Chapter 10

Volcanoes

Our early ancestors created stories to explain volcanic eruptions. For example, it was thought that the volcanic island Vulcano off the coast of Italy was a smoke stack for Vulcan, the Roman god of fire and metalworking. Today, volcanic eruptions make the news when they occur. What do you know about volcanoes? How do you think they are connected to plate tectonics?

Key Questions

1. ***What does the inside of a volcano look like?***
2. ***Where do we find volcanoes on Earth?***
3. ***What are the different kinds of volcanoes?***

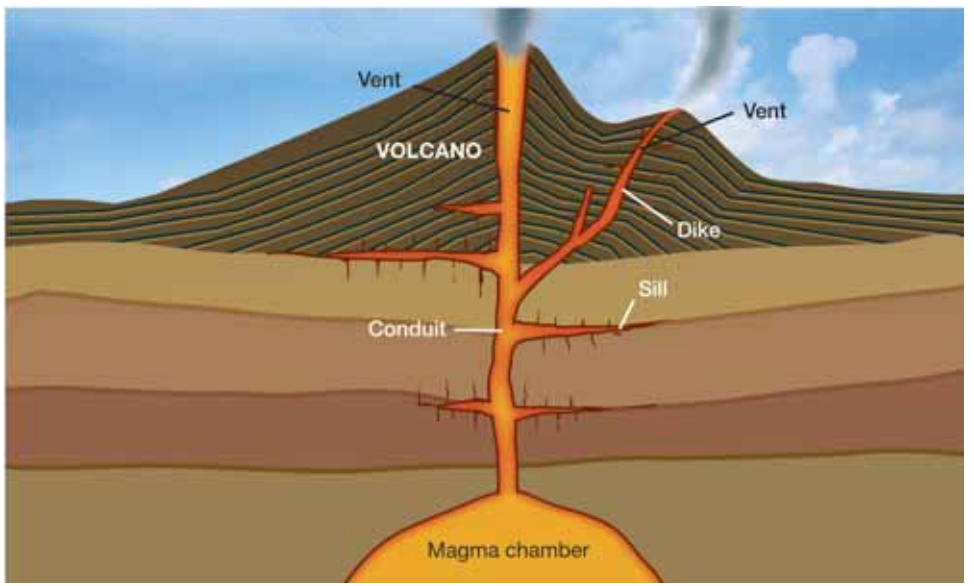
10.1 What Is a Volcano?

Volcanoes are spectacular when they erupt but they can be dangerous! You have probably seen a volcanic eruption on television. Mount St. Helens in Washington is a famous volcano that erupted in 1980 (Figure 10.1). What is a volcano? A **volcano** is a site where melted rock and other materials from Earth's mantle are released.

Looking inside a volcano

The parts of a volcano

During an eruption, melted rock called **magma** leaves the **magma chamber** and moves up the *conduit*. The magma leaves the conduit at the *vent*. Magma may leave the vent gently, or with violent force. Magma is called **lava** after it leaves the vent. Magma may leave the conduit by moving sideways along weaknesses between rock layers. This sideways movement of magma forms a *sill*. Magma may also move upward in a sheet to form a *dike*. If a sill or a dike breaks through to the surface, another vent will form.



VOCABULARY

volcano - an erupting vent through which molten rock reaches Earth's surface, or a mountain built from the products of an eruption.

magma - underground melted rock.

magma chamber - a location where magma collects inside Earth.

lava - magma that has reached and cooled on Earth's surface.

Figure 10.1: *Mount St. Helens is a type of volcano called a* composite volcano *(also known as a* stratovolcano*).*

What happens after a volcano erupts?

Formation of a caldera

Eventually, all volcanic eruptions end. The magma drains back down the conduit. The vent winds up looking like a bowl. This bowl is called the **caldera** and may be very large.

Resurgent dome

If magma begins to return back up the conduit, a mound called a **resurgent dome** may form on the caldera floor. Another kind of volcano, a *cinder cone*, may also form in the caldera. You'll learn about cinder cones in Section 10.3.

Lava lake

Water may fill the caldera forming a lake. It's also possible that the magma may not drain completely. In that case, the caldera will contain lava and become a **lava lake** (Figure 10.2).

VOCABULARY

caldera - the bowl-shaped vent of a volcano after it has erupted.

resurgent dome - a mound in the vent of an erupted volcano.

lava lake - a lake that contains lava that has formed in a caldera.

Figure 10.2: *A lava lake.*

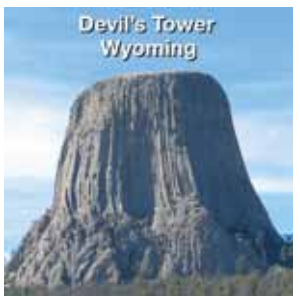
The life of a volcano

Volcanoes have a lifetime Volcanoes are not permanent features on the surface of Earth. They have a lifetime that occurs in phases. Volcanoes are described according to the phase they are in. The three phases are active, dormant, and extinct.

Active volcanoes An **active volcano** is the most vigorous kind of volcano. Active volcanoes are erupting or have erupted recently, and are expected to erupt again in the near future. However, volcanic activity during the life of a volcano doesn't last forever. Eventually, the conditions that make a volcano active change and the volcano becomes dormant.

Dormant volcanoes A **dormant volcano** is a quiet volcano. "Dormant" means sleeping. Dormant volcanoes are not active now, but may become active again in the future. Most of the volcanoes along the northern Pacific coast of North America are dormant.

Extinct volcanoes An **extinct volcano** is at the end of its life and is no longer able to erupt. As the volcano erodes, a core of now-solid magma, called a volcanic neck, may be exposed.



A **volcanic neck** is the solid remains of magma that filled the conduit. Figure 10.3 is a photo of Ship Rock in New Mexico. The "ship" is a volcanic neck. Devil's Tower National Monument in Wyoming is another famous volcanic neck. You can see the remains of several dikes running out from the neck. Devil's Tower was featured in the 1977 Steven Spielberg movie *Close Encounters of the Third Kind*!

VOCABULARY

active volcano - a volcano that is erupting or that has erupted recently.

dormant volcano - a volcano that is not erupting now, but that may erupt in the future.

extinct volcano - a volcano that no longer erupts and is in the process of eroding.

volcanic neck - solid remains of magma that filled the conduit of an extinct volcano. The neck is exposed as the volcano erodes.

Figure 10.3: *The volcanic neck of Ship Rock in New Mexico has been exposed by erosion.*

Making magma

Where does magma come from?

Earth's crust is so cool that it's brittle. Nevertheless, hot, melted rock makes its way to Earth's surface and comes out of volcanoes as lava. What makes rock melt so that it becomes magma and then explodes out onto Earth's surface?

Temperature

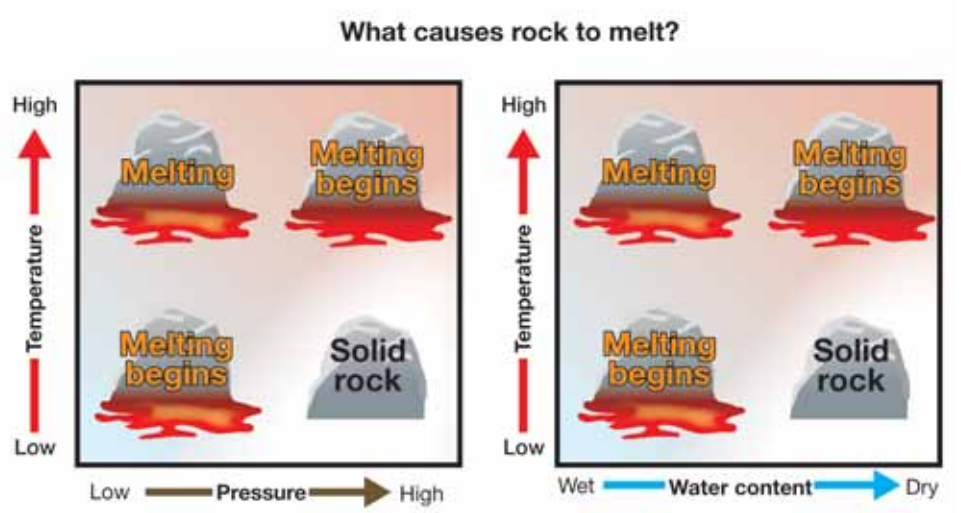
You know that heating ice, butter, and a lot of other solids will make them melt. At high enough temperatures, solid rock will melt too. However, the lithosphere is not hot enough to melt rock.

