10 Volcanoes and Other Igneous Activity

Big idea

Dynamic Earth

Q: Where does new lithosphere come from?

Molten lava pours over the edge of the big island of Hawaii and into the sea, producing clouds of steam. The eruption of deep-ocean volcanoes is what produced these islands.

VIRGINIA SCIENCE STANDARDS OF LEARNING

ES.1.a, ES.2.c, ES.6.a, ES.7.a, ES.7.b. **See lessons for details.**

INQUIRY

TRY IT!

WHERE ARE VOLCANOES LOCATED?

Procedure

1. Use the Internet and library resources to locate at least 15 active volcanoes and 10 historical volcanic eruptions.
2. Plot the locations of these volcanoes on a copy of a world map or on an overlay for a world atlas.
3. Neatly label the volcanoes on the map or overlay.
4. Compare your volcano map with the map of the worldwide distribution of earthquakes on page 231 and the map of plate boundaries on pages 262–263.

Think About It

1. **Observe** What is the relationship between the locations of the volcanoes you plotted and the earthquake epicenters and plate boundaries on the maps?
2. **Infer** If there have been numerous volcanic eruptions in an area, would the area be a likely place for earthquakes to occur? Explain your answer.
3. **Predict** Use your volcano map to predict if a volcanic eruption would be likely or not likely in each of the following areas: eastern coast of North America, Spain, eastern coast of South America, Italy, and Japan.

10.1 Volcanoes and Plate Tectonics

ES.7 The student will investigate and understand geologic processes including plate tectonics. Key concepts include **b.** tectonic processes.

Key Questions

How does magma form?

What is the relationship between plate boundaries and volcanic activity?

Vocabulary

- decompression melting
- Ring of Fire
- intraplate volcanism
- hot spot

Reading Strategy

Outline After you read, make an outline of the most important ideas in the section.

Volcanoes and Plate Tectonics

I. Origin of Magma
  A. Heat
  B. ____?____
II. ____?____

STARTING IN 1999, the 5000-meter-high Tungurahua volcano in Ecuador began to erupt. It spewed glowing chunks of lava, volcanic ash, and gases into the sky. In August 2006, streams of hot gas and rock exploded down the volcano's sides. Villagers fled as ash blanketed their farms and homes.

Tungurahua volcano is one of more than 800 active volcanoes on Earth. The process leading to a volcanic eruption begins deep beneath the surface where magma forms.

Origin of Magma

Recall that magma is molten rock beneath Earth's surface. Magma is a complex mixture that contains partly melted mineral crystals, dissolved gases, and water. **Magma forms in the crust and upper mantle when solid rock partially melts. The formation of magma depends on several factors, including heat, pressure, and water content.**

Heat What source of heat is sufficient to melt rock? At a depth of 100 kilometers, the temperature of the mantle ranges from 1400°C to 1600°C. At these temperatures, the solid rock of the lower crust and upper mantle is near, but not quite at, its melting point. The additional heat needed to produce magma comes from three sources. First, friction generates heat as huge slabs of lithosphere slide past each other in subduction zones. Second, the mantle itself heats these subducting slabs. Third, hot mantle rock can rise and intrude into the cooler lithosphere, heating it.

Pressure You have learned that pressure increases with depth inside Earth. Increasing pressure raises the melting point of rock deep beneath the surface. Decreasing pressure, in contrast, lowers rock's melting point. **Decompression melting** occurs when rock rises and melts due to reduced pressure. This process typically takes place as hot yet solid mantle rock rises because it is less dense than the surrounding rock. As the rock rises, pressure on the rock decreases. As you can see in **Figure 2,** this decrease in pressure lowers the rock's melting point, forming pockets of magma.

FIGURE 1 Eruption
Tungurahua volcano in Ecuador erupted violently in 2006.

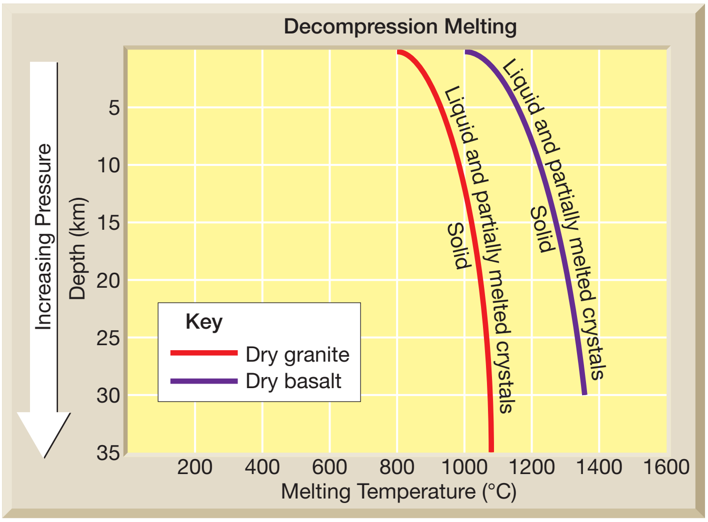


FIGURE 2 Decompression Melting For granite and basalt that are "dry" (have low water content), decompression melting occurs as pressure decreases near the surface.
Interpret Graphs *What is basalt's melting temperature at a depth of 7 km?*

Water Content Increasing water content of rock also lowers the rock's melting temperature. Because of this, "wet" rock deep beneath the surface melts at a much lower temperature than does "dry" rock of the same composition and under the same pressure. Laboratory studies have shown that the melting point of basalt can be lowered by up to 100°C when basalt's water content is increased from zero to 0.1 percent.

☑ **Reading Checkpoint** *How does higher water content affect rock's melting point?*

Volcanoes and Plate Boundaries

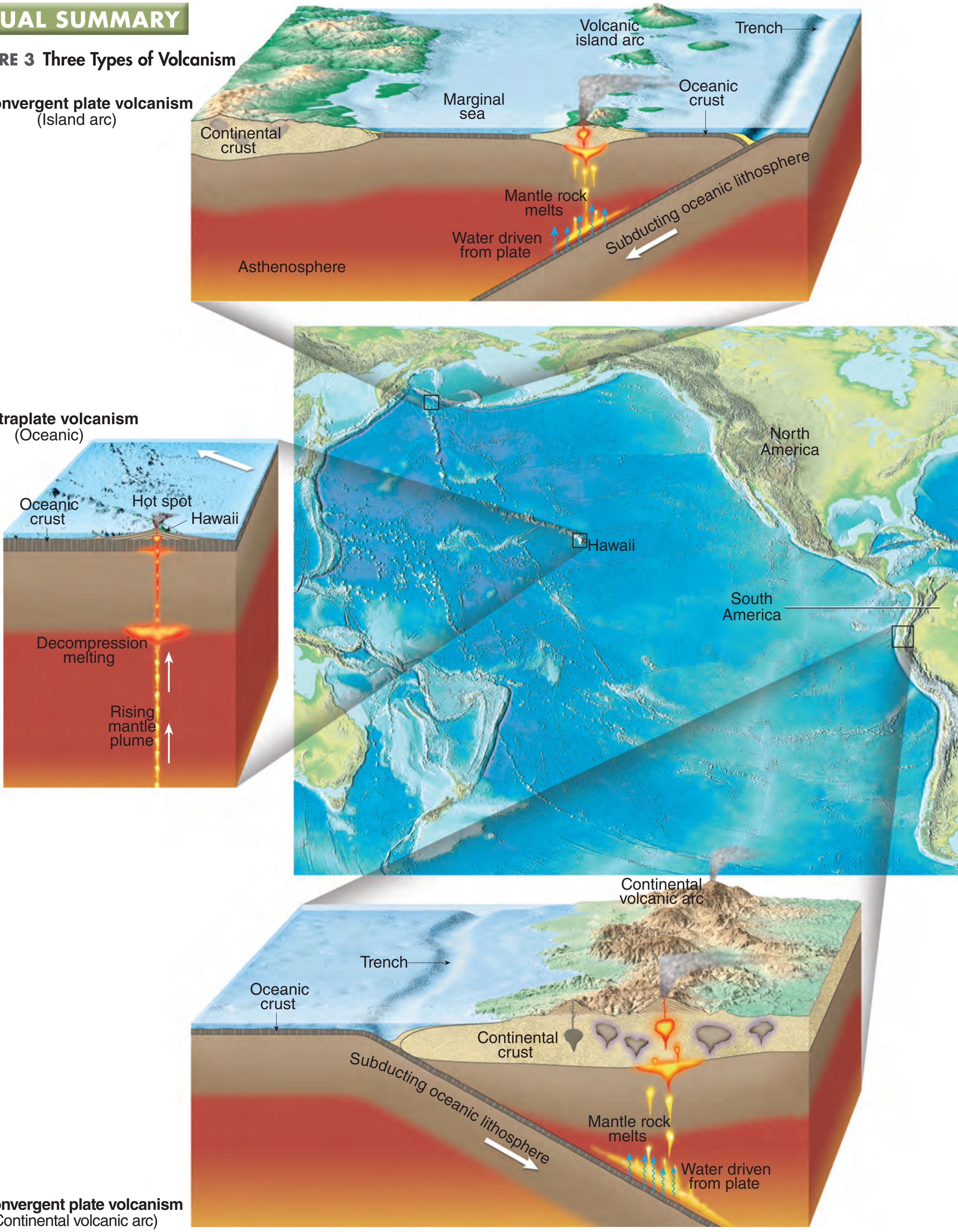
Fortunately, magma only reaches the surface in certain areas. What determines where volcanoes form? **Most volcanoes form along divergent and convergent plate boundaries. Some volcanoes form far from plate boundaries above "hot spots" in the crust.** You can see different types of volcanic activity associated with plate boundaries in **Figure 3**, which begins on the next page.

Divergent Boundary Volcanism At divergent boundaries, volcanic activity occurs where the plates pull apart. Mantle rock rises to fill the gap between the plates. As the rock rises, decompression melting occurs. This forms magma, which erupts through a spreading center.

Although most spreading centers are located along mid-ocean ridges, some are not. The Great Rift alley in eastern Africa is an area where continental crust is being pulled apart along a divergent boundary. Mount Kilimanjaro in Tanzania is one of many volcanoes that have formed near the rift v lley.

