

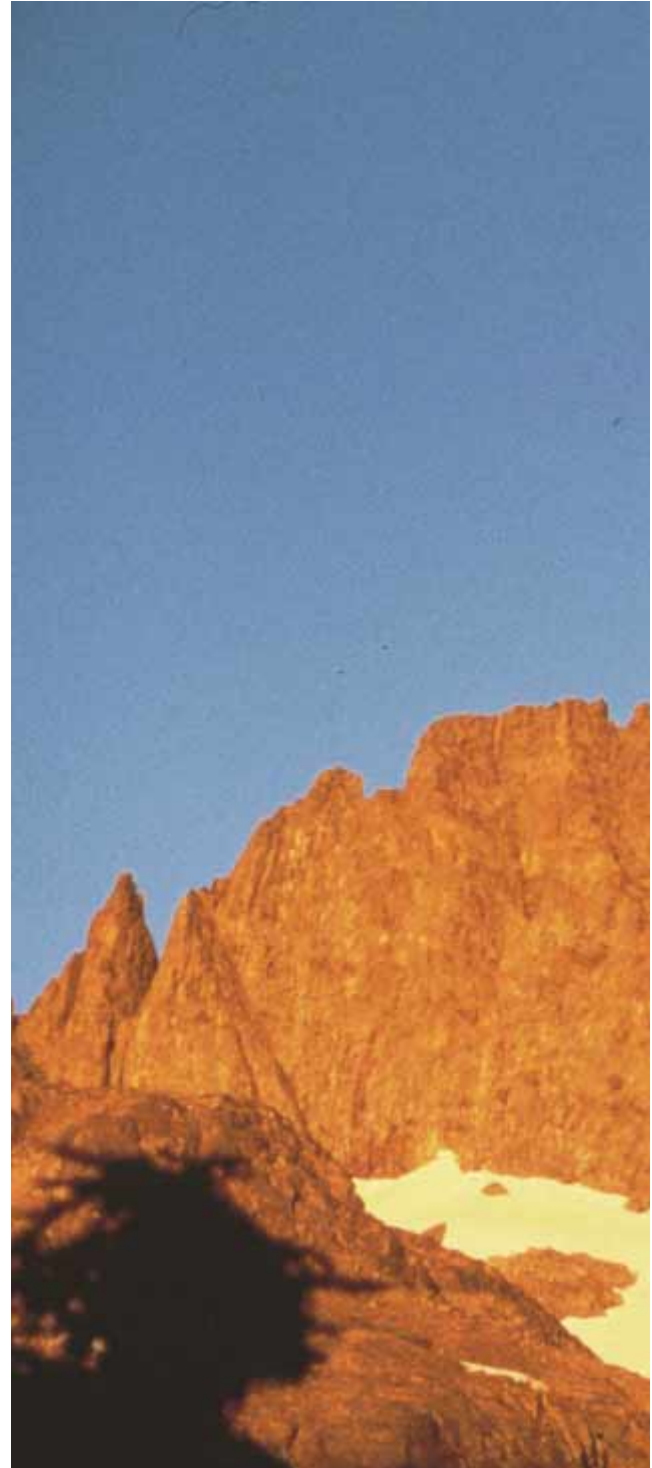
## CHAPTER

# 4

## Igneous Rocks

The Earth is almost entirely rock to a depth of 2900 kilometers, where the solid mantle gives way to the liquid outer core. Even casual observation reveals that rocks are not all alike. The great peaks of the Sierra Nevada in California are hard, strong granite. The red cliffs of the Utah desert are soft sandstone. The top of Mount Everest is limestone, composed of clamshells and the remains of other small marine animals.

The marine fossils of Mount Everest tell us that the limestone formed in the sea. What forces lifted the rock to the highest point of the Himalayas? Where did the vast amounts of sand in the Utah sandstone come from? How did the granite of the Sierra Nevada form? All of these questions ask about the processes that formed the rocks and about the events that moved and shaped them throughout geologic history. In the following five chapters, we will study rocks: how they form and what they are made of. In later chapters we will use our understanding of rocks to interpret the Earth's geologic history.



The Minaret Peaks in the eastern Sierra are composed of volcanic rocks.



## ► 4.1 ROCKS AND THE ROCK CYCLE

Geologists group rocks into three categories on the basis of how they form: **igneous rocks**, **sedimentary rocks**, and **metamorphic rocks**.

Under certain conditions, rocks of the upper mantle and lower crust melt, forming a hot liquid called **magma** (Fig. 4-1). An igneous rock forms when magma solidifies. About 95 percent of the Earth's crust consists of igneous rock and metamorphosed igneous rock. Although much of this igneous foundation is buried by a relatively thin layer of sedimentary rock, igneous rocks are conspicuous because they make up some of the world's most spectacular mountains. **Granite** and **basalt** are two common and familiar igneous rocks (Fig. 4-2).

Rocks of all kinds decompose, or weather, at the Earth's surface. Weathering breaks rocks into smaller

fragments such as gravel, sand, and clay. At the same time, rainwater may dissolve some of the rock. Streams, wind, glaciers, and gravity then erode the weathered particles, carry them downhill, and deposit them at lower elevations. All such particles, formed by weathering and then eroded, transported, and deposited in layers, are called sediment. The sand on a beach and mud on a mud flat are examples of sediment that accumulated by these processes.

A sedimentary rock forms when sediment becomes cemented or compacted into solid rock. When the beach sand is cemented, it becomes **sandstone**; the mud becomes **shale**. Sedimentary rocks make up less than 5 percent of the Earth's crust. However, because sediment accumulates on the Earth's surface, sedimentary rocks form a thin layer over about 80 percent of all land. For this reason, sedimentary rocks seem more abundant than they really are (Fig. 4-3).

A metamorphic rock forms when any preexisting rock is altered by heating, increased pressure, or tectonic deformation. Tectonic processes can depress the Earth's surface to form a basin that may be hundreds of kilometers in diameter and thousands of meters deep. Sediment accumulates in the depression, burying the lowermost layers to great depths. When a rock is buried, its temperature and pressure increase, causing changes in both the minerals and the texture of the rock. These changes are called metamorphism, and the rock formed by these processes is a metamorphic rock. Metamorphism also occurs when magma heats nearby rock, or when tectonic forces deform rocks (Fig. 4-4). Schist, gneiss, and marble are common metamorphic rocks.

