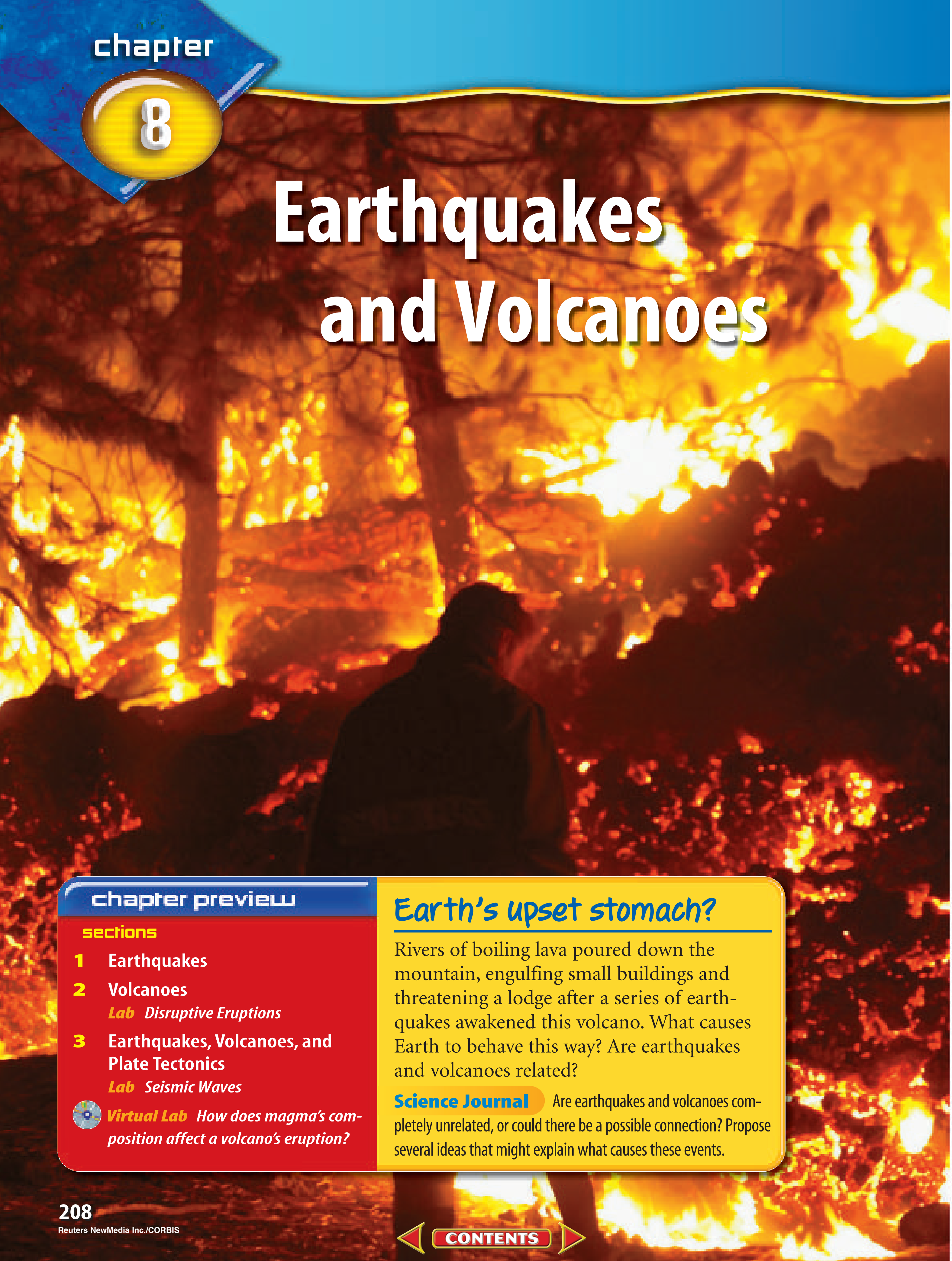
chapter 8

Earthquakes and Volcanoes



chapter preview

Earth's upset stomach?

Rivers of boiling lava poured down the mountain, engulfing small buildings and threatening a lodge after a series of earthquakes awakened this volcano. What causes Earth to behave this way? Are earthquakes and volcanoes related?

Science Journal Are earthquakes and volcanoes completely unrelated, or could there be a possible connection? Propose several ideas that might explain what causes these events.

Reuters NewMedia Inc./CORBIS

Start-Up Activities

Launch LAB

Construct with Strength

One of the greatest dangers associated with an earthquake occurs when people are inside buildings during the event. In the following lab, you will see how construction materials can be used to help strengthen a building.

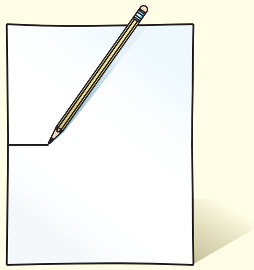
1. Using wooden blocks, construct a building with four walls. Place a piece of cardboard over the four walls as a ceiling.
2. Gently shake the table under your building. Describe what happens.
3. Reconstruct the building. Wrap large rubber bands around each section, or wall, of blocks. Then wrap large rubber bands around the entire building.
4. Gently shake the table again.
5. **Think Critically** In your Science Journal, note any differences you observed as the two buildings were shaken. Hypothesize how the construction methods you used in this activity might be applied to the construction of real buildings.

Science Online — Preview this chapter's content and activities at blue.msscience.com

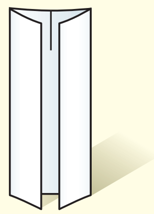
FOLDABLES™ Study Organizer

Earthquakes and Volcanoes Make the following Foldable to help you compare and contrast the characteristics of earthquakes and volcanoes.

STEP 1 **Draw** a mark at the midpoint of a vertical sheet of paper.

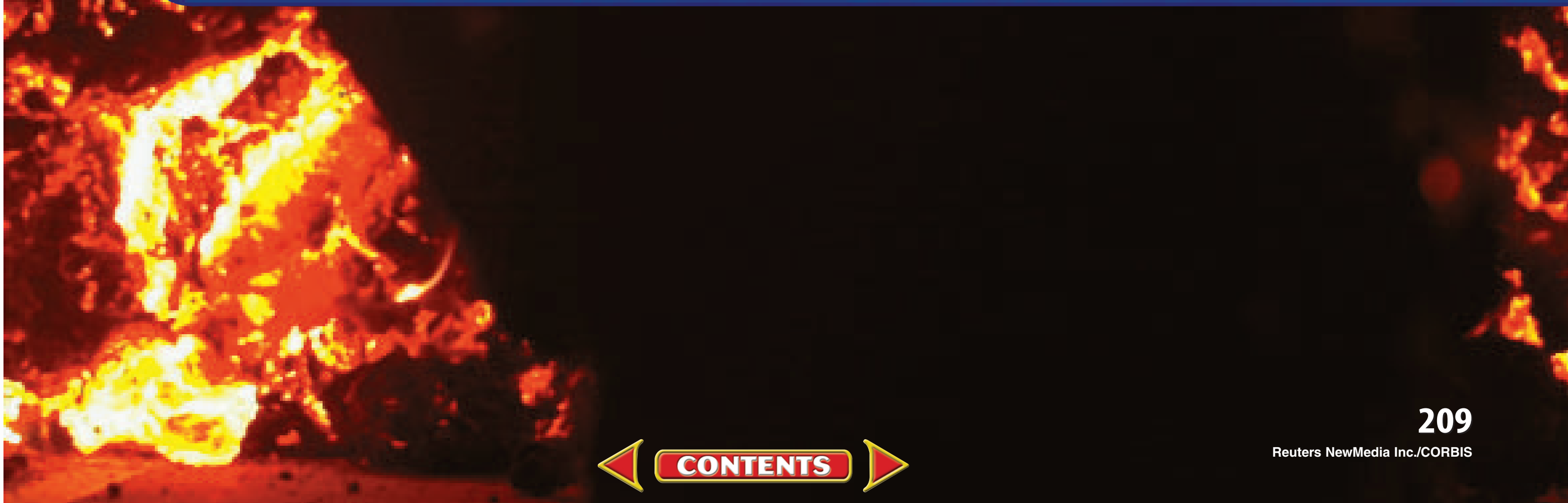


STEP 2 **Turn** the paper horizontally and **fold** the outside edges in to touch at the midpoint mark.



STEP 3 **Draw** a volcano on one flap and label the flap *Volcanoes*. Draw an earthquake on the other flap and label it *Earthquakes*. The inside portion should be labeled *Both* and include characteristics that both events share.

Analyze and Critique Before you read the chapter, write what you know about earthquakes and volcanoes on the back of each flap. As you read the chapter, add more information about earthquakes and volcanoes.



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section 1

Earthquakes

as you read

What You'll Learn

- **Explain** how earthquakes are caused by a buildup of strain in Earth's crust.
- **Compare and contrast** primary, secondary, and surface waves.
- **Recognize** earthquake hazards and how to prepare for them.

Why It's Important

Studying earthquakes will help you learn where they might occur and how you can prepare for their hazards.

Review Vocabulary

energy: the ability to cause change

New Vocabulary

- earthquake
- fault
- seismic wave
- focus
- epicenter
- seismograph
- magnitude
- tsunami
- seismic safe

What causes earthquakes?

If you've gone for a walk in the woods lately, maybe you picked up a stick along the way. If so, did you try to bend or break it? If you've ever bent a stick slowly, you might have noticed that it changes shape but usually springs back to normal form when you stop bending it. If you continue to bend the stick, you can do it for only so long before it changes permanently. When this elastic limit is passed, the stick may break, as shown in **Figure 1.** When the stick snaps, you can feel vibrations in the stick.

Elastic Rebound As hard as they seem, rocks act in much the same way when forces push or pull on them. If enough force is applied, rocks become strained, which means they change shape. They may even break, and the ends of the broken pieces may snap back. This snapping back is called elastic rebound.

Rocks usually change shape, or deform, slowly over long periods of time. As they are strained, potential energy builds up in them. This energy is released suddenly by the action of rocks breaking and moving. Such breaking, and the movement that follows, causes vibrations that move through rock or other earth materials. If they are large enough, these vibrations are felt as **earthquakes.**

Reading Check *What is an earthquake?*

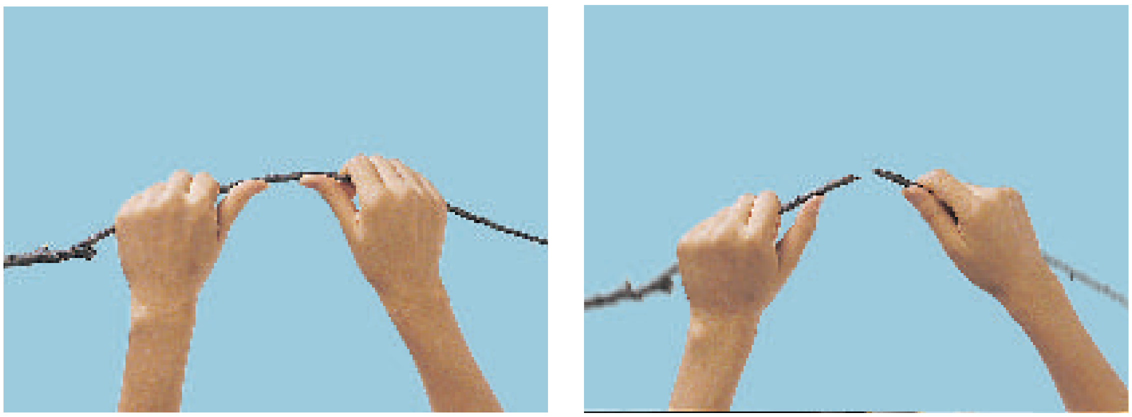


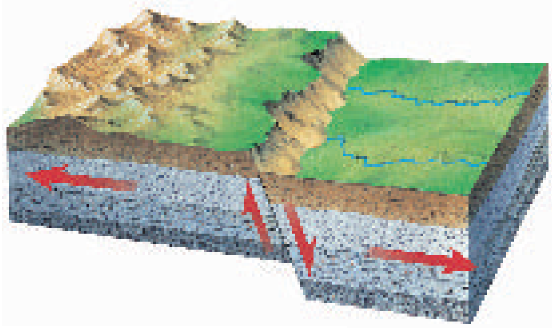
Figure 1 A stick can bend only so far before it breaks.

