Section 1 Volcanoes and Plate Tectonics

Reading Preview

Key Concepts

- Where are most of Earth's volcanoes found?
- How do hot spot volcanoes form?

Key Terms

- volcano • magma • lava
- Ring of Fire • island arc
- hot spot

Target Reading Skill

Asking Questions Before you read, preview the red headings. In a graphic organizer like the one below, ask a *where, what,* or *how* question for each heading. As you read, write the answers to your questions.

Volcanoes and Plate Tectonics

Question	Answer
Where are volcanoes found?	Most volcanoes are found along plate boundaries.

Lab zone Discover Activity

Where Are Volcanoes Found on Earth's Surface?

1. Look at the map of Earth's Active Volcanoes in Figure 2. What symbols are used to represent volcanoes? What other symbols are shown on the map?
2. Do the locations of the volcanoes form a pattern? Do the volcanoes seem related to any other features on Earth's surface?

Think About It

Developing Hypotheses Develop a hypothesis to explain where Earth's volcanoes are located.

In 2002, Mount Etna erupted in glowing fountains and rivers of molten rock. Located on the island of Sicily in the Mediterranean Sea, Mount Etna is Europe's largest volcano. Over the last 2,500 years, it has erupted often. The ancient Greeks believed that Mount Etna was one home of Hephaestus, the Greek god of fire. Beneath the volcano was the forge where Hephaestus made beautiful metal objects for the other Greek gods.

The eruption of a volcano is among the most awe-inspiring events on Earth. A **volcano** is a weak spot in the crust where molten material, or magma, comes to the surface. **Magma** is a molten mixture of rock-forming substances, gases, and water from the mantle. When magma reaches the surface, it is called **lava.** After lava has cooled, it forms solid rock. Lava released during volcanic activity builds up Earth's surface.

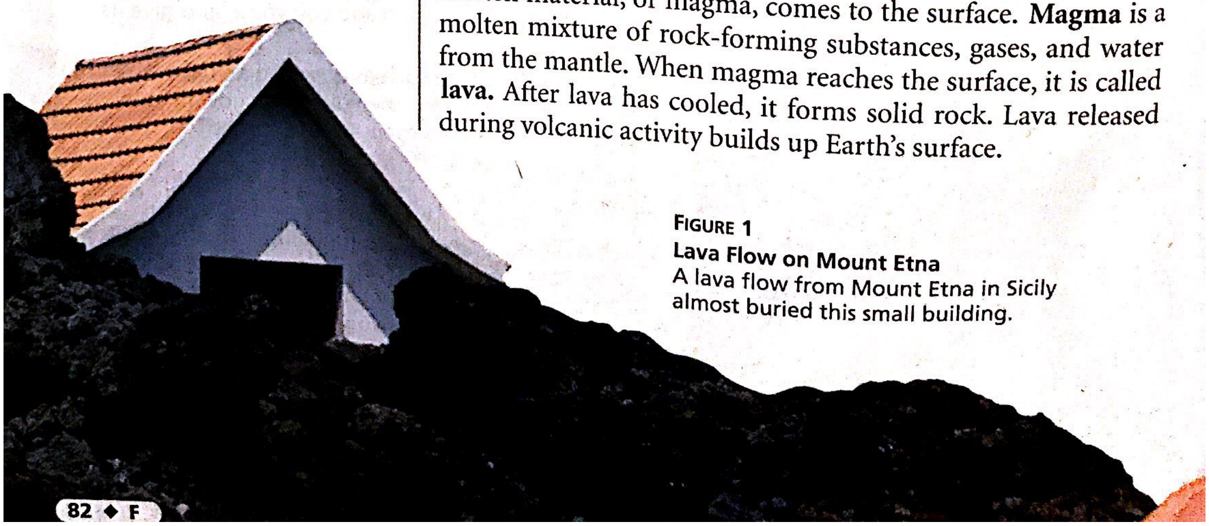

FIGURE 1
Lava Flow on Mount Etna
A lava flow from Mount Etna in Sicily almost buried this small building.

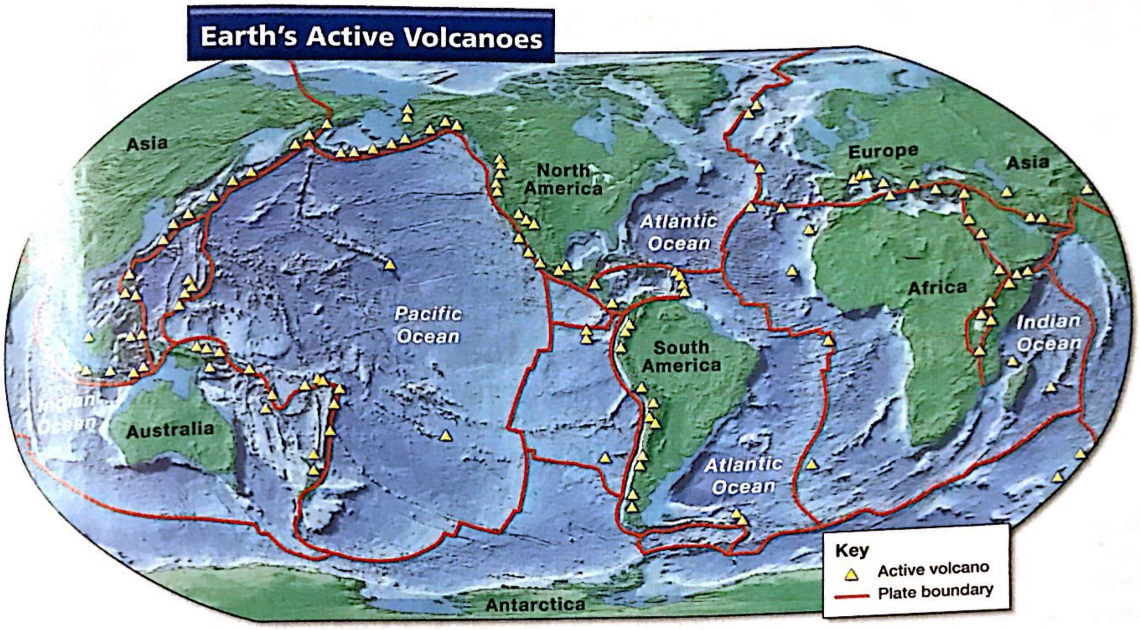

FIGURE 2
Many of Earth's volcanoes are located along the boundaries of tectonic plates. The Ring of Fire is a belt of volcanoes that circles the Pacific Ocean. **Observing** *What other regions have a large number of volcanoes?*

Volcanoes and Plate Boundaries

There are about 600 active volcanoes on land. Many more lie beneath the sea, where it is difficult for scientists to observe and map them. Figure 2 shows the location of some of Earth's major volcanoes. Notice how volcanoes occur in belts that extend across continents and oceans. One major volcanic belt is the **Ring of Fire,** formed by the many volcanoes that rim the Pacific Ocean.

Volcanic belts form along the boundaries of Earth's plates. At plate boundaries, huge pieces of the crust diverge (pull apart) or converge (push together). As a result, the crust often fractures, allowing magma to reach the surface. Most volcanoes form along diverging plate boundaries such as mid-ocean ridges and along converging plate boundaries where subduction takes place. For example, Mount Etna formed near the boundary of the Eurasian and African plates.

Diverging Boundaries Volcanoes form along the mid-ocean ridges, which mark diverging plate boundaries. Recall that ridges are long, underwater mountain ranges that sometimes have a rift valley down their center. Along the rift valley, lava pours out of cracks in the ocean floor, gradually building new mountains. Volcanoes also form along diverging plate boundaries on land. For example, there are several large volcanoes along the Great Rift Valley in East Africa.

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Converging Boundaries Many volcanoes form near converging plate boundaries where oceanic plates return to the mantle. Volcanoes may form where two oceanic plates collide or where an oceanic plate collides with a continental plate. Figure 3 shows how converging plates produce volcanoes.