Pressure and water

There are two other ways to make rock melt that are very important. One way is to reduce the pressure. The other way is to mix water with the hot rock. The conditions needed to melt rock are very special and they exist inside our planet. They are listed in Figure 10.4 and illustrated below.

Where does magma form?

You will learn where magma is made in Section 10.3. For now, you can make predictions about where the conditions for making magma occur by answering the questions in the Challenge box.



Conditions that melt rock

Changes in pressure

Rock under high pressure melts at a higher temperature.

Rock under low pressure melts at a lower temperature.

Adding water to hot rock

Dry rock melts at a higher temperature.

Rock that contains water melts at a lower temperature.

Figure 10.4: *Conditions for making magma.*

CHALLENGE

Make predictions about where rocks melt! Pick your answers from this list: crust, core, mid-ocean ridge, subduction zone, and transform fault boundary.

1. Where would rocks experience decreasing temperature and lowering pressure?

2. Where would rocks experience lowering temperature and the addition of water?

10.1 Section Review

1. What is the difference between magma and lava?
2. Imagine a volcano with only one vent. What change might cause a second vent to appear on the side of the volcano?
3. About 7,000 years ago, Mount Mazama erupted and the summit (top) of the volcano collapsed forming a depression that was then filled with rain and melted snow. The depression is now called Crater Lake. Mount Mazama is an extinct volcano. What is the best term to describe the depression that holds Crater Lake?
4. Which kind of volcano is being described? Write *active*, *dormant*, or *extinct* for each item below.
   a. No longer erupting
   b. Could be described as "sleeping"
   c. May erupt in the future but is not erupting at present or recently
   d. Erupting on a regular basis
   e. The volcano is eroding and a volcanic neck is exposed
5. What is the difference between a dormant volcano and an active volcano?
6. Based on your reading in this section, answer these questions:
   a. Under what conditions of temperature and pressure does a solid rock begin to melt?
   b. Under what conditions of temperature and water content does a solid rock begin to melt?

SOLVE IT!

Volcano Trivia

You will need to do research to answer each question.

1. Where does the word "volcano" come from?
2. What is the Roman god Vulcan known for?
3. How many active volcanoes are on Earth right now?
4. What is the most volcanic moon in our solar system?
5. What is the biggest volcano on Earth?
6. Come up with three more volcano trivia questions (and their answers) to ask your friends!

10.2 Where Do You Find Volcanoes?

Early humans could not travel easily and only knew of a few local volcanoes. They couldn't see a pattern among volcanoes and made up stories to explain why volcanoes occurred. As explorers started traveling the world, map makers noticed that many volcanoes were located along coastlines, but they didn't know why. Do you? In this section, you will learn about where Earth's volcanoes are found.

VOCABULARY

Ring of Fire - a region of Earth's plate boundaries where oceanic crust is subducting under other plates.

Volcanoes at plate boundaries

Where are most volcanoes located?

Most volcanoes are located along plate boundaries. About half of the active surface volcanoes on Earth occur along the shores of the Pacific Ocean! This region is called the Ring of Fire.

The Ring of Fire

The **Ring of Fire** coincides with regions where the oceanic crust of the Pacific Plate is subducting under other plates. Mount St. Helens is one of the volcanoes within the Ring of Fire (Figure 10.5).

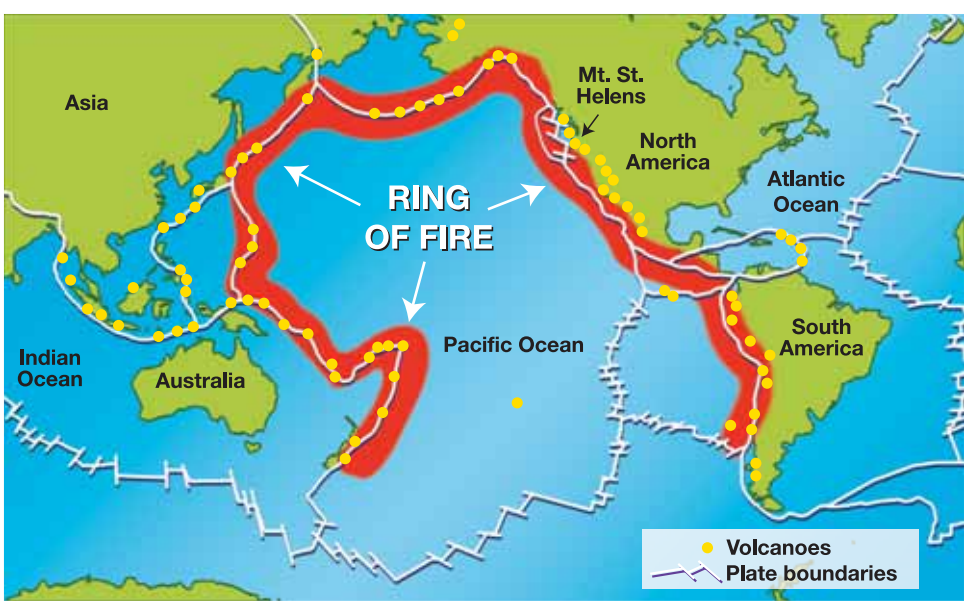


Figure 10.5: *Mount St. Helens before and after its eruption. This volcano formed when the small Juan de Fuca Plate subducted under the North American Plate.*

Volcanoes at mid-ocean ridges

Pressure decreases at mid-ocean ridges

Mid-ocean ridges occur at diverging plate boundaries. Convection currents in the lower mantle pull the plates away from each other (Figure 10.6). As the plates move apart, lower mantle material is drawn toward Earth's surface. The rock of the lower mantle is hot, flexible, and solid. This rock is solid because of the great pressure of the layers above it. However, as the rock of the lower mantle rises, the pressure drops and the material melts.

Basalt and silica

The melted lower mantle material forms basalt magma. **Basalt** is a dark-colored rock that is not silica-rich. **Silica** makes magma thick and sticky. Basalt magma is runny because of its low silica content. *Quartz* is a mineral that you may be familiar with. Quartz is made of silica.

Photo courtesy U.S House Subcommittee on Energy and Natural Resources

Runny lava

If a lot of silica makes magma thick and sticky, then magma without much silica must be thin and runny! When runny basalt lava oozes out at a mid-ocean ridge, it immediately hits cold seawater. The seawater cools the lava, forming a crust. But soon the crust cracks and another jet of basalt magma squirts out. This cycle repeats over and over, forming lava that looks like a pile of pillows. You read about this distinctive lava called *pillow lava* in Section 8.3. The presence of pillow lava can be a clue for the location of ancient mid-ocean ridges.

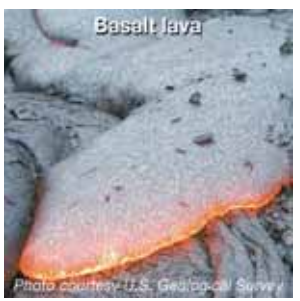


Photo courtesy U.S. Geological Survey

VOCABULARY

basalt - a dark-colored rock that is not silica-rich.

silica - an ingredient in magma and lava that makes them thick and sticky; quartz is a mineral made of silica.

