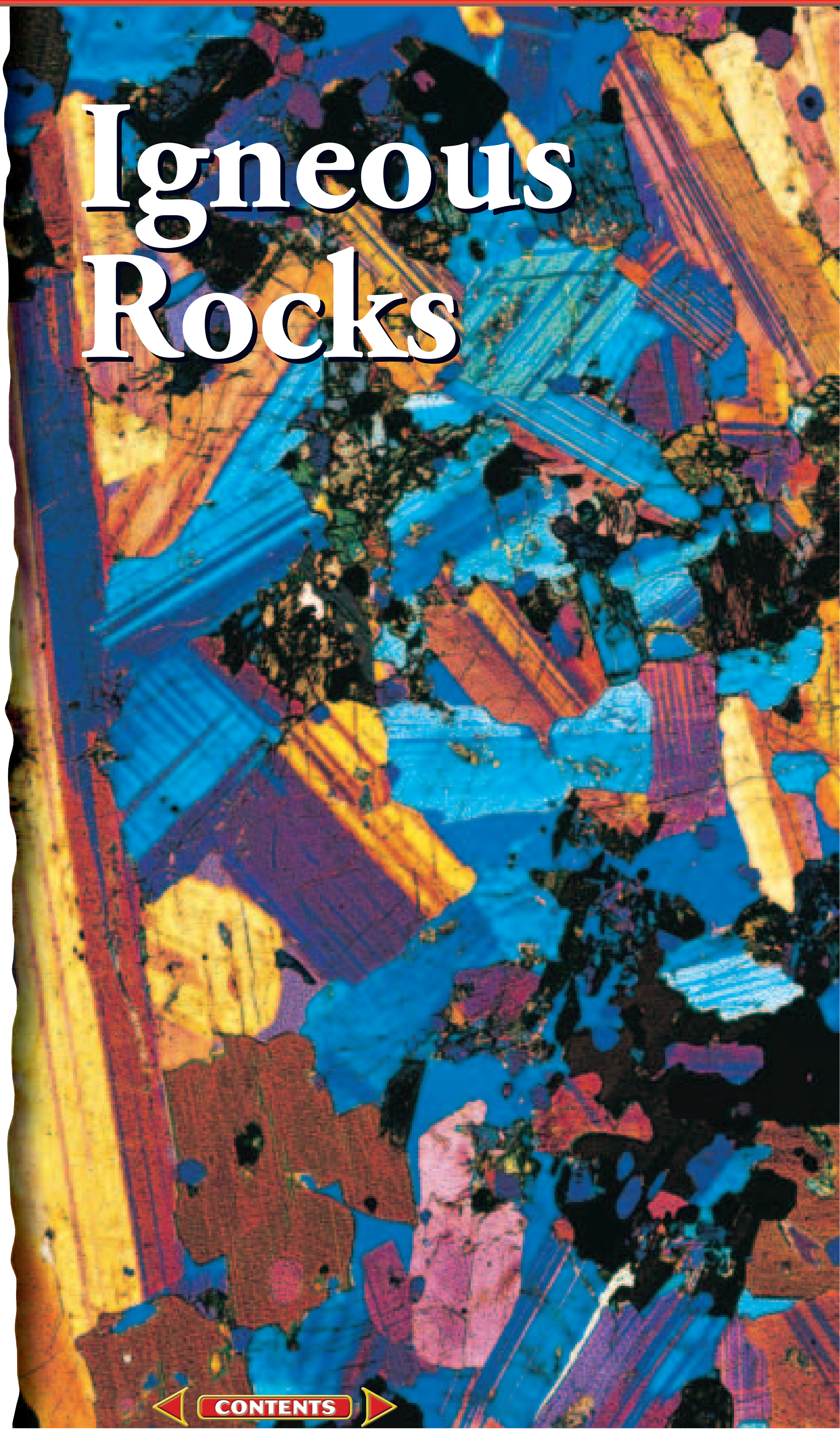
Chapter 5

Igneous Rocks



What You'll Learn

- How magma melts and crystallizes to form igneous rocks.
- How igneous rocks are classified.
- How igneous rocks are used.