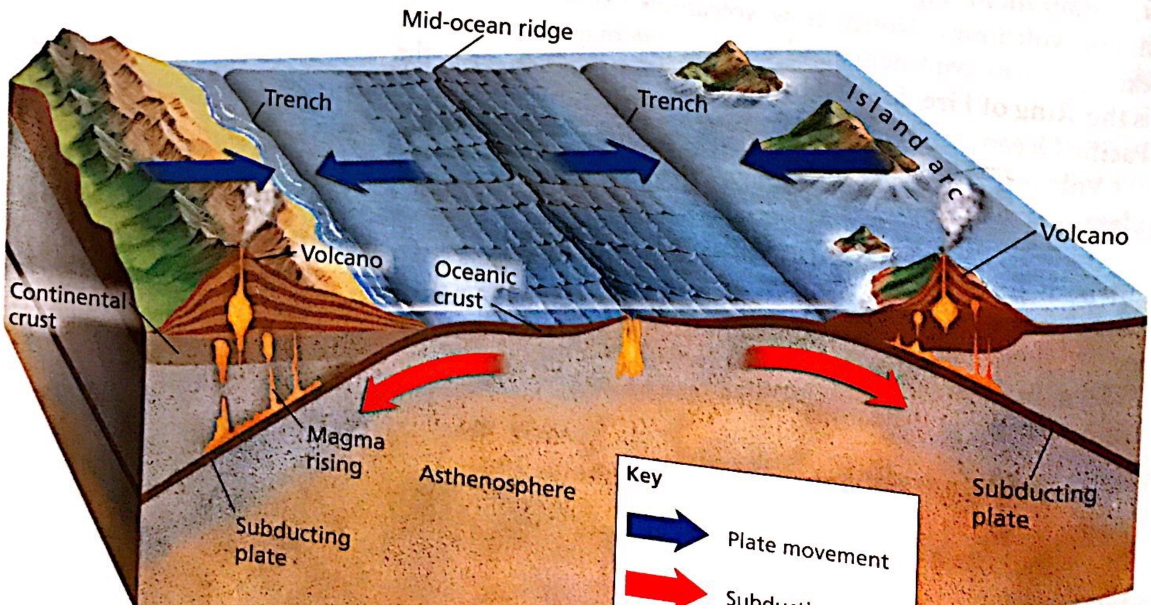
Many volcanoes occur near boundaries where two oceanic plates collide. Through subduction, the older, denser plate sinks beneath a deep-ocean trench into the mantle. Some of the rock above the subducting plate melts and forms magma. Because the magma is less dense than the surrounding rock, it rises toward the surface. Eventually, the magma breaks through the ocean floor, creating volcanoes.

The resulting volcanoes create a string of islands called an **island arc.** The curve of an island arc echoes the curve of its deep-ocean trench. Major island arcs include Japan, New Zealand, Indonesia, the Philippines, the Aleutians, and the Caribbean islands.

Volcanoes also occur where an oceanic plate is subducted beneath a continental plate. Collisions of this type produced the volcanoes of the Andes Mountains in South America and the volcanoes of the Pacific Northwest in the United States.

Reading Checkpoint How did the volcanoes in the Andes Mountains form?

FIGURE 3
Volcanoes at Converging Boundaries
Volcanoes often form where two oceanic plates collide or where an oceanic plate collides with a continental plate. In both situations, an oceanic plate sinks beneath a trench. Rock above the plate melts to form magma, which then erupts to the surface as lava.



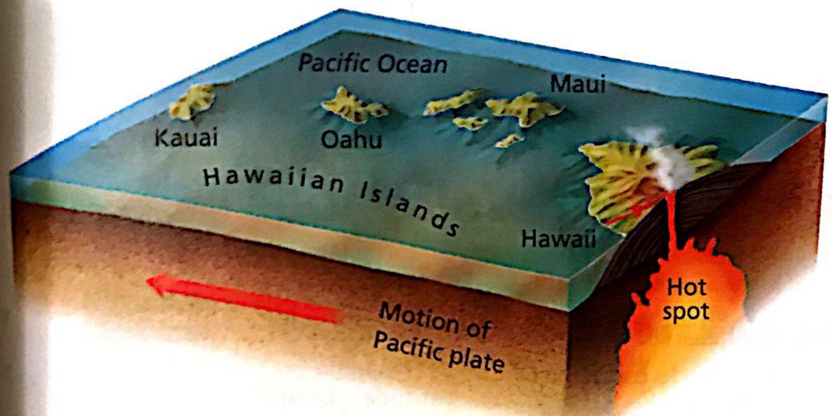


FIGURE 4
Hot Spot Volcanoes
Eventually, the Pacific plate's movement will carry the island of Hawaii away from the hot spot.
Inferring *Which island on the map formed first?*

Hot Spot Volcanoes

Some volcanoes result from "hot spots" in Earth's mantle. A **hot spot** is an area where material from deep within the mantle rises and then melts, forming magma. **A volcano forms above a hot spot when magma erupts through the crust and reaches the surface.** Some hot spot volcanoes lie in the middle of plates far from any plate boundaries. Other hot spots occur on or near plate boundaries.

A hot spot in the ocean floor can gradually form a series of volcanic mountains. For example, the Hawaiian Islands formed one by one over millions of years as the Pacific plate drifted over a hot spot. Hot spots can also form under the continents. Yellowstone National Park in Wyoming marks a hot spot under the North American plate.

Lab zone Try This Activity

Hot Spot in a Box

1. Fill a plastic box half full of cold water. This represents the mantle.
2. Mix red food coloring with hot water in a small, narrow-necked bottle to represent magma.
3. Hold your finger over the mouth of the bottle as you place the bottle in the center of the box. The mouth of the bottle must be under water.
4. Float a flat piece of plastic foam on the water above the bottle to model a tectonic plate.
5. Take your finger off the bottle and observe what happens to the "magma."

Making Models Move the plastic foam slowly along. Where does the magma touch the "plate"? How does this model a hot spot volcano?

Section 1 Assessment

Target Reading Skill Asking Questions Work with a partner to check the answers in your graphic organizer.

Reviewing Key Concepts

1. a. **Defining** What is a volcano?
   b. **Reviewing** Where are most volcanoes located?
   c. **Relating Cause and Effect** What causes volcanoes to form at a diverging plate boundary?
2. a. **Defining** What is a hot spot?
   b. **Summarizing** How does a hot spot volcano form?
   c. **Predicting** What features form as an oceanic plate moves across a hot spot?

Writing in Science

Travel Brochure As a travel agent, you are planning a Pacific Ocean cruise that will visit volcanoes in the Ring of Fire and Hawaii. Write a travel brochure describing the types of volcanoes the group will see and explaining why the volcanoes formed where they did.

2 Properties of Magma

Reading Preview

Key Concepts

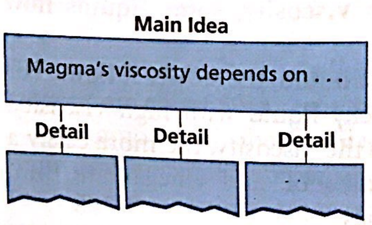
- Why is it helpful to know the physical and chemical properties of a substance?
- What causes some liquids to flow more easily than others?
- What factors determine the viscosity of magma?

Key Terms

- element
- compound
- physical property
- chemical property
- viscosity
- silica
- pahoehoe
- aa

Target Reading Skill

Identifying Main Ideas
As you read Viscosity of Magma, write the main idea in a graphic organizer like the one below. Then write three supporting details that further explain the main idea.



Lab zone Discover Activity

How Fast Do Liquids Flow?

1. Fill one third of a small plastic cup with honey. Fill one third of another cup with cooking oil.
2. Hold the cup containing honey over a third cup and tip it until the liquid begins to flow out of the cup. Time how long it takes from the time the cup was tipped until all the liquid drains out of the cup. Record the time.
3. Repeat Step 2 with the cup filled with oil.

Think About It
Forming Operational Definitions The tendency of a fluid to resist flowing is called viscosity. How did you measure the viscosity of honey and cooking oil? Which had a greater viscosity?

Measured from the bottom of the Pacific Ocean, the Big Island of Hawaii is the largest mountain on Earth. The island is made up of massive volcanoes. One of these volcanoes, Mount Kilauea (kee loo AY uh) erupts frequently and produces huge amounts of lava.

At a temperature of around 1,000°C, lava from Mount Kilauea is very dangerous. Yet most of the time, the lava moves slower than a person can walk—about 1 kilometer per hour. Some types of lava move much more slowly—less than the length of a football field in an entire day. How fast lava flows depends on the properties of the magma from which it formed.

