

Chapter 13

Volcanoes

Chapter Outline

1 Volcanoes and Plate Tectonics

Formation of Magma

Volcanism

Major Volcanic Zones

Intrusive Activity

2 Volcanic Eruptions

Types of Eruptions

Types of Pyroclastic Material

Types of Volcanoes

Calderas


Predicting Volcanic Eruptions



Why It Matters

Volcanic eruptions can build landforms such as mountains and islands. Volcanic eruptions can also be dangerous to human life and property. Learning about volcanoes helps scientists better predict eruptions and warn people to leave an area where an eruption is likely.

Inquiry Lab

 20 min

Temperature and Flow Properties

Put one **teaspoon** of **corn syrup** into each of **two small beakers**. Place one beaker into a **hot-water bath**, and place the other beaker into a **cold-water bath**. Leave the beakers in the water baths for ten min.

Make a ramp by leaning a piece of **stiff cardboard** against some **blocks**. Pour the hot and cold syrup side by side on the ramp at the same time. Observe the speed and shape of the two flows of syrup.

Questions to Get You Started

1. How did temperature affect the speed and shape of the syrup flows?
2. How might your observations apply to other fluids?



Science Terms

Everyday Words Used in Science Many words used in science are familiar words from everyday speech. However, when these words are used in science, their meanings are often different from the everyday meanings. Knowing the definitions of such words lets you use them correctly in scientific contexts.

Your Turn As you read Section 2, make a table like the one below for the terms *volcanic ash*, *volcanic dust*, *volcanic bombs*, and *volcanic blocks*. Include the scientific context of the term and the everyday meaning of the word that comes after the word *volcanic*.

| Term | Scientific Context | Everyday Meaning |
|--------------|---|---|
| volcanic ash | pyroclastic particles that are less than 2 mm in diameter | ash—the powder that is left after something is burned |

Frequency

Some, Many, or Most? Many statements include a word that tells you how often the statement is true. Examples of frequency words are *sometimes*, *commonly*, and *usually*. Words such as *some*, *many*, and *most* tell you about frequency in number.

Your Turn As you read Section 2, make a list of statements that contain frequency words. For each statement in your list, underline the word or phrase that tells how frequently the statement is true. An example is given below.

Frequency Statement:
Most volcanic dust and ash settles on the land that immediately surrounds the volcano.

Note Taking

Summarizing Ideas Summarizing the text under a heading is a simple way to take notes. Tips on summarizing are listed below.

- 1 Summary statements should be short but should fully express the idea.
- 2 Many paragraphs start or end with a sentence that summarizes the main idea of the paragraph.
- 3 In some cases, you may need more than one sentence to summarize a paragraph.

Your Turn Use summarizing to take notes for Section 1. Include the section titles and red or green headings. The example below can help you get started.

Section 1—Volcanoes and Plate Tectonics

- Many volcanic eruptions are caused by the movement of tectonic plates.

Formation of Magma

- Rock can melt into magma when the rock's temperature rises, the pressure on the rock is lowered, or fluids are added.

SECTION
1

Volcanoes and Plate Tectonics

Key Ideas

- Describe the three conditions under which magma can form.
- Explain what volcanism is.
- Identify three tectonic settings where volcanoes form.
- Describe how magma can form plutons.

Key Terms

magma
volcanism
lava
volcano
hot spot

Why It Matters

The heat associated with volcanic activity can be used as a source of nonpolluting geothermal energy. Volcanoes are a window into this underground resource.

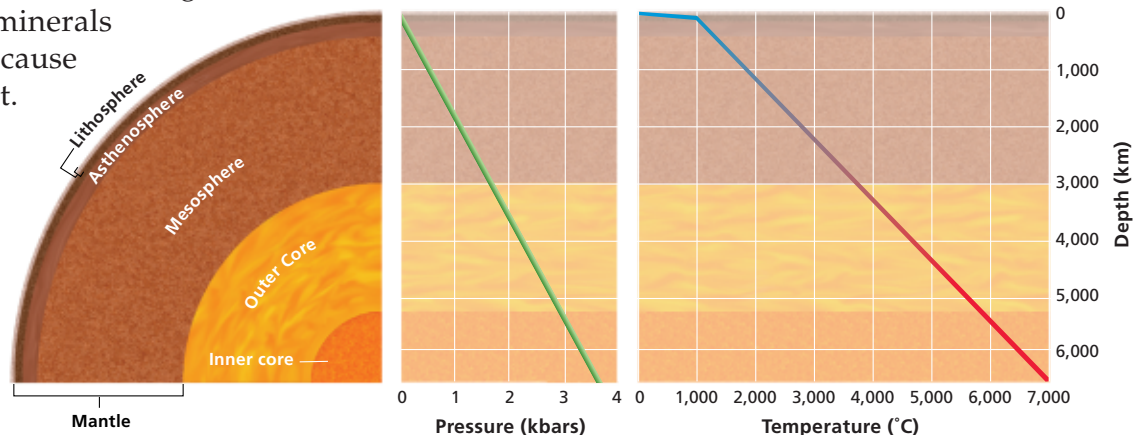
Volcanic eruptions can cause some of the most dramatic changes to Earth's surface. Some eruptions can be more powerful than the explosion of an atomic bomb. The cause of many of these eruptions is the movement of tectonic plates. The movement of tectonic plates is driven by Earth's internal heat.

By studying temperatures within Earth, scientists can learn more about volcanic eruptions. **Figure 1** shows estimates of Earth's inner temperatures and pressures. The combined temperature and pressure in the lower part of the mantle keeps the rocks below their melting point.

Formation of Magma

Despite the high temperature in the mantle, most of this zone remains solid because of the large amount of pressure from the surrounding rock. Sometimes, however, solid mantle and crust melt to form **magma**, or liquid rock that forms under Earth's surface.

Magma can form under three conditions. First, if the temperature of rock rises above the melting point of the minerals the rock is composed of, the rock will melt. Second, if enough pressure is removed from the rock, the melting point will decrease and the rock will melt. Third, the addition of fluids, such as water, may decrease the melting point of some minerals in the rock and cause the rock to melt.



magma liquid rock produced under Earth's surface

Figure 1 Temperature and pressure increase as depth beneath Earth's surface increases. So, rock in the lower mantle stays below its melting point.

volcanism any activity that includes the movement of magma toward or onto Earth's surface

lava magma that flows onto Earth's surface; the rock that forms when lava cools and solidifies

volcano a vent or fissure in Earth's surface through which magma and gases are expelled

Academic Vocabulary

expel (ek SPEL) to eliminate or drive out a contained substance

READING TOOLBOX

Some, Many, or Most?

As you read this section, make a list of frequency statements that describe volcanism.

Volcanism

Any activity that includes the movement of magma onto Earth's surface is called **volcanism**. Magma rises upward through the crust because the magma is less dense than the surrounding rock. As bodies of magma rise toward the surface, they can become larger in two ways. First, because they are so hot, they can melt some of the surrounding rock. Second, as the magma rises, it is forced into cracks in the surrounding rock. This process causes large blocks of overlying rock to break off and melt. Both of these processes add material to the magma body.

