mountains and form deep valleys. As rocks move along strike-slip faults, rocks that were once in continuous layers can become separated by hundreds of kilometers.

7.1 Review

KEY CONCEPTS

1. What causes earthquakes?
2. Why do most earthquakes occur along tectonic plate boundaries?
3. What is the main direction of stress on blocks of rock at normal faults, reverse faults, and strike-slip faults?

CRITICAL THINKING

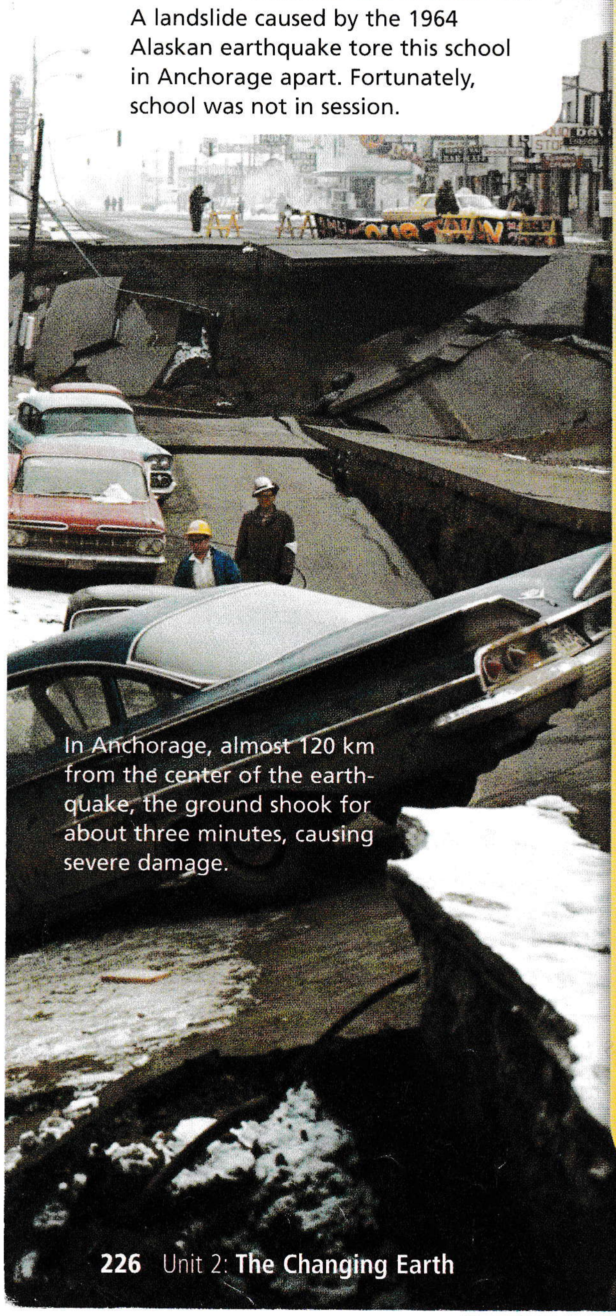
4. **Compare and Contrast** Make a chart showing the similarities and differences between normal and reverse faults.
5. **Connect** Japan is near a subduction zone. What type of faults would you expect to be responsible for many of the earthquakes there? Explain.

CHALLENGE

6. **Analyze** What evidence from rock layers could show a scientist that earthquakes had occurred in an area before written records were kept?

When Earth Shakes

A landslide caused by the 1964 Alaskan earthquake tore this school in Anchorage apart. Fortunately, school was not in session.



In Anchorage, almost 120 km from the center of the earthquake, the ground shook for about three minutes, causing severe damage.

Alaskan Earthquake Sinks Louisiana Boats

The most powerful earthquake ever recorded in the United States struck Prince William Sound in Alaska on March 27, 1964. Plates that had been moving a few centimeters per year lurched 9 meters (30 ft), causing the ground to shake for more than three minutes. When energy from the earthquake reached Louisiana, more than 5000 kilometers (3000 mi) away, it caused waves high enough to sink fishing boats in a harbor.

Wall of Water Higher than 20-Story Building

The 1964 Alaskan earthquake caused buildings to crumble and collapse. It also produced tsunamis—water waves caused by a sudden movement of the ground during an earthquake, landslide, or volcanic eruption. In Alaska's Valdez Inlet, a landslide triggered by the earthquake produced a tsunami 67 meters (220 ft) high—taller than a 20-story building.

Missouri Earthquakes Ring Massachusetts Bells

Earthquakes near New Madrid, Missouri, in 1811 and 1812 caused church bells in Boston, Massachusetts—nearly 1600 kilometers (1000 mi) away—to ring.

Five Largest Earthquakes Since 1900

Location	Date	Moment Magnitude
Off the coast of Chile	1960	9.5
Prince William Sound, Alaska	1964	9.2
Andreanof Islands, Alaska	1957	9.1
Kamchatka Peninsula, Russia	1952	9.0
Off the coast of Sumatra	2004	9.0

Largest Earthquake Ever

The most powerful earthquake ever recorded hit Chile in 1960. This earthquake released almost 10 times as much energy as the 1964 earthquake in Alaska—and about 600 times the energy of the earthquake that destroyed much of San Francisco in 1906.

EXPLORE

1. **EXPLAIN** How were the 1964 Alaskan earthquake and the 1960 Chilean earthquake related to movements along tectonic plate boundaries?
2. **CHALLENGE** An inlet is a narrow body of water connected to a lake or ocean. Why might a tsunami be higher in an inlet than along the coastline around it?

KEY CONCEPT

7.2 Earthquakes release energy.

BEFORE, you learned

- Most earthquakes occur along tectonic plate boundaries
- Different directions of stress cause normal, reverse, and strike-slip faults

NOW, you will learn

- How energy from an earthquake travels through Earth
- How an earthquake's location is determined

VOCABULARY

seismic wave p. 227
focus p. 228
epicenter p. 228
seismograph p. 232

EXPLORE Movement of Energy

How does energy travel?

PROCEDURE

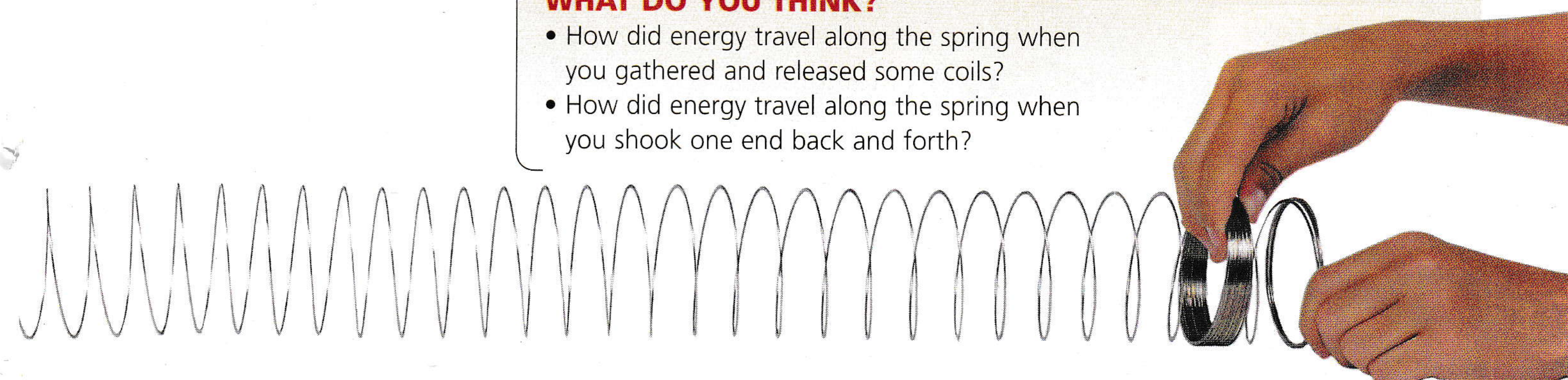
1. On a flat surface, hold one end of a spring toy while a partner holds the other end. Stretch the spring, then squeeze some coils together and release them.
2. Again, hold one end of the spring while your partner holds the other end. Shake your end of the spring back and forth.

MATERIALS

spring toy

WHAT DO YOU THINK?

- How did energy travel along the spring when you gathered and released some coils?
- How did energy travel along the spring when you shook one end back and forth?



Energy from earthquakes travels through Earth.

MAIN IDEA AND DETAILS
Record information about the energy released by earthquakes.

When you throw a rock into a pond, waves ripple outward from the spot where the rock hits the water. The energy released by an earthquake travels in a similar way through Earth. Unlike the pond ripples, though, earthquake energy travels outward in all directions—up, down, and to the sides. The energy travels as **seismic waves,** (SYZ-mihk) which are vibrations caused by earthquakes. Seismic waves from even small earthquakes can be recorded by sensitive instruments around the world.

READING TIP

The prefix *epi-* comes from a Greek word meaning "on top of." An earthquake's epicenter is directly over its focus.