Physical and Chemical Properties

Like all substances, magma and lava are made up of elements and compounds. An **element** is a substance that cannot be broken down into other substances. Carbon, hydrogen, and oxygen are examples of elements. A **compound** is a substance made of two or more elements that have been chemically combined. Water, carbon dioxide, and table salt are familiar compounds. **Each substance has a particular set of physical and chemical properties. These properties can be used to identify a substance or to predict how it will behave.**

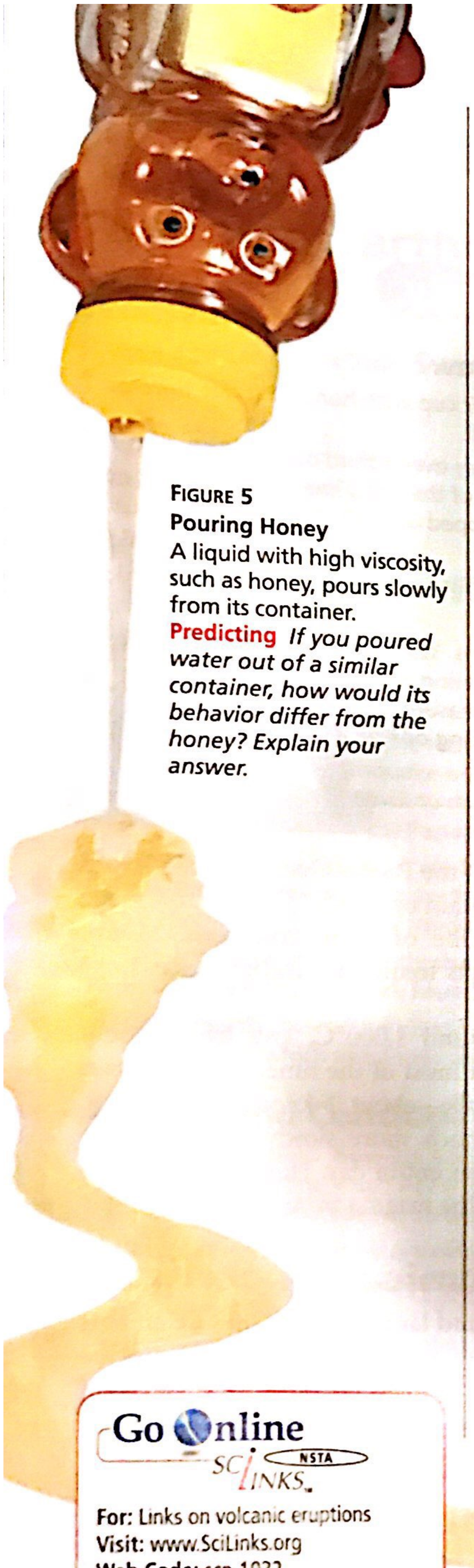


FIGURE 5
Pouring Honey
A liquid with high viscosity, such as honey, pours slowly from its container.
Predicting *If you poured water out of a similar container, how would its behavior differ from the honey? Explain your answer.*

Physical Properties A **physical property** is any characteristic of a substance that can be observed or measured without changing the composition of the substance. Examples of physical properties include density, hardness, melting point, boiling point, and whether a substance is magnetic. A substance always has the same physical properties under particular conditions. Under normal conditions at sea level, for example, water's freezing point is 0°C and its boiling point is 100°C. Between its freezing and boiling points, water is a liquid.

Chemical Properties A **chemical property** is any property that produces a change in the composition of matter. Examples of chemical properties include a substance's ability to burn and its ability to combine, or react, with other substances. You can often tell that one substance has reacted with another if it changes color, produces a gas, or forms a new, solid substance. For example, a piece of silver jewelry darkens when exposed to air. This change indicates that silver has reacted with oxygen to form tarnish. The ability to react with oxygen is a chemical property of silver.

Reading Checkpoint **Is the boiling point of a substance a physical property or a chemical property?**

What Is Viscosity?

When you pour yourself a glass of milk, you are making use of a familiar physical property of liquids. Because particles in a liquid are free to move around one another, a liquid can flow from place to place. The physical property of liquids called **viscosity** (vis KAHS uh tee) is the resistance of a liquid to flowing. **Because liquids differ in viscosity, some liquids flow more easily than others.**

The greater the viscosity of a liquid, the slower it flows. For example, honey is a thick, sticky liquid with high viscosity. Honey flows slowly. The lower the viscosity, the more easily a liquid flows. Water, rubbing alcohol, and vinegar are thin, runny liquids with low viscosities.

Why do different liquids have different viscosities? The answer lies in the movement of the particles that make up each type of liquid. In some liquids, there is a greater degree of friction among the liquid's particles. These liquids have higher viscosity.

Reading Checkpoint **Why do liquids differ in viscosity?**

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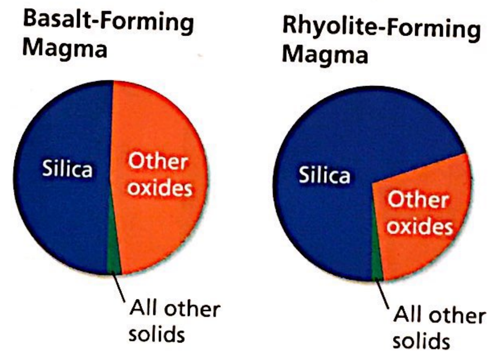
Math Analyzing Data

Magma Composition

Magma varies in composition and is classified according to the amount of silica it contains. The graphs show the average composition of two types of magma. Use the graphs to answer the questions.

1. **Reading Graphs** Study both graphs. What materials make up both types of magma?
2. **Reading Graphs** Which type of magma has more silica? About how much silica does this type of magma contain?
3. **Estimating** A third type of magma has a silica content that is halfway between that of the other two types. About how much silica does this magma contain?
4. **Predicting** What type of magma would have a higher viscosity? Explain.

Types of Magma



Viscosity of Magma

At the extremely high temperatures and pressures inside Earth, mantle rock sometimes melts to form magma. Surprisingly, the properties of magma can vary. For example, not all types of magma have the same viscosity. **The viscosity of magma depends upon its silica content and temperature.**

Silica Content Magma is a complex mixture, but its major ingredient is silica. The compound **silica** is made up of particles of the elements oxygen and silicon. Silica is one of the most abundant materials in Earth's crust. The silica content of magma ranges from about 50 percent to 70 percent.

The amount of silica in magma helps to determine its viscosity. The more silica magma contains, the higher its viscosity. Magma that is high in silica produces light-colored lava that is too sticky to flow very far. When this type of lava cools, it forms the rock rhyolite, which has the same composition as granite.

The less silica magma contains, the lower its viscosity. Low-silica magma flows readily and produces dark-colored lava. When this kind of lava cools, it forms rocks like basalt.

FIGURE 6
Sampling Magma
A geologist samples magma from a lava flow in Hawaii.

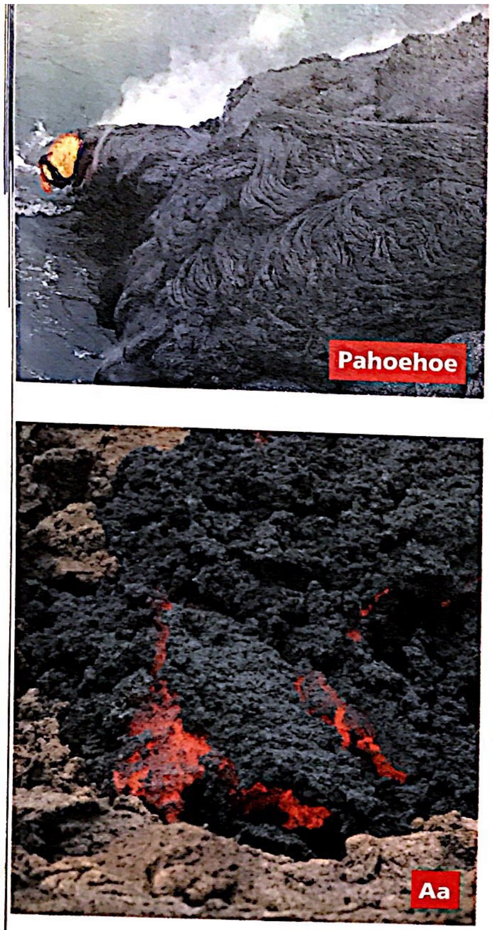


FIGURE 7
Pahoehoe and Aa
Both pahoehoe and aa can come from the same volcano. Pahoehoe flows easily and hardens into a rippled surface. Aa hardens into rough chunks. **Inferring** *Which type of lava has lower viscosity?*

Temperature How does temperature affect viscosity? Viscosity increases as temperature decreases. On a hot day, honey pours easily. But if you put the honey in the refrigerator, its viscosity increases. The cold honey flows very slowly.

The temperature of magma and lava can range from about 750°C to 1,175°C. The hotter the magma is, the lower its viscosity and the more rapidly it flows. Cooler types of magma have high viscosity and flow very slowly.

In Figure 7, you can see how temperature differences produce two different types of lava: pahoehoe and aa. **Pahoehoe** (pah HOH ee hoh ee) is fast-moving, hot lava that has low viscosity. The surface of a lava flow formed from pahoehoe looks like a solid mass of wrinkles, billows, and ropelike coils. Lava that is cooler and slower-moving is called **aa** (AH ah). Aa has higher viscosity than pahoehoe. When aa hardens, it forms a rough surface consisting of jagged lava chunks.

Reading Checkpoint How hot are magma and lava?

Section 2 Assessment

Target Reading Skill Identifying Main Ideas Use your graphic organizer to help you answer Question 3 below.