Why It's Important

This photograph shows a microscopic view of gabbro, a type of igneous rock. Igneous rocks are the most abundant rocks in Earth's crust. Many important mineral and metal deposits are associated with igneous rocks.

Earth Science Online

To find out more about igneous rocks, visit the Earth Science Web Site at earthgeu.com

CONTENTS

Discovery Lab Identifying Minerals

Rocks are mixtures of minerals, organic matter, and other materials. Sometimes, it's possible to identify the different minerals in a sample of rock.

1. Examine a sample of granite from a distance of about 1 m. Record your observations.
2. Use a magnifying glass or stereomicroscope to observe the granite sample. Record your observations.

Observe In your science journal, draw a picture of what you saw through the magnifying glass or stereomicroscope. Include a scale for your drawing. How many different minerals did you observe in the rock? What minerals can you identify? Describe the sizes and shapes of the minerals. Do you see any evidence that these minerals crystallized from molten rock? Explain.

SECTION 5.1 What are igneous rocks?

OBJECTIVES

- **Compare** *and* **contrast** *intrusive and extrusive igneous rocks.*
- **Describe** *the composition of magma.*
- **Discuss** *the factors that affect how rocks melt and crystallize.*

VOCABULARY

igneous rock
lava
extrusive
intrusive
partial melting
fractional crystallization
Bowen's reaction series

In the *Discovery Lab,* you examined the minerals in a piece of granite. Granite is an igneous rock formed from magma, which, as you learned in Chapter 4, is molten rock below Earth's surface. **Igneous rocks** are formed from the crystallization of magma. The term *igneous* comes from the Latin word *ignis,* which means "fire" because early geologists often associated igneous rocks with fiery lava flows. **Lava** is magma that flows out onto Earth's surface.

TYPES OF IGNEOUS ROCKS

If you live near an active volcano, you can literally watch igneous rocks form. A hot, molten mass of rock may solidify into solid rock overnight. Fine-grained igneous rocks that cool quickly on Earth's surface are called **extrusive** igneous rocks. Coarse-grained igneous rocks that cool slowly beneath Earth's surface are called **intrusive** igneous rocks. Granite is the most common intrusive igneous rock. Initially, scientists did not believe that granite was igneous in origin because it was coarse grained and thus unlike the fine-grained surface rocks that formed from lava. In the late 1700s, however, careful study of granite rock formations revealed that they cut across other rock formations.