No rock is permanent over geologic time; instead, all rocks change slowly from one of the three rock types to another. This continuous process is called the **rock**



**Figure 4-1** Magma rises from Pu'u O'o vent during an eruption in June 1986. (U.S. Geological Survey, J. D. Griggs)



**Figure 4-2** The peaks of Sam Ford Fiord, Baffin Island, are part of a large granite pluton.





**Figure 4-3** Sedimentary layers of sandstone and coal form steep cliffs near Bryce, Utah.

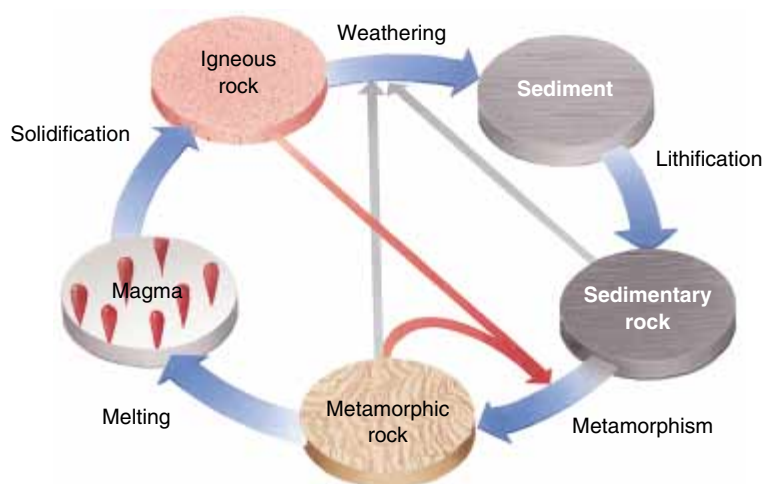


**Figure 4-4** Metamorphic rocks are commonly contorted as a result of tectonic forces that deform them.

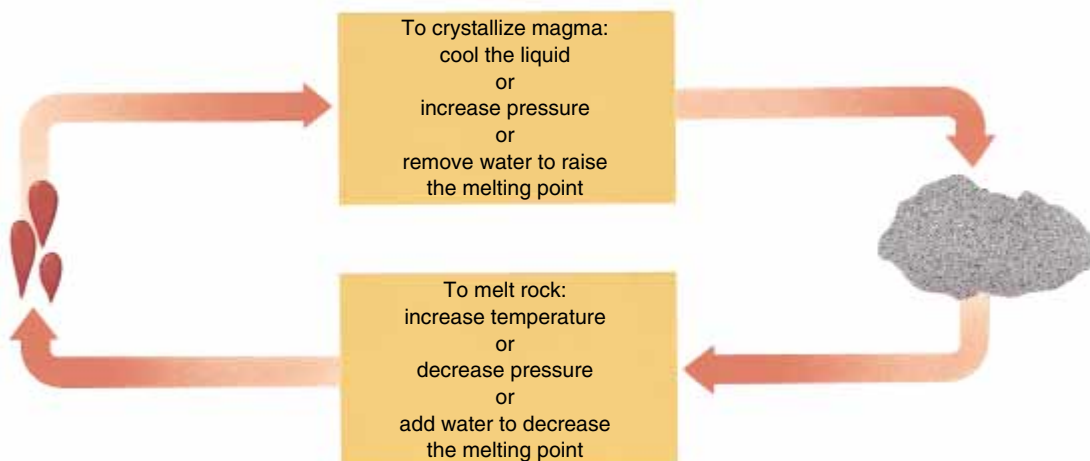
which then becomes cemented to form a sedimentary rock. An igneous rock may be metamorphosed. The rock cycle simply expresses the idea that rock is not permanent but changes over geologic time.

## ► 4.2 IGNEOUS ROCKS: THE ORIGINS OF MAGMA

If you drilled a well deep into the crust, you would find that Earth temperature rises about 30°C for every kilometer of depth. Below the crust, temperature continues to rise, but not as rapidly. In the asthenosphere (between depths of about 100 to 350 kilometers), the temperature



**Figure 4-5** The rock cycle shows that rocks change continuously over geologic time. The arrows show paths that rocks can follow as they change.



**Figure 4-6** The lower box shows that increasing temperature, addition of water, and decreasing pressure all melt rock to form magma. The upper box shows that cooling, increasing pressure, and water loss all solidify magma to form an igneous rock.

is so high that rocks melt in certain environments to form magma.

### PROCESSES THAT FORM MAGMA

Three different processes melt the asthenosphere: rising temperature, decreasing pressure, and addition of water (Fig. 4-6). We will consider these processes and then look at the tectonic environments in which they generate magma.

#### *Rising Temperature*

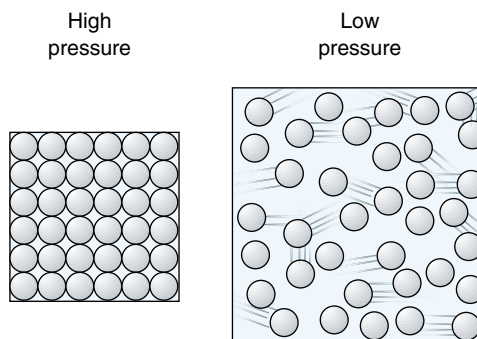
Everyone knows that a solid melts when it becomes hot enough. Butter melts in a frying pan, and snow melts under the spring sun. For similar reasons, an increase in temperature will melt a hot rock. Oddly, however, increasing temperature is the least important cause of magma formation in the asthenosphere.

#### *Decreasing Pressure*

A mineral is composed of an ordered array of atoms bonded together. When a mineral melts, the atoms become disordered and move freely, taking up more space than when they were in the solid mineral. Consequently, magma occupies about 10 percent more volume than the rock that melted to form it. As an analogy, think of a crowd of people sitting in an auditorium listening to a concert. At first, they sit in closely packed, orderly rows. But if everyone gets up to dance, they need more room

because spaces open up between the dancers as they move.

If a rock is heated to its melting point on the Earth's surface, it melts readily because there is little pressure to keep it from expanding. The temperature in the asthenosphere is more than hot enough to melt rock, but there, the high pressure prevents the rock from expanding, and it cannot melt (Fig. 4-7). However, if the pressure were to decrease, large volumes of the asthenosphere would melt. Melting caused by decreasing pressure is called **pressure-release melting**. In the section entitled "Environments of Magma Formation" we will see how certain tectonic processes decrease pressure on parts



**Figure 4-7** When most minerals melt, the volume increases. If a deeply buried mineral is near its melting point, high pressure prevents expansion and it doesn't melt. If the pressure decreases, the mineral can expand more easily and it melts, even though the temperature remains constant.

of the asthenosphere and cause large-scale melting and magma formation.

