

Chapter 18

What You'll Learn

- How magma forms.
- What kinds of features form as the result of igneous activity within Earth.
- How volcanoes form and how they can be classified.

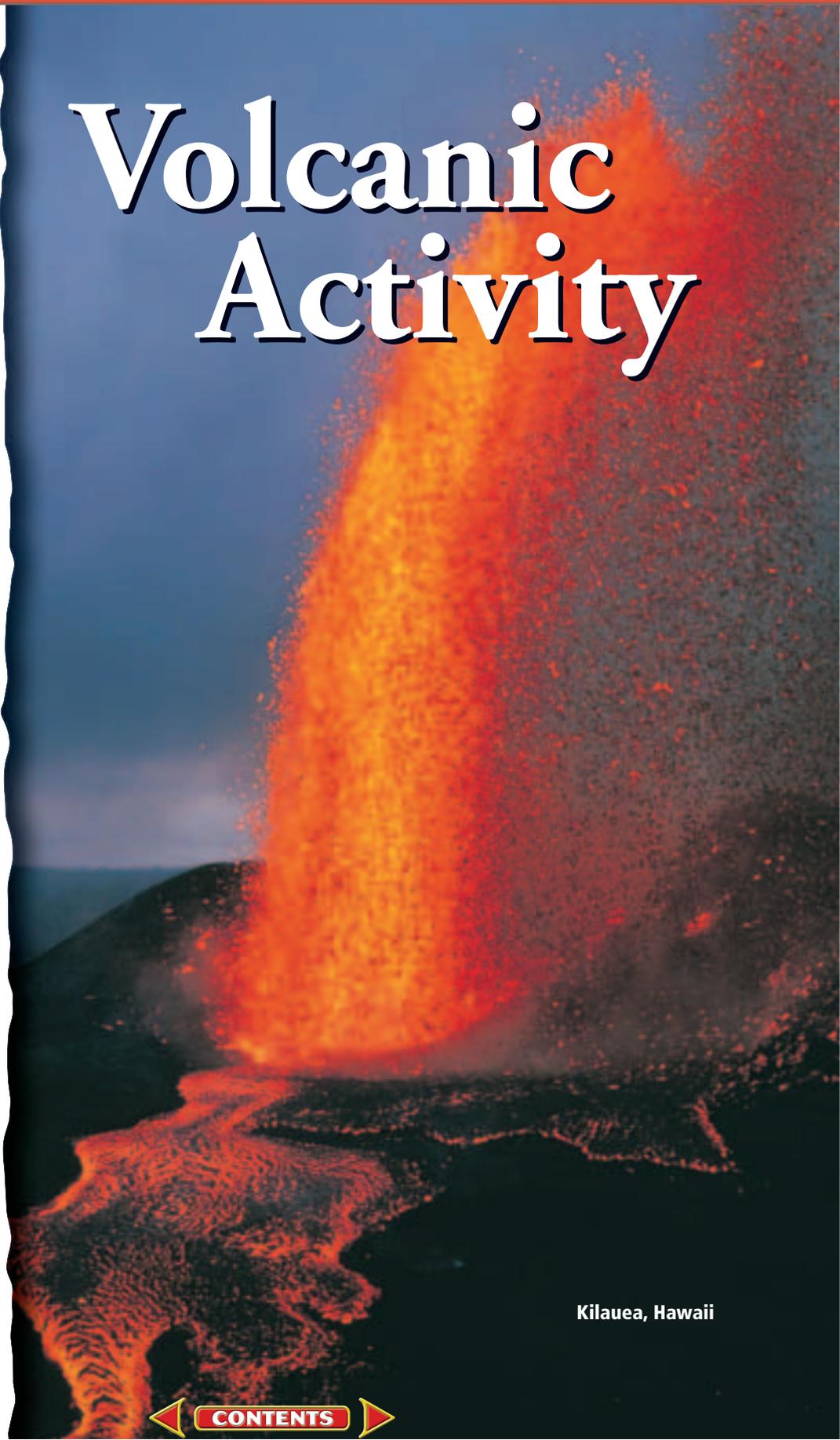
Why It's Important

Many of Earth's internal processes help to shape our planet's surface. Igneous activity deep within Earth and at its surface produce many of the mountains and rock formations on Earth.



To learn more about volcanic activity, visit the Earth Science Web Site at earthgeu.com

Volcanic Activity



Kilauea, Hawaii

Discovery Lab

Model Magma Movement

Magma is molten rock beneath Earth's surface that rises because it is less dense than the surrounding rock. In this activity, you will model how magma moves within Earth.

1. Fill a 250-mL beaker with 175 mL of ice-cold water.
2. Carefully fill a 100-mL beaker with very hot tap water. Add 2–3 drops of food coloring to the water and stir well.
3. Carefully fill a dropper with the hot, colored water.
4. Slowly insert the full dropper into the 250-mL beaker until the tip of the dropper is 1 cm from the

bottom of the beaker. Squeeze the dropper and keep the bulb depressed as you slowly pull the dropper back out of the cold water.

 **CAUTION:**
Always wear safety goggles and an apron in the lab.

Observe In your science journal, describe what happened to the colored water when it entered the beaker. How might this be similar to what happens to magma beneath Earth's surface? Infer what would have happened if you had released the hot water at the surface of the cold water.



SECTION

18.1

Magma

OBJECTIVES

- **Describe** factors that affect the formation of magma.
- **Compare and contrast** the different types of magma.

VOCABULARY

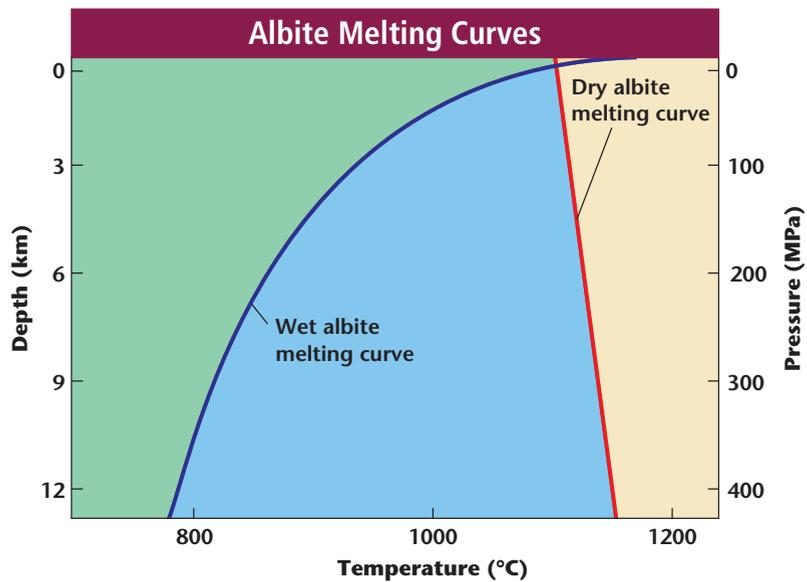
viscosity

Volcanic eruptions are spectacular events. The ash that spews from some volcanoes can form billowy clouds that travel around the world before raining back down to Earth. The red-hot lava that erupts from other volcanoes, such as the Hawaiian volcano Kilauea shown on the facing page, can destroy everything in their paths. In the last 10 000 years, more than 1500 different volcanoes have erupted—providing evidence that Earth is indeed geologically active. Where do ash, lava, and other types of volcanic debris come from?