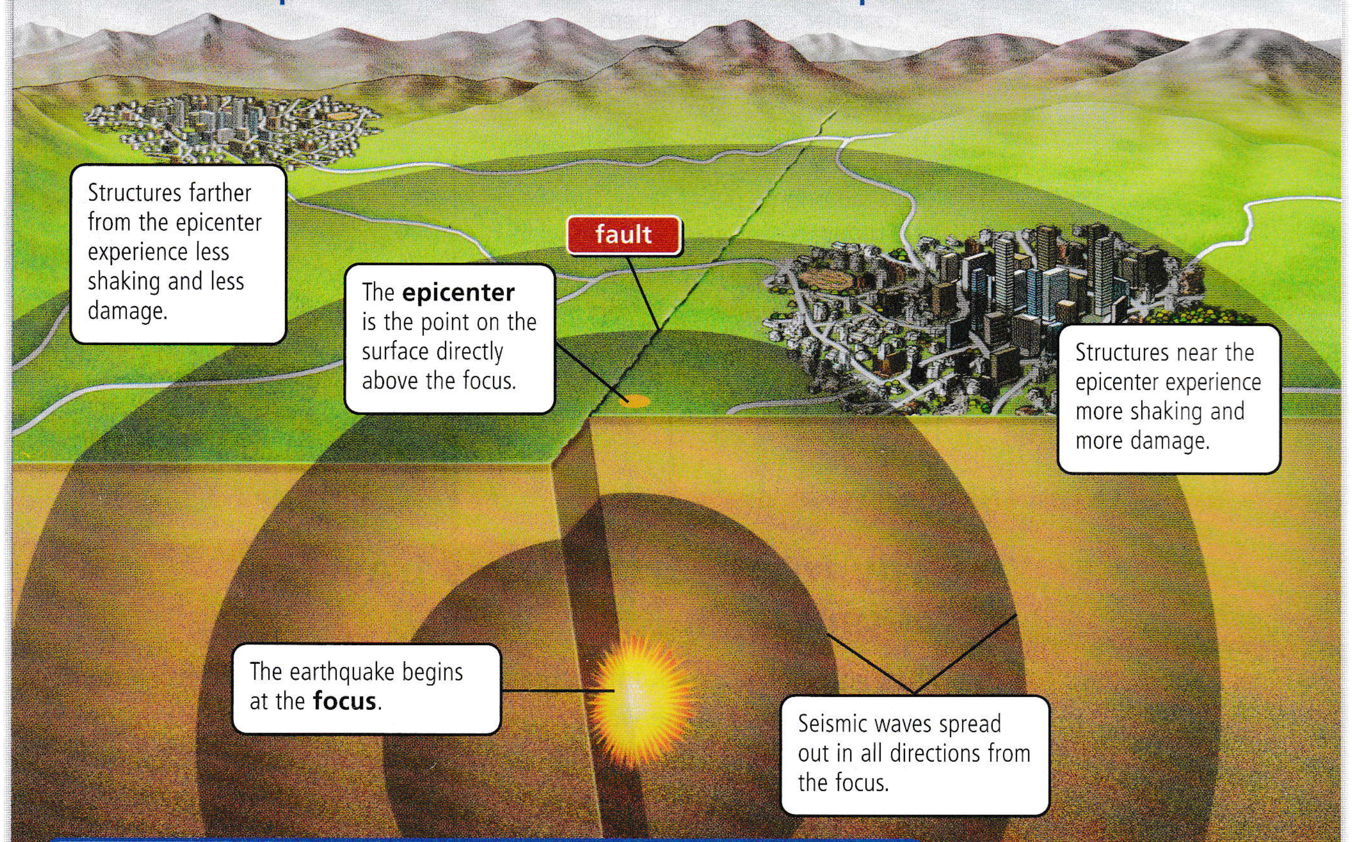
All earthquakes start beneath Earth's surface. The **focus** of an earthquake is the point underground where rocks first begin to move. Seismic waves travel outward from the earthquake's focus. The **epicenter** (EHP-ih-SEHN-tuhr) is the point on Earth's surface directly above the focus. Scientists often name an earthquake after the city that is closest to its epicenter.

In general, if two earthquakes of equal strength have the same epicenter, the one with the shallower focus causes more damage. Seismic waves from a deep-focus earthquake lose more of their energy as they travel farther up to Earth's surface.

The depths of earthquakes along tectonic plate boundaries are related to the directions in which the plates move. For example, an earthquake along a mid-ocean spreading center has a shallow focus. There, the plates are pulling apart, and the new crust that forms is thin. Subduction zones have a wide range of earthquake depths, from shallow to very deep. Earthquakes can occur anywhere along the sinking plates.

Focus and Epicenter

Seismic waves spread out from the focus of an earthquake.



READING VISUALS What is the difference between the focus and the epicenter of an earthquake?

INVESTIGATE Subduction-Zone Earthquakes

Why are some earthquakes deeper than others?

PROCEDURE

1. Cut the first string into 4 pieces that are 4 cm long. Cut the second string into 3 pieces that are 8 cm long, and the third string into 4 pieces that are 15 cm long.
2. Use the key on the Earthquake Map to match string lengths with earthquake depths.
3. Tape one end of the pieces of string to the map at the earthquake locations, as shown in the photograph. Always cover the same amount of string with tape.
4. Hold the map upside down, with the strings hanging down. Observe the patterns of earthquake locations and depths.

WHAT DO YOU THINK?

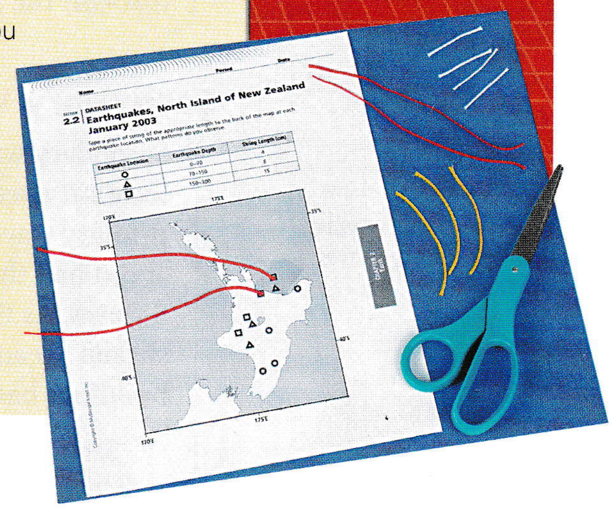
- What patterns among the strings do you observe? How do you explain them?
- How might the earthquake depths relate to the sinking of a tectonic plate in a subduction zone?

CHALLENGE Draw a line on the map, showing where the subduction zone might be at Earth's surface. How might the depths of the earthquakes be different if the subduction zone were on the other side of the island?

SKILL FOCUS
Analyzing

MATERIALS
- different colors of string
- ruler
- scissors
- Earthquake Map
- tape

TIME
20 minutes



Waves and Energy

Waves are part of your everyday life. For example, music reaches your ears as sound waves. All waves, including seismic waves, carry energy from place to place. As a wave moves through a material, particles of the material move out of position temporarily, causing the particles next to them to move. After each particle moves, it returns to its original position. In this way, energy moves through the material, but matter does not.

On October 17, 1989, an earthquake stopped baseball's World Series at Candlestick Park in San Francisco. As the seismic waves arrived, fans heard a low rumble; then for about 15 seconds the stadium shook from side to side and up and down. About 20 minutes after the earthquake was felt at the stadium, the seismic waves had traveled to the other side of Earth. There, the waves did not shake the ground hard enough for people to notice. The waves could be detected only by scientific instruments.

Earthquakes produce three types of seismic waves: primary waves, secondary waves, and surface waves. Each type moves through materials differently. In addition, the waves can reflect, or bounce, off boundaries between different layers. The waves can also bend as they pass from one layer into another. Scientists learn about Earth's layers by studying the paths and speeds of seismic waves traveling through Earth.

Primary Waves

READING TIP

One meaning of *primary* is "first." Primary waves arrive before secondary waves.

The fastest seismic waves are called primary waves, or P waves. These waves are the first to reach any particular location after an earthquake occurs. Primary waves travel through Earth's crust at an average speed of about 5 kilometers per second (3 mi/s). Primary waves can travel through solids, liquids, and gases. As they pass through a material, the particles of the material are slightly pushed together and pulled apart. Buildings also experience this push and pull as primary waves pass through the ground they are built on.

Secondary Waves

VISUALIZATION
CLASSZONE.COM

Explore primary-wave and secondary-wave motion.

Secondary waves are the second seismic waves to arrive at any particular location after an earthquake, though they start at the same time as primary waves. Secondary waves travel through Earth's interior at about half the speed of primary waves. Secondary waves are also called S waves. As they pass through a material, the material's particles are shaken up and down or from side to side. Secondary waves rock small buildings back and forth as they pass.

Secondary waves can travel through rock, but unlike primary waves they cannot travel through liquids or gases. Look at the illustrations on page 231. As a primary wave passes through a material, the volume and density of the material change slightly. But as a secondary wave passes, the material changes slightly in shape. Liquids and gases do not have definite shapes. These materials flow—that is, particles in them do not return to their original positions after being moved. When scientists learned that secondary waves cannot pass through Earth's outer core, they realized that the outer core is not solid.

CHECK YOUR READING Why can't secondary waves travel through liquids or gases?

Surface Waves

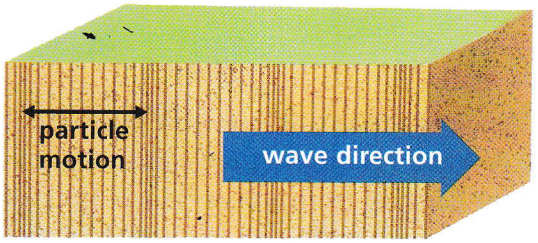
Surface waves are seismic waves that move along Earth's surface, not through its interior. They make the ground roll up and down or shake from side to side. Surface waves cause the largest ground movements and the most damage. Surface waves travel more slowly than the other types of seismic waves.