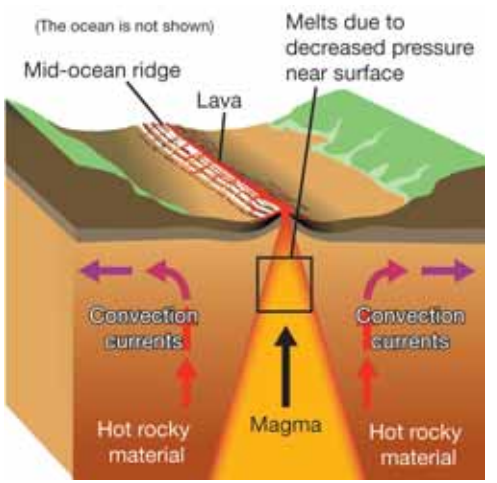


Figure 10.6: *As the plates move apart at a mid-ocean ridge, the mantle material is drawn upward. The pressure decreases as this material rises. This causes mantle material to melt.*

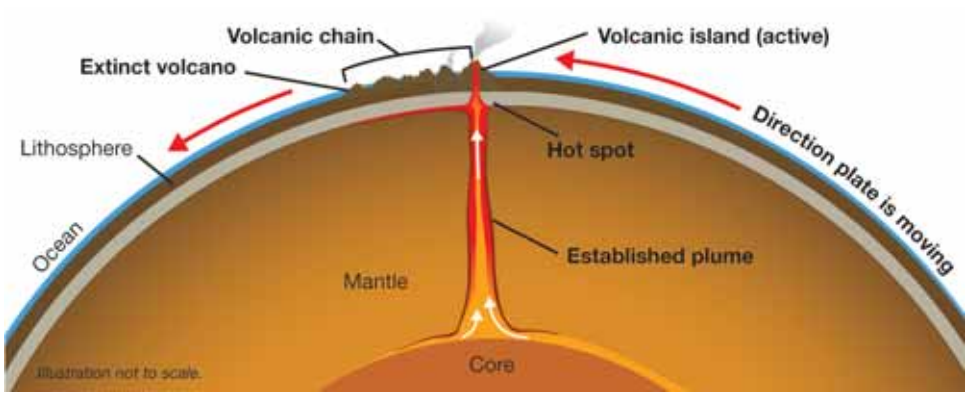
Volcanic chains

Away from plate boundaries

A **volcanic island** is not formed at a plate boundary. It forms as a result of narrow *mantle plumes* bringing material from deep within the lower mantle. The magma of both volcanic islands and mid-ocean ridges forms as hot, but solid rock moves closer to Earth's surface. As the hot rock rises, the pressure drops, and the rock melts, forming magma.

A volcanic island is born

The melted lower mantle material forms runny basalt magma that is less dense than the surrounding rock. The basalt magma melts its way through the lithospheric plate above it. An underwater volcano forms when the magma breaks through the surface of the plate. If the eruption is strong enough, the magma will reach the surface of the sea, forming a volcanic island.



Volcanic island chains

The plate on which a volcanic island sits is moving, but the mantle plumes stay in one place. The top of an established mantle plume is called a **hot spot**. As the plate moves, it carries the volcanic island away from the hot spot that formed it. Without the hot spot to supply magma, the volcano becomes extinct. At the same time, the hot spot begins to form a new volcano beside the old one (Figure 10.7). In this way, a **volcanic island chain** is formed.

VOCABULARY

volcanic island - a volcano that forms away from a plate boundary on an oceanic plate.

hot spot - the top of an established mantle plume.

volcanic island chain - a series of volcanoes formed by a hot spot as a lithospheric plate moves over the hot spot.

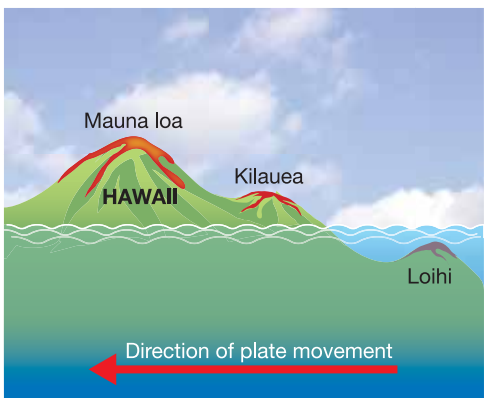


Figure 10.7: *The island of Hawaii sits on top of a hot spot. The hot spot has formed the Mauna Loa and Kilauea volcanoes on the island. Currently, the hot spot is making the undersea volcano Loihi to the southeast of the island. When Loihi gets bigger and reaches the ocean surface, it will increase the size of Hawaii.*

Using island chains to measure the motion of a plate

The Hawaiian Islands

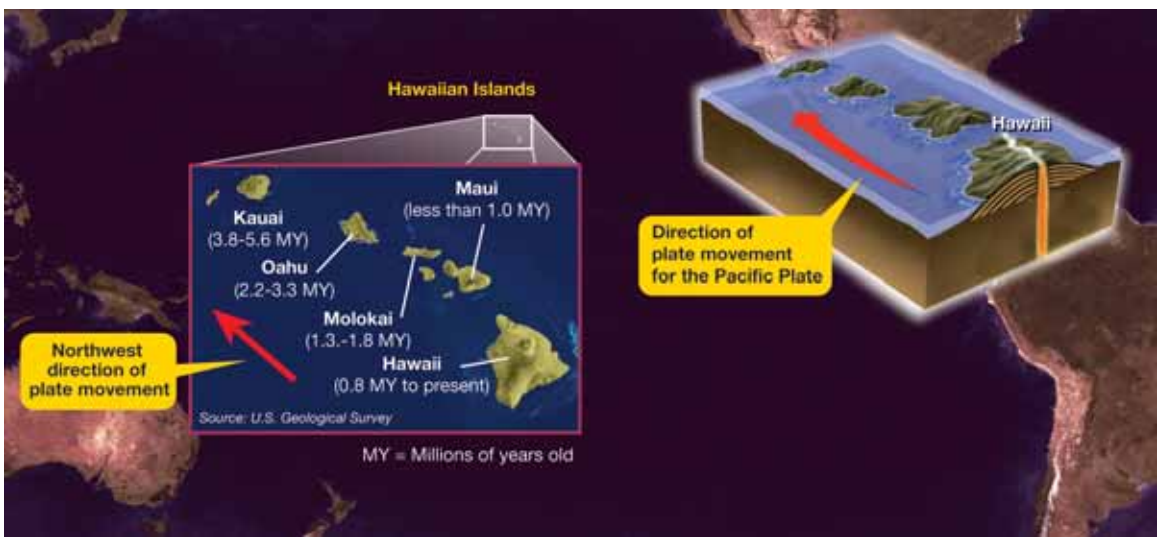
The Hawaiian Islands are an example of a volcanic island chain. The biggest island, Hawaii, is over the hot spot now and has active volcanoes. Hawaii has been on top of this hot spot for the last 800,000 years (0.8 million years). The islands to the northwest of Hawaii are older and their volcanoes are either dormant or extinct.

Island chains and the speed of plates

By studying the direction, age, and length of a volcanic chain, scientists can determine the direction and speed that a plate is moving. The Hawaiian Chain shows us that the Pacific Plate is moving northwest at nearly nine centimeters per year.

Adding to a volcanic island

To the southeast of the Hawaiian Chain, the mantle plume under Hawaii is making a new volcano—Loihi. Loihi is an undersea volcano (Figure 10.7). When enough lava builds up so that Loihi is above sea level, it will extend the eastern border of Hawaii!