When a stick is bent, potential energy is stored in the stick.

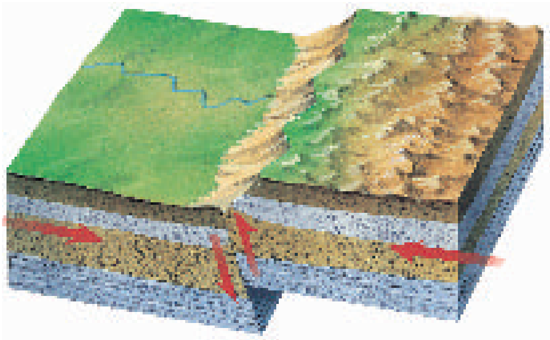
The energy is released as vibrations when the stick breaks.

KS Studios

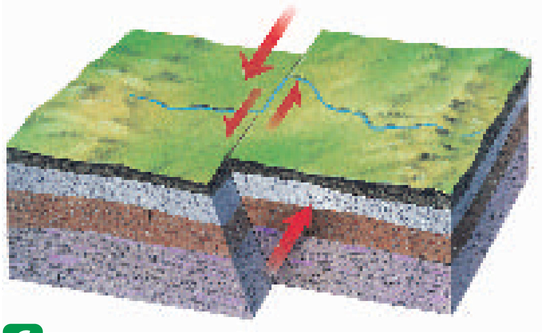
Figure 2 When rocks change shape by breaking, faults form. The type of fault formed depends on the type of stress exerted on the rock.



A When rocks are pulled apart, a normal fault may form.



B When rocks are compressed, a reverse fault may form.



C When rocks are sheared, a strike-slip fault may form.

Types of Faults When a section of rock breaks, rocks on either side of the break along which rocks move might move as a result of elastic rebound. The surface of such a break along which rocks move is called a **fault.** Several types of faults exist. The type that forms depends on how forces were applied to the rocks.

When rocks are pulled apart under tension forces, normal faults form, as shown in **Figure 2A.** Along a normal fault, rock above the fault moves down compared to rock below the fault. Compression forces squeeze rocks together, like an accordion. Compression might cause rock above a fault to move up compared to rock below the fault. This movement forms reverse faults, as shown in **Figure 2B.** As illustrated in **Figure 2C,** rock experiencing shear forces can break to form a strike-slip fault. Shear forces cause rock on either side of a strike-slip fault to move past one another in opposite directions along Earth's surface. You could infer the motion of a strike-slip fault while walking along and observing an offset feature, such as a displaced fence line, on Earth's surface.

Where do the forces come from that cause rocks to deform by bending or breaking? Why do faults form and why do earthquakes occur in certain areas? As you'll learn later in this chapter, forces inside Earth are caused by the constant motion of plates, or sections, of Earth's crust and upper mantle.

Mini LAB

Observing Deformation

WARNING: *Do not taste or eat any lab materials. Wash hands when finished.*

Procedure

1. Remove the wrapper from three bars of **taffy.**
2. Hold a bar of taffy lengthwise between your hands and gently push on it from opposite directions.
3. Hold another bar of taffy and pull it in opposite directions.

Analysis

1. Which of the procedures that you performed on the taffy involved applying tension? Which involved applying compression?
2. Infer how to apply a shear stress to the third bar of taffy.

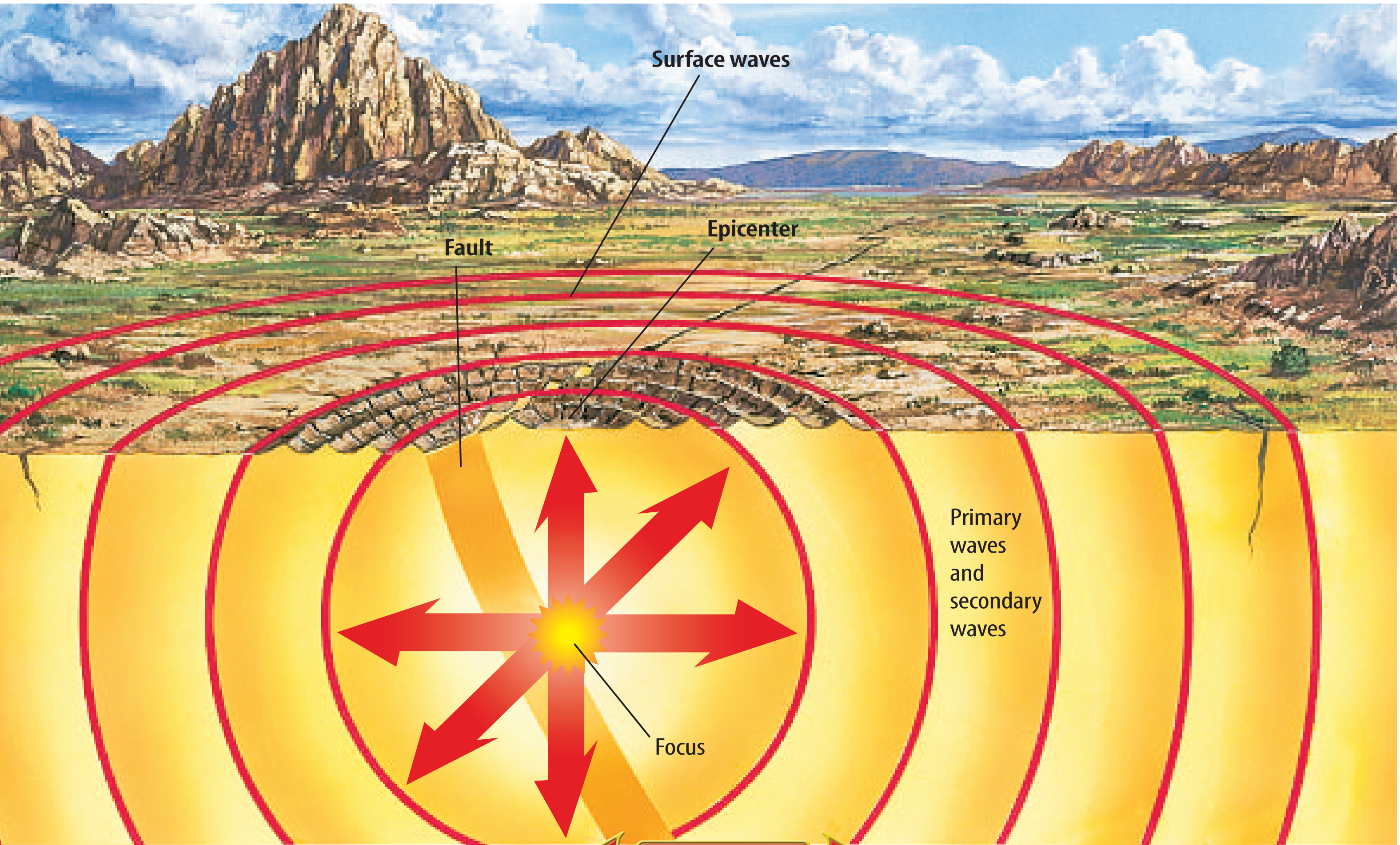
Making Waves

Do you recall the last time you shouted for a friend to save you a seat on the bus? When you called out, energy was transmitted through the air to your friend, who interpreted the familiar sound of your voice as belonging to you. These sound waves were released by your vocal cords and were affected by your tongue and mouth. They traveled outward through the air. Earthquakes also release waves. Earthquake waves are transmitted through materials in Earth and along Earth's surface. Earthquake waves are called **seismic waves.** In the two-page activity, you'll make waves similar to seismic waves by moving a coiled spring toy.

Earthquake Focus and Epicenter Movement along a fault releases strain energy. Strain energy is potential energy that builds up in rock when it is bent. When this potential energy is released, it moves outward from the fault in the form of seismic waves. The point inside Earth where this movement first occurs and energy is released is called the **focus** of an earthquake, as shown in **Figure 3.** The point on Earth's surface located directly above the earthquake focus is called the **epicenter** of the earthquake.

Reading Check *Where is the focus of an earthquake located?*

Figure 3 During an earthquake, several types of seismic waves form. Primary and secondary waves travel in all directions from the focus and can travel through Earth's interior. Surface waves travel at shallow depths and along Earth's surface.
Infer *Which seismic waves are the most destructive?*



Seismic Waves After they are produced at the focus, seismic waves travel away from the focus in all directions, as illustrated in **Figure 3.** Some seismic waves travel throughout Earth's interior, and others travel along Earth's surface. The surface waves cause the most damage during an earthquake event.

Primary waves, also known as P-waves, travel the fastest through rock material by causing particles in the rock to move back and forth, or vibrate, in the same direction as the waves are moving. Secondary waves, known as S-waves, move through rock material by causing particles in the rock to vibrate at right angles to the direction in which the waves are moving. P- and S-waves travel through Earth's interior. Studying them has revealed much information about Earth's interior.

Surface waves are the slowest and largest of the seismic waves, and they cause most of the destruction during an earthquake. The movements of surface waves are complex. Some surface waves move along Earth's surface in a manner that moves rock and soil in a backward rolling motion. They have been observed moving across the land like waves of water. Some surface waves vibrate in a side-to-side, or swaying, motion parallel to Earth's surface. This motion can be particularly devastating to human-built structures.

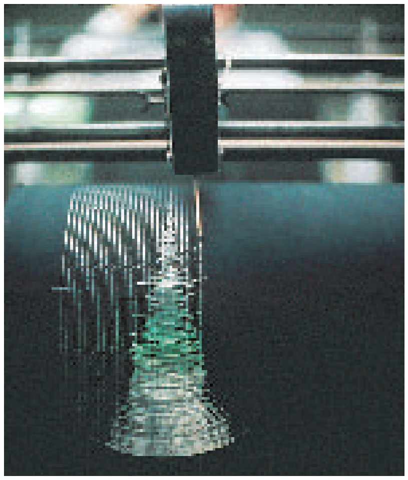
Learning from Earthquakes

On your way to lunch tomorrow, suppose you were to walk twice as fast as your friend does. What would happen to the distance between the two of you as you walked to the lunchroom? The distance between you and your friend would become greater the farther you walked, and you would arrive first. Using this same line of reasoning, scientists use the different speeds of seismic waves and their differing arrival times to calculate the distance to an earthquake epicenter.

Earthquake Measurements Seismologists are scientists who study earthquakes and seismic waves. The instrument they use to obtain a record of seismic waves from all over the world is called a **seismograph,** shown in the top photo of **Figure 4.**

One type of seismograph has a drum holding a roll of paper on a fixed frame. A pendulum with an attached pen is suspended from the frame. When seismic waves are received at the station, the drum vibrates but the pendulum remains at rest. The pen on the pendulum traces a record of the vibrations on the paper. The height of the lines traced on the paper is a measure of the energy released by the earthquake, also known as its **magnitude**.

Figure 4 Scientists study seismic waves using seismographs located around the world.



This seismograph records incoming seismic waves using a fixed mass.

Some seismographs collect and store data on a computer.

(t)Krafft/Explorer/Photo Researchers, (b)Jean Miele/The Stock Market/CORBIS

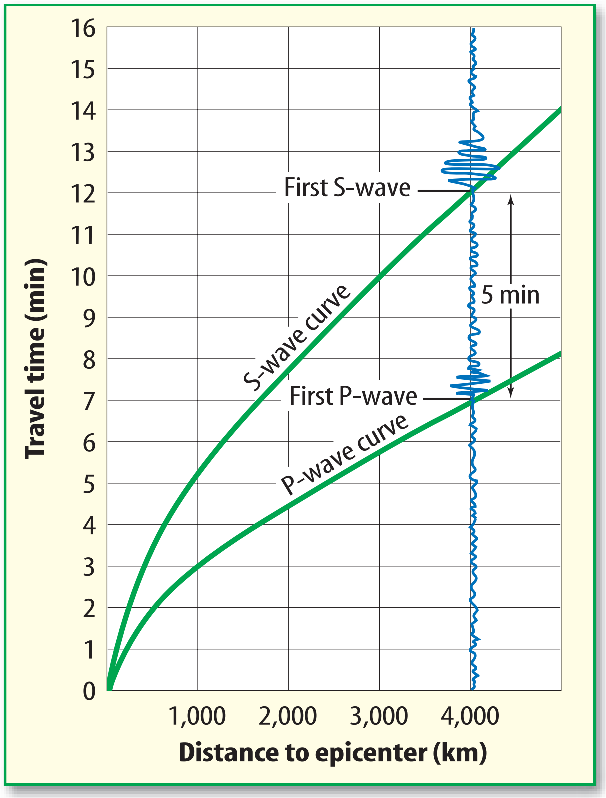


Figure 5 P-waves and S-waves travel at different speeds. These speeds are used to determine how close a seismograph station is to an earthquake.