Seismic Waves

Earthquakes produce three types of seismic waves.

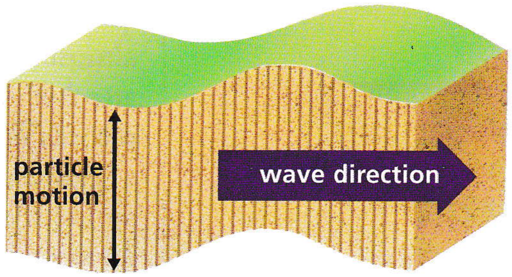
Primary Waves

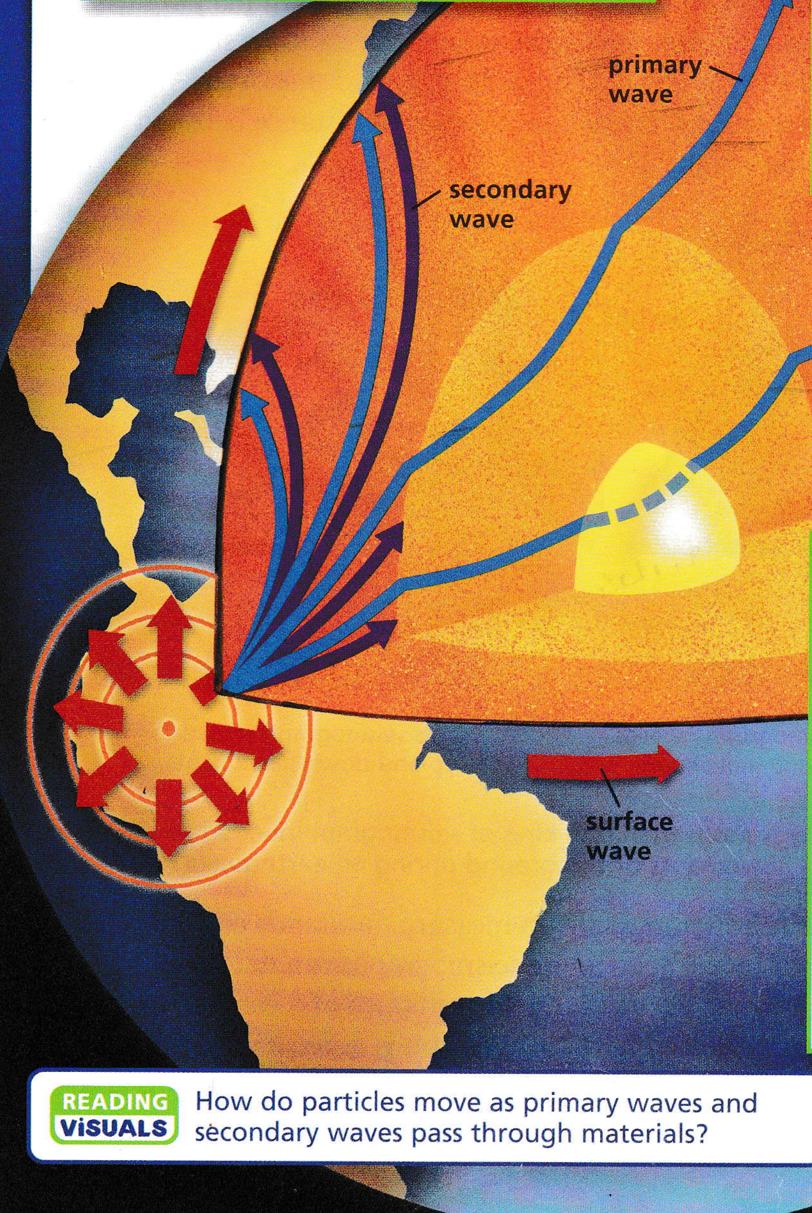
In primary waves, the particles of materials are slightly pushed together and pulled apart in the direction of the waves' travel.



Secondary Waves

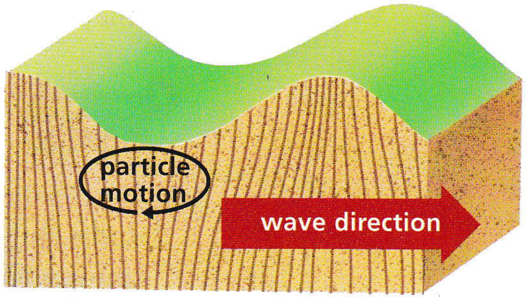
In secondary waves, the particles of materials move at a right angle to the direction of the waves' travel.





Surface Waves

Surface waves are seismic waves trapped near Earth's surface. As depth within Earth increases, motion due to surface waves decreases, then stops.



READING VISUALS How do particles move as primary waves and secondary waves pass through materials?

Seismic waves can be measured.

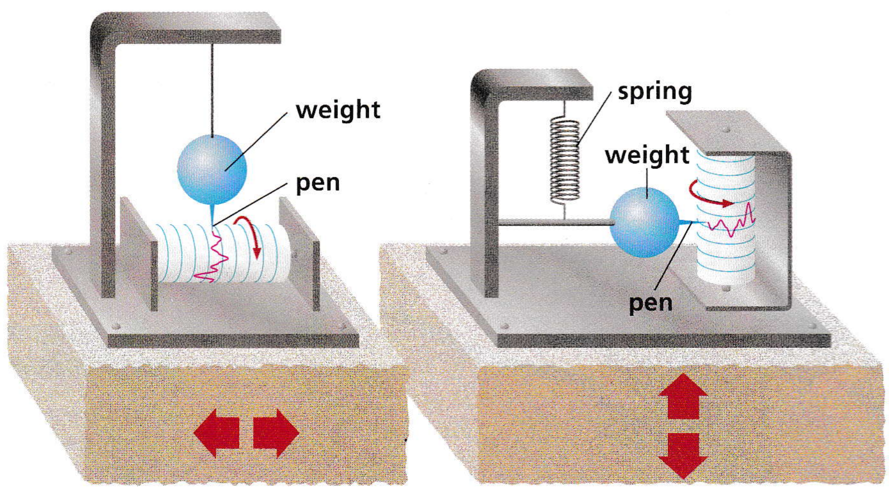
VOCABULARY
Add a magnet word diagram for *seismograph* to your notebook.

Without listening to the news, scientists at seismic stations all over the world know when an earthquake occurs. Seismic stations are places where ground movements are measured. A **seismograph** (SYZ-muh-GRAF) is an instrument that constantly records ground movements. The recording of an earthquake looks like a group of wiggles in a line. The height of the wiggles indicates the amount of ground movement produced by seismic waves at the seismograph's location.

Using Seismographs

RESOURCE CENTER
CLASSZONE.COM
Learn more about seismology.

Separate seismographs are needed to record side-to-side movements and up-and-down movements. A seismograph that measures side-to-side movements has a heavy weight hanging from a wire. The weight remains almost still as the ground moves back and forth beneath it. A pen attached to the weight records the movements. A seismograph that records up-and-down movements has a heavy weight hanging from a spring. As the ground moves, the weight stays almost still as the spring absorbs the movement by getting longer or shorter. A pen attached to the weight records the changes in distance between the ground and the weight.



This seismograph records side-to-side movements.

This seismograph records up-and-down movements.

CHECK YOUR READING Why is more than one kind of seismograph needed to record all the movements of the ground during an earthquake?

Scientists use seismographs to measure thousands of earthquakes, large and small, every year. Some seismographs can detect ground movements as small as one hundred-millionth of a centimeter. The recording produced by a seismograph is called a seismogram. By studying seismograms, scientists can determine the locations and strengths of earthquakes.

Locating an Earthquake

To locate the epicenter of an earthquake, scientists must have seismograms from at least three seismic stations. The procedure for locating an epicenter has three steps:

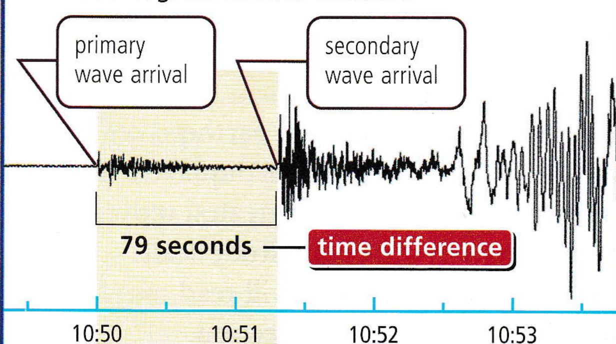
1. Scientists find the difference between the arrival times of the primary and the secondary waves at each of the three stations.
2. The time difference is used to determine the distance of the epicenter from each station. The greater the difference in time, the farther away the epicenter is.
3. A circle is drawn around each station, with a radius corresponding to the epicenter's distance from that station. The point where the three circles meet is the epicenter.

Finding an Epicenter

Seismograms provide data used to find an earthquake's epicenter.