### Addition of Water

A wet rock generally melts at a lower temperature than an otherwise identical dry rock. Thus, addition of water to rock that is near its melting temperature can melt the rock. Certain tectonic processes add water to the hot rock of the asthenosphere to form magma.

## ENVIRONMENTS OF MAGMA FORMATION

Magma forms in three tectonic environments: spreading centers, mantle plumes, and subduction zones. Let us consider each environment to see how the three aforementioned processes melt the asthenosphere to create magma.

### Magma Production in a Spreading Center

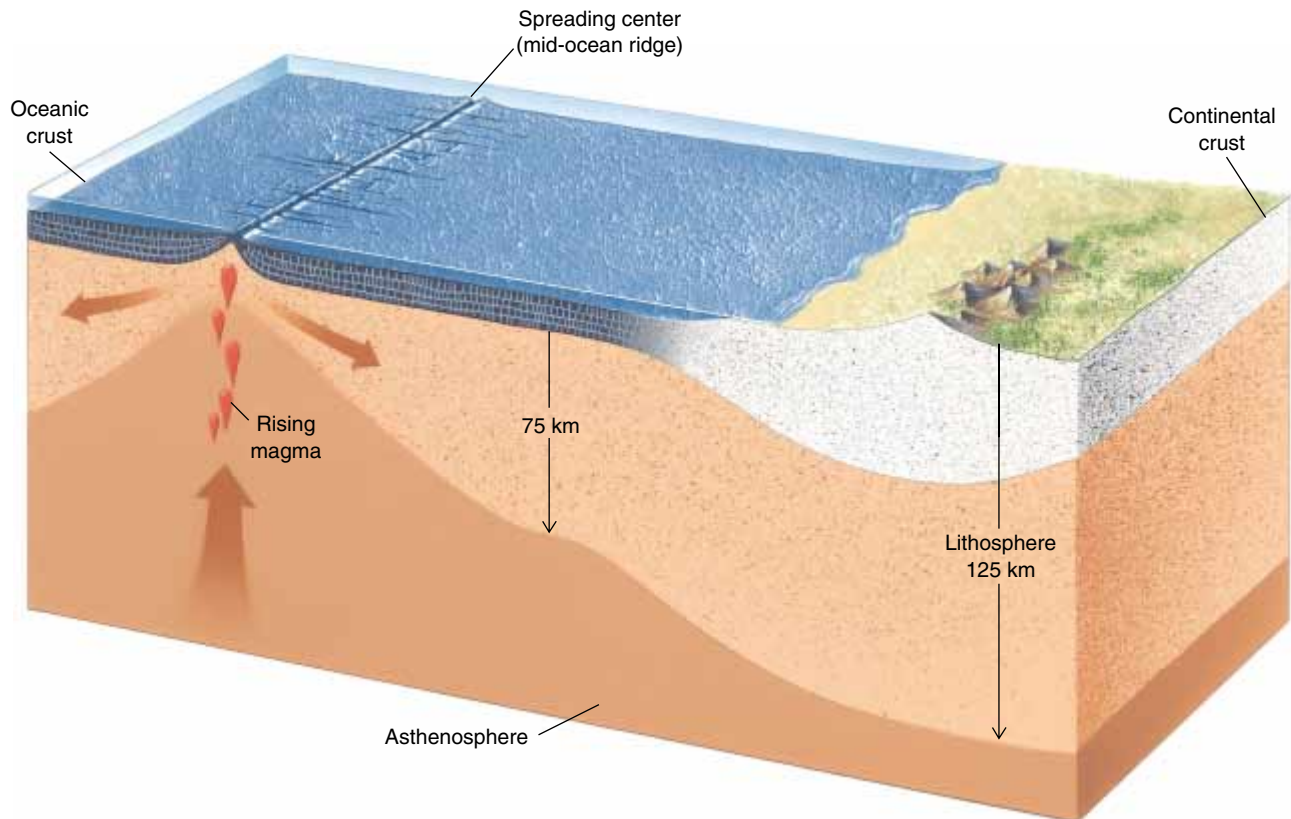
As lithospheric plates separate at a spreading center, hot, plastic asthenosphere oozes upward to fill the gap (Fig. 4–8). As the asthenosphere rises, pressure drops and

pressure-release melting forms basaltic magma (the terms *basaltic* and *granitic* refer to magmas with the chemical compositions of basalt and granite, respectively). Because the magma is of lower density than the surrounding rock, it rises toward the surface.

Most of the world's spreading centers are in the ocean basins, where they form the mid-oceanic ridge. The magma created by pressure-release melting forms new oceanic crust at the ridge. The oceanic crust then spreads outward, riding atop the separating tectonic plates. Nearly all of the Earth's oceanic crust is created in this way at the mid-oceanic ridge. Some spreading centers, like the East African rift, occur in continents, and here, too, basaltic magma erupts onto the Earth's surface.

### Magma Production at a Hot Spot

Recall from Chapter 2 that a mantle plume is a rising column of hot, plastic mantle rock that originates deep within the mantle. The plume rises because it is hotter than the surrounding mantle and, consequently, is buoy-



**Figure 4–8** Pressure-release melting occurs where hot asthenosphere rises beneath a spreading center.



## F O C U S O N

## TERMS COMMONLY USED BY GEOLOGISTS

The terms **basement rock**, **bedrock**, **parent rock**, and **country rock** are commonly used by geologists.

