

Volcanoes

Molten lava at Hawaii's Mauna Loa volcano tends to keep flowing until it cools down to 770°C (1418°F).

Scientists need to wear protective clothing when collecting lava samples.

Why would scientists risk their lives to study volcanoes?



PREVIEW

► **FOCUS QUESTIONS** In this chapter you will study volcanoes and learn more about the key questions below.

Section 1 How and where do volcanoes form?

Section 2 Why are some volcanoes explosive?

Section 3 What kind of landforms are produced by volcanic eruptions?

Section 4 Where can volcanoes be found in the solar system?

► **REVIEW TOPICS** As you investigate volcanoes, you will need to use information from earlier chapters.

- asthenosphere (p. 73)
- magma (p. 118)
- plate tectonics (p. 172)
- subduction boundary (p. 177)

► **READING STRATEGY****PREVIEW**

Before you read, look through Chapter 9, noting the key ideas, key vocabulary, headings, images, and captions.



At our Web site, you will find the following Internet support for this chapter.

DATA CENTER**EARTH NEWS****VISUALIZATIONS**

- Volcanism at a Subduction Zone
- Volcanism at a Rift Zone
- Volcanic Island Formation over a Hot Spot
- Erupted Materials

LOCAL RESOURCES**INVESTIGATIONS**

- How Are Volcanoes Related to Plate Tectonics?
- How Fast Do Gases from Volcanic Eruptions Travel?
- Is It Safe to Live Near a Volcano?

9.1

KEY IDEA

Volcanoes form where magma reaches Earth's surface.

KEY VOCABULARY

- volcano
- hot spot



How Are Volcanoes Related to Plate Tectonics? Plot volcano locations. Examine maps and 3D diagrams to explore volcanism at plate boundaries.
Keycode: ES0901

How and Where Volcanoes Form

One of the most dramatic activities associated with plate tectonics is the eruption of a volcano. The term **volcano** refers both to the opening in Earth's crust through which molten rock, gases, and ash erupt and to the landform that develops around this opening.

Magma Formation

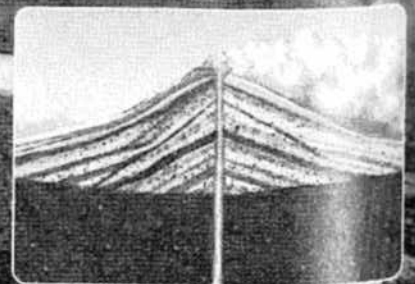
A volcanic eruption occurs when magma—molten rock that has formed deep within Earth—rises to the surface. Most of the asthenosphere is solid because of the pressure exerted by the lithosphere above it. This pressure raises the melting temperatures of materials in the asthenosphere. Yet for magma to form, some of these materials must melt. The following three conditions allow magma to form:

- A decrease in pressure can lower the melting temperatures of materials in the asthenosphere. Such a decrease takes place along the rift valley at a mid-ocean ridge, where the lithosphere is thinner and exerts less pressure.
- An increase in temperature can cause materials in the asthenosphere to melt. Such an increase occurs at a hot spot.
- An increase in the amount of water in the asthenosphere can lower the melting temperatures of materials there. Such an increase occurs at subduction boundaries.

Conditions at both divergent and subduction boundaries are ideal for magma formation. Most volcanoes are found along mid-ocean ridges, where plates are moving apart, and at subduction boundaries, where plates are being forced under other plates.

Once magma forms, it tends to rise to the surface because its density is lower than that of the solid materials surrounding it. The characteristics of a magma and the rates at which it rises depend upon the amount of silica it contains.

VOLCANO The diagram (inset) shows magma rising inside a volcano. Rising magma can lead to an explosive eruption like this one at Alaska's Mt. Augustine in 1986.



At Subduction Boundaries

As you may recall from Chapter 8, subduction boundaries are places where lithospheric plates collide. The diagrams below show the two processes by which volcanoes form: first, when an oceanic plate is forced beneath a continental plate, and second, when one oceanic plate is forced beneath another oceanic plate.

At a subduction boundary, volcanoes always form on the overriding plate. Where an oceanic plate collides with a continental plate, the volcanoes form on the overriding continental plate. The Cascade Range, which extends along the Pacific coast from northern California to British Columbia, Canada, is made up of volcanoes that have formed at an oceanic-continental subduction boundary.

Where two oceanic plates collide, the volcanoes create a chain of volcanic islands, called a volcanic island arc, on the overriding plate. The Mariana Islands in the Pacific Ocean are an example of a volcanic island arc formed at such a subduction boundary.

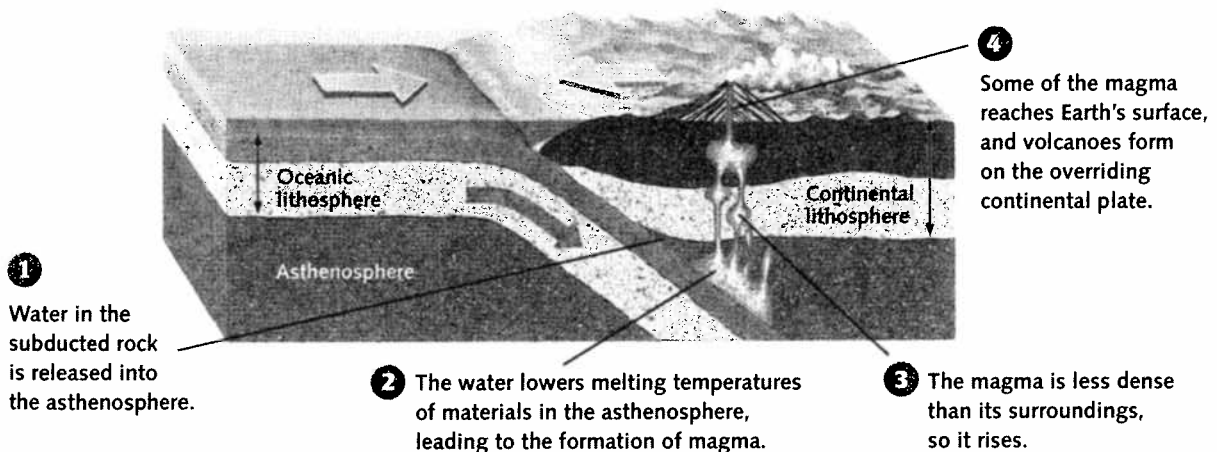


Observe an animation of volcanism at a subduction zone.

Keycode: ES0902

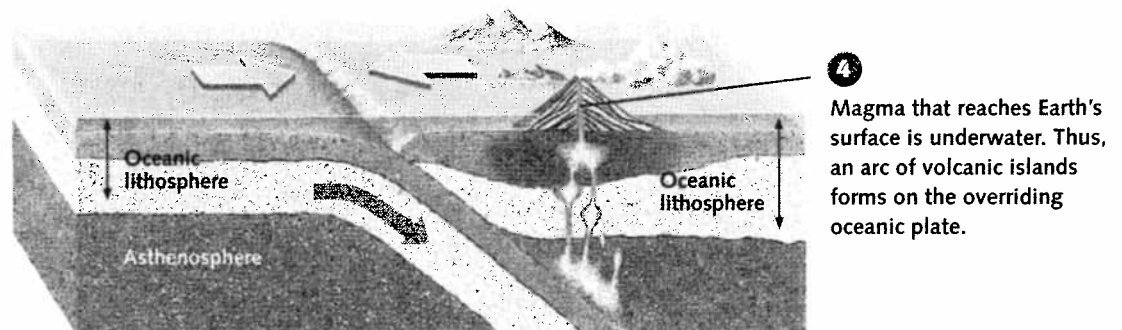
Volcanic Activity at a Subduction Boundary

BETWEEN AN OCEANIC PLATE AND A CONTINENTAL PLATE



BETWEEN OCEANIC PLATES

The process by which magma forms at an oceanic-oceanic subduction boundary is similar to the process at an oceanic-continental boundary. Notice that the difference between the two processes occurs at step 4.