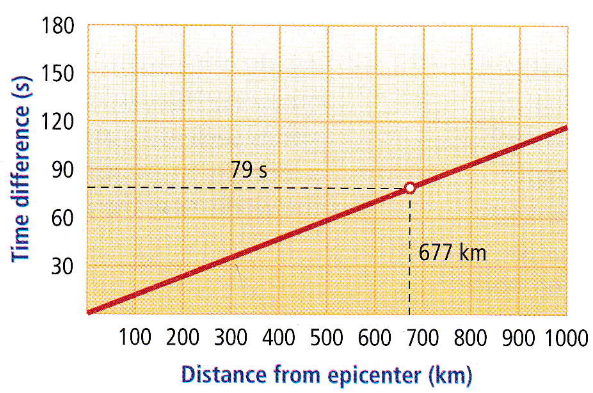
1 Determining Arrival Times

The time difference between the arrival of primary and secondary waves is recorded on a seismogram at each location.



2 Calculating Distance

The arrival-time difference is used to determine the distance of the epicenter from the station.



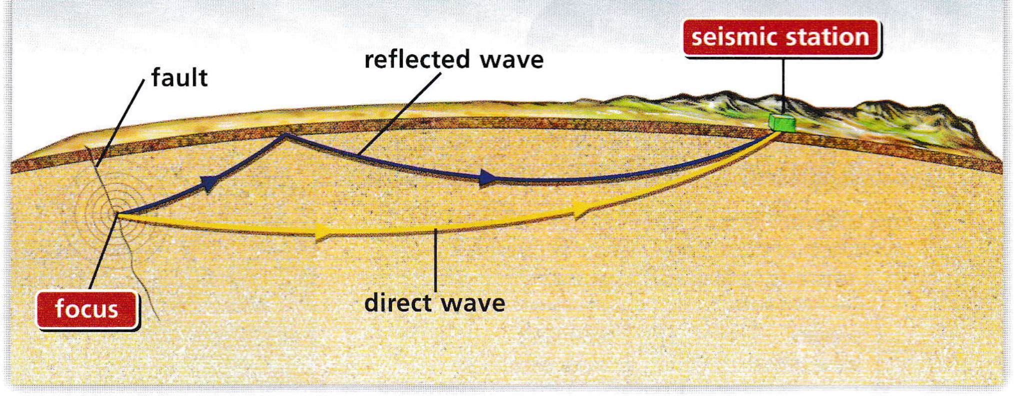
3 Plotting Distance

The distance from the station is used to plot a circle on a map. At least three circles are needed to locate the epicenter.

Scientists can also use seismograph data to locate the focus of an earthquake. They study seismograms to identify waves that have reflected off boundaries inside Earth. Some of these waves help the scientists to determine the earthquake's depth.

A seismogram records the time when the first primary wave arrives. This wave travels by a direct path. The data also show when the first reflected primary wave arrives. After leaving the focus, this wave reflects from Earth's surface and then travels to the seismic station. The reflected wave takes a longer path, so it arrives slightly later. The difference in arrival times indicates the depth of the focus. Scientists can make the necessary calculations, but more commonly a computer is used to calculate the location of an earthquake's epicenter and focus.

An earthquake's depth is determined from the difference in arrival times of direct and reflected seismic waves.



READING TIP

The word *magnitude* comes from the Latin word *magnitudo,* meaning "greatness."

Scientists also use seismograms to determine earthquakes' magnitudes, or strengths. The more energy an earthquake releases, the greater the ground movement recorded. The greatest movement determines the earthquake's strength on a magnitude scale. Stronger earthquakes get higher numbers. You will read more about earthquake magnitude scales in the next section.

7.2 Review

KEY CONCEPTS

1. Why does the greatest shaking of the ground occur near an earthquake's epicenter?
2. What information do you need to completely describe where an earthquake started?
3. What types of information can a scientist get by studying seismograms?

CRITICAL THINKING

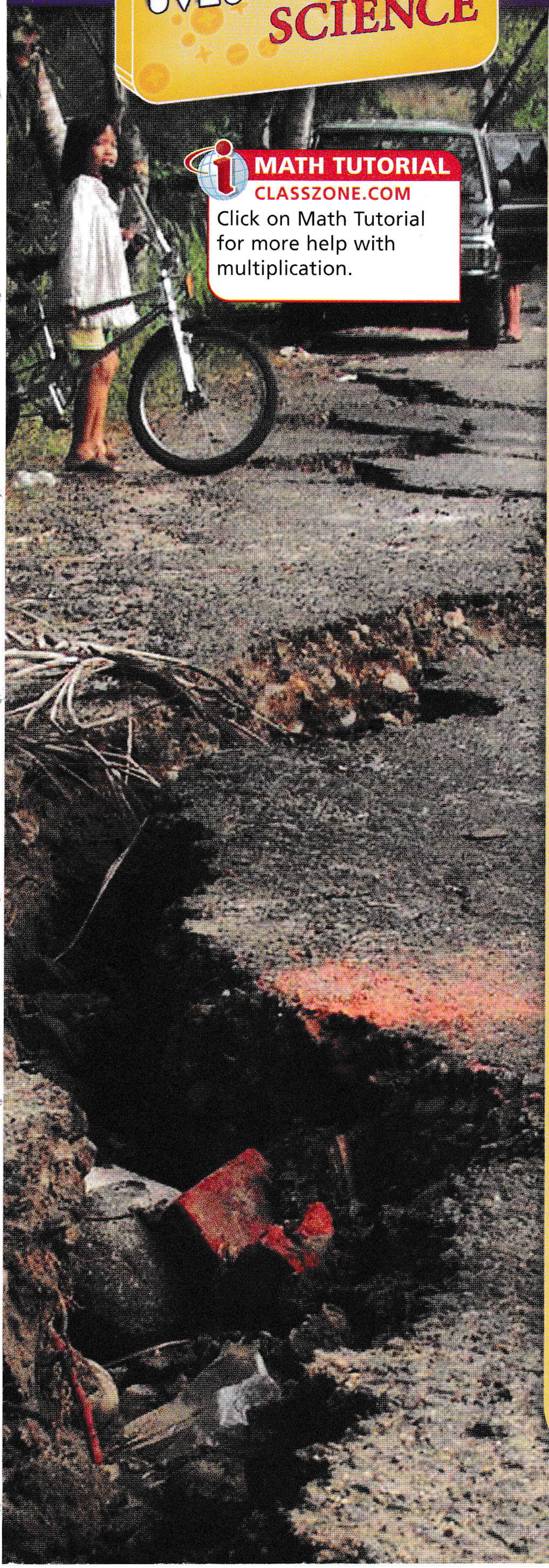
4. **Compare and Contrast** How are primary and secondary waves similar? How are they different?
5. **Apply** What information could you get about an earthquake's location from only two seismic stations' data? Explain.

CHALLENGE

6. **Apply** Why might an earthquake's primary waves, but not its secondary waves, reach a location on the other side of the world from the epicenter?

MATH in SCIENCE

SKILL: MULTIPLICATION



MATH TUTORIAL
CLASSZONE.COM
Click on Math Tutorial for more help with multiplication.

Earthquake Energy

Seismologists use the moment magnitude scale to describe the energies of earthquakes. Because earthquakes vary from quite weak to very strong, the scale is designed to cover a wide range of energies. Each whole number increase in magnitude represents the release of about 32 times as much energy. For example, a magnitude 5 earthquake releases about 32 times as much energy as a magnitude 4 earthquake.

Magnitude	1	2	3	4	5	6	7	8	9	10
Energy	×32	×32	×32	×32	×32	×32	×32	×32	×32	

Similarly, a magnitude 6 earthquake releases about 32 times as much energy as a magnitude 5 earthquake, and a magnitude 7 earthquake releases about 32 times as much energy as a magnitude 6 earthquake. You can use multiplication to compare the energies of earthquakes.

Example

Compare the energy of a magnitude 4 earthquake to the energy of a magnitude 7 earthquake. Give your answer to the nearest 1000.

SOLUTION

Magnitude	1	2	3	4	5	6	7	8	9	10
Energy	×32	×32	×32	×32	×32	×32	×32	×32	×32	

(1) Multiply: $32 \times 32 \times 32 =$ **32,768**

(2) Round your answer to the nearest 1000: **33,000**

ANSWER A magnitude 7 earthquake releases about 33,000 times as much energy as a magnitude 4 earthquake.

Compare the energies of two earthquakes:

1. Magnitude 4 and magnitude 6; give your answer to the nearest 100
2. Magnitude 5 and magnitude 9; give your answer to the nearest 100,000
3. Magnitude 3.3 and magnitude 4.3

CHALLENGE What is the magnitude of an earthquake that releases about 1000 times the energy of a magnitude 2 earthquake?

KEY CONCEPT

7.3 Earthquake damage can be reduced.

BEFORE, you learned

- Seismic waves travel through Earth
- An earthquake's location and magnitude can be determined

NOW, you will learn

- How an earthquake's magnitude is related to the damage it causes
- How structures are built to withstand most earthquakes
- How scientists estimate the earthquake risk in an area

VOCABULARY

aftershock p. 238
liquefaction p. 238
tsunami p. 238

EXPLORE Shaking

What happens as materials are shaken?

PROCEDURE

1. Pour a pile of sand on a newspaper. Place a metal washer on top of the sand. Shake the paper and observe what happens to the sand and the washer.
2. Now place the washer on top of a flat rock. Shake the rock and observe what happens.

MATERIALS

- sand
- newspaper
- flat rock
- washer

WHAT DO YOU THINK?

- How did the washer, the sand, and the rock react differently to shaking?
- How might the washer, the sand, and the rock model what happens to buildings and land during earthquakes?

Earthquakes can cause severe damage and loss of life.

MAIN IDEA AND DETAILS
Record information about the effects of earthquakes in your notebook.