Figure 6 After distances from at least three seismograph stations are determined, they are plotted as circles with radii equal to these distances on a map. The epicenter is the point at which the circles intersect.

Epicenter Location When seismic-wave arrival times are recorded at a seismograph station, the distance from that station to the epicenter can be determined. The farther apart the arrival times for the different waves are, the farther away the earthquake epicenter is. This difference is shown by the graph in **Figure 5.** Using this information, scientists draw a circle with a radius equal to the distance from the earthquake for each of at least three seismograph stations, as illustrated in **Figure 6.** The point where the three circles meet is the location of the earthquake epicenter. Data from many stations normally are used to determine an epicenter location.

How strong are earthquakes?

As shown in **Table 1,** major earthquakes cause much loss of life. For example, on September 20, 1999, a major earthquake struck Taiwan, leaving more than 2,400 people dead, more than 8,700 injured, and at least 100,000 homeless. Sometimes earthquakes are felt and can cause destruction in areas hundreds of kilometers away from their epicenters. The Mexico City earthquake in 1985 is an example of this. The movement of the soft sediment underneath Mexico City caused extensive damage to this city, even though the epicenter was nearly 400 km away.

The Richter Scale Richter (RIHK tur) magnitude is based on measurements of amplitudes, or heights, of seismic waves as recorded on seismographs. Richter magnitude describes how much energy an earthquake releases. For each increase of 1.0 on the Richter scale, the amplitude of the highest recorded seismic wave increases by 10. However, about 32 times more energy is released for every increase of 1.0 on the scale. For example, an earthquake with a magnitude of 7.5 releases about 32 times more energy than one with a magnitude of 6.5, and the wave height for a 7.5-magnitude quake is ten times higher than for a quake with a magnitude of 6.5.

Earthquake Damage Another way to measure earthquakes is available. The modified Mercalli intensity scale measures the intensity of an earthquake. Intensity is a measure of the amount of structural and geologic damage done by an earthquake in a specific location. The range of intensities spans Roman numerals I through XII. The amount of damage done depends on several factors—the strength of the earthquake, the nature of the surface material, the design of structures, and the distance from the epicenter. An intensity-I earthquake would be felt only by a few people under ideal conditions. An intensity-VI earthquake would be felt by everyone. An intensity-XII earthquake would cause major destruction to human-built structures and Earth's surface. The 1994 earthquake in Northridge, California was a Richter magnitude 6.7, and its intensity was listed at IX. An intensity-IX earthquake causes considerable damage to buildings and could cause cracks in the ground.

Table 1 Strong Earthquakes

Year	Location	Magnitude	Deaths
1989	Loma Prieta, CA	7.1	62
1990	Iran	7.7	50,000
1993	Guam	8.1	none
1993	Maharashtra, India	6.4	30,000
1994	Northridge, CA	6.7	61
1995	Kobe, Japan	6.8	5,378
1999	Taiwan	7.7	2,400
2000	Indonesia	7.9	103
2001	India	7.7	20,000
2003	Iran	6.6	30,000

Tsunamis Most damage from an earthquake is caused by surface waves. Buildings can crack or fall down. Elevated bridges and highways can collapse. However, people living near the seashore must protect themselves against another hazard from earthquakes. When an earthquake occurs on the ocean floor, the sudden movement pushes against the water and powerful water waves are produced. These waves can travel outward from the earthquake thousands of kilometers in all directions.

When these seismic sea waves, or **tsunamis**, are far from shore, their energy is spread out over large distances and great water depths. The wave heights of tsunamis are less than a meter in deep water, and large ships can ride over them and not even know it. In the open ocean, the speed of tsunamis can reach 950 km/h. However, when tsunamis approach land, the waves slow down and their wave heights increase as they encounter the bottom of the seafloor. This creates huge tsunami waves that can be as much as 30 m in height. Just before a tsunami crashes to shore, the water near a shoreline may move rapidly out toward the sea. If this should happen, there is immediate danger that a tsunami is about to strike. **Figure 7** illustrates the behavior of a tsunami as it approaches the shore.

Science Online

Topic: Earthquake Magnitude

Visit blue.msscience.com for Web links to information about determining earthquake magnitudes.

Activity Create a table that compares the damage in dollars, the magnitude, and the general location of six recent earthquakes.

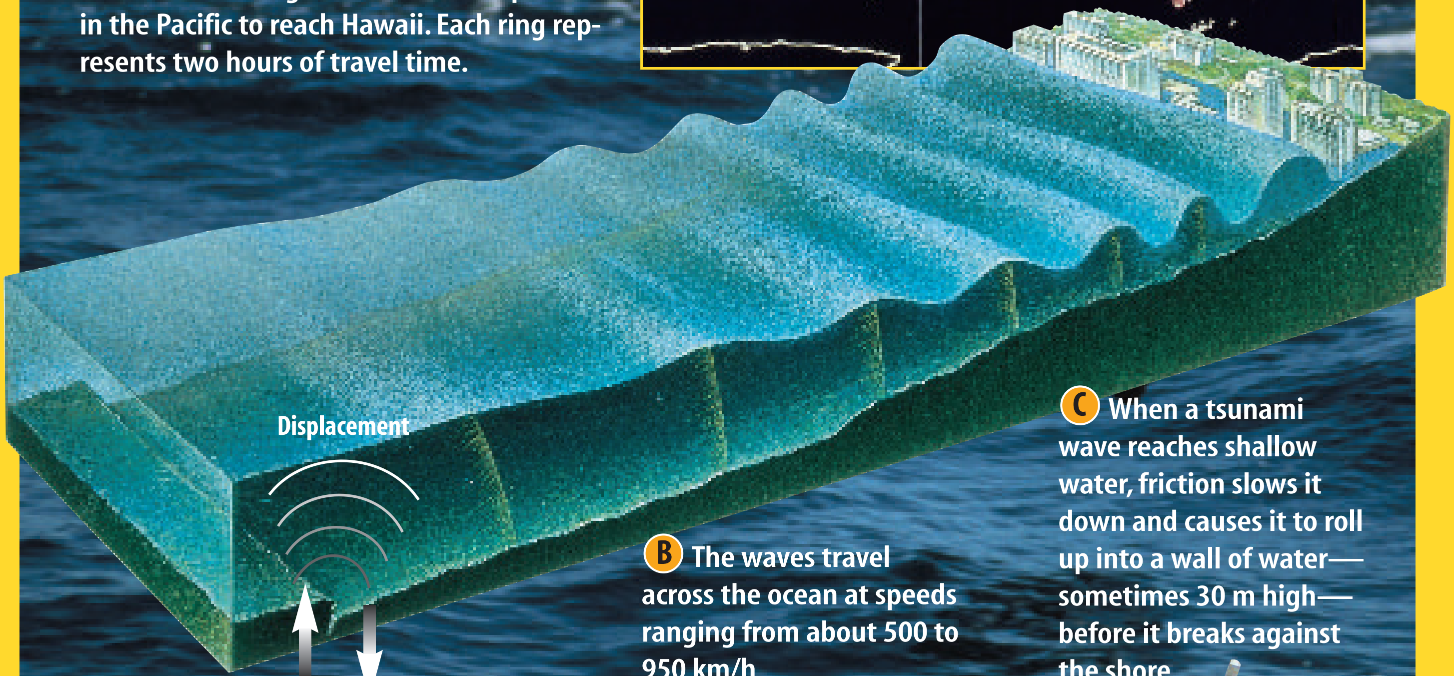
NATIONAL GEOGRAPHIC

VISUALIZING TSUNAMIS

Figure 7

The diagram below shows stages in the development of a tsunami. A tsunami is an ocean wave that is usually generated by an earthquake and is capable of inflicting great destruction.

▶ **TSUNAMI ALERT** The red dots on this map show the tide monitoring stations that make up part of the Tsunami Warning System for the Pacific Ocean. The map shows approximately how long it would take for tsunamis that originate at different places in the Pacific to reach Hawaii. Each ring represents two hours of travel time.



A The vibrations set off by a sudden movement along a fault in Earth's crust are transferred to the water's surface and spread across the ocean in a series of long waves.

B The waves travel across the ocean at speeds ranging from about 500 to 950 km/h

C When a tsunami wave reaches shallow water, friction slows it down and causes it to roll up into a wall of water—sometimes 30 m high—before it breaks against the shore.

Tsunami Warning System buoy

(bkgd)Galen Rowell/CORBIS, (others)NOAA

Earthquake Safety

You've just read about the destruction that earthquakes cause. Fortunately, there are ways to reduce the damage and the loss of life associated with earthquakes.

Learning the earthquake history of an area is one of the first things to do to protect yourself. If the area you are in has had earthquakes before, chances are it will again and you can prepare for that.

Is your home seismic safe? What could you do to make your home earthquake safe? As shown in **Figure 8,** it's a good idea to move all heavy objects to lower shelves so they can't fall on you. Make sure your gas hot-water heater and appliances are well secured. A new method of protecting against fire is to place sensors on your gas line that would shut off the gas when the vibrations of an earthquake are felt.

In the event of an earthquake, keep away from all windows and avoid anything that might fall on you. Watch for fallen power lines and possible fire hazards. Collapsed buildings and piles of rubble can contain many sharp edges, so keep clear of these areas.

Seismic-Safe Structures If a building is considered **seismic safe,** it will be able to stand up against the vibrations caused by most earthquakes. Residents in earthquake-prone areas are constantly improving the way structures are built. Since 1971, stricter building codes have been enforced in California. Older buildings have been reinforced. Many high-rise office buildings now stand on huge steel-and-rubber supports that could enable them to ride out the vibrations of an earthquake. Underground water and gas pipes are replaced with pipes that will bend during an earthquake. This can help prevent broken gas lines and therefore reduce damage from fires.

Seismic-safe highways have cement pillars with spiral reinforcing rods placed within them. One structure that was severely damaged in the 1989 Loma Prieta, California earthquake was Interstate Highway 880. The collapsed highway was due to be renovated to make it seismic safe. It was built in the 1950s and did not have spiral reinforcing rods in its concrete columns. When the upper highway went in one direction, the lower one went in the opposite direction. The columns collapsed and the upper highway came down onto the lower one.

Figure 8 You can minimize your risk of getting hurt by preparing for an earthquake in advance.

Placing heavy or breakable objects on lower shelves means they won't fall too far during an earthquake.

Vibration sensors on gas lines shut off the supply of gas automatically during an earthquake.
Draw Conclusions *What hazard can be prevented if the gas is turned off?*

(t)KS Studios, (b)Pacific Seismic Products, Inc.

Figure 9 One way to monitor changes along a fault is to detect any movement that occurs.

Predicting Earthquakes Imagine how many lives could be saved if only the time and location of a major earthquake could be predicted. Because most injuries from earthquakes occur when structures fall on top of people, it would help if people could be warned to move outside of buildings.

Researchers try to predict earthquakes by noting changes that precede them. That way, if such changes are observed again, an earthquake warning may be issued.

For example, movement along faults is monitored using laser-equipped, distance-measuring devices, such as the one shown in **Figure 9.** Changes in groundwater level or in electrical properties of rocks under stress have been measured by some scientists. Some people even study rock layers that have been affected by ancient earthquakes. Whether any of these studies will lead to the accurate and reliable prediction of earthquakes, no one knows. A major problem is that no single change in Earth occurs for all earthquakes. Each earthquake is unique.

Long-range forecasts predict whether an earthquake of a certain magnitude is likely to occur in a given area within 30 to 100 years. Forecasts of this nature are used to update building codes to make a given area more seismic safe.

section 1 review

Summary

What causes earthquakes?

- The sudden release of energy in rock and the resulting movement causes an earthquake.
- Faults are breaks in rocks along which movement occurs.