HOW MAGMA FORMS

All volcanoes are fueled by magma deep beneath Earth's surface. Recall from Chapter 5 that magma is a mixture of molten rock, suspended mineral grains, and dissolved gases deep beneath Earth's surface. Magma forms when temperatures are high enough to melt the rocks involved. Depending on their composition, most rocks begin to melt at temperatures between 800°C and 1200°C. Such

Figure 18-1 Both pressure and the presence of water affect the melting temperature of minerals and thus, rocks.



temperatures exist at the base of the lithosphere and in the asthenosphere, the plasticlike portion of the mantle directly beneath the lithosphere. Recall that temperature increases with depth beneath Earth’s surface. If rocks melt at temperatures found in the asthenosphere, and temperature increases with depth, then why isn’t the entire mantle liquid? What other factors, besides temperature, affect the formation of magma?

Pressure Pressure is one factor that determines whether rocks will melt to form magma. Like temperature, pressure increases with depth because of the weight of overlying rocks. Laboratory experiments have shown that as pressure increases, the temperature at which a substance melts also increases. *Figure 18-1* shows two melting curves for a variety of feldspar called albite. Find the line that represents the dry melting curve. Note that at Earth’s surface, dry albite melts at about 1100°C, but at a depth of about 12 km, the melting point of dry albite is about 1150°C. At a depth of about 100 km, the melting point of dry albite increases to 1440°C. The effect of pressure explains why most of the rocks in Earth’s lower crust and upper mantle do not melt to form magma, even though the temperatures are high enough.

Water The presence of water also influences whether a rock will melt. Recall that water can be found in the pore spaces of some rocks and can be bound into the crystal structure of some minerals. Even a small amount of water can have a significant effect on a mineral’s, and thus a rock’s, melting point. At any given pressure, a wet mineral or rock will melt at a lower temperature than the same mineral or rock under dry conditions. Locate the melting curve of wet albite in

Figure 18-1. How does the melting point of wet albite compare to that of dry albite at a depth of 3 km? At a depth of 12 km?

TYPES OF MAGMA

Recall from Chapter 5 that the three major igneous rock types are basalt, andesite, and granite. These rocks form from three major types of magma: basaltic magma, andesitic magma, and rhyolitic magma. The term *rhyolitic* is used to describe the magma that solidifies to form granite because magmas are named after extrusive rocks.

Basaltic magma has the same composition as basalt. Locate the Hawaiian Islands in **Figure 18-2**, which shows some of Earth's active volcanoes. The volcanoes that make up the Hawaiian Islands, which include Kilauea and Mauna Loa, are made of basalt. Surtsey, which formed south of Iceland in 1963, is another basaltic volcano.

Andesitic magma has the same composition as andesite. Mount St. Helens in Washington State and Tambora in Indonesia are two andesitic volcanoes. You will find out more about Tambora in the *Science & the Environment* feature at the end of this chapter. Rhyolitic magma has the same composition as granite. The dormant volcanoes in Yellowstone National Park in the western United States were fueled by rhyolitic magma.

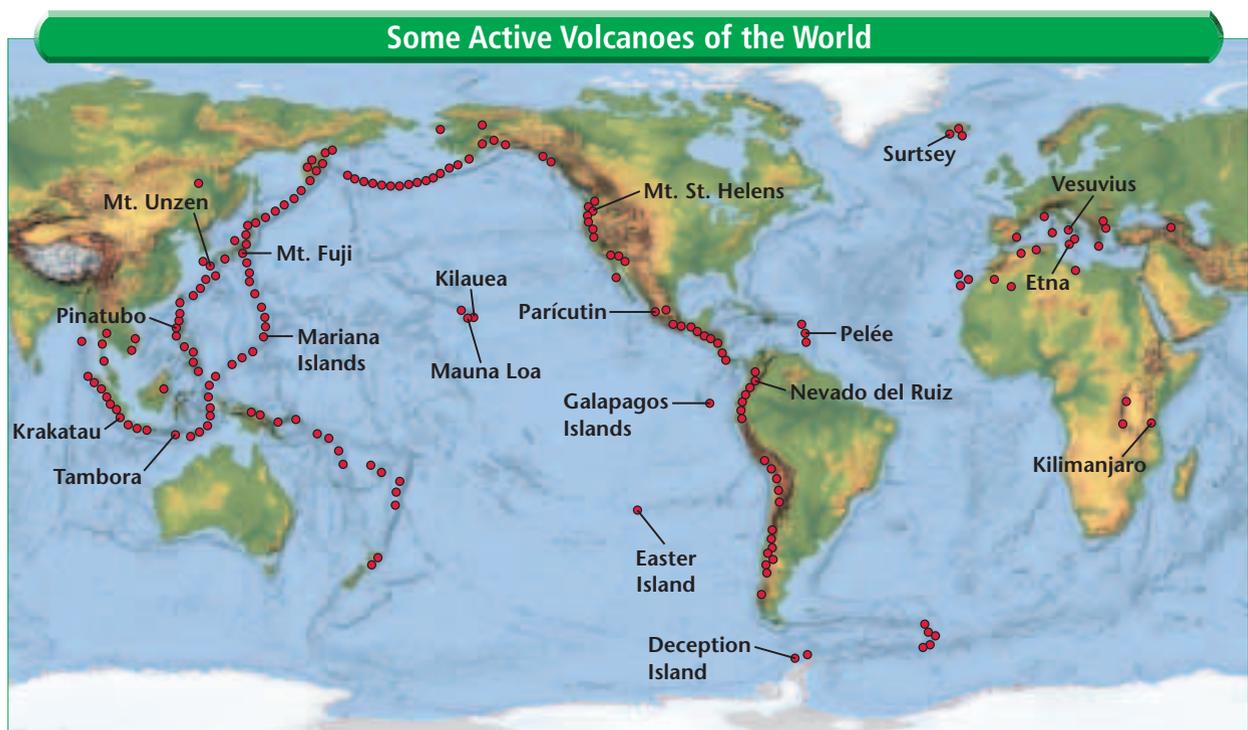


Figure 18-2 Compare this map of some of Earth's active volcanoes to the map shown in **Figure 17-13** on page 455. *Where are most active volcanoes located?*

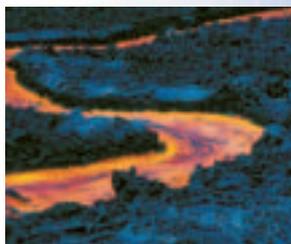
MiniLab

How does silica affect lava flow?

Model the changes in lava viscosity with the addition of silica.



CAUTION: Always wear safety goggles and an apron in the lab.



Procedure

1. Pour 120 mL of dishwashing liquid into a 250-mL beaker.
2. Stir the liquid with a stirring rod. Describe the viscosity.
3. Add 30 g of NaCl (table salt) to the liquid. Stir well. Describe what happens.
4. Repeat step 3 three more times.

Analyze and Conclude

1. What do the liquid and NaCl represent?
2. How does an increase in silica affect lava viscosity?
3. Basaltic eruptions are called flows because of the way they move across Earth's surface. What can you infer about the silica content of a basaltic flow?

Magma Composition What accounts for the different types of magma? A number of factors determine the composition of magma, as shown in *Table 18-1*. One of these factors is **viscosity**, the internal resistance to flow. Substances such as honey, liquid soap, and motor oil have a higher viscosity than water, vinegar, and gasoline. Refer to *Table 18-1*. What kind of magma has a viscosity similar to that of honey? You can model the effect of silica content on viscosity in the *MiniLab* on this page.

Basaltic Magma Basaltic magma typically forms when rocks in the upper mantle melt. Most basaltic magma rises relatively rapidly to Earth's surface and reacts very little with crustal rocks because of its low viscosity. Because basaltic magma contains small amounts of dissolved gases and silica, the volcanoes it fuels erupt relatively quietly.