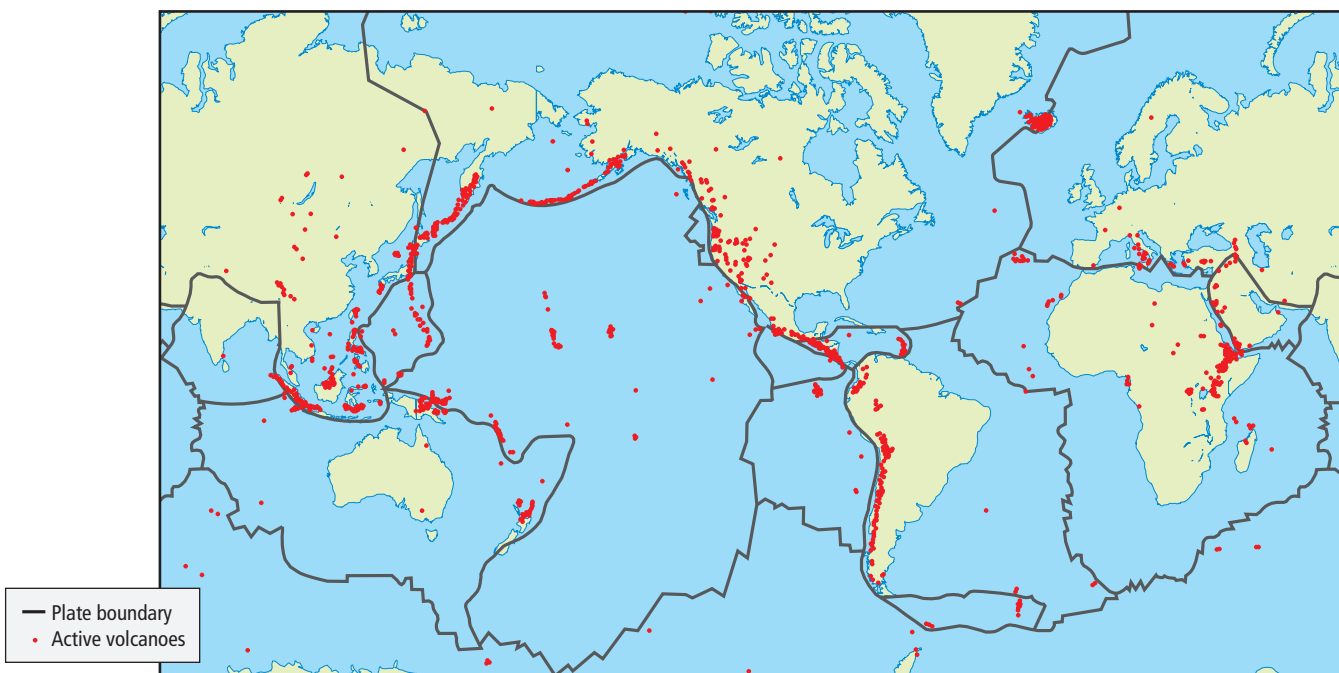
When magma erupts onto Earth's surface, the magma is then called **lava**. As lava flows from an opening, or *vent*, it might build up as a cone of material that eventually forms a mountain. The vent in Earth's surface through which magma and gases are expelled is called a **volcano**.

Major Volcanic Zones

If you were to plot the locations of the volcanoes that have erupted in the past 50 years, you would see that the locations form a pattern across Earth's surface. Like earthquakes, most active volcanoes occur in zones near both convergent and divergent boundaries of tectonic plates, as shown in **Figure 2**.

A major zone of active volcanoes encircles the Pacific Ocean. This zone, called the Pacific Ring of Fire, is formed by the subduction of plates along the Pacific coasts of North America, South America, Asia, and the islands of the western Pacific Ocean. The Pacific Ring of Fire is also one of Earth's major earthquake zones.

Figure 2 This map shows the locations of major tectonic plate boundaries and active volcanoes.



Subduction Zones

Many volcanoes are located along *subduction zones*, where one tectonic plate moves under another. When a plate that consists of oceanic lithosphere meets a plate that consists of continental lithosphere, the denser oceanic lithosphere moves beneath the continental lithosphere. A deep *trench* forms on the ocean floor along the edge of the continent where the plate is subducted. The plate that consists of continental lithosphere buckles and folds to form a line of mountains along the edge of the continent.

As the oceanic plate sinks into the asthenosphere, fluids such as water from the subducting plate combine with crust and mantle material. These fluids decrease the melting point of the rock and cause the rock to melt and form magma. When the magma rises through the lithosphere and erupts on Earth's surface, lines of volcanic mountains form along the edge of the tectonic plate.

If two plates that have oceanic lithosphere at their boundaries collide, one plate subducts, and a deep trench forms. As when oceanic lithosphere collides with continental lithosphere, magma forms as fluids are introduced into the mantle. Some of the magma breaks through the overriding plate to Earth's surface. Over time, a string of volcanic islands, called an *island arc*, forms on the overriding plate, as shown in **Figure 3**. The early stages of this type of subduction produce an arc of small volcanic islands, such as the Aleutian Islands, which are in the North Pacific Ocean and between Alaska and Siberia. As more magma reaches the surface, the islands become larger and join to form one landmass, such as the volcanic islands that joined to form present-day Japan.

Reading Check When a plate that consists of oceanic crust and a plate that consists of continental crust meet, which plate subducts beneath the other plate? (See Appendix G for answers to Reading Checks.)

Quick Lab



5 min

Changing Melting Point

Procedure

- 1 Place a **piece of ice** on a small **paper plate**.
- 2 Wait 1 min, and observe how much ice has melted. Remove the meltwater from the plate.
- 3 Pour **1/4 teaspoon of salt** onto a **second piece of ice**.
- 4 Wait 1 min, and observe how much ice has melted.

Analysis

1. What happened to the rate of melting when you added salt to the ice?
2. In this model, what is represented by the ice? by the salt?

Figure 3 The Aleutian Islands (below) formed when oceanic lithosphere subducted beneath oceanic lithosphere and caused magma to rise to the surface and erupt to form volcanic islands (left).

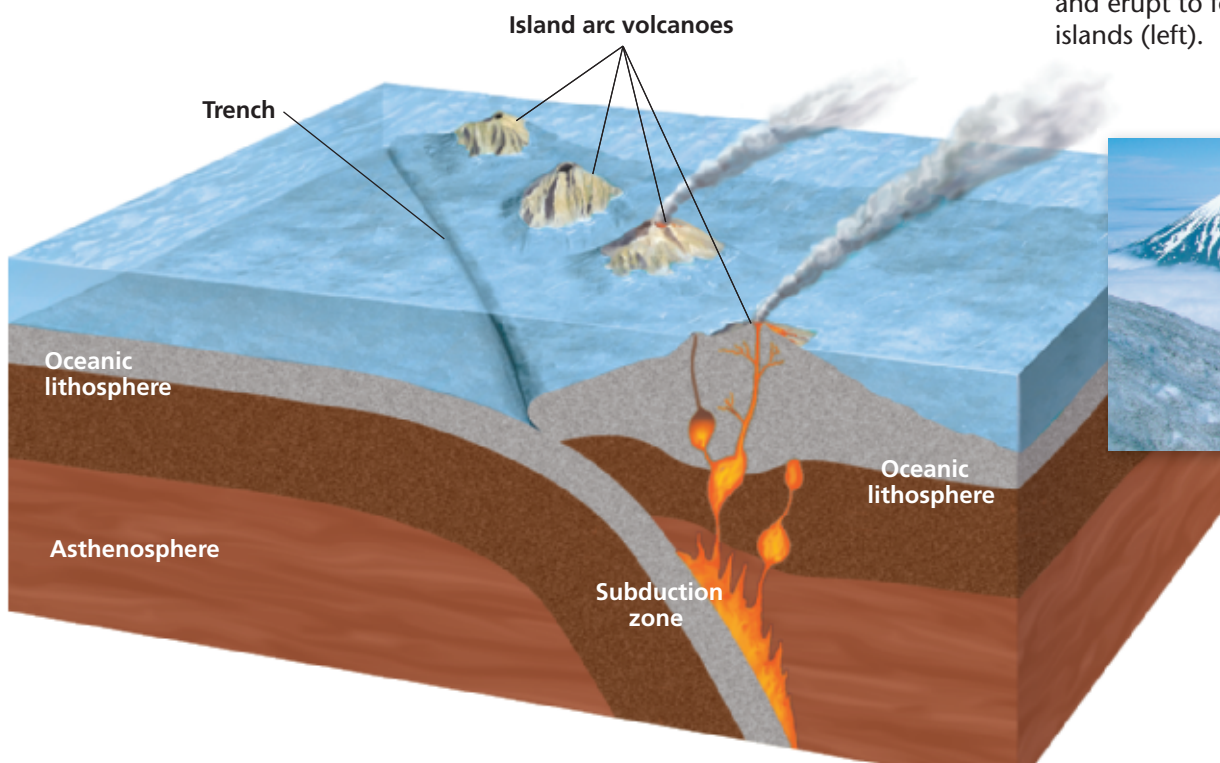




Figure 4 When water rapidly cools hot lava, a hard, pillow-shaped crust forms. As the crust cools, it contracts and cracks. Hot lava flows through the cracks in the crust and then cools quickly to form another pillow-shaped structure.

Mid-Ocean Ridges

The largest amount of magma comes to the surface where plates are moving apart at mid-ocean ridges. Thus, the interconnected mid-ocean ridges that circle Earth form a major zone of volcanic activity. As plates pull apart, magma flows upward along the rift zone. The upwelling magma adds material to the mid-ocean ridge and creates new lithosphere along the rift. This magma erupts to form underwater volcanoes. **Figure 4** shows pillow lava, an example of volcanic rock that forms underwater at a mid-ocean ridge. Pillow lava is named for its pillow shape, which is caused by the water that rapidly cools the outer surface of the lava.