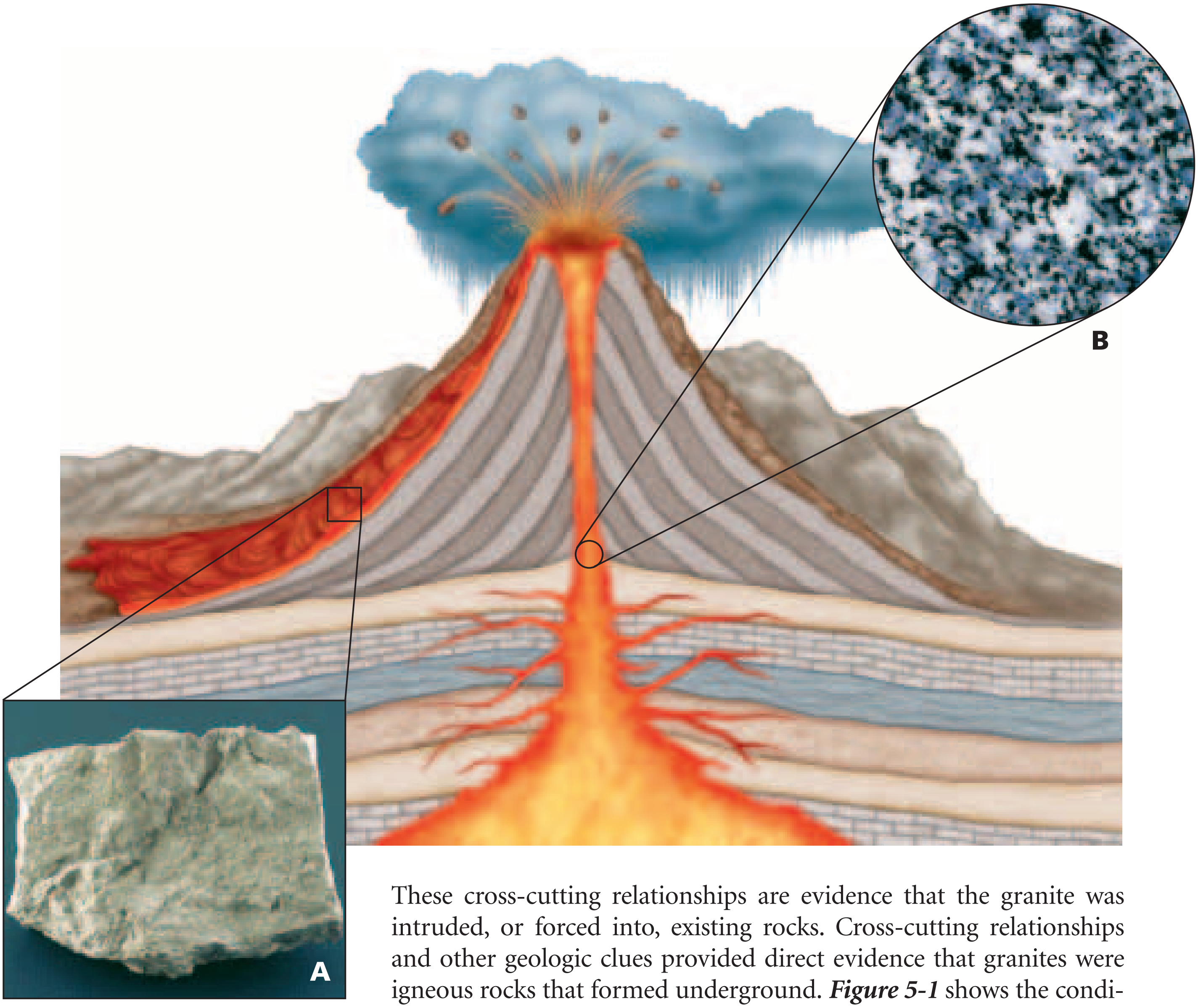


Figure 5-1 Lava cools quickly on Earth's surface and forms fine-grained igneous rocks such as rhyolite **(A).** Magma cools slowly beneath Earth's surface and forms coarse-grained igneous rocks such as granite. **(B).**

These cross-cutting relationships are evidence that the granite was intruded, or forced into, existing rocks. Cross-cutting relationships and other geologic clues provided direct evidence that granites were igneous rocks that formed underground. ***Figure 5-1*** shows the conditions under which granite and other igneous rocks form.

Composition of Magma

Magma is often a slushy mix of molten rock, gases, and mineral crystals. The elements found in magma are the same major elements found in Earth's crust: oxygen (O), silicon (Si), aluminum (Al), iron (Fe), magnesium (Mg), calcium (Ca), potassium (K), and sodium (Na). Of all the compounds found in magma, silica (SiO_2) is the most abundant and has the greatest effect on magma characteristics. As summarized in ***Table 5-1,*** magmas are classified as basaltic, andesitic, and rhyolitic, based on the amount of SiO_2 they contain. Silica content affects melting temperature and also impacts how quickly magma flows.

Origins of Magma

In the laboratory, most rocks must be heated to temperatures of 800°C to 1200°C before they melt. In nature, these temperatures are found in the upper mantle and lower crust. Where does this heat come from? Scientists theorize that the remaining energy from Earth's molten formation and the heat generated from the decay of radioactive elements are the sources of Earth's thermal energy.