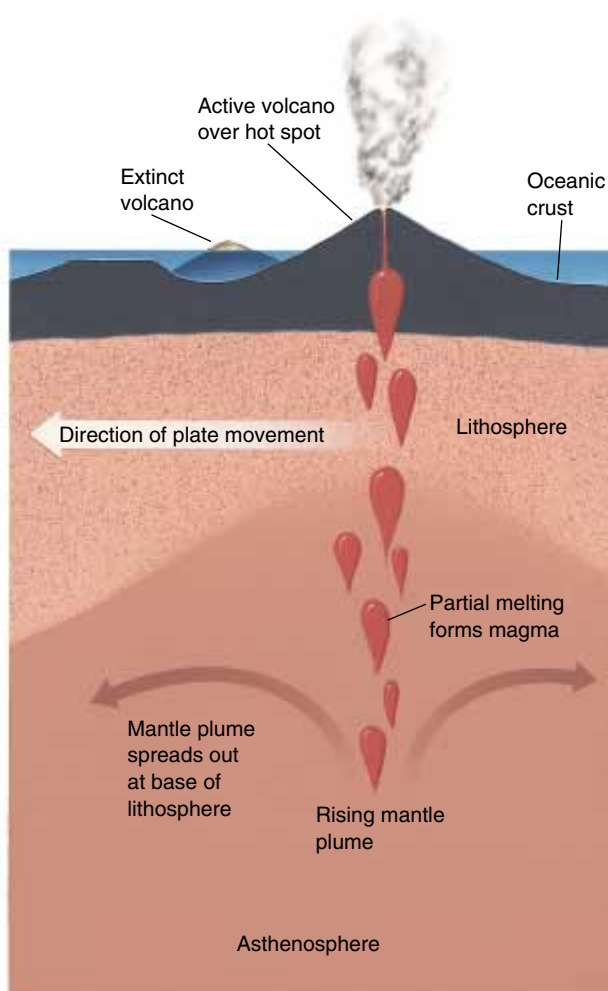
**Basement rock** is the igneous and metamorphic rock that lies beneath the thin layer of sediment and sedimentary rocks covering much of the Earth's surface, and thus it forms the basement of the crust.

**Bedrock** is the solid rock that lies beneath soil or unconsolidated sediments. It can be igneous, metamorphic, or sedimentary.

**Parent rock** is any original rock before it is changed by metamorphism or any other geologic process.

The rock enclosing or cut by an igneous intrusion or by a mineral deposit is called **country rock**.

ant. As a mantle plume rises, pressure-release melting forms magma that erupts onto the Earth's surface (Fig. 4–9). A **hot spot** is a volcanically active place at the



**Figure 4–9** Pressure-release melting occurs in a rising mantle plume, and magma rises to form a volcanic hot spot.

Earth's surface directly above a mantle plume. Because mantle plumes form below the asthenosphere, hot spots can occur within a tectonic plate. For example, the Yellowstone hot spot, responsible for the volcanoes and hot springs in Yellowstone National Park, lies far from the nearest plate boundary. If a mantle plume rises beneath the sea, volcanic eruptions build submarine volcanoes and volcanic islands.

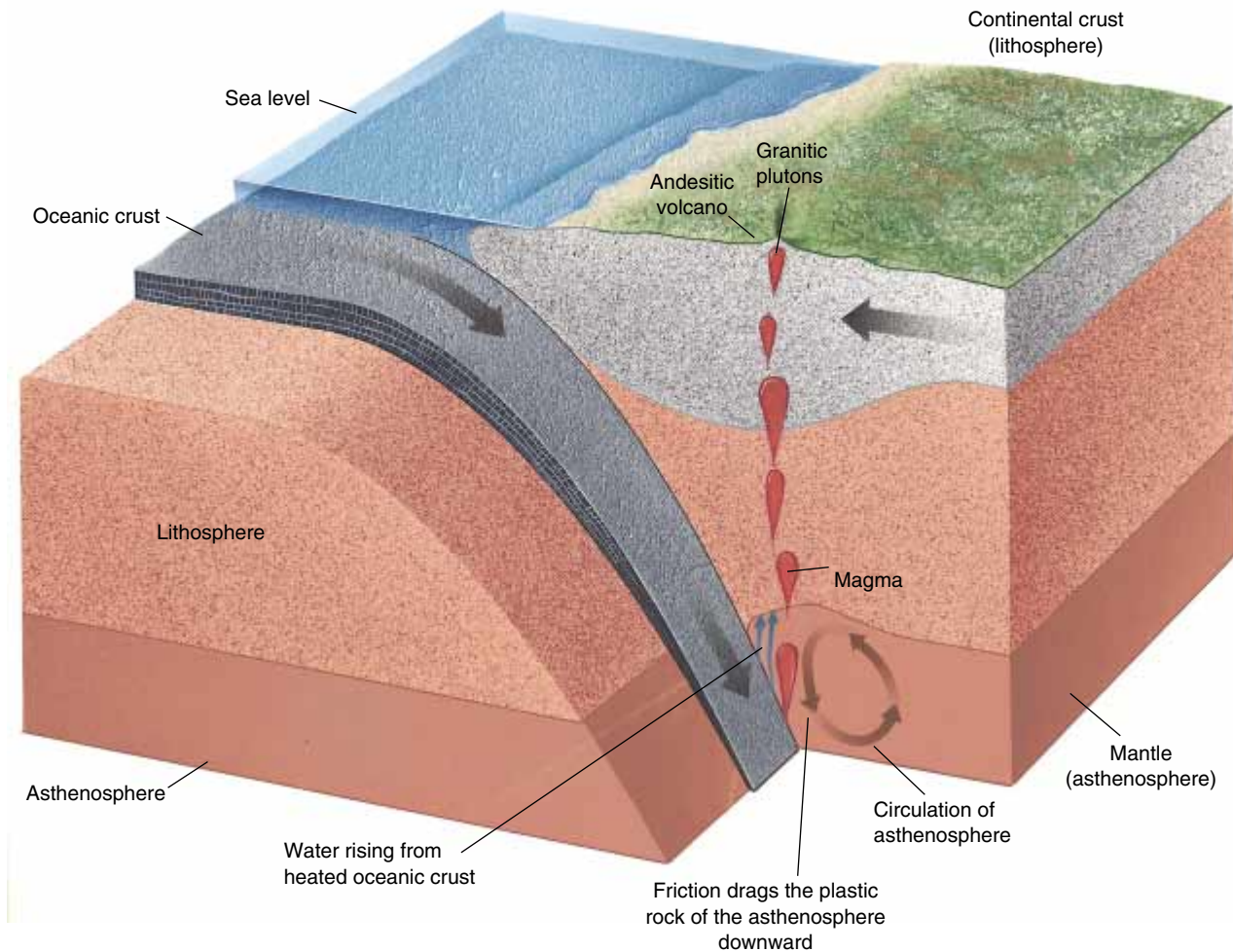
### Magma Production in a Subduction Zone

At a subduction zone, a lithospheric plate sinks hundreds of kilometers into the mantle (Fig. 4–10). As you learned in Chapter 2, a subducting plate is covered by oceanic crust, which, in turn, is saturated with seawater. As the wet rock dives into the mantle, rising temperature drives off the water, which ascends into the hot asthenosphere directly above the sinking plate.