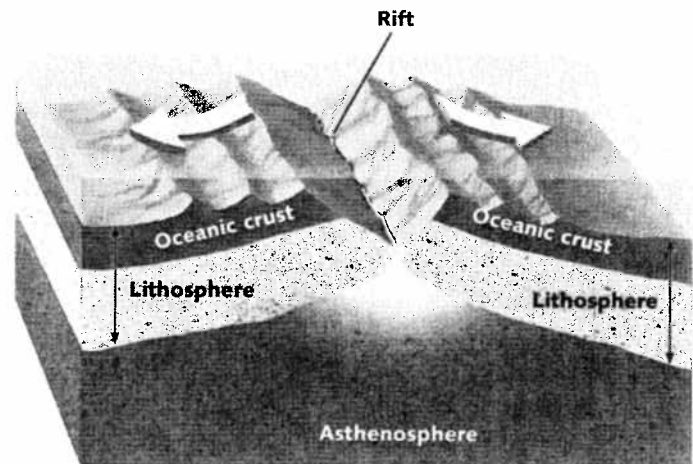


At Divergent Boundaries

Below a rift, mantle material rises from deeper, hotter regions within Earth. Also, because of the rift, the pressure is lower than it is elsewhere in the mantle. This decrease in pressure lowers melting temperatures. The combination of high temperature and low pressure causes large amounts of magma to form. Like the magma formed at subduction boundaries, the magma formed at divergent boundaries is less dense than the materials around it. The magma therefore rises through the rift to the surface.



Observe an animation of volcanism along a rift zone.
Keycode: ES0903



MAGMA FORMATION AT A MID-OCEAN RIDGE

Scientific Thinking

ANALYZE

Volcanic activity in Iceland can cause problems, but it also provides a nearly inexhaustible source of energy, such as that produced by the geothermal plant below. Find information about the uses of Iceland's geothermal resources.

COMMUNICATE

Use the information to present a summary of the risks and benefits associated with living in an area with Iceland's level of volcanic activity.

Most of the magma that reaches Earth's surface does so at divergent boundaries, along the mid-ocean ridges. Because most mid-ocean ridges are underwater, you can understand why most of Earth's volcanic activity takes place beneath its oceans.

One place where a mid-ocean ridge rises above sea level is Iceland. Here the rifts associated with the Mid-Atlantic Ridge mark the surface of the land. Much of Iceland is volcanically active, and sometimes this volcanic activity is harmful to living things. In 1783 the Icelandic volcano Laki erupted, releasing lava, ash, and poisonous gases including sulfur dioxide. This eruption killed over three-fourths of Iceland's livestock. It also caused flooding. The destruction of crops and livestock resulted in the deaths of nearly 10,000 people from starvation or disease.

ICELAND uses geothermal energy from the Mid-Atlantic Ridge.

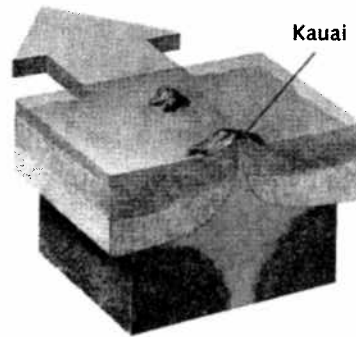
Over Hot Spots

Not all volcanic activity occurs at plate boundaries. **Hot spots** refer to areas of volcanic activity that result from plumes of hot solid material that have risen from deep within Earth's mantle. As the material rises, it melts at areas of lower pressure. Some scientists estimate that the sources of magma producing such hot spots are anywhere from 670 kilometers to nearly 2900 kilometers beneath the surface.

A hot spot remains in the same place even as a lithospheric plate moves across it. As the diagram below shows, the Hawaiian Islands have formed as the Pacific plate has moved northwest over a hot spot. The largest and youngest island, Hawaii, currently lies above the hot spot. As you might expect, this island is volcanically active. Extending northwest is a chain of extinct volcanoes, many of which have sunk below sea level as erosion has worn them away. Each volcano in that chain formed over the hot spot that now lies below Hawaii. The chain also includes underwater volcanoes called seamounts which are not shown in the illustration below.

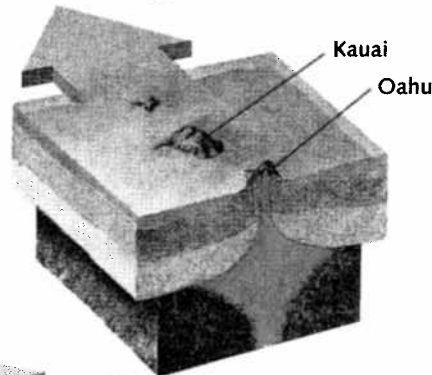
5.3 TO 4.9 MILLION YEARS AGO

The island of Kauai formed as molten rock hardened and built up on the seafloor over the hot spot. As the plate moved northwest, it carried the island away from the hot spot.

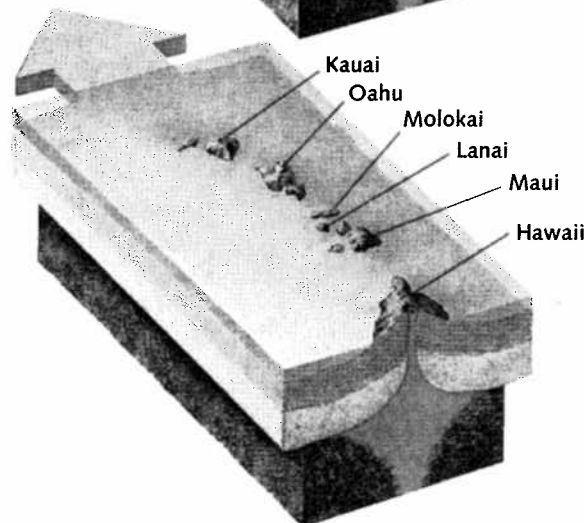


3.8 TO 2.5 MILLION YEARS AGO

The island of Oahu formed after the volcano on Kauai had moved away from the hot spot. Again, molten rock hardened and built up until Oahu rose above sea level.



TODAY The island of Hawaii now sits over the hot spot. The hot spot fuels three active volcanoes, including one underwater (not shown here). This seamount is located to the east of the island.

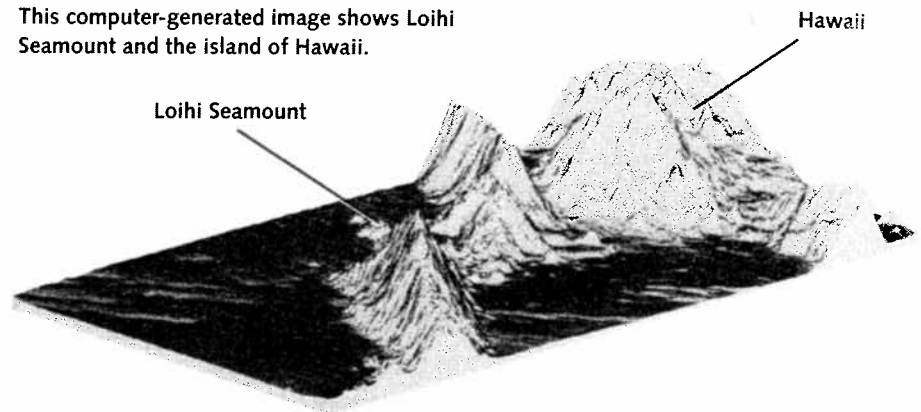


Observe an animation of volcanic islands forming over a hot spot.
Keycode: ES0904

Island formation continues about 30 kilometers off the coast of the island of Hawaii, where scientists are studying a young, very active underwater volcano called Loihi Seamount. These scientists predict that tens of thousands of years from now, the peak of Loihi will reach sea level and become a new Hawaiian island. In the meantime, studies of Loihi are revealing important information about hot spots, deep-sea geology, and the effects of seamounts on marine life.