Most volcanic eruptions that happen along mid-ocean ridges are unnoticed by humans because the eruptions take place deep in the ocean. An exception is found on Iceland. Iceland is one part of the Mid-Atlantic Ridge that is above sea level. One-half of Iceland is on the North American plate and is moving westward. The other half is on the Eurasian plate and is moving eastward. The middle of Iceland is cut by large *fissures*, which are cracks through which lava flows to Earth's surface.

Why It Matters

Energy Underfoot

Volcanic activity and heat go together! People can harness this energy as a clean and renewable power source. Iceland, a volcanic island, is rich in geothermal resources. Swimmers enjoy Iceland's Blue Lagoon, formed by water released from a geothermal power plant. Using geothermal energy decreases the need for oil and other fuels.



The Geysers, near San Francisco, is a group of power plants that use geothermal energy to produce non-polluting steam. The steam turns turbines that generate electricity.



California uses geothermal energy to generate some of the electricity it consumes. This map shows California's major geothermal fields in red.

YOUR TURN

UNDERSTANDING CONCEPTS

What are some advantages of using geothermal energy?

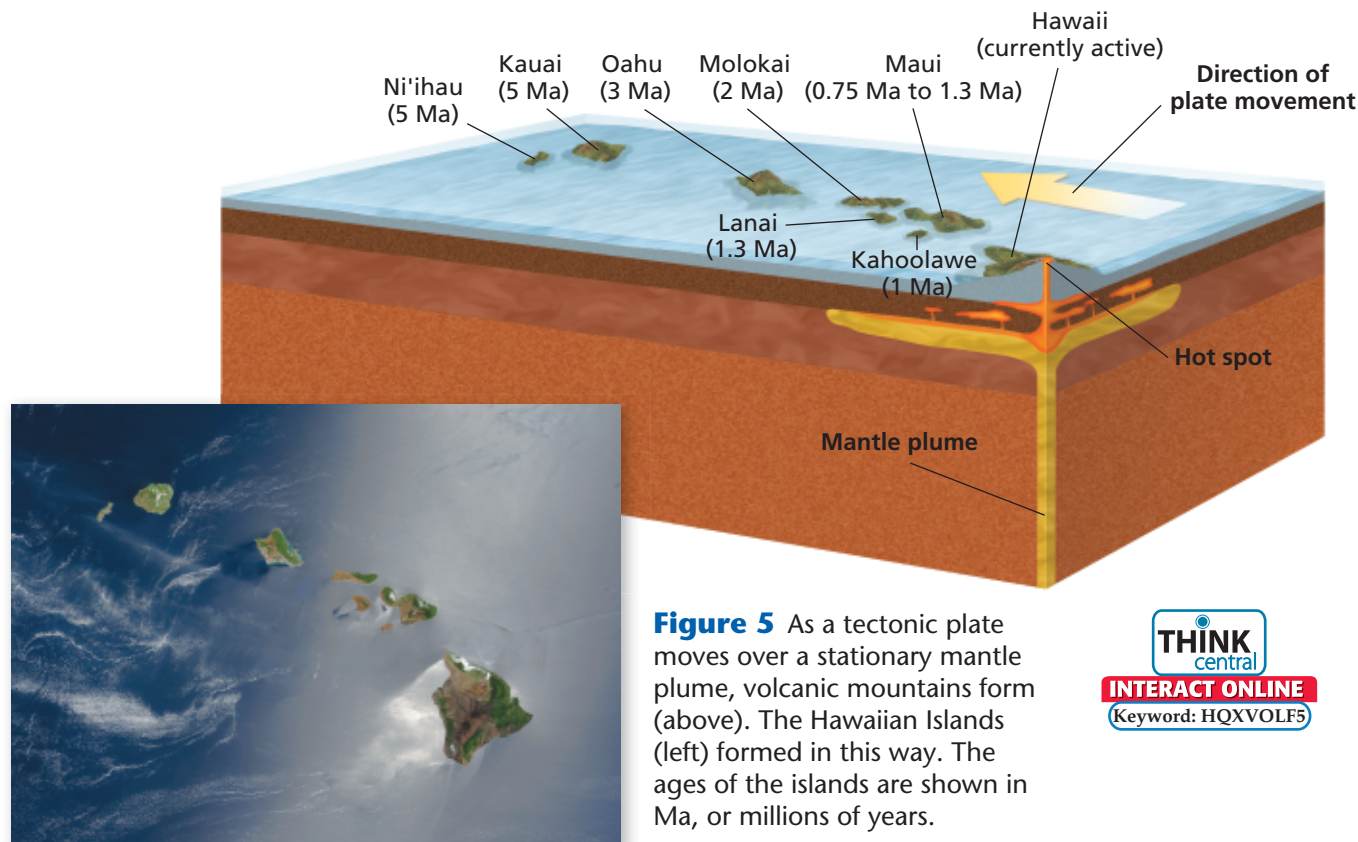


Figure 5 As a tectonic plate moves over a stationary mantle plume, volcanic mountains form (above). The Hawaiian Islands (left) formed in this way. The ages of the islands are shown in Ma, or millions of years.

THINK
central
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Hot Spots

Not all volcanoes develop along plate boundaries. Areas of volcanism within the interiors of lithospheric plates are called **hot spots**. Most hot spots form where columns of solid, hot material from the deep mantle, called *mantle plumes*, rise and reach the lithosphere. When a mantle plume reaches the lithosphere, the plume spreads out. As magma rises to the surface, it breaks through the overlying crust. Volcanoes can then form in the interior of a tectonic plate, as shown in **Figure 5**.

Mantle plumes appear to remain nearly stationary. However, the lithospheric plate above a mantle plume continues to drift slowly. So, the volcano on the surface is eventually carried away from the mantle plume. The activity of the volcano stops because it has moved away from the hot spot that supplied it with magma. A new volcano forms, however, at the point on the plate's surface that is now over the mantle plume.

Some mantle plumes are long and linear. As magma generated by these plumes rises through cracks in Earth's crust, a line of hot-spot volcanoes forms. Unlike volcanoes that form individually as a plate moves over a mantle plume, hot-spot volcanoes that form in lines over a long plume do not have any particular age relationship to each another.

Reading Check Explain how one mantle plume can form several volcanic islands.

hot spot a volcanically active area of Earth's surface, commonly far from a tectonic plate boundary

Figure 6 Devils Tower in Wyoming is an example of a pluton, a formation caused by the cooling of magma beneath Earth's surface. Erosion of surrounding rock has revealed this igneous formation.



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Topic: Volcanic Zones

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Intrusive Activity

Because magma is less dense than solid rock, magma rises through the crust toward the surface. As the magma moves upward, it pushes into, or *intrudes*, the overlying rock. Because of magma's high temperature, magma affects surrounding rock in a variety of ways. Magma may melt surrounding rock, or it may change the rock. Magma may also fracture surrounding rock and cause fissures to form, or it may cause the surrounding rock to break apart and fall into the magma. Rock that falls into the magma may eventually melt, or the rock may be included as foreign pieces within the new *igneous rock*, which is rock that forms when the magma cools.

When magma does not reach Earth's surface, the magma may cool and solidify inside the crust. This process results in large formations of igneous rock called *plutons*, as shown in **Figure 6**. Plutons can vary greatly in size and shape. Small plutons called *dikes* are tabular in shape and may be only a few centimeters wide. *Batholiths* are large plutons that cover an area of at least 100 km² when they are exposed on Earth's surface.

Section 1 Review

Key Ideas

- 1. Describe** three conditions that affect whether magma forms.
- 2. Explain** how magma reaches Earth's surface.
- 3. Compare** magma with lava.
- 4. Describe** how subduction produces magma.
- 5. Identify** three tectonic settings where volcanoes commonly occur.
- 6. Summarize** the formation of hot spots.
- 7. Describe** two igneous structures that form under Earth's surface.

Critical Thinking

- 8. Identifying Relationships** Describe how the presence of ocean water in crustal rock might affect the formation of magma.
- 9. Applying Ideas** Yellowstone National Park in Wyoming is far from any plate boundary. How would you explain the volcanic activity in the park?

Concept Mapping

- 10.** Use the following terms to create a concept map: *magma*, *volcanism*, *vent*, *volcano*, *subduction zone*, *hot spot*, *dike*, and *pluton*.