As the subducting plate descends, it drags plastic asthenosphere rock down with it, as shown by the elliptical arrows in Figure 4–10. Rock from deeper in the asthenosphere then flows upward to replace the sinking rock. Pressure decreases as this hot rock rises.

Finally, friction generates heat in a subduction zone as one plate scrapes past the opposite plate. Figure 4–10 shows that addition of water, pressure release, and frictional heating combine to melt portions of the asthenosphere, at a depth of about 100 kilometers, where the subducting plate passes into the asthenosphere. Addition of water is probably the most important factor in magma production in a subduction zone, and frictional heating is probably the least important.

As a result of these processes, igneous rocks are common features of a subduction zone. The volcanoes of the Pacific Northwest, the granite cliffs of Yosemite, and the Andes Mountains are all examples of igneous rocks formed at subduction zones. The “ring of fire” is a zone of concentrated volcanic activity that traces the subduction zones encircling the Pacific Ocean basin. About 75



**Figure 4-10** Three factors contribute to melting of the asthenosphere and production of magma at a subduction zone: (1) Friction heats rocks in the subduction zone; (2) water rises from oceanic crust on top of the subducting plate; and (3) circulation in the asthenosphere decreases pressure on hot rock.

percent of the Earth's active volcanoes (exclusive of the submarine volcanoes at the mid-oceanic ridge) lie in the ring of fire (Fig. 4-11).

### CHARACTERISTICS OF MAGMA

We have just described how, why, and where magma forms. Now we consider its properties and behavior.

#### Temperature

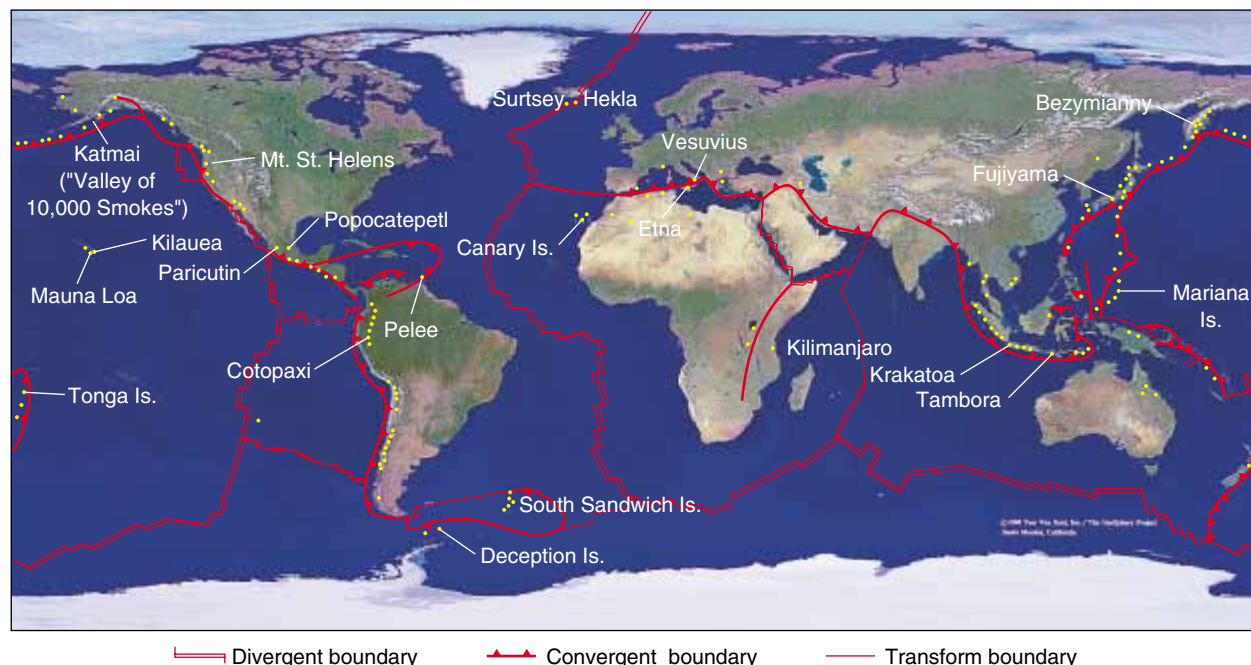
The temperature of magma varies from about 600° to 1400°C, depending on its chemical composition and the depth at which it forms. Generally, basaltic magma forms at great depth and has a temperature near the high end of this scale. Granitic magmas, which form at shallower depths, tend to lie near the cooler end of the scale. As a

comparison, an iron bar turns red hot at about 600°C and melts at slightly over 1500°C.

#### Chemical Composition

Because oxygen and silicon are the two most abundant elements in the crust and mantle, nearly all magmas are silicate magmas. In addition to oxygen and silicon, they also contain lesser amounts of the six other common elements of the Earth's crust: aluminum, iron, magnesium, calcium, potassium, and sodium. The main variations among different types of magmas are differences in the relative proportions of these eight elements. For example, basaltic magma contains more iron and magnesium than granitic magma, but granitic magma is richer in silicon, potassium, and sodium. A few rare magmas are of carbonate composition. The rocks that form from these





**Figure 4-11** Seventy-five percent of the Earth's active volcanoes (yellow dots) lie in the "ring of fire," a chain of subduction zones (heavy red lines with teeth) that encircles the Pacific Ocean. (Tom Van Sant, Geosphere Project)

are called carbonatites and contain carbonate minerals such as calcite and dolomite.

### Behavior

When a silicate rock melts, the resulting magma expands by about 10 percent. It is then of lower density than the rock around it, so magma rises as it forms—much as a hot air balloon ascends in the atmosphere. When magma rises, it enters the cooler, lower-pressure environment near the Earth's surface. When temperature and pressure drop sufficiently, it solidifies to form solid igneous rock.

## ► 4.3 CLASSIFICATION OF IGNEOUS ROCKS

Magma can either rise all the way through the crust to erupt onto the Earth's surface, or it can solidify within the crust. An **extrusive igneous rock** forms when magma erupts and solidifies on the Earth's surface. Because extrusive rocks are so commonly associated with volcanoes, they are also called **volcanic rocks** after Vulcan, the Greek god of fire.