LOIHI SEAMOUNT

This computer-generated image shows Loihi Seamount and the island of Hawaii.



Monitoring an underwater volcano involves unique difficulties. Although Loihi is taller than Mount St. Helens was before its eruption in 1980, its peak is still about 900 meters below sea level. Since 1996, scientists have been using submersibles to study the site. In 1997, an undersea observatory was deployed at Loihi's summit. This observatory allows scientists to monitor eruptions and earthquakes with an underwater microphone, a seismometer, and a pressure sensor.

9.1 Section Review

- 1 Describe how magma forms at a subduction boundary.
- 2 Explain the difference between the volcanic activity that occurs at a hot spot and the volcanic activity that occurs at a subduction boundary between an oceanic plate and a continental plate.
- 3 Describe the volcanic activity that occurs at a divergent boundary.
- 4 **CRITICAL THINKING** Make a concept map or other graphic organizer that shows how the following geologic features are related: subduction boundary, divergent boundary, hot spot, overriding plate, subducting plate, volcano. You may add other words to your concept map if you wish.
- 5 **GEOGRAPHY** Use the map of plate boundaries on pages 712–713. Identify the plates associated with the development of the Cascade Range and those associated with the development of the Mariana Islands.

Magma and Erupted Materials

Kilauea, a volcano on the island of Hawaii, has spewed molten rock for decades. In contrast, Mount St. Helens exploded violently in 1980 after more than a century of being a quiet, snow-capped mountain. Differences in the volcanic activity at these two sites result partly from differences in the magmas that rise to the surface there.

Types of Magma

Silica, a principal ingredient in all magmas, determines a magma's **viscosity**, or resistance to flow. Magmas high in silica resist flow, whereas magmas with lower silica content flow more easily. Basaltic magmas contain the least silica; as a result, they flow most easily. Andesitic and rhyolitic magmas contain more silica and are more resistant to flow.

Magmas also contain gases—mainly water vapor and carbon dioxide. The gases, dissolved in the magmas at the depths where they form, may bubble out of solution as the magmas rise. Most gases escape easily from basaltic magmas. When these magmas reach the surface, any remaining gases usually produce relatively harmless fountains and floods. Gases in more viscous andesitic and rhyolitic magmas, however, cannot escape as easily. As such magmas rise, the gases expand and propel the magma rapidly to the surface. The result can be an explosive eruption of gas and debris, such as the one at Mount St. Helens.

Each type of magma tends to form at specific locations. Basaltic magmas form at rifts and at oceanic hot spots. Andesitic magmas tend to form at subduction boundaries. Rhyolitic magmas generally form where hot spots underlie continental plates.

9.2




KEY IDEA

The composition of magma largely determines how explosive a volcanic eruption will be.

KEY VOCABULARY

- viscosity
- lava
- pahoehoe
- aa
- pillow lava
- pyroclastic material
- pyroclastic flow

SUMMARY Characteristics of Magma

	Basaltic Magma	Andesitic Magma	Rhyolitic Magma
Silica content	Least (about 50%)	Intermediate (about 60%)	Most (about 70%)
Gas content	Least	Intermediate	Most
Viscosity	Least viscous	Intermediate	Most viscous
Type of eruption	Rarely explosive	Sometimes explosive	Usually explosive
Melting temperature	Highest	Intermediate	Lowest
Location	Rifts, oceanic hot spots	Subduction boundaries	Continental hot spots
			
	Kilauea	Mount St. Helens	Yellowstone caldera



25-Minute

Mini LAB

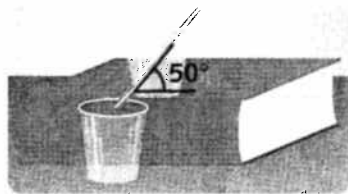
Modeling Viscosity

Materials

- 2 disposable cups
- 3 straws
- water
- eyedropper
- stopwatch
- syrup
- vegetable oil

Procedure

- 1 Poke a hole in a cup and position a straw through the hole and down to the second cup as shown. The straw should be tilted about 50°.



- 2 Fill an eyedropper with water. Squeeze the water into the straw. Time how long it takes for all of the liquid to exit the straw into the cup.
- 3 Repeat step 2, using vegetable oil. Then use syrup. Use a new straw for each liquid.

Analysis

Compare the three liquids to the types of magma described in the chart on page 199.

Which of the liquids is most like basaltic magma? Most like andesitic magma? Most like rhyolitic magma? Explain.

VOCABULARY STRATEGY

In the word *pyroclastic*, *pyro-* comes from a Greek word meaning "fire," and *-clastic* from a Greek word meaning "broken."

Lava Flows

Magma that reaches Earth's surface is called **lava**. Like magma, lava is primarily molten rock. The composition of lava may differ from that of magma, however, because materials may be added to or removed from the magma as it rises to the surface.

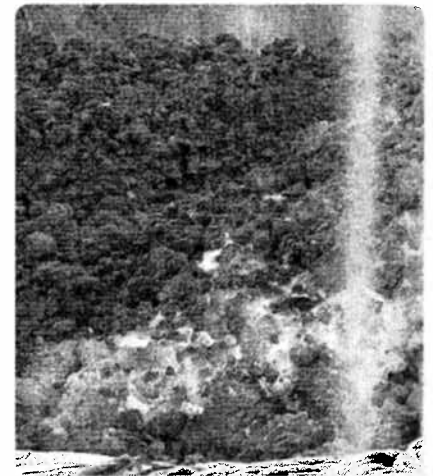
Lava Flows on Land

Basaltic lava flows are usually associated with less-explosive eruptions. As these flows cool, they form basaltic rock. The temperature and speed of a basaltic flow affect the appearance of its hardened surface. Volcanologists use two Hawaiian terms to describe solidified lava flows on land, **pahoehoe** (puh-HOH-eh-HOH) and **aa** (AH-ah).

Basaltic lava at a high temperature flows quickly out of vents, forming **pahoehoe**, lava with smooth, ropelike surfaces. Cooler basaltic lava moves more slowly. It cools quickly into **aa**, with rough, jagged surfaces.



PAHOEHOE Smooth, ropelike surfaces characterize this cooling pahoehoe.



AA Sharp, jagged surfaces characterize this cooling aa.


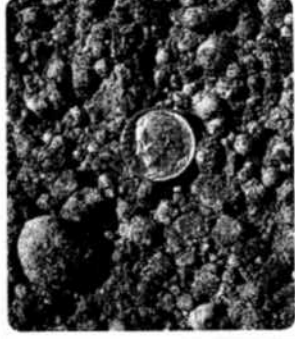

Underwater Lava Flows

Whether it comes from an underwater eruption or flows from land into the sea, lava that cools underwater has a distinctive shape—a rounded, pillowlike form with a hard crust. Pressure builds up inside the lava until its crust cracks, and more lava pours out, forming yet another pillow shape. The resulting mass of rounded lumps is called **pillow lava**.

Ash and Rock Fragments

More explosive eruptions usually involve magmas which contain trapped gases. When these gases are released, solid fragments called **pyroclastic material** may be ejected. A combination of pyroclastic material and fluid lava is common in most volcanic eruptions.

Pyroclastic materials are classified by size. The smallest pieces are called *ash*, pieces of intermediate size are called *lapilli*, and the largest fragments are called *blocks* and *bombs*. The classification chart below compares pyroclastic materials.

Classification of Pyroclastic Materials		
Ash	Lapilli	Block or Bomb
Diameter less than 2 mm	Diameter from 2 to 64 mm	Diameter greater than 64 mm
		

In some violent eruptions, pyroclastic material combines with hot gases to form a **pyroclastic flow**—a dense, superheated cloud that travels downhill with amazing speed. The cloud may follow the course of a valley, moving faster than 100 kilometers per hour. The eruption of Mount Vesuvius in A.D. 79 produced a pyroclastic flow that buried the Roman city of Pompeii under pumice and ash.