VISUAL SUMMARY

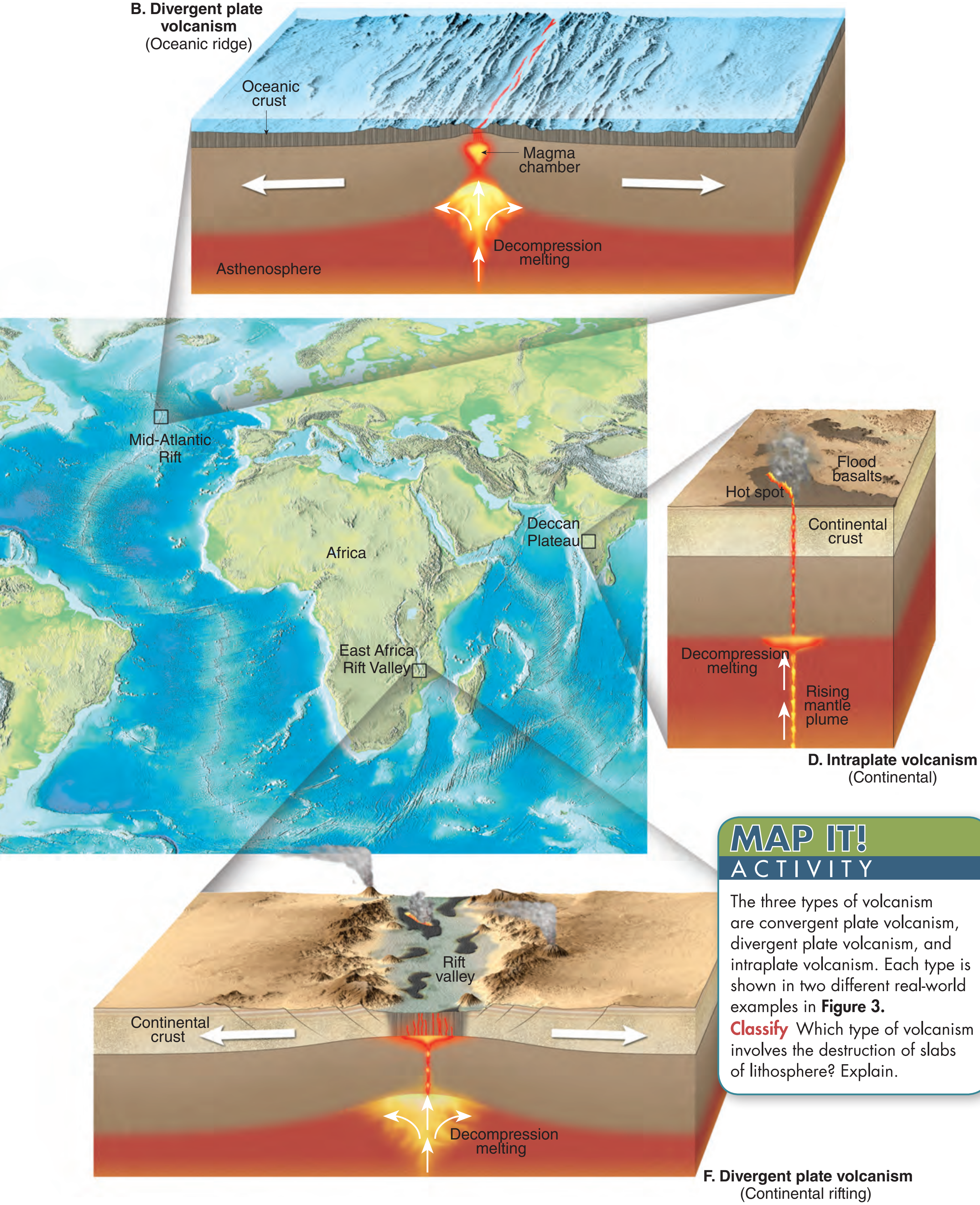
FIGURE 3 Three Types of Volcanism



A. Convergent plate volcanism
(Island arc)

C. Intraplate volcanism
(Oceanic)

E. Convergent plate volcanism
(Continental volcanic arc)



MAP IT! ACTIVITY

The three types of volcanism are convergent plate volcanism, divergent plate volcanism, and intraplate volcanism. Each type is shown in two different real-world examples in **Figure 3.**

Classify Which type of volcanism involves the destruction of slabs of lithosphere? Explain.

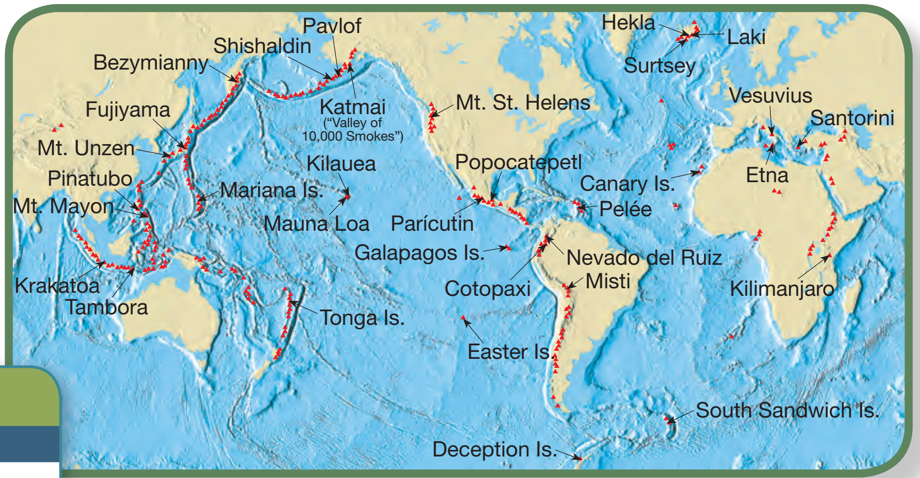


FIGURE 4 **Major Volcanoes**

MAP IT!
ACTIVITY

In **Figure 4**, note the volcanoes encircling the Pacific basin, known as the "Ring of Fire."
Infer How are the volcanoes in the middle of the Atlantic Ocean related to a plate boundary?

Convergent Boundary Volcanism Volcanoes form at convergent plate boundaries where slabs of oceanic crust subduct into the mantle. As a slab sinks deeper into the mantle, the increase in temperature and pressure drives water from the oceanic lithosphere. Once the sinking slab reaches a depth of about 100 to 150 kilometers, this water reduces the melting point of hot mantle rock low enough for melting to begin. Magma migrates upward through the overlying plate, forming volcanoes.

If the affected part of the overlying plate is made of oceanic lithosphere, the process produces a chain of volcanoes on the ocean floor. Eventually, these volcanic mountains may grow large enough to rise above the surface. If that happens, the volcanoes are called a *volcanic island arc*. Numerous volcanic island arcs, such as the Mariana islands, are found near subduction zones of the Pacific Ocean. Together with other volcanoes bordering the Pacific, they form the Ring of Fire, shown in **Figure 4.** The **Ring of Fire** is the long belt of volcanoes that circles much of the Pacific Ocean.

Volcanism may also occur at convergent plate boundaries where a slab of oceanic lithosphere is subducted under continental lithosphere. The result is a *continental volcanic arc*. The process is basically the same as for an island arc. Tungurahua and the other volcanoes of the Andes in South America form a continental volcanic arc. These volcanoes formed as the Nazca plate was subducted beneath the South American plate.

PLANET DIARY

For links about **Volcanoes**, visit PlanetDiary.com/HSES.

☑ **Reading Checkpoint** *What process formed the volcanoes of the Andes?*

Intraplate Volcanism Hawaii's Mount Kilauea is Earth's most active volcano. But Kilauea is in the middle of the Pacific plate, thousands of kilometers from a plate boundary and the Ring of Fire. Another volcanic region, centered on the hot springs and geysers of the Yellowstone National Park, is in the middle of the North American plate. Both Kilauea and Yellowstone are examples of **intraplate volcanism**—volcanic activity that occurs within a plate.

Most intraplate volcanism occurs where a mass of hotter-than-normal mantle material, called a mantle plume, rises toward the surface. As the plume nears the top of the mantle, decompression melting forms magma. The result may be a small volcanic region a few hundred kilometers across called a **hot spot.** More than 40 hot spots are known. Most of these hot spots have lasted for millions of years.

The volcanic mountains that make up the Hawaiian Islands have formed as the Pacific plate moves over a hot spot. As shown in **Figure 5,** the age of each volcano indicates the time when it was over the hot spot. Kauai is the oldest of the major islands in the Hawaiian chain. Its volcanoes are not likely to erupt again. The more recently formed island of Hawaii has two active volcanoes—Mauna Loa and Kilauea.

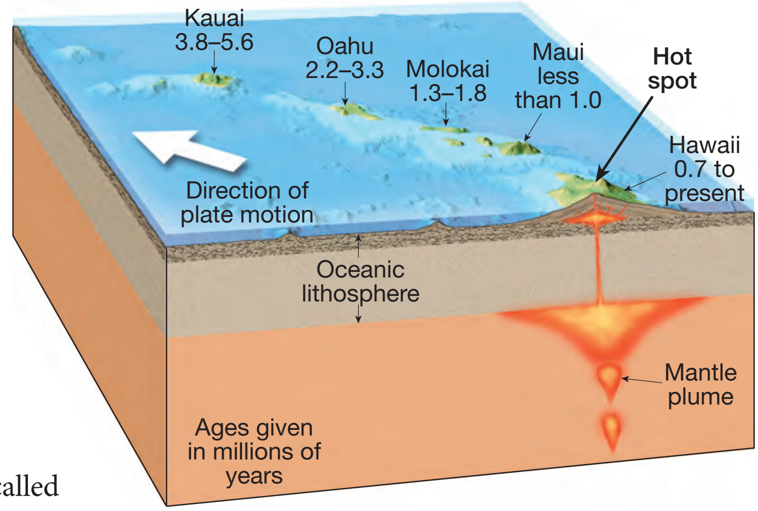
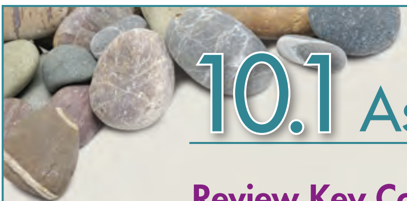


FIGURE 5 Intraplate Volcano
The Hawaiian hot spot activity is currently centered beneath Kilauea and is an example of intraplate volcanic activity.



10.1 Assessment

Review Key Concepts

1. What three factors affect how magma forms?
2. How are the locations of volcanoes related to plate boundaries?
3. What causes intraplate volcanism?
4. What is the Ring of Fire?
5. How is magma formed through decompression melting?

Think Critically

6. **Review** Describe how an island arc forms at a convergent boundary.
7. **Infer** Geologists have found ancient deposits of lava and volcanic ash extending southwest from the Yellowstone hot spot to Nevada. What can you infer from this observation?

