CHAPTER 18 Volcanism

BIG Idea **Volcanoes develop from magma moving upward from deep within Earth.**

18.1 Volcanoes

MAIN Idea The locations of volcanoes are mostly determined by plate tectonics.

18.2 Eruptions

MAIN Idea The composition of magma determines the characteristics of a volcanic eruption.

18.3 Intrusive Activity

MAIN Idea Magma that solidifies below ground forms geologic features different from those formed by magma that cools at the surface.

GeoFacts

- All the lava from Kilauea could pave a road three times around Earth.
- There are 500 active volcanoes on Earth today.
- Magma comes from the Greek word meaning *dough.*
- Many of Earth's geographic features are caused by volcanoes.

Matt Meadows

LAUNCH Lab

What makes magma rise?

Magma is molten rock that lies beneath Earth's surface. In this activity, you will model the movement of magma within Earth by making a "lava lamp."

Procedure

1. Read and complete the lab safety form.
2. Pour about 300 mL of **water** into a **600-mL beaker.**
3. Pour about 80 mL of **vegetable oil** into the beaker.
4. Sprinkle **table salt** on top of the oil while you slowly count to 5.
5. Add more salt to keep the movement going.

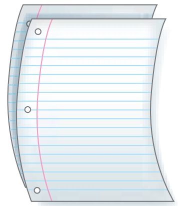
Analysis

1. **Identify** which component of your model represents magma.
2. **Describe** what happened to the oil before and after you added the salt.
3. **Hypothesize** what causes the "magma" to rise.

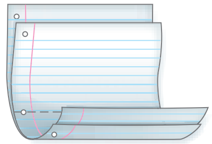
FOLDABLES™ Study Organizer

Classification of Volcanoes Make this Foldable to help you understand volcanoes.

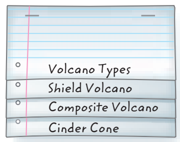
STEP 1 Stack two sheets of notebook paper approximately 1.5 cm apart.



STEP 2 Fold up the bottom edges to form four tabs.



STEP 3 Staple along the folded edge. With the stapled end at the top, label the tabs as follows: *Volcano Types, Shield Volcano, Composite Volcano*, and *Cinder Cone*.



FOLDABLES Use this Foldable with Section 18.1. As you study the section, write about the characteristics of each kind of volcano under each tab.

Earth Science Online

Visit glencoe.com to

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  - Interactive Figures
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Section 18.1

Objectives

- **Describe** how plate tectonics influences the formation of volcanoes.
- **Locate** major zones of volcanism.
- **Identify** the parts of a volcano.
- **Differentiate** between volcanic landforms.

Review Vocabulary

convergent: tending to move toward one point or to approach each other

New Vocabulary

volcanism
hot spot
flood basalt
fissure
conduit
vent
crater
caldera
shield volcano
cinder cone
composite volcano

Volcanoes

MAIN Idea The locations of volcanoes are mostly determined by plate tectonics.

Real-World Reading Link Road crews spread salt on icy winter roads because salt makes the ice melt at a lower temperature. At extremely high temperatures, rocks can melt. Often, if heated rocks are in contact with water, they melt more easily.

Zones of Volcanism

Volcanoes are fueled by magma. Recall from Chapter 5 that magma is a slushy mixture of molten rock, mineral crystals, and gases. As you observed in the Launch Lab, once magma forms, it rises toward Earth's surface because it is less dense than the surrounding mantle and crust. Magma that reaches Earth's surface is called lava. **Volcanism** describes all the processes associated with the discharge of magma, hot fluids, and gases.

As you read this, approximately 20 volcanoes are erupting. In a given year, volcanoes will erupt in about 60 different places on Earth. The distribution of volcanoes on Earth's surface is not random. A map of active volcanoes, shown in **Figure 18.1,** reveals striking patterns on Earth's surface. Most volcanoes form at plate boundaries. The majority form at convergent boundaries and divergent boundaries. Along these margins, magma rises toward Earth's surface. Only about 5 percent of magma erupts far from plate boundaries.

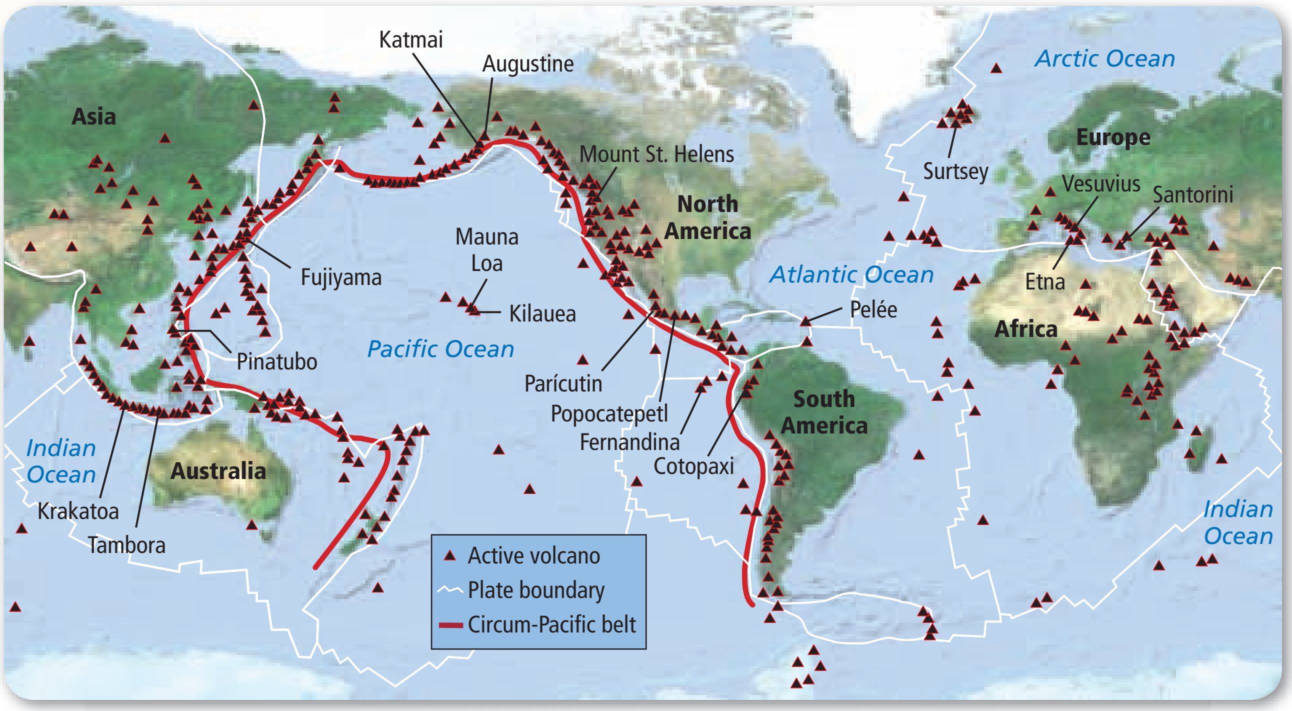


Figure 18.1 Most of Earth's active volcanoes are located along plate boundaries.

Convergent volcanism Recall from Chapter 17 that tectonic plates collide at convergent boundaries, which can form subduction zones—places where slabs of oceanic crust descend into the mantle. As shown in **Figure 18.2,** an oceanic plate descends below another plate into the mantle. As the oceanic plate descends, magma forms. The magma moves upward because it is less dense than the surrounding solid material. As it rises, the magma mixes with rock, minerals, and sediment from the overlying plate. Most volcanoes located on land result from oceanic-continental subduction. These volcanoes are characterized by explosive eruptions

Reading Check **Define** What is convergent volcanism?

Two major belts The volcanoes associated with convergent plate boundaries form two major belts, shown in **Figure 18.1.** The larger belt, the Circum-Pacific Belt, is also called the Pacific Ring of Fire. The name *Circum-Pacific* gives a hint about the location of the belt. *Circum* means *around* (as in circumference). The outline of the belt corresponds to the outline of the Pacific Plate. The belt 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 volcanoes in Italy. Its general outlines correspond to the boundaries between the Eurasian, African, and Arabian plates.

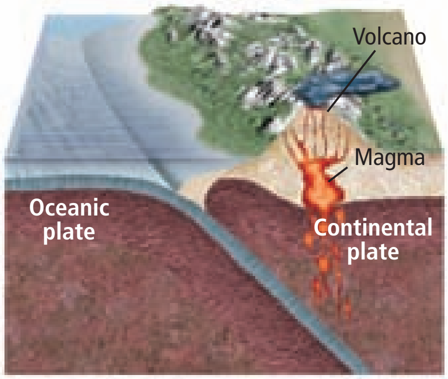


Figure 18.2 In an oceanic-continental subduction zone, the denser oceanic plate slides under the continental plate into the hot mantle. Parts of the plate melt and magma rises, eventually leading to the formation of a volcano.
Identify ***a volcano from Figure 18.1 that is associated with oceanic-continental convergence.***

Concepts In Motion

Interactive Figure To see an animation of subduction, visit glencoe.com.

DATA ANALYSIS LAB

Based on Real Data*

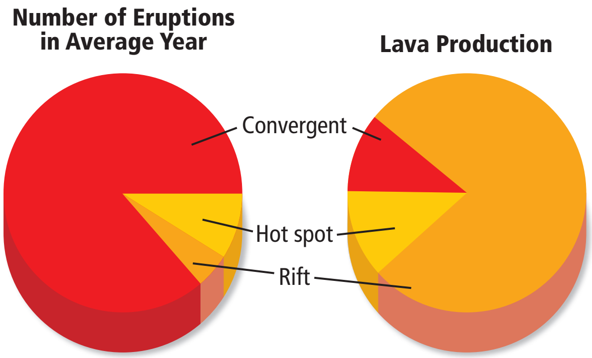
Interpret the Graph

How do zones of volcanism relate to lava production? Researchers classify types of volcanic eruptions and study how much lava each type of volcano emits during an average year. The circle graphs show data from 5337 eruptions and annual lava production for each zone.