Andesitic Magma Andesitic magma is found along continental margins, where oceanic crust is subducted into Earth's mantle. The source material for this magma can be either oceanic crust or oceanic sediments. As shown in *Table 18-1*, andesitic magma contains about 60 percent silica. This high silica content results in its having an intermediate viscosity. Thus, the volcanoes it fuels are said to have intermediate eruptions.

Table 18-1 Magma Composition and Characteristics

Composition	Source Material	Viscosity	Gas Content	Silica Content	Explosiveness	Location of Magma
Basaltic magma	Upper mantle	Low	1–2%	about 50%	Least	Both oceanic and continental crust
Andesitic magma	Oceanic crust and oceanic sediments	Intermediate	3–4%	about 60%	Intermediate	Continental margins associated with subduction zones
Rhyolitic magma	Continental crust	High	4–6%	about 70%	Greatest	Continental crust



Rhyolitic Magma Rhyolitic magma forms when molten material rises and mixes with the overlying silica- and water-rich continental crust. The high viscosity of rhyolitic magma inhibits its movement. This resistance to flow, along with the large volume of gas trapped within this magma, makes the volcanoes fueled by rhyolitic magma very explosive.

VISCOSITY

The viscosity of magma and of its surface counterpart, lava, depends on both temperature and composition. The hotter the magma or lava, the lower the viscosity. The temperatures of basaltic lavas are generally between 1000°C and 1250°C. Rhyolitic lava temperatures are usually between 700°C and 900°C. Which type of lava, basaltic or rhyolitic, has a greater viscosity as a result of its temperature? What do you think happens to viscosity as magma or lava cools?

The amount of silica in magma or lava increases the viscosity, as you discovered in the *MiniLab* on the previous page. Thus, magmas and lavas high in silica have higher viscosities than magmas and lavas low in silica. As shown in **Table 18-1**, rhyolitic magmas have the highest silica content, basaltic magmas the lowest, and andesitic magmas have silica contents between these two extremes. Based on composition, which type of lava, basaltic lava or andesitic lava, has a lower viscosity? Basaltic lavas, because of their low silica content, have a lower viscosity than andesitic lavas. The basaltic lava flows that often erupt from Mauna Loa in Hawaii, which is shown in **Figure 18-3**, have been clocked at 16 km/h!



Figure 18-3 Basaltic lava has a low viscosity, and thus, flows relatively quickly from a volcano. The basaltic volcano shown here is Mauna Loa, one of the many volcanoes that make up the Hawaiian Islands.

SECTION ASSESSMENT

- Describe three factors that affect the formation of magma.
- How does the presence of water affect the melting temperature of a rock?
- Compare and contrast the properties of the three types of magma.
- Refer to **Table 18-1**. Where does andesitic magma form? What is the source material of this type of magma?
- Explain the relationship between the viscosity of a magma and its temperature.
- Thinking Critically** A volcano violently erupted in Indonesia in 1883. What can you infer about the composition of the magma that fueled the volcano? If people

witnessed the eruption, what do you think they were able to observe about the lava flow?

SKILL REVIEW

- Concept Mapping** Use the following terms to construct a concept map to organize the major ideas in this section. For more help, refer to the *Skill Handbook*.

quiet eruption

explosive eruption

moderate eruption

high silica

low silica

intermediate silica

basaltic magma

andesitic magma

rhyolitic magma

OBJECTIVES

- **Explain** how magma affects overlying crustal rocks.
- **Compare and contrast** intrusive igneous rock bodies.

VOCABULARY

pluton
 batholith
 stock
 laccolith
 sill
 dike

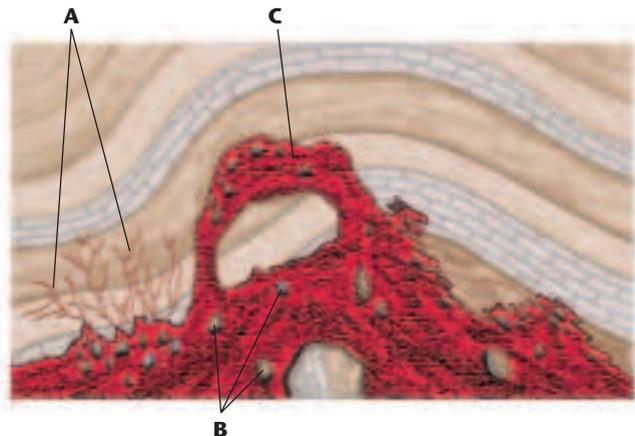
Magma, because it is molten, is less dense than surrounding rocks. This density difference, which you modeled in the *Discovery Lab*, forces magma to move upward and eventually come into contact with, or intrude, the overlying crust. Intruding magma can affect the crust in several ways, as shown in **Figure 18-4**. Magma can force the overlying rock apart and enter the newly formed fissures. Magma can also cause blocks of rock to break off and sink into the magma, where the rocks may eventually melt. Finally, magma can melt the rock into which it intrudes. But what happens deep in the magma chamber as the magma slowly cools?

PLUTONS

Recall from Chapter 5 that when magma cools, minerals form. Over a very long period of time, these minerals will combine to form intrusive igneous rock bodies. Some of these rock bodies are thin, ribbonlike features only a few centimeters thick and several hundred meters long. Others are very large, ranging in size from about 1 km³ to hundreds of cubic kilometers. These intrusive igneous rock bodies, called **plutons**, can be exposed at Earth's surface as a result of uplift and erosion and are classified based on their size, shape, and relationship to surrounding rocks.

Batholiths and Stocks The largest plutons are called **batholiths**. These irregularly shaped masses of coarse-grained igneous rocks cover at least 100 km² and take millions of years to form. Batholiths are common in the interiors of major mountain chains. Many batholiths in North America are composed primarily of granite, the

Figure 18-4 Magma can enter fissures in rocks (**A**). Magma can also cause blocks of rock to break off the overlying rock into which the magma intrudes. These blocks of rock become part of the magma body (**B**). Magma can cause the rocks with which it comes in contact to melt (**C**).