WRITING IN SCIENCE

8. **Explain** Recall what you learned about convection currents in Chapter 9. Explain how convection currents could affect the depth at which molten rocks are found.

10.2 The Nature of Volcanic Eruptions

ES.7 The student will investigate and understand geologic processes including plate tectonics. Key concepts include **a.** geologic processes and their resulting features.

Key Questions

What determines the type of volcanic eruption?

What materials are ejected from volcanoes?

What are the three main types of volcanoes?

What other landforms are associated with eruptions?

Vocabulary

- viscosity • vent
- pyroclastic material
- volcano • crater
- shield volcano
- cinder cone
- composite cone
- caldera • volcanic neck
- lava plateau • lahar

Reading Strategy

Preview Copy the table. Before reading the section, rewrite the orange topic headings as questions. As you read, answer the questions.

The Nature of Volcanic Eruptions	
What factors affect an eruption?	a. ?

ON MAY 18, 1980, Mount St. Helens erupted with tremendous force. The blast blew out the entire north side of the volcano. The eruption ejected nearly a cubic kilometer of ash and other debris, producing a dramatic change in scenery captured in **Figure 6**.

Factors Affecting Eruptions

Why did Mount St. Helens erupt explosively, while others, such as Kilauea, erupt slowly and more quietly? **The primary factors that determine whether a volcano erupts explosively or quietly include characteristics of the magma and the amount of dissolved gases in the magma.**

Viscosity

Magma's viscosity—whether the magma is thick and sticky or thin and runny—affects the type of eruption that occurs. **Viscosity** is a substance's resistance to flow. For example, maple syrup is more viscous than water, so it flows more slowly. Magma from an explosive eruption may be thousands of times more viscous than magma that erupts quietly. The temperature and chemical composition of magma determine the magma's viscosity. The same is true for *lava*, which is magma that has reached the surface.

If you heat maple syrup, it becomes more fluid and less viscous. In the same way, the viscosity of magma and lava are strongly affected by temperature. As lava flow cools and hardens, its viscosity increases. The lava flow slows, halts, and eventually becomes rock.

Chemical composition is the more important factor in determining type of eruption. In general, the more silica in magma, the greater its viscosity. Because of their high silica content, granitic lavas are very viscous and will erupt explosively. Basaltic lavas, which contain less silica, are less viscous and tend to erupt quietly.

FIGURE 6 Mount St. Helens
A Mount St. Helens before the May 18, 1980, eruption.
B After the eruption, Spirit Lake filled with debris.

Table 1 Magma Composition					
Composition	**Silica Content**	**Viscosity**	**Gas Content**	**Tendency to Form Pyroclastics (ejected rock fragments)**	**Volcanic Landform**
Basaltic	Least (about 50%)	Least	Least (1–2%)	Least	Shield volcanoes Basalt plateaus Cinder cones
Andesitic	Intermediate (about 60%)	Intermediate	Intermediate (3–4%)	Intermediate	Composite cones
Granitic	Most (about 70%)	Greatest	Most (4–6%)	Greatest	Pyroclastic flows Volcanic domes

Dissolved Gases During explosive eruptions, the gases trapped in magma provide the force to propel lava out of the **vent,** which is a volcano's opening at the surface. As magma approaches the surface, the pressure is greatly reduced, allowing dissolved gases such as water vapor and carbon dioxide to be released explosively. Basaltic magma allows gases to bubble upward and escape relatively easily. Therefore, eruptions of fluid basaltic lava are relatively quiet. Granitic magma is slow to release expanding gases. The gases collect in bubbles and pockets that increase in size until they explode from a vent. The characteristics of basaltic, andesitic, and granitic magma are summarized in **Table 1**. As you will learn on the following pages, the different types of magma build different types of volcanic landforms.

Reading Checkpoint *What causes the dissolved gases in magma to be released?*

INQUIRY QUICK LAB

WHY ARE SOME VOLCANOES EXPLOSIVE?

Procedure

1. Obtain two bottles of noncarbonated water and two bottles of club soda.
2. Open one bottle of the noncarbonated water and one bottle of the club soda. Record your observations.
3. Gently shake each of the remaining unopened bottles. **CAUTION:** *Wear safety goggles and point the bottles away from everyone.*
4. Carefully open each bottle over a sink or outside. Record your observations.

Analyze and Conclude

1. **Observe** What happened when the bottles were opened?
2. **Infer** Which bottle represents lava with the most dissolved gas?

Volcanic Material

Lava may appear to be the main material produced by a volcano, but this is not always the case. Just as often, explosive eruptions eject huge quantities of broken rock, lava bombs, fine ash, and dust. **Depending on the type of eruption, volcanoes may produce lava flows or eject pyroclastic materials, or both. All volcanic eruptions also emit large amounts of gases.**

Lava Flows

As with magma, silica content and temperature affect the characteristics of lava flows. Hot basaltic lavas are usually very fluid because of their low silica content. Flow rates between 10 and 300 meters per hour are common. In contrast, the flow of silica-rich, granitic lava is often too slow to be visible.

Temperature differences produce two types of basaltic lava: *pahoehoe* and *aa*. Pahoehoe (pah hoh ay HOH ay) is hotter, fast-moving basaltic lava. Pahoehoe forms a relatively smooth, blue-black skin that wrinkles as the still-molten subsurface lava continues to flow. **Figure 7A** shows that pahoehoe resembles the braids in twisted ropes. Aa (AH ah) is cooler, slower-moving basaltic lava, which forms a surface of rough, jagged blocks with sharp, spiny projections, as shown in **Figure 7B**.

Gases

Magmas and lavas contain varied amounts of dissolved gases held under pressure in the molten rock, just as carbon dioxide is held in soft drinks. As with soft drinks, as soon as the pressure is reduced, the gases begin to escape. The gaseous portion of most lavas is only about 1 to 6 percent of the total weight. The percentage may be small, but the actual quantity of emitted gas can exceed thousands of tons each day. Gas samples collected during a Hawaiian eruption consisted of about 70 percent water vapor, 15 percent carbon dioxide, 5 percent nitrogen, 5 percent sulfur, and lesser percentages of chlorine, hydrogen, and argon. Sulfur compounds are easily recognized because they smell like rotten eggs and readily form sulfuric acid, a natural source of air pollution.

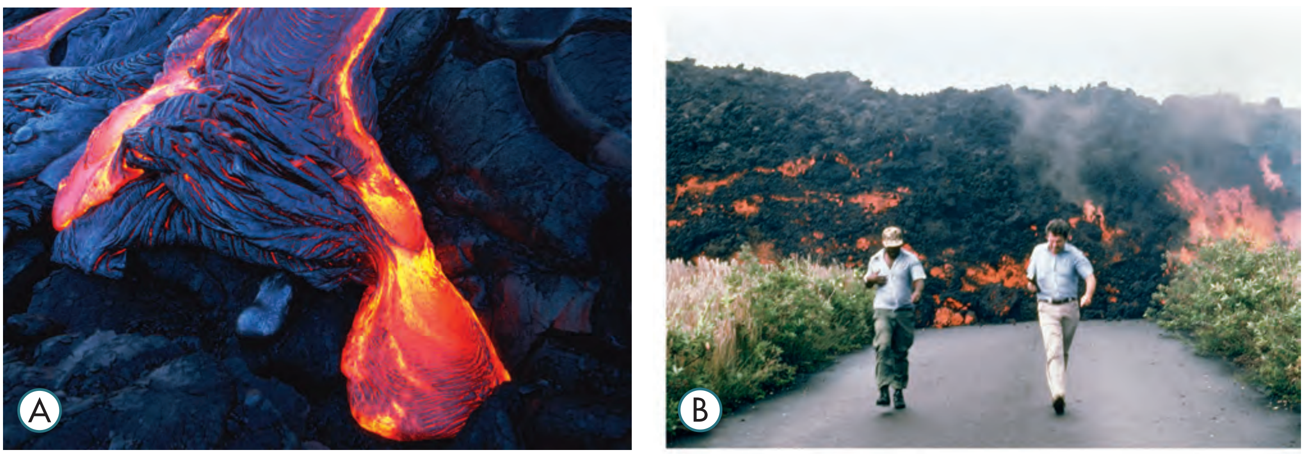


FIGURE 7 Lava Flows, Mount Kilauea, Hawaii Pahoehoe (**A**) is hotter and faster moving than aa (**B**).
Draw Conclusions *Which type of lava is more viscous?*

Pyroclastic Materials Particles produced in volcanic eruptions are called **pyroclastic materials.** When basaltic lava is extruded, dissolved gases propel blobs of lava to great heights. Some of this ejected material may land near the vent. As it cools and hardens over time, the ejected material builds a cone-shaped structure. The wind will carry smaller particles great distances. Viscous granitic magmas are highly charged with gases. As the gases expand, pulverized rock and lava fragments are blown from the vent.

The fragments ejected during eruptions range in size from very fine dust and volcanic ash (less than 2 millimeters) to pieces that weigh several tons. Particles that range in size from small beads to walnuts (2–64 millimeters) are called *lapilli*, or cinders. Particles larger than 64 millimeters in diameter are called *blocks* when they are made of hardened lava and *bombs* when they are ejected as glowing lava.

☑ **Reading Checkpoint** *What is a volcanic bomb?*

Types of Volcanoes

Volcanic landforms come in a wide variety of shapes and sizes. Each structure has a unique eruptive history. **The three main volcanic types are shield volcanoes, cinder cones, and composite cones.**

Anatomy of a Volcano Volcanic activity often begins when a fissure, or crack, develops in the crust as magma is forced toward the surface. The magma collects in a pocket beneath the surface called the magma chamber. The gas-rich magma rises from the magma chamber, travels through a circular pipe, and reaches the surface at a vent, as shown in **Figure 8.** Repeated eruptions of lava or pyroclastic material eventually build a mountain called a **volcano.** Located at the summit of many volcanoes is a steep-walled depression called a **crater.**

The form of a volcano is largely determined by the composition of the magma. As you will see, fluid lavas tend to produce broad structures with gentle slopes. More viscous, silica-rich lavas produce cones with moderate to steep slopes.