Table 5-1
Types of Magma

Group	SiO_2 content
Rhyolitic	70 percent
Andesitic	60 percent
Basaltic	50 percent

Factors That Affect Magma Formation The main factors involved in the formation of magma are temperature, pressure, water content, and mineral composition. Temperature generally increases with depth in Earth's crust. This temperature increase, known as the geothermal gradient, is plotted in ***Figure 5-2A.*** Oil-well drillers and miners, such as those shown in ***Figure 5-2B,*** have firsthand experience with the geothermal gradient. Temperatures encountered when drilling deep oil wells can exceed 200°C.

Pressure also increases with depth. This is a result of the weight of overlying rock. Laboratory experiments show that as pressure on a rock increases, its melting point also increases. Thus, a rock may melt at 1100°C at Earth's surface, but the same rock will melt at 1400°C under the intense pressure found at a depth of 100 km.

The third factor that affects the formation of magma is water content. Rocks and minerals often contain small percentages of water, which changes the melting point of the rocks. As water content increases, the melting point decreases.

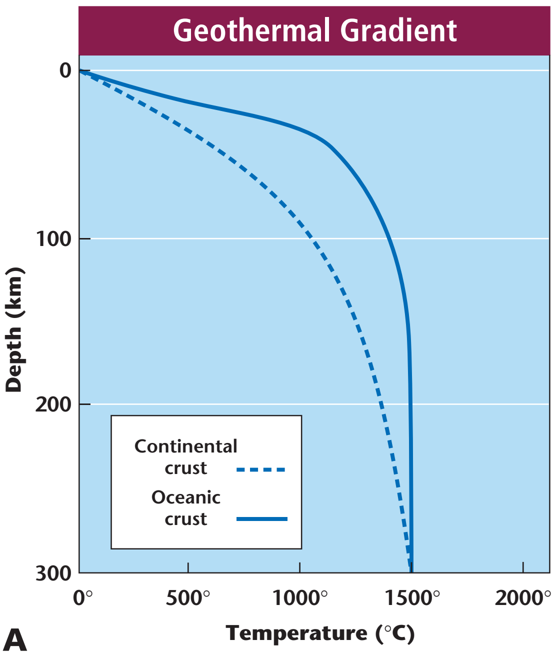
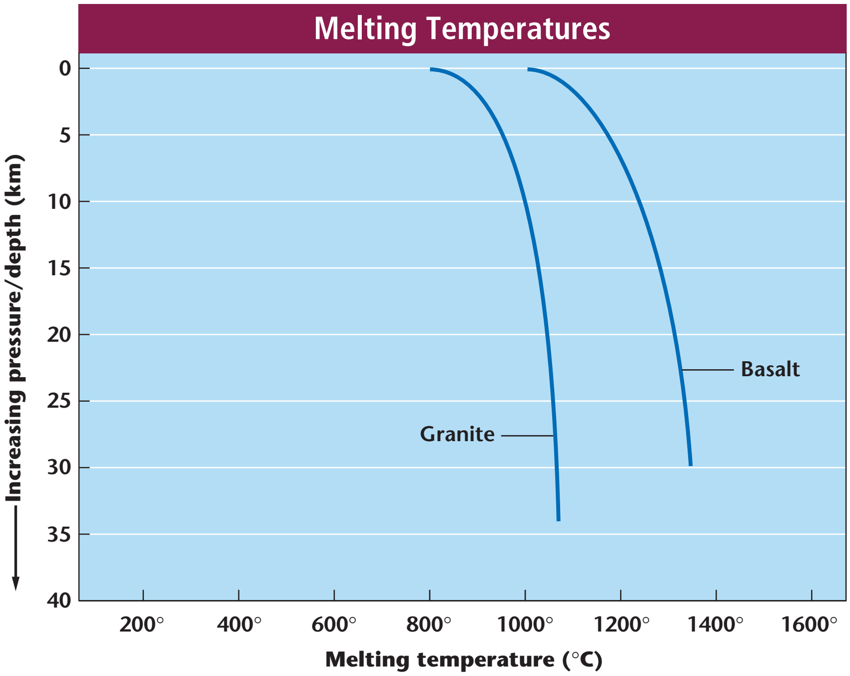


Figure 5-2 Differences in mineral composition cause the geothermal gradient to be higher in oceanic crust than in continental crust **(A),** as you'll learn on the next page. Also, the geothermal gradient causes temperatures in deep mines to be quite high **(B).**

Figure 5-3 Granite's higher water content and mineral composition cause it to melt at lower temperatures than basalt.