Think Critically

1. **Describe** the relationship between the type of volcanism and annual lava production.
2. **Consider** Why is it important for scientists to study this relationship?
3. **Evaluate** What could be the next step in the researchers' investigation?

Data and Observations



*Data obtained from: Crisp, J. 1984. Rates of magma emplacement and volcanic output. *Journal of Volcanology and Geothermal Research* 20: 177–211.

Figure 18.3 Eruptions at divergent boundaries tend to be nonexplosive. At the divergent boundary on the ocean floor, eruptions often form huge piles of lava called pillow lava.

Concepts In Motion

Interactive Figure To see an animation of divergent plate boundaries, visit glencoe.com.

Divergent volcanism Recall from Chapter 17 that at divergent plate boundaries tectonic plates move apart and new ocean floor is produced as magma rises to fill the gap. At ocean ridges, this lava takes the form of giant pillows like those in **Figure 18.3,** and is called pillow lava. Unlike the explosive volcanoes detailed in **Figure 18.4,** volcanism at divergent boundaries tends to be nonexplosive, with effusions of large amounts of lava. About two-thirds of Earth's volcanism occurs underwater along divergent boundaries at ocean ridges.

Vocabulary

Science usage v. Common usage

Plume

Science usage: an elongated column

Common usage: a large, showy feather of a bird

Reading Check **Convert** the fraction of volcanism that happens underwater to a percentage.

Hot spots Some volcanoes form far from plate boundaries over hot spots. Scientists hypothesize that **hot spots** are unusually hot regions of Earth's mantle where high-temperature plumes of magma rise to the surface.

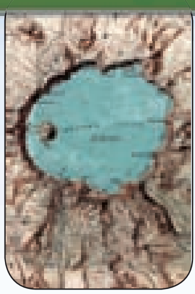
Figure 18.4

Volcanoes in Focus

Volcanoes constantly shape Earth's surface.

6000 B.C.

3000 B.C.



4845 B.C. Mount Mazama erupts in Oregon. The mountain collapses into a 9-km-wide depression, known today as Crater Lake (topographic map).

1630 B.C. In Greece, Santorini explodes, causing tsunamis 200 m high. Nearby, Minoan civilization on the Isle of Crete disappears.

A.D. 79 Mount Vesuvius in Italy erupts, burying two cities in ash.

(t)Science VU/NURP/Visuals Unlimited, (bl)courtesy of University of Oregon, (br)Roger Ressmeyer/CORBIS

Hot spot volcanoes Some of Earth's best-known volcanoes formed as a result of hot spots under the ocean. For example, the Hawaiian islands, shown in the map in **Figure 18.5,** are located over a plume of magma. As the rising magma melted through the crust, it formed volcanoes. The hot spot formed by the magma plume remained stationary while the Pacific Plate slowly moved northwest. Over time, the hot spot has left a trail of volcanic islands on the floor of the Pacific Ocean. The volcanoes on the oldest Hawaiian island, Kauai, are inactive because the island no longer sits above the stationary hot spot. Even older volcanoes to the northwest are no longer above sea level. The world's most active volcano, Kilauea, on the Big Island of Hawaii, is currently located over the hot spot. Another volcano, Loihi, is forming on the seafloor southeast of the Big Island of Hawaii and might eventually rise above the ocean surface to form a new island.

Hot spots and plate motion Chains of volcanoes that form over stationary hot spots provide information about plate motions. The rate and direction of plate motion can be calculated from the positions of these volcanoes. The map in **Figure 18.5** shows that the Hawaiian islands are at one end of the Hawaiian-Emperor volcanic chain. The oldest seamount, Meiji, is at the other end of the chain and is about 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 43 mya.

Hawaiian-Emperor Volcanic Chain

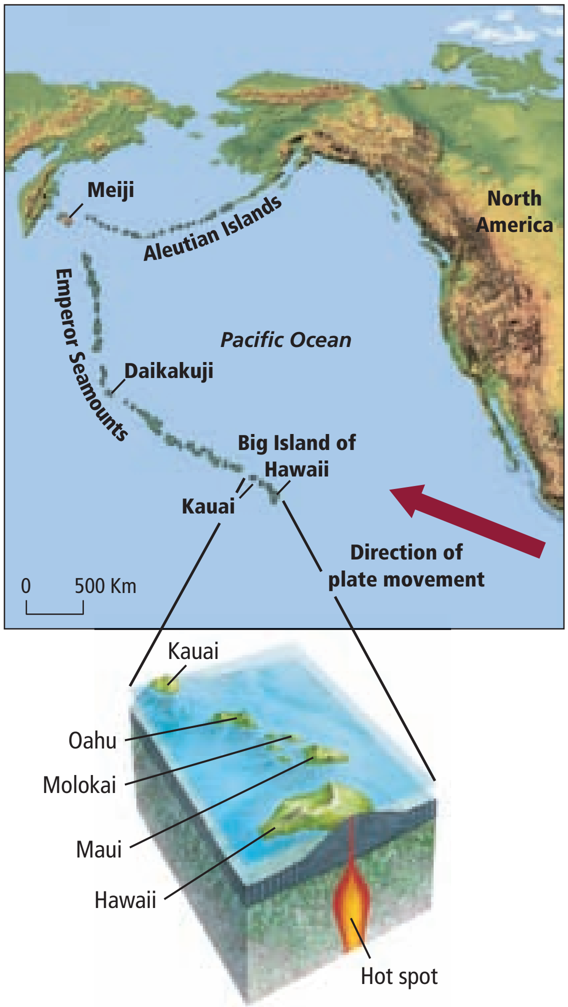
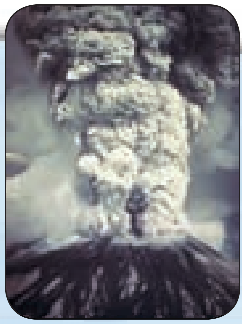


Figure 18.5 The Hawaiian islands have been forming for millions of years as the Pacific Plate moves slowly over a stationary hot spot that is currently located under the Big Island of Hawaii.



1980 In Washington, Mount St. Helens' eruption blasts through the side of the volcano. Most of the 57 fatalities are from ash inhalation.

1991 Mount Pinatubo erupts in the Philippines, releasing 10 km³ of ash, reducing global temperatures by 0.5°C.

1800 — 1900 — 2000

1883 In Indonesia, Krakatoa erupts, destroying two-thirds of the island and generating a tsunami that kills more than 36,000 people.

1912 Katmai erupts in Alaska with ten times more force than Mount St. Helens. This eruption is one of the most powerful in recorded history.

Concepts In Motion

Interactive Time Line To learn more about these discoveries and others, visit glencoe.com. Earth Science Online

■ **Figure 18.6** Huge amounts of lava erupting from fissures accumulate on the surface, often forming layers 1 km thick. Over time, streams and other geologic forces erode the layers of basalt, leaving plateaus like this one in Palouse Canyon, Washington.

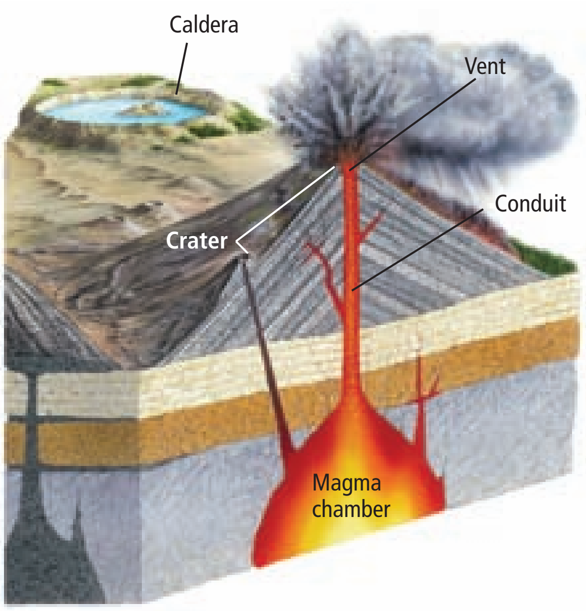
Michael T. Sedam/CORBIS

■ **Figure 18.7** More than 17 mya, enormous amounts of lava poured out of large fissures, producing a basaltic plateau more than 1 km thick in the northwestern part of the United States.

Flood basalts When hot spots occur beneath continental crust, they can lead to the formation of flood basalts. **Flood basalts** form when lava flows out of long cracks in Earth's crust. These cracks are called **fissures.** Over hundreds or even thousands of years, these fissure eruptions can form flat plains called plateaus, as shown in **Figure 18.6.** As in other eruptions, when the lava flows across Earth's surface, water vapor and other gases escape.

Columbia River Basalts The volume of basalt erupted by fissure eruptions can be tremendous. For example, the Columbia River basalts, located in the northwestern United States and shown on the map in **Figure 18.7,** contain 170,000 km^3 of basalt. This volume of basalt could fill Lake Superior, the largest of the Great Lakes, 15 times. However, the Columbia River Basalts are small in comparison to the Deccan Traps.

Deccan Traps About 65 mya in India, a huge flood basalt eruption created an enormous plateau called the Deccan Traps. The volume of basalt in the Deccan Traps is estimated to be about 512,000 km^3. That volume would cover the island of Manhattan with a layer 10,000 km thick, or the entire state of New York with a layer 4 km thick. Some geologists hypothesize that the eruption of the Deccan Traps caused a global change in climate that might have influenced the extinction of the dinosaurs.