Reviewing Key Concepts

1. a. **Defining** What is a physical property?
   b. **Defining** What is a chemical property?
   c. **Classifying** Magma is a hot, liquid mixture that changes to solid rock when it cools and hardens. Which of these characteristics are physical properties?
2. a. **Identifying** What is viscosity?
   b. **Applying Concepts** Which has a higher viscosity, a fast-flowing liquid or a slow-flowing liquid?
   c. **Inferring** What can you infer about the amount of friction among the particles of a liquid that has low viscosity?
3. a. **Reviewing** What two main factors affect magma's viscosity?
   b. **Predicting** A lava flow cools as it moves away from the vent. How would this affect the surface appearance of the lava flow?

Lab zone At-Home Activity

Cooling Lava Place cold water in one cup and hot tap water in another. Ask members of your family to predict what will happen when melted candle wax drops into each cup of water. Have an adult family member drip melted wax from a candle into each cup. **CAUTION:** *Handle the lit candle carefully.* Explain how this models what happens when lava cools quickly or slowly.

3 Volcanic Eruptions

Reading Preview

Key Concepts

- What happens when a volcano erupts?
- What are the two types of volcanic eruptions?
- What are a volcano's stages of activity?

Key Terms

- magma chamber
- pipe
- vent
- lava flow
- crater
- pyroclastic flow
- dormant
- extinct

Target Reading Skill

Using Prior Knowledge Before you read, look at the section headings to see what the section is about. Then write what you know about how a volcano erupts in a graphic organizer like the one below. As you read, write what you learn.

What You Know

1. Lava flows out of a volcano.
2.

What You Learned

1.
2.

Lab zone Discover Activity

What Are Volcanic Rocks Like?

Volcanoes produce lava, which hardens into rock. Two of these rocks are pumice and obsidian.

1. Observe samples of pumice and obsidian with a hand lens.
2. How would you describe the texture of the pumice? What could have caused this texture?
3. Observe the surface of the obsidian. How does the surface of the obsidian differ from pumice?

Pumice

Obsidian

Think It Over

Developing Hypotheses What could have produced the difference in texture between the two rocks? Explain your answer.

In Hawaii, there are many myths about Pele (PAY lay), the fire goddess of volcanoes. Pele lives in the depths of Hawaii's erupting volcanoes. According to legend, when Pele is angry, she causes a volcanic eruption. One result of an eruption is "Pele's hair," a fine, threadlike rock formed by lava. Pele's hair forms when lava sprays out of the ground like water from a fountain. As it cools, the lava stretches and hardens into thin strands, as shown in Figure 8.

Where does this lava come from? Lava begins as magma, which usually forms in the asthenosphere. The materials of the asthenosphere are under great pressure. Liquid magma is less dense than the solid material around it. Therefore, magma flows upward into any cracks in the rock above. As magma rises, it sometimes becomes trapped beneath layers of rock. But if an opening in weak rock allows the magma to reach the surface, a volcano forms.

FIGURE 8
Pele's Hair
Pele's hair is a type of rock formed from lava. Each strand is as fine as spun glass.

Section 3

Volcanic Eruptions

Reading Preview

Key Concepts

- What happens when a volcano erupts?
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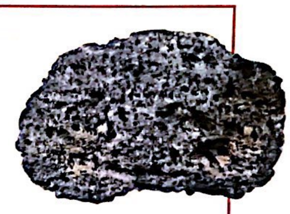

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Obsidian

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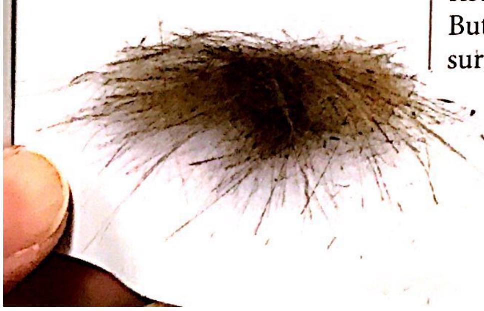

FIGURE 8
Pele's Hair
Pele's hair is a type of rock formed from lava. Each strand is as fine as spun glass.

Magma Reaches Earth's Surface

A volcano is more than a large, cone-shaped mountain. Inside a volcano is a system of passageways through which magma moves.

Inside a Volcano All volcanoes have a pocket of magma beneath the surface and one or more cracks through which the magma forces its way. Beneath a volcano, magma collects in a pocket called a **magma chamber.** The magma moves upward through a **pipe,** a long tube in the ground that connects the magma chamber to Earth's surface. You can see these features in Figure 10.

Molten rock and gas leave the volcano through an opening called a **vent.** Often, there is one central vent at the top of a volcano. However, many volcanoes also have other vents that open on the volcano's sides. A **lava flow** is the area covered by lava as it pours out of a vent. A **crater** is a bowl-shaped area that may form at the top of a volcano around the central vent.

A Volcanic Eruption What pushes magma to the surface? The explosion of a volcano is similar to the soda water bubbling out of a warm bottle of soda pop. You cannot see the carbon dioxide gas in a bottle of soda pop because it is dissolved in the liquid. But when you open the bottle, the pressure is released. The carbon dioxide expands and forms bubbles, which rush to the surface. Like the carbon dioxide in soda pop, dissolved gases are trapped in magma. These dissolved gases are under tremendous pressure.

FIGURE 9
Lava Burp
During an eruption on Mount Kilauea, the force of a bursting gas bubble pushes up a sheet of red-hot lava.

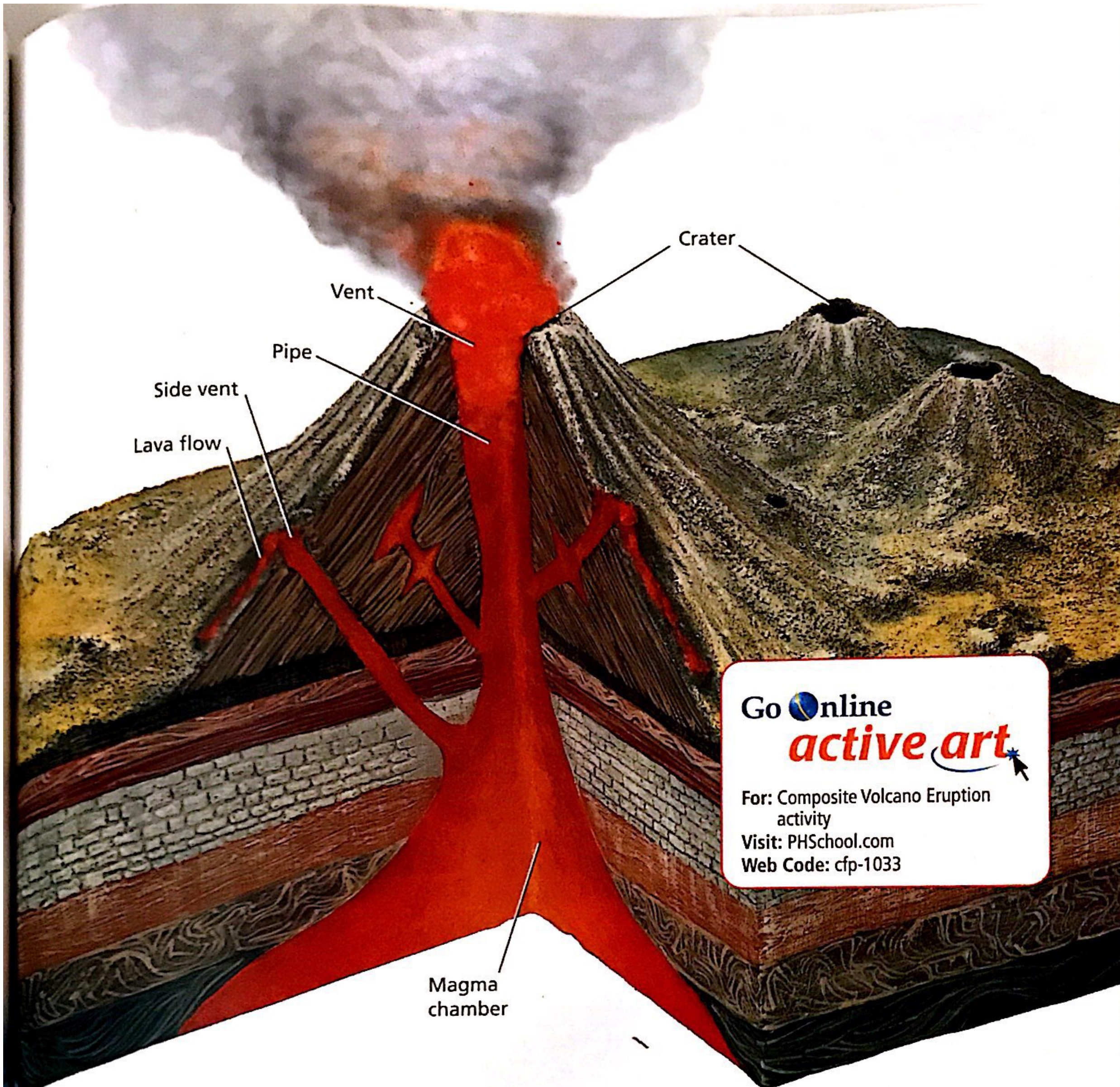

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FIGURE 10
A Volcano Erupts
A volcano forms where magma breaks through Earth's crust and lava flows over the surface.
Interpreting Diagrams *What part of a volcano connects the vent with the magma chamber?*

As magma rises toward the surface, the pressure of the surrounding rock on the magma decreases. The dissolved gases begin to expand, forming bubbles. As pressure falls within the magma, the size of the gas bubbles increases greatly. These expanding gases exert an enormous force. **When a volcano erupts, the force of the expanding gases pushes magma from the magma chamber through the pipe until it flows or explodes out of the vent.** Once magma escapes from the volcano and becomes lava, the remaining gases bubble out.