ACTIVE ART

For: Composite Volcano Eruption activity
Visit: PearsonSchool.com
Web Code: czp-3102

FIGURE 8 Anatomy of a "Typical" Volcano This cross section shows a typical composite cone.
Interpret Visuals *How was the volcano in the diagram formed?*

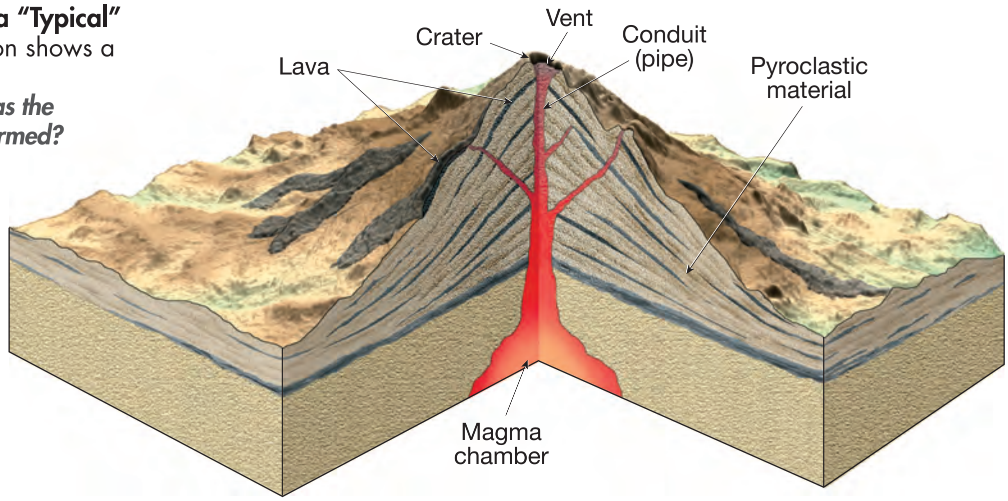
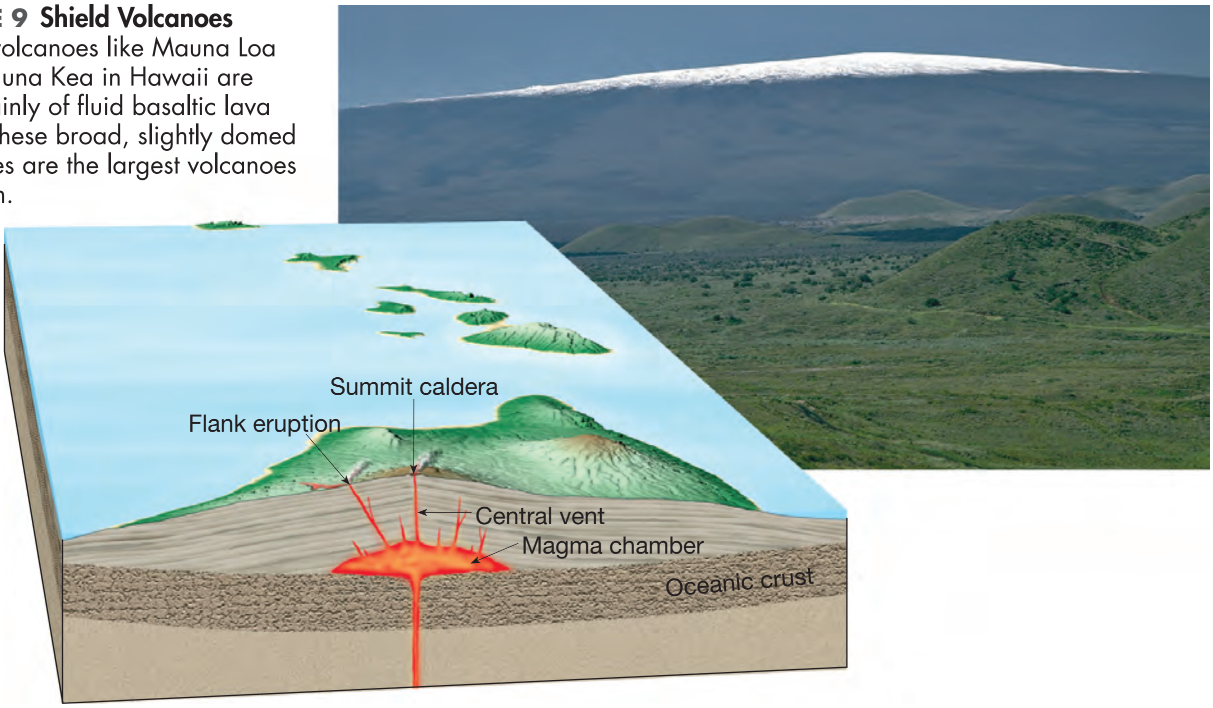


FIGURE 9 Shield Volcanoes
Shield volcanoes like Mauna Loa and Mauna Kea in Hawaii are built mainly of fluid basaltic lava flows. These broad, slightly domed structures are the largest volcanoes on Earth.



Shield Volcanoes **Shield volcanoes** are produced by the accumulation of fluid basaltic lavas. Shield volcanoes have the shape of a broad, slightly domed structure that resembles a warrior's shield, as shown in **Figure 9.** Most shield volcanoes have grown up from the deep-ocean floor to form islands. Examples of shield volcanoes include those in the Hawaiian Islands and Iceland.

Cinder Cones Ejected lava fragments that harden in the air and fall around a vent can build a **cinder cone.** The fragments consist mostly of lapilli. Cinder cones are usually a product of relatively gas-rich basaltic or granitic magma. The shape of a cinder cone is determined by the steep-sided slope that forms as loose pyroclastic material builds up around the vent. Cinder cones are usually the product of a single eruption that sometimes lasts only a few weeks and rarely more than a few years. Once the eruption ends, the magma in the pipe connecting the vent to the magma chamber solidifies, and the volcano never erupts again. As shown in **Figure 11,** cinder cones are relatively small compared to other volcanoes.

FIGURE 10 Cinder Cones
A A typical cinder cone has steep slopes of 30–40 degrees. **B** Many cinder cones, like this one near Flagstaff, Arizona, are located in volcanic fields. Others form on the sides of larger volcanoes.
Infer *What feature is shown in the lower part of the photograph?*

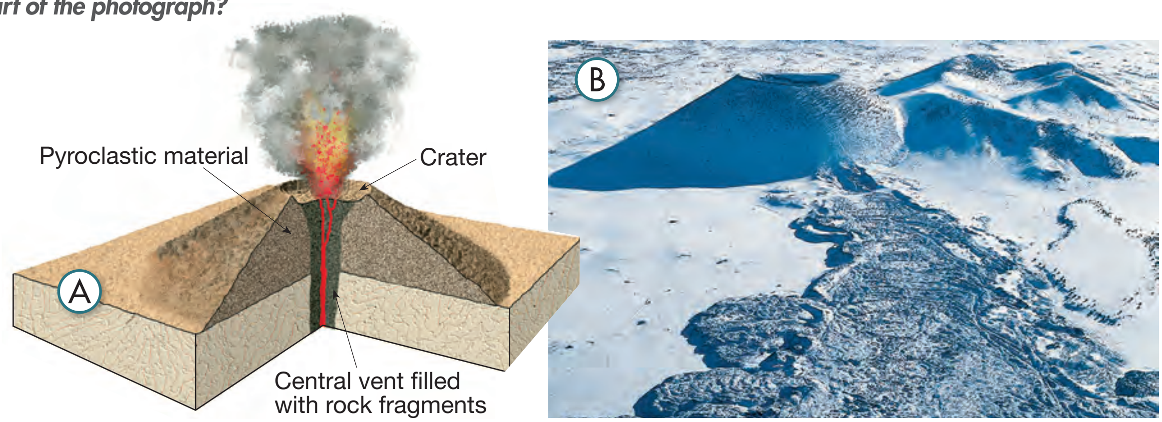
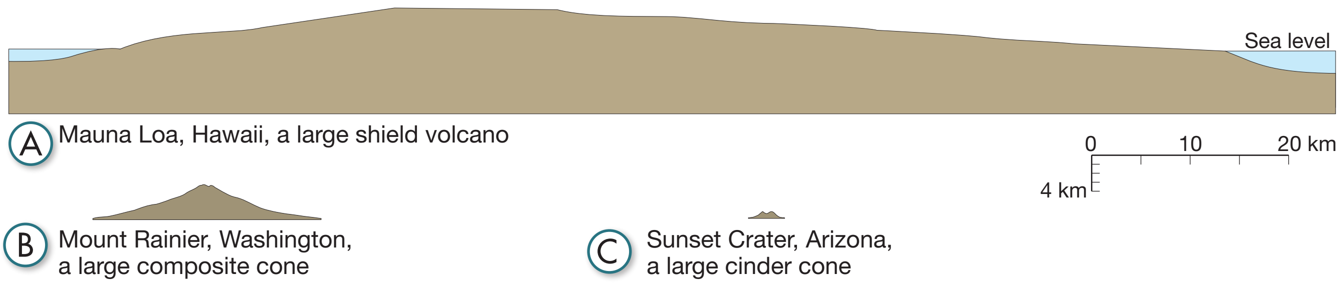


FIGURE 11 Comparing Volcanic Landforms Cinder cones and composite cones are small in comparison with a large shield volcano such as Mauna Loa in Hawaii.



Composite Cones Earth's most dangerous volcanoes are composite cones, or *stratovolcanoes*. A **composite cone** is a large, nearly symmetrical volcanic mountain composed of layers of both lava and pyroclastic deposits. For the most part, composite cones are the product of gas-rich magma having an andesitic composition. The silica-rich magmas typical of composite cones generate viscous lavas that can travel only short distances. Composite cones generate explosive eruptions, ejecting huge quantities of pyroclastic material.

Most composite cones are located in a relatively narrow zone that rims the Pacific Ocean, called the Ring of Fire. The Ring of Fire includes the large cones of the Andes in South America and the Cascade Range of the western United States and Canada. The Cascade Range includes Mount St. Helens, Mount Rainier, and Mount Shasta, shown in **Figure 12.** The most active regions in the Ring of Fire are located along volcanic island arcs next to deep ocean trenches. This nearly continuous chain of volcanoes stretches from the Aleutian Islands to Japan, the Philippines, and New Zealand.

FIGURE 12 Composite Cone Mount Shasta, California, is one of the largest composite cones in the Cascade Range. Shastina is the smaller cone that formed on the left flank of Mt. Shasta.

Other Volcanic Landforms

Volcanic mountains are not the only landforms that result from volcanic activity. **Volcanic landforms also include calderas, volcanic necks, and lava plateaus.** Each of these features forms in a different way. Long after eruptions have ended, these landforms can provide evidence of volcanic activity.

Calderas One spectacular reminder of what can happen when a volcano's activity ends is the caldera. A **caldera** is a depression in a volcanic mountain. Most calderas form in one of two ways: by the collapse of the top of a composite volcano after an explosive eruption, or from the collapse of the top of a shield volcano after the magma chamber is drained.