■ **Figure 18.8** Magma moves upward from deep within Earth through a conduit and erupts at Earth's surface through a vent. The area around the vent is called a crater. A caldera can form when the crust collapses into an empty magma chamber.

Concepts In Motion **Interactive Figure** To see an animation of caldera formation, visit glencoe.com.

Anatomy of a Volcano

As you read in Chapter 5, when magma reaches Earth's surface it is called lava. Lava reaches the surface by traveling through a tubelike structure called a **conduit,** and emerges through an opening called a **vent.** As lava flows through the vent and out onto the surface, it cools and solidifies around the vent. Over time, layers of solidified 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 conduit. Locate the crater, conduit, and vent of the volcano shown in **Figure 18.8.**

Volcanic craters are usually less than 1 km in diameter. Larger depressions, called **calderas,** can be up to 50 km in diameter. Calderas often form after the magma chamber beneath a volcano empties from a major eruption. The summit or the side of a volcano collapses into the emptied magma chamber, leaving an expansive, circular depression. After the surface material collapses, water sometimes fills the caldera, forming scenic lakes. The caldera known as Crater Lake in southern Oregon formed when Mount Mazama collapsed.

MiniLab

Model a Caldera

How do calderas form? Calderas are volcanic craters that form when the summit or the side of a volcano collapses into the magma chamber that once fueled the volcano.

David Muench/CORBIS

Procedure

1. Read and complete the lab safety form.
2. Obtain a **small box,** a **10-cm length of rubber tubing,** a **clamp,** and a **balloon** from your teacher.
3. Line the box with **newspaper** and make a small hole in the box and the newspaper with **scissors.**
4. Thread the neck of the balloon through the hole, insert the rubber tubing into the neck, securing it with **tape,** inflate the balloon by blowing through the tubing, and use the clamp to close the tubing.
5. Pour six cups of **flour** over the balloon.
6. Sculpt the flour into the shape of a volcano. You might need to vary the amount of flour and type of box to reach the desired effect.
7. Remove the clamp, releasing the air from the balloon. Observe your caldera forming, and record your observations
8. Compare your caldera to your classmates'.

Analysis

1. **Sequence** the formation of the caldera.
2. **Compare** the features of a caldera with those of a crater.
3. **Infer** how the caldera will form if you vary how much you inflate the balloon.

Concepts In Motion

Interactive Table To explore more about types of volcanoes, visit glencoe.com.

Table 18.1 Types of Volcanoes

<table>
<tr><th>Description</th><th>Example of Volcanoes</th></tr>
<tr><td>

Shield Volcanoes

- Largest of the three types of volcanoes
- Long, gentle slopes
- Composed of layers of solidified basaltic lava
- Quiet eruptions

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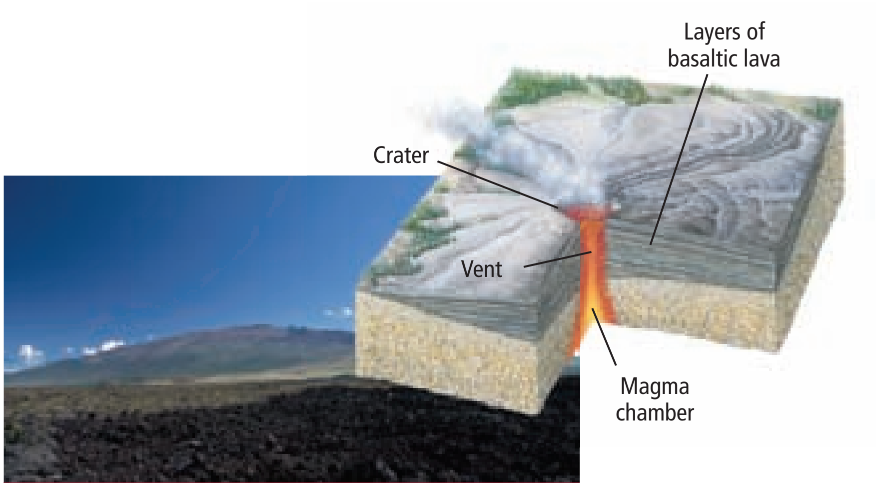

Mauna Loa, Hawaii

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Cinder Cones

- Smallest of the three types of volcanoes
- Steep-sloped, cone-shaped
- Usually composed of basaltic lava
- Explosive eruptions
- Usually form at edges of larger volcanoes

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Lassen Volcanic Park, California

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Composite Volcanoes

- Considerably larger than cinder cones
- Tall, majestic mountains
- Composed of layers of granitic rock and lava flows
- Cycle through periods of quiet and explosive eruptions

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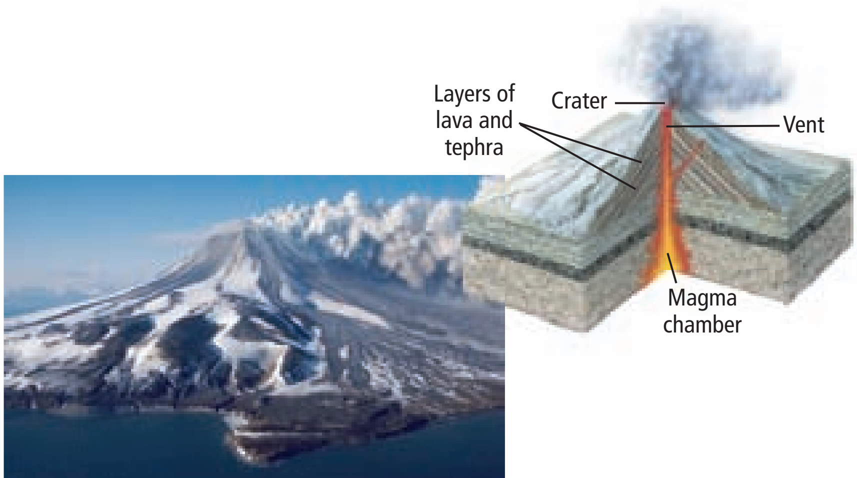

Mount Augustine, Alaska

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(t)Roger Ressmeyer/CORBIS, (c)Kevin Schafer/CORBIS, (b)Steve Kaufman/Accent Alaska

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 and are shown in **Table 18.1.** 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 layers of lava accumulate during nonexplosive eruptions. They are the largest type of volcano. Mauna Loa, which is shown in **Table 18.1,** is a shield volcano.

Cinder cones When eruptions eject small pieces of magma into the air, **cinder cones** form as this material, called tephra, falls back to Earth and piles up around the vent. Cinder cones have steep sides and are generally small; most are less than 500 m high. The Lassen Volcanic Park cinder cone shown in **Table 18.1** is 700 m high. Cinder cones often form on or very near larger volcanoes.

Composite volcanoes **Composite volcanoes** are formed of layers of hardened chunks of lava from violent eruptions alternating with layers of lava that oozed downslope before solidifying. Composite volcanoes are generally cone-shaped with concave slopes, and are much larger than cinder cones. Because of their explosive nature, they are potentially dangerous to humans and the environment. Some examples of these are Mount Augustine in Alaska, shown in **Table 18.1,** and several in the Cascade Range of the western United States, such as Mount St. Helens.

CAREERS IN EARTH SCIENCE

Volcanologist Scientists who study eruptions, lava, magma, and the conditions under which these form are volcanologists. Some work in the field, studying active volcanoes. Many volcanologists also work in the laboratory to understand how rocks melt to form magma. To learn more about Earth science careers, visit glencoe.com.

FOLDABLES

Incorporate information from this section into your Foldable.

Section 18.1 Assessment

Section Summary

- Volcanism includes all the processes in which magma and gases rise to Earth's surface.
- Most volcanoes on land are part of two major volcanic chains: the Circum-Pacific Belt and the Mediterranean Belt.
- Parts of a volcano include a vent, magma chamber, crater, and caldera.
- Flood basalts form when lava flows from fissures to form flat plains or plateaus.
- There are three major types of volcanoes: shield, composite, and cinder cone.

Understand Main Ideas

1. MAIN Idea **Explain** how the location of volcanoes is related to the theory of plate tectonics.
2. **Identify** two volcanoes in the Mediterranean Belt.
3. **Draw** a volcano, labeling the parts.
4. **Propose** Yellowstone National Park is an area of previous volcanism. Using a map of the United States, suggest the type(s) of tectonic processes associated with this area.

Think Critically

5. **Evaluate** the following statement: Volcanoes are only found along coastlines.
6. **Decide** whether a flood basalt is or is not a volcano.

MATH in Earth Science

7. If the Pacific Plate has moved 500 km in the last 4.7 million years, calculate its average velocity in centimeters per year. Refer to the *Skillbuilder Handbook* for more information.

Earth Science Online Self-Check Quiz glencoe.com

Section 18.2

Eruptions

MAIN Idea **The composition of magma determines the characteristics of a volcanic eruption.**

Real-World Reading Link Have you ever shaken a can of soda and then opened it? If so, it probably sprayed your hand, clothes, and maybe even your friends. This is similar to the process that underlies explosive volcanic eruptions.

Objectives

- **Explain** how magma type influences volcanic activity.
- **Describe** the role of pressure and dissolved gases in eruptions.
- **Recognize** classifications of material ejected by eruptions.

Review Vocabulary

basaltic: relates to a group of rocks rich in dark-colored minerals containing magnesium and iron

New Vocabulary

viscosity
tephra
pyroclastic flow

Making Magma

What makes the eruption of one volcano quiet, and the eruption of another explosively violent? The activity of a volcano depends on the composition of the magma. As shown in **Figure 18.9,** lava from an eruption can be thin and runny or thick and lumpy. In order to understand why volcanic eruptions are not all the same, you first need to understand how rocks melt to make magma.