VISUALIZATIONS
CLASSZONE.COM

Examine video clips of erupted materials.
Keycode: ES0905

9.2 Section Review

- 1 How do basaltic, rhyolitic, and andesitic magmas differ?
- 2 Describe pahoehoe, aa, and pillow lava.
- 3 Explain why rhyolitic and andesitic magmas are associated with more-explosive eruptions, whereas basaltic magma is associated with less-explosive eruptions.
- 4 **CRITICAL THINKING** Use the information in this section to infer whether a volcano that erupts explosively would be more likely to form at a subduction boundary or at a divergent boundary.
- 5 **MATHEMATICS** One of the fastest recorded lava flows in Hawaii traveled over land at an average speed of 2.7 meters per second. Work with a partner to estimate your running speed. Predict how successful you would be if you tried to outrun such a lava flow.

9.3

Volcanic Landforms

KEY IDEA

The shape of a volcanic landform is determined by the materials produced during an eruption.

KEY VOCABULARY

- shield volcano
- cinder cone
- composite volcano
- lahar
- caldera
- lava plateau

The term *volcano* refers not only to a volcanic vent, but also to the landform that develops as the materials from a volcanic eruption harden. The shape and structure of a volcano are determined by the nature of its eruptions and the materials it ejects.

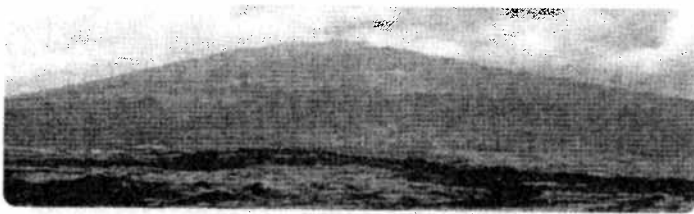
Shield Volcanoes

Because of its low viscosity, basaltic lava tends to flow long distances before hardening. In some cases, the lava builds up in layers, forming **shield volcanoes** with broad bases and gently sloping sides. The broad base of a shield volcano can support a mountain of enormous height. For example, Mauna Loa, a volcano on the island of Hawaii, rises 4170 meters above sea level and its base is 5000 meters below sea level; thus, its total height is 9170 meters.

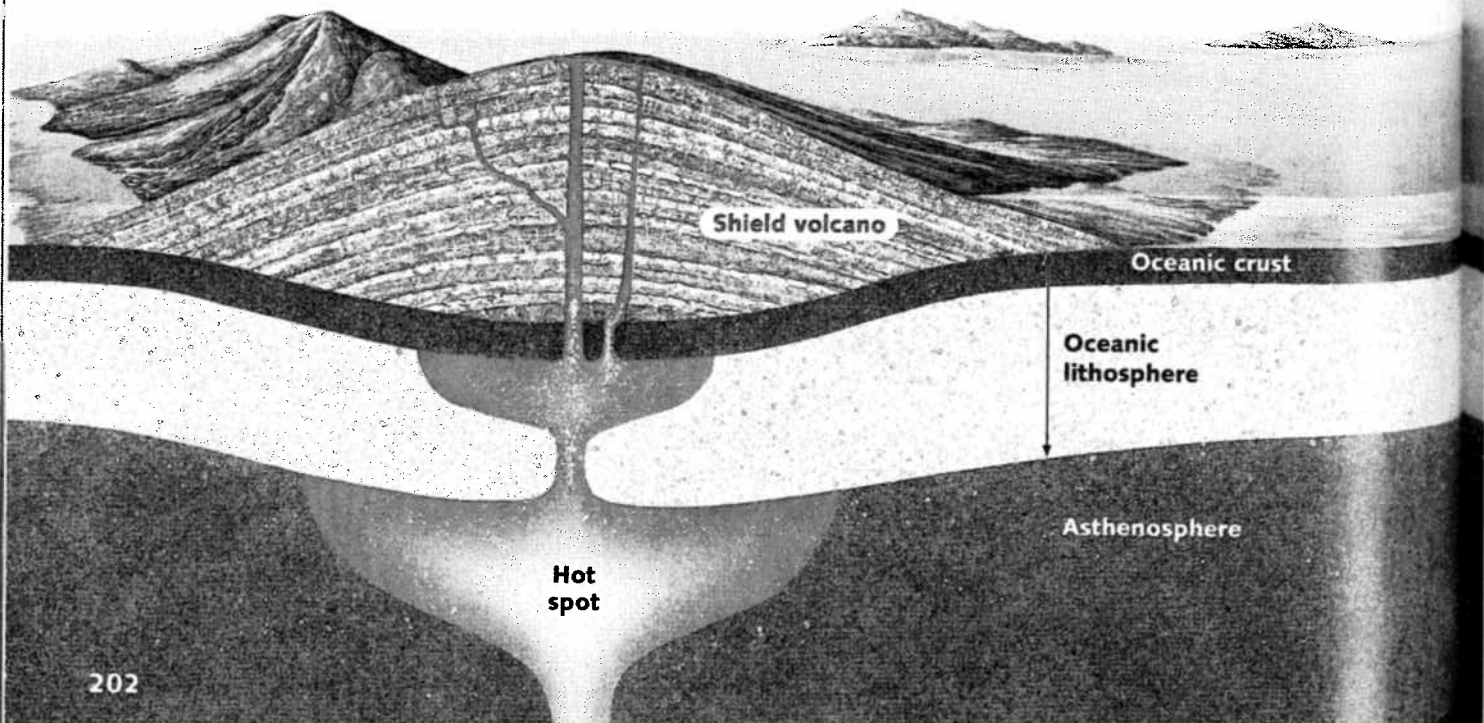
Because shield volcanoes discharge basaltic lavas, they tend to be less explosive than other types of volcanoes. Basaltic lava flows, however, may be frequent and copious, causing damage to homes, highways, and other property.

Cinder Cones

A **cinder cone**, perhaps the simplest type of volcano, forms when molten lava is thrown into the air from a vent. As it falls, the lava breaks into fragments that harden before hitting the ground. These fragments accumulate, forming a cone-shaped mound with an oval base. Cinder cones, which tend to be smaller than other types of volcanoes, typically form in groups and on the sides of larger volcanoes.



MAUNA LOA is a shield volcano on the island of Hawaii.



Composite Volcanoes

Composite volcanoes develop when layers of materials from successive explosive eruptions accumulate around a vent. The materials include hardened lava flows and other pyroclastic material.

The 1980 eruption of Mount St. Helens illustrates some of the forces and events involved in shaping a composite volcano. Except for a few minor eruptions, Mount St. Helens had been quiet since 1857. In the spring of 1980, however, earthquake activity increased, a bulge in the north face of the volcano's peak grew larger, and small eruptions of steam and ash occurred.

Eventually, an earthquake burst the bulge that had been forming on the volcano. Magma, water, and gases exploded in a massive cloud of superheated ash and stones. Some of the hot ash mixed with the snow and ice on the mountain to form a fast-moving mudflow called a **lahar** (LAH-hahr). In some areas, the debris from the lahar and landslides reached a depth of about 46 meters.

After a violent eruption, a composite volcano may remain relatively quiet for a long period of time. Beneath the surface, however, gas-rich magma may again be building up pressure, eventually leading to another explosive eruption.