Volcanic Eruptions

Key Ideas

- Explain how the composition of magma affects volcanic eruptions and lava flow.
- Describe the five major types of pyroclastic material.
- Identify the three main types of volcanic cones.
- Describe how a caldera forms.
- List three events that may signal a volcanic eruption.

Key Terms

mafic
felsic
pyroclastic material
caldera

Why It Matters

Understanding factors that lead to a quiet or explosive volcanic eruption lets scientists determine hazards associated with a particular volcano. By recognizing signs that an eruption may soon occur, scientists can issue warnings and save lives.

Volcanoes can be thought of as windows into Earth's interior. Lava that erupts from them provides an opportunity for scientists to study the nature of Earth's crust and mantle. By analyzing the composition of volcanic rocks, geologists have concluded that there are two general types of magma. **Mafic** (MAF ik) describes magma or rock that is rich in magnesium and iron and is commonly dark in color. **Felsic** (FEL sik) describes magma or rock that is rich in light-colored silicate materials. Mafic rock commonly makes up the oceanic crust, whereas felsic rock is more common than mafic rock in continental crust.

Types of Eruptions

The *viscosity*, or resistance to flow, of magma affects the force with which a particular volcano will erupt. The viscosity of magma is determined by the magma's composition. Because mafic magmas produce runny lava that has a low viscosity, they typically cause quiet eruptions. Because felsic magmas produce sticky lava that has a high viscosity, they typically cause explosive eruptions. Magma that contains large amounts of trapped, dissolved gases is more likely to produce explosive eruptions than is magma that contains small amounts of dissolved gases.

Quiet Eruptions

Oceanic volcanoes commonly form from mafic magma. Because of mafic magma's low viscosity, gases can easily escape from mafic magma. Eruptions from oceanic volcanoes, such as those in Hawaii, shown in **Figure 1**, are usually quiet.

mafic describes magma or igneous rock that is rich in magnesium and iron and that is generally dark in color
felsic describes magma or igneous rock that is rich in feldspars and silica and that is generally light in color

Figure 1 Lava flows from a quiet eruption like a red-hot river would flow. This lava flowed several miles from the Kilauea volcano to the sea.



Figure 2 Types of Mafic Lava Flows



Pahoehoe is the least viscous type of mafic lava. It forms wrinkly volcanic rock when it cools.



Aa lava is more viscous than pahoehoe lava and forms sharp volcanic rock when it cools.



Blocky lava is the most viscous type of mafic lava and forms chunky volcanic rock when it cools.

Math Skills

A Lot of Lava Since late 1986, Kilauea volcano in Hawaii has been erupting mafic lava. In 2003, the total volume of lava that had been produced by this eruption was 0.6 mi^3 , or 2.5 km^3 . Calculate the average amount of lava, in cubic meters, that erupts from Kilauea each year.

Lava Flows

When mafic lava cools rapidly, a crust forms on the surface of the flow. If the lava continues to flow after the crust forms, the crust wrinkles to form a volcanic rock called *pahoehoe* (pah HOH ee HOH ee), which is shown in **Figure 2**. Pahoehoe forms from hot, fluid lava. As it cools, it forms a smooth, ropy texture. Pahoehoe actually means “ropy” in Hawaiian.

If the crusted-over surface of the lava deforms rapidly or grows too thick to form wrinkles, the surface breaks into jagged chunks to form *aa* (AH AH). Aa forms from lava that has the same composition as pahoehoe lava. Aa lava’s texture results from differences in gas content and in the rate and slope of the lava flow.

Blocky lava has a higher silica content than aa lava does, which makes blocky lava more viscous than aa lava. The high viscosity causes the cooled lava at the surface to break into large chunks, while the hot lava underneath continues to flow. This process gives the lava flow a blocky appearance.

Reading Check How do flow rate and gas content affect the appearance of lavas?

Explosive Eruptions

Unlike the fluid lavas produced by oceanic volcanoes, the felsic lavas of continental volcanoes, such as Mount St. Helens, tend to be cooler and stickier. Felsic lavas also contain large amounts of trapped gases, such as water vapor and carbon dioxide. When a volcano erupts, the dissolved gases within the lava escape and send molten and solid particles shooting into the air. So, felsic lava tends to explode and throw pyroclastic material into the air. **Pyroclastic material** consists of fragments of rock that form during a volcanic eruption.

pyroclastic material fragments of rock that form during a volcanic eruption

Types of Pyroclastic Material

Some pyroclastic materials form when magma breaks into fragments during an eruption because of the rapidly expanding gases in the magma. Other pyroclastic materials form when fragments of erupting lava cool and solidify as they fly through the air.

Scientists classify pyroclastic materials according to the sizes of the particles, as shown in **Figure 3**. Pyroclastic particles that are less than 2 mm in diameter are called *volcanic ash*. Volcanic ash that is less than 0.25 mm in diameter is called *volcanic dust*. Usually, most volcanic ash settles on the land surrounding the volcano. However, some of the smallest dust particles may travel around Earth in the upper atmosphere.

Large pyroclastic particles that are less than 64 mm in diameter are called *lapilli* (luh PIL ie), which is from a Latin word that means “little stones.” Lapilli generally fall near the vent.

Large clots of lava may be thrown out of an erupting volcano while they are red-hot. As they spin through the air, they cool and develop a round or spindle shape. These pyroclastic particles are called *volcanic bombs*. The largest pyroclastic materials, known as *volcanic blocks*, form from solid rock that is blasted from the vent. Some volcanic blocks are the size of a small house.

READING TOOLBOX

Summarizing Ideas

As you read about types of pyroclastic material, summarize their characteristics.

Volcanic ash



Figure 3 During an explosive eruption, like this one at Mount St. Helens, ash, blocks, and other pyroclastic materials are ejected violently from the volcano.



Volcanic blocks



Lapilli



Types of Volcanoes

Academic Vocabulary

variety (vuh RIE uh tee) a collection of things that are very different from each other; diversity

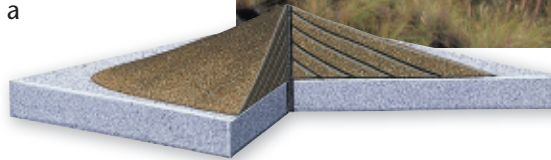
Volcanic activity produces a variety of characteristic features that form during both quiet and explosive eruptions. The lava and pyroclastic material that are ejected during volcanic eruptions build up around the vent and form volcanic cones. There are three main types of volcanic cones, as described in **Table 1**.

The funnel-shaped pit at the top of a volcanic vent is known as a *crater*. The crater forms when material is blown out of the volcano by explosions. A crater usually becomes wider as weathering and erosion break down the walls of the crater and allow loose materials to collapse into the vent. Sometimes, a small cone forms within a crater. This formation occurs when subsequent eruptions cause material to build up around the vent.

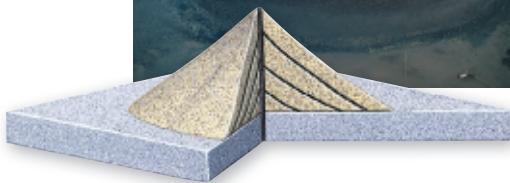
Table 1 Volcanic cones are classified into three main categories. *Which type of volcano would form from lava that is highly viscous?*

Types of Volcanoes

Shield Volcanoes Volcanic cones that are broad at the base and have gently sloping sides are called *shield volcanoes*. A shield volcano covers a wide area and generally forms from quiet eruptions. Layers of hot, mafic lava flow out around the vent, harden, and slowly build up to form the cone. The Hawaiian Islands are a chain of shield volcanoes that built up from the ocean floor at a hot spot, forming the largest volcanoes on Earth.



Cinder Cones A type of volcano that has very steep slopes is a cinder cone. The slope angles of cinder cones can be close to 40° , and the cones are rarely more than a few hundred meters high. Cinder cones form from small explosive eruptions and are made of pyroclastic material. Cinder cones are usually quite small in comparison to shield volcanoes or composite volcanoes.



Composite Volcanoes Composite volcanoes are made of alternating layers of hardened lava flows and pyroclastic material. During a quiet eruption, lava flows cover the sides of the cone. Then, when an explosive eruption occurs, large amounts of pyroclastic material are deposited around the vent. The explosive eruption is followed again by quiet lava flows. Composite volcanoes, also known as *stratovolcanoes*, commonly develop to form large volcanic mountains.