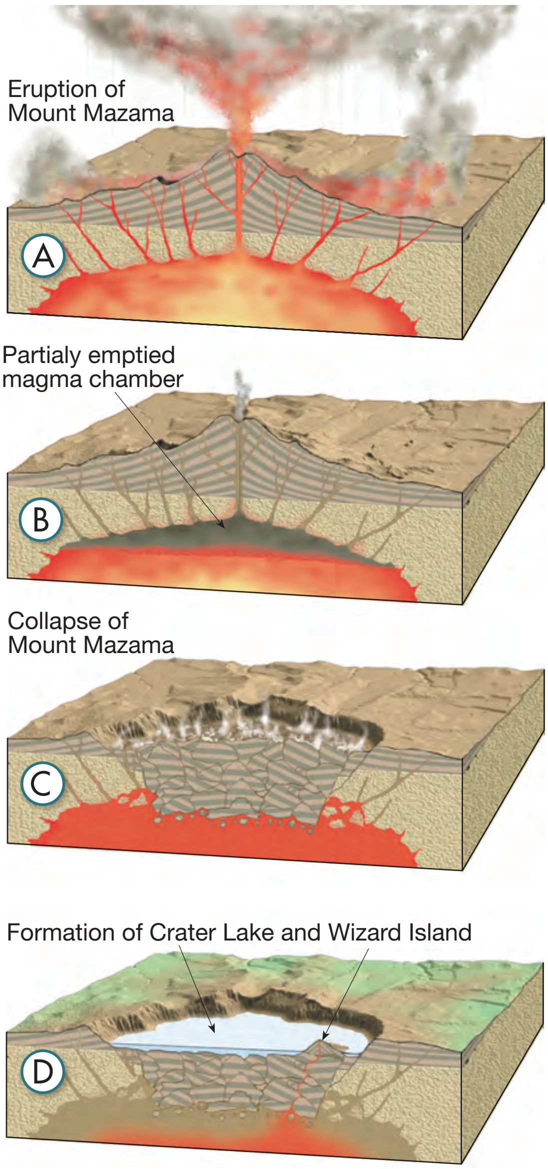
Crater Lake in Oregon occupies a caldera. This caldera formed about 7000 years ago when a composite cone, Mount Mazama, erupted violently, as shown in **Figure 13.** The eruption of Mount Mazama partly emptied the magma chamber. The roof of the magma chamber collapsed, forming a huge depression that became Crater Lake. A later eruption produced Wizard Island, the small cinder cone in the lake.

There are several other large calderas in the United States. In Hawaii, the vast "crater" atop Mount Haleakala on the island of Maui is, in fact, a caldera. In the Yellowstone caldera in Wyoming and the Valles caldera in northern New Mexico, hot springs are evidence of past, and perhaps future, volcanic activity.

VISUAL SUMMARY

CALDERA FORMATION

FIGURE 13 Crater Lake in Oregon occupies a caldera about 10 kilometers in diameter that formed about 7000 years ago.



Volcanic Necks Another volcanic landform that provides evidence of past volcanic activity is the volcanic neck. A **volcanic neck** is a landform made of magma that hardened in a volcano's conduit, or pipe, and later was exposed by erosion. Recall that a volcano's pipe connects the magma chamber with the surface. When a volcano's activity ends, magma remaining in the pipe hardens to form igneous rock.

FIGURE 14 Volcanic Neck Ship Rock, New Mexico, is a volcanic neck. Ship Rock consists of igneous rock that crystallized in the pipe of a volcano that then was eroded away.

Weathering and erosion act constantly to wear away volcanoes. For example, cinder cones are easily eroded because they are made up of loose materials. But the rock in a volcano's pipe is more resistant to erosion, so it stands alone above the surrounding land after the cone has been eroded. Ship Rock, shown in **Figure 14,** is a volcanic neck in New Mexico.

Reading Checkpoint *What is a volcanic neck?*

Lava Plateaus If you visited the Columbia River gorge in Washington state, you would see huge cliffs made up of layers of dark, volcanic rock. These layers of rock are part of the Columbia plateau, a huge lava plateau that covers parts of Washington, Oregon, and Idaho. A **lava plateau** is a volcanic landform produced by repeated eruptions of very fluid, basaltic lava. As shown in **Figure 15,** the lava that forms a lava plateau erupts through long cracks called fissures. Instead of building a cone, the lava spreads out over a wide area.

The Columbia plateau is nearly 1.6 kilometers thick. The plateau formed over hundreds of thousands of years as a series of lava flows, some 50 meters thick, buried the landscape. Another major lava plateau is the Deccan plateau in India.

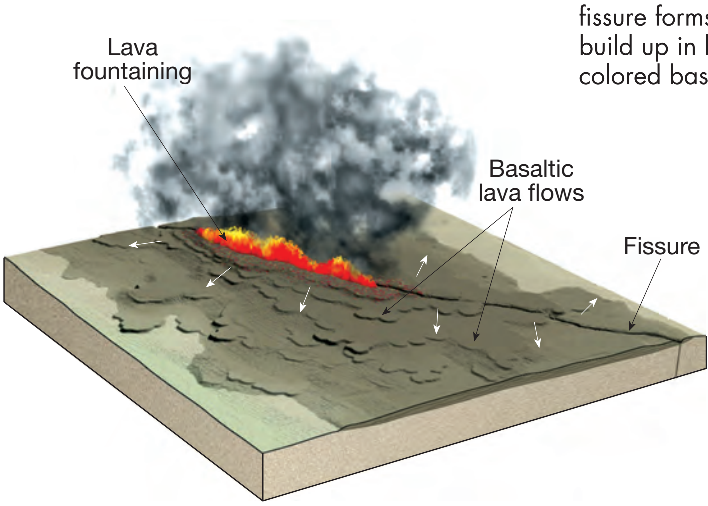
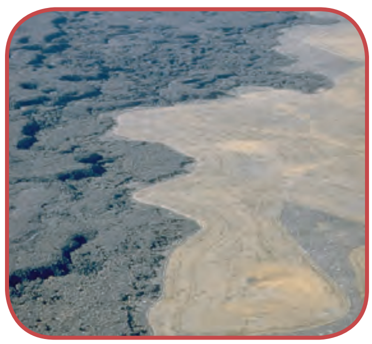


FIGURE 15 Lava Plateau Lava erupting from a fissure forms fluid lava flows called flood basalts that build up in layers to form a lava plateau. These dark-colored basalt flows are near Idaho Falls, Idaho.



Volcanic Hazards

Throughout history, people often have settled near volcanoes because rich volcanic soils are good for farming. They may not realize that an active or dormant volcano can erupt at any time, even centuries after the last eruption. **Volcanic hazards include lava flows, volcanic ash, pyroclastic flows, and mudflows.**

Lava flows are a major volcanic hazard. For example, the frequent lava flows from Mount Kilauea in Hawaii sometimes destroy homes and other structures in their path.

Active composite volcanoes, such as those in the Cascade Range of the Pacific Northwest, are among the most dangerous volcanoes. A composite volcano can eject huge quantities of volcanic ash, burying widespread areas under thick ash deposits. In the year 79, ash from the eruption of Italy's Mount Vesuvius completely buried Pompeii.

An explosive eruption can also release a *pyroclastic flow,* a scorching mixture of glowing volcanic particles and gases that sweeps rapidly down a volcano's flanks. In 1902, a pyroclastic flow from Mount Pelée on the the island of Martinique in the Caribbean killed 29,000 people. Volcanoes may emit poisonous gases such as hydrochloric acid and hydrogen sulfide.

Composite volcanoes may also produce mudflows called lahars. A **lahar** occurs when water-soaked volcanic ash and rock slide rapidly downhill. Ice and snow melted by an eruption or by heavy rains can trigger a lahar. In 1985, a lahar caused by the eruption of Nevada del Ruiz in Colombia killed 23,000 people.

Volcanoes usually give some warning that an eruption is near. For example, seismographs can detect the small earthquakes caused by movement of magma beneath the surface. Gases and ash released by a volcano may also signal an approaching eruption.

10.2 Assessment

Review Key Concepts

1. What factors determine the type of volcanic eruption?
2. List the materials ejected from volcanoes.
3. Describe the three main types of volcanoes.
4. List three volcanic landforms.

Think Critically

5. **Relate Cause and Effect** What propels magma out of a volcano during an eruption?
6. **Compare and Contrast** Compare and contrast the magma that forms a shield volcano with the magma that forms a composite cone.
7. **Explain** Explain how a caldera forms.
8. **Form an Opinion** Should a resort hotel be built on the side of an active composite volcano? Explain.

BIGIDEA DYNAMIC EARTH

9. **Communicate** Research a volcanic eruption. Write a paragraph describing the eruption. Make sure to classify the type of volcano that erupted and identify the plate boundary or hot spot associated with the volcano.

10.3 Intrusive Igneous Activity

ES.7 The student will investigate and understand geologic processes including plate tectonics. Key concepts include **a.** geologic processes and their resulting features.

VOLCANIC ROCK made of hardened lava covers large parts of Earth's surface. But you may be surprised to learn that most magma cools and hardens deep within Earth. This magma forms the roots of mountain ranges and a variety of landscape features.

Recall that magma rises through the crust toward the surface. As it rises, the magma may rise through fractures in the rock or force its way between rock layers. The magma may form thin sheets a few centimeters thick or collect in vast pools that can be many kilometers wide and several kilometers thick.

Classifying Plutons

The structures that result from the cooling and hardening of magma beneath Earth's surface are called **plutons.** The word *pluton* is derived from *Pluto,* the name of the mythological Roman god of the underworld. Plutons form in continental crust wherever magma slowly crystallizes and forms intrusive igneous rock. Over millions of years, uplift nd erosion can expose plutons at the surface.

There are several types of plutons. **Types of plutons include sills, laccoliths, and dikes. Geologists classify plutons and other bodies of intrusive igneous rock according to their size, shape, and relationship to surrounding rock layers.**

FIGURE 16 Dike This dike in the Grand Canyon in Arizona is a pluton that cuts across layers of sandstone.

Key Questions

What are the different types of plutons, and how are they classified?

What is a batholith?