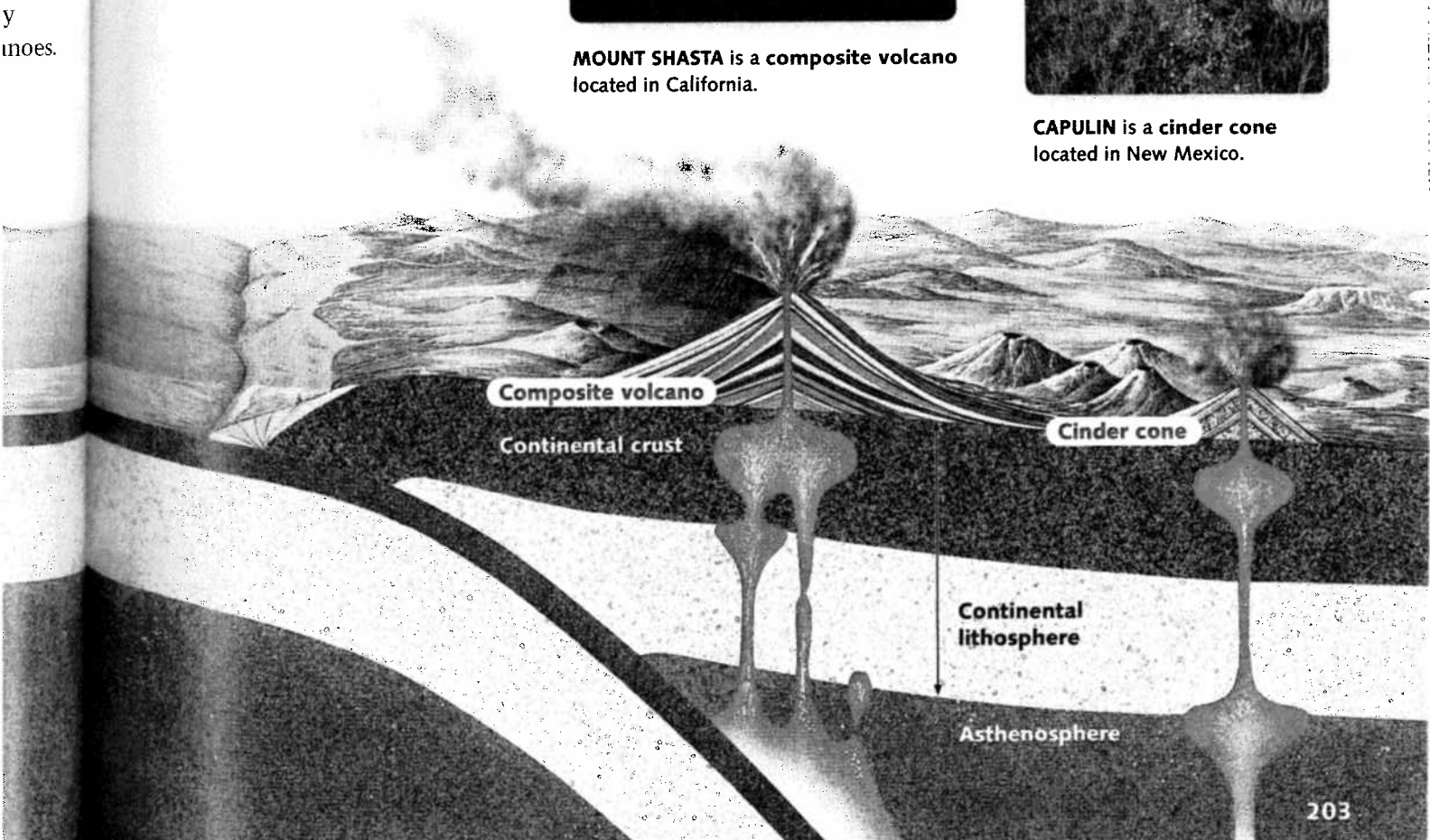
The illustrations on these pages show three volcanic landforms and the processes which formed each type.



MOUNT SHASTA is a composite volcano located in California.



CAPULIN is a cinder cone located in New Mexico.



Calderas

Sometimes magma beneath a volcano is released after the top of the volcano collapses, forming a large crater-shaped basin called a **caldera** (kal-DAIR-uh). Many active volcanoes have calderas at their summits. In some cases, a caldera fills with water to form a lake.

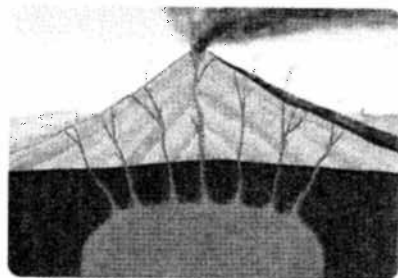
Crater Lake in Oregon is an example of a caldera. About 7000 years ago, a volcano exploded in a cataclysmic eruption. The collapse of the cone's top created a caldera. Gradually, the caldera filled with water to form Crater Lake, shown at left.

Some calderas, such as the one in Yellowstone National Park in the western United States, are still active. Beneath Earth's surface, magma superheats the water which feeds the hot springs and geysers at Yellowstone. Geologists estimate that the eruption that produced the Yellowstone caldera may have been 1000 times more powerful than the 1980 Mount St. Helens blast.

CRATER LAKE is a caldera that has filled with water.



Formation of Crater Lake



- 1 About 7700 years ago, a volcanic eruption partially emptied an underground magma chamber.



- 2 The top of the cone collapsed inward, forming a basin known as a caldera.



- 3 Over time, rainwater filled the caldera, forming Crater Lake. Additional volcanic activity formed the small cone in the center.

Lava Plateaus

Sometimes plate tectonics results in the formation of a long, narrow crack or fissure in Earth's surface. Basaltic lava pouring from the fissure spreads across the land, forming a **lava plateau**. The basaltic lava that formed the Columbia Plateau in the northwestern United States is over one kilometer thick in some places and covers an area of about 164,000 square kilometers.

9.3 Section Review

- 1 Compare and contrast the ways in which shield volcanoes and cinder cones are formed.
- 2 **CRITICAL THINKING** Describe the formation of a composite volcano.
- 3 **WRITING** The eruption of Mount Rainier, a composite volcano, could pose a serious threat to local residents. Write a description of the potential hazards that people living near Mount Rainier might face.

SCIENCE & Society

Predicting Eruptions, Saving Lives

Consider two of the deadliest eruptions of the past century:

- 1902** An eruption of Mount Pelée on Martinique kills nearly 30,000 people.
- 1985** Lahars triggered by an eruption of Colombia's Nevado del Ruiz volcano sweep through the town of Armero, killing over 20,000 people.



DEVASTATION The 1985 eruption of Nevado del Ruiz, in Colombia, caused extensive damage and casualties.

Can such tragedies be prevented? Is it possible to predict a volcanic eruption in time to save lives?

When Mount Pinatubo, a volcano in the Philippines, rumbled to life in April 1991, scientists quickly set up a station to monitor its activity. They also collected samples of the gas escaping from the summit of the mountain. Toward the end of May, they detected an increase in sulfur dioxide emissions, which led them to conclude that magma was rising. In early June, they observed that the side of the volcano was swelling. Meanwhile, seismic activity was increasing. All evidence suggested that a large eruption was about to occur.

From June 9 through June 15, Mount Pinatubo erupted in a series of increasingly violent explosions. Fortunately, scientists and public officials had worked together to set up a plan for educating and alerting the population. Some 58,000 people had been evacuated from the areas predicted to be in the greatest danger. Eventually, as many as 200,000 people were forced to evacuate their homes. The evacuees were spared from the dangerous lahars the eruption produced. Thousands of lives had been saved

from what proved to be one of the most destructive eruptions of the 20th century. ■

Extension

SCIENCE NOTEBOOK

Consider ways in which predictions made by scientists promote safety. Explain how scientific predictions might affect your life.



How Fast Do Gases from Volcanic Eruptions Travel?

Use satellite images of Mount Pinatubo to calculate the speed of volcanic ash and gases moving through the atmosphere.

Keycode: ES0906



EVACUATING People carry their belongings away from a dangerous area near Mount Pinatubo.

9.4

KEY IDEA

Extraterrestrial volcanoes have been active and are currently active in the solar system.