Island arcs are features near plate boundaries

An island chain occurs on a lithospheric plate. For example, the Hawaiian Chain is in the middle of the Pacific Plate located away from the plate's boundaries.

In contrast, an *island arc* is a string of volcanic islands that forms close to a plate boundary. The island of Japan and neighboring islands are an island arc at the subduction zone where three plates come together.

Eventually, plate movements at a subduction zone bring the islands and continents together. In this way, continents grow larger! Scientists can detect where island arcs have increased the size of the North American continent on both the west and east coasts.

Volcanoes at subduction zones

What happens when a plate subducts?

A subducting plate bends and passes under a more buoyant, less dense plate. As the subducting plate sinks into the mantle, mud and water are carried along. As the plate sinks further, the water is released. Water combines with the hot mantle rock of the aesthenosphere (the part of the upper mantle just under the crust). The combination of water and hot mantle rock allows the rock to melt at a lower temperature. This magma is less dense than the surrounding rock so it rises. Eventually, the magma melts through the edge of the overlying plate forming a volcano (Figure 10.8).

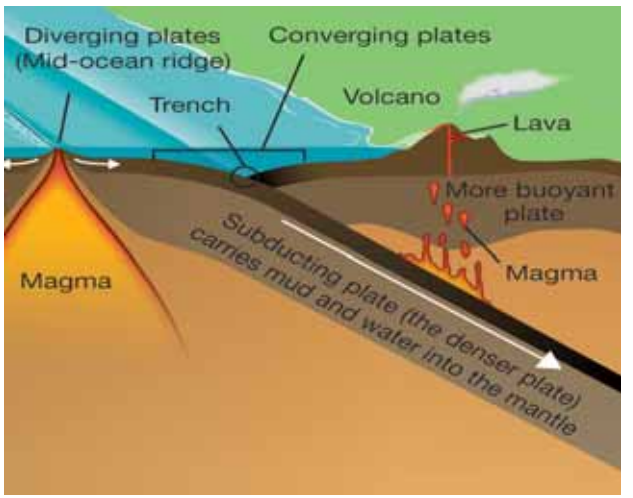


Figure 10.8: *Forming magma at a subduction zone.*

Thick and sticky magma

Through a complex process, the magma that forms volcanoes in this way is rich in silica. Silica-rich magma is light in color, thick, sticky, and less dense than basalt magma. When cooled, the silica-rich magma forms granite and other closely-related rocks.

The famous granite domes of Yosemite National Park in California were formed as silica-rich magma rose through the edge of the overlying North American Plate at a subduction zone that no longer exists. When subduction stopped, the flow of magma stopped too (Figure 10.9). The magma below the surface cooled where it was. The surrounding land later eroded away, exposing the granite domes.

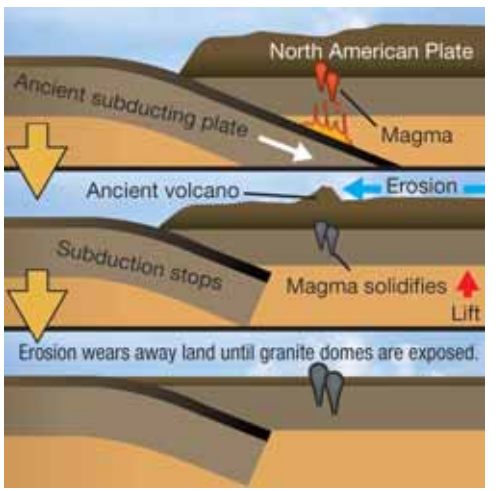


Figure 10.9: *Diagram of how the granite domes of Yosemite formed.*

Granite is silica-rich

Continents are made of granite (and andesite). Silica-rich granite is not as dense as the basalt of the ocean floor. This is why continental plates float high on the lower mantle. Because they float high, they stand above the oceans and provide us with dry land.

10.2 Section Review

1. What did early map makers notice about the locations of volcanoes?
2. What causes the region called the Ring of Fire?
3. If you could melt a piece of quartz in some lava, would the lava get more sticky or less sticky? Explain your answer.
4. Where is runny lava found: (a) On a continental plate, or (b) on an oceanic plate?
5. Where is thick and sticky lava found: (a) On a continental plate, or (b) on an oceanic plate?
6. When volcanic island chains are formed, what moves? Pick the correct answer:

a. the mantle plume
b. the plate above the mantle plume
c. both the plate and the plume
d. nothing moves

7. Which of the Hawaiian Islands formed first and how long ago did it form?
8. What kind of geologic formation is Loihi? Is it a part of the Hawaiian Chain? Explain your answer.
9. How have scientists figured out that the Pacific Plate is moving at about 9 centimeters per year?
10. The Pacific Plate is moving at 9 centimeters per year.
    a. How long will it take for this plate to travel 4.5 meters?
    b. How far will the plate have travelled in meters after 3 years?
11. What are the names of the items (A–C) on the graphic in Figure 10.10?
12. Name a difference between an island chain and an island arc.

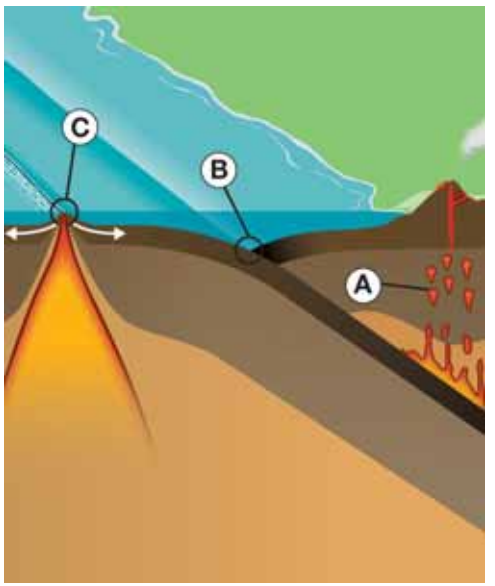


Figure 10.10: *Use this graphic to answer question 11.*

MY JOURNAL

Write an essay about your observations and experiences during a visit to a national park. Write about Yosemite National Park if you have been there. Or, write about another special park you have visited. In particular, write about the geology of the park. Include drawings, diagrams, and/or photographs with your essay.

10.3 Types of Volcanoes

Why do volcanoes come in different shapes? The shape of a volcano and its type of eruption depend on what kind of magma it has. In this section, you will learn about the different types of volcanoes and magma!

Types of magma

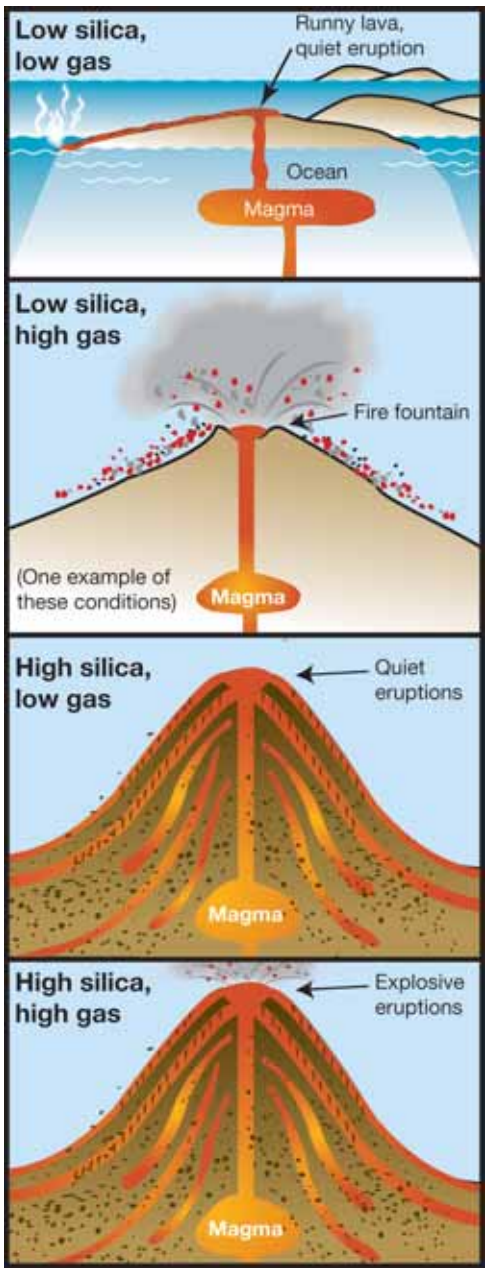
Silica in magma Remember, an important property of magma is how much silica it has. One kind of magma has little silica and the other has a lot of silica. Magma with little silica makes runny magma. Magma with a lot of silica makes thick, sticky magma.