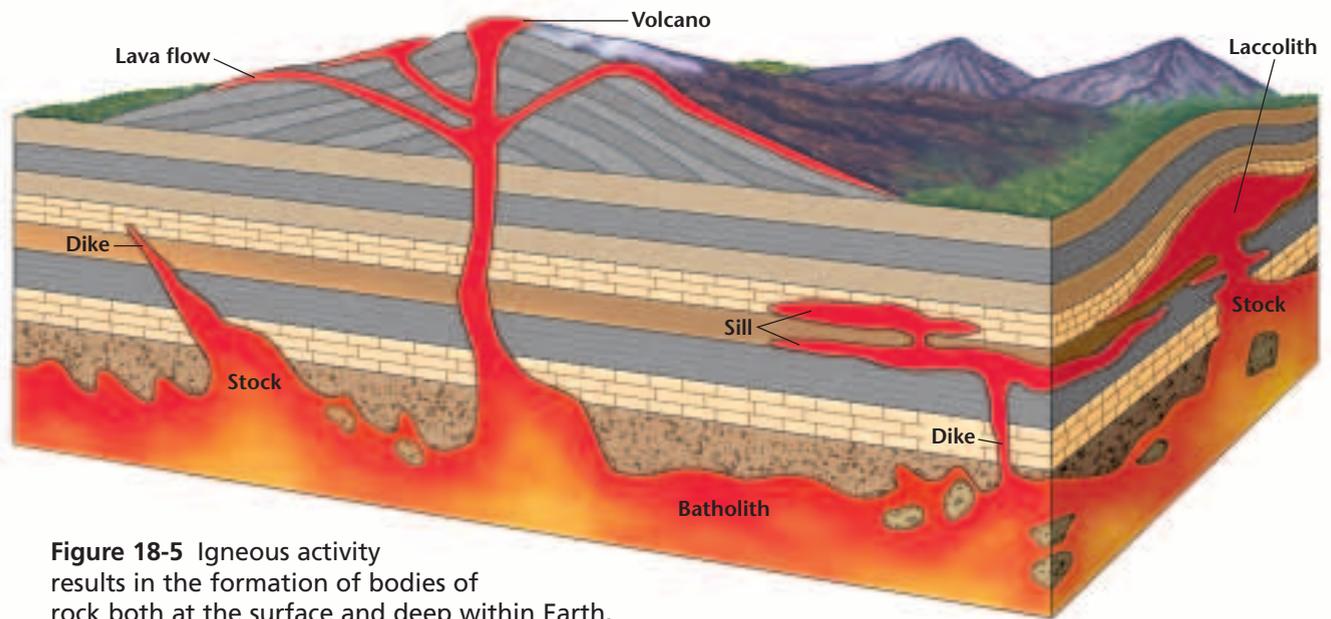


Figure 18-5 Igneous activity results in the formation of bodies of rock both at the surface and deep within Earth.

most common rock type found in plutons. However, gabbro and diorite, the intrusive equivalents of basalt and andesite, are also found in batholiths. The largest batholith in North America, the Coast Range Batholith in British Columbia, is more than 1500 km long. Irregularly shaped plutons that are similar to batholiths but smaller in size are called **stocks**. Both batholiths and stocks, as shown in *Figure 18-5*, cut across older rocks and generally form 10–30 km beneath Earth’s surface.

Laccoliths Sometimes, when magma intrudes into parallel rock layers close to Earth’s surface, some of the rocks bow upward as a result of the intense heat and pressure of the magma body. When the magma solidifies, a laccolith forms. As shown in *Figure 18-5*, a **laccolith** is a mushroom-shaped pluton with a round top and flat bottom. Compared to batholiths and stocks, laccoliths are relatively small; they are, at most, up to 16 kilometers wide. Laccoliths exist in the Black Hills of South Dakota, the Henry Mountains of Utah, and the Judith Mountains of Montana, among other places.

Sills and Dikes A **sill** is a pluton that forms when magma intrudes parallel to layers of rock, as shown in *Figure 18-5*. A sill can range from only a few centimeters to hundreds of meters in thickness. The Palisades Sill, which is exposed in the cliffs above the Hudson River near New York City, is about 300 m thick. What effect do you think this sill, shown on the next page, had on the sedimentary rocks into which it intruded?



Figure 18-6 The Palisades Sill in New York State formed over 200 million years ago when magma forced its way into layers of parallel rock.



Figure 18-7 Note that, unlike a sill, this dike, which is in Arizona, cuts across the rocks it intrudes.

Unlike the sill shown in *Figure 18-6*, which is parallel to the rocks it intrudes, a **dike** is a pluton that cuts across preexisting rocks, as shown in *Figure 18-7*. Dikes often form when magma invades cracks in surrounding rock bodies. Most dikes are a few centimeters to several meters wide and up to tens of kilometers long. The Great Dike in Zimbabwe, Africa, however, is an exception: it is about 8 km wide and 500 km long.

While the textures of sills and dikes vary, many of these plutons are coarse grained. Recall from Chapter 5 that grain size is related to the rate of cooling. Coarse-grained sills and dikes are thought to have formed deep in Earth's crust, where the magma cooled relatively slowly to yield large mineral grains.

PLUTONS AND TECTONICS

Many plutons are formed as the result of mountain-building processes. In fact, batholiths are found at the cores of many of Earth's mountain ranges. Where did the enormous volume of magma that cooled to form these igneous bodies come from? Recall from Chapter 17 that many major mountain chains formed along continental-continental convergent plate boundaries. Scientists hypothesize that these collisions might have forced continental crust down into the upper mantle, where it melted, intruded into the overlying rocks, and eventually cooled to form batholiths.



Figure 18-8 The granite cliffs that tower over Yosemite National Park in California are parts of the Sierra Nevada batholith that have been exposed at Earth's surface.

Batholiths are also thought to have formed as a result of oceanic-oceanic convergence. Again, recall from Chapter 17 that when two oceanic plates converge, one plate is subducted into the mantle. Parts of this subducted plate melt to form magma. The Sierra Nevada batholith, which has been exposed at Earth's surface as a result of uplift and erosion, formed from at least five episodes of igneous activity beneath what is now California. The famous granite cliffs found in Yosemite National Park, some of which are shown in **Figure 18-8**, are relatively small parts of this extensive batholith.

The plutons that form deep beneath Earth's surface represent the majority of igneous activity on our planet. Nevertheless, most people think of volcanoes when they hear the words *igneous activity*. These often-spectacular examples of igneous activity at Earth's surface are discussed in the next section.

SECTION ASSESSMENT

1. Discuss three ways in which magma affects the crust into which it intrudes.
2. What are plutons, and how are they classified?
3. How are sills and dikes similar? How do they differ? Give an example of each.
4. What is a laccolith?
5. **Thinking Critically** Sometimes, the texture in the same sill varies: finer grains are

found along the margins and coarser grains are found toward the middle of the pluton. What might cause this difference in texture?

SKILL REVIEW

6. **Making a Table** Make a table in which you compare and contrast the different types of intrusive igneous bodies. For more help, refer to the *Skill Handbook*.

OBJECTIVES

- **Describe** the major parts of a volcano.
- **Compare and contrast** shield, cinder-cone, and composite volcanoes.
- **Contrast** the volcanism that occurs at plate boundaries.
- **Explain** the relationship between volcanism and hot spots.

VOCABULARY

vent
crater
caldera
shield volcano
cinder-cone volcano
composite volcano
tephra
pyroclastic flow
hot spot

What comes to mind when you hear the word *volcano*? Do you picture clouds of ash and jagged rocks being thrown violently into the air? Or do you envision rivers of reddish-orange lava flowing down the slopes of a steep volcanic peak? Both of these represent volcanic activity on Earth's surface. Volcanism produces various features that alter Earth's landscape. In this section, you will examine some of these features, beginning with the one created at the point where magma reaches the surface: the vent.

ANATOMY OF A VOLCANO

At the beginning of this chapter, you learned that magma chambers deep within Earth fuel the volcanoes that erupt at the planet's surface. Also recall that when magma reaches Earth's surface, it is called lava. Lava erupts through an opening in the crust called a **vent**. As lava flows out onto the surface, it cools and solidifies around the vent. Over time, the lava can accumulate to form a mountain known as a volcano. At the top of a volcano, around the vent, is a bowl-shaped depression called a **crater**. The crater is connected to the magma chamber by the vent. Locate the crater of the volcano shown in *Figure 18-9*.

Figure 18-9 A crater is the bowl-shaped depression that surrounds the central vent at a volcano's summit. The volcano shown below is one of many that dot the northern Arizona landscape near Flagstaff.





Figure 18-10 The caldera now known as Crater Lake is located in Oregon. This caldera formed about 6600 years ago as a result of numerous volcanic eruptions of Mount Mazama.

Volcanic craters are usually less than 1 km in diameter. Larger depressions called **calderas**, which can be up to 50 km in diameter, however, can form when the summit or the side of a volcano collapses into the magma chamber that once fueled the volcano. The caldera now known as Crater Lake formed in this way, as shown in **Figure 18-11**. The caldera walls, which are visible in the photograph in **Figure 18-10**, form cliffs that tower nearly 600 m above the water's surface. Wizard Island, which is located in the center of the lake, is actually a small volcanic cone that formed after the caldera collapsed.