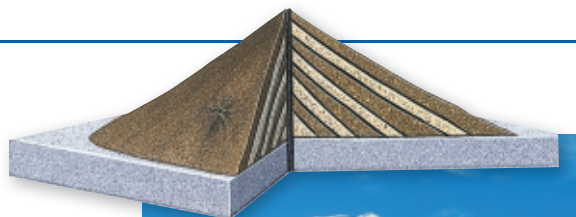
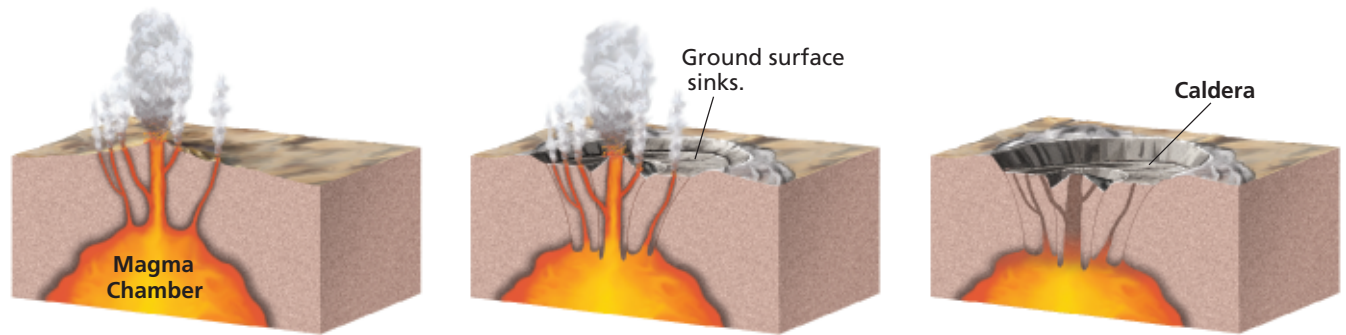


Figure 4 Formation of a Caldera



A cone forms from volcanic eruptions.

Volcanic eruptions partially empty the magma chamber.

The top of the cone collapses inward to form a caldera.

Calderas

When the magma chamber below a volcano empties, the volcanic cone may collapse and leave a large, basin-shaped depression called a **caldera** (kal DER uh). The process of caldera formation is shown in **Figure 4**.

Eruptions that discharge large amounts of magma can also cause a caldera to form. Krakatau, a volcanic island in Indonesia, is an example of this type of caldera. When the volcanic cone exploded in 1883, a caldera with a diameter of 6 km formed.

Calderas may later fill with water to form lakes. Thousands of years ago, the cone of Mount Mazama in Oregon collapsed during a massive eruption and formed a caldera. The caldera eventually filled with water and is now called Crater Lake.

caldera a large, circular depression that forms when the magma chamber below a volcano partially empties and causes the ground above to sink

Reading Check Describe two ways that calderas form.

Quick Lab Volcanic Cones



 25 min

Procedure

- 1 Pour **1/2 cup (about 4 oz)** of dry plaster of Paris into a **measuring cup**.
- 2 Use a **graduated cylinder** to measure **60 mL of water**, and add the water to the dry plaster in the measuring cup. Use a **mixing spoon** to blend the mixture until it is smooth.
- 3 Hold the measuring cup about 2 cm over a **paper plate**. Pour the contents slowly and steadily onto the center of the plate. Allow the plaster to dry.
- 4 On a clean paper plate, pour **dry oatmeal or potato flakes** slowly until the mound is approximately 5 cm high.

- 5 Without disturbing the mound, use a **protractor** to measure its slope.
- 6 When the plaster cone is hardened, remove it from the plate. Measure the average slope angle of the cone.

Analysis

1. Which cone represents a cinder cone? Which cone represents a shield volcano? Compare the slope angles formed by these cones.
2. How would the slope be affected if the oatmeal were rounder? How would the slope be affected if the oatmeal were thicker?
3. How would you use the same supplies to model a composite volcano?



Figure 5 These scientists are sampling gases emitted from the fumarole field on Vulcano Island in Italy.

Predicting Volcanic Eruptions

A volcanic eruption can be one of Earth's most destructive natural phenomena. Scientists, such as those in **Figure 5**, look for a variety of events that may signal the beginning of an eruption.

Earthquake Activity

One of the most important warning signals of a volcanic eruption is a change in earthquake activity around the volcano. Growing pressure on the surrounding rock from magma that is moving upward causes small earthquakes. Temperature changes within the rock and fracturing of the rock around a volcano also cause small earthquakes. An increase in the strength and frequency of earthquakes may be a signal that an eruption is about to occur.

Patterns in Activity

Before an eruption, the upward movement of magma beneath the surface may cause the surface of the volcano to bulge outward. Special instruments can measure small changes in the tilt of the ground surface on the volcano's slopes.

Predicting the eruption of a particular volcano also requires some knowledge of its previous eruptions. Scientists compare the volcano's past behavior with current daily measurements of earthquakes, surface bulges, and changes in the amount and composition of the gases that the volcano emits. Unfortunately, only a few of the active volcanoes in the world have been studied by scientists long enough to establish any activity patterns. Also, volcanoes that have been dormant for long periods of time may, with little warning, suddenly become active.

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Topic: Predicting Volcanic Eruptions
Code: HQX1209

Section 2 Review

Key Ideas

1. **Summarize** the difference between mafic and felsic magma.
2. **Explain** how the composition of magma affects the force of volcanic eruptions.
3. **Compare** three major types of lava flows.
4. **Define** *pyroclastic material*, and list three examples.
5. **Identify** the three main types of volcanic cones.
6. **Describe** how calderas form.
7. **List** three events that may precede a volcanic eruption.

Critical Thinking

8. **Applying Ideas** Would quiet eruptions or explosive eruptions be more likely to increase the steepness of a volcanic cone? Explain your answer.
9. **Drawing Conclusions** Why would a sudden increase in earthquake activity around a volcano indicate a possible eruption?

Concept Mapping

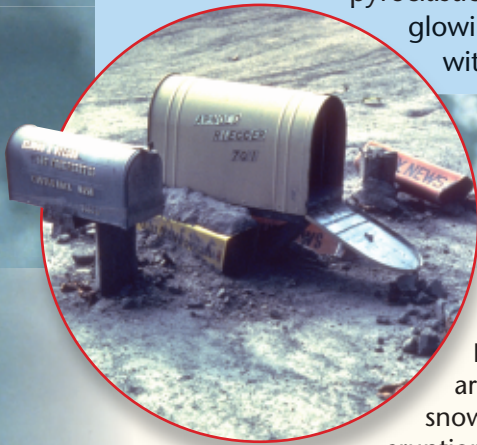
10. Use the following terms to create a concept map: *mafic lava*, *felsic lava*, *pahoehoe*, *aa*, *shield volcano*, *pyroclastic material*, *lapilli*, *volcanic bomb*, *volcanic block*, *volcanic ash*, and *volcanic dust*.

Why It Matters

Just How Dangerous Are Volcanoes?



Lava flows can be devastating, but volcanoes have many other powerful ways to cause death and destruction. For example, the 1980 eruption of Mount St. Helens included the initial landslide and explosion followed by heavy falls of volcanic ash and mudflows. Mount St. Helens is one of thirteen active volcanoes in the Cascade Range. Eruptions of Cascade volcanoes tend to be extremely explosive. In addition to other hazards, such eruptions can also produce pyroclastic flows—fast-moving flows of glowing-hot volcanic material mixed with deadly volcanic gases.



A volcanic mudflow partly buried these mailboxes. Many Cascade volcanoes are topped with ice and snow that can melt during an eruption. The water then mixes with volcanic ash to form mudflows resembling fast-moving rivers of cement.

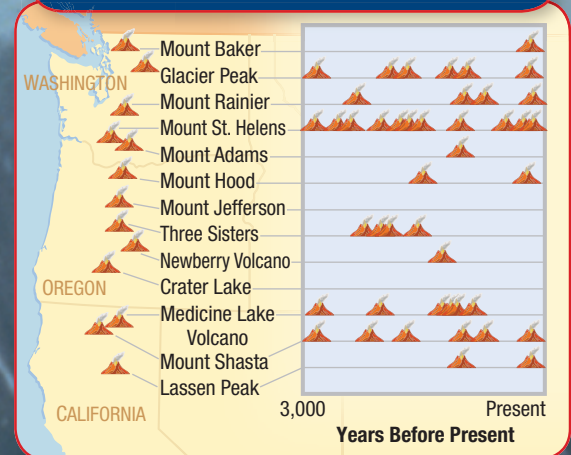


More than one million people live in the Seattle-Tacoma area near Mount Rainier, an active volcano.