Dissolved gas in magma Another important property of magma is how much gas is dissolved in it. Little dissolved gas makes magma that doesn't have bubbles. This magma is "flat"—like soda that has lost its fizz. Magma with a lot of dissolved gas is like soda before you open it. It can be bubbly or, under the right conditions, it can explode out just like when you open a shaken bottle of soda.

Volcanic eruptions The nature of a volcanic eruption depends on what kind of magma is in the volcano. Study the table below and the graphic at the right to see the kinds of eruptions that occur with each kind of magma.

Table 10.1: Comparing magma.

	Low gas content	High gas content
Low silica content	• Runny magma, like syrup	• Runny magma, bubbly
	• Quiet eruption, lava flows easily	• Fire fountain, lava flows easily
High silica content	• Thick, sticky magma	• Thick, sticky magma
	• Quiet eruption	• Explosive eruption



Volcanoes with low silica magma

Shield volcanoes

Low silica magma produces a **shield volcano**. This magma can either have low or high levels of dissolved gas. Because low silica magma is runny, it can't build up a tall, cone-shaped volcano. Instead, this magma produces a volcano that is a flattened mound—it resembles a warrior's shield lying on the ground. The volcanoes of the Hawaiian Islands are shield volcanoes. If you have ever visited the Hawaiian volcanoes, you know that they are not explosive.

Fire fountains

When low silica magma has high levels of dissolved gas, the gas bubbles out as it reaches the volcano vent. The effect is identical to shaking a soda bottle to produce a shower of soda. The high-gas magma produces a spectacular *fire fountain* (Figure 10.11). The spatters of glowing magma cool in the air and hit the ground as solid lava cinders.

Cinder cones

The lava cinders form a cone around the vent called a **cinder cone**. Cinder cones are a common form of volcano. They are often found on the flanks of both shield volcanoes and composite volcanoes (see the next page). Cinder cones may also form in the caldera of dormant volcanoes. Cinder cones are structurally weak because they are simply a pile of rock bits.

VOCABULARY

shield volcano - a flat and wide volcano that has low-silica magma with low or high levels of dissolved gas.

cinder cone - a volcano that has low-silica magma with high levels of dissolved gas; these volcanoes produce "fire fountain" eruptions.

Figure 10.11: *A fire fountain in Hawaii Volcanoes National Park. 1972–1974 eruption of the Kilauea Volcano.*

Volcanoes with high silica magma

Composite volcanoes

Island arcs and most coastal volcanoes are created at subduction zones. The magma of these volcanoes is thick and sticky because it is silica-rich. Over time, layers of this thick lava and ash build a tall cone called a **composite volcano** (Figure 10.12).

Dissolved gas in sticky magma

When silica-rich magma is low in dissolved gas, the magma will come out like toothpaste and form volcanic glass, called obsidian. But if the silica-rich magma contains high levels of dissolved gas, pressure usually builds inside the volcano. The magma of shield volcanoes is so runny that dissolved gas simply bubbles out. But silica-rich magma is too sticky. Before a composite volcano eruption, the magma may be under so much gas pressure that the composite volcano cone bulges (middle image, Figure 10.12).

Pumice and ash

When a composite volcano cone bulges like this, either the eruption will subside and the magma will return down the conduit, or the cone will explode. The cone may explode near the vent, throwing a column of gas and lava bits high into the atmosphere. The lava bits puff up and rip apart as the dissolved gas expands inside each bit. This puffing up action produces two forms of rock: pumice and ash. *Pumice* is a dark rock with lots of holes. Pumice has a low density because of its holes (which were made by air bubbles) and will float in water. *Ash* is smaller, like fine sand. Because ash is so fine, it drifts with the wind and may settle over a very wide area.

VOCABULARY

composite volcano - a tall, explosive, cone-shaped volcano formed by layers of silica-rich lava and ash.

Figure 10.12: *Mount St. Helens, a composite volcano, before and after an explosive eruption.*

Explosive eruptions

Pyroclastic flows When a column of exploding material collapses, it races down the side of a composite volcano as a **pyroclastic flow**. The speed (more than a 100 km/h), force, and heat (greater than 500 °C) of the pyroclastic flow make it extremely destructive.

Lava bombs Blobs of glowing lava may be thrown far from the base of the composite volcano. These blobs, called **lava bombs**, can be the size of watermelons. Sometimes the composite volcano explodes again, further down its side, adding more material to the expanding lava explosion.

Lahars Mount Saint Helens erupted in Washington State in 1980. This was a classic silica-rich, gas-rich composite volcano eruption. Magma pressure formed a large bulge on the side of the mountain. The eruption was triggered when a portion of the bulge slid off. This created a weakness in the cone that was containing the pressure. An enormous explosion blew off a huge part of the mountain. The combination of landslide, explosion, and pyroclastic flow killed 57 people. If water is present in the ground, mudflows may accompany a composite volcano eruption like this. The mudflows, called **lahars** (Figure 10.13), in this eruption destroyed forests and property and added to the death toll.

VOCABULARY

pyroclastic flow - a destructive cloud of volcanic material that moves quickly down the side of a volcano after an explosive eruption.

lava bombs - blobs of glowing lava thrown from an explosive eruption.

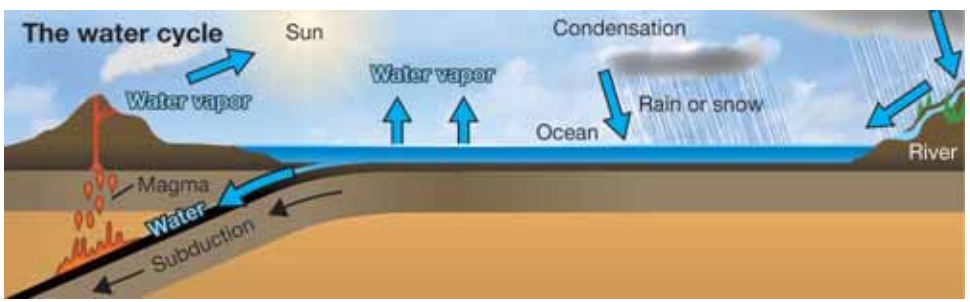
lahars - a mudflow that results from a volcanic eruption.

Figure 10.13: *An example of a lahar, a mudflow that results from pyroclastic flow mixing with water and mud.*

Water and volcanoes

Volcanoes are part of the water cycle

Volcanoes are part of Earth's water cycle. The **water cycle** is a set of processes that keep water moving from place to place. When a volcano erupts, water that is in the magma is released as water vapor into the atmosphere. This water vapor condenses and falls into the ocean as rain. Or, the rain may fall on land and eventually get deposited into the ocean by rivers or streams. Recall that when rivers and streams are swollen by rain, they are able to carry sediments and rocks into the ocean. In this way, the water cycle is connected to Earth's **geological cycle**, a set of processes that keep rocky material moving from place to place in and on Earth.