Reading Checkpoint **What happens to the pressure in magma as the magma rises toward the surface?**

Lab zone Try This Activity

Gases in Magma

This activity models the gas bubbles in a volcanic eruption.

1. In a 1- or 2-liter plastic bottle, mix 10 g of baking soda into 65 mL of water.
2. Put about six raisins in the water.
3. While swirling the water and raisins, add 65 mL of vinegar and stir vigorously.
4. Once the liquid stops moving, observe the raisins.

Making Models What happens after you add the vinegar? What do the raisins and bubbles represent? How is this model similar to the way magma behaves in a volcano?

Kinds of Volcanic Eruptions

Some volcanic eruptions occur gradually. Others are dramatic explosions. **Geologists classify volcanic eruptions as quiet or explosive.** The physical properties of its magma determine how a volcano erupts. Whether an eruption is quiet or explosive depends on the magma's silica content and viscosity.

Quiet Eruptions A volcano erupts quietly if its magma is low in silica. Low-silica magma has low viscosity and flows easily. The gases in the magma bubble out gently. Lava with low viscosity oozes quietly from the vent and can flow for many kilometers. Quiet eruptions can produce both pahoehoe and aa.

The Hawaiian Islands were formed from quiet eruptions. On the Big Island of Hawaii, lava pours out of the crater near the top of Mount Kilauea. But lava also flows out of long cracks on the volcano's sides. Quiet eruptions have built up the Big Island over hundreds of thousands of years.

Explosive Eruptions A volcano erupts explosively if its magma is high in silica. High-silica magma has high viscosity, making it thick and sticky. The high-viscosity magma does not always flow out of the crater. Instead, it builds up in the volcano's pipe, plugging it like a cork in a bottle. Dissolved gases, including water vapor, cannot escape from the thick magma. The trapped gases build up pressure until they explode. The erupting gases and steam push the magma out of the volcano with incredible force. That's what happened during the eruption of Mount St. Helens, shown in Figure 11.

An explosive eruption breaks lava into fragments that quickly cool and harden into pieces of different sizes. The smallest pieces are volcanic ash—fine, rocky particles as small as a speck of dust. Pebble-sized particles are called cinders. Larger pieces, called bombs, may range from the size of a baseball to the size of a car. A **pyroclastic flow** (py roh KLAS tik) occurs when an explosive eruption hurls out a mixture of hot gases, ash, cinders, and bombs.

Pumice and obsidian, which you observed if you did the Discover Activity, form from high-silica lava. Obsidian forms when lava cools very quickly, giving it a smooth, glossy surface like glass. Pumice forms when gas bubbles are trapped in fast-cooling lava, leaving spaces in the rock.

Reading Checkpoint **What is a pyroclastic flow?**

FIGURE 11
An Explosive Eruption
Mount St. Helens in Washington State erupted at 8:30 A.M. on May 18, 1980. The explosion blew off the top of the mountain, leaving a huge crater and causing great destruction.

Scanned with CamScanner

Volcano Hazards Although quiet eruptions and explosive eruptions produce different hazards, both types of eruption can cause damage far from the crater's rim.

During a quiet eruption, lava flows from vents, setting fire to, and then burying, everything in its path. A quiet eruption can cover large areas with a thick layer of lava.

During an explosive eruption, a volcano can belch out hot clouds of deadly gases as well as ash, cinders, and bombs. Volcanic ash can bury entire towns. If it becomes wet, the heavy ash can cause roofs to collapse. If a jet plane sucks ash into its engine, the engine may stall. Eruptions can cause landslides and avalanches of mud, melted snow, and rock. The Science and History timeline shows the effects of several explosive eruptions.

Reading Checkpoint **How does volcanic ash cause damage?**

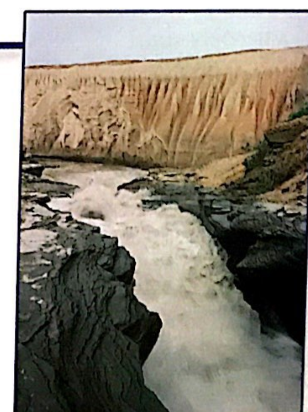
Science and **History**

The Power of Volcanoes

Within the last 150 years, major volcanic eruptions have greatly affected the land and people around them.

1883 Krakatau
The violent eruption of Krakatau volcano in Indonesia threw 18 cubic kilometers of ash skyward. The blast was heard 5,000 kilometers away.

1902 Mount Pelée
Mount Pelée, a Caribbean volcano, spewed out a burning cloud of hot gas and pyroclastic flows. The cloud killed 29,000 residents of St. Pierre, a city on the volcano's flank. Only two people survived.



1912 Mount Katmai
Today, a river in Alaska cuts through the thick layer of volcanic ash from the eruption of Mount Katmai.

1850 | 1875 | 1900

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Stages of Volcanic Activity

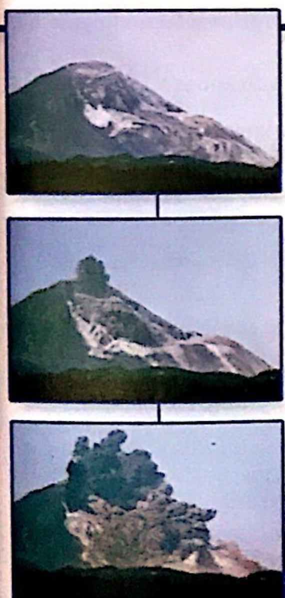
The activity of a volcano may last from less than a decade to more than 10 million years. Most long-lived volcanoes, however, do not erupt continuously. Geologists try to determine a volcano's past and whether the volcano will erupt again.

Life Cycle of a Volcano **Geologists often use the terms *active, dormant,* or *extinct* to describe a volcano's stage of activity.** An active, or live, volcano is one that is erupting or has shown signs that it may erupt in the near future. A dormant, or sleeping, volcano is like a sleeping bear. Scientists expect a **dormant** volcano to awaken in the future and become active. An **extinct,** or dead, volcano is unlikely to erupt again.

The time between volcanic eruptions may span hundreds to many thousands of years. People living near a dormant volcano may be unaware of the danger. But a dormant volcano can become active at any time.

Writing in Science

Research and Write People have written eyewitness accounts of famous volcanic eruptions. Research one of the eruptions in the timeline. Then write a letter describing what someone observing the eruption might have seen.



1980 Mount St. Helens
When Mount St. Helens in Washington exploded, it blasted one cubic kilometer of volcanic material skyward.

1991 Mount Pinatubo
Pinatubo in the Philippines spewed out huge quantities of ash that rose high into the atmosphere and buried nearby areas.

2002 Mount Etna
Bulldozers constructed a wall against a scalding river of lava creeping down the slopes of Mount Etna in Sicily.

1950 1975 2000

FIGURE 12
Volcano Watch
Near Mount Kilauea in Hawaii, these geologists are testing instruments to monitor temperatures in and around a crater.

Monitoring Volcanoes Geologists have been more successful in predicting volcanic eruptions than in predicting earthquakes. Geologists use instruments to detect changes in and around a volcano. These changes may give warning a short time before a volcano erupts. But geologists cannot be certain about the type of eruption or how powerful it will be.

Geologists use tiltmeters and other instruments to detect slight surface changes in elevation and tilt caused by magma moving underground. They monitor any gases escaping from the volcano. A temperature increase in underground water may be a sign that magma is nearing the surface. Geologists also monitor the many small earthquakes that occur around a volcano before an eruption. The upward movement of magma triggers these quakes.

Reading Checkpoint How do geologists monitor volcanoes?

Section 3 Assessment

Target Reading Skill **Using Prior Knowledge** Review your graphic organizer and revise it based on what you just learned in the section.