Every year, on average, an extremely powerful earthquake—one with a magnitude of 8 or higher—strikes somewhere on Earth. Such an earthquake can destroy almost all the buildings near its epicenter and cause great loss of life.

Earthquakes are most dangerous when they occur near areas where many people live. Most injuries and deaths due to earthquakes are not directly caused by the movement of the ground. They are caused by collapsing buildings and other structures and by fires. After an earthquake, fires may start due to broken natural-gas lines, broken electrical power lines, or overturned stoves.

Earthquake Magnitude

A very powerful earthquake can release more energy than 1 million weak earthquakes combined. Earthquake magnitude scales give scientists and engineers a simple way to describe this huge range in energy.

The first scale of earthquake magnitude was developed in California during the 1930s by the scientists Charles Richter (RIHK-tuhr) and Beno Gutenberg. In this scale, called the Richter scale, an earthquake's magnitude is based on how fast the ground moves at a seismic station. However, most scientists today prefer to use a newer, more accurate scale: the moment magnitude scale. This scale is based on the total amounts of energy released by earthquakes. The moment magnitude scale is used for all earthquake magnitudes given in this chapter.

Both the Richter scale and the moment magnitude scale are often shown with a top value of 10, but neither actually has a maximum value. On each scale, an increase of one whole number indicates an increase of 32 times more energy. For example, a magnitude 5 earthquake releases 32 times as much energy as a magnitude 4 earthquake and about 1000 times as much energy as a magnitude 3 earthquake.

Magnitude and Effects Near Epicenter

More powerful earthquakes have higher magnitude values.

Magnitude	Effects Near Epicenter
0–3.9 Very Minor to Minor	rarely noticed
4.0–4.9 Light	slight damage
5.0–5.9 Moderate	some structures damaged
6.0–6.9 Strong	major damage to structures
7.0–7.9 Major	some well-built structures destroyed
8.0 and above Great	major to total destruction

Damage from Powerful Earthquake

This road collapsed during a magnitude 6.9 earthquake in California on October 17, 1989. About 140 earthquakes with magnitudes of 6 or higher occur each year around the world.

VOCABULARY
Add magnet word diagrams for *aftershock* and *liquefaction* to your notebook.

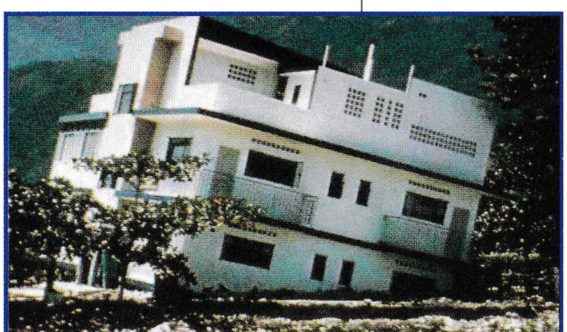
The moment magnitude scale is more accurate for larger earthquakes than the Richter scale. Another advantage of the moment magnitude scale is that it can be used for earthquakes that occurred before seismographs were invented. Geologists can measure the strength of the rocks and the length they moved along a fault to calculate a past earthquake's magnitude. This information is important for geologists to know when they determine an area's earthquake risk.

CHECK YOUR READING What are two advantages of the moment magnitude scale over the Richter scale?

Damage from Earthquakes

Movement of the blocks of rock on either side of a fault can crack roads, buildings, dams, and any other structures on the fault. As blocks of rock move, they can also raise, lower, or tilt the ground surface. Sometimes structures weakened by an earthquake collapse during shaking caused by aftershocks. An **aftershock** is a smaller earthquake that follows a more powerful earthquake in the same area. Also, fires that break out can cause great damage if broken water pipes keep firefighters from getting water. In the 1906 San Francisco earthquake, fires caused more than 90 percent of the building damage.

Earthquakes can cause major damage by affecting the soil and other loose materials. For example, landslides often occur as a result of earthquakes. A landslide is a movement of soil and rocks down a hill or mountain. Earthquakes can cause soil **liquefaction,** a process in which shaking of the ground causes soil to act like a liquid. For a short time the soil becomes like a thick soup. Liquefaction occurs only in areas where the soil is made up of loose sand and silt and contains a large amount of water. As the shaking temporarily changes the wet soil, structures either sink down into the soil or flow away with it. Shaking of the ground also affects areas that have mixtures of soils. Some soil types pack together more than others when shaken.



This building in Venezuela tilted and sank as the ground beneath it collapsed during an earthquake in 1967.

CHECK YOUR READING List five ways in which earthquakes can cause damage.

Damage from Tsunamis

If you sit on an ocean beach, you can watch the depth of the water change as waves come in. If you watch for a longer time, you may notice bigger changes as the tide rises or falls. A special type of wave, however, can make water rise more than the height of a 20-story building. This wave, known as a **tsunami** (tsu-NAH-mee), is a water wave triggered by an earthquake, volcanic eruption, or landslide. Tsunamis are sometimes called tidal waves, but they are not caused by the forces that produce tides. A tsunami may not be a single wave but several waves that can have different heights and can arrive hours apart.

RESOURCE CENTER
CLASSZONE.COM
Explore tsunamis.

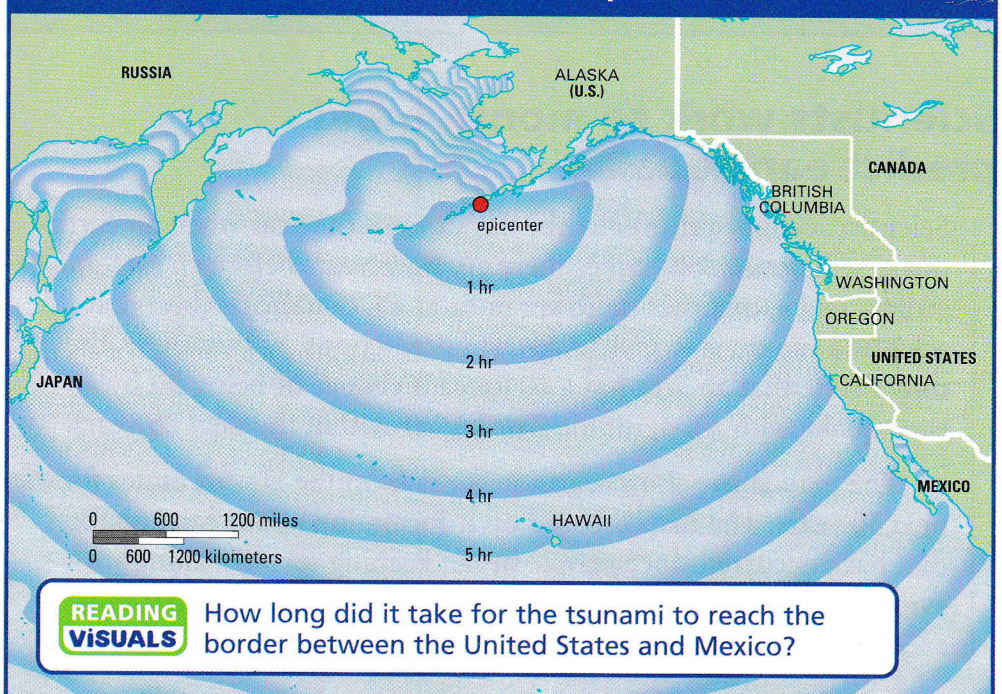
Tsunamis move quickly and can travel thousands of kilometers without weakening. In deep water, they can reach speeds of about 700 kilometers per hour (430 mi/h). A tsunami in the deep water of the open ocean may be less than one meter (3 ft) in height at the surface. As a tsunami reaches shallow water around an island or continent, however, it slows down, and its height greatly increases.

A 1946 earthquake on Alaska's coast caused a tsunami that swept across the entire Pacific Ocean. In Alaska the tsunami destroyed a new U.S. Coast Guard lighthouse that otherwise would have been able to send warnings to other areas. In less than five hours, the tsunami reached Hawaii as a series of waves. The highest wave was about 17 meters (55 ft) tall. Because people did not know of the danger, no one had evacuated, and 159 people were killed.


In 1993, a tsunami from a powerful earthquake in Japan threw boats onto land.