Temperature Depending on their composition, most rocks begin to melt at temperatures between 800°C and 1200°C. Such temperatures are found in the crust and upper mantle. Recall from Chapter 5 that temperature increases with depth beneath Earth's surface. In addition to temperature, pressure and the presence of water also affect the formation of magma.

Pressure Pressure increases with depth because of the weight of overlying rocks. As pressure increases, the temperature at which a substance melts also increases. **Figure 18.10** shows two melting curves for a type of feldspar called albite. Note that at Earth's surface, albite, in the absence of water, melts at about 1100°C, but at a depth of about 12 km, its melting point 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.

Figure 18.9 The way in which lava flows depends on the composition of the magma. Mount Etna's lava is thin and runny compared to the thick and lumpy lava that erupts at Mount St. Helens.

Mount Etna

Mount St. Helens

Composition of Magma

The composition of magma determines a volcano's explosivity, which is how it erupts and how its lava flows. What are the factors that determine the composition of magma? Scientists now know that the factors include magma's interaction with overlying crust, its temperature, pressure, amounts of dissolved gas, and—very significantly—the amount of silica a magma contains. Understanding the factors that determine the behavior of magma can aid scientists in predicting the explosivity of volcanic eruptions.

Dissolved gases In general, as the amount of gases in magma increases, the magma's explosivity also increases. In the same way that gas dissolved in soda gives the soda its fizz, the gases dissolved in magma give a volcano its "bang." Important gases in magma are water vapor, carbon dioxide, sulfur dioxide, and hydrogen sulfide. Water vapor is the most common dissolved gas in magma. The presence of water vapor determines where magma forms. As shown in **Figure 18.10,** minerals in the mantle, such as albite melt at high temperatures. The presence of dissolved water vapor lowers the melting temperature of minerals, causing mantle material to melt into magma. This eventually forms volcanoes and fuels their eruptions.

Viscosity The physical property that describes a material's resistance to flow is called **viscosity**. Temperature and silica content affect the viscosity of a magma. In general, cooler magma has a higher viscosity. In other words, cool magma, much like chilled honey, tends to resist flowing.

Reading Check **Infer** Which has a higher viscosity: syrup or water?

Magma with high silica content tends to be thick and sticky. Because it is thick, magma with high silica content tends to trap gases, which produces explosive eruptions. In general, magma with low silica content has low viscosity—it tends to be thin and runny, like warm syrup. Magma with low silica content tends to flow easily and produce quiet, nonexplosive eruptions.

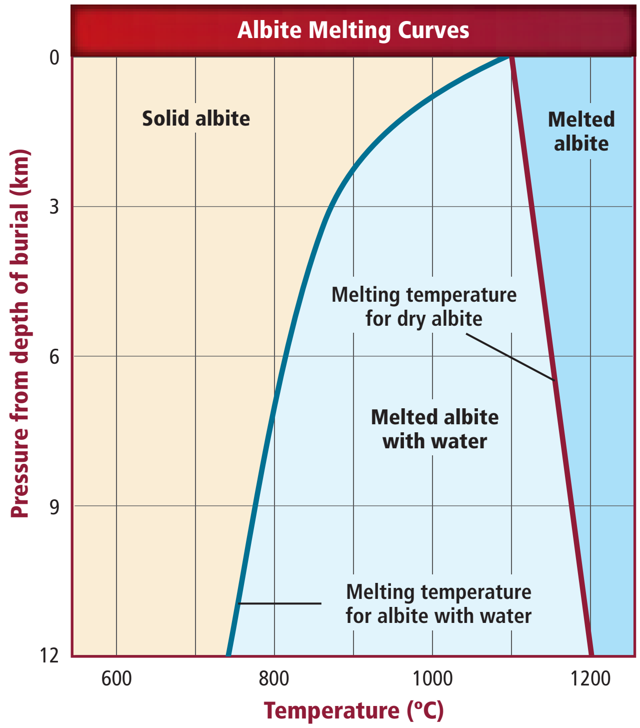
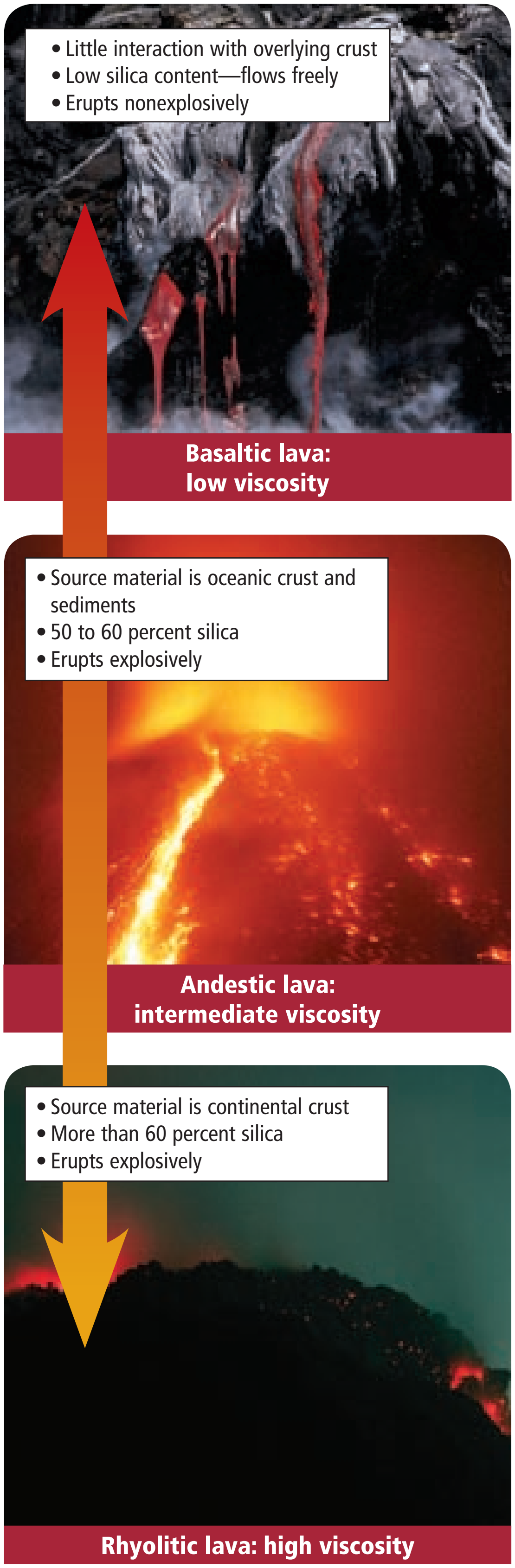


Figure 18.10 Both the pressure and water content of the mineral albite affect how the mineral melts.
Locate *the melting curve of wet albite. How does the melting point of wet albite compare to that of dry albite at a depth of 3 km? At a depth of 12 km?*

Vocabulary
Academic vocabulary
Aid
to provide with what is useful or necessary in achieving an end
Glasses aid Omar in seeing clearly.

■ **Figure 18.11** Generally, magma and lava with a low percentage of silica have low viscosity, and those with a higher percentage of silica have high viscosity.



Types of Magma

The silica content of magma determines not only its explosivity and viscosity, but also which type of volcanic rock it forms as lava cools. Refer to **Figure 18.11** to summarize types of magma.

Basaltic magma When rock in the upper mantle melts, basaltic magma typically forms. Basaltic magma has the same silica content as the rock basalt—less than 50 percent silica. This magma rises from the upper mantle to Earth's surface and reacts very little with overlying continental crust or sediments. Its low silica content produces low-viscosity magma. Dissolved gases escape easily from basaltic magma. The resulting volcano is characterized by quiet eruptions. **Figure 18.12** shows how properties of magma affect the types of eruptions that occur. Volcanoes such as Kilauea and Mauna Loa actively produce basaltic magma. Surtsey, a volcano that was formed south of Iceland in 1963, is another volcano that produces basaltic magma.