Reviewing Key Concepts

1. a. **Listing** What are the main parts of a volcano?
   b. **Sequencing** Describe the order of parts through which magma travels as it moves to the surface.
   c. **Relating Cause and Effect** As a volcano erupts, what force pushes magma out of a volcano onto the surface?
2. a. **Identifying** What are the two main kinds of volcanic eruptions?
   b. **Explaining** What properties of magma help to determine the type of eruption?
   c. **Inferring** What do lava flows made of pahoehoe and aa indicate about the type of volcanic eruption that occurred?
3. a. **Naming** What are the three stages of volcanic activity?
   b. **Predicting** Which is more likely to be dangerous—a volcano that erupts frequently or a volcano that has been inactive for a hundred years? Why?

Writing in Science

Interview You are a television news reporter who will be interviewing a geologist. The geologist has just returned from studying a nearby volcano that may soon erupt. Write the questions that you would ask. Be sure to ask about the evidence that an eruption is coming, the type of eruption expected, and any hazards that will result. Write an answer for each question.

Section 4

Volcanic Landforms

Reading Preview

Key Concepts

- What landforms do lava and ash create?
- How does magma that hardens beneath the surface create landforms?
- What other distinctive features occur in volcanic areas?

Key Terms

- shield volcano
- cinder cone
- composite volcano
- caldera
- volcanic neck
- dike
- sill
- batholith
- geothermal activity
- geyser

Target Reading Skill

Outlining As you read, make an outline about volcanic landforms that you can use for review. Use the red headings for main topics and the blue headings for subtopics.

Volcanic Landforms

I. Landforms From Lava and Ash
  A. Shield Volcanoes
  B.
  C.
  D.
  E.
II. Landforms From Magma

Lab zone Discover Activity

How Can Volcanic Activity Change Earth's Surface?

1. Use tape to secure the neck of a balloon over one end of a straw.
2. Place the balloon in the center of a box with the straw protruding.
3. Partially inflate the balloon.
4. Put damp sand on top of the balloon until it is covered.
5. Slowly inflate the balloon more. Observe what happens to the surface of the sand.

Think It Over

Making Models This activity models one of the ways in which volcanic activity can cause a mountain to form. What do you think the sand represents? What does the balloon represent?

Volcanoes have created some of Earth's most spectacular landforms. The perfect cone of Mount Fuji in Japan, shown in Figure 13, is famous around the world.

For much of Earth's history, volcanic activity on and beneath the surface has built up Earth's land areas. Volcanic activity also formed the rock of the ocean floor. Some volcanic landforms arise when lava flows build up mountains and plateaus on Earth's surface. Other volcanic landforms are the result of the buildup of magma beneath the surface.

FIGURE 13
Mount Fuji
The almost perfect volcanic cone of Mount Fuji in Japan has long been a favorite subject for artists.

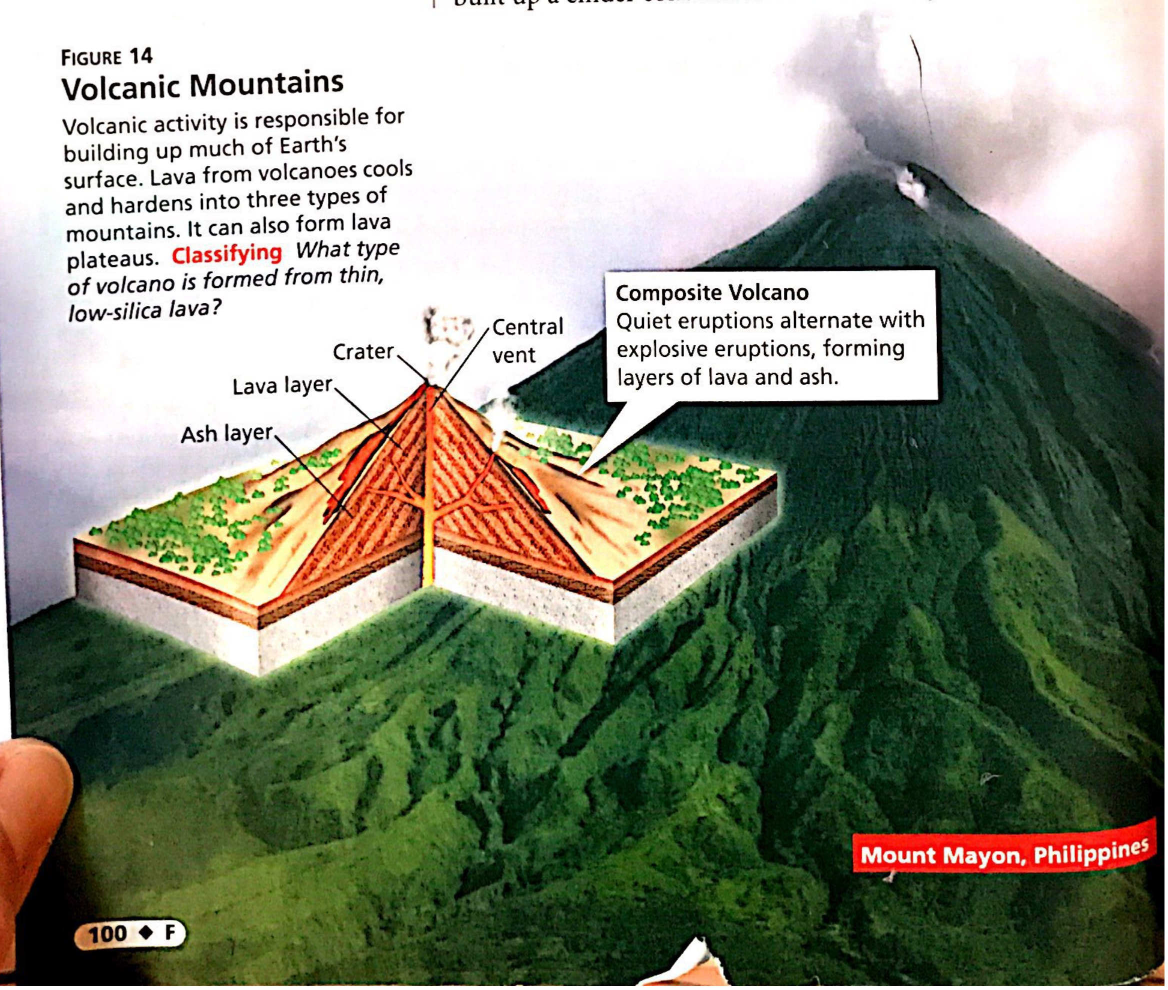
Landforms From Lava and Ash

Volcanic eruptions create landforms made of lava, ash, and other materials. These landforms include shield volcanoes, cinder cone volcanoes, composite volcanoes, and lava plateaus. Look at Figure 14 to see these features. Another landform results from the collapse of a volcanic mountain.

Shield Volcanoes At some places on Earth's surface, thin layers of lava pour out of a vent and harden on top of previous layers. Such lava flows gradually build a wide, gently sloping mountain called a **shield volcano.** Shield volcanoes rising from a hot spot on the ocean floor created the Hawaiian Islands.

Cinder Cone Volcanoes If a volcano's lava has high viscosity, it may produce ash, cinders, and bombs. These materials build up around the vent in a steep, cone-shaped hill or small mountain called a **cinder cone.** For example, Paricutín in Mexico erupted in 1943 in a farmer's cornfield. The volcano built up a cinder cone about 400 meters high.

FIGURE 14
Volcanic Mountains
Volcanic activity is responsible for building up much of Earth's surface. Lava from volcanoes cools and hardens into three types of mountains. It can also form lava plateaus. **Classifying** *What type of volcano is formed from thin, low-silica lava?*



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Composite Volcanoes Sometimes, lava flows alternate with explosive eruptions of ash, cinder, and bombs. The result is a composite volcano. **Composite volcanoes** are tall, cone-shaped mountains in which layers of lava alternate with layers of ash. Examples of composite volcanoes include Mount Fuji in Japan and Mount St. Helens in Washington State.

Lava Plateaus Instead of forming mountains, some eruptions of lava form high, level areas called lava plateaus. First, lava flows out of several long cracks in an area. The thin, runny lava travels far before cooling and solidifying. Again and again, floods of lava flow on top of earlier floods. After millions of years, these layers of lava can form high plateaus. One example is the Columbia Plateau, which covers parts of the states of Washington, Oregon, and Idaho.