An **intrusive igneous rock** forms when magma solidifies *within* the crust. Intrusive rocks are sometimes

called **plutonic rocks** after Pluto, the Greek god of the underworld.

### TEXTURES OF IGNEOUS ROCKS

The **texture** of a rock refers to the size, shape, and arrangement of its mineral grains, or crystals (Table 4-1). Some igneous rocks consist of mineral grains that are too small to be seen with the naked eye; others are made up of thumb-size or even larger crystals. Volcanic rocks are usually fine grained, whereas plutonic rocks are medium or coarse grained.

**Table 4-1 • IGNEOUS ROCK TEXTURES BASED ON GRAIN SIZE**

GRAIN SIZE	NAME OF TEXTURE
No mineral grains (obsidian)	Glassy
Too fine to see with naked eye	Very fine grained
Up to 1 millimeter	Fine grained
1–5 millimeters	Medium grained
More than 5 millimeters	Coarse grained
Relatively large grains in a finer-grained matrix	Porphyritic



**Figure 4-12** Basalt is a fine-grained volcanic rock. The holes are gas bubbles that were preserved as the magma solidified in southeastern Idaho.

### *Extrusive (Volcanic) Rocks*

After magma erupts onto the relatively cool Earth surface, it solidifies rapidly—perhaps over a few days or years. Crystals form but do not have much time to grow. The result is a very fine-grained rock with crystals too small to be seen with the naked eye. Basalt is a common very fine-grained volcanic rock (Fig. 4-12).



**Figure 4-13** Porphyry is an igneous rock containing large crystals embedded in a fine-grained matrix. This rock is rhyolite porphyry with large pink feldspar phenocrysts.

If magma rises slowly through the crust before erupting, some crystals may grow while most of the magma remains molten. If this mixture of magma and crystals then erupts onto the surface, it solidifies quickly, forming **porphyry**, a rock with the large crystals, called **phenocrysts**, embedded in a fine-grained matrix (Fig. 4-13).

In unusual circumstances, volcanic magma may solidify within a few hours of erupting. Because the magma hardens so quickly, the atoms have no time to align themselves to form crystals. The result is the volcanic glass called **obsidian** (Fig. 4-14).



**Figure 4-14** Obsidian is natural volcanic glass. It contains no crystals. (Geoffrey Sutton)



(a) Granite



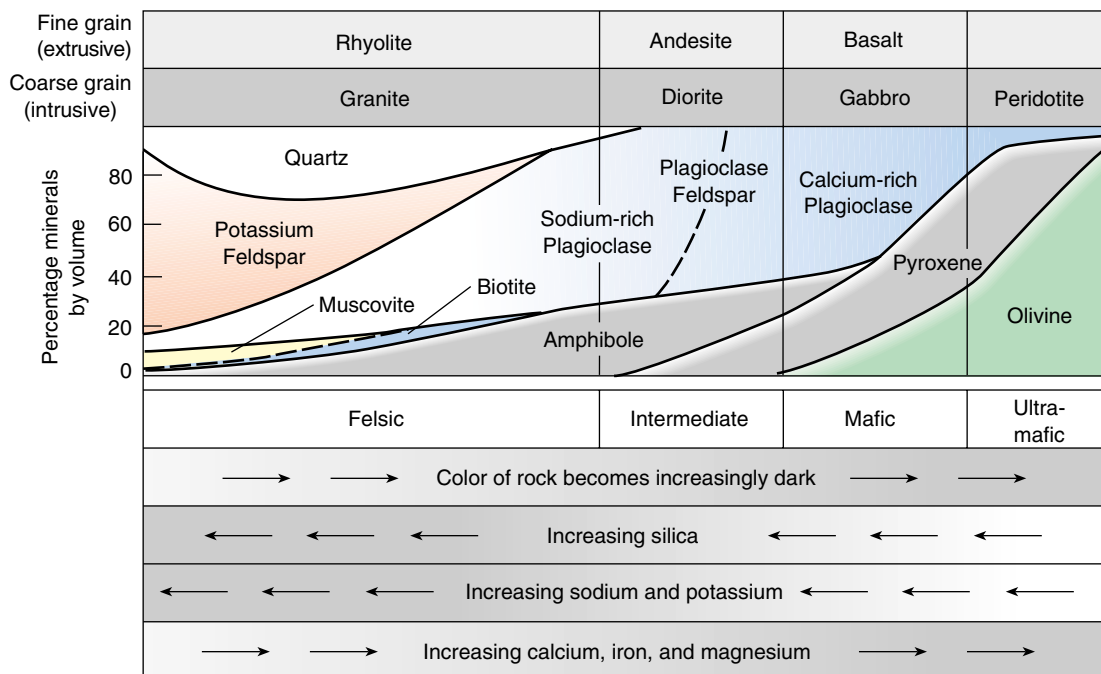
(b) Rhyolite

**Figure 4-15** Although granite (a) and rhyolite (b) contain the same minerals, they have very different textures because granite cools slowly and rhyolite cools rapidly.

### Intrusive (Plutonic) Rocks

When magma solidifies within the crust, the overlying rock insulates the magma like a thick blanket. The magma then crystallizes slowly, and the crystals may have hundreds of thousands or even millions of years in which

to grow. As a result, most plutonic rocks are medium to coarse grained. Granite, the most abundant rock in continental crust, is a medium- or coarse-grained plutonic rock.



**Figure 4-16** The names of common igneous rocks are based on the minerals and texture of a rock. In this figure, a mineral's abundance in a rock is proportional to the thickness of its colored band beneath the rock name. If a rock has a fine grain texture, its name is found in the top row of rock names; if it has a coarse grain texture, its name is in the second row.



## NAMING IGNEOUS ROCKS

Geologists use both the minerals and texture to classify and name igneous rocks. For example, any medium- or coarse-grained igneous rock consisting mostly of feldspar and quartz is called granite. **Rhyolite** also consists mostly of feldspar and quartz but is very fine grained (Fig. 4–15). The same magma that erupts onto the Earth's surface to form rhyolite can also solidify slowly within the crust to form granite.

Like granite and rhyolite, most common igneous rocks are classified in pairs, each member of a pair containing the same minerals but having a different texture. The texture depends mainly on whether the rock is volcanic or plutonic. Figure 4–16 shows the minerals and textures of common igneous rocks.