Mineral content also impacts how magma is formed. Different minerals have different melting points. For example, rocks formed of olivine, calcium feldspar, and pyroxene melt at higher temperatures than rocks containing quartz and potassium feldspar. In general, oceanic crust is rich in iron and magnesium and therefore melts at higher temperatures than continental crust, which contains higher levels of silicon and aluminum. Rocks melt only under certain conditions—the right combination of temperature, pressure, and composition must be present. ***Figure 5-3*** shows the melting curves of both granite and basalt. As you can see, granite has a lower melting point. This is because it contains more water than basalt and is made up of minerals that melt at lower temperatures.

How Rocks Melt

Suppose you froze bits of candle wax and water in an ice-cube tray. If you took the tray out of the freezer and left it at room temperature, the ice would melt but the candle wax would not. Why? The two substances have different melting points. Rocks melt in a similar way because the minerals they contain have different melting points.

Partial Melting Because different minerals have different melting points, not all parts of a rock melt at the same time. This explains why magma is often a slushy mix of crystals and molten rock. The process whereby some minerals melt at low temperatures while other minerals remain solid is called **partial melting.** Partial melting is

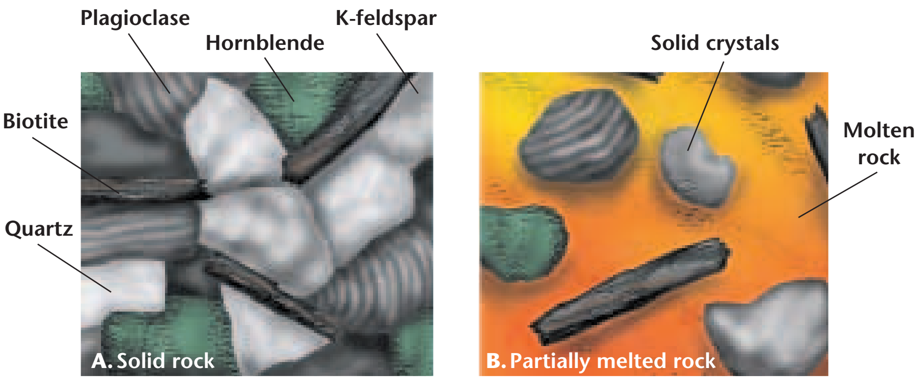
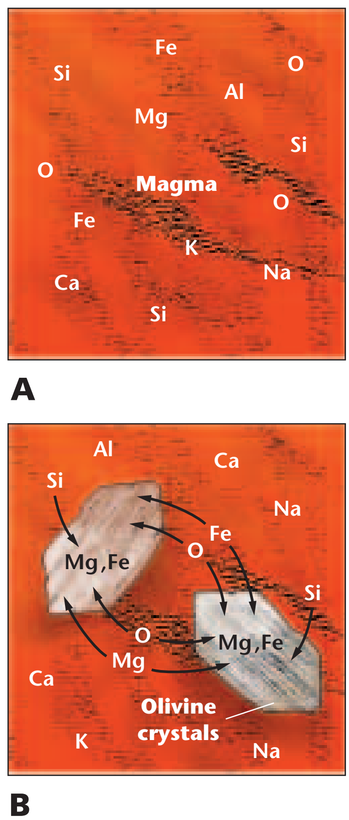


Figure 5-4 A rock is made up of different minerals that melt at different temperatures **(A).** Thus, during the melting process, some minerals are molten while others remain solid **(B).**

illustrated in ***Figure 5-4.*** As each group of minerals melts, different elements are added to the magma "stew," thereby changing its composition. If temperatures are not great enough to melt the entire rock, the resulting magma will have a different chemistry from that of the original rock. This is one way in which different types of igneous rocks form.