Vocabulary

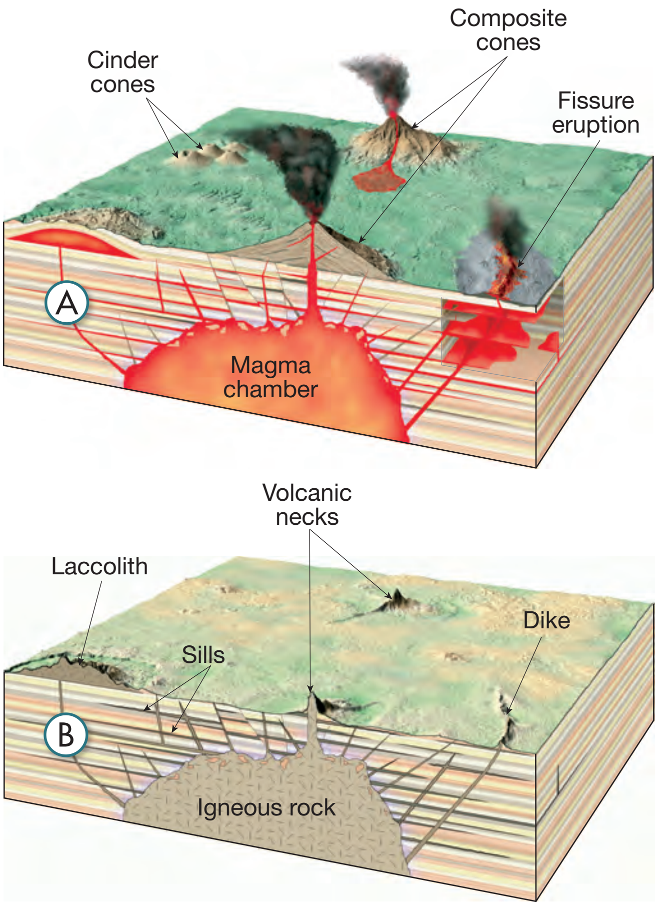
- pluton
- sill
- laccolith
- dike
- batholith

Reading Strategy

Compare and Contrast
After you read, compare the types of intrusive igneous features by completing the table.

Types of Intrusive Igneous Features	Description
Sill	a. ___?___
Laccolith	b. ___?___
Dike	c. ___?___

FIGURE 17 Sills, Laccoliths, and Dikes
A Plutons form as magma intrudes into cracks in rock or between rock layers.
B Erosion later exposes the plutons. A sill forms a horizontal band, laccoliths push overlying layers upward, and dikes cut across rock layers.
Infer *How could you determine if a horizontal igneous rock layer was a lava flow or a sill?*



Sills and Laccoliths

Sills and laccoliths are plutons that form when magma intrudes between rock layers close to the surface. Sills and laccoliths differ in shape and often differ in composition. A **sill** is a pluton that forms where magma flows between parallel layers of sedimentary rock. Horizontal sills, like the one shown in **Figure 17,** are the most common.

Sills form only at shallow depths, where the pressure exerted by the weight of overlying rock layers is low. Why is this? For a sill to form, the magma must lift he overlying rock to a height equal to the thickness of the sill. You might think that this would require a great deal of energy. But forcing the magma between rock layers often requires less energy than forcing the magma up to the surface.

A **laccolith** is a lens-shaped pluton that has pushed the overlying rock layers upward. As with sills, laccoliths form when magma intrudes between sedimentary rock layers close to the surface. But the magma that forms laccoliths has higher viscosity than the magma that forms sills. For this reason, the magma collects in a mass that bulges upward instead of spreading out in an even layer.

Dikes

Some plutons form when magma from a large magma chamber moves into fractures in the surrounding rocks. A **dike** is a pluton that forms when magma moves into fractures that cut across rock layers. Dikes are sheetlike structures that can range in thickness from less than a centimeter to more than a kilometer. Most dikes are a few meters thick and extend laterally for no more than a few kilometers.

☑ **Reading Checkpoint** *What is a laccolith?*

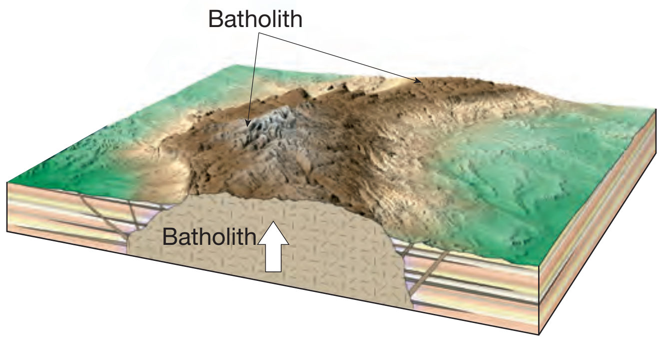
Batholiths

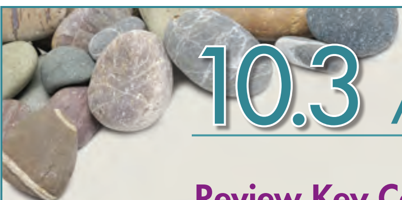
Batholiths are the largest bodies of intrusive igneous rocks. **A batholith is a body of intrusive igneous rock that has a surface exposure of more than 100 square kilometers.** Much larger than a pluton, a batholith can be hundreds of kilometers long and tens of kilometers across. Gravity studies and seismic evidence indicate that batholiths are also very thick, possibly extending dozens of kilometers into the crust. A body of igneous rock similar to a batholith, but having an area of less than 100 square kilometers, is called a *stock*.

How are batholiths formed? Batholiths are made of many individual plutons that begin as blobs of magma deep beneath the surface. The plutons slowly rise through the crust. They clump together, forming a huge irregular mass. But this mass of magma never erupts to the surface. Instead, it cools slowly deep underground, forming granitic rock. Over millions of years, uplift nd erosion gradually expose the batholith at the surface. Weathering gradually shapes the batholith into distinct mountains.

Batholiths form the core of many of Earth's great mountain ranges. For example, the Idaho batholith forms part of the northern Rocky Mountains. This batholith has an area of more than 40,000 square kilometers. The Sierra Nevada in California, shown in **Figure 18,** is also formed from a huge batholith. An even larger batholith makes up the coastal mountains of British Columbia in Canada.

FIGURE 18 Batholiths Mount Whitney in California makes up just a tiny portion of the Sierra Nevada batholith, a huge structure that extends for approximately 400 kilometers.





10.3 Assessment

Review Key Concepts

1. List three different types of plutons.
2. How are plutons classified?
3. Write a definition of *batholith* in your own words.
4. Explain how a laccolith forms.

Think Critically

5. **Compare and Contrast** Describe the difference between a sill and a dike.
6. **Infer** What can you infer about the origin of mountain ranges made of granitic rock, such as the Sierra Nevada? Explain.

CONNECTING CONCEPTS

7. **Predict** Recall what you learned about the texture of igneous rocks in Chapter 3. Predict how the texture of the rock in a batholith would compare with the texture of the rock in a sill. Explain.

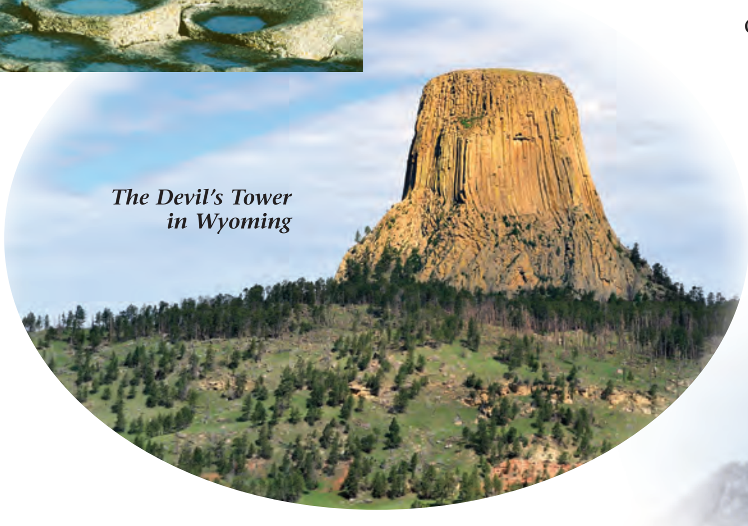
How Earth Works

Effects of Volcanoes

A **volcano** is an opening in Earth's crust from which **lava,** or molten rock, escapes to the surface. Some volcanoes erupt dramatically, flinging hot rocks in all directions and releasing huge clouds of scorching ash and gases. Other volcanoes release lava and gases in a smooth steady flow. No matter how they erupt, all volcanoes have both immediate and long-lasting effects on the landscape and even the weather. Soil may become more fertile when enriched with nutrients from volcanic ash. Islands, mountains, and other landforms may be created from the material emitted by volcanoes.

The Giant's Causeway in Northern Ireland

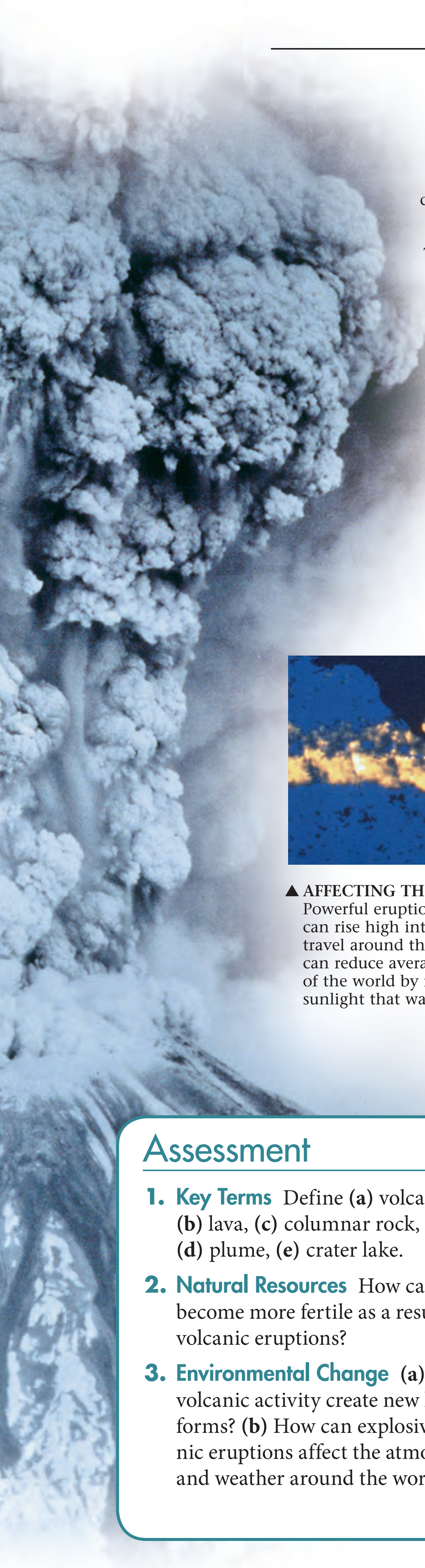
◀ **DRAMATIC ROCK FORMATIONS**
Molten rock can create amazing rock formations. When molten rock cools, contracts, and hardens, sometimes **columnar rocks** are produced. The Devil's Tower in Wyoming (below) is one example of a columnar rock that formed when magma gradually cooled underground. The columnar rocks of Giant's Causeway (left) in Northern Ireland are the result of a lava flow that erupted millions of years ago. ▼



The Devil's Tower in Wyoming

DUST AND GAS ▶
Composite cones, such as Mount St. Helens in Washington (right), spit clouds of ash and fumes into the sky. The debris can completely cover human communities. Another hazard is that volcanic gases may be deadly poisons.