Discovery Channel School

Volcanoes

Video Preview
▶ Video Field Trip
Video Assessment

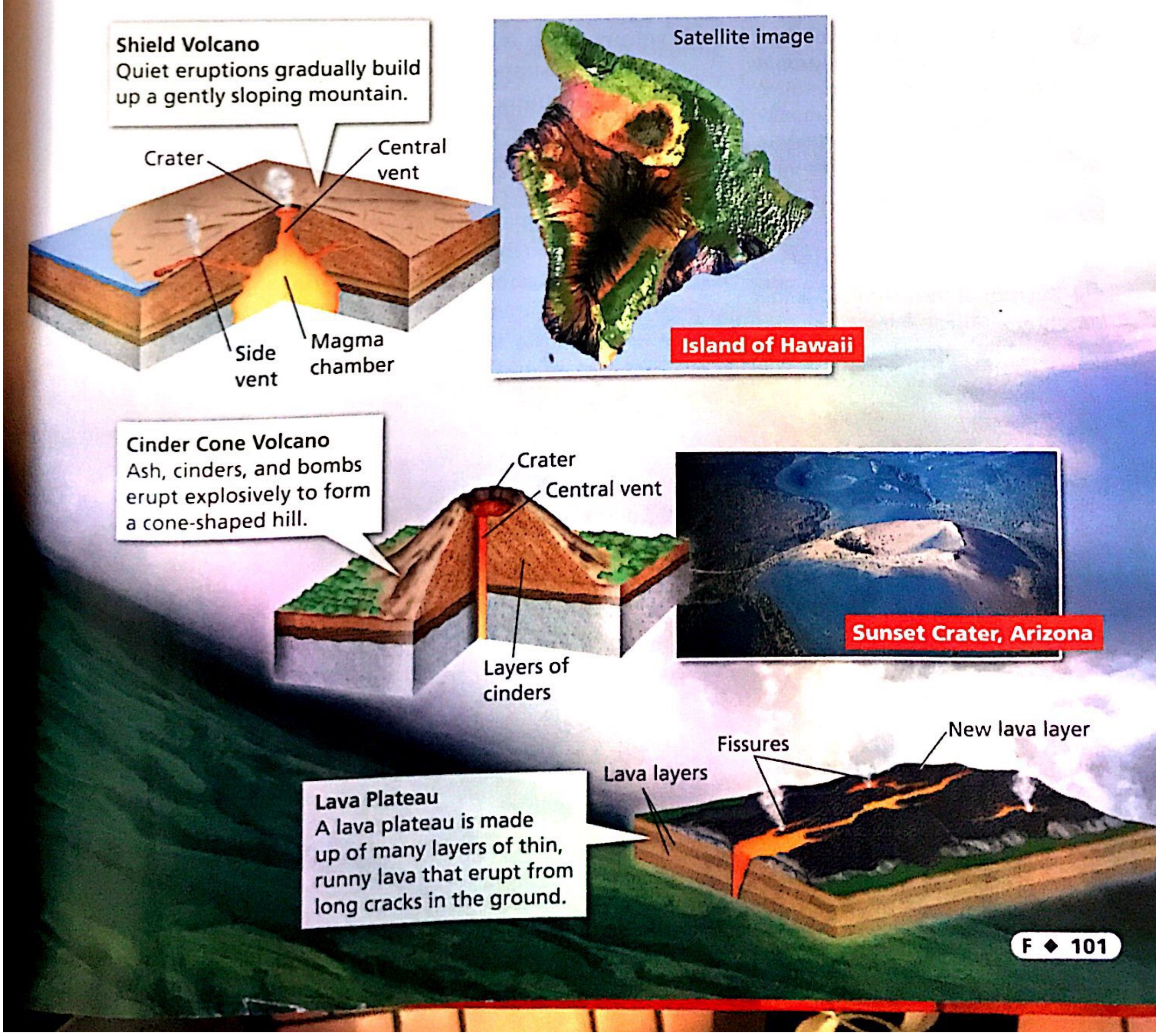
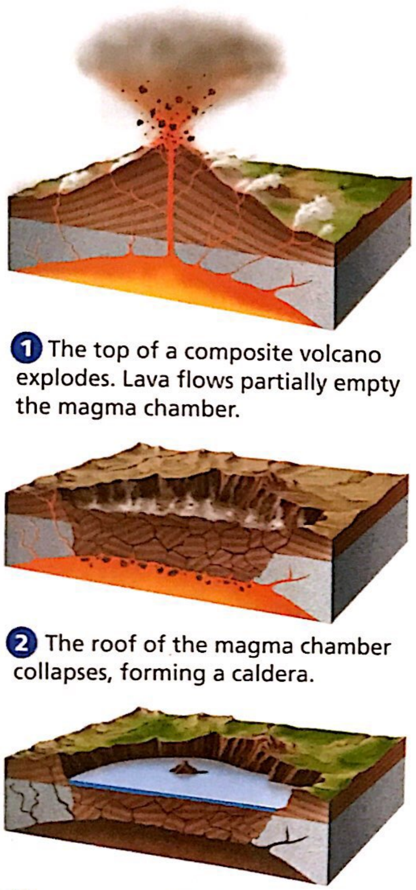


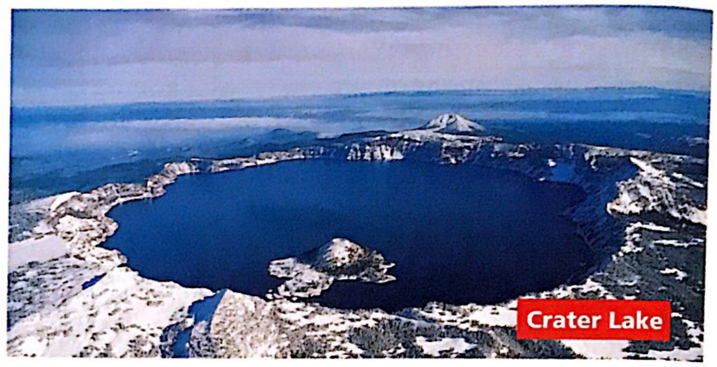
FIGURE 15
How a Caldera Forms
Today, Crater Lake (right) fills an almost circular caldera. A caldera forms when a volcano's magma chamber empties and the roof of the chamber collapses.



❶ The top of a composite volcano explodes. Lava flows partially empty the magma chamber.

❷ The roof of the magma chamber collapses, forming a caldera.

❸ Later, a small cinder cone forms in the caldera, which partly fills with water.



Calderas The huge hole left by the collapse of a volcanic mountain is called a **caldera** (kal DAIR uh). The hole is filled with the pieces of the volcano that have fallen inward, as well as some lava and ash.

How does a caldera form? Enormous eruptions may empty the main vent and the magma chamber beneath a volcano. The mountain becomes a hollow shell. With nothing to support it, the top of the mountain collapses inward, forming a caldera.

In Figure 15 you can see steps in the formation of Crater Lake, a caldera in Oregon. Crater Lake formed about 7,700 years ago when a huge explosive eruption partly emptied the magma chamber of a volcano called Mount Mazama. When the volcano exploded, the top of the mountain was blasted into the atmosphere. The caldera that formed eventually filled with water from rain and snow. Wizard Island in Crater Lake is a small cinder cone that formed during a later eruption inside the caldera.

Soils From Lava and Ash Why would anyone live near an active volcano? People often settle close to volcanoes to take advantage of the fertile volcanic soil. The lava, ash, and cinders that erupt from a volcano are initially barren. Over time, however, the hard surface of the lava breaks down to form soil. When volcanic ash breaks down, it releases potassium, phosphorus, and other substances that plants need. As soil develops, plants are able to grow. Some volcanic soils are among the richest soils in the world. Saying that soil is rich means that it's fertile, or able to support plant growth.

Reading Checkpoint How are volcanic soils important?

Landforms From Magma

Sometimes magma forces its way through cracks in the upper crust, but fails to reach the surface. There the magma cools and hardens into rock. Over time, the forces that wear away Earth's surface—such as flowing water, ice, or wind—may strip away the layers above the hardened magma and finally expose it. **Features formed by magma include volcanic necks, dikes, and sills, as well as batholiths and dome mountains.**

Volcanic Necks A volcanic neck looks like a giant tooth stuck in the ground. A **volcanic neck** forms when magma hardens in a volcano's pipe. The softer rock around the pipe wears away, exposing the hard rock of the volcanic neck. Ship Rock in New Mexico, shown in Figure 16, is a volcanic neck formed from a volcano that erupted about 30 million years ago.

Dikes and Sills Magma that forces itself across rock layers hardens into a **dike.** Sometimes, a dike can be seen slanting through bedrock along a highway cut.

When magma squeezes between horizontal layers of rock, it forms a **sill.** One famous example of a sill is the Palisades in New York State and New Jersey. The Palisades form a series of long, dark cliffs. These cliffs stretch for about 30 kilometers along the west bank of the Hudson River.