A scientist monitors one of the Three Sisters volcanoes in Oregon for signs of an eruption or landslide.



Eruptions of Cascade Volcanoes



YOUR TURN

UNDERSTANDING CONCEPTS

What dangers are associated with explosive volcanic eruptions?

CRITICAL THINKING

What dangers are associated with volcanoes do not erupt explosively?

What You'll Do

- › **Create** a working apparatus to test carbon dioxide levels.
- › **Analyze** the levels of carbon dioxide emitted from a model volcano.
- › **Predict** the possibility of an eruption from a model volcano.

What You'll Need

baking soda, 15 cm³
 drinking bottle, 16 oz
 box or stand for plastic cup
 clay, modeling
 coin
 cup, clear plastic, 9 oz
 graduated cylinder
 limewater, 1 L
 straw, drinking, flexible
 tissue, bathroom (2 sheets)
 vinegar, white, 140 mL
 water, 100 mL

Safety



Volcano Verdict

You will need to have a partner for this lab. You and your partner will act as geologists who work in a city located near a volcano. City officials are counting on you to predict when the volcano will erupt next. You and your partner have decided to use limewater as a gas-emissions tester. You will use this tester to measure the levels of carbon dioxide emitted from a simulated volcano. The more active the volcano is, the more carbon dioxide it releases.

Procedure

- 1 Carefully pour limewater into the plastic cup until the cup is three-fourths full. Place the cup on a box or stand. This will be your gas-emissions tester.
- 2 Now, build a model volcano. Begin by pouring 50 mL of water and 70 mL of vinegar into the drink bottle.
- 3 Form a plug of clay around the short end of the straw. The clay plug must be large enough to cover the opening of the bottle. Be careful not to get the clay wet.

Step 6



- 4 Sprinkle 5 cm³ of baking soda along the center of a single section of bathroom tissue. Then, roll the tissue, and twist the ends so that the baking soda cannot fall out.
- 5 Drop the tissue into the drink bottle, and immediately put the short end of the straw inside the bottle and make a seal with the clay.
- 6 Put the other end of the straw into the limewater.
- 7 Record your observations. You have just taken your first measurement of gas levels from the volcano.
- 8 Imagine that it is several days later and that you need to test the volcano again to collect more data. Before you continue, toss a coin. If it lands heads up, go to step 9. If it lands tails up, go to step 10. Write down the step that you follow.
- 9 Repeat steps 1–7. But use 2 cm³ of baking soda in the tissue in step 4 instead of 5 cm³. (Note: You must use fresh water, vinegar, and limewater.) Record your observations.
- 10 Repeat steps 1–7. But use 8 cm³ of baking soda in the tissue in step 4 instead of 5 cm³. (Note: You must use fresh water, vinegar, and limewater.) Record your observations.

Analysis

1. **Explaining Events** How do you explain the difference in the appearance of the limewater from one trial to the next?
2. **Recognizing Patterns** What does the data that you collected tell you about the activity in the volcano?
3. **Evaluating Results** Based on your results in step 9 or 10, do you think it would be necessary to evacuate the city?
4. **Applying Conclusions** How would a geologist use a gas-emissions tester to predict volcanic eruptions?

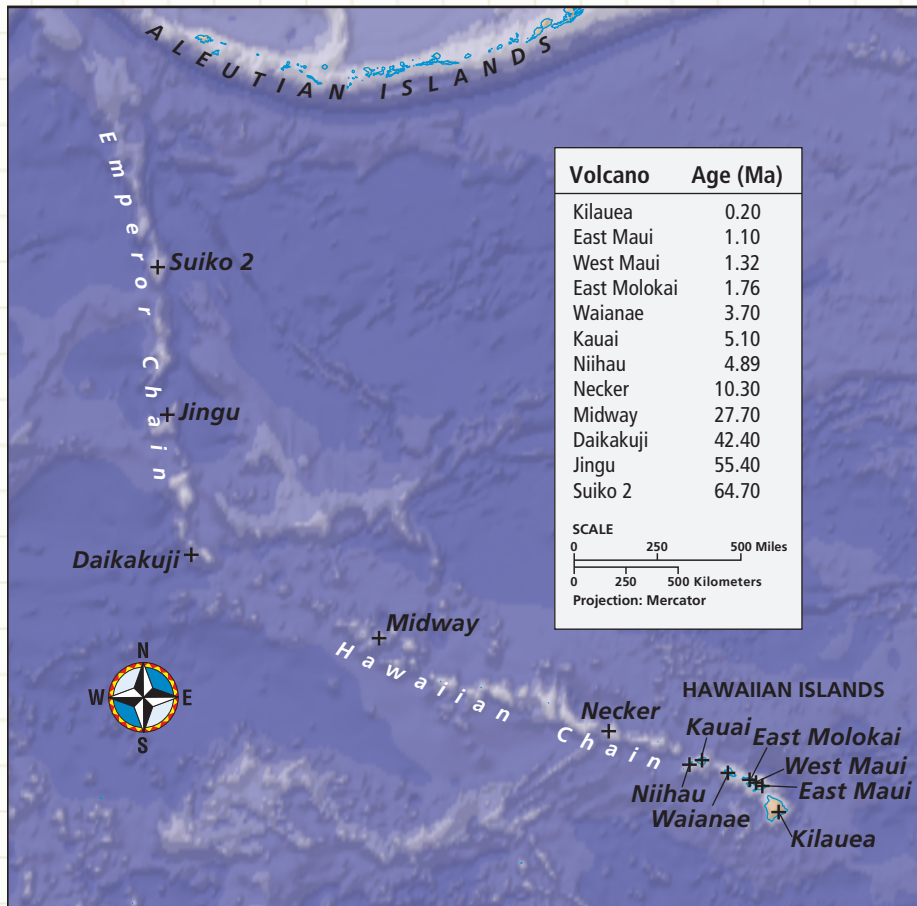
Extension

Evaluating Data Scientists base their predictions of eruptions on a variety of evidence before recommending an evacuation. What other forms of evidence would a scientist need to know to predict an eruption?



Mount Usu, 770 kilometers from Tokyo in Japan, erupted on March 31, 2000.

The Hawaiian-Emperor Seamount Chain



Map Skills Activity

This map shows the locations and ages of islands and seamounts in the Hawaiian-Emperor seamount chain, which is located in the Pacific Ocean. Use the map to answer the questions below.

- 1. Inferring Relationships** Under which volcano is the hot spot presently located?
- 2. Using a Key** Which volcano is the oldest?
- 3. Evaluating Data** A seamount is a submarine volcanic mountain. Would you expect older volcanoes to be seamounts or islands? Explain your answer.
- 4. Analyzing Data** Which island signifies a change in direction of the movement of the Pacific plate? Explain your answer.
- 5. Identifying Trends** In which direction has the Pacific plate been moving since the formation of the islands in the seamount chain changed direction?
- 6. Analyzing Relationships** How many years ago did the Pacific plate change its direction?
- 7. Analyzing Data** What is the average speed of the Pacific plate over the last 65 million years?
- 8. Predicting Consequences** Where would you expect a new volcano to form 1 million years from now?

Section 1**Section 2****Key Ideas****Volcanoes and Plate Tectonics**

- ▶ Magma can form when temperature increases in or pressure decreases on mantle rock. Magma also may form when water is added to hot rock.
- ▶ Volcanism is any activity that includes the movement of magma toward or onto Earth's surface.
- ▶ Volcanism is common at convergent and divergent boundaries between tectonic plates. Hot spots are areas of volcanic activity that are located over rising mantle plumes, which can exist far from tectonic plate boundaries.
- ▶ Magma that cools below Earth's surface forms intrusive igneous rock bodies called plutons.

Volcanic Eruptions

- ▶ Hotter, less viscous, mafic lava commonly causes quiet eruptions. Cooler, more viscous, felsic lava commonly causes explosive eruptions, especially if it contains trapped gases.
- ▶ The five major types of pyroclastic materials are, from smallest to largest, volcanic dust, volcanic ash, lapilli, volcanic bombs, and volcanic blocks.
- ▶ Volcanic cones are classified into three categories—shield volcanoes, cinder cones, and composite volcanoes—based on composition and form.
- ▶ A caldera forms where a volcanic cone collapses during a massive eruption and leaves a large, basin-shaped depression.
- ▶ Events that might signal a volcanic eruption include changes in earthquake activity, changes in the volcano's shape, changes in composition and amount of gases emitted, and changes in the patterns of the volcano's normal activity.