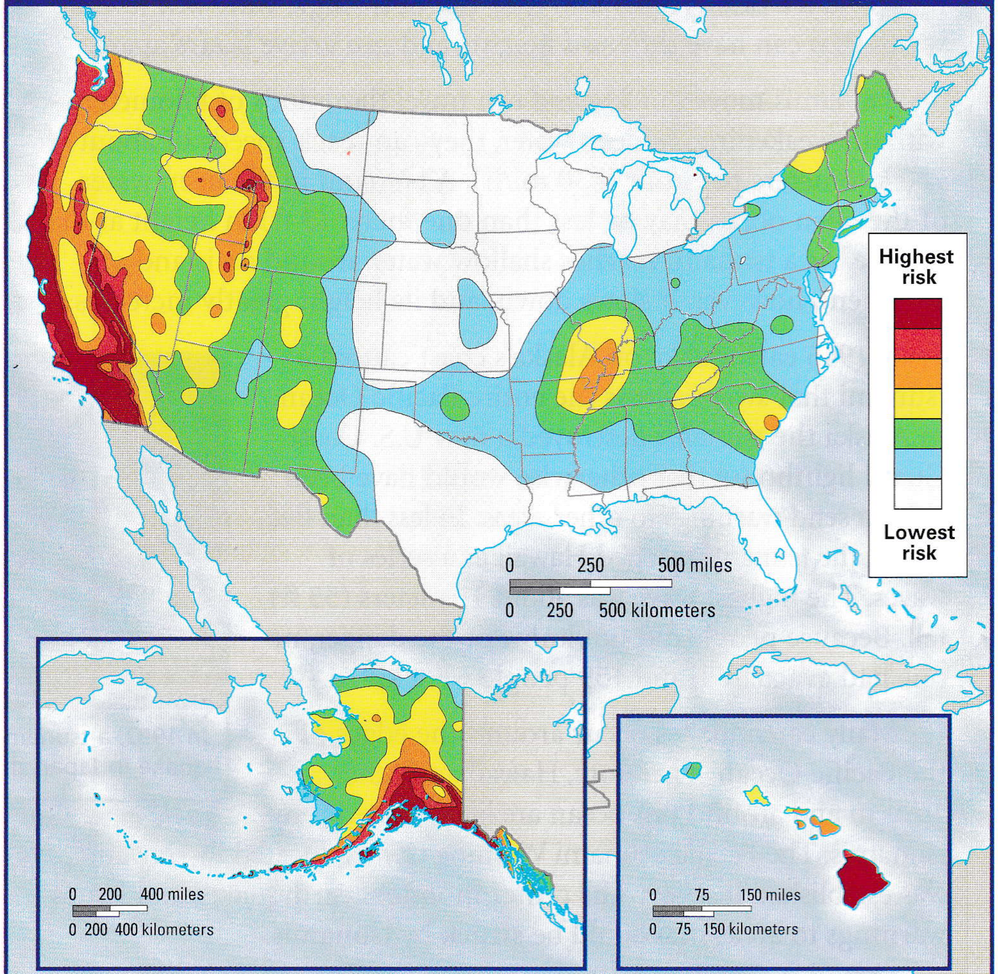
Many earthquakes occur around the edges of the Pacific Ocean. Therefore, Hawaii and other areas in and around this ocean are likely to be hit by tsunamis. The Pacific Tsunami Warning Center, located in Hawaii, was established in 1949. The center monitors earthquakes and issues warnings to areas that could be struck by tsunamis.

Tsunami Travel Time, 1946 Alaskan Earthquake



READING VISUALS How long did it take for the tsunami to reach the border between the United States and Mexico?

Earthquake Risk in the United States



READING VISUALS How does the earthquake risk where you live compare with the risk in southern Alaska?

Scientists work to monitor and predict earthquakes.

READING TIP

A prediction is a statement about an event before it occurs. Scientists use their knowledge to make predictions about when earthquakes might occur.

Scientists cannot yet predict the day or even the year when an earthquake will occur. Sometimes there are signs years before an earthquake strikes, and sometimes there are none at all. Usually the best that scientists can do is to give long-term predictions. For example, they might state that an area has a 60 percent chance of being hit by an earthquake with a magnitude 7 or higher within the next 25 years.

The map above shows earthquake risks in the United States for the next 50 years. The map is based on information about earthquakes that have occurred since people began keeping records, along with evidence of earlier earthquakes preserved in rocks. Note that most areas with the highest earthquake risks are near the Pacific Ocean.

To learn more about earthquakes and to find ways of predicting them, scientists all over the world study seismic activity along faults. They monitor whether stress is building up in the rocks along faults. Such signs include

- tilts or changes in the elevation of the ground
- slow movements or stretching in rock
- the development of small cracks in the ground

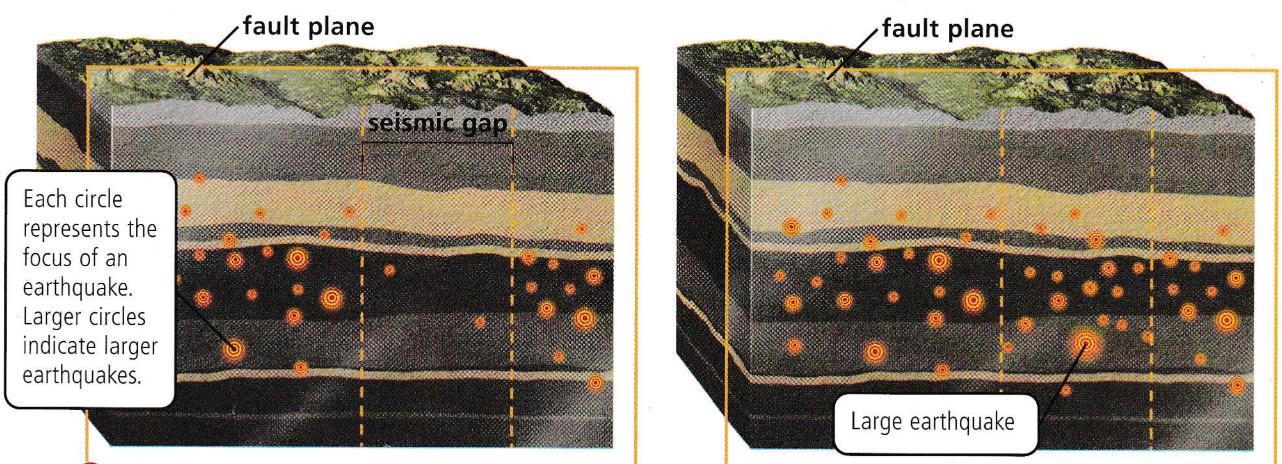
An increase in small earthquakes can be a sign that stress is building up along a fault and that a large earthquake is likely to occur. But an increase in small earthquakes can also be a sign that a fault is releasing stress bit by bit, decreasing the likelihood of a major earthquake.

Scientists also look for areas where earthquakes have not occurred along an otherwise active fault. They make diagrams in which they plot the locations where earthquakes have started, as shown below. Sometimes such a diagram shows an area of few or no earthquakes that is surrounded by many earthquakes. This area is called a seismic gap. A seismic gap can indicate a location where a fault is stuck. Movement along other parts of the fault can increase stress along the stuck part. This stress could be released by a major earthquake.

CHECK YOUR READING Why can a lack of earthquakes in an area near an active fault cause concern?

Seismic Gaps

A seismic gap is a section of a fault with few earthquakes compared with sections of the fault on either side of the gap.



1 Over several years many earthquakes have occurred along this fault. However, one section of the fault has had little earthquake activity. Stress is building up along this section.

2 A large earthquake and its aftershocks have occurred, releasing built-up stress. Over just a few weeks the seismic gap has been filled in.

Structures can be designed to resist earthquake damage.

READING TIP

Here, the term *structure* refers to office buildings, homes, bridges, dams, factories—all the things that people build.

For safety, it might be best to be outdoors, far from any buildings, during an earthquake. But there is no way to tell just when or where an earthquake will occur. For this reason, the best way to reduce deaths, injuries, and damage from earthquakes is to build structures able to withstand strong ground shaking. The first step is to understand what the risks from earthquakes are in an area. The second step is to build structures that are appropriate for the area.

Scientists make maps of areas to show the locations of fault zones, past earthquakes, and areas likely to experience flooding, landslides, or liquefaction. In Japan, California, and other areas that have many earthquakes, planners use these maps to develop rules for building new structures and strengthening older ones. The maps are also used to select building locations that are stable—unlikely to experience landslides or liquefaction.

Earthquake damage to small buildings, such as most houses, often occurs when the buildings are shaken off their foundations. Small buildings are better protected when they are firmly fastened to their foundations. Also, their walls need to be strong. Some houses were built before modern safety rules were in place. The walls of these houses can be made stronger by adding supports. Supports are particularly important in brick walls, which can easily collapse in an earthquake. A special type of steel is commonly used for the supports because it is strong and is able to bend, then return to its original shape.

SAFETY TIPS

Earthquakes

Before

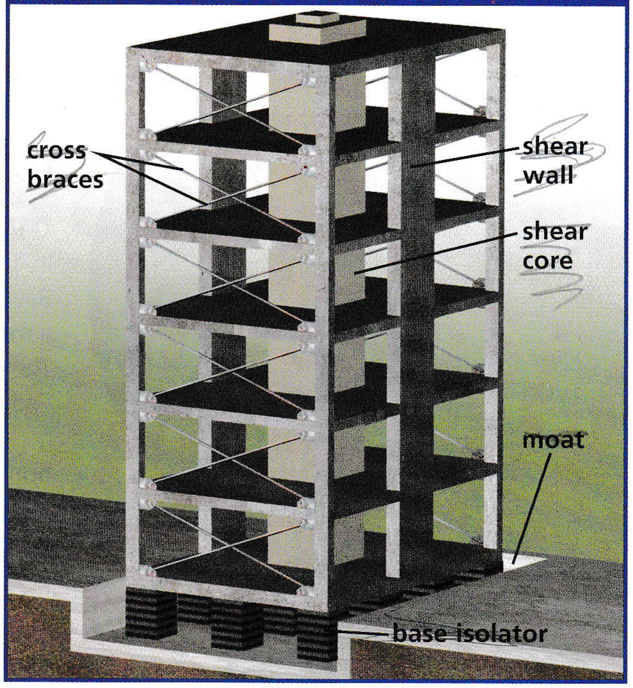
- Fasten heavy objects, such as bookcases, to floors or walls to keep them from falling.
- Put latches on cabinets to keep dishes from falling out.
- Identify safe spots in every room, such as the space under a strong table.
- Keep an emergency supply of bottled water.