Extraterrestrial Vulcanism

Earthbound scientists knew, even before probes landed on Mars, that volcanic activity existed elsewhere in our solar system. As scientists gather and interpret data from telescopes and orbiting probes, their understanding of volcanic activity elsewhere in the solar system grows.

The Moon

About 15 percent of the moon's surface is covered by dark areas. Early astronomers, looking at the moon without telescopes, originally thought that these dark areas might be seas. For this reason, the areas came to be known as *maria* (from the Latin word for seas). Scientists have determined the maria consist mostly of basaltic lava flows, the result of volcanic activity that began between 3 billion and 4 billion years ago. Radioactive elements beneath the moon's surface probably provided the energy necessary for the volcanic activity to begin.

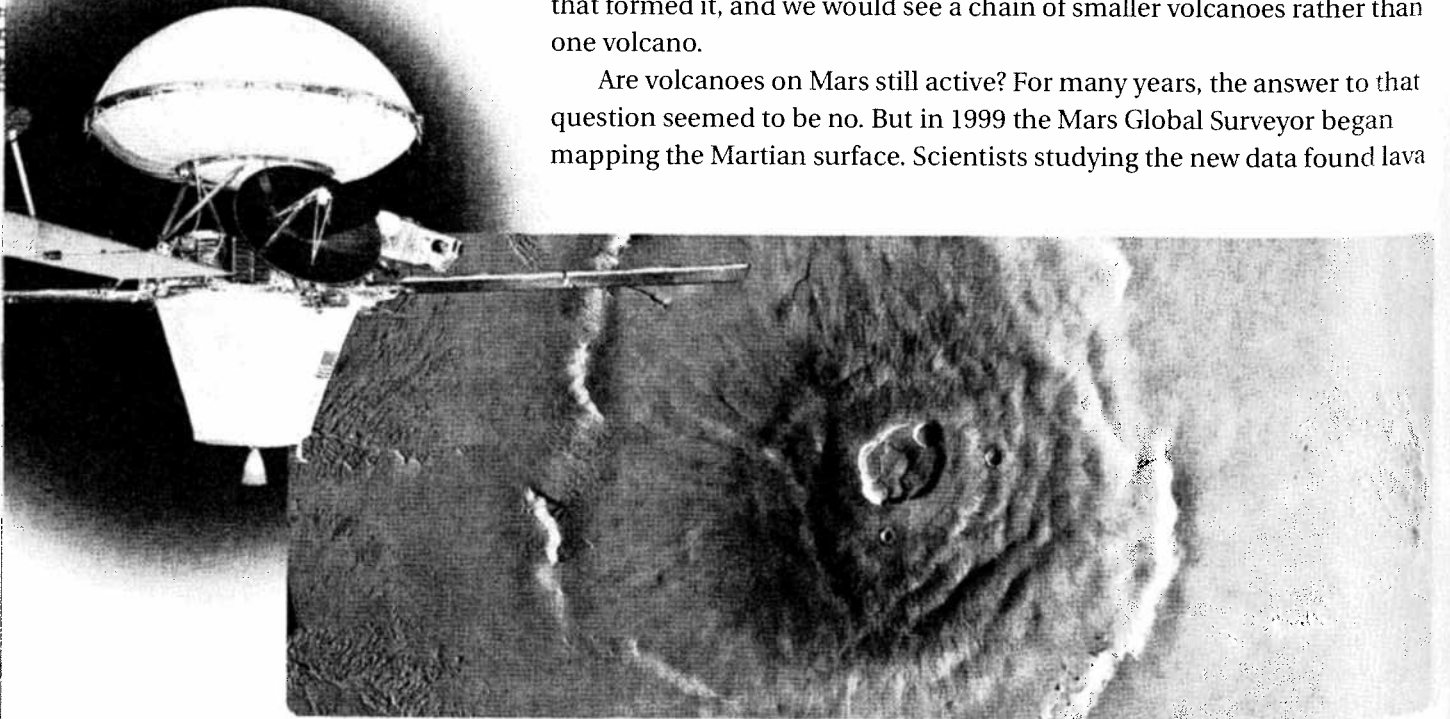
Scientists rely, in part, on photographs to understand the history of volcanic activity on the moon. For example, if a photograph shows an impact crater filled with lava, scientists know that the lava flow is younger than the crater. They also use rock samples. The oldest samples of lunar lava that have been found are about 4.2 billion years old. The youngest are about 3.1 billion years old.

Mars

Mars is home to a number of shield volcanoes. One of these, Olympus Mons, is the largest known volcano in the solar system. It measures 600 kilometers across its base and towers about 27 kilometers above the surrounding terrain. Its huge size suggests that Mars does not have moving plates. If it did, Olympus Mons would have moved away from the hot spot that formed it, and we would see a chain of smaller volcanoes rather than one volcano.

Are volcanoes on Mars still active? For many years, the answer to that question seemed to be no. But in 1999 the Mars Global Surveyor began mapping the Martian surface. Scientists studying the new data found lava

OLYMPUS MONS, MARS Images taken by the Viking 1 Orbiter were used to create this view of Olympus Mons.



flows that appeared to be 20 million to 60 million years old. Though this sounds like a great age, it really amounts to the blink of an eye in the long history of Mars. For this reason, some scientists wonder whether volcanoes on Mars could erupt in the future.

Venus

Orbiting spacecraft have used radar to penetrate the thick clouds around Venus and to map its surface, revealing more than 1600 large volcanoes, as well as volcanic features such as lava flows and calderas. Countless smaller volcanoes also cover the surface of Venus. Most of the volcanoes are shield volcanoes. The largest are as broad as those on Mars but much flatter.

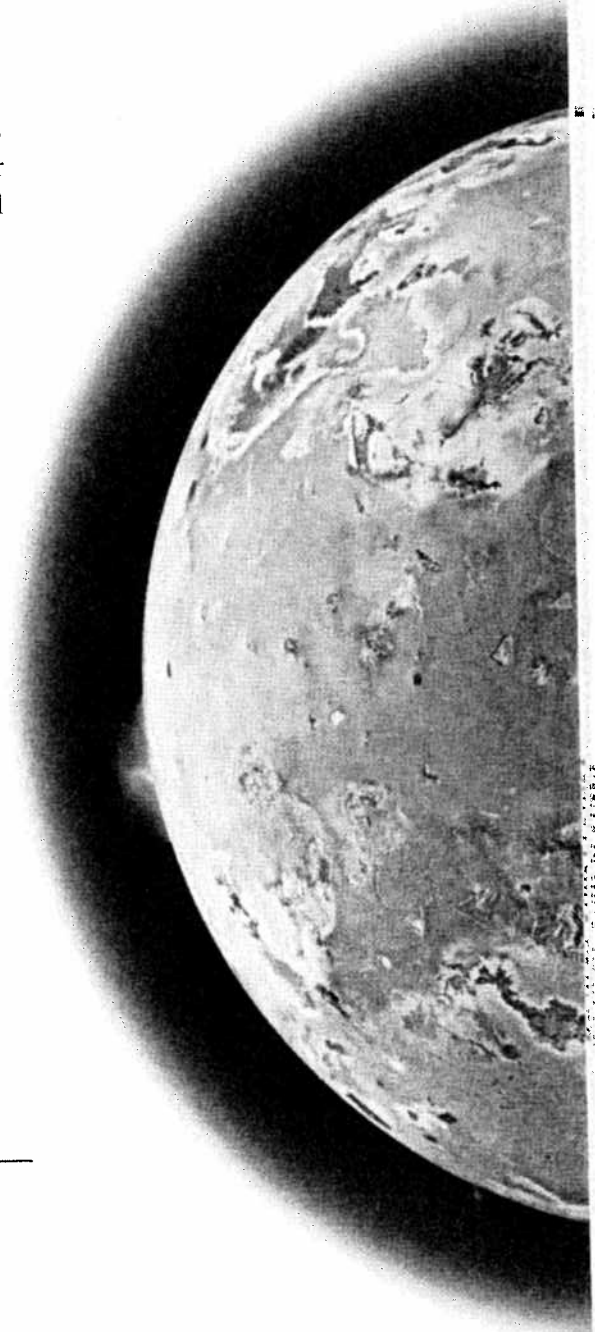
Although most volcanoes on Venus are probably inactive, some may still be active. Computer models have suggested that volcanic activity could account for the scorching 460°C (860°F) surface temperatures on Venus. Gases escaping from volcanoes could be interacting with the planet's atmosphere to continually trap heat at Venus's surface.