TYPES OF VOLCANOES

The appearance of a volcano depends on two factors: the type of material that forms the volcano and the type of eruptions that occur. Based on these two criteria, three major types of volcanoes have been identified: shield volcanoes, cinder-cone volcanoes, and composite volcanoes. Each differs in size, shape, and composition.

Shield Volcanoes A **shield volcano** is a mountain with broad, gently sloping sides and a nearly circular base. Shield volcanoes form when layer upon layer of basaltic lava accumulates during

Figure 18-11 Crater Lake formed as the result of many eruptions.

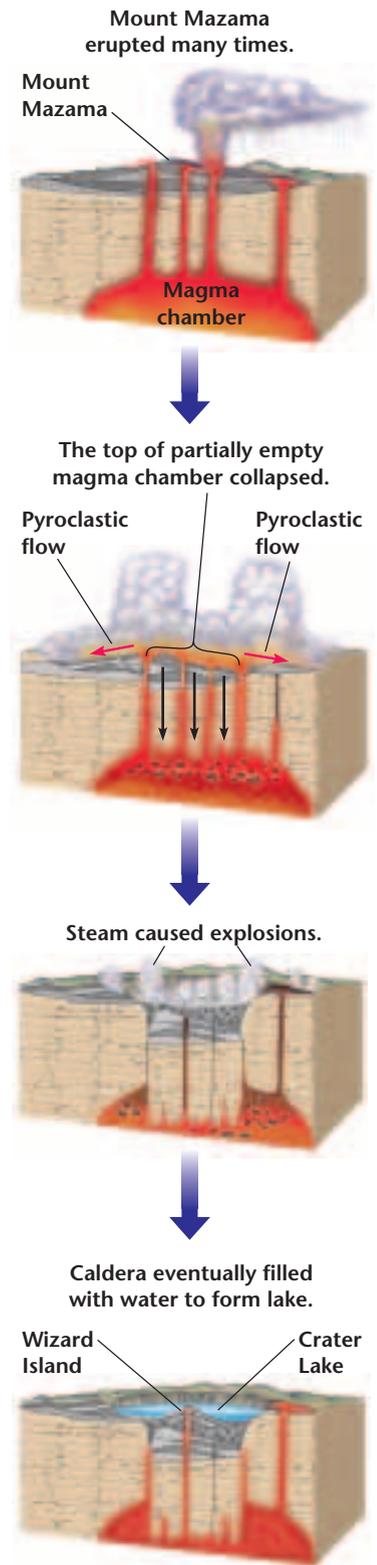




Figure 18-12 Mauna Loa, shown in the distance, is a shield volcano in Hawaii. A small cinder-cone volcano on the flank of Mauna Kea is visible in the foreground.

nonexplosive eruptions. Recall that eruptions involving basaltic lava are less explosive than other eruptions. This is because basaltic lava has a low viscosity as a result of the relatively small amounts of gases and silica it contains. The shield volcanoes that make up the Hawaiian Islands are made of basalt. Mauna Loa, which is shown in *Figure 18-12*, is one such volcano.

Cinder-Cone Volcanoes A **cinder-cone volcano** forms when material ejected high into the air falls back to Earth and piles up around the vent. Cinder-cone volcanoes have steep sides, as shown in *Figure 18-13*, and are generally small; most are less than 500 m high. The magma that fuels cinder-cone volcanoes contains more water and silica than the magma that fuels shield volcanoes. This more viscous magma also contains large volumes of gases, which make cinder-cone volcanoes more explosive in nature than shield volcanoes.

Composite Volcanoes **Composite volcanoes** form when layers of volcanic fragments alternate with lava. As with cinder-cone volcanoes, the magma that forms composite volcanoes commonly contains large amounts of silica, water, and gases. Composite volcanoes are much larger than cinder-cone volcanoes, and, because of their violently explosive nature, they are potentially dangerous to humans and the environment. Two composite volcanoes of the Cascade Range in the western United States, Mount St. Helens and Mount Rainier, are shown in *Figure 18-14*.

NATIONAL GEOGRAPHIC

To learn more about volcanoes, go to the [National Geographic Expedition](#) on page 886.



Figure 18-13 The Izalco volcano in El Salvador shows the typical profile of a cinder-cone volcano.



Figure 18-14 Two months before it erupted in 1980, Mount St. Helens, foreground, displayed the steeply sloping sides of a typical composite volcano. Mount Rainier, another composite volcano, is shown in the background.

Size and Slope Look at the small sketches that show the relative sizes of the three types of volcanoes in *Figures 18-12* through *18-14*. These diagrams are drawn to scale. As you can see, shield volcanoes are by far the largest. The smallest volcanoes are cinder-cone volcanoes, which often form on or very near larger volcanoes. Notice, too, that cinder-cone volcanoes have the steepest slopes, while shield volcanoes have the gentlest slopes. The slopes of cinder-cone and composite volcanoes are concave, and the slopes of shield volcanoes are straight. These differences in both size and slope are the result of many factors, including the different kinds of materials that make up each volcano, the vegetation that grows on the volcano's slopes, local climate, and the eruptive history of the volcano.

VOLCANIC MATERIAL

Rock fragments thrown into the air during a volcanic eruption are called **tephra**. Tephra can be newly cooled and hardened lava, mineral grains that started to crystallize prior to the eruption, or pieces of the volcanic cone. Tephra are classified by size. The smallest fragments, called dust, are less than 0.25 mm in diameter. Ash, another kind of tephra, is larger than dust but less than 2 mm in diameter. Somewhat larger fragments of tephra are called lapilli, an Italian word that means “little stones.” Lapilli are larger than 2 mm but less than 64 mm in diameter. The largest tephra thrown from a volcano

Figure 18-15 More than 29 000 people died as a result of the pyroclastic flow that accompanied the 1902 eruption of Mount Pelée on the island of Martinique. Note that much of the city of St. Pierre was destroyed.



can be the size of a car or a small building. When these large volcanic fragments are angular, they are called volcanic blocks. Volcanic blocks as large as houses have been ejected more than 10 km into the air during some eruptions. When blobs of lava are forcefully ejected from a volcano, they may cool to form rounded or streamlined tephra called volcanic bombs. Volcanic bombs may harden in the air or they may flatten and solidify after they hit the ground.

Pyroclastic Flows Some tephra cause tremendous damage and kill thousands of people. Violent volcanic eruptions can send clouds of gas, ash, and other tephra down a slope at incredible speeds. This rapidly moving volcanic material, which is called a **pyroclastic flow**, can travel at speeds of nearly 200 km/h and may contain hot, poisonous gases. The temperature at the center of a pyroclastic flow can exceed 700°C. One of the most widely known and deadly pyroclastic flows occurred in 1902 on Mount Pelée, on the island of Martinique in the Caribbean Sea. More than 29 000 people suffocated or were burned to death. What little was left of the town of St. Pierre after the eruption is shown in *Figure 18-15*.

WHERE DO VOLCANOES OCCUR?

The distribution of volcanoes on Earth's surface is not random. Most volcanoes form at plate boundaries. In fact, about 80 percent of all volcanoes are found along convergent boundaries, and about 15 percent are found along divergent boundaries. Only about 5 percent of extrusive igneous activity occurs far from plate boundaries.



Topic: Mt. St. Helens

To learn more about damage caused by volcanoes, visit the Earth Science Web Site at earthgeu.com

Activity: Research the eruption of Mt. St. Helens in 1980. Prepare a brief report or media presentation describing the change in the landscape that occurred.