During and After

- If you are inside a building, stay inside until the shaking stops. Objects falling from buildings cause many injuries.
- If you are outdoors, move away from buildings, poles, and trees.
- Make a family plan for contacting a person who lives in another town. As people call to say they are safe, this person can pass on the information.

Many of the methods used to make larger buildings and other structures safer are designed to reduce the amount they shake during an earthquake. One method is to use devices called base isolators, as shown in the illustration. Base isolators are placed between a building and its foundation. The isolators are made of flexible materials that are stacked in layers like pancakes. When an earthquake occurs, the isolators absorb much of the ground motion. Any shaking that does reach the building is slower and smoother.

Earthquake-Resistant Building



A building may also have an open space, or moat, around it. The moat, which may be covered at the surface with sidewalks and landscaping, lets the building shake more gently than the ground during an earthquake.

Special walls, called shear walls, add strength to a structure. These walls contain steel supports. Shear walls in the center of a building are often built around a stairwell or an elevator shaft. These walls make up a part of the building known as the shear core.

Walls can also be made stronger by adding braces. Pairs of braces that form an X shape are called cross braces. They help a structure keep its shape while it is being shaken.

CHECK YOUR READING Describe two methods used to make buildings stronger.

7.3 Review

KEY CONCEPTS

1. How is an earthquake magnitude scale related to the amounts of energy released by earthquakes?
2. What are the major dangers to people from an earthquake?
3. Name three methods of improving a building's safety before an earthquake.

CRITICAL THINKING

4. **Apply** What might people living next to the ocean do to protect themselves if they were given a two-hour warning of an approaching tsunami?
5. **Connect** If you lived in an area where earthquakes were common, what could you do to make your room safer?

CHALLENGE

6. **Analyze** Earthquakes release stress that has built up in rocks. Why do you think aftershocks occur?

CHAPTER INVESTIGATION

How Structures React in Earthquakes

DESIGN — YOUR OWN —

OVERVIEW AND PURPOSE

In 1989 a magnitude 6.9 earthquake struck the San Francisco Bay area, killing 62 people and leaving 12,000 homeless. In 1988 a magnitude 6.9 earthquake occurred near Spitak, Armenia. There, nearly 25,000 people died and 514,000 lost their homes. The difference in the effects of these two earthquakes was largely due to differences in construction methods. In this investigation you will

- build a structure and measure how long it can withstand shaking on a shake table provided by your teacher
- explore methods of building earthquake-resistant structures

Problem

Write It Up

How can structures be built to withstand most earthquakes?

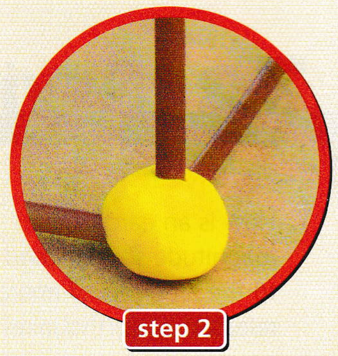
Hypothesize

Write It Up

Write a hypothesis to explain how structures can be built to withstand shaking. Your hypothesis should take the form of an "If . . . , then . . . , because . . ." statement.

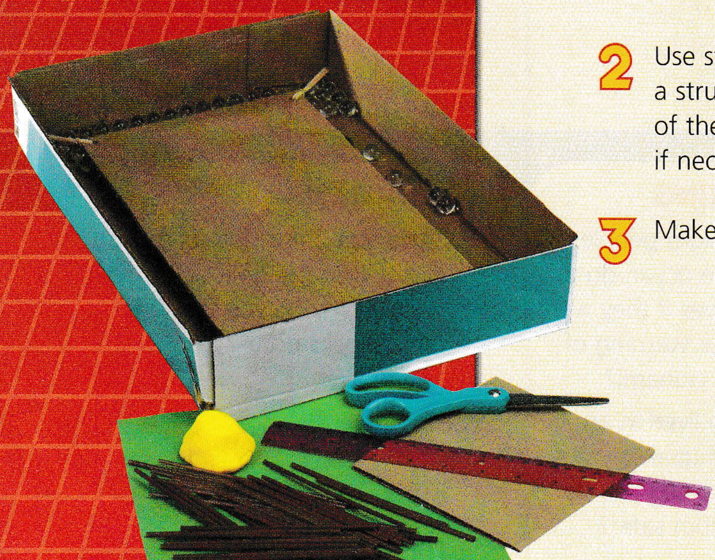
Procedure

1. Make a data table like the one shown on the next page.
2. Use stirrers joined with clay to build a structure at least 20 cm tall on top of the cardboard. Cut the stirrers if necessary.
3. Make a diagram of your structure.

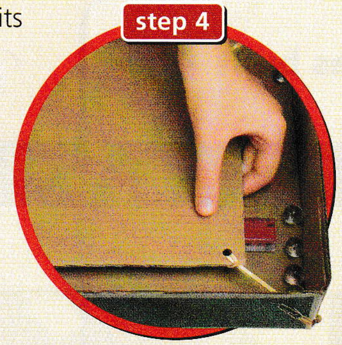

step 2

MATERIALS

- modeling clay
- stirrer straws
- piece of thin cardboard 15 cm on each side
- scissors
- ruler
- shake table



4 Lift your structure by its cardboard base and place it on the shake-table platform. Pull the platform 2 centimeters to one side and release it.



5 Repeat step 4 until the structure begins to collapse.

Observe and Analyze

Write It Up

1. **RECORD** Complete your data table and make notes about the collapse, including areas of possible weakness in your structure.
2. **INFER** Use your observations to design a structure that will better withstand shaking.

Conclude

Write It Up

1. **INTERPRET** Compare your results with your hypothesis. Do your observations support your hypothesis?
2. **INFER** How would you use the shake table to model earthquakes of different magnitudes?
3. **IDENTIFY VARIABLES** How might your results differ if you always pulled the platform to the same side or if you pulled it to different sides?
4. **IDENTIFY LIMITS** In what ways might a building's behavior during an earthquake differ from the behavior of your structure on the shake table?
5. **COMPARE** Examine the diagrams of the three structures that lasted longest in your class. What characteristics, if any, did they have in common?
6. **APPLY** Based on your results, write a list of recommendations for building earthquake-resistant structures.

INVESTIGATE Further

CHALLENGE Have a contest to see who can build the most earthquake-resistant structure. Design your structure as if you were an earthquake engineer. Make a model of your structure at least 30 centimeters tall, using the types of materials you used in this investigation. Test the structure on the shake table. What design features helped the winning structure to resist shaking the longest?

How Structures React in Earthquakes

Problem How can structures be built to withstand most earthquakes?

Hypothesize

Observe and Analyze

Table 1. Number of Trials Until Collapse of Structure

Trial	Distance Platform Pulled to Side (cm)	Notes
1	2	
2	2	
3	2	
4	2	

Conclude

7 Chapter Review

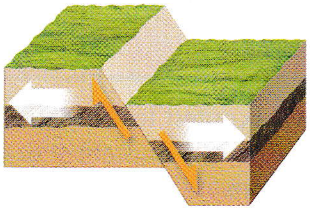
the BIG idea

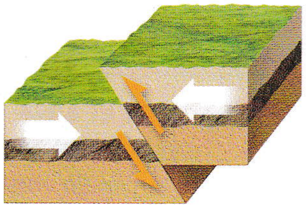
Earthquakes release stress that has built up in rocks.

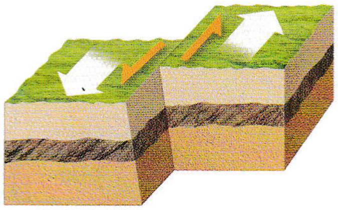
CONTENT REVIEW
CLASSZONE.COM

KEY CONCEPTS SUMMARY

1 Earthquakes occur along faults.

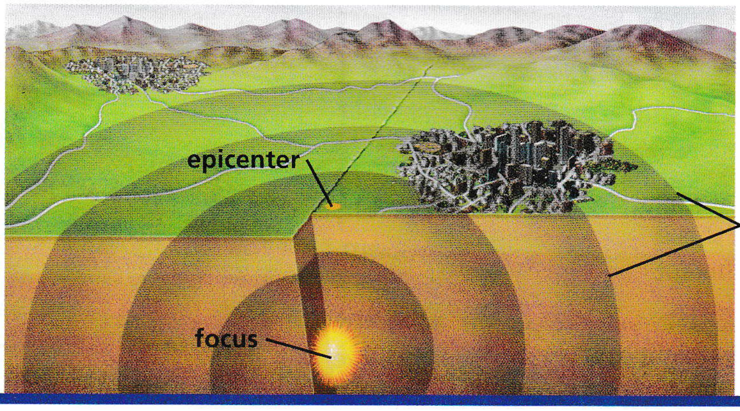

Normal faults form as rocks are pulled apart.


Reverse faults form as rocks are pushed together.


Strike-slip faults form as rocks are pushed horizontally in opposite directions.

VOCABULARY
fault p. 221
stress p. 221
earthquake p. 221

2 Earthquakes release energy.

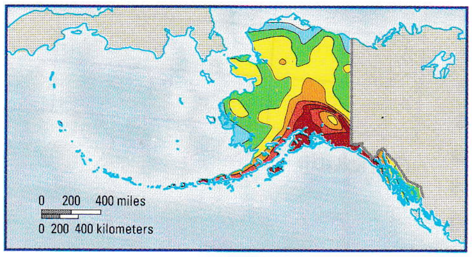


Seismic waves move out from the focus in all directions.