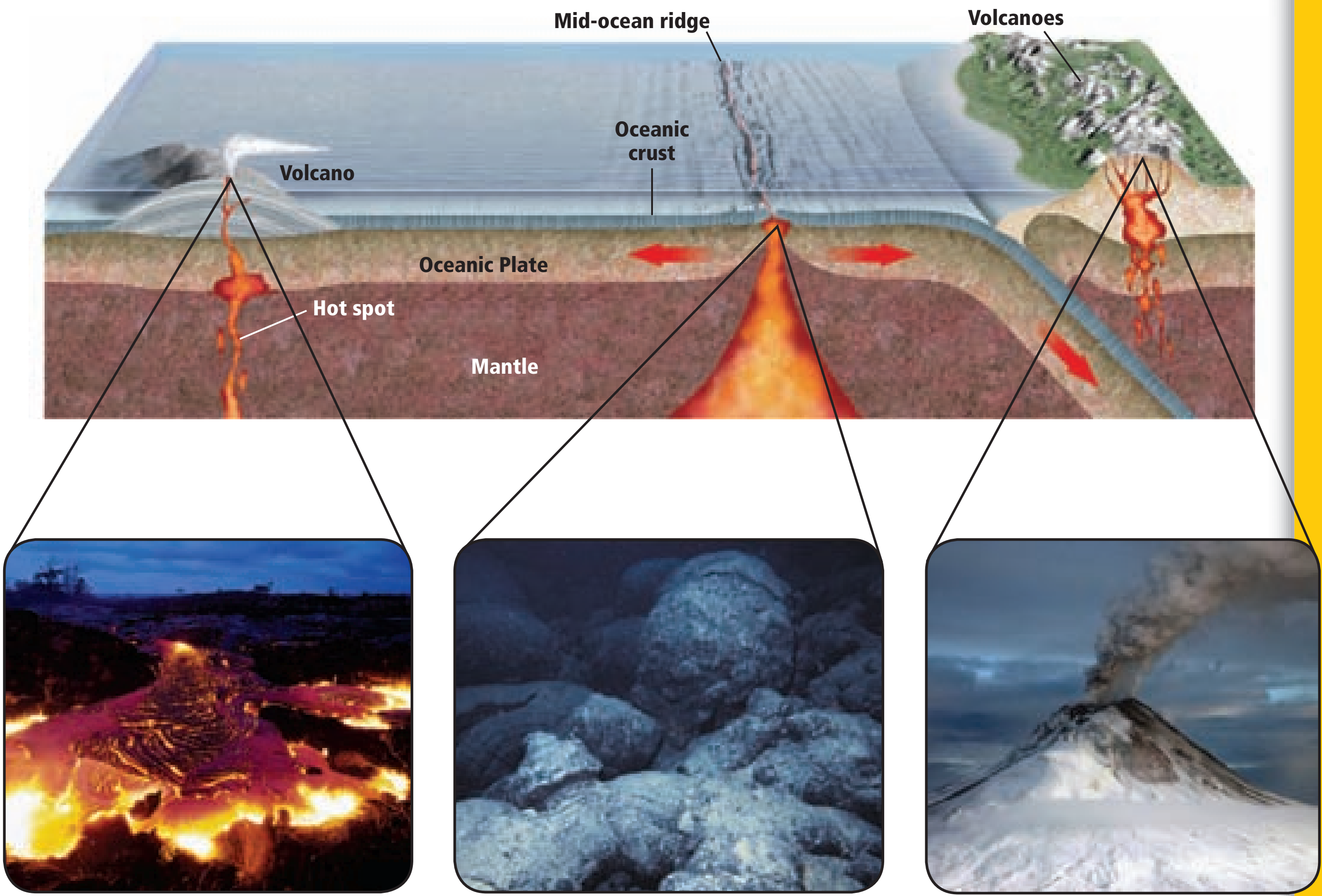
Andesitic magma Andesitic (an duh SIH tihk) magma has the same silica content as the rock andesite—50 to 60 percent silica. Andesitic magma is found along oceanic-continental subduction zones. The source material for this magma can be either oceanic crust or oceanic sediments. The higher silica content results in a magma that has intermediate viscosity. Thus, the volcanoes it fuels are said to have intermediate explosivity. Colima Volcano in Mexico and Tambora in Indonesia are two examples of andesitic volcanoes. Both volcanoes have produced massive explosions that sent huge volumes of ash and debris into the atmosphere. This not only devastated the local communities, but also impacted the global environment.

Rhyolitic magma When molten material rises and mixes with the overlying continental crust rich in silica and water, it forms rhyolitic (ri uh LIH tihk) magma. Rhyolitic magma has the same composition as the rock granite—more than 60 percent silica. The high viscosity of rhyolitic magma slows down its movement. High viscosity, along with the large volume of gas trapped within this magma, makes the volcanoes fueled by rhyolitic magma very explosive. The dormant volcanoes in Yellowstone National Park in the western United States were fueled by rhyolitic magma. The most recent of these eruptions, which occurred 640,000 years ago, was so powerful that it released 1000 km^3 of volcanic material into the air.

Visualizing Eruptions

NATIONAL GEOGRAPHIC

Figure 18.12 As magma rises due to plate tectonics and hot spots, it mixes with Earth's crust. This mixing causes differences in the temperature, silica content, and gas content of magma as it reaches Earth's surface. These properties of magma determine how volcanoes erupt.



Quiet eruptions Earth's most active volcanoes are associated with hot spots under oceanic crust. Magma that upwells through oceanic crust maintains high temperature and low silica and gas contents. Lava oozes freely out of these volcanoes in eruptions that are relatively gentle.

Underwater eruptions The most common type of lava on Earth is pillow lava. Most pillow lava forms at diverging plate boundaries along oceanic crust. Lava oozes out of fissures in the ocean floor and forms bubble-shaped lumps as it cools.

Explosive eruptions Dangerous eruptions occur where magma high in silica passes through continental crust. This magma traps gases, causing tremendous pressure to build. The release of pressure drives violent eruptions.

Concepts In Motion To explore more about plate tectonics resulting in volcanism, visit glencoe.com.

Earth Science Online

(l)Paul A. Souders/CORBIS, (c)Robert Hessler/Planet Earth Pictures, (r)Game McGimsey/Epa/CORBIS

■ **Figure 18.13** Fine ash is the smallest type of tephra. The block shown here, ejected from Cotopaxi in Ecuador, is an example of the largest category of tephra.
Compare *the two types of tephra. What do they have in common?*

Explosive Eruptions

When lava is too viscous to flow freely from the vent, pressure builds up in the lava until the volcano explodes, throwing lava and rock into the air. The erupted materials are called **tephra.** Tephra can be pieces of lava that solidified during the eruption, or pieces of the crust carried by the magma before the eruption. Tephra are classified by size. The smallest fragments, with diameters less than 2 mm, are called ash, as shown in **Figure 18.13.** The largest tephra thrown from a volcano are called blocks. The one shown in **Figure 18.13** is only about 1 m high, but some blocks can be the size of a car. Large explosive eruptions can disperse tephra over much of the planet. Ash can rise 40 km into the atmosphere during explosive eruptions and pose a threat to aircraft and can even change the weather. The 1991 eruption of Mount Pinatubo in the Philippines, shown in **Figure 18.14,** sent up a plume of ash 40 km high. Tiny sulfuric acid droplets and particles remained in the stratosphere for about two years, blocking the Sun's rays and lowering global temperatures.

■ **Figure 18.14** In 1991, the eruption of Mount Pinatubo in the Philippines sent so much ash into the stratosphere that it lowered global temperatures for two years.

(tl)Dr. John D. Cunningham/Visuals Unlimited, (tr)Jeremy Horner/CORBIS, (br)StockTrek/Getty Images


Pyroclastic flow


1902 Eruption of Mount Pelée

Figure 18.15 A pyroclastic flow from Mount Pelée was so powerful that it destroyed the entire town of St. Pierre in only a few minutes.

Pyroclastic Flows

Some tephra cause tremendous damage and kill thousands of people. Violent volcanic eruptions can send clouds of ash and other tephra down a slope at speeds of nearly 200 km/h. Rapidly moving clouds of tephra mixed with hot, suffocating gases are called **pyroclastic flows.** They can have internal temperatures of more than 700°C. **Figure 18.15** shows a pyroclastic flow pouring down Mayon Volcano in Mexico in 2000. One widely known and deadly pyroclastic flow 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.**

Section 18.2 Assessment

Section Summary

- There are three major types of magma: basaltic, andesitic, and rhyolitic.
- Because of their relative silica contents, basaltic magma is the least explosive magma and rhyolitic magma is the most explosive.
- Temperature, pressure, and the presence of water are factors that affect the formation of magma.
- Rock fragments ejected during eruptions are called tephra.

Understand Main Ideas

1. MAIN Idea **Discuss** how the composition of magma determines an eruption's characteristics.
2. **Restate** how the viscosity of magma is related to its explosivity.
3. **Predict** the explosivity of a volcano having magma with high silica content and high gas content.
4. **Differentiate** between sizes of tephra.

Think Critically

5. **Compare and contrast** the tectonic processes that made Kilauea and Mount Etna.
6. **Infer** the composition of magma that fueled the A.D. 79 eruption of Mount Vesuvius that buried the town of Pompeii.

WRITING in Earth Science

7. Write a news report covering the 1902 eruption of Mount Pelée.

Section 18.3

Objectives

- **Compare and contrast** features formed from magma that solidifies near the surface with those that solidify deep underground
- **Classify** the different types of intrusive rock bodies.
- **Describe** how geologic processes result in intrusive rocks that appear at Earth's surface.

Review Vocabulary

igneous rock: rock formed by solidification of magma

New Vocabulary

pluton
batholith
stock
laccolith
sill
dike

Intrusive Activity

MAIN Idea Magma that solidifies below ground forms geologic features different from those formed by magma that cools at the surface.

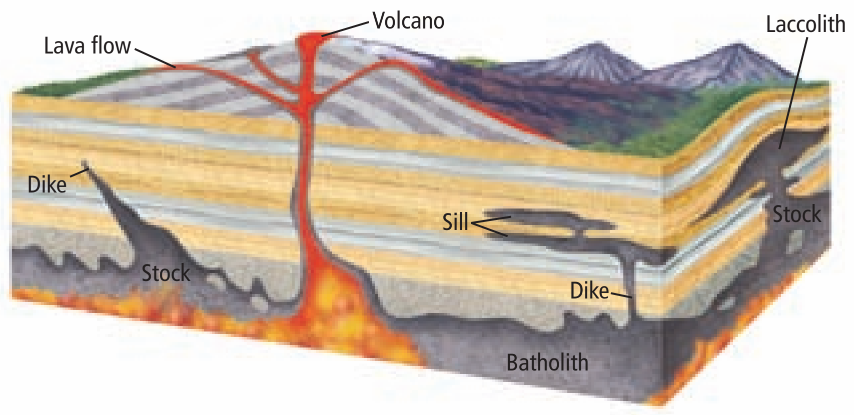
Real-World Reading Link Have you ever been surprised when the icing on the inside of a layer cake was a different color or flavor than the icing on the outside? You might also be surprised if you could look inside Earth's layers because much volcanism cannot be seen at Earth's surface.