Convergent Volcanism Recall from Chapter 17 that plates come together along convergent boundaries. Also recall that convergence involving oceanic plates creates subduction zones, places where slabs of oceanic crust descend into the mantle and eventually melt. The magma generated is forced upward through the overlying plate and forms volcanoes when it reaches the surface.

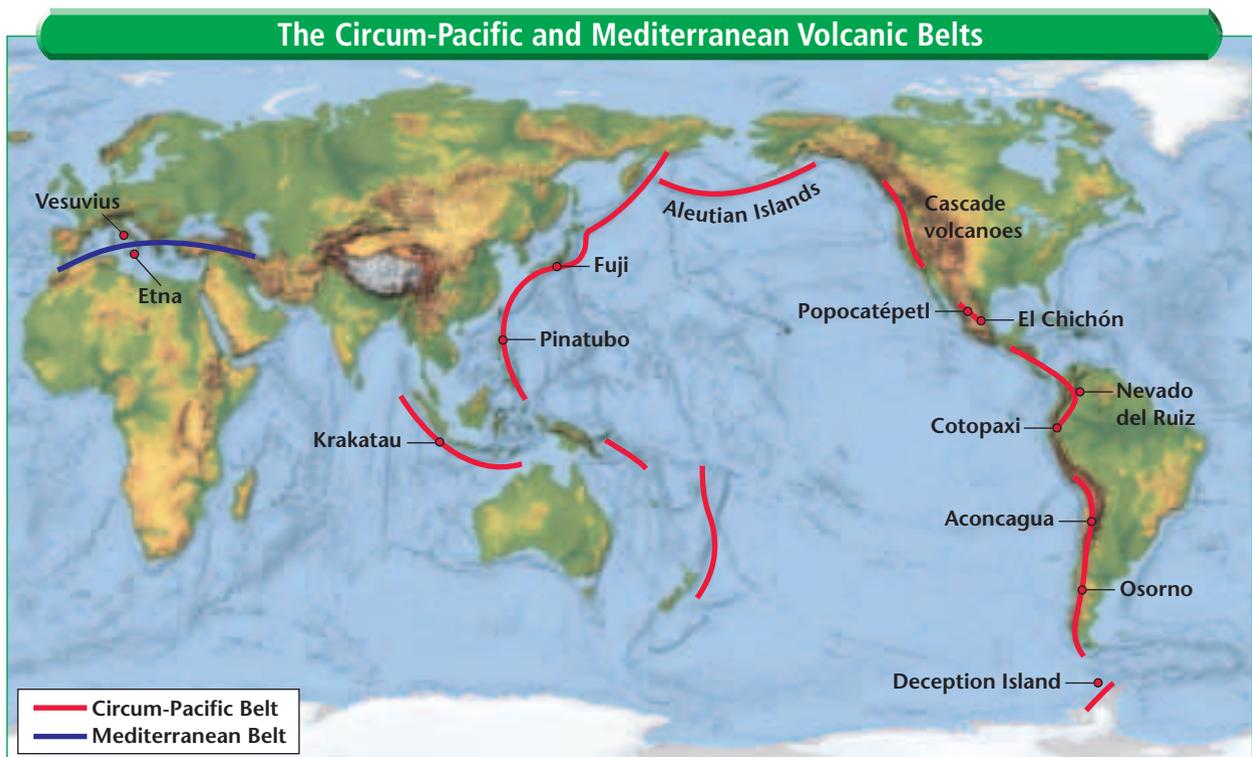
The volcanoes associated with convergent plate boundaries form two major belts, as shown in *Figure 18-16*. The larger belt, the Circum-Pacific Belt, is also called the Pacific Ring of Fire. It stretches along the western coasts of North and South America, across the Aleutian Islands, and down the eastern coast of Asia. Volcanoes in the Cascade Range of the western United States, and Mount Pinatubo in the Philippines are some of the volcanoes in the Circum-Pacific Belt. The smaller belt, which is called the Mediterranean Belt, includes Mount Etna and Mount Vesuvius, two composite volcanoes in Italy.

Divergent Volcanism Volcanic activity is also common along divergent plate boundaries, where two plates are moving apart. Magma is forced upward into the fractures and faults that form as the plates separate. These areas of major faults and fractures are called rift zones. Most of the world's rift volcanism occurs under water along ocean ridges. Recall from Chapter 17 that this type of volcanism results in the formation of new ocean floor during the



Update For an online update of recent volcanic eruptions, visit the Earth Science Web Site at earthgeu.com

Figure 18-16 Most of Earth's volcanoes form two distinct volcanic belts: the larger Circum-Pacific Belt and the much smaller Mediterranean Belt.





Using Numbers Look at **Figure 18-17**. Note that the distance from Daikakuji Seamount to Hawaii is about 3500 km. Daikakuji is 43 million years old. What is the average speed of the Pacific Plate?

process of seafloor spreading. One of the few places where rift volcanism can be observed above sea level today is in Iceland. This island is a part of the Mid-Atlantic Ridge, and consequently, several active volcanoes dot the landscape.

Hot Spots Some volcanoes are located far from plate boundaries. These volcanoes form as the result of **hot spots**, which are unusually hot regions of Earth’s mantle where high-temperature plumes of mantle material rise toward the surface. Plumes originate deep within the mantle, or perhaps even near the core-mantle boundary. The intense heat of the plumes melts rock, which is then forced upward toward the crust as magma. The magma, in turn, melts through the crust to form volcanoes. While a plume does move vertically, it does not move laterally. As a result, a trail of progressively older volcanoes forms as a plate moves over a hot spot.

Some of Earth’s best known volcanoes formed as a result of hot spots under the Pacific Ocean. The Hawaiian Islands, for example, continue to rise above the ocean floor as the Pacific Plate moves slowly over a hot spot. The volcanoes on the oldest island, Kauai, are inactive because the island no longer sits above the hot spot. The world’s most active volcano, Kilauea, is on the big island of Hawaii and is currently located over the hot spot. Another volcano, Loihi, is forming on the seafloor east of the big island of Hawaii and may eventually break the ocean surface to form a new island.

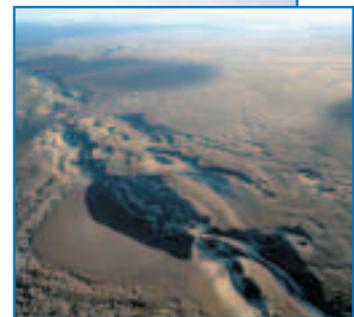
Problem-Solving Lab

Making and Using Graphs

Calculate and graph how fast lava flows On June 8, 1783, the Laki fissure zone in Iceland began to erupt in what would become the largest flood basalt in recent history. A flood basalt forms when lava flows from fissures to create a vast plain or plateau. The Laki eruption resulted in a total volume of 14.73 km³ of basalt, which covered 565 km². The lava erupted from fissures located 45 km from the coast, and flowed at speeds averaging 0.4 km/h.

Analysis

1. Design a data table to show the distance traveled by the lava over a five-day period. Calculate the distance every 12 hours.
2. Plot the data on a graph: put time on the x-axis and distance on the y-axis.



Thinking Critically

3. How long did it take the lava to reach the coast?
4. How many kilometers did the lava travel in three days?

The chains of volcanoes that form over hot spots provide important information about plate motions. The rate and direction of motion can be calculated from the positions of these volcanoes. Even changes in plate motion that occurred in the distant past can be determined. Look at **Figure 18-17**. Note that the Hawaiian Islands are at one end of the 5800-km Hawaiian-Emperor volcanic chain. The oldest seamount, Meiji, is at the other end of the chain and is about 75–80 million years old, which indicates that this hot spot has existed for at least that many years. The bend in the chain at Daikakuji Seamount records a change in the direction of the Pacific Plate that occurred about 43 million years ago.