Making Waves

- The focus is where an earthquake occurs. The epicenter is directly above it.
- Earthquakes generate seismic waves.

How strong are earthquakes?

- The Richter Scale measures magnitude.
- The modified Mercalli scale measures intensity.

Earthquake Safety

- Structures can be made seismic safe.

Self Check

1. **Explain** what happens to rocks after their elastic limit is passed.
2. **Identify** Which seismic waves cause most of the damage during an earthquake?
3. **Apply** What has been done to make structures more seismic safe?
4. **Summarize** How can seismic waves be used to determine an earthquake's epicenter?
5. **Think Critically** Explain how a magnitude-8.0 earthquake could be classified as a low-intensity earthquake.

Applying Skills

6. **Make and Use Tables** Use **Table 1** to research the earthquakes that struck Indonesia in 2000, Loma Prieta, California in 1989, and Iran in 1990. Why was there such a great difference in the number of deaths?

Roger Ressmeyer/CORBIS

Science Online blue.msscience.com/self_check_quiz

CONTENTS

section 2

Volcanoes

How do volcanoes form?

Much like air bubbles that are forced upward toward the bottom of an overturned bottle of denser syrup, molten rock material, or magma, is forced upward toward Earth's surface by denser surrounding rock. Rising magma eventually can lead to an eruption, where magma, solids, and gas are spewed out to form cone-shaped mountains called **volcanoes.** As magma flows onto Earth's surface through a vent, or opening, it is called **lava.** Volcanoes have circular holes near their summits called craters. Lava and other volcanic materials can be expelled through a volcano's crater.

Some explosive eruptions throw lava and rock thousands of meters into the air. Bits of rock or solidified lava dropped from the air are called tephra. Tephra varies in size from volcanic ash to cinders to larger rocks called bombs or blocks.

Where Plates Collide Some volcanoes form because of collision of large plates of Earth's crust and upper mantle. This process has produced a string of volcanic islands, much like those illustrated in **Figure 10,** which includes Montserrat. These islands are forming as plates made up of oceanic crust and mantle collide. The older and denser oceanic plate subducts, or sinks beneath, the less dense plate, as shown in **Figure 10.** When one plate sinks under another plate, rock in and above the sinking plate melts, forming chambers of magma. This magma is the source for volcanic eruptions that have formed the Caribbean Islands.

as you read

What You'll Learn

- **Explain** how volcanoes can affect people.
- **Describe** how types of materials are produced by volcanoes.
- **Compare** how three different volcano forms develop.

Why It's Important

Volcanic eruptions can cause serious consequences for humans and other organisms.

Review Vocabulary

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

New Vocabulary

- volcano
- lava
- shield volcano
- cinder cone volcano
- composite volcano

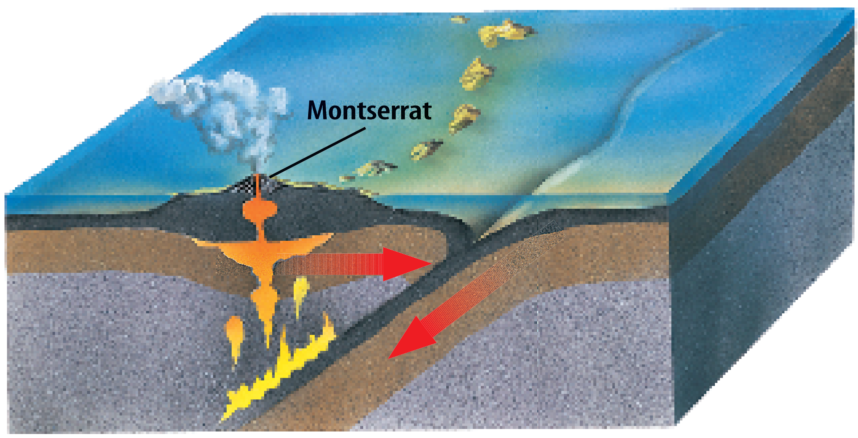


Figure 10 A string of Caribbean Islands known as the Lesser Antilles formed because of subduction. The island of Montserrat is among these.

Figure 11 Several volcanic hazards are associated with explosive activity.

Volcanic ash blanketing an area can cause collapse of structures or—when mixed with precipitation—mudflows.

Objects in the path of a pyroclastic flow are subject to complete destruction.

Mini LAB

Modeling an Eruption

Procedure

1. Place **red-colored gelatin** into a **self-sealing plastic bag** until the bag is half full.
2. Seal the bag and press the gelatin to the bottom of the bag.
3. Put a hole in the bottom of the bag with a **pin.**

Analysis

1. What parts of a volcano do the gelatin, the plastic bag, and the hole represent?
2. What force in nature did you mimic as you moved the gelatin to the bottom of the bag?
3. What factors in nature cause this force to increase and lead to an eruption?

Try at Home

Eruptions on a Caribbean Island Soufrière (soo free UR) Hills volcano on the island of Montserrat was considered dormant until recently. However, in 1995, Soufrière Hills volcano surprised its inhabitants with explosive activity. In July 1995, plumes of ash soared to heights of more than 10,000 m. This ash covered the capital city of Plymouth and many other villages, as shown at left in **Figure 11.**

Every aspect of a once-calm tropical life changed when the volcano erupted. Glowing avalanches and hot, boiling mudflows destroyed villages and shut down the main harbor of the island and its airport. During activity on July 3, 1998, volcanic ash reached heights of more than 14,000 m. This ash settled over the entire island and was followed by mudflows brought on by heavy rains.

Pyroclastic flows are another hazard for inhabitants of Montserrat. They can occur anytime on any side of the volcano. Pyroclastic flows are massive avalanches of hot, glowing rock flowing on a cushion of intensely hot gases, as shown at right in **Figure 11.** Speeds at which these flows travel can reach 200 km/h.

More than one half of Montserrat has been converted to a barren wasteland by the volcano. Virtually all of the farmland is now unusable, and most of the island's business and leisure centers are gone. Many of the inhabitants of the island have been evacuated to England, surrounding islands, or northern Montserrat, which is considered safe from volcanic activity.

AP/Wide World Photos

Volcanic Risks According to the volcanic-risk map shown in **Figure 12,** inactive volcanic centers exist at Silver Hill, Centre Hill, and South Soufrière Hills. The active volcano, Soufrière Hills volcano, is located just north of South Soufrière Hills. The risk map shows different zones of the island where inhabitants still are able to stay and locations from which they have been evacuated. Twenty people who had ignored evacuation orders were killed by pyroclastic flows from the June 25, 1997, event. These are the first and only deaths that have occurred since July 1995.

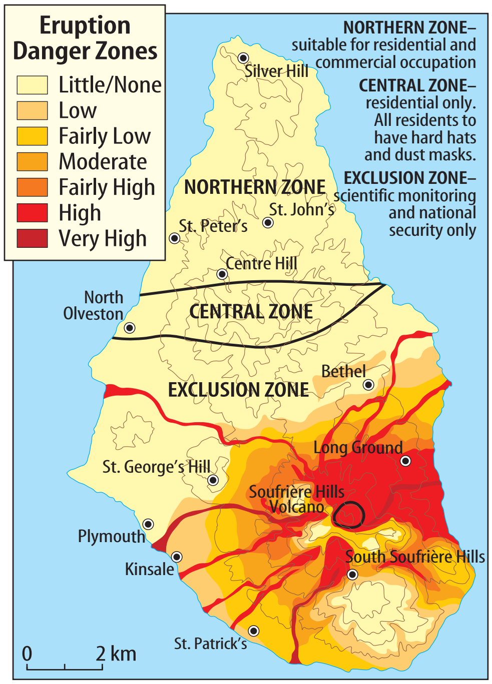


Figure 12 A volcanic risk map for Montserrat was prepared to warn inhabitants and visitors about unsafe areas on the island.

Forms of Volcanoes

As you have learned, volcanoes can cause great destruction. However, volcanoes also add new rock to Earth's crust with each eruption. The way volcanoes add this new material to Earth's surface varies greatly. Different types of eruptions produce different types of volcanoes.

INTEGRATE Chemistry

What determines how a volcano erupts? Some volcanic eruptions are violent, while during others lava flows out quietly around a vent. The composition of the magma plays a big part in determining the manner in which energy is released during a volcanic eruption. Lava that contains more silica, which is a compound consisting of silicon and oxygen, tends to be thicker and is more resistant to flow. Lava containing more iron and magnesium and less silica tends to flow easily. The amount of water vapor and other gases trapped in the lava also influences how lava erupts.

When you shake a bottle of carbonated soft drink before opening it, the pressure from the gas in the drink builds up and is released suddenly when the container is opened. Similarly, steam builds pressure in magma. This pressure is released as magma rises toward Earth's surface and eventually erupts. Sticky, silica-rich lava tends to trap water vapor and other gases.

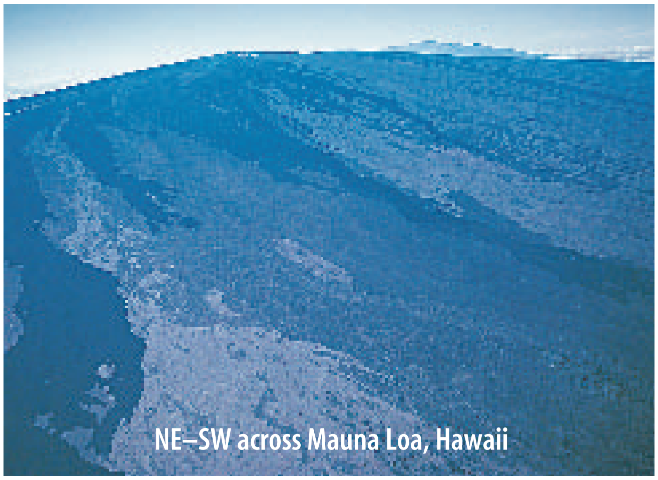
Water is carried down from the surface of Earth into the mantle when one plate subducts beneath another, as in the case of the Lesser Antilles volcanoes. In hotter regions of Earth's interior, part of a descending plate and nearby rock will melt to form magma. The magma produced is more silica rich than the rock that melts to form the magma. Superheated steam produces tremendous pressure in such thick, silica-rich magmas. After enough pressure builds up, an eruption occurs. The type of lava and the gases contained in that lava determine the type of eruption that occurs.

Science Online

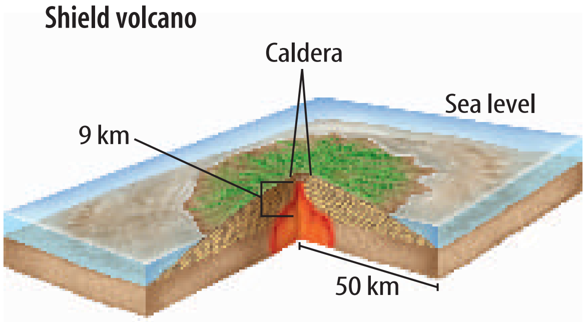
Topic: Montserrat Volcano
Visit blue.msscience.com for Web links to an update of data on Soufrière Hills volcano on Montserrat.

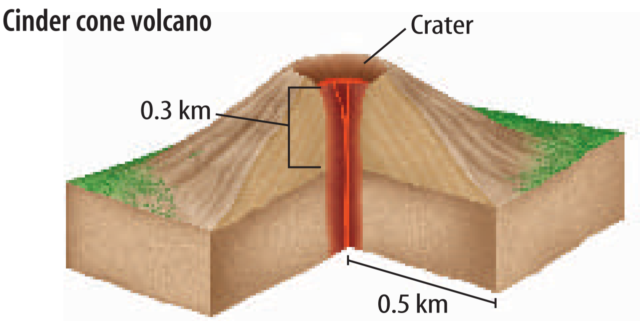
Activity Compare the recent activity of the Soufrière Hills volcano to another recently active volcano. Gather your findings into a table and include dates as well as amount of area destroyed in your report.

Figure 13 Volcanic landforms vary greatly in size and shape.



A The fluid nature of basaltic lava has produced extensive flows at Mauna Loa, Hawaii—the largest active volcano on Earth.





B Sunset Crater is small and steep along its flanks—typical of a cinder cone. Compare the scale given for Sunset Crater with that shown in Figure 13A.