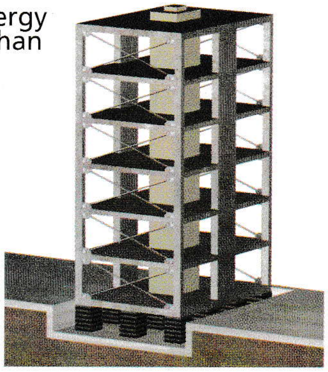
VOCABULARY
seismic wave p. 227
focus p. 228
epicenter p. 228
seismograph p. 232

3 Earthquake damage can be reduced.

A powerful earthquake releases more energy and causes more shaking of the ground than does a weak earthquake.



An area's risk of earthquakes can be predicted.

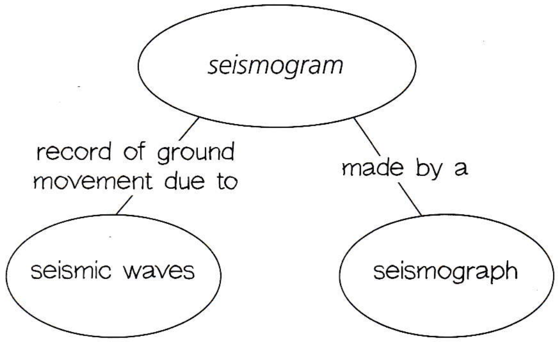

Structures can be designed for greater safety in an earthquake.

VOCABULARY
aftershock p. 238
liquefaction p. 238
tsunami p. 238

Reviewing Vocabulary

On a separate sheet of paper, draw a diagram to show the relationships among each set of words. One set has been done as an example.

seismograph, seismic waves, seismogram



1. earthquake, epicenter, focus
2. earthquake, tsunami, liquefaction
3. fault, stress, earthquake, aftershock
4. tsunami, epicenter, seismogram

Reviewing Key Concepts

Multiple Choice *Choose the letter of the best answer.*

5. What causes an earthquake?
   - **a.** a rise of magma in the mantle
   - **b.** a sudden movement of blocks of rock
   - **c.** a buildup of seismic waves
   - **d.** a change in Earth's magnetic poles

6. Earthquakes release energy in the form of
   - **a.** seismic waves
   - **b.** faults
   - **c.** stress lines
   - **d.** seismograms

7. Most damage from an earthquake usually occurs
   - **a.** below the focus
   - **b.** far from the epicenter
   - **c.** at the focus
   - **d.** near the epicenter

8. To locate the epicenter of an earthquake, scientists need seismograms from at least _____ seismic stations.
   - **a.** two
   - **b.** three
   - **c.** four
   - **d.** five

9. The seismic waves that usually cause the most damage are
   - **a.** surface waves
   - **b.** tsunami waves
   - **c.** primary waves
   - **d.** secondary waves

10. Earthquakes release _____ that has built up in rocks.
    - **a.** water
    - **b.** magnetism
    - **c.** stress
    - **d.** electricity

11. About 80 percent of all earthquakes occur in a belt around the
    - **a.** Pacific Ocean
    - **b.** San Andreas Fault
    - **c.** North American Plate
    - **d.** African Rift Valley

12. In a strike-slip fault, blocks of rock move _____ along the fault plane.
    - **a.** up
    - **b.** down
    - **c.** sideways
    - **d.** up and down

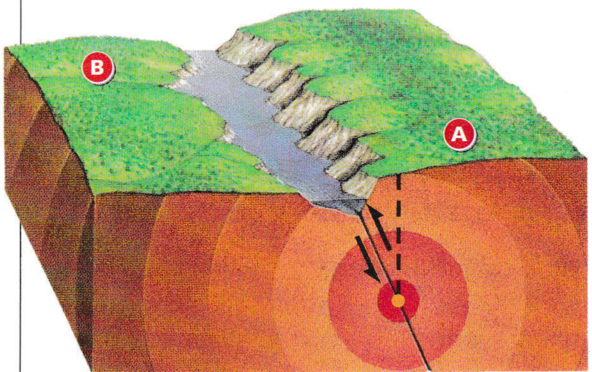
13. One method of making a building earthquake resistant is to
    - **a.** add sand under the foundation
    - **b.** reduce the use of steel
    - **c.** make the walls of brick
    - **d.** use cross braces

Short Answer *Write a short answer to each question.*

14. Why do most earthquakes occur at or near tectonic plate boundaries?
15. How do data from seismic waves indicate that Earth's outer core is liquid?
16. What causes most of the injuries and deaths due to earthquakes?

Thinking Critically

Study the illustration below, showing the epicenter and focus of an earthquake, then answer the following six questions.



17. **APPLY** What type of fault is shown in the illustration? How do you know?

18. **APPLY** Where on the surface is the greatest shaking likely to occur?

19. **INFER** What does the set of circles around the focus represent?

20. **EXPLAIN** In what ways would the times of arrival of primary and secondary waves be different at points *A* and *B*?

21. **IDENTIFY EFFECTS** The land surface to the left of the fault is lower than the land surface to the right. How might this be related to movements along the fault?

22. **ANALYZE** What are the main directions of stress on the blocks of rock on either side of the fault?

23. **APPLY** A builder is planning to construct a new house near a fault along which earthquakes are common. Write a list of guidelines that the builder might use to decide where and how to build the house.

24. **ANALYZE** Identify two areas of the United States where earthquakes are most likely to occur. Explain your choices in terms of plate tectonics.

25. **IDENTIFY EFFECTS** A town has been struck by an earthquake with a magnitude of 5.8. The epicenter was 10 kilometers (6 mi) away, and the focus was shallow. What sort of damage would you expect to find in the town?

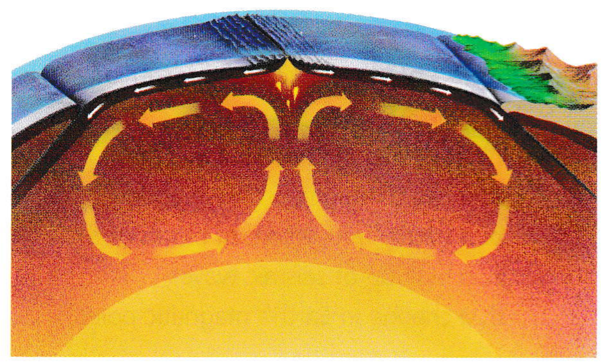
26. **ANALYZE** What role do earthquakes play in shaping Earth's surface?

27. **CALCULATE** If primary waves travel at a speed of about 5 kilometers per second, how long would it take them to arrive at a seismic station located 695 kilometers from an earthquake's focus?

the BIG idea

28. **CONNECT** Look again at the photograph of earthquake damage on pages 218–219. Explain how energy released by an earthquake can travel through rock and cause damage at Earth's surface.

29. **SYNTHESIZE** The illustration below shows convection in Earth's mantle. What are the relationships among the heat inside Earth, the movements of tectonic plates, and the occurrences of earthquakes?



UNIT PROJECTS

If you need to do an experiment for your unit project, gather the materials. Be sure to allow enough time to observe results before the project is due.

Standardized Test Practice

For practice on your state test, go to . . . TEST PRACTICE CLASSZONE.COM

Analyzing Data

The following tables show magnitudes and average numbers of earthquakes in the world per year, and states in which two or more major earthquakes have been recorded. Use the information in the tables to answer the questions below.

Earthquakes in the World per Year

Classification	Magnitude	Average Number per Year
Great	8.0 and higher	1
Major	7.0–7.9	18
Strong	6.0–6.9	120
Moderate	5.0–5.9	800
Light	4.0–4.9	6200
Minor	3.0–3.9	49,000

States That Have Recorded Two or More Major Earthquakes

State	Number of Major Earthquakes
Alaska	74
Arkansas	2
California	16
Hawaii	4
Missouri	2
Nevada	3

1. A major earthquake can have a magnitude of
a. 6.0–6.9
b. 6.0 and higher
c. 7.4
d. 8.2

2. The most major earthquakes have been recorded in which state?
a. Arkansas
b. Hawaii
c. Missouri
d. Nevada

3. A magnitude 3.2 earthquake is classified as
a. major
b. strong
c. moderate
d. minor

4. The world's most powerful earthquakes occur along reverse faults. In which state are reverse faults most likely to be common?
a. Alaska
b. California
c. Hawaii
d. Nevada

5. In which state is a tectonic plate boundary most likely to be located?
a. Arkansas
b. California
c. Hawaii
d. Nevada

6. Compared to the number of major earthquakes each year, the number of moderate earthquakes is
a. about 40 times greater
b. about 4 times greater
c. about equal
d. smaller

7. Alaska has recorded a total of 82 earthquakes with magnitudes of 7.0 and higher. How many of these earthquakes are classified as "great"?
a. 0
b. 8
c. 56
d. 74

8. An earthquake of which classification releases the most energy?
a. great
b. major
c. strong
d. minor

Extended Response

Answer the two questions below in detail. Include some of the terms shown in the word box. In your answers underline each term you use.

seismic waves	primary	secondary	surface
stress	fault	plate boundary	

9. During an earthquake, Dustin felt a small amount of shaking. About 15 seconds later, he felt some more shaking. Then about 45 seconds later he felt the strongest shaking. Explain what happened.

10. The island of Sumatra is located in an area where the Pacific Plate sinks under the Eurasian Plate. Explain why Sumatra has many earthquakes.