In addition to seamount chains, hot spots can result in the formation of flood basalts. Flood basalts erupt from fissures rather than a central vent and form flat plains or plateaus rather than volcanic mountains. The volume of basalt in these eruptions can be tremendous. The Columbia River Basalts in the northwestern United States, for example, contain 170 000 km³ of basalt. The volume of basalt in the Deccan Traps in India is estimated to be 512 000 km³. The volume of basalt in the Laki eruption in Iceland, which you can analyze in the *Problem-Solving Lab* on page 486, is small by comparison at 14.73 km³.

Volcanic activity is proof that Earth is a dynamic planet. And, while many volcanic eruptions can be spectacular events, these geologic phenomena can pose risks to humans and their environment. In the *Internet GeoLab* that follows, you will research and rank some of Earth's potentially dangerous volcanoes.

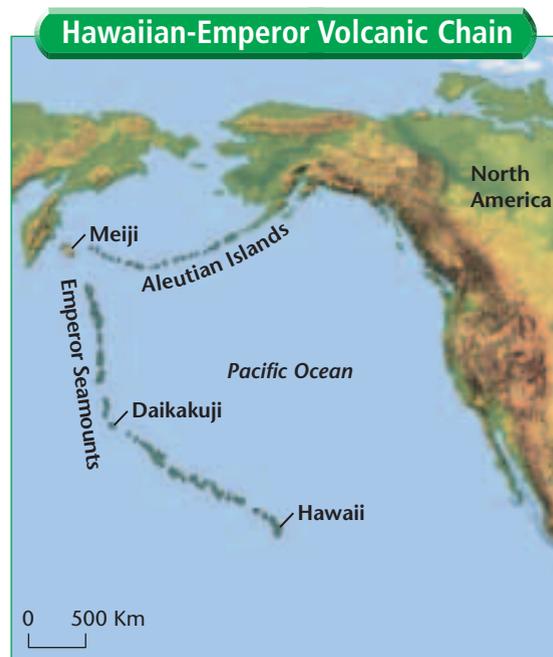


Figure 18-17 The Emperor Seamounts and the Hawaiian Islands continue to form as the Pacific Plate moves over a stationary hot spot in the mantle.

SECTION ASSESSMENT

1. What is a volcanic crater, and how does it differ from a caldera?
2. Describe the different kinds of tephra.
3. Explain why volcanic blocks would be uncommon on shield volcanoes.
4. What is a pyroclastic flow? What are the characteristics of a pyroclastic flow that make them so dangerous?
5. Where are Earth's major volcanic belts located?
6. What are hot spots?
7. **Thinking Critically** The slopes of composite volcanoes are notoriously unstable and prone to landslides. Why?

SKILL REVIEW

8. **Comparing and Contrasting** Compare and contrast the characteristics of the three major types of volcanoes. For more help, refer to the *Skill Handbook*.

Ranking Hazardous Volcanoes

Some volcanoes can be explosively dangerous. Along with clouds of ash and other volcanic debris that can linger in the air for years after an eruption, pyroclastic flows, landslides, and mudflows are common volcanic hazards. An explosive volcano may not be a hazard to human life and property, however, if it is located in a remote area or erupts infrequently. A number of factors must be taken into account to determine if a particular volcano poses a risk.

Preparation

Problem

Which volcanoes on our planet pose the greatest risk to human life and property?



Mount St. Helens May 18, 1980

Hypothesis

Form a hypothesis about where you think the most hazardous volcanoes are located on Earth. Think about the potential risk to people and property near the volcano when formulating your hypothesis.

Objectives

- **Gather and communicate** data about three volcanoes in different parts of the world.
- **Form conclusions** about the hazards posed by the volcanoes based on their location, size, lava type, and eruptive history.

Data Sources

Go to the Earth Science Web Site at earthgeu.com to find links to volcano data on the Internet. You can also use current reference books and scientific magazines to aid in the collection of data.

RANKING OF SOME HAZARDOUS VOLCANOES

Volcano name			
Country			
Location of volcano (latitude and longitude)			
Type of volcano			
Composition of lava/ Explosiveness			
Date of last eruption			
Eruption interval (number of eruptions over a period of time)			
Height of volcano			
Distance to nearest population center			
Approximate number of people living near the volcano			
Type(s) of potential hazards			
Human hazard ranking (high, medium, low)			

Procedure

1. Select a country and find out if there are any volcanoes in that country. If there are no volcanoes, choose another country. If there are a lot of volcanoes in that country, narrow your search.
2. Repeat step 1 for at least two other volcanoes. Copy and complete the data table with the information about each of the volcanoes you selected.

Conclude & Apply

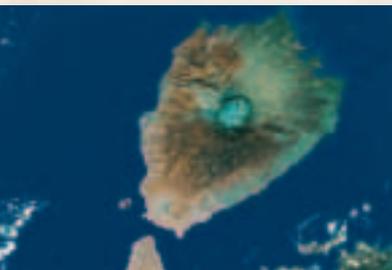
Sharing Your Data Find this Internet GeoLab on the Earth Science Web Site at earthgeu.com. Post your data in the table provided for this activity. Use the additional data from other students to complete your chart and answer the Conclude & Apply questions.

1. Which of the volcanoes you researched threatens the greatest

number of people? Where is this volcano located?

2. Analyze the data posted by others at the earthgeu.com site. Which country has the greatest number of potentially dangerous volcanoes? Why?
3. Which country has the greatest total population threatened by volcanoes?

Science & the Environment



Tambora

The Year Without a Summer

In 1816, Chauncey Jerome, a Connecticut clockmaker, reported that the clothes his wife had hung out to dry the day before had frozen overnight. This would not have been significant, except for the date—it was June 10.

What Jerome and other New Englanders experienced during the cold summer of 1816 was directly linked to an event that had occurred one year earlier and thousands of kilometers away. On April 5, 1815, Mount Tambora, a dormant volcano in Indonesia, came alive in a series of explosive eruptions.

Tambora's Direct Impact

Historic reports attest to Tambora's explosive power. The eruption was heard on Jakarta, which is more than 1200 km away. Over the course of that April week, the volcano ejected an estimated 150 km³ of tephra into the ocean and onto surrounding islands. By contrast, the volume of debris erupted during the 1980 explosion of Mount St. Helens was only 1 km³.

Volcanic ash from Tambora hung thickly in the sky and caused a three-day period of darkness within 600 km of the island. By the time the eruptions stopped, more than a third of the 3900-m mountain had been blown off. Some 12 000 people were killed directly by volcanic fallout, and more than 80 000 died soon after from famine and disease. The disaster, however, was not over. Its global effects would be felt around the world the following year—the year without a summer.

Indirect Consequences

Tambora spewed an immense amount of volcanic dust and gases such as sulfur dioxide into the atmosphere. These particles prevented sun-

light from reaching Earth's surface. In effect, the short wavelengths of incoming sunlight, which are similar in size to particles of dust and gas, collided with the particles and were reflected back into space. The problem was worsened when heat radiated from Earth's surface, which takes the form of longer wavelengths, escaped into space.

The net result was wildly fluctuating weather on a global scale. A snowfall in southern Italy, unusual in itself, caused widespread alarm because the snow was tinted red from the volcanic ash. In New England, summer temperatures dipped and soared from about 2°C to over 31°C within a matter of days. Crops were devastated.

At the time, the cause of the climatic changes was not understood; no one linked the changes to the eruption of Tambora. Today, however, we know that volcanic gases can linger in the atmosphere for years after an eruption and wreak havoc on the weather.