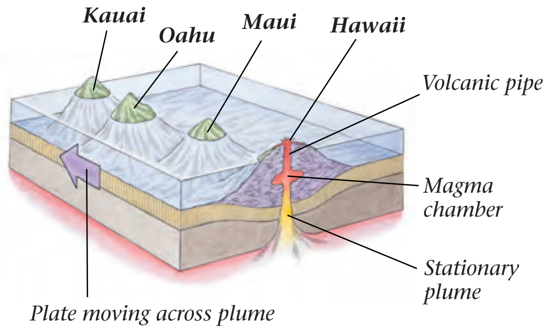
◀ **ERUPTING LAVA**
Red-hot lava is hurled into the air during an eruption of a volcano on Stromboli, an island off the coast of southern Italy. The Stromboli volcano is one of only a few volcanoes to display continuous eruptive activity over a period of more than a few years.

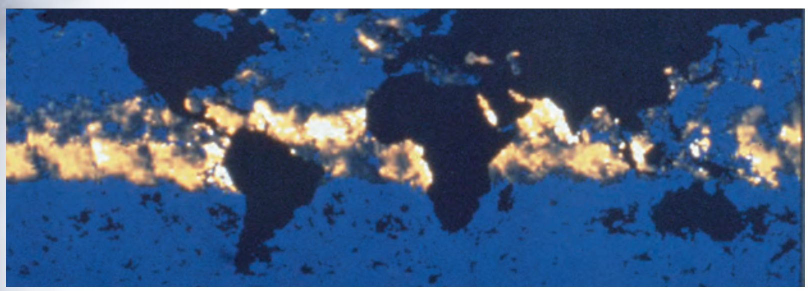


A CRATER LAKE ▶
A **crater lake** is a body of water that occupies a bowl-shaped depression around the opening of a dormant volcano. A future eruption could hurl the water out of the crater. The water could then mix with hot rock and debris and race downhill in a deadly mudslide.

A crater lake in Iceland

A STRING OF ISLANDS ▶
The Hawaiian Islands are the tops of volcanic mountains. They have developed over millions of years above a hot spot in Earth's mantle and have erupted great amounts of lava. As the Pacific plate moves over the stationary plume, it carries older islands in the chain to the northwest. Today, active volcanoes are found on the island of Hawaii and the newly forming island of Loihi.





A satellite image shows the global spread of emissions from the 1991 eruptions of Mount Pinatubo in the Philippines. (Volcanic emissions over land are not shown in this satellite image.)

▲ AFFECTING THE WORLD'S WEATHER
Powerful eruptions emit gas and dust that can rise high into the atmosphere and travel around the world. Volcanic material can reduce average temperatures in parts of the world by filtering out some of the sunlight that warms Earth.

A few lichens find a home on the lava.

Plants take root in the beginnings of topsoil.

▲ LIFE AFTER LAVA
In time, plant life grows on hardened lava. Lichen and moss often appear first. Grass and larger plants slowly follow. The upper surface of the rock is gradually weathered by physical and biological processes to form soil. One example of a biological process is when plant roots grow into tiny cracks of the rock, breaking it apart. After many generations, the land may become lush and fertile again.

Assessment

1. **Key Terms** Define (**a**) volcano, (**b**) lava, (**c**) columnar rock, (**d**) plume, (**e**) crater lake.
2. **Natural Resources** How can soil become more fertile as a result of volcanic eruptions?
3. **Environmental Change** (**a**) How can volcanic activity create new landforms? (**b**) How can explosive volcanic eruptions affect the atmosphere and weather around the world?
4. **Natural Hazards** What are some of the ways in which a volcanic eruption can devastate nearby human settlements?
5. **Critical Thinking** **Sequencing** Study the diagram of the Hawaiian Islands and the caption that accompanies it. (**a**) Which island on the diagram is probably the oldest? Why do you think so? (**b**) What will happen to the volcanoes on the island of Hawaii as a result of plate movement?

INQUIRY
EXPLORATION LAB

Melting Temperatures of Rocks

Problem How can rocks melt to form magma in the crust and uppermost mantle?

Materials photocopy of Temperature Curves graph, colored pencils (three different colors), ruler

Skills Analyze Data, Graph, Calculate

Connect to the Big idea Measurements of temperatures in wells and mines have shown that Earth's internal temperatures increase with depth. Recall that this rate of temperature increase is called the geothermal gradient. Although the geothermal gradient varies from place to place, it is possible to calculate an average. In this lab, you will investigate Earth's internal temperatures and the temperatures at which rocks melt. You will also investigate the effect of water on the melting temperatures of rock.

Procedure

1. Obtain a photocopy of the unfilled Temperature Curves graph on page 301. Use it to plot the average temperature gradient for Earth's interior. Use the photocopied graph, or make your own version on a sheet of graph paper or by using graphing software.
2. Plot the temperature values from **Table 1** on your graph. Then draw a single best-fit line through the points with a colored pencil. Extend your line from the surface (0) to 200 kilometers. Label the line "Temperature Gradient."
3. The melting temperature of a rock changes as pressure increases deeper within Earth. The approximate melting points of the igneous rocks, granite and basalt, under various pressures (depths) have been determined in the laboratory and are shown in **Table 2.** Granite and basalt were used because they are common materials in the upper layer of Earth. Plot the melting temperatures from Table 2 on the same graph you made above. Use a different colored pencil to plot each set of points and draw the best-fit lines.
4. Label the two lines "Melting Curve for Wet Granite" and "Melting Curve for Basalt."

Table 1 Idealized Internal Temperatures of Earth

Depth (kilometers)	Temperature (°C)
0	20
25	600
50	1000
75	1250
100	1400
150	1700
200	1800

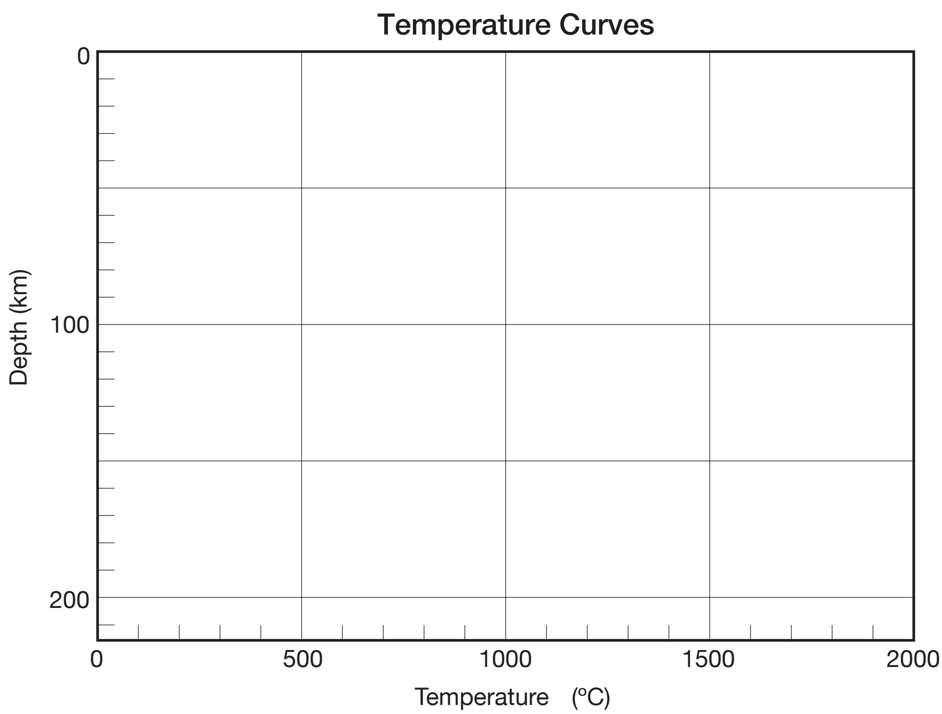
Table 2 Melting Temperatures of Granite (with water) and Basalt at Various Depths Within Earth

Granite (with water)		Basalt	
Depth (km)	Melting Temperature (°C)	Depth (km)	Melting Temperature (°C)
0	950	0	1100
5	700	25	1160
10	660	50	1250
20	625	100	1400
40	600	150	1600

Analyze and Conclude

1. **Interpret Graphs** Does the rate of increase of Earth's internal temperature stay the same or change with increasing depth?
2. **Interpret Graphs** Is the rate of temperature increase greater from the surface to a depth of 100 kilometers or below 100 kilometers?
3. **Interpret Graphs** What is the temperature at 100 kilometers below the surface?
4. **Calculate** Use the data and your graph to calculate the average temperature gradient for the upper 100 kilometers of Earth in °C/100 kilometers and in °C/kilometer.
5. **Draw Conclusions** Based on your data, at approximately what depth within Earth would wet granite reach its melting temperature and begin to form magma? Explain.
6. **Draw Conclusions** Based on your data, at what depth will basalt have reached its melting temperature and begin to form magma?

GO FURTHER What is the name of the layer within Earth's upper mantle that is below about 100 kilometers? Why do scientists theorize that this zone is capable of "flowing" more easily than other mantle rock, allowing the lithosphere to move across it?



ES.1 The student will plan and conduct investigations in which **a.** volume, area, mass, elapsed time, direction, temperature, pressure, distance, density, and changes in elevation/depth are calculated utilizing the most appropriate tools. **ES.2** The student will demonstrate an understanding of the nature of science and scientific reasoning and logic. Key concepts include **c.** observation and logic are essential for reaching a conclusion. **ES.6** The student will investigate and understand the differences between renewable and nonrenewable resources. Key concepts include **a.** fossil fuels, minerals, rocks, water, and vegetation.