Shield Volcanoes Basaltic lava, which is high in iron and magnesium and low in silica, flows in broad, flat layers. The buildup of basaltic layers forms a broad volcano with gently sloping sides called a **shield volcano.** Shield volcanoes, shown in **Figure 13A,** are the largest type of volcano. They form where magma is being forced up from extreme depths within Earth, or in areas where Earth's plates are moving apart. The separation of plates enables magma to be forced upward to Earth's surface.

Reading Check *What materials are shield volcanoes composed of?*

Cinder Cone Volcanoes Rising magma accumulates gases on its way to the surface. When the gas builds up enough pressure, it erupts. Moderate to violent eruptions throw volcanic ash, cinders, and lava high into the air. The lava cools quickly in midair and the particles of solidified lava, ash, and cinders fall back to Earth. This tephra forms a relatively small cone of volcanic material called a **cinder cone volcano.** Cinder cones are usually less than 300 m in height and often form in groups near other larger volcanoes. Because the eruption is powered by the high gas content, it usually doesn't last long. After the gas is released, the force behind the eruption is gone. Sunset Crater, an example of a cinder cone near Flagstaff, Arizona, is shown in **Figure 13B.**

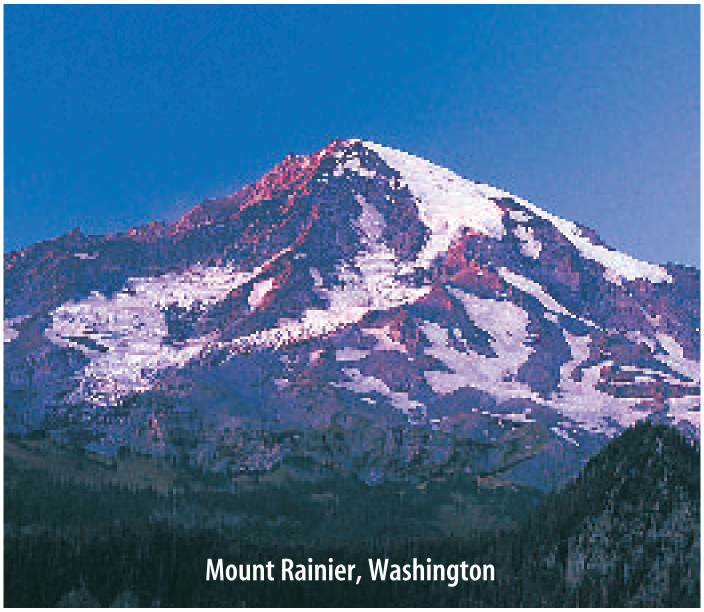
(t)Breck P. Kent/Earth Scenes, (b)Dewitt Jones/CORBIS

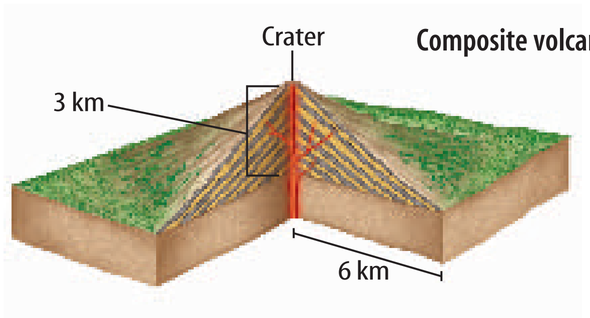
Composite Volcanoes Steep-sided mountains composed of alternating layers of lava and tephra are **composite volcanoes**. They sometimes erupt violently, releasing large quantities of ash and gas. This forms a tephra layer of solid materials. Then a quieter eruption forms a lava layer.

Composite volcanoes form where one plate sinks beneath another. Soufrière Hills volcano is an example of a composite volcano. Another volcanic eruption from a composite volcano was the May 1980 eruption of Mount St. Helens in the state of Washington. It erupted explosively, spewing ash that fell on regions hundreds of kilometers away from the volcano. A composite volcano is shown in **Figure 13C.**

Fissure Eruptions Magma that is highly fluid can ooze from cracks or fissures in Earth's surface. This is the type of magma that usually is associated with fissure eruptions. The lava that erupts has a low viscosity, which means it can flow freely across the land to form flood basalts. Flood basalts that have been exposed to erosion for millions of years can become large, relatively flat landforms known as lava plateaus, as shown in **Figure 13D.** The Columbia River Plateau in the northwestern United States was formed about 15 million years ago when several fissures erupted and the flows built up layer upon layer.

C Composite cones are intermediate in size and shape compared to shield volcanoes and cinder cone volcanoes.





D No modern example compares with the extensive flood basalts making up the Columbia River Plateau.

(t)Lynn Gerig/Tom Stack & Assoc., (b)Milton Rand/Tom Stack & Assoc.

Table 2 Seven Selected Eruptions in History

Volcano (Year)	Type	Eruptive Force	Silica Content	Gas Content	Eruption Products
Krakatau, Indonesia (1883)	composite	high	high	high	gas, cinders, ash
Katmai, Alaska (1912)	composite	high	high	high	lava, ash, gas
Paricutín, Mexico (1943)	cinder cone	moderate	high	low	gas, cinders, ash
Helgafell, Iceland (1973)	cinder cone	moderate	low	high	gas, ash
Mount St. Helens, Washington (1980)	composite	high	high	high	gas, ash
Kilauea Iki, Hawaii (1989)	shield	low	low	low	gas, lava
Soufrière Hills, Montserrat (1995–)	composite	high	high	high	gas, ash, rocks

You have read about some variables that control the type of volcanic eruption that will occur. Examine **Table 2** for a summary of these important factors. In the next section, you'll learn that the type of magma produced is associated with properties of Earth's plates and how these plates interact.

section 2 review

Summary

How do volcanoes form?

- Some volcanoes form as two or more large plates collide.
- The Caribbean Islands formed from volcanic eruptions as one plate sinks under another plate.

Forms of volcanoes

- Lava high in silica produces explosive eruptions, lava low in silica but high in iron and magnesium produces more fluid eruptions.
- The amount of water vapor and gases impacts how volcanoes erupt.
- The types of volcanoes include shield, cinder cone and composite volcanoes, and fissure eruptions.

Self Check

1. **Identify** Which types of lava eruptions cover the largest area on Earth's surface?
2. **Describe** the processes that have led to the formation of the Soufrière Hills volcano.
3. **Explain** why a cinder cone has steep sides?
4. **List** What types of materials are volcanoes like Mount St. Helens made of?
5. **Think Critically** Why is silica-rich magma explosive?

Applying Math

6. **Solve One-Step Equations** Mauna Loa in Hawaii rises 9 km above the seafloor. Sunset Crater in Arizona rises to an elevation of 300 m. How many times higher is Mauna Loa than Sunset Crater?

Science Online blue.msscience.com/self_check_quiz

LAB

Disruptive Eruptions

A volcano's structure can influence how it erupts. Some volcanoes have only one central vent, while others have numerous fissures that allow lava to escape. Materials in magma influence its viscosity, or how it flows. If magma is a thin fluid—not viscous—gases can escape easily. But if magma is thick—viscous—gases cannot escape as easily. This builds up pressure within a volcano.

Real-World Question

What determines the explosiveness of a volcanic eruption?

Goals

- **Infer** how a volcano's opening contributes to how explosive an eruption might be.
- **Hypothesize** how the viscosity of magma can influence an eruption.

Materials

plastic film canisters
baking soda ($NaHCO_3$)
vinegar (CH_3COOH)
50-mL graduated cylinder
teaspoon

Safety Precautions

This lab should be done outdoors. Goggles must be worn at all times. The caps of the film canisters fly off due to the chemical reaction that occurs inside them. Never put anything in your mouth while doing the experiment.

Procedure

1. Watch your teacher demonstrate this lab before attempting to do it yourself.
2. Add 15 mL of vinegar to a film canister.
3. Place 1 teaspoon of baking soda in the film canister's lid, using it as a type of plate.

4. Place the lid on top of the film canister, but do not cap it. The baking soda will fall into the vinegar. Move a safe distance away. Record your observations in your Science Journal.
5. Clean out your film canister and repeat the lab, but this time cap the canister quickly and tightly. Record your observations.

Conclude and Apply

1. **Identify** Which of the two labs models a more explosive eruption?
2. **Explain** Was the pressure greater inside the canister during the first or second lab? Why?
3. **Explain** What do the bubbles have to do with the explosion? How do they influence the pressure in the container?
4. **Infer** If the vinegar were a more viscous substance, how would the eruption be affected?

Communicating Your Data

Research three volcanic eruptions that have occurred in the past five years. Compare each eruption to one of the eruption styles you modeled in this lab. Communicate to your class what you learn.

Otto Hahn/Peter Arnold, Inc.

section 3

Earthquakes, Volcanoes, and Plate Tectonics

as you read

What You'll Learn

- **Explain** how the locations of volcanoes and earthquake epicenters are related to tectonic plate boundaries.
- **Explain** how heat within Earth causes Earth's plates to move.

Why It's Important

Most volcanoes and earthquakes are caused by the motion and interaction of Earth's plates.

Review Vocabulary

asthenosphere: plasticlike layer of mantle under the lithosphere

New Vocabulary

- rift
- hot spot

Earth's Moving Plates

At the beginning of class, your teacher asks for volunteers to help set up the cafeteria for a special assembly. You and your classmates begin to move the tables carefully, like the students shown in **Figure 14.** As you move the tables, two or three of them crash into each other. Think about what could happen if the students moving those tables kept pushing on them. For a while one or two of the tables might keep another from moving. However, if enough force were used, the tables would slide past one another. One table might even slide up on top of another. It is because of this possibility that your teacher has asked that you move the tables carefully.

The movement of the tables and the possible collisions among them is like the movement of Earth's crust and uppermost mantle, called the lithosphere. Earth's lithosphere is broken into separate sections, or plates. When these plates move around, they collide, move apart, or slide past each other. The movement of these plates can cause vibrations known as earthquakes and can create conditions that cause volcanoes to form.

Figure 14 Like the tables pictured here, Earth's plates are in contact with one another and can slide beneath each other. The way Earth's plates interact at boundaries is an important factor in the locations of earthquakes and volcanoes.

Spencer Grant/PhotoEdit, Inc.