The chemical compositions of common igneous rocks are summarized in Figure 4–17. Granite and rhyolite contain large amounts of feldspar and silica, and so are called **felsic rocks**. Basalt and gabbro are called **mafic rocks** because of their high magnesium and iron contents (*ferrum* is the Latin word for iron). Rocks with especially high magnesium and iron concentrations are

called **ultramafic**. Rocks with compositions between those of granite and basalt are called **intermediate rocks**.

Once you learn to identify the rock-forming minerals, it is easy to name a plutonic rock using Figure 4–17 because the minerals are large enough to be seen. It is more difficult to name many volcanic rocks because the minerals are too small to identify. A field geologist often uses color to name a volcanic rock. Figure 4–17 shows that rhyolite is usually light in color: White, tan, red, and pink are common. Many andesites are gray or green, and basalt is commonly black. The minerals in many volcanic rocks cannot be identified even with a microscope because of their tiny crystal sizes. In this case, definitive identification is based on chemical and X-ray analyses carried out in the laboratory.

## ► 4.4 COMMON IGNEOUS ROCKS

### GRANITE AND RHYOLITE

Granite is a felsic rock that contains mostly feldspar and quartz. Small amounts of dark biotite or hornblende of-

Descriptive Terms	Felsic (granitic)	Intermediate (andesitic)	Mafic (basaltic)	Ultramafic
Intrusive	Granite	Diorite	Gabbro	Peridotite
Extrusive	Rhyolite	Andesite	Basalt	
Composition	<p>Aluminum oxide 14% Iron oxides 3% Magnesium oxide 1% Other 10% Silica 72%</p>	<p>Iron oxides 8% Magnesium oxide 3% Other 13% Aluminum oxide 17% Silica 59%</p>	<p>Magnesium oxide 7% Iron oxides 11% Aluminum oxide 16% Other 16% Silica 50%</p>	<p>Other 8% Magnesium oxide 31% Iron oxides 12% Aluminum oxide 4% Silica 45%</p>
Major minerals	Quartz Potassium feldspar Sodium feldspar (plagioclase)	Amphibole Intermediate plagioclase feldspar	Calcium feldspar (plagioclase) Pyroxene	Olivine Pyroxene
Minor minerals	Muscovite Biotite Amphibole	Pyroxene	Olivine Amphibole	Calcium feldspar (plagioclase)
Most common color	Light colored	Medium gray or medium green	Dark gray to black	Very dark green to black

**Figure 4–17** Chemical compositions, minerals, and typical colors of common igneous rocks.



**Figure 4-18** The authors on Inugsuin Point Buttress, a granite wall on Baffin Island. (Steve Sheriff)

ten give it a black and white speckled appearance. Granite (and metamorphosed granitic rocks) are the most common rocks in continental crust. They are found nearly everywhere beneath the relatively thin veneer of sedimentary rocks and soil that cover most of the continents. Geologists often call these rocks **basement rocks** because they make up the foundation of a continent. Granite is hard and resistant to weathering; it forms steep, sheer cliffs in many of the world's great mountain ranges. Mountaineers prize granite cliffs for the steepness and strength of the rock (Fig. 4-18).

As granitic magma rises through the Earth's crust, some of it may erupt from a volcano to form rhyolite, while the remainder solidifies beneath the volcano, forming granite. Most obsidian forms from magma with a granitic (rhyolitic) composition.

### BASALT AND GABBRO

Basalt is a mafic rock that consists of approximately equal amounts of plagioclase feldspar and pyroxene. It makes up most of the oceanic crust as well as huge **basalt plateaus** on continents (Fig. 4-19). **Gabbro** is the plutonic counterpart of basalt; it is mineralogically identical but consists of larger crystals. Gabbro is uncommon at the Earth's surface, although it is abundant in deeper

parts of oceanic crust, where basaltic magma crystallizes slowly.

### ANDESITE AND DIORITE

**Andesite** is a volcanic rock intermediate in composition between basalt and granite. It is commonly gray or green and consists of plagioclase and dark minerals (usually biotite, amphibole, or pyroxene). It is named for the Andes mountains, the volcanic chain on the western edge of South America, where it is abundant. Because it is volcanic, andesite is typically very fine grained.

**Diorite** is the plutonic equivalent of andesite. It forms from the same magma as andesite and, consequently, often underlies andesitic mountain chains such as the Andes.

### PERIDOTITE

**Peridotite** is an ultramafic igneous rock that makes up most of the upper mantle but is rare in the Earth's crust. It is coarse grained and composed of olivine, and it usually contains pyroxene, amphibole, or mica but no feldspar.

## ► 4.5 PARTIAL MELTING AND THE ORIGINS OF COMMON IGNEOUS ROCKS

### BASALT AND BASALTIC MAGMA

Recall that oceanic crust is mostly basalt and that basaltic magma forms by melting of the asthenosphere. However, the asthenosphere is made of peridotite. Figure 4-18 shows that basalt and peridotite are quite different in composition: Peridotite contains about 40 percent silica, but basalt contains about 50 percent. Peridotite contains considerably more iron and magnesium than basalt. How does peridotite melt to create basaltic magma? Why does the magma have a composition different from that of the rock that melted to produce it?

Any pure substance, such as ice, has a definite melting point. Ice melts at exactly 0°C. In addition, ice melts to form water, which has exactly the same composition as the ice, pure H<sub>2</sub>O. A rock does not behave in this way because it is a *mixture* of several minerals, each of which melts at a different temperature. If you heat peridotite slowly, the minerals with the lowest melting point begin to melt first, while the other minerals remain solid. This phenomenon is called **partial melting**. (Of course, if the temperature is high enough, the whole rock will melt.)

In general, minerals with the highest silica contents melt at the lowest temperatures. Silica-poor minerals melt only at higher temperatures. In parts of the as-

thenosphere where magma forms, the temperature is only hot enough to melt the minerals with the lowest melting points. As a result, magma is always richer in silica than the rock that melted to produce it. In this way, basaltic magma forms from peridotite rock at a temperature of about 1100°C. When the basaltic magma rises toward the Earth's surface, it leaves silica-depleted peridotite in the asthenosphere.

### GRANITE AND GRANITIC MAGMA

Granite contains more silica than basalt and therefore melts at a lower temperature—typically between 700° and 900°C. Thus, basaltic magma is hot enough to melt granitic continental crust. In certain tectonic environments, the asthenosphere melts beneath a continent, forming basaltic magma that rises into continental crust. These environments include a subduction zone, a continental rift zone, and a mantle plume rising beneath a continent.