Water in volcanoes

In Section 10.1, you learned that water is important for making magma. Water combines with hot rock when a subducting plate sinks into the mantle. The combination of water and hot mantle rock has a lower melting temperature and the mantle rock melts, forming magma. This magma rises forming a volcano.

Geysers and hot springs

You learned about geysers and hot springs in Chapter 4. These volcanic features are the result of water in the ground coming in contact with magma-heated rock below the surface. The hot rock heats the water. Whether a geyser or a hot spring forms depends on the temperature of the rock, the amount of water present, and the shape of the water passage. Water that evaporates from a geyser or hot spring also becomes part of the water cycle (Figure 10.14).

VOCABULARY

water cycle - a set of processes energized by the Sun that keep water moving from place to place on Earth.

geologic cycle - a set of processes that keep rocky material moving from place to place on Earth.

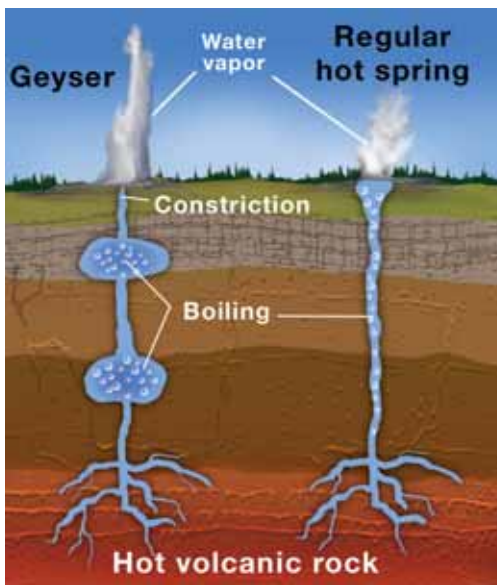


Figure 10.14: *A diagram of a geyser and a hot spring.*

10.3 Section Review

1. What two ingredients in magma affect the type of explosion and shape of a volcano?
2. Under what conditions will magma be very thick and sticky?
3. Describe what a shield volcano's eruption is like. Then, describe a composite volcano's eruption.
4. Compare and contrast pumice, obsidian, and ash.
5. For each of the following statements, indicate which volcano is being described:
   a. a cone composed of layers
   b. forms in calderas
   c. forms from a buildup of lava on the ocean floor

Table 10.2: Summary of types of magma and eruptions associated with various volcano types

	Low gas content	High gas content
Low silica content	• Runny magma, like syrup	• Runny magma, bubbles at vent
	• Quiet eruption, lava flows easily	• Fire fountain at vent, flows away easily
	• Forms shield volcanoes	• Forms shield volcanoes and cinder cones
	• Forms basalt and gabbro rocks	• Forms basalt and gabbro rocks
High silica content	• Thick, sticky magma	• Thick, sticky magma
	• Quiet eruption, lava forms piles	• Explosive eruption, pyroclastic flow, lava bombs
	• Forms composite volcanoes	• Forms composite volcanoes
	• Forms obsidian rock	• Forms granite, andesite, pumice, and scoria rocks

Keeping up with explosive terms

How can you remember volcanic terms? It helps if you find fun facts about the terms.

For example...

Another name for a composite volcano is stratovolcano. Look up the meaning of the word "stratum."

What characteristic of this kind of volcano do both of these names—composite and stratovolcano—refer to?

Look up the word "lahar." From which language does it come? Is your region likely to have mudflows? Why or why not?

Pick three terms from this chapter. Find fun facts about each term. Write each term and facts about it on an index card.

10.4 Igneous Rocks

Rocks formed from magma or lava are called **igneous rocks**. The kind of igneous rock depends on the type of magma and the conditions under which it cooled.

Types of igneous rocks

Crystals are tightly locked together

Igneous rocks are formed as melted rock cools and crystallizes. A characteristic of igneous rocks is that their crystals are tightly locked together. Melted rock that cools quickly produces small crystals. Slow cooling produces larger crystals.

Crystal size

Crystal size can tell us a lot about how a rock formed. Underground magma cools slowly and produces large crystals. On Earth's surface, magma (lava) cools quickly and produces small crystals.

Basalt versus gabbro

Basalt and *gabbro* are made from the same silica-poor basalt magma. Basalt has fine crystals, but gabbro has large crystals. Can you tell where these rocks formed? You are correct if you thought that basalt is a surface-formed rock and gabbro is formed below Earth's surface.

Granite, rhyolite, and obsidian

Granite, *rhyolite*, and *obsidian* (Figure 10.15) all come from the same silica-rich magma. Granite cools underground and has large crystals. Rhyolite cools on the surface and has fine crystals. Obsidian cools so fast that it has no crystals. Obsidian is often called volcanic glass.

Basalt, granite, and Earth's crust

You learned about the main rock types making up Earth's crust—basalt and granite—in Chapter 7. *Basalt* is the rock that makes up oceanic plates and is more dense than granite. Basalt, as you just learned, has fine crystals and is made from low-silica magma. **Granite** makes up continental plates. It is less dense than basalt, is made of high-silica magma, and has large crystals.

VOCABULARY

igneous rocks - rocks that are formed from magma or lava.

granite - a light-colored igneous rock with large, visible quartz and feldspar crystals made from silica-rich magma.

Figure 10.15: *Obsidian is often called volcanic glass. Obsidian cools so quickly that it lacks crystals.*

How gas in magma affects igneous rocks

You have learned that silica makes magma thick and sticky. Silica also prevents dissolved gas from escaping easily. The same magma that produces granite, rhyolite, and obsidian can also produce pumice. The difference is that the gas in the magma puffs up before the pumice cools to a solid. Pumice is so light due to the trapped bubbles that it floats. At the bottom of the page is an image of a pumice mine (located near a volcano) where pumice is harvested to make abrasive cleaning products.

Scoria is another gas-puffed rock. Scoria may be made of silica-poor basalt magma or silica-rich granite magma. Scoria has a heavier, more crystalline texture than pumice.

Welded tuff

The pyroclastic flow from a composite volcano eruption may form a thick layer of hot cinders and ash. This layer is so hot that the pieces become welded together. At first, there may be holes between the pieces. But as the layer gets thicker, the holes become flattened. This type of rock, called *welded tuff,* is often orange-tan in color with small, flat streaks of obsidian in it (Figure 10.16).

Figure 10.16: *This is a photograph of welded tuff. The spaces made by gas bubbles have been flattened by the weight of material that pressed down while the tuff was still forming.*

10.4 Section Review

1. Describe two characteristics of an igneous rock.
2. If lava on Earth's surface cools very quickly, will the crystals in the resulting igneous rock be small or large?
3. Which of the following pieces of information can you learn by looking at an igneous rock. List all correct answers.

a. how old it is	b. how fast it cooled
c. how much it weighs	d. whether it formed above ground or under ground
e. how long it will take to metamorphose	f. what time of day it formed

4. How is gabbro similar to granite?
5. Make a table that compares and contrasts basalt and granite.
6. Granite, rhyolite, and obsidian are shown in Figure 10.17. Determine which photograph represents each rock.
7. You want to take a vacation to a place where you could find igneous rocks. To which of these places would you go? Justify your answer. Note: You could find igneous rocks at any of these places.

a. Niagara Falls	b. Las Vegas
c. The Hawaiian Islands	d. Your own backyard

8. The Mid-Atlantic Ridge goes through the country of Iceland. Would you expect to find igneous rocks in Iceland? Explain your answer.