Key Terms

magma, p. 345
volcanism, p. 346
lava, p. 346
volcano, p. 346
hot spot, p. 349

mafic, p. 351
felsic, p. 351
pyroclastic material,
 p. 352
caldera, p. 355

- 1. Everyday Words Used in Science** Find the everyday meanings of the words *mantle* and *plume*. Then, compare the everyday meanings of these words with the scientific meaning of *mantle plume*.



USING KEY TERMS

Use each of the following terms in a separate sentence.

2. *volcanism*
3. *hot spot*
4. *pyroclastic material*

For each pair of terms, explain how the meanings of the terms differ.

5. *magma* and *lava*
6. *mafic* and *felsic*
7. *shield volcano* and *composite volcano*
8. *crater* and *caldera*

UNDERSTANDING KEY IDEAS

9. A characteristic of lava that determines the force of a volcanic eruption is
 - a. color.
 - b. viscosity.
 - c. density.
 - d. age.
10. Island arcs form when oceanic lithosphere subducts under
 - a. continental lithosphere.
 - b. calderas.
 - c. volcanic bombs.
 - d. oceanic lithosphere.
11. Areas of volcanism within tectonic plates are called
 - a. hot spots.
 - b. cones.
 - c. calderas.
 - d. fissures.
12. Explosive volcanic eruptions commonly result from

| | |
|------------------|-------------------|
| a. mafic magma. | c. aa lava. |
| b. felsic magma. | d. pahoehoe lava. |

13. Pyroclastic materials that form rounded or spindle shapes as they fly through the air are called
 - a. ash.
 - b. volcanic bombs.
 - c. lapilli.
 - d. volcanic blocks.
14. A cone formed by only solid fragments built up around a volcanic opening is a
 - a. shield volcano.
 - b. cinder cone.
 - c. composite volcano.
 - d. stratovolcano.
15. The depression that results when a volcanic cone collapses over an emptying magma chamber is a
 - a. crater.
 - b. caldera.
 - c. vent.
 - d. fissure.
16. Scientists have discovered that before an eruption, earthquakes commonly
 - a. stop.
 - b. increase in number.
 - c. have no relationship with volcanism.
 - d. decrease in number.

SHORT ANSWER

17. At what point does magma become lava?
18. Describe how tectonic movement can form volcanoes.
19. Name the process that includes the movement of magma onto Earth's surface.
20. What may happen to magma that does not reach Earth's surface?
21. How is the composition of magma related to the force of volcanic eruptions?
22. List and describe the major types of pyroclastic material.
23. Compare the three main types of volcanic cones.
24. What signs can scientists study to try to predict volcanic eruptions?

CRITICAL THINKING

- 25. Analyzing Ideas** Why is most lava that forms on Earth's surface unnoticed and unobserved?
- 26. Identifying Relationships** The Pacific Ring of Fire is a zone of major volcanic activity because of tectonic plate boundaries. Identify another area of Earth where you might expect to find volcanic activity.
- 27. Analyzing Processes** Why does felsic lava tend to form composite volcanoes and cinder cones rather than shield volcanoes?
- 28. Making Inferences** How might geologists distinguish an impact crater on Earth, such as Meteor Crater in Arizona, from a volcanic crater?
- 29. Making Comparisons** Sinkholes form when the roof of an underground cave is not supported by groundwater. Compare this process to the process by which calderas form.

CONCEPT MAPPING

- 30.** Use the following terms to create a concept map: *magma, lava, volcano, pluton, mafic lava, felsic lava, pyroclastic material, volcanic ash, volcanic dust, lapilli, volcanic bomb, volcanic block, volcanic cone, shield volcano, cinder cone, and composite volcano.*

MATH SKILLS

Math Skills

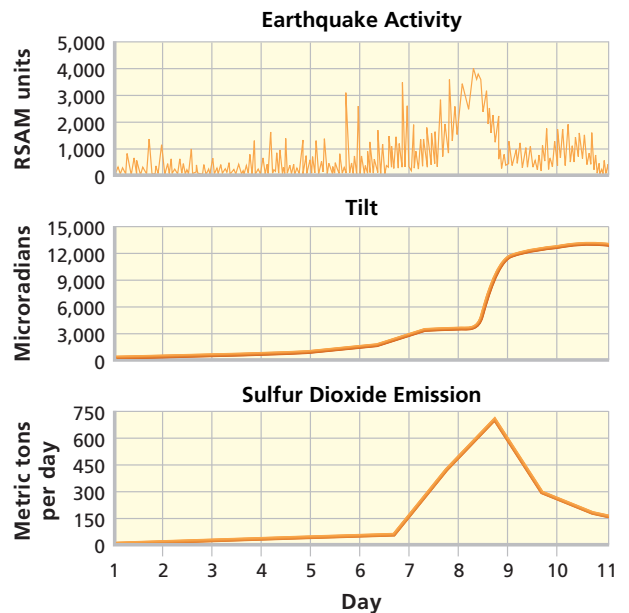
- 31. Making Calculations** On day 1, a volcano expelled 5 metric tons of sulfur dioxide. On day 2, the same volcano expelled 12 metric tons of sulfur dioxide. What is the percentage increase in sulfur dioxide expelled from day 1 to day 2?
- 32. Interpreting Statistics** A lava flow traveled for 7.3 min before it flowed into the ocean. The speed of the lava was 3 m/s. How far did the lava flow travel?

WRITING SKILLS

- 33. Outlining Topics** Outline the essential steps in the process of caldera formation.
- 34. Communicating Main Ideas** Write an essay describing the formation of a volcano.

INTERPRETING GRAPHICS

The graphs below show data about earthquake activity; the slope angle, or *tilt*, of the ground; and the amount of gas emitted for a particular volcano over a period of 10 days. Use the graphs to answer the questions that follow.



- 35.** On what day did the volcano erupt? Explain your answer.
- 36.** For how many days before the eruption did gas emission increase?
- 37.** Why do you think the slope angle of the ground did not return to its original angle after the eruption?

Understanding Concepts

Directions (1–5): For each question, write on a separate sheet of paper the letter of the correct answer.

1. What type of volcanic rock commonly makes up much of the continental crust?
 - A. basalt rock that is rich in olivines
 - B. felsic rock that is rich in silicates
 - C. limestone that is rich in calcium carbonate
 - D. mafic rock that is rich in iron and magnesium
2. Which of the following formations results from magma that cools before it reaches Earth's surface?
 - F. batholiths
 - H. volcanic blocks
 - G. mantle plumes
 - I. aa lava
3. How does volcanic activity contribute to plate margins where new crust is being formed?
 - A. Where plates collide at subduction zones, rocks melt and form pockets of magma.
 - B. Between plate boundaries, hot spots may form a chain of volcanic islands.
 - C. When plates pull apart at oceanic ridges, magma creates new ocean floor.
 - D. At some boundaries, new crust is formed when one plate is forced on top of another.
4. An important warning sign of volcanic activity
 - F. would be a change in local wind patterns.
 - G. is a bulge in the surface of the volcano.
 - H. might be a decrease in earthquake activity.
 - I. is a marked increase in local temperatures.
5. Which aspect of mafic lava is important in the formation of smooth, ropy pahoehoe lava?
 - A. a fairly high viscosity
 - B. a fairly low viscosity
 - C. rapidly deforming crust
 - D. rapid underwater cooling

Directions (6–7): For each question, write a short response.

6. What is the name of rounded blobs of lava formed by the rapid, underwater cooling of lava?
7. Where is the Ring of Fire located?

Reading Skills

Directions (8–10): Read the passage below. Then, answer the questions.

Volcanoes That Changed the Weather

In 1815, Mount Tambora in Indonesia erupted violently. Following this eruption, one of the largest recorded weather-related disruptions of the last 10,000 years occurred throughout North America and Western Europe. The year 1816 became known as “the year without a summer.” Snowfalls and a killing frost occurred during the summer months of June, July, and August of that year. A similar, but less severe episode of cooling followed the 1991 eruption of Mount Pinatubo. Eruptions such as these can send gases and volcanic dust high into the atmosphere. Once in the atmosphere, the gas and dust travel great distances, block sunlight, and cause short-term cooling over large areas of the globe. Some scientists have even suggested a connection between volcanoes and the ice ages.