Go Online SCI LINKS NSTA

For: Links on volcanic effects
Visit: www.SciLinks.org
Web Code: scn-1034

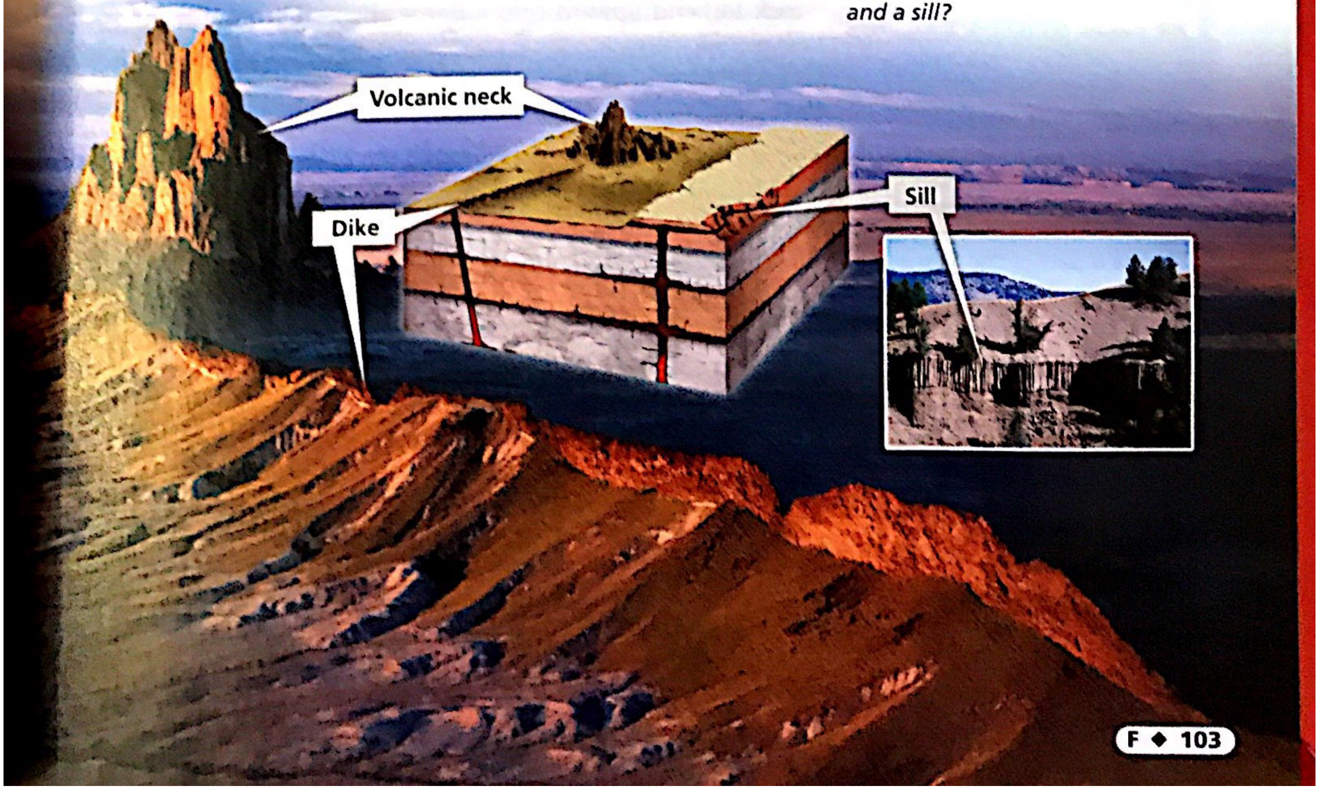


FIGURE 16
Volcanic Necks, Dikes, and Sills
Magma that hardens beneath the surface may form volcanic necks, dikes, and sills. A dike extends outward from Ship Rock, a volcanic neck in New Mexico.
Comparing and Contrasting *What is the difference between a dike and a sill?*

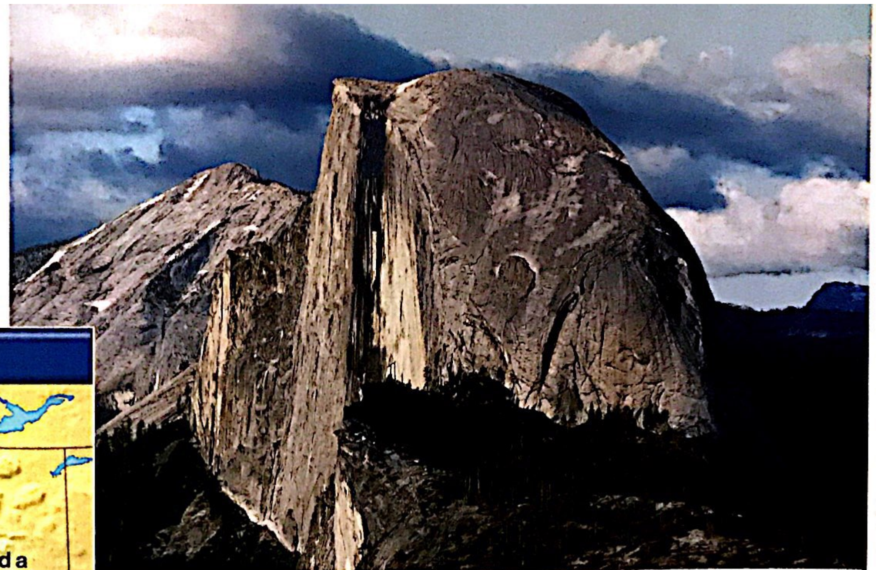


FIGURE 17
Batholiths
Several large batholiths form the core of mountain ranges in western North America. Half Dome in Yosemite National Park, California is part of the Sierra Nevada batholith.

Batholiths Large rock masses called batholiths form the core of many mountain ranges. A **batholith** (BATH uh lith) is a mass of rock formed when a large body of magma cools inside the crust. The map in Figure 17 shows just how big batholiths really are. The photograph shows how a batholith looks when the layers of rock above it have worn away.

Dome Mountains Other, smaller bodies of hardened magma can create dome mountains. A dome mountain forms when uplift pushes a batholith or smaller body of hardened magma toward the surface. The hardened magma forces the layers of rock to bend upward into a dome shape. Eventually, the rock above the dome mountain wears away, leaving it exposed. This process formed the Black Hills in South Dakota.

Geothermal Activity

The word *geothermal* comes from the Greek *geo* meaning "Earth" and *therme* meaning "heat." In **geothermal activity,** magma a few kilometers beneath Earth's surface heats underground water. A variety of geothermal features occur in volcanic areas. **Hot springs and geysers are types of geothermal activity that are often found in areas of present or past volcanic activity.**

Hot Springs A hot spring forms when groundwater is heated by a nearby body of magma or by hot rock deep underground. The hot water rises to the surface and collects in a natural pool. (Groundwater is water that has seeped into the spaces among rocks deep beneath Earth's surface.) Water from hot springs may contain dissolved gases and other substances from deep within Earth.

Geysers Sometimes, rising hot water and steam become trapped underground in a narrow crack. Pressure builds until the mixture suddenly sprays above the surface as a geyser. A **geyser** (GY zur) is a fountain of water and steam that erupts from the ground. Figure 18 shows one of Earth's most famous geysers.

Geothermal Energy In some volcanic areas, water heated by magma can provide an energy source called geothermal energy. The people of Reykjavik, Iceland, pipe this hot water into homes for warmth. Geothermal energy can also be used as a source of electricity. Steam from underground is piped into turbines. Inside a turbine, the steam spins a wheel in the same way that blowing on a pinwheel makes the pinwheel turn. The moving wheel in the turbine turns a generator that changes the energy of motion into electrical energy. Geothermal energy provides some electrical power in California and New Zealand.

Reading Checkpoint **How can geothermal energy be used to generate electricity?**

FIGURE 18
A Geyser Erupts
Old Faithful, a geyser in Yellowstone National Park, erupts about every 33 to 93 minutes. That's how long it takes for the pressure to build up again after each eruption.

Section 4 Assessment

Target Reading Skill **Outlining** Use the information in your outline about volcanic landforms to help you answer the questions below.

Reviewing Key Concepts

1. a. **Identifying** What are the three main types of volcanoes?
   b. **Comparing and Contrasting** Compare the three types of volcanic mountains in terms of shape, type of eruption, and the materials that make up the volcano.
2. a. **Listing** What features form as a result of magma hardening beneath Earth's surface?
   b. **Explaining** What are two ways in which mountains can form as a result of magma hardening beneath Earth's surface?
   c. **Predicting** After millions of years, what landform forms from hardened magma in the pipe of an extinct volcano?
3. a. **Listing** What are some features found in areas of geothermal activity?
   b. **Relating Cause and Effect** What causes a geyser to erupt?

Writing in Science

Explaining a Process Write an explanation of the process that formed Crater Lake. In your answer, include the type of volcanic mountain and eruption involved, as well as the steps in the process. (*Hint:* Look at the diagram in Figure 15 before you write.)