Plutons

Most of Earth's volcanism happens below the surface because not all magma emerges at the surface. Before it gets to the surface, rising magma can interact with the crust in several ways, as illustrated in **Figure 18.16.** 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 eventually melt. Finally, magma can melt its way through the rock into which it intrudes. What happens deep in Earth as magma slowly cools? Recall from Chapter 5 that when magma cools, minerals begin to crystallize.

Over a long period of time, minerals in the magma solidify, forming intrusive igneous rock bodies. Some of these rock bodies are ribbonlike features only a few centimeters thick and several hundred meters long. Others are massive, and range in volume from about 1 km^3 to hundreds of cubic kilometers. These intrusive igneous rock bodies, called **plutons** (PLOO tahns), 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.

Figure 18.16 Magma moving upward solidifies and forms bodies of rock both at the surface and deep within Earth.



Batholiths and stocks The largest plutons are called batholiths. **Batholiths** (BATH uh lihths) are irregularly shaped masses of coarse-grained igneous rocks that cover at least 100 km^2 and take millions of years to form. Batholiths are common in the interior of major mountain chains.

Many batholiths in North America are composed primarily of granite—the 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 is the Coast Range Batholith in British Columbia, shown in **Figure 18.17;** it 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, shown in **Figure 18.16,** cut across older rocks and generally form 5 to 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 pressure of the magma body. When the magma solidifies, a laccolith forms, as shown in **Figure 18.16.** A **laccolith** (LA kuh lihth) is a lens-shaped pluton with a round top and flat bottom. Compared to batholiths and stocks, laccoliths are relatively small; at most, they are 16 km wide. **Figure 18.17** shows a laccolith in Red and White Mountain, Colorado. Laccoliths also exist in the Black Hills of South Dakota, and the Judith Mountains of Montana, among other places.

Reading Check **Contrast** What is the difference between a laccolith and a batholith?

Sills A **sill** forms when magma intrudes parallel to layers of rock, as shown in **Figure 18.16.** A sill can range from only a few centimeters to hundreds of meters in thickness. **Figure 18.17** shows the Palisades Sill, which is exposed in the cliffs above the Hudson River near New York City and is about 300 m thick. The rock that was originally above the sill has eroded. What effect do you think this sill had on the sedimentary rocks into which it intruded? One effect is to lift the rock above it. Because it takes great amounts of force to lift entire layers of rock, most sills form relatively close to the surface. Another effect of sills is to metamorphose the surrounding rocks.

Figure 18.17 Batholiths, laccoliths, and sills form when magma intrudes into the crust and solidifies.

The Coast Range Batholith in British Columbia formed 5 to 30 km below Earth's surface.

Laccoliths push Earth's surface up, creating a rounded top and flat bottom.

The Palisades Sill in New York state formed more than 200 mya.

■ **Figure 18.18** Unlike sills, dikes cut across the rock into which they intrude. Sometimes dikes intrude into the conduit of a volcano. When the volcano erodes, the more erosion-resistant dike is left standing. Try to imagine the volcano that once surrounded this volcanic neck in New Mexico.
Infer ***how big the volcano must have been.***


Dike


Volcanic neck

(tc)Marli Miller/Visuals Unlimited, (tr)Jess Alford/Getty Images, (bl)Jerome Wyckoff/Animals Animals, (br)Dr. Marli Miller/Visuals Unlimited

Dikes Unlike a sill, which is parallel to the rocks it intrudes, a **dike** is a pluton that cuts across preexisting rocks. Dikes often form when magma invades cracks in surrounding rock bodies. Dikes range in size from a few centimeters to several meters wide and can be tens of kilometers long. The Great Dike in Zimbabwe, Africa is an exception—it is about 8 km wide and 500 km long.

Some dikes intrude into the vent of a volcano. When the volcano around it erodes, these dikes, called volcanic necks, are exposed at Earth's surface, leaving a structure like the one called Ship Rock in New Mexico, shown in **Figure 18.18.**

Textures While the textures of sills and dikes vary, most are coarse-grained. Recall from Chapter 5 that grain size is related to the rate of cooling. The coarse-grained texture of most sills and dikes suggests that they formed deep in Earth's crust, where magma cooled slowly enough for large mineral grains to develop, as shown in **Figure 18.19.** Dikes and sills with a fine-grained texture formed closer to the surface where many crystals began growing at the same time, such as minerals of the sill in **Figure 18.19.**

■ **Figure 18.19** Plutons forming deep in Earth cool slowly, giving crystals time to grow. Larger crystals produce a coarse-grained rock. Intrusive rocks that form closer to Earth's surface cool more quickly. As a result, many crystals form rapidly at the same time, and the rock is finer-grained.


Coarse-grained dike


Fine-grained sill

Plutons and Tectonics

Many plutons form as the result of mountain-building processes. In fact, batholiths are found at the cores of many of Earth's mountain ranges. From where did the enormous volume of cooled magma that formed these igneous bodies come? The processes that result in batholiths are complex. Recall from Chapter 17 that many major mountain chains formed along continental-continental convergent plate boundaries. Scientists think that some of 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.

Plutons are also thought to form as a result of tectonic convergence. Again, recall from Chapter 17 that a subduction zone develops when an oceanic plate converges with another plate. Water from the subducted plate causes the overlying mantle to melt. Plutons often form when the melted material rises but does not erupt at the surface.

The Sierra Nevada batholith formed from at least five episodes of this type of igneous activity beneath what is now California. The famous granite cliffs found in Yosemite National Park, some of which are shown in **Figure 18.20,** are part of this vast batholith. Although they were once far below Earth's surface, uplift and erosion have brought them to their present position.

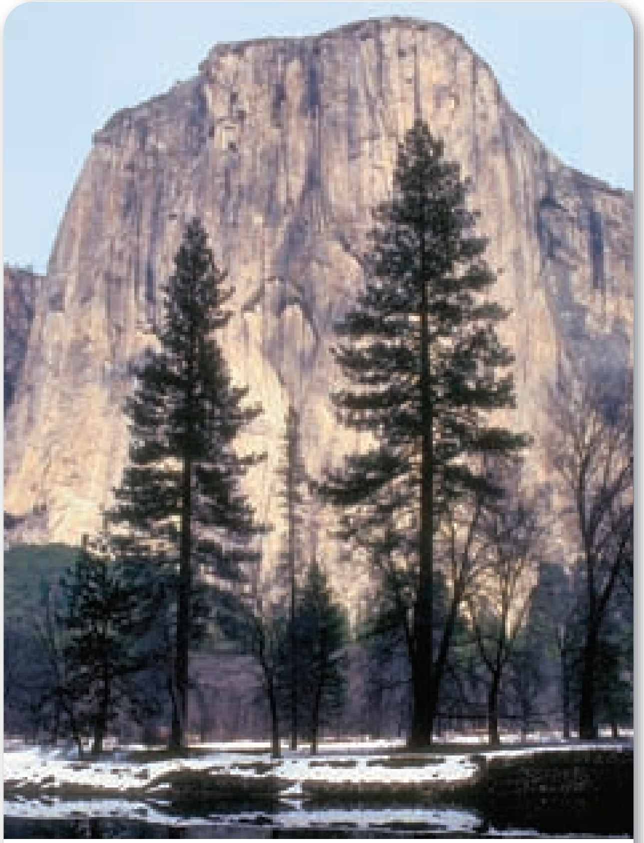


Figure 18.20 The granite cliffs that tower over Yosemite National Park in California are part of the Sierra Nevada batholith that has been exposed at Earth's surface.

Section 18.3 Assessment

Section Summary

- Intrusive igneous rocks are classified according to their size, shape, and relationship to the surrounding rocks.
- Most of Earth's volcanism happens below Earth's surface.
- Magma can intrude into rock in different ways, taking different forms when it cools.
- Batholiths form the core of many mountain ranges.

Understand Main Ideas

1. MAIN Idea **Compare and contrast** volcanic eruptions at Earth's surface with intrusive volcanic activity.
2. **Describe** the different types of plutons.
3. **Relate** the size of plutons to the locations where they are found.
4. **Identify** processes that expose plutons at Earth's surface.

Think Critically

5. **Predict** why the texture in the same sill might vary with finer grains along the margin and coarser grains toward the middle.
6. **Infer** what type of pluton might be found at the base of an extinct volcano.

WRITING in Earth Science

7. Write a defense or rebuttal for this statement: Of the different types of plutons, sills form at the greatest depths beneath Earth's surface.

NATIONAL GEOGRAPHIC **eXpeditions!**

ON SITE:

HAWAIIAN VOLCANO OBSERVATORY

Volcanologists often wear helmets, climbing gear, heat-resistant clothing, gas masks, and other gear to protect themselves from dangerous conditions in and around active volcanoes. Once this volcanologist climbs down to the test site, he will put on heat-resistant gloves.

Carsten Peter/National Geographic Image Collection

Kilauea, a shield volcano on the island of Hawaii, is one of the world's most active volcanoes and the most dangerous volcano in the United States, according to the United States Geological Survey (USGS). Scientists monitor the conditions of Kilauea at the nearby Hawaiian Volcano Observatory (HVO). The observatory also serves as a laboratory where samples gathered in and around Kilauea can be studied.

Lava collection Imagine standing next to moving lava that is 1170°C. To get a direct measurement of the temperature or to collect a sample, scientists must withstand high temperatures and watch where they step. Samples are collected with heat-resistant materials and immediately cooled in a container with water to prevent contamination from the surrounding air. To protect themselves, volcanologists wear some of the gear shown in the photo.

Seismic activity Earthquake activity beneath a volcano is an indicator of impending eruptions. One way to monitor earthquakes is to check seismic activity. Scientists place seismometers in and around the vents of volcanoes to monitor seismic activity.

Gas samples Volcanologists collect samples of gases released at vents that they will analyze for sulfur dioxide and carbon dioxide in the HVO laboratory. An increase in sulfur-dioxide or carbon-dioxide emission can indicate a potential eruption.