10 Study Guide

Big idea Dynamic Earth

10.1 Volcanoes and Plate Tectonics

Magma forms in the crust and upper mantle when solid rock partially melts. The formation of magma depends on several factors, including heat, pressure, and water content.

Most volcanoes form along divergent and convergent plate boundaries. Some volcanoes form far from plate boundaries above "hot spots" in the crust.

decompression melting (280)
Ring of Fire (284)
intraplate volcanism (285)
hot spot (285)

10.2 The Nature of Volcanic Eruptions

The primary factors that determine whether a volcano erupts explosively or quietly include characteristics of the magma and the amount of dissolved gases in the magma.

Depending on the type of eruption, volcanoes may produce lava flows or eject pyroclastic materials, or both. All volcanic eruptions also emit large amounts of gases.

The three main volcanic types are shield volcanoes, cinder cones, and composite cones.

Volcanic landforms also include calderas, volcanic necks, and lava plateaus.

Volcanic hazards include lava flows, volcanic ash and gases, pyroclastic flows, and mudflows.

viscosity (286)
vent (287)
pyroclastic material (289)
volcano (289)
crater (289)
shield volcano (290)
cinder cone (290)
composite cone (291)
caldera (292)
volcanic neck (293)
lava plateau (293)
lahar (294)

10.3 Intrusive Igneous Activity

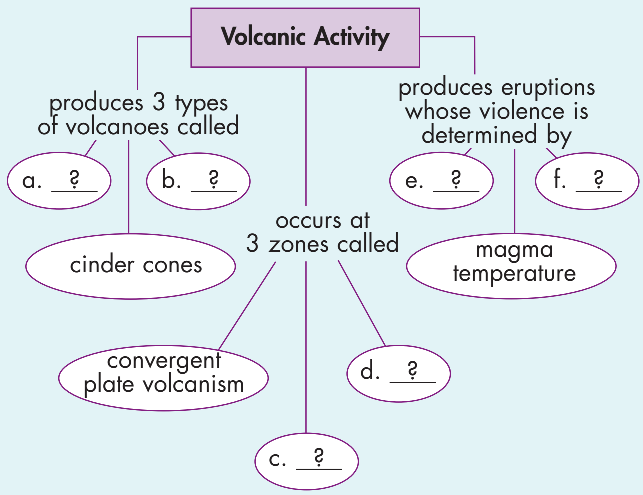
Types of plutons include sills, laccoliths, and dikes. Geologists classify plutons and other bodies of intrusive igneous rock according to their size, shape, and relationship to surrounding rock layers.

A batholith is a body of intrusive igneous rock that has a surface exposure of more than 100 square kilometers.

pluton (295)
sill (296)
laccolith (296)
dike (296)
batholith (297)

Think Visually

Review Copy the web diagram below and use information from the chapter to complete it.



10 Assessment

Review Content

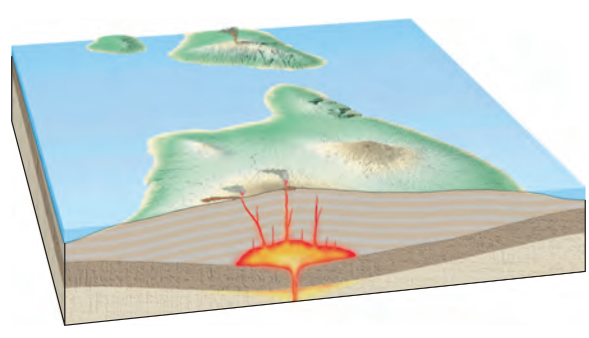
Choose the letter that best answers the question or completes the statement.

1. Underground igneous rock bodies are called
   a. lava flows. **c.** volcanoes.
   b. plutons. **d.** calderas.
2. The greatest volume of volcanic material is produced by
   a. eruptions of cinder cones.
   b. eruptions of composite cones.
   c. eruptions along ocean ridges.
   d. eruptions of shield volcanoes.
3. The most explosive type of volcanic activity is associated with
   a. cinder cones. **c.** composite cones.
   b. sills. **d.** shield volcanoes.
4. A magma's viscosity is directly related to its
   a. depth. **c.** color.
   b. age. **d.** silica content.
5. What are the pulverized rock, lava, ash, and other fragments ejected from the vent of a volcano called?
   a. sills **c.** pahoehoes
   b. craters **d.** pyroclastic material
6. Which type of volcano consists of layers of lava flows and pyroclastic material?
   a. composite cone **c.** shield volcano
   b. cinder cone **d.** laccolith
7. The hotter of two types of basaltic lava commonly forms
   a. aa flows. **c.** pyroclastic flows.
   b. pahoehoe flows. **d.** lapilli flows.
8. What is the very large depression at the top of some volcanoes called?
   a. a vent **c.** a volcanic neck
   b. a lava plateau **d.** a caldera
9. When silica-rich magma is extruded, ash, hot gases, and larger fragments propelled from the vent at high speeds may produce which of the following?
   a. a lava plateau **c.** a pahoehoe flow
   b. a lahar **d.** a pyroclastic flow
10. What feature may form in an intraplate area over a rising plume of hot mantle material?
    a. a hot spot **c.** a subduction zone
    b. a dike **d.** an ocean ridge

Understand Concepts

11. What is a volcanic neck, and how does it form?
12. Describe the Ring of Fire.
13. The Hawaiian Islands and Yellowstone National Park are associated with which of the three types of volcanism?
14. What is the chain of volcanoes called that forms at a convergent boundary between a subducting oceanic plate and a continental plate? What type of volcano commonly forms?
15. Explain how scientists think most magma is formed.

Use the diagram below to answer Questions 16 and 17.



16. Identify the type of volcano shown in the diagram.
17. What types of eruptions are commonly associated with this type of volcano?
18. How do hot spots form?
19. How are pyroclastic materials classified?
20. What is viscosity, and how does it affect volcanic eruptions?
21. Give an example of each of the three types of volcanoes.
22. How do dikes form?

Think Critically

23. **Apply Concepts** How might a laccolith be detected at Earth's surface before being exposed by erosion?
24. **Infer** Why is a volcano fed by a highly viscous magma likely to be a greater threat to people than a volcano fed by very fluid magma?
25. **Compare and Contrast** Compare pahoehoe lava flows and aa lava flows.
26. **Relate Cause and Effect** What is a lahar? Explain why a lahar can occur on a volcano without an eruption.
27. **Draw Conclusions** Why are cinder cones usually small?

Analyze Data

Use the data table below to answer Questions 28–31.

Notable Volcanic Eruptions

Volcano	Date	Volume Ejected	Height of Plume
Toba	74,000 years ago	2800 km^3	50–80 km
Vesuvius	A.D. 79	4 km^3	32 km
Tambora	1815	150 km^3	44 km
Krakatau	1883	21 km^3	36 km
Mount St. Helens	1980	1 km^3	19 km
Mount Pinatubo	1991	5 km^3	35 km

28. **Interpret Tables** Which volcanic eruption listed in the data table ejected the greatest volume of pyroclastic material?
29. **Calculate** How many times larger than the volume of material ejected by the eruption of Krakatau was the volume of material ejected by the eruption of Tambora?
30. **Form a Hypothesis** Develop a hypothesis to explain why the eruption of Mount Vesuvius in a.d . 79 was more deadly than the eruption of Mount Pinatubo in 1991, even though the eruptions were approximately the same size.
31. **Calculate** Calculate how much higher the plume of volcanic debris during the eruption of Tambora in 1815 was than the plume from the 1980 eruption of Mount St. Helens. Calculate the difference in kilometers and as a percent.

Concepts in Action

32. **Form a Hypothesis** Large volcanic eruptions eject large amounts of gas, dust, and ash into the atmosphere. This volcanic material can affect the world's climate by blocking incoming solar radiation. An eruption from what type of volcano is most likely to cause global climate changes? Explain your answer.
33. **Classify** On the side of a composite cone you see a large area where there are no trees, and the ground surface looks disturbed. What possible volcanic feature or event could have caused this?
34. **Apply Concepts** Would you be safer from a violent, explosive eruption while vacationing in Arizona near a cinder cone or while skiing in the Andes Mountains of South America? Explain.
35. **Review** Write a paragraph describing what an eruption of a nearby composite cone might be like.

Performance-Based Assessment

Communicate Make a poster illustrating the internal and external features that are typical of a composite cone. Include on your poster copies of photographs of some classic composite cones. Also explain some of the possible dangers associated with living near a composite cone.

Virginia SOL Test Prep

Tips for Success

Paying Attention to the Details Sometimes two or more answers to a question may seem correct. If you do not read the question and answer choices carefully, you may select an incorrect answer by mistake. In the question below, two answer choices, (A) dissolved gases and (B) gravity, would seem to be possible correct answers to the question. However, the question asks what force extrudes magma from the vent, not down the slopes of the volcano. So only the answer choice, (A) dissolved gases, is correct.

What provides the force that propels magma from a volcanic vent?

A dissolved gases
B gravity
C the magma's heat
D the volcano's slope

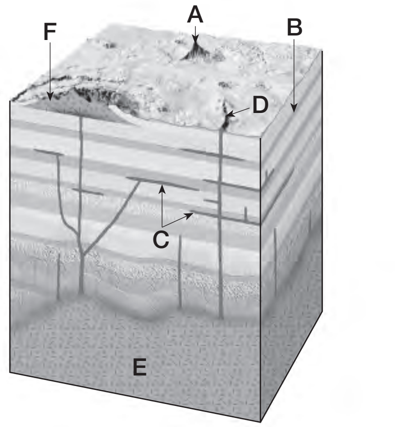
(Answer: A)

Choose the letter that best answers the question.

1 **Which of the following is *not* a factor that determines if a volcano erupts explosively or quietly?**
A temperature of the magma
B size of the volcanic cone
C the magma's composition
D amount of dissolved gases in the magma
ES.7.a

2 **How does an increase in pressure affect a rock's melting temperature?**
F The melting temperature increases.
G The melting temperature decreases.
H The melting temperature is stabilized.
J It has no effect on the melting temperature.
ES.7.a

Use the diagram below to answer Questions 3 and 4.



3 **What intrusive igneous feature in the diagram is labeled C?**
A a dike
B a sill
C a batholith
D a laccolith
ES.7.a

4 **If the feature labeled E extended for over 100 square kilometers after being exposed by erosion, what would it be classified as?**
F a dike
G a stock
H a laccolith
J a batholith
ES.7.a

If You Have Trouble With . . .				
Question	1	2	3	4
See Lesson	10.2	10.1	10.3	10.3