Fractional Crystallization When magma cools, it crystallizes in the reverse order of partial melting—the first minerals to crystallize from magma are the last minerals to melt during partial melting. The process wherein different minerals form at different temperatures is called **fractional crystallization.** This process, which is illustrated in ***Figure 5-5,*** is similar to partial melting in that the composition of magma may change. However, during fractional crystallization, the changes occur because as each group of minerals crystallizes, it removes elements from the remaining magma instead of adding new elements.

Figure 5-5 Magma is made up of different minerals that crystallize at different temperatures **(A).** Thus, during the crystallization process, some minerals become solid while others remain molten **(B).**

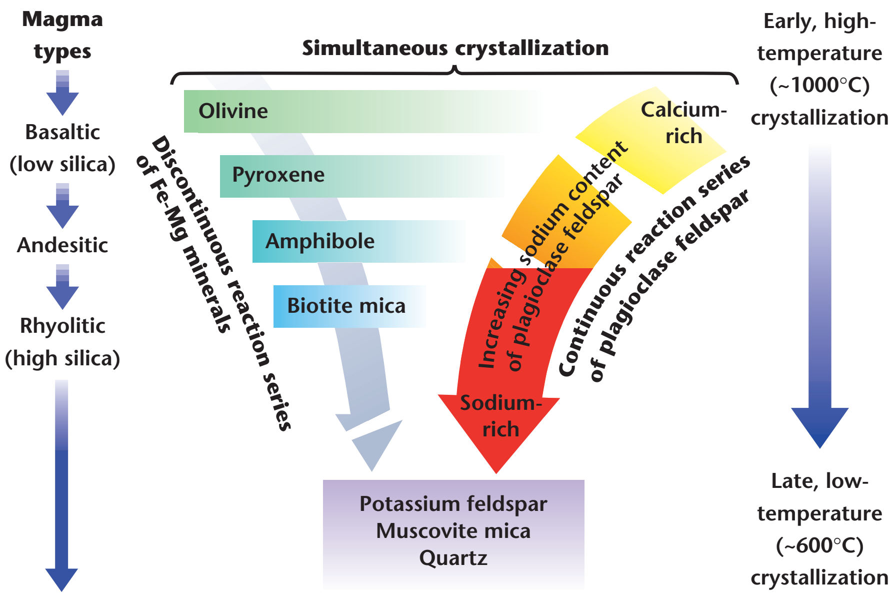


Bowen's Reaction Series

In the early 1900s, Canadian geologist N. L. Bowen demonstrated that as magma cools, minerals form in predictable patterns. **Bowen's reaction series** illustrates this relationship between cooling magma and mineral formation. Bowen discovered two main patterns, or branches, of crystallization. The first pattern is characterized by a continuous, gradual change of mineral compositions in the feldspar group. The second pattern is characterized by an abrupt change of mineral type in the iron-magnesium groups. ***Figure 5-6*** on page 104 illustrates Bowen's reaction series.

Feldspars In Bowen's reaction series, the right branch represents the feldspar minerals, which undergo a continuous change of composition.

Figure 5-6 In the left branch of Bowen's reaction series, Fe-Mg minerals change to different minerals during the crystallization process. In the right branch, calcium-rich feldspars change gradually to sodium-rich feldspars.



As magma cools, the first feldspars to form are rich in calcium. As cooling continues, these feldspars react with magma, and their calcium-rich compositions change to sodium-rich compositions. In some instances, as when magma cools rapidly, the calcium-rich cores are unable to react completely with the magma. The result is a zoned crystal that has sodium-rich outer layers and calcium-rich cores, as shown in ***Figure 5-7.***

Figure 5-7 When magma cools quickly, a feldspar crystal may not have time to react completely with the magma and it retains a calcium-rich core **(A).** The result is a crystal with distinct zones **(B).**

Iron-Rich Minerals The left branch of Bowen's reaction series represents the iron-rich minerals. These minerals undergo abrupt changes during fractional crystallization. For example, when a