Ground monitoring An instrument called an electronic distance meter (EDM) helps scientists monitor the ground around volcanoes and predict an eruption. As magma rises toward Earth's surface, the ground might tilt, sink, or bulge from pressure.

Volcanologists at HVO are constantly recording data, running tests, and making advances around the world. Without their research, we might not understand volcanoes as well as we do today.

WRITING in Earth Science

Research the methods scientists use to predict time, size, and type of eruption. Visit glencoe.com for more information. Summarize your findings and share your research with your classmates.

GEOLAB

INTERNET: PREDICT THE SAFETY OF A VOLCANO

Roger Ressmeyer/CORBIS

Background: Some volcanoes are explosively dangerous. Along with clouds of ash and other volcanic debris, pyroclastic flows, landslides, and mudflows are common volcanic hazards. However, an explosive volcano might not be a hazard to human life and property if it is located in a remote area or if it erupts infrequently.

Question: *What factors should be considered when evaluating a volcano?*

Helicopters transport researchers to remote volcanic sites. Researchers analyze data to determine hazards to humans.

Materials

Internet access to glencoe.com or volcano data provided by your teacher
current reference books with additional volcano data
markers or colored pencils

Procedure

Imagine that you work for the United States Geological Survey (USGS) and are asked to evaluate several volcanoes around the world. Your job is to determine if the volcanoes are safe for the nearby inhabitants. If the volcanoes are not safe, you must make recommendations to ensure the safety of the people around them.

1. Read and complete the lab safety form.
2. Form a team of scientists of three to four people.
3. Within your team, brainstorm some factors you might use to evaluate the volcanoes. Record your ideas. You might include factors such as eruption interval, composition of lava, approximate number of people living near the volcano, and the date of the last known eruption.
4. With your group, decide which factors you will include.
5. Use the factors you have chosen to create a data table. Make sure your teacher approves your table and your factors before you proceed.
6. Visit glencoe.com (or use the information your teacher provides) and select a country where there is a known volcano.
7. Complete your data table for your first country. Repeat Step 6 for at least two more countries.
8. Repeat Steps 6 and 7 for two more countries.

Analyze and Conclude

1. **Interpret Data** Is it safe for people to live close to any of the volcanoes? Why or why not?
2. **Interpret Data** Do any of the volcanoes pose an immediate threat to the people who might live nearby? Why or why not?
3. **Conclude** Prepare to present your findings to a group of scientists from around the world. Be sure to include your predictions and recommendations, and be prepared for questions. Display your data table to help communicate your findings.

SHARE YOUR DATA

Peer Review Visit glencoe.com and post a summary of your recommendations for each of your volcanoes. Compare and contrast your data with that of other students who completed this lab.

CHAPTER 18

Study Guide

Download quizzes, key terms, and flash cards from glencoe.com.

BIG Idea Volcanoes develop from magma moving upward from deep within Earth.

Vocabulary	Key Concepts
Section 18.1 Volcanoes	
• caldera (p. 505) • cinder cone (p. 507) • composite volcano (p. 507) • conduit (p. 505) • crater (p. 505) • fissure (p. 504) • flood basalt (p. 504) • hot spot (p. 502) • shield volcano (p. 507) • vent (p. 505) • volcanism (p. 500)	**MAIN Idea** The locations of volcanoes are mostly determined by plate tectonics. • Volcanism includes all the processes in which magma and gases rise to Earth's surface. • Most volcanoes on land are part of two major volcanic chains: the Circum-Pacific Belt and the Mediterranean Belt. • Parts of a volcano include a vent, magma chamber, crater, and caldera. • Flood basalts form when lava flows from fissures to form flat plains or plateaus. • There are three major types of volcanoes: shield, composite, and cinder cone.
Section 18.2 Eruptions	
• pyroclastic flow (p. 513) • tephra (p. 512) • viscosity (p. 509)	**MAIN Idea** The composition of magma determines the characteristics of a volcanic eruption. • There are three major types of magma: basaltic, andesitic, and rhyolitic. • Because of their relative silica contents, basaltic magma is the least explosive magma and rhyolitic magma is the most explosive. • Temperature, pressure, and the presence of water are factors that affect the formation of magma. • Rock fragments ejected during eruptions are called tephra.
Section 18.3 Intrusive Activity	
• batholith (p. 515) • dike (p. 516) • laccolith (p. 515) • pluton (p. 514) • sill (p. 515) • stock (p. 515)	**MAIN Idea** Magma that solidifies below ground forms geologic features different from those formed by magma that cools at the surface. • Intrusive igneous rocks are classified according to their size, shape, and relationship to the surrounding rocks. • Most of Earth's volcanism happens below Earth's surface. • Magma can intrude into rock in different ways, taking different forms when it cools. • Batholiths form the core of many mountain ranges.

CHAPTER 18 Assessment

Vocabulary Review

Make each of the following sentences true by replacing the italicized words with terms from the Study Guide.

1. In the most explosive types of eruptions, lava accumulates to form a *shield volcano.*

2. Lava travels through a conduit to erupt through a *fissure* at the top of a volcano.

3. *Hot spots* refer to all processes associated with the discharge of magma, hot water, and steam.

4. Ash is the smallest type of *lava flow.*

Complete the sentences below using vocabulary terms from the Study Guide.

5. A(n) ________ is a bowl-shaped depression that surrounds the vent at a volcano's summit.

6. A(n) ________ forms in the depression left when an empty magma chamber collapses.

7. The type of volcano that is the smallest and has the steepest slopes is called a(n) ________.

Match each description below with the correct vocabulary term from the Study Guide.

8. any rock body that has formed at great depths underground

9. plutons having an area of more than 100 km^2; often forms the core of mountains

10. flowing cloud of tephra and lava mixed with hot, suffocating gases

11. formed when magma intrudes across existing rock

Use what you know about the vocabulary terms on the Study Guide to describe what the terms in each pair have in common.

12. laccolith, sill

13. shield volcano, flood basalt

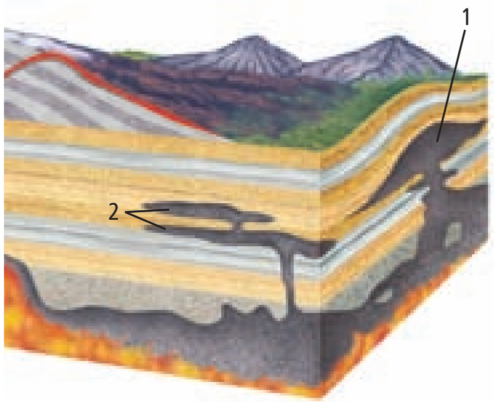
14. fissure, conduit

15. sill, dike

Understand Key Concepts

16. Which area is surrounded by the Ring of Fire?
- **A.** the Atlantic Ocean
- **B.** the United States
- **C.** the Mediterranean Sea
- **D.** the Pacific Ocean

Use the diagram below to answer Questions 17 and 18.

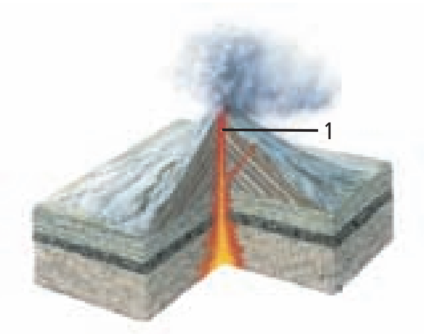


17. In the diagram, what is the structure labeled *1*?
- **A.** batholith
- **B.** laccolith
- **C.** dike
- **D.** sill

18. In the diagram, what is the structure labeled *2*?
- **A.** batholith
- **B.** laccolith
- **C.** dike
- **D.** sill

19. Which is not true?
- **A.** An increase in silica increases the viscosity of a magma.
- **B.** Andesitic magma has both an intermediate gas content and explosiveness.
- **C.** An increase in temperature increases a magma's viscosity.
- **D.** Basaltic magma has a low viscosity and retains little gas.

Use the figure below to answer Questions 20 and 21.



20. Which type of volcano is shown?
A. shield volcano
B. composite volcano
C. flood basalt volcano
D. cinder cone

21. What is the feature labeled *1*?
A. crater
B. cinder cone
C. vent
D. magma chamber

22. What causes the magma to rise upward in a mantle plume?
A. The magma is less dense than the surrounding material.
B. The magma is denser than the surrounding material.
C. The magma is pulled upward by the air pressure.
D. The magma is pushed upward by the surrounding rock.

23. Which type of volcanism produces the most lava annually?
A. convergent
B. divergent
C. hot spot
D. rifting

Constructed Response

24. Differentiate among batholiths, stocks, and laccoliths according to their relative sizes and shapes.

25. Infer A particular outcrop has a narrow ribbon of basalt that runs almost perpendicular to several layers of sandstone. What feature is shown?

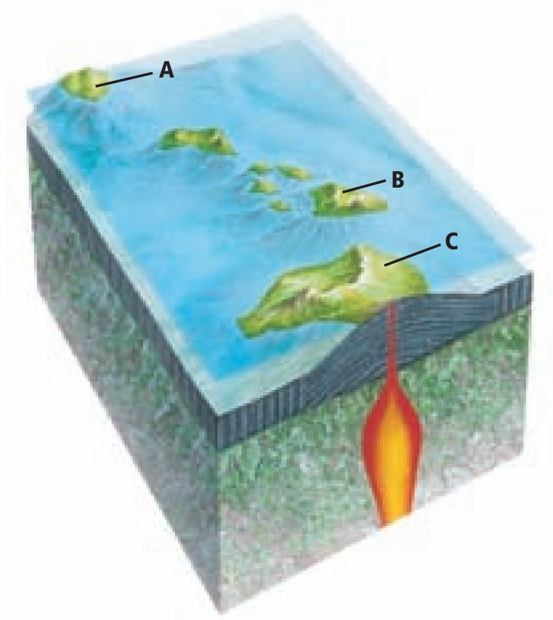
26. Describe hot spots.