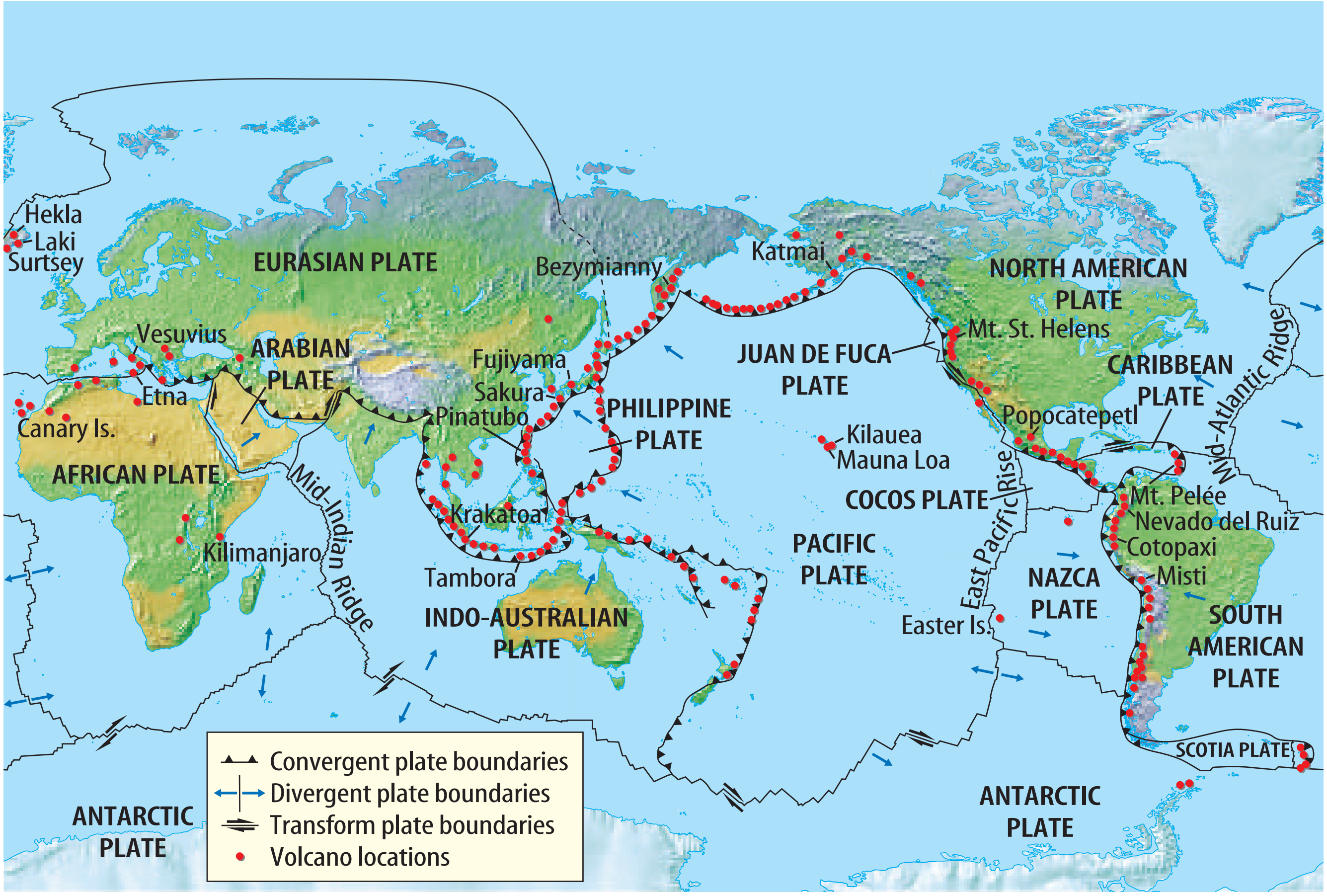


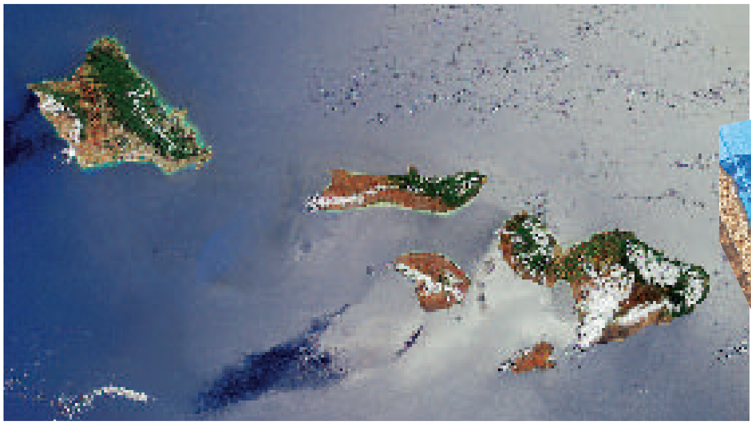
Figure 15 Earth's lithosphere is divided into about 13 major plates. Where plates collide, separate, and slip past one another at plate boundaries, interesting geological activity results.

Where Volcanoes Form

A plot of the location of plate boundaries and volcanoes on Earth shows that most volcanoes form along plate boundaries. Examine the map in **Figure 15.** Can you see how this indicates that plate tectonics and volcanic activity are related? Perhaps the energy involved in plate tectonics is causing magma to form deep under Earth's surface. You'll recall that the Soufrière Hills volcano formed where plates converge. Plate movement often explains why volcanoes form in certain areas.

Divergent Plate Boundaries Tectonic plates move apart at divergent plate boundaries. As the plates separate, long cracks called **rifts** form between them. Rifts contain fractures that serve as passageways for magma originating in the mantle. Rift zones account for most of the places where lava flows onto Earth's surface. Fissure eruptions often occur along rift zones. These eruptions form lava that cools and solidifies into basalt, the most abundant type of rock in Earth's crust.

Reading Check *Where does magma along divergent boundaries originate?*



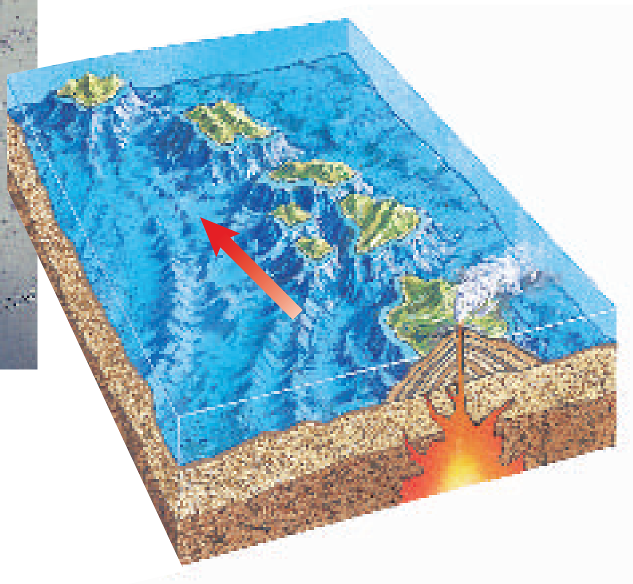


Figure 16 The Hawaiian Islands have formed, and continue to form, as the Pacific Plate moves over a hot spot. The arrow shows that the Pacific Plate is moving north-northwest.

INTEGRATE Chemistry

Melting Points The melting point of a substance is the temperature at which a solid changes to a liquid. Depending on the substance, a change in pressure can raise or lower the melting point. Do research to find out how pressure affects the formation of magma in a mantle plume in a process called decompression melting.

Convergent Plate Boundaries A common location for volcanoes to form is along convergent plate boundaries. More dense oceanic plates sink beneath less dense plates that they collide with. This sets up conditions that form volcanoes.

When one plate sinks beneath another, basalt and sediment on an oceanic plate move down into the mantle. Water from the sediment and altered basalt lowers the melting point of the surrounding rock. Heat in the mantle causes part of the sinking plate and overlying mantle to melt. This melted material then is forced upward. Volcanoes have formed in this way all around the Pacific Ocean, where the Pacific Plate, among others, collides with several other plates. This belt of volcanoes surrounding the Pacific Ocean is called the Pacific Ring of Fire.

Hot Spots The Hawaiian Islands are volcanic islands that have not formed along a plate boundary. In fact, they are located well within the Pacific Plate. What process causes them to form? Large bodies of magma, called **hot spots,** are forced upward through Earth's mantle and crust, as shown in **Figure 16.** Scientists suggest that this is what is occurring at a hot spot that exists under the present location of Hawaii.

Reading Check *What is a hot spot?*

Volcanoes on Earth usually form along rift zones, subduction zones (where one plate sinks beneath another), or over hot spots. At each of these locations, magma from deep within Earth is forced upward toward the surface. Lava breaks through and flows out, where it piles up into layers or forms a volcanic cone.

Image courtesy NASA/GSFC/JPL, MISR Team

Moving Plates Cause Earthquakes

Place two notebooks on your desk with the page edges facing each other. Then push them together slowly. The individual sheets of paper gradually will bend upward from the stress. If you continue to push on the notebooks, one will slip past the other suddenly. This sudden movement is like an earthquake.

Now imagine what would happen if tectonic plates were moving like the notebooks. What would happen if the plates collided and stopped moving? Forces generated by the locked-up plates would cause strain to build up. Both plates would begin to deform until the elastic limit was passed. The breaking and elastic rebound of the deformed material would produce vibrations felt as earthquakes.

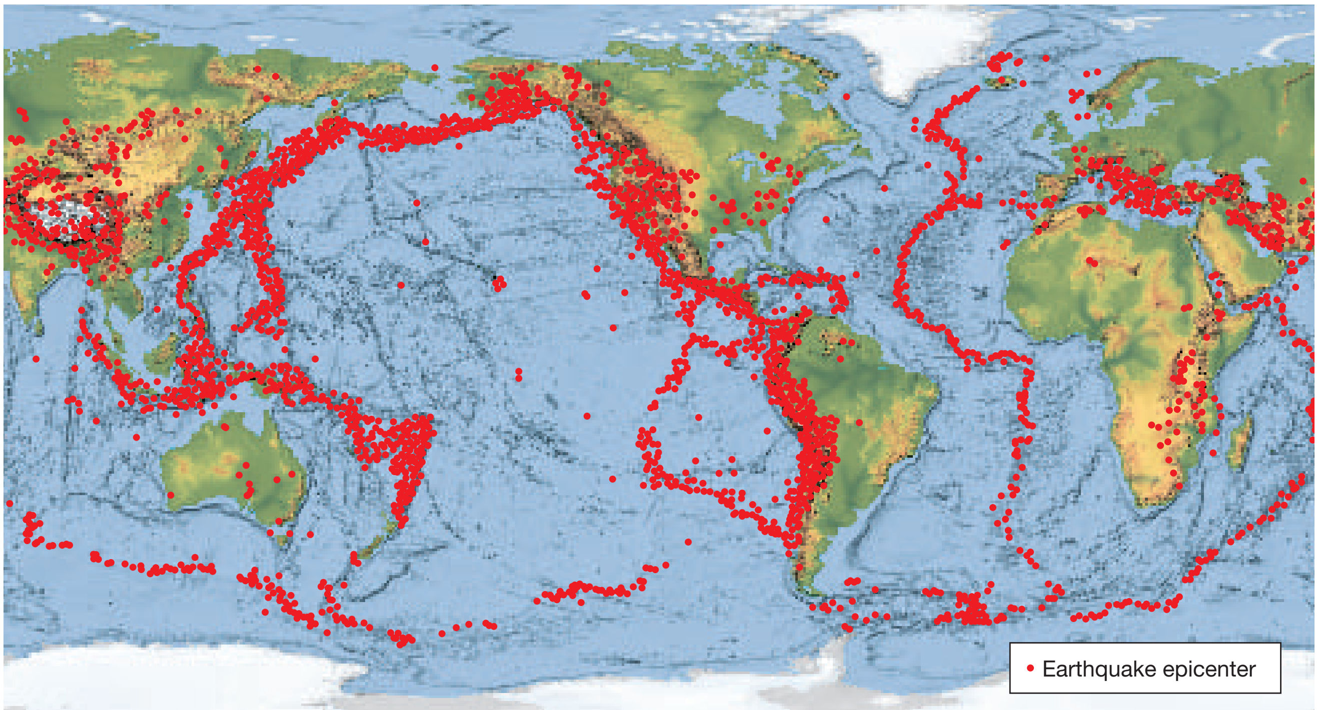
Earthquakes often occur where tectonic plates come together at a convergent boundary, where tectonic plates move apart at a divergent boundary, and where tectonic plates grind past each other, called a transform boundary.

Earthquake Locations If you look at a map of earthquakes, you'll see that most occur in well-known belts. About 80 percent of them occur in the Pacific Ring of Fire—the same belt in which many of Earth's volcanoes occur. If you compare **Figure 17** with **Figure 15,** you will notice a definite relationship between earthquake epicenters and tectonic plate boundaries. Movement of the plates produces forces that generate the energy to cause earthquakes.

INTEGRATE Language Arts

Friction Friction is a force that opposes the motion of two objects in contact. Do research to find out different types of friction in a literary and figurative sense.

Figure 17 Locations of earthquakes that have occurred between 1990 and 2000 are plotted below.



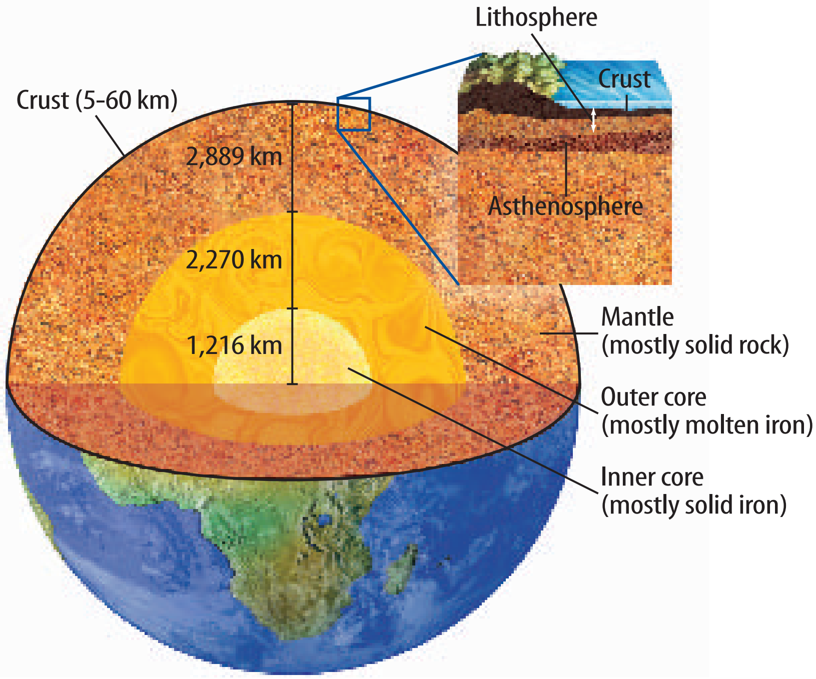


Figure 18 Seismic waves generated by earthquakes allow researchers to figure out the structure and composition of Earth's layers.