Internet

Not all volcanic eruptions have negative effects. Go to earthgeu.com for links to information on the eruptions that occurred in northern Arizona some 1000 years ago. How did these eruptions affect the Sinagua? What positive impacts did the eruptions have?



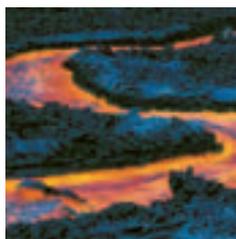
CHAPTER 18

Study Guide

Summary

SECTION 18.1

Magma



Main Ideas

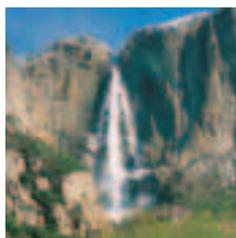
- Temperature, pressure, and the presence of water are factors that affect the formation of magma.
- As pressure increases, the temperature at which a substance melts also increases. At any given pressure, the presence of water will cause a substance to melt at a lower temperature than the same substance under dry conditions.
- There are three major types of magma: basaltic magma, andesitic magma, and rhyolitic magma. These magmas differ in the source rock from which they form, viscosity, silica content, gas content, and explosiveness. Basaltic magma is the least explosive magma; rhyolitic magma is the most explosive.

Vocabulary

viscosity (p. 474)

SECTION 18.2

Intrusive Activity



Main Ideas

- Magmatic intrusions affect the crust in several ways. Magma can force overlying rock apart and enter the newly formed fissures. Magma can also cause blocks of rock to break off and sink into the magma chamber. Magma can melt the rock into which it intrudes.
- Batholiths, stocks, sills, dikes, and laccoliths are plutons that are classified according to their size, shape, and relationship to surrounding rocks. Batholiths are the largest plutons and often form the cores of many of Earth's major mountain chains.

Vocabulary

batholith (p. 476)
dike (p. 478)
laccolith (p. 477)
pluton (p. 476)
sill (p. 477)
stock (p. 477)

SECTION 18.3

Volcanoes



Main Ideas

- Lava flows onto Earth's surface through a vent. Over time, multiple lava flows may accumulate to form a volcano. A crater is a depression that forms around the vent at the summit of a volcano. A caldera is a large crater that forms when a volcano collapses during or after an eruption.
- There are three types of volcanoes: shield volcanoes, cinder-cone volcanoes, and composite volcanoes.
- Rock fragments ejected during eruptions are called tephra.
- Most volcanoes form along convergent and divergent plate boundaries. Volcanoes also form over hot spots, which are unusually hot areas in the mantle that are stationary for long periods of time.
- Flood basalts form when lava flows from fissures to form flat plains or plateaus.

Vocabulary

caldera (p. 481)
cinder-cone volcano (p. 482)
composite volcano (p. 482)
crater (p. 480)
hot spot (p. 486)
pyroclastic flow (p. 484)
shield volcano (p. 481)
tephra (p. 483)
vent (p. 480)



CHAPTER 18 Assessment

Understanding Main Ideas

- Which of the following does NOT play a role in magma formation?
 - temperature
 - pressure
 - presence of water
 - tephra type
- Which of the following is true?
 - An increase in pressure results in a higher melting temperature of a dry substance.
 - A decrease in pressure increases the temperature at which a dry substance melts.
 - The addition of water increases the melting temperature of a substance.
 - An increase in pressure decreases the melting temperature of a dry substance.
- Which of the following melts to form rhyolitic magma?
 - continental crust
 - oceanic crust
 - oceanic sediment
 - the upper mantle
- Which type of pluton is completely parallel to the rock layers into which it intrudes?
 - dike
 - sill
 - laccolith
 - stock
- The Hawaiian volcanoes formed as a result of which of the following?
 - divergence
 - a hot spot
 - subduction
 - subsidence
- Which of the following is NOT true?
 - An increase in silica increases the viscosity of a magma.
 - Andesitic magma has both an intermediate gas content and explosiveness.
 - An increase in temperature increases a magma's viscosity.
 - Basaltic magma has a low viscosity and contains little gas.

- What is the largest type of tephra?
 - ash
 - volcanic blocks
 - dust
 - lapilli
- Which of the following has broad, gently sloping sides and a circular base?
 - hot spot
 - cinder-cone volcano
 - composite cone
 - shield volcano
- What is the Ring of Fire, and why does it exist?
- Explain the relationship between hot spots and volcanism.

Use the table to answer questions 11–15.

Economic Losses (millions of dollars) from the 1980 Eruption of Mount St. Helens

Sector	Federal	Private	State	Local
Forestry	168.0	218.1	63.7	—
Clean-up	307.9	9.7	5.0	41.3
Property	43.6	44.8	2.5	16.0
Agriculture	—	39.1	—	—
Income	—	8.9	—	—
Transportation	—	—	—	2.1

- What was the total economic cost of cleaning up after the eruption?
- What was the total economic loss from this eruption?
- What percent of the total loss was caused by property damage?
- Which sector suffered the smallest loss?
- Which sector suffered the greatest economic loss? What percent of the total was this?

Test-Taking Tip

STANDARDIZED TEST FORMS Fill in one answer bubble as you answer each question. If you need to skip a question, make sure you skip the corresponding bubble on the answer sheet also.

CHAPTER 18 Assessment

Applying Main Ideas

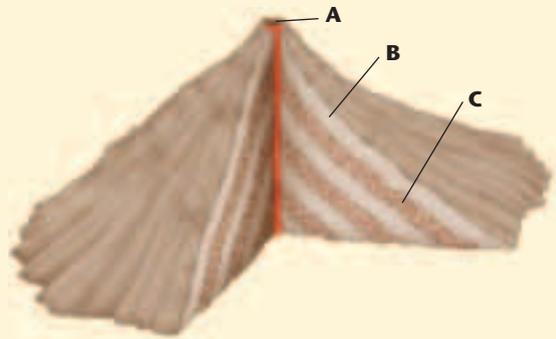
- As rhyolitic magma rises to Earth's surface, pressure decreases and water escapes from the magma. What effect does this have on the melting temperature? How might this cause the magma to solidify before reaching the surface?
- How does magma affect the rocks into which it intrudes?
- Hawaiian lava flows can travel great distances through underground passageways called lava tubes. Why would lava flow faster through a lava tube than it would above ground?
- Describe batholiths and explain where and how they form.
- What is a laccolith and how does it form?
- Explain the relationship among a vent, a crater, and a caldera.

Thinking Critically

- Soils that form from volcanic debris are very productive. What are some reasons for the high fertility of volcanic soils?
- Pumice, a volcanic glass that contains such a large percentage of holes that it floats in water, is almost never basaltic in composition. Why?
- Which type of volcano would you expect to produce the largest volume of tephra? Explain.
- Why do shield volcanoes have gentle slopes and large bases?
- Geothermal energy associated with magma chambers close to Earth's surface can be used to produce electricity. Name several places in the United States where the use of this energy might be possible.

Standardized Test Practice

INTERPRETING DIAGRAMS Use the diagram below to answer the following questions.



- What kind of volcano is shown in the diagram?
 - cinder-cone volcano
 - composite volcano
 - shield volcano
 - hot-spot volcano
- What kind of volcanic feature is designated by the letter A?
 - the vent
 - the magma chamber
 - the crater
 - the sill
- What type of material makes up the layer designated by the letter B?
 - lava
 - flood basalts
 - tephra
 - volcanic gases
- What type of material makes up the layer designated by the letter C?
 - lava
 - flood basalts
 - tephra
 - volcanic gases
- Which of the following is NOT true of this type of volcano?
 - It erupts violently.
 - The magma that fuels it is rich in silica.
 - It forms over a hot spot in Earth's mantle.
 - It has concave slopes.