Because the lower continental crust is hot, even a small amount of basaltic magma melts large quantities of the continent to form granitic magma. Typically, the granitic magma then rises a short distance and then solidifies within the crust to form plutonic rocks. Most granitic plutons solidify at depths between a few kilometers and about 20 kilometers. Some of the magma may rise to the Earth's surface to erupt rhyolite and similar volcanic rocks. Small amounts of the original basaltic magma may erupt with the rhyolite or solidify at depth with the granite.

### ANDESITE AND ANDESITIC MAGMA

Igneous rocks of intermediate composition, such as andesite and diorite, form by processes similar to those that generate granitic magma. Their magmas contain less silica than granite, either because they form by melting of continental crust that is lower in silica or because the basaltic magma from the mantle has contaminated the granitic magma.



**Figure 4–19** Lava flows of the Columbia River basalt plateau are well exposed along the Columbia River.

## SUMMARY

Geologists separate rocks into three classes based on how they form: **igneous rocks**, **sedimentary rocks**, and **metamorphic rocks**. Igneous rocks form when a hot, molten liquid called **magma** solidifies. Sedimentary rocks form when loose **sediment**, such as sand and clay, becomes cemented to form a solid rock. Metamorphic

rocks form when older igneous, sedimentary, or other metamorphic rocks change because of high temperature and/or pressure or are deformed during mountain building. The **rock cycle** shows that all rocks change slowly over geologic time from one of the three rock types to another.



Three different processes—rising temperature, lowering of pressure, and addition of water—melt portions of the Earth’s asthenosphere. These processes form great quantities of magma in three geologic environments: spreading centers, mantle plumes, and subduction zones. The temperature of magma varies from about 600° to 1400°C. Nearly all magmas are silicate magmas. Magma usually rises toward the Earth’s surface because it is of lower density than rocks that surround it.

An **extrusive**, or **volcanic**, igneous rock forms when magma erupts and solidifies on the Earth’s surface. An **intrusive**, or **plutonic**, rock forms when magma cools and solidifies below the surface. Plutonic rocks typically have medium- to coarse-grained textures, whereas volcanic rocks commonly have very fine- to fine-grained textures. A **porphyry** consists of larger crystals imbedded in a fine-grained matrix.

The two most common types of igneous rocks in the Earth’s crust are **granite**, which comprises most of the continental crust, and **basalt**, which makes up oceanic crust. The upper mantle is composed of **peridotite**.

An igneous rock is classified and named according to its texture and mineral composition. The textures, mineral contents, and names of the common igneous rocks are summarized in Figures 4–16 and 4–17.

A **mafic** rock is low in silica, high in iron and magnesium, and dark in color. Basalt is a common mafic rock. A **felsic** rock is rich in feldspar and silicon, low in iron and magnesium, and light in color. Granite is a common felsic rock. An **intermediate** rock has a composition and color that lie between those of mafic and felsic rocks. The most common intermediate rock is **andesite**. **Ultramafic** rocks have the lowest silicon and aluminum content and the highest amounts of magnesium and iron. Peridotite, an ultramafic rock, is rare in the crust but abundant in the mantle.

Magmas invariably have a higher silica content than the rocks that melt to produce them, due to the phenomenon of **partial melting**.

Important Igneous Rocks				
Extrusive Intrusive	Rhyolite Granite	Andesite Diorite	Basalt Gabbro	Peridotite

## KEY WORDS

magma 58  
igneous rock 58  
sedimentary rock 58  
metamorphic rock 58  
rock cycle 58  
pressure-release  
melting 60

hot spot 62  
extrusive igneous rock 64  
volcanic rock 64  
intrusive igneous rock 64

plutonic rocks 64  
texture 64  
porphyry 65  
phenocryst 65  
obsidian 65  
felsic rock 67

mafic rock 67  
ultramafic rock 67  
intermediate rock 67  
basalt plateau 68  
partial melting 68

## REVIEW QUESTIONS

- Describe the three main classes of rocks.
- What criteria are used to categorize rocks into the three classes that you described in question 1?
- List two common rock types in each of the three main classes of rocks. Were these rock names familiar to you before you read this chapter?
- What is the most important concept described by the rock cycle?
- What is magma?
- Describe and explain each of the three processes that melt rock to form magma.
- Describe each of the three main geologic environments in which magma forms in large quantities.
- Describe the processes that melt rock to generate magma in each of the three environments that you discussed in the previous question.
- Explain how oceanic crust forms only at the mid-oceanic ridge but makes up the entire sea floor.
- Describe the locations of some volcanically active regions associated with subduction zones.
- What is the temperature of magma?

12. What is the general chemical composition of most magmas?
13. Why do magmas begin to rise through the Earth's outer layers as soon as they form?
14. How would you distinguish a plutonic rock from a volcanic rock in the field?
15. What factor distinguishes obsidian from all other types of igneous rocks?
16. What are the most common minerals in igneous rocks? Why?
17. What do the terms *mafic*, *ultramafic*, *felsic*, and *intermediate* mean?
18. Describe the mineralogy, texture, and common geologic occurrence of the following types of igneous rocks: granite, rhyolite, basalt, gabbro, andesite, and peridotite.
19. What type of igneous rock is the most abundant constituent of continental crust? What type makes up most oceanic crust?
20. Why is it sometimes difficult to identify a volcanic rock accurately in the field?
21. Why does magma normally have a higher silica content than the rock from which it formed?

## DISCUSSION QUESTIONS

1. The temperature of most magma is thought to be approximately equal to the initial melting temperature of the rock from which the magma formed, rarely much hotter. Why do magmas not get much hotter than their initial melting points?
2. Why is oceanic crust predominantly basalt, whereas continental crust is mainly of granitic composition?
3. Devise a scheme for naming and classifying igneous rocks that is different from the one based on mineral content presented in Figure 4–16.
4. Explain why feldspar is the most abundant mineral in the Earth's crust and yet is nearly completely absent from the peridotite of the upper mantle.
5. What could you infer about the history of another planet if you discovered extrusive igneous rocks but no intrusive igneous rocks on its surface?
6. Draw a graph with silica content on the Y-axis and felsic, intermediate, mafic, and ultramafic rocks on the X-axis. Draw similar graphs for aluminum, magnesium, iron, and potassium contents.