Earth's Plates and Interior

Researchers have learned much about Earth's interior and plate tectonics by studying seismic waves. The way in which seismic waves pass through a material depends on the properties of that material. Seismic wave speeds, and how they travel through different levels in the interior, have allowed scientists to map out the major layers of Earth, as shown in **Figure 18.**

For example, the asthenosphere was discovered when seismologists noted that seismic waves slowed when they reached the base of the lithosphere of the Earth. This partially molten layer forms a warmer, softer layer over which the colder, brittle, rocky plates move.

Applying Math — Calculate

P-WAVE TRAVEL TIME There is a relationship between the density of a region in Earth and the velocity of P-waves. How can you calculate the time it would take P-waves to travel 100 km in the crust of Earth?

Density and Wave Velocity

Region	Density	P-Wave Velocity
Crust	2.8 g/cm^3	6 km/s
Upper mantle	3.3 g/cm^3	8 km/s

Solution

1 *This is what you know:*
- velocity: $v = 6$ km/s
- distance: $d = 100$ km

2 *This is what you need to find:* How long would it take a P wave to travel?

3 *This is the procedure you need to use:*
- $t = d/v$
- $t = (100 \text{ km})/(6 \text{ km/s}) = 16.7 \text{ s}$

4 *Check your answer:* Solve $v = d/t = (100 \text{ km})/(16.7 \text{ s}) = 6 \text{ km/s}$

Practice Problems

1. Calculate the time it takes P-waves to travel 300 km in the upper mantle.
2. How long will it take a P-wave to travel 500 km in the crust?

Science Online — For more practice, visit blue.msscience.com/math_practice

CONTENTS

What is driving Earth's plates? There are several hypotheses about where all the energy comes from to power the movement of Earth's plates.

In one case, mantle material deep inside Earth is heated by Earth's core. This hot, less dense rock material is forced toward the surface. The hotter, rising mantle material eventually cools. The cooler material then sinks into the mantle toward Earth's core, completing the convection current. Convection currents inside Earth, shown in **Figure 19,** provide the mechanism for plate motion, which then produces the conditions that cause volcanoes and earthquakes. Sometimes magma is forced up directly within a plate. Volcanic activity in Yellowstone National Park is caused by a hot spot beneath the North American Plate. Such hot spots might be related to larger-scale convection in Earth's mantle.

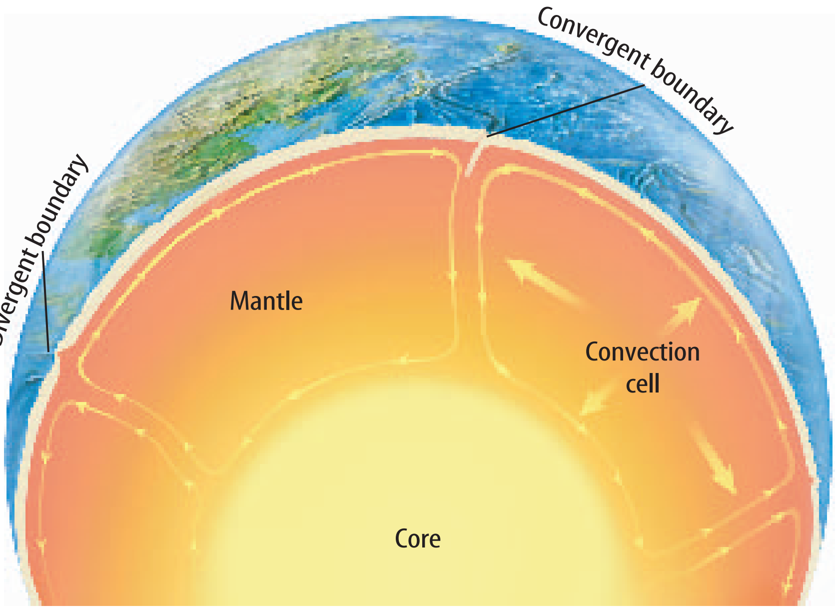


Figure 19 Convection of material in Earth's interior drives the motion of tectonic plates.

section 3 review

Summary

Earth's Moving Plates

- Earth's lithosphere is broken into plates that move around the planet.

Where Volcanoes Form

- Plates move apart at divergent plate boundaries, creating fissure eruptions.
- Plates collide at convergent plate boundaries.
- Many volcanoes form at convergent plate boundaries.
- Volcanoes may also form along rift zones, subduction zones, or over hot spots.

Moving Plates Cause Earthquakes

- Earthquakes often form at plate boundaries.
- Seismic waves have been used to determine the characteristics of Earth's interior.
- Convection currently may drive tectonic plate movement.

Self Check

1. **Identify** Along which type of plate boundary has the Soufrière Hills volcano formed?
2. **Predict** At which type of plate boundary does rift-volcanism occur?
3. **Explain** how volcanoes in Hawaii form.
4. **Recognize Cause and Effect** Why do most deep earthquakes occur at convergent boundaries?
5. **Think Critically** Subduction occurs where plates converge. This causes water-rich sediment and altered rock to be forced down to great depths. Explain how water can help form a volcano.

Applying Skills

6. **Form Hypotheses** Write a hypothesis concerning the type of lava that will form a hot spot volcano. Consider that magma in a hot spot comes from deep inside Earth's mantle.

LAB

Seismic Waves

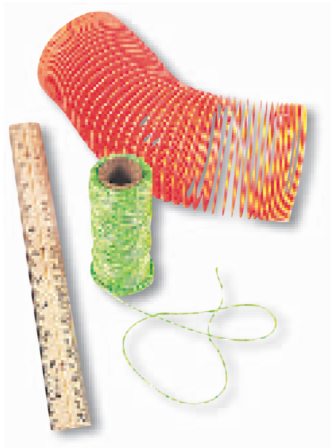
Goals
- **Demonstrate** the motion of primary, secondary, and surface waves.
- **Identify** how parts of the spring move in each of the waves.

Materials
coiled spring toy
yarn or string
metric ruler

Safety Precautions

Real-World Question

If you and one of your friends hold a long piece of rope between you and move one end of the rope back and forth, you can send a wave through the length of the rope. Hold a ruler at the edge of a table securely with one end of it sticking out from the table's edge. If you bend the ruler slightly and then release it, what do you experience? How does what you see in the rope and what you feel in the ruler relate to seismic waves? How do seismic waves differ?



Procedure

1. Copy the following data table in your Science Journal.
2. Tie a small piece of yarn or string to every tenth coil of the spring.
3. Place the spring on a smooth, flat surface. Stretch it so it is about 2 m long (1 m for shorter springs).
4. Hold your end of the spring firmly. Make a wave by having your partner snap the spring from side to side quickly.
5. **Record** your observations in your Science Journal and draw the wave you and your partner made in the data table.
6. Have your lab partner hold his or her end of the spring firmly. Make a wave by quickly pushing your end of the spring toward your partner and bringing it back to its original position.

Comparing Seismic Waves

Observation of Wave	Observation of Yarn or String	Drawing	Wave Type
	Do not write in this book.		

Aaron Haupt

7. **Record** your observations of the wave and of the yarn or string and draw the wave in the data table.
8. Have your lab partner hold his or her end of the spring firmly. Move the spring off of the table. Gently move your end of the spring side to side while at the same time moving it in a rolling motion, first up and away and then down and toward your partner.
9. **Record** your observations and draw the wave in the data table.

Conclude and Apply

1. Based on your observations, detrmine which of the waves that you and your partner have generated demonstrates a primary, or pressure, wave. Record in your data table and explain why you chose the wave you did.
2. Do the same for the secondary, or shear wave, and for the surface wave. Explain why you chose the wave you did.
3. **Explain** Based on your observations of wave motion, which of the waves that you and your partner generated probably would cause the most damage during an earthquake?
4. **Observe** What was the purpose of the yarn or string?
5. **Compare and contrast** the motion of the yarn or string when primary and secondary waves travel through the spring. Which of these waves is a compression wave? Explain your answer.
6. **Compare and Contrast** Which wave most closely resembled wave motion in a body of water? How was it different? Explain.

Communicating Your Data

Compare your conclusions with those of other students in your class. **For more help, refer to the Science Skill Handbook.**

Aaron Haupt

quake

The 1906 San Francisco earthquake taught people valuable lessons

It struck without warning. “We found ourselves staggering and reeling. It was as if the earth was slipping gently from under our feet. Then came the sickening swaying of the earth that threw us flat upon our faces. We struggled in the street. We could not get on our feet. Then it seemed as though my head were split with the roar that crashed into my ears. Big buildings were crumbling as one might crush a biscuit in one’s hand.”

That’s how survivor P. Barrett described the San Francisco earthquake of 1906. Duration of the quake on the morning of April 18—one minute. Yet, in that short time, Earth opened a gaping hole stretching more than 430 km. The tragic result was one of the worst natural disasters in U.S. history.

Fires caused by falling chimneys and fed by broken gas mains raged for three days. Despite the estimated 3,000 deaths and enormous devastation to San Francisco, the earthquake did have a positive effect. It led to major building changes that would help protect people and property from future quakes.

Computers analyze information from seismographs that have helped to map the San Andreas Fault—the area along which many California earthquakes take place. This information is helping scientists better understand how and when earthquakes might strike.

The 1906 quake also has led to building codes that require stronger construction materials for homes, offices, and bridges. Laws have been passed saying where hospitals, homes, and nuclear power plants can be built—away from soft ground and away from the San Andreas Fault.

Even today, scientists can’t predict an earthquake. But thanks to what they learned from the 1906 quake—and others—people are safer today than ever before.

Write **Prepare a diary entry pretending to be a person who experienced the 1906 San Francisco earthquake. Possible events to include in your entry: What were you doing at 5:15 A.M.? What began to happen around you? What did you see and hear?**

Science Online
For more information, visit blue.msscience.com/time

(t)Ted Streshinky/CORBIS, (b)Underwood & Underwood/CORBIS

Reviewing Main Ideas

Section 1 Earthquakes

1. Earthquakes occur whenever rocks inside Earth pass their elastic limit, break, and experience elastic rebound.
2. Seismic waves are vibrations inside Earth. P- and S-waves travel in all directions away from the earthquake focus. Surface waves travel along the surface.
3. Earthquakes are measured by their magnitudes—the amount of energy they release—and by their intensity—the amount of damage they produce.

Section 2 Volcanoes

1. The Soufrière Hills volcano is a composite volcano formed by converging plates.
2. The way a volcano erupts is determined by the composition of the lava and the amount of water vapor and other gases in the lava.
3. Three different forms of volcanoes are shield volcanoes, cinder cone volcanoes, and composite volcanoes.

Section 3 Earthquakes, Volcanoes, and Plate Tectonics

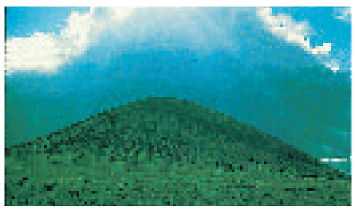
1. The locations of volcanoes and earthquake epicenters are related to the locations of plate boundaries.
2. Volcanoes occur along rift zones, subduction zones, and at hot spots.
3. Most earthquakes occur at convergent, divergent, and transform plate boundaries.

Visualizing Main Ideas

Copy and complete the following table comparing characteristics of shield, composite, and cinder cone volcanoes.