27. Identify one specific example of the three types of volcanoes.

28. Compare and contrast Kilauea and the Columbia River flood basalt in terms of the processes related to their development.

29. Analyze why volcanic blocks are uncommon on shield volcanoes.

Use the diagram below to answer Question 30.



30. Distinguish which island is the oldest and in which direction the plate is moving. Explain your reasoning.

31. Decide Is the Pacific Ring of Fire an accurate name? Explain.

32. Explain the relationship between the viscosity of a magma and its temperature.

33. Explain how volcanic activity can affect global weather.

34. Draw a diagram of the three volcano types, showing their relative sizes.

35. Analyze why smaller plutons are more likely to be fine-grained, and larger plutons more likely to be coarse-grained.

Think Critically

Use the table below to answer Questions 29 to 30.

Magma Composition and Characteristics

	Basaltic Magma	Andesitic Magma	Rhyolitic Magma
Source material	upper mantle	oceanic crusts and sediments	continental crust
Viscosity	low	intermediate	high
Gas content	1–2%	3–4%	4–6%
Silica content	about 50%	about 60%	about 70%
Location of magma	both oceanic and continental crust	continental margins associated with subduction zones	continental crust

36. Analyze and rank the types of magma in terms of explosiveness based on the data. Explain your reasoning.

37. Categorize each of the three types of volcanoes in terms of the characteristics of magma shown in the table.

38. Predict what would happen if there were no plate tectonics.

Concept Mapping

39. Create a concept map using the following terms: *pluton, vertical, batholith, cuts across, stock, parallel, laccolith, sill,* and *dike.* For more help refer to the *Skillbuilder Handbook.*

Challenge Question

40. Formulate a way to recognize the difference between an ancient lava flow and an intrusive igneous rock.

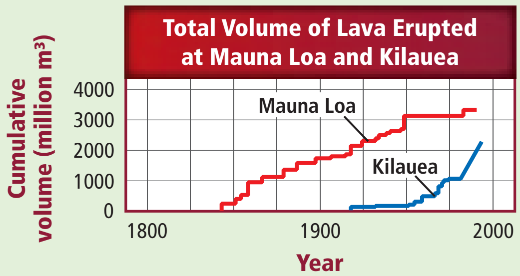
Additional Assessment

41. WRITING in **Earth Science** Imagine you are in charge of a volcano observatory. One day, GPS measurements indicate that a volcano is expanding, there have been several earthquakes, and the flux of volcanic gases has increased. Should you issue a warning of an impending eruption? Write a press release to warn people about the situation.

Document–Based Questions

Data obtained from: Takada, A. 1999. Variations in magma supply and magma partitioning: the role of tectonic settings. *Journal of Volcanic Geothermal Research* 83:93–110.

Studying the history of past eruptions yields important data for making estimations about predicting eruptions. The graph below shows the total volume of lava erupted at two Hawaiian island over 200 years.



42. In what years did the two largest eruptions occur at Mauna Loa?

43. What is the average volume of lava at Mauna Loa between 1840 and 1990?

44. Can you predict when the next eruption will occur? Explain your answer.

45. Eruptions at Mauna Loa are large and last a short length of time. What feature of the graph shows this? Compare and contrast the last eruption at Kilauea with eruptions at Mauna Loa.

Cumulative Review

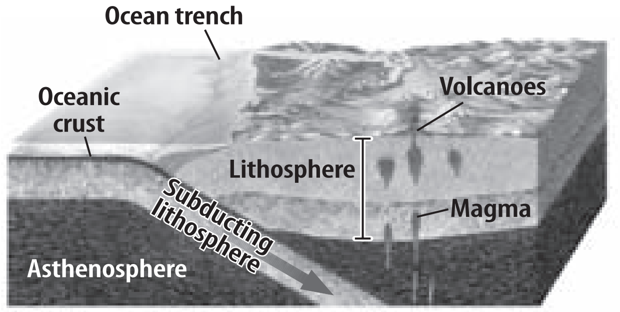
46. List six of the most important mineral properties used in mineral identification. **(Chapter 4)**

47. What observations support the theory of plate tectonics? **(Chapter 17)**

Standardized Test Practice

Multiple Choice

Use the figure below to answer Questions 1 and 2.



1. What process is occurring in the figure above?
A. continental-continental divergence
B. oceanic-continental divergence
C. continental-continental subduction
D. oceanic-continental subduction

2. How does an increase in confining pressure affect a rock's melting temperature?
A. The melting temperature increases.
B. The melting temperature decreases.
C. The melting temperature is stabilized.
D. It has no effect on the melting temperature.

3. Which evidence was not used by Wegener to support his hypothesis of continental drift?
A. coal beds in America
B. fossils of land-dwelling animals
C. glacial deposits
D. paleomagnetic data

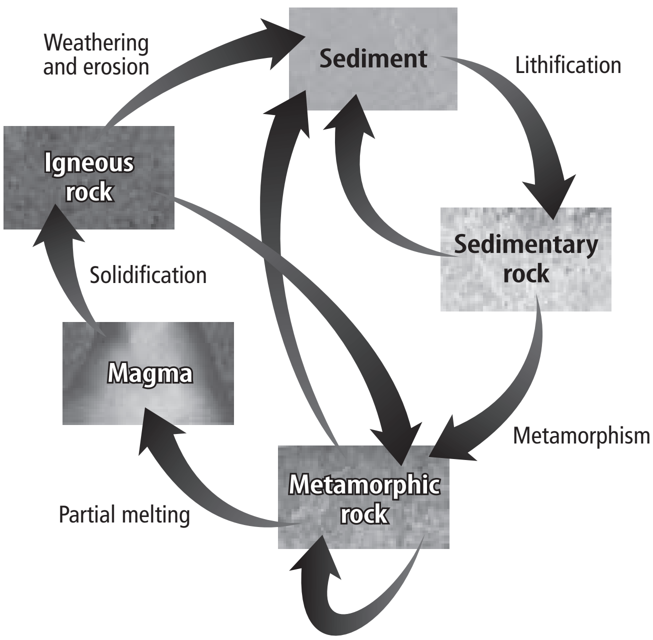
4. What is the name for the constant production of new ocean floor?
A. continental drift
B. hot spot
C. seafloor spreading
D. subduction

5. The weight of a subducting plate helps pull the trailing lithosphere into a subduction zone in which process?
A. ridge pull
B. ridge push
C. slab pull
D. slab push

6. What type of model uses molded clay, soil, and chemicals to simulate a volcanic eruption?
A. conceptual model
B. physical model
C. mathematical model
D. computer model

7. Which of these processes of the water cycle is a direct effect of the Sun's energy?
A. formation of precipitation
B. runoff of water over soil
C. evaporation
D. seeping of water into soil

Use the figure below to answer Questions 8 and 9.



8. Which process brings rocks to Earth's surface where they can be eroded?
A. lithification
B. weathering
C. solidification
D. metamorphism

9. What rock type is produced when magma solidifies?
A. metamorphic rock
B. sedimentary rock
C. igneous rock
D. lava

Short Answer

Use the table below to answer Questions 10–12.

Notable Volcanic Eruptions			
Volcano	**Date**	**Volume Ejected**	**Height of Plume**
Toba	74,000 years ago	2,800 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

10. Order the volcanic eruptions according to the quantities of pyroclastic material produced.

11. Hypothesize why the eruption of 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.

12. Calculate the difference in plume height of volcanic debris during the eruption of Tambora in 1815 compared to the plume from the 1980 eruption of Mount St. Helens.

13. Distinguish between the everyday use of the term *theory* and its true scientific meaning.

14. When a tropical rain forest is cleared, why does the soil usually become useless for growing crops after only a few years?

15. What role do glaciers play in Earth's rock cycle?

16. Write a list of numbered statements that summarizes the major steps in the water cycle.

Reading for Comprehension

Eruption of Mount Pinatubo

On June 15, 1991, Mount Pinatubo roared awake after a six-century sleep. The 1760-m volcano belched clouds of gas and ash known as pyroclastic material. Their temperature: 816°C. Streams of ash and sulfur dioxide rocketed 40 km into the stratosphere. Another blast at dawn blew away the side of the mountain. So much ash and pumice choked the air that the sky grew black by afternoon, and chunks of volcanic rock fell with a force similar to hail. That evening, earthquakes struck the already-damaged city. Pinatubo's eruption had created an underground cavern that caved in on itself.

17. What can be inferred from this text?
- **A.** Volcanoes are unpredictable and can erupt at any time.
- **B.** Volcanoes always erupt explosively.
- **C.** Volcanoes can change the surface of Earth in many ways.
- **D.** Volcanoes are always accompanied by earthquakes.

18. According to this text, which statement is false?
- **A.** Volcanoes can release gases into the stratosphere.
- **B.** The eruption of Mount Pinatubo was caused by the collapse of an underground cavern.
- **C.** The gas and ash released during the 1991 eruption was as hot as 816°C.
- **D.** Volcanic eruptions can change the shape of the mountain.

19. In the days leading up to the June 15th eruption, towns in areas surrounding Mount Pinatubo were evacuated. Based on the text above, explain why it would be necessary to evacuate these areas.

NEED EXTRA HELP?

If You Missed Question . . .	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Review Section . . .	17.3	5.1	17.1	17.2	17.4	1.3	9.1	6.1	5.1	18.1	18.3	18.3	1.3	8.3	3.3	9.1