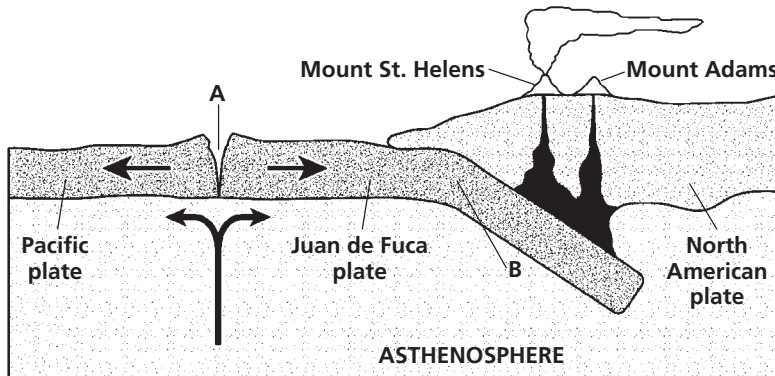
8. What can be inferred from the passage?
 - F. Earthquakes can create the same atmospheric effects as volcanoes do.
 - G. Volcanic eruptions can have effects far beyond their local lava flows.
 - H. Major volcanic eruptions are common events.
 - I. The year 1815 also had a number of earthquakes and other natural disasters.
9. According to the passage, which of the following statements is false?
 - A. The year 1816 became known as “the year without a summer.”
 - B. The world experienced a period of unusually warm weather after Mount Pinatubo erupted.
 - C. Mount Pinatubo erupted in 1991.
 - D. Eruptions send gas and dust into the atmosphere, where they travel around the globe.
10. The eruptions described in the passage changed the weather briefly. Some scientists believe that periods of severe volcanic activity can produce long-term changes in climate. Suggest one specific way in which the materials sent into the atmosphere by volcanoes might cause long-term changes in global climate and temperature.

Interpreting Graphics

Directions (11–13): For each question below, record the correct answer on a separate sheet of paper.

Base your answers to question 11 on the cross section below, which shows volcanic activity in the Cascade region of the Pacific West Coast.

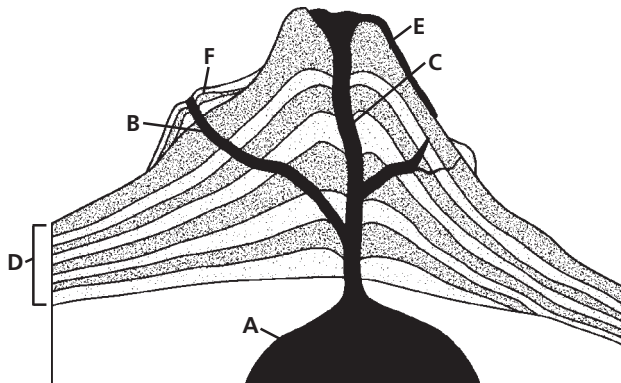
Cross Section of the Juan de Fuca Ridge



11. Explain how the tectonic activity near point B causes the volcanic activity at Mount St. Helens and Mount Adams in the Cascade Range.

Base your answers to questions 12 and 13 on the diagram of the interior of a volcano shown below.

Interior of a Volcano



12. What is the term for the underground pool of molten rock, marked by the letter A, that feeds the volcano?
- F. fissure
 - G. intrusion
 - H. lava pool
 - I. magma chamber
13. Letter D shows alternating layers in the volcanic cone. What are these layers made of, and what does this lead you to believe about the type of volcano that is represented in the diagram above?

Test Tip

When using a diagram to answer questions, carefully study each part of the diagram as well as any lines or labels used to indicate parts of the diagram.

Geology Connections

Science, technology, and society are closely linked. This flowchart shows just a few of the connections in the history of geology.

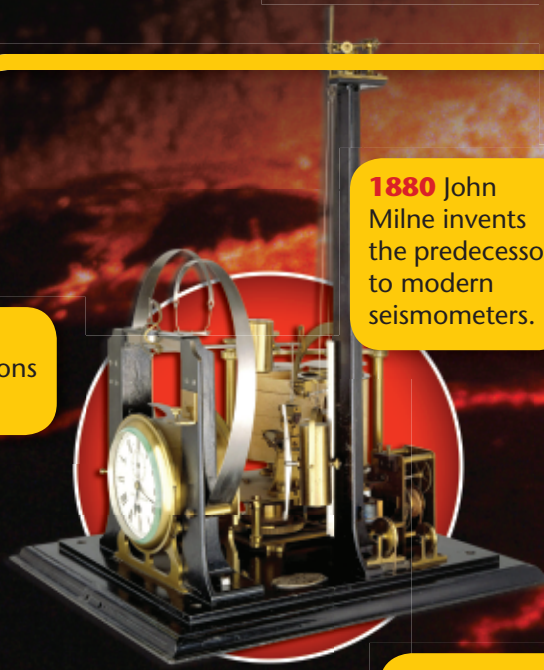


132 C.E. Chinese philosopher Zhang Heng invents a seismoscope.

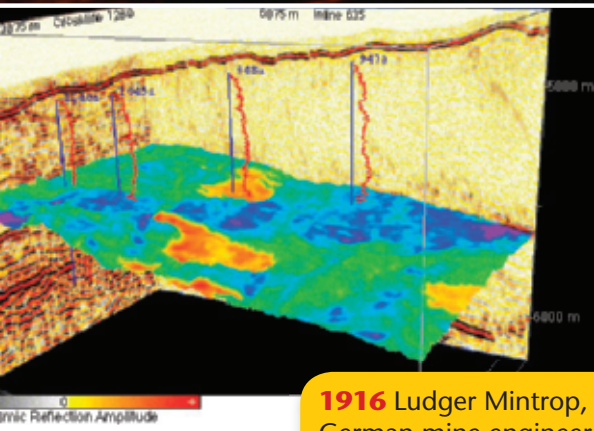


1851 Robert Mallet uses dynamite to create explosions to study seismic waves.

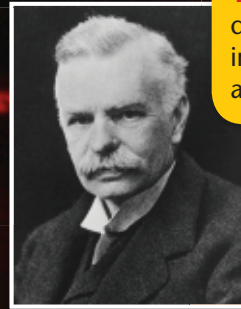
1880 John Milne invents the predecessor to modern seismometers.



1906 R.D. Oldham discovers shadow zones, indicating that Earth has a central core.



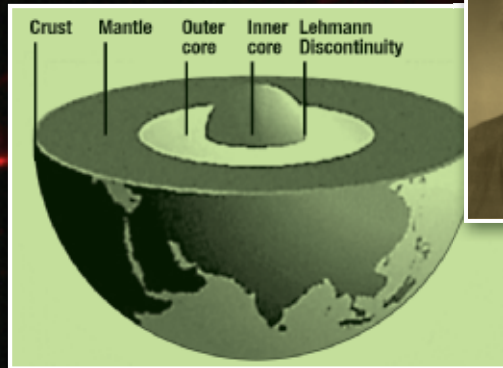
1916 Ludger Mintrop, a German mine engineer, proposes using seismic waves to study underground rock layers.



1936 Inge Lehman uses data from earthquakes to determine that Earth has an inner core that is solid.



1921 John Clarence Karcher tests the use of seismic waves for the purpose of locating oil.



HISTORY IN SCIENCE



79 C.E. Pliny the Younger describes the eruption of Mt. Vesuvius.

1960 A magnitude 9.5 earthquake in Chile causes a tsunami that strikes Hawaii.



1968 The Pacific Tsunami Warning and Mitigation System is established.



1906 Seismometers all around the world record an earthquake in California.

1985 Nevada del Ruiz erupts, killing 25,000 people in Colombia.



1986 The U.S. forms the Volcano Disaster Assistance Program (V.D.A.P).



1912 The Hawaiian Volcano Observatory is formed at Kilauea.

1991 The V.D.A.P. successfully predicts the eruption of Mt. Pinatubo.



2004 A tsunami in the Indian Ocean prompts the development of a tsunami warning system in the Indian Ocean.

YOUR TURN

UNDERSTANDING CONCEPTS
For how many years have people been studying earthquakes?

CRITICAL THINKING
How did John Milne help save thousands of lives in 1991 when Mt. Pinatubo erupted?

2006 Thirty nations participate in a test of the Pacific Tsunami Warning System.