Volcanoes

Characteristic	Shield Volcano	Cinder Cone Volcano	Composite Volcano
Relative size	large		
Nature of eruption			moderate to high eruptive force
Materials extruded	lava, gas	cinders, gas	
Composition of lava			high silica
Ability of lava to flow		low	variable



(t)James L. Amos/CORBIS, (c)Michael Collier, (b)Phillip Wallick/The Stock Market/CORBIS

Using Vocabulary

cinder cone volcano p. 222	magnitude p. 213
composite volcano p. 223	rift p. 227
earthquake p. 210	seismic safe p. 217
epicenter p. 212	seismic wave p. 212
fault p. 211	seismograph p. 213
focus p. 212	shield volcano p. 222
hot spot p. 228	tsunami p. 215
lava p. 219	volcano p. 219

Explain the differences between the vocabulary words in each of the following sets.

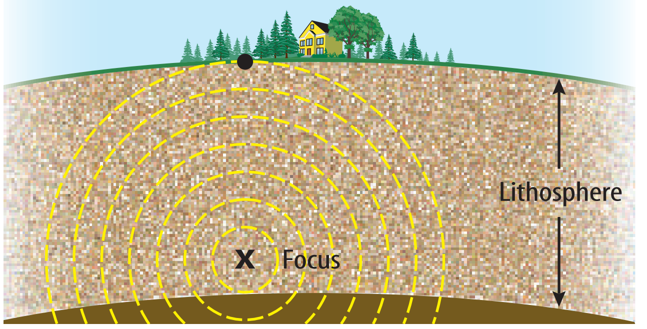
1. fault—earthquake
2. shield volcano—composite volcano
3. focus—epicenter
4. seismic wave—seismograph
5. tsunami—seismic wave
6. epicenter—earthquake
7. cinder cone volcano—shield volcano

Checking Concepts

Choose the word or phrase that best answers the question.

8. Which type of plate boundary caused the formation of the Soufrière Hills volcano?
   A) divergent **C)** rift
   B) transform **D)** convergent
9. What is a cone-shaped mountain that is built from layers of lava?
   A) volcano **C)** vent
   B) lava flow **D)** crater
10. What is the cause of the volcanoes on Hawaii?
    A) rift zone
    B) hot spot
    C) divergent plate boundary
    D) convergent plate boundary
11. Which type of lava flows easily?
    A) silica-rich **C)** basaltic
    B) composite **D)** smooth
12. Which type of volcano is built from alternating layers of lava and tephra?
    A) shield **C)** lava dome
    B) cinder cone **D)** composite
13. Which type of volcano is relatively small with steep sides?
    A) shield **C)** lava dome
    B) cinder cone **D)** composite
14. Which seismic wave moves through Earth at the fastest speed?
    A) primary wave
    B) secondary wave
    C) surface wave
    D) tsunami
15. Which of the following is a wave of water caused by an earthquake under the ocean?
    A) primary wave
    B) secondary wave
    C) surface wave
    D) tsunami

Use the illustration below to answer question 16.



16. What is the point on Earth's surface directly above an earthquake's focus?
    A) earthquake center
    B) epicenter
    C) fault
    D) focus

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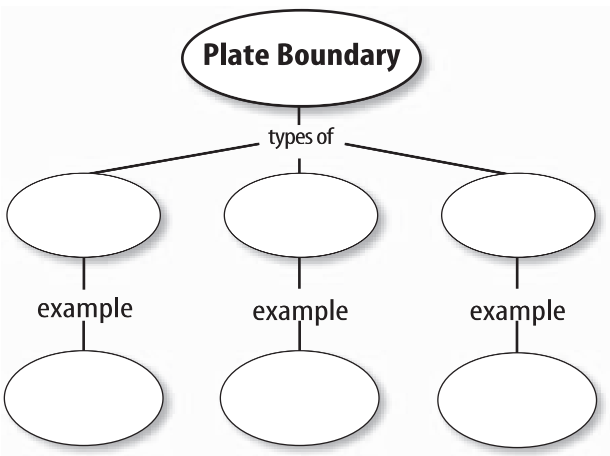
CONTENTS

Thinking Critically

17. **Infer** Why does the Soufrière Hills volcano erupt so explosively?
18. **Compare and contrast** composite and cinder cone volcanoes.
19. **Explain** how the composition of magma can affect the way a volcano erupts.
20. **Evaluate** What factors determine an earthquake's intensity on the modified Mercalli scale?
21. **Compare and contrast** magnitude and intensity.
22. **Make Models** Select one of the three forms of volcanoes and make a model, using appropriate materials.
23. **Draw Conclusions** You are flying over an area that has just experienced an earthquake. You see that most of the buildings are damaged or destroyed and much of the surrounding countryside is disrupted. What level of intensity would you conclude for this earthquake?
24. **Concept Map** Copy and complete this concept map on examples of features produced along plate boundaries. Use the following terms: *Mid-Atlantic Ridge, Soufrière Hills volcano, divergent, San Andreas Fault, convergent,* and *transform.*

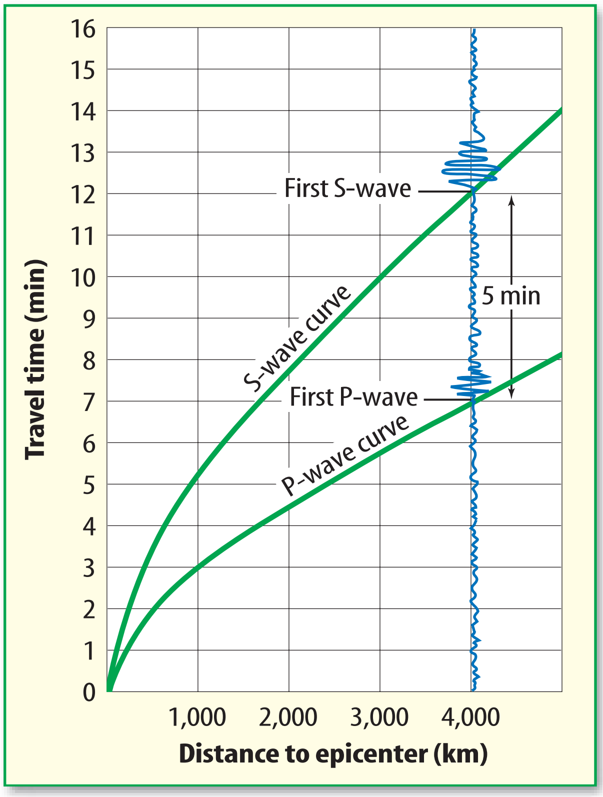


Performance Activities

25. **Oral Presentation** Research the earthquake or volcano history of your state or community. Find out how long ago your area experienced earthquake- or volcano-related problems. Present your findings in a speech to your class.

Applying Math

Use the graph below to answer questions 26 and 27.



26. **Earthquake Epicenter** If a P-wave arrives at a seismograph station at 9:07 AM and the S-wave arrives at the same seismograph station at 9:09 AM, about how far is that station from the epicenter of the earthquake?
27. **Arrival Time** A seismograph station is 2,500 km from the epicenter of an earthquake. What is the difference in time between the P-wave arrival time and the S-wave arrival time?

Part 1 Multiple Choice

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

Use the table below to answer questions 1 and 2.

Plate Boundaries		
Plate	**Number of convergent boundaries**	**Number of divergent boundaries**
African	1	4
Antarctic	1	2
Indo-Australian	4	2
Eurasian	4	1
North American	2	1
Pacific	6	2
South American	2	1

1. Which plate has the most spreading boundaries?
   A. African
   B. Indo-Australian
   C. Pacific
   D. Antarctic

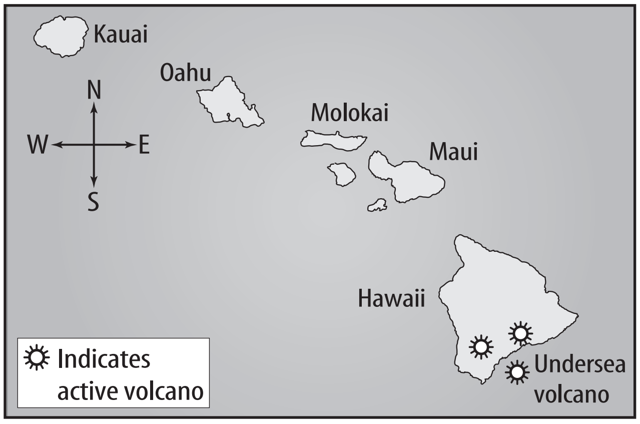
2. If composite volcanoes often form along convergent boundaries, which plate should be surrounded by the most composite volcanoes?
   A. Pacific **C.** Eurasian
   B. Antarctic **D.** Indo-Australian

3. Which of the following best describes a fault?
   A. the point on Earth's surface located directly above the earthquake focus
   B. the point inside Earth where movement first occurs during an earthquake
   C. the surface of a break in a rock along which there is movement
   D. the snapping back of a rock that has been strained by force

4. Waves created by earthquakes that travel through Earth's interior and along Earth's surface are called
   A. sound waves. **C.** light waves.
   B. energy waves. **D.** seismic waves.

5. Volcanoes are associated with all of the following areas EXCEPT
   A. rift zones. **C.** subduction zones.
   B. epicenters. **D.** hot spots.

Use the figure below to answer question 6 and 7.



6. In which direction is the Pacific Plate moving?
   A. north-northwest
   B. north-northeast
   C. south-southwest
   D. south-southeast

7. Which of the following islands is the oldest?
   A. Kauai **C.** Maui
   B. Molokai **D.** Hawaii

Test-Taking Tip

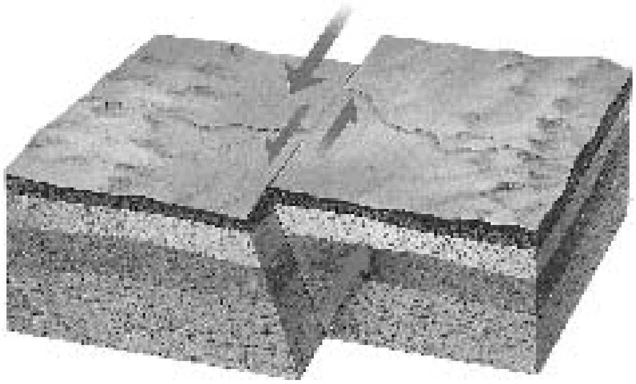
Watch the Time If you are taking a timed test, keep track of time during the test. If you find you're spending too much time on a multiple-choice question, mark your best guess and move on.

Part 2 Short Response/Grid In

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

8. What is an earthquake?

Use the figure below to answer questions 9 and 10.



9. Identify the type of fault shown here.

10. Explain how this type of fault is formed.

11. What is a tsunami? What happens when a tsunami enters shallow water?

12. The lava of a particular volcano is high in silica and water vapor and other gases. What kind of eruptive force will likely result from this volcano?

13. Suppose a tsunami begins near the Aleutian Islands in Alaska. The wave reaches the Hawaiian Islands, a distance of 3800 km, 5 hours later. At what speed is the wave traveling?

14. What is elastic rebound? How does it relate to strain energy and earthquakes?

15. Describe a volcanic crater. Where is it located? What is its shape?

16. What is a seismograph? How does it work?

Part 1 Multiple Choice

Record your answers on a sheet of paper.

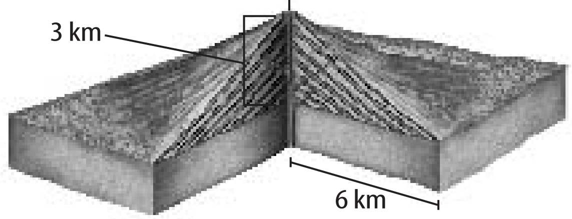
17. Identify the characteristics associated with a shield volcano. How does a shield volcano form?

18. Compare and contrast divergent plate boundaries and convergent plate boundaries.

19. Explain how convection currents may be related to plate tectonics.

20. Describe each of the three types of seismic waves.

Use the figure below to answer question 21.



21. Which type of volcano is shown in the figure? Explain how you know this. Where does this type of volcano form?

22. Explain the relationship between faults and earthquakes.

23. Some surface waves vibrate in a side-to-side, or swaying, motion parallel to Earth's surface. Why is this type of motion so devastating to human-built structures?

24. What type of magma is associated with fissure eruptions? What type of features can these eruptions form?