Io

One of the most volcanically active places in the solar system is Io (EYE-oh), Jupiter's third largest moon. Io is caught in a gravitational tug of war between Jupiter and two other moons. As a result, some parts of Io's surface regularly move up and down by as much as 100 meters. The resulting friction is the source of heat that powers Io's volcanic activity, which continually changes this moon's surface. In the photograph to the right, the small light blue patch extending into space is a 140-kilometer-high plume erupting from a volcano called Pillan Patera.

Lava temperatures at Pillan Patera may be as high as 1720°C . Volcanic activity on Earth has not produced such high temperatures for billions of years, and some scientists think that lavas on Io may resemble those of early Earth. It is possible that studies of Io will provide a window into Earth's own history.

10 The volcanic plume of Pillan Patera is 140 kilometers high.



9.4 Section Review

- 1 What type of lava flows are found on the moon?
- 2 Why is Olympus Mons much larger than Earth's shield volcanoes?
- 3 How do scientists know that there are volcanoes on Venus?
- 4 What is the source of heat responsible for the volcanic activity on Io?
- 5 **CRITICAL THINKING** Would you expect to find composite volcanoes on Mars? Explain your reasoning.
- 6 **MATHEMATICS** Look back at the description of Mauna Loa on page 202. Use a ratio to compare its height with the height of Olympus Mons.

Where Are Active Volcanoes?

SKILLS AND OBJECTIVES

- **Plot** the locations of active volcanoes on a world map.
- **Hypothesize** why volcanic activity occurs in certain locations.
- **Predict** where volcanic activity is likely to occur in the future.

MATERIALS

- **Lab Sheet 9** *World Map with Latitude and Longitude Grid*
- **Appendix B** *Earth's Tectonic Plates Map*, pages 712–713
- colored pencils

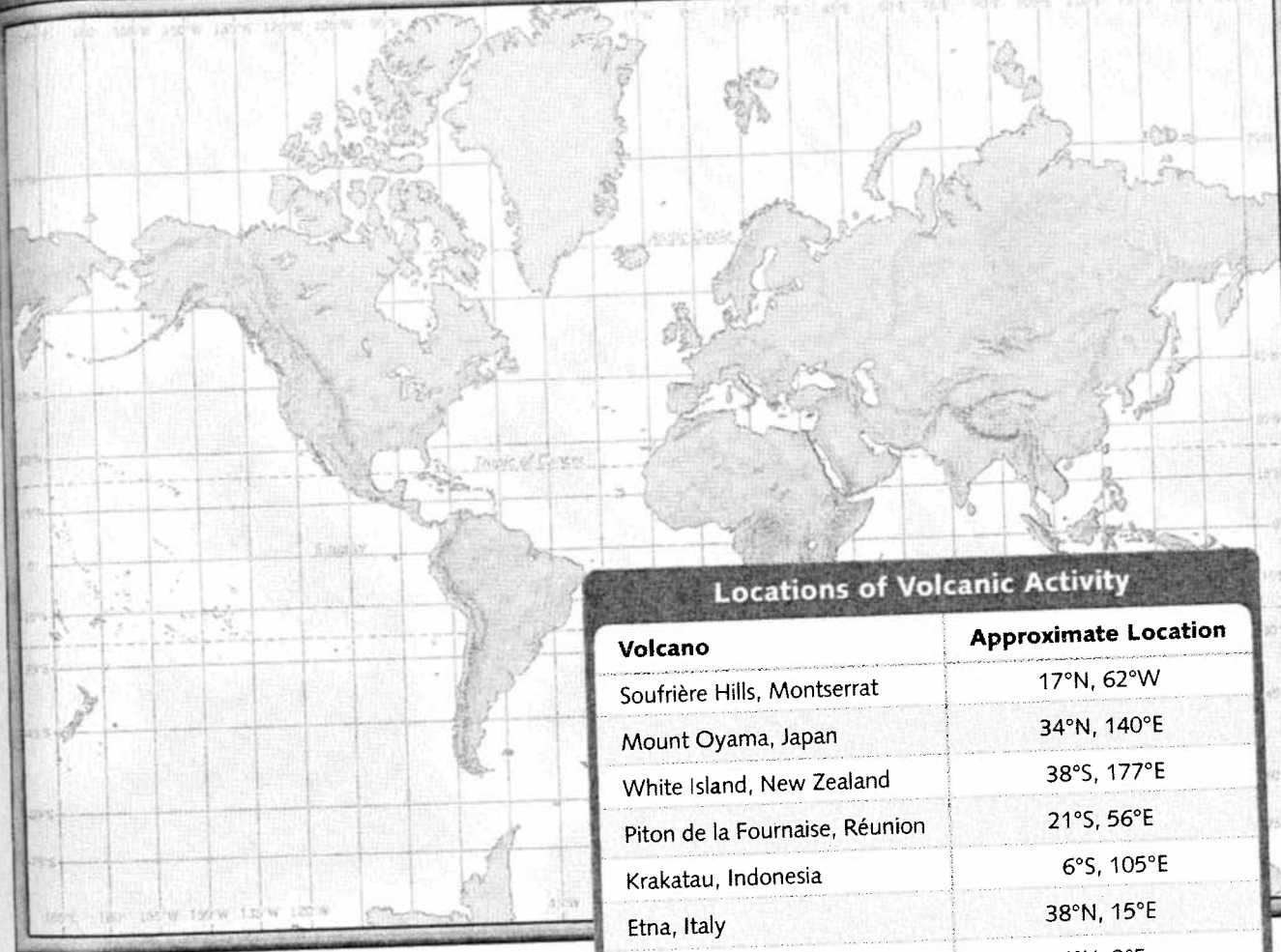
At this very moment, somewhere in the world a volcano is erupting or is about to erupt. In this map activity, you will use your knowledge of latitude and longitude to locate volcanic activity around the world. What patterns do you see?

Procedure

- 1 Refer to the table on page 209 showing approximate locations of volcanic activity. The table lists locations on land where volcanic activity was recorded during a five-month period.
- 2 Use the latitude and longitude coordinates in the table to identify and mark each location on the map on Lab Sheet 9.
- 3 Compare the patterns of volcanic activity as shown on your map with the map showing plate boundaries on pages 712–713.
- 4 Record your answers to the Analysis and Conclusions questions in your science notebook.

Analysis and Conclusions

1. Identify the plate boundaries that are close to sites of volcanic activity.
2. Hypothesize why volcanic activity occurs in the locations you have marked on Lab Sheet 9.
3. Which volcanoes occur at subduction boundaries? at diverging plate boundaries? at hot spots?
4. From the information you have on your lab sheet, describe where you see the most volcanic activity. For example, is volcanic activity more prevalent at a particular longitude?
5. Of the volcanoes listed in the table, find the ratio of the number of active volcanoes in the Pacific Ring of Fire to the total number of active volcanoes. How can you use this ratio to predict the likelihood that an eruption occurring on Earth will occur in the Pacific Ring of Fire?
6. Based on your analysis, where would you expect most future volcanic activity on Earth to take place?