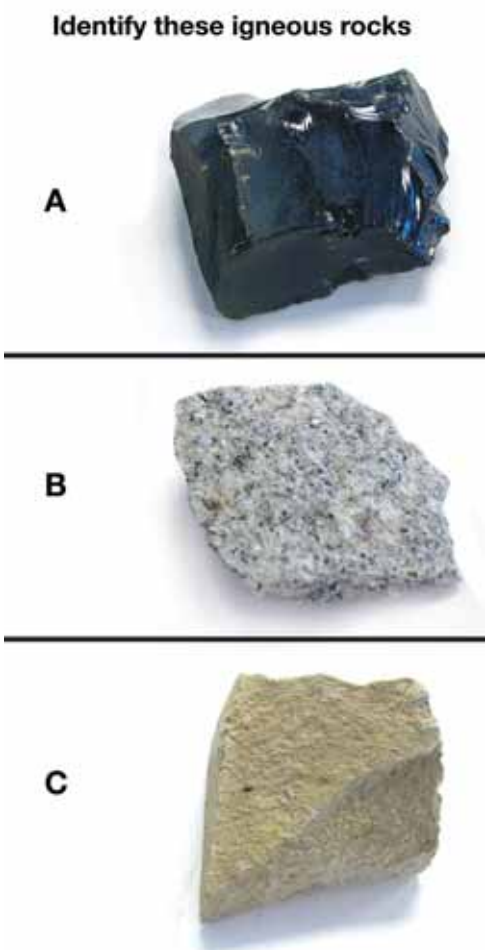


Figure 10.17: *Use this graphic to answer question 6.*

GEOLOGY CONNECTION

Western Region Volcanoes

Streams of molten lava, rocks glowing fiery red inside, steam spewing from a mountaintop—does this sound like a volcano you could see in Hawaii? It is true that Hawaii has some picturesque and spectacular volcanoes, but there are many volcanoes on the mainland of the United States too.

Why do some regions of the world have volcanoes while others do not? Volcanoes typically happen along the boundaries of the Earth's massive tectonic plates. The plates move and shift, creating both volcanoes and earthquakes. Volcanoes may also occur in the middle of plates or sometimes over places called "hot spots."

In the recorded history of Earth, more than 500 volcanoes have erupted. In the United States, 50 volcanoes have erupted. The three countries with the most active volcanoes are Indonesia, Japan, and the United States. Around the rim of the Pacific Ocean, also called the Ring of Fire, there are more than 1,000 volcanoes.

Ring of Fire

The western part of United States is in this Pacific Ring of Fire. Alaska, Washington, Oregon, and California all have volcanoes in the ring. Not including Alaska and Hawaii, there are 40 volcanoes in the United States, and you might recognize some of these famous ones out West.

Washington's big five

There are five major volcanoes, called composite volcanoes, in Washington. These steep-sided conical volcanoes are, from north to south, Mount Baker, Glacier Peak, Mount Rainier, Mount St. Helens, and Mount Adams, and with Mount Hood in Oregon, they are part of the Cascade Range, a volcanic arch that stretches from British Columbia to California.

Mount Rainier, at 14,411 feet (4,392 meters), is Washington's highest mountain. Its most recent eruption was in the early 1800s. Located near Seattle, it is closely monitored for activity. Approximately 30 earthquakes occur under Mount Rainier each year, making it a very earthquake active area. In 1899, Mount Rainier became the country's fifth national park.

Mount St. Helens erupting in 1980

Nearby stands another famous volcano: Mount St. Helens. It had been quiet for over 100 years until on the morning of May 18, 1980, it erupted violently for nine hours. A magnitude 5.1 earthquake kicked off the huge explosion. In just minutes, the 9,677-foot-high mountain collapsed, reduced 1,200 feet by the explosion and mammoth landslide. So much ash was released that the sky got dark. Recently, Mount St. Helens has erupted again. Scientists view each eruption as a chance to learn more about volcanoes.

Oregon's user-friendly Mount Hood

Moving south along the Cascades, you come to Mount Hood, 11,239 feet high and Oregon's highest peak. The last big eruptions took place 200 and 1,500 years ago. Mount Hood is one of the most climbed peaks in the Pacific Northwest. At 6,000 feet you find the famous Timberline Lodge, built in 1938 and where scenes from *The Shining*, the 1980 movie based on the Stephen King novel, were shot. The slopes of the volcano are used almost year-round for skiing and snowboarding. The nearby ski area is known for having the longest ski season in the United States.

California's hot spots

When you think of California, you typically think of perfect weather, golden beaches, and great surf. But the Golden State is also home to several volcanoes. Active or possibly active volcanoes include Black Butte, Lassen Peak, Long Valley Caldera, Medicine Lake, and Mount Shasta.

Still part of the Cascades, and one of the world's largest composite volcanoes (14,161 feet), Mount Shasta is located 265 miles north of San Francisco. The most recent eruption is thought to have occurred in 1786. The mountain is part of the Shasta-Trinity National Forest, the largest national forest in California.

In east-central California, the Long Valley Caldera stands along the east side of the Sierra Nevada. Rocks formed in the past 2 million years from volcanic eruptions cover most of the area.

Our tour comes to an end south of both Shasta and Medicine Lake at Lassen Peak, the baby of the Cascades, one of the youngest of the major volcanoes in those mountains.

Cascades Volcano Observatory

After the eruption of Mount St. Helens, the U.S. Geological Survey created the Cascades Volcano Observatory (CVO). CVO monitors volcanoes and related dangers such as earthquakes and landslides. Thousands of visitors are attracted each year to the spectacular volcanic scenery of the Cascades, but they should not forget the mountains' potential hazards and how they are monitored.

Questions:

1. Why does the Cascade Range have so many volcanoes?
2. Identify and describe two mainland U.S. volcanoes that erupted in the 20th century?
3. What benefits resulted from the eruption of Mount St. Helens?

CHAPTER ACTIVITY

The Geological Cycle

The geological cycle is a set of processes that keep rocky material moving from place to place on Earth.

The processes that keep rock material moving through the geologic cycle are:

- weathering of mountains, volcanoes, and rocks into sediments by the water cycle,
- transport, layering, and compaction of sediments to form sedimentary rocks (you will learn about sedimentary rocks in Chapter 11),
- melting of rocks in the mantle when subduction occurs,
- crystallizing of magma and lava to form igneous rocks,
- metamorphism to form metamorphic rocks, and
- the formation of mountains when two continental plates come together.

Plate tectonics plays an important role in the geological cycle. Rocks melt or metamorphose when they are subducted into the mantle. The coming together of tectonic plates creates mountains. Were it not for mountain building, the weathering of rocks over time would leave the continents smooth and flattened.

The combined influence of the Sun's energy and the water cycle weather (wear down) mountains and rocks. *Weathering* is the process of breaking down rocks.

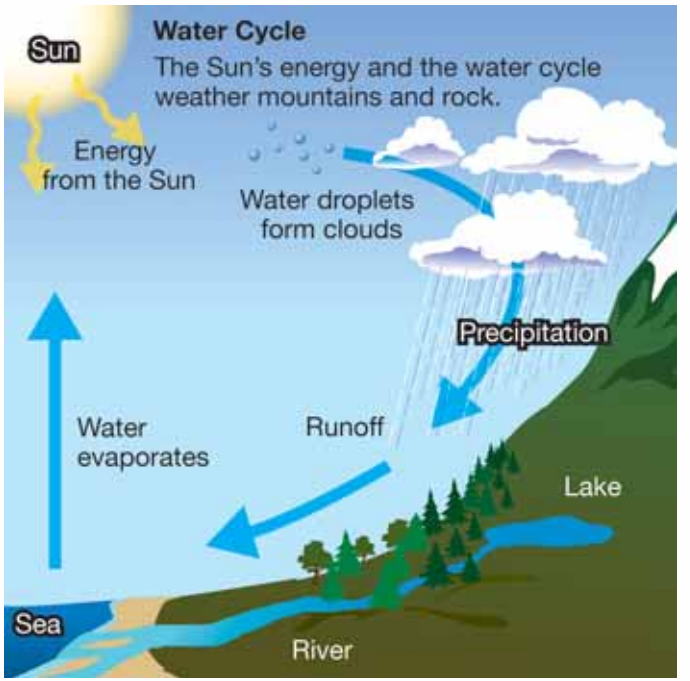
It takes millions of years for one cycle of the geologic cycle to be completed.