Locations of Volcanic Activity

Volcano	Approximate Location
Soufrière Hills, Montserrat	17°N, 62°W
Mount Oyama, Japan	34°N, 140°E
White Island, New Zealand	38°S, 177°E
Piton de la Fournaise, Réunion	21°S, 56°E
Krakatau, Indonesia	6°S, 105°E
Etna, Italy	38°N, 15°E
Mount Cameroon, Cameroon	4°N, 9°E
Popocatepetl, Mexico	19°N, 99°W
Kavachi, Solomon Islands	9°S, 158°E
San Cristóbal, Nicaragua	13°N, 87°W
Tungurahua, Ecuador	1°S, 78°W
Shishaldin, USA	55°N, 164°W
Usu, Japan	43°N, 141°E
Guagua Pichincha, Ecuador	0°S, 79°W
Mayon, Philippines	13°N, 124°E
Bezymianny, Russia	56°N, 161°E
Pacaya, Guatemala	14°N, 91°W
Hekla, Iceland	64°N, 20°W
Kilauea, USA	19°N, 155°W
Karymsky, Russia	54°N, 159°E

7. Find the data on volcanic activity from the past 12 months. Plot the locations of this volcanic activity using a different colored pencil. Use the completed lab sheet to test the predictions you made in Question 6.



Find out more about current volcanic activity.

Keycode: ES0908

CHAPTER 9

REVIEW

Summary of Key Ideas

9.1 Volcanic activity takes place primarily at subduction boundaries and at divergent boundaries, where the combination of temperature, pressure, and water content are right for the formation of magma. Magma and volcanoes also form at hot spots.

9.2 The amount of silica in magma affects its viscosity. Basaltic magma has the least silica, so it flows easily. Andesitic and rhyolitic magmas have more silica, so they are more resistant to flow. Gases escape easily from basaltic magma, generating relatively quiet eruptions. But gases tend to be trapped in andesitic and rhyolitic magmas, leading to explosive eruptions.

9.3 A volcano's shape and structure depend on how it erupts and what materials are released. Shield volcanoes are formed by basaltic lava that flows long distances before hardening. Cinder cones are formed when molten lava is thrown into the air from a vent and breaks into drops. These drops harden into cinders that form a steep cone around the vent. Composite volcanoes are formed by layers of pyroclastic materials and lava that have erupted in the past.

9.4 Volcanic activity has occurred in the past on the moon, Mars, and Venus. Jupiter's moon Io is currently volcanically active.

KEY VOCABULARY

aa (p. 200)	pahoehoe (p. 200)
caldera (p. 204)	pillow lava (p. 200)
cinder cone (p. 202)	pyroclastic flow (p. 201)
composite volcano (p. 203)	pyroclastic material (p. 200)
hot spot (p. 197)	shield volcano (p. 202)
lahar (p. 203)	viscosity (p. 199)
lava (p. 200)	volcano (p. 194)
lava plateau (p. 204)	

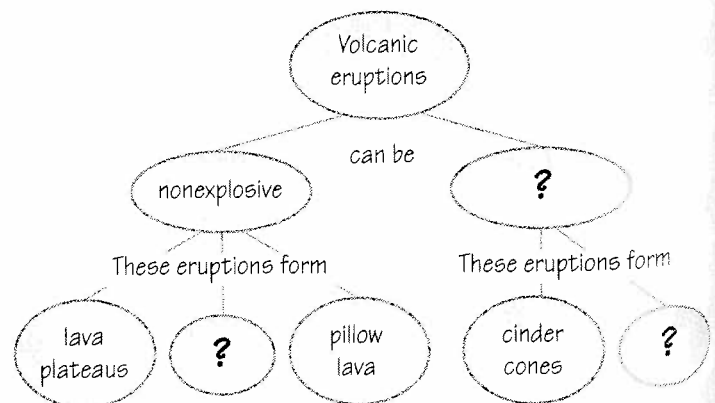
Vocabulary Review

Write the term from the key vocabulary list that best completes the sentence.

1. An area of volcanic activity in the middle of a lithospheric plate is called a _____.
2. When lava cools underwater, _____ often forms.
3. In an explosive eruption, a composite volcano may erupt ash and other solid fragments called _____.
4. Because it has greater resistance to flow, andesitic magma is said to have greater _____ than basaltic magma.

Concept Review

5. Where does most of Earth's volcanic activity occur?
6. How did the Hawaiian Islands form?
7. Describe some risks and benefits of living near a volcano.
8. Which types of magma are most likely to result in an explosive eruption? Why?
9. Describe three types of volcanoes and give an example of each.
10. Explain how lava plateaus form, and give an example of one.
11. What do scientists think has caused the volcanic activity on the moon? On Io?
12. **Graphic Organizer** Copy and complete the concept map below. There may be more than one possible answer. Justify your answer.



Critical Thinking

13. **Infer** The rate of movement of subducting plates differs from one subduction boundary to the next.
- How might this fact affect the rate at which magma is produced in the asthenosphere? Explain your thinking.
 - How might the rate of magma production affect the number of volcanic eruptions at a subduction boundary?
 - How might your answers to parts (a) and (b) explain why Indonesia usually has one major volcanic eruption each year while the Cascade Range in Washington state has only occasional eruptions? Explain.
14. **Predict** What relationship would you expect to find between the sizes of particles in a pyroclastic deposit and the distance from the volcanic source of the material? Explain your thinking.

Interpreting Graphs

The graph shows some of the extinct volcanoes of the Hawaiian Island chain. The vertical axis of the graph shows the approximate age of each volcano, and the horizontal axis shows the distance of each volcano from Kilauea, the youngest volcano on the Big Island of Hawaii. Kilauea is still an active volcano.

- Which volcano was over the hot spot about 7 million years ago?
- What is the age difference between Haleakala, which is on the island of Maui, and Waianae, which is on the island of Oahu?
- If a volcano of the Hawaiian Island chain were located 600 kilometers from Kilauea, what would you expect its age to be?
- About how far away from Kilauea would an island be if its rocks were 4 million years old?
- Which volcano in the graph is oldest? About how old is it, and about how far is it from Kilauea?
- About how fast, in centimeters per year, has the Pacific Plate been moving over the hot spot? Explain your thinking.

Internet Extension



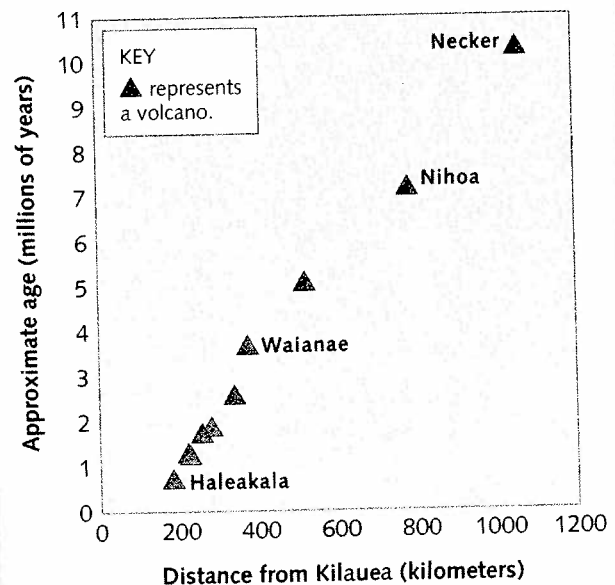
Is It Safe to Live Near a Volcano? Analyze what happened at Mount St. Helens to understand volcanoes in the northwestern United States. Develop an evacuation plan for the area surrounding Mount Rainier in Washington state.

Keycode: ES0907

Writing About the Earth System

SCIENCE NOTEBOOK One of the most catastrophic volcanic events in history occurred when the Indonesian volcano Krakatau erupted in 1883. Do some research to find information about the 1883 eruption of Krakatau. Using the information, explain the impact of this eruption on the geosphere, the hydrosphere, the atmosphere, and the biosphere.

Ages of Selected Hawaiian Volcanoes



Note: In the graph above, only the volcanoes mentioned in the exercises are labeled.