What you will do

1. With a partner or group, create a diagram that shows all the parts of the geological cycle.
2. In your diagram, include all the processes listed above in the blue box in your diagram.
3. You may need to make a large sketch to figure out how all the parts work together. Then, make a final version of your diagram in color.

Applying your knowledge

a. What would Earth's surface look like over a long time if mountains stopped being formed?
b. Would the geological cycle work without the Sun? Why or why not?
c. Look around your yard at home or around your school yard. Do you see evidence of the geological cycle at work? Explain your answer.



Chapter 10 Assessment

Vocabulary

Select the correct term to complete the sentences. NOTE: Not all terms will be used.

volcano	geological cycle	magma	pyroclastic flow	Ring of Fire
cinder cone	lava	extinct volcano	shield volcanoes	composite volcano
dormant volcano	magma chamber	volcanic neck	active volcano	volcanic island
resurgent dome	igneous rock	basalt	caldera	hot spot
lava lake	dormant volcano	silica	volcanic neck	volcanic island chain
lava bombs	lahars	pyroclastic flow	obsidian	water cycle

Section 10.1

1. The products of an eruption can build a mountainous _____.
2. _____ is magma that has reached and cooled on Earth's surface.
3. A _____ is a place where magma collects underground.
4. A bowl-shaped volcanic feature is a _____.
5. A _____ is a volcanic feature that occurs when water fills a caldera and lava oozes into the water.
6. A _____ occurs when a mound of magma forms on the floor of a caldera.
7. A(n) _____ is a volcano that is erupting or that has erupted recently.

Section 10.2

8. The _____ is a region where about half of the active surface volcanoes on Earth occur.
9. _____ makes magma thick and sticky.
10. A volcanic island forms over a(n) _____.

Section 10.3 and Section 10.4

11. A _____ can form on the sides of either a shield volcano or a composite volcano.
12. After an explosive eruption, a _____ moves quickly down the side of a volcano and can cause a great deal of destruction.
13. Water released from a volcanic eruption can become part of _____, an important cycle energized by the Sun.
14. Low gas, high silica magma forms _____ rocks.
15. High gas, low silica magma forms _____ rocks.

Concepts

Section 10.1

1. What is the difference between a conduit and a vent on a volcano?
2. Describe the three phases of the lifetime of a volcano.
3. Is the material that forms a volcanic neck considered to be solidified magma or lava? Explain your answer.
4. How are pressure and heat involved in melting rock in the mantle?

Section 10.2

5. What is the Ring of Fire? About how much of Earth's volcanic activity is found there?

6. Mount St. Helens formed at what kind of plate boundary?

a. a subduction zone	b. a transform plate boundary
c. a divergent plate boundary	c. where two continental plates came together

7. How is pressure involved in melting mantle material at a mid-ocean ridge?
8. How does plate tectonics cause volcanic islands to form in chain?
9. What volcanic land feature has helped the east and west coast of North America grow bigger?
10. Describe how the granite domes of Yosemite National Park were formed.

Section 10.3

11. Describe the magma of fire fountain eruptions in terms of silica and gas content.
12. Explain how a shield volcano differs from a composite volcano.
13. Where do composite volcanoes tend to be found?

a. a subduction zone	b. a transform plate boundary
c. a divergent plate boundary	c. where two continental plates came together

14. The Hawaiian Islands are what type of volcano? What causes these volcanoes to form?
15. Volcanoes found near subduction zones have:
    a. magma with high silica content
    b. an explosive eruption
    c. large amounts of gas released during the eruption
    d. All of the above
16. What is the difference between a pyroclastic flow and a lahar?

Section 10.4

17. How do igneous rocks form?
18. What about the appearance of an igneous rock gives you a clue about whether it cooled slowly or quickly?

Math and Writing Skills

Section 10.1

1. Mount Kilimanjaro in Tanzania is Africa's highest mountain and a controversial volcano. Research this volcano to find out whether experts think it is extinct, dormant, or active. Write your findings in a short paragraph.

Section 10.2

2. This image shows Hot Creek, a stream that is heated by volcanic activity below the surface. This creek is associated with the Long Valley Caldera in eastern California. The heat in the water is uneven. Some places are cool, but places where hot springs feed into the creek are so hot that you would be scalded. Nevertheless, the creek has fish! Research Hot Creek and describe what causes it to be hot.

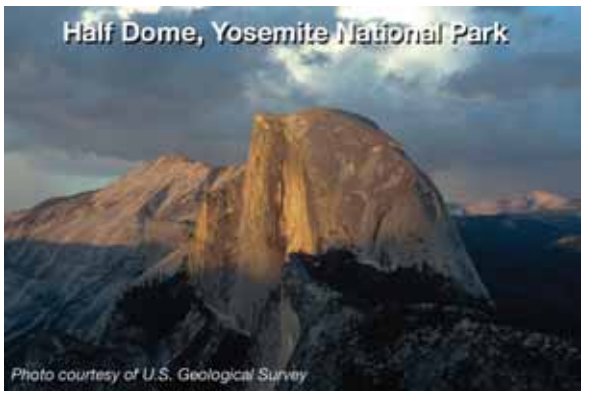
3. Volcanic activity occurs at convergent and divergent plate boundaries. Why do you think this is?
4. A volcanologist finds that the silica content of the volcanic rock near an ancient volcano is high. From this information, describe the probable type of volcano and its eruption. Where might the volcano be located?

Section 10.3

5. The speed of a pyroclastic flow is 100 km/h. How far would this flow travel in 10 minutes?
6. How do volcanoes participate in Earth's water cycle?
7. What role does water play in the geological cycle?

Section 10.4

8. Pumice is mined and used in commercial cleaning products as an abrasive. Research pumice and find out more about its uses.
9. In Yosemite National Park there is a large granite formation called Half Dome. The distance from the bottom of the valley to the top of Half Dome is 1 kilometer. The top of Half Dome is rounded instead of peaked the way most mountains look. How do you think Half Dome formed? To develop a hypothesis, answer the following questions.
   a. What kind of rock is granite?
   b. Did Half Dome form as a result of a volcanic eruption? Did it form as a result of two continents pushing against each other?
   c. Why might Half Dome be rounded?
   d. Develop a hypothesis about Half Dome: In your opinion, how did this rock formation form?
   e. Extension: Now research the geology of Half Dome on the Internet or in your local library. How did it form? Compare your research findings with your hypothesis.



10. Write a story about the formation of igneous rocks in the rock cycle. Pretend you are the igneous rock being formed, and include as many other fictitious characters as possible.

Chapter Project—Eye-witness Account

Choose a famous volcanic eruption that has happened in the past and research the eruption. Visit the United States Geological Survey web site to find out about present day and past volcanic eruptions (www.usgs.gov).

Write a letter to a local newspaper from the point of view of an eye-witness who survived the eruption. In your letter include details about what happened before, during, and after the eruption. You should include the type of volcano, the type of lava you witnessed during the eruption. Also, include information about the damage and destruction caused by the volcano. Finally, your letter should include the environmental impact that the eruption had. How far around the world was the impact felt? In order to capture the readers attention make your letter as personal and captivating as possible. Include pictures or drawings of the volcano before, during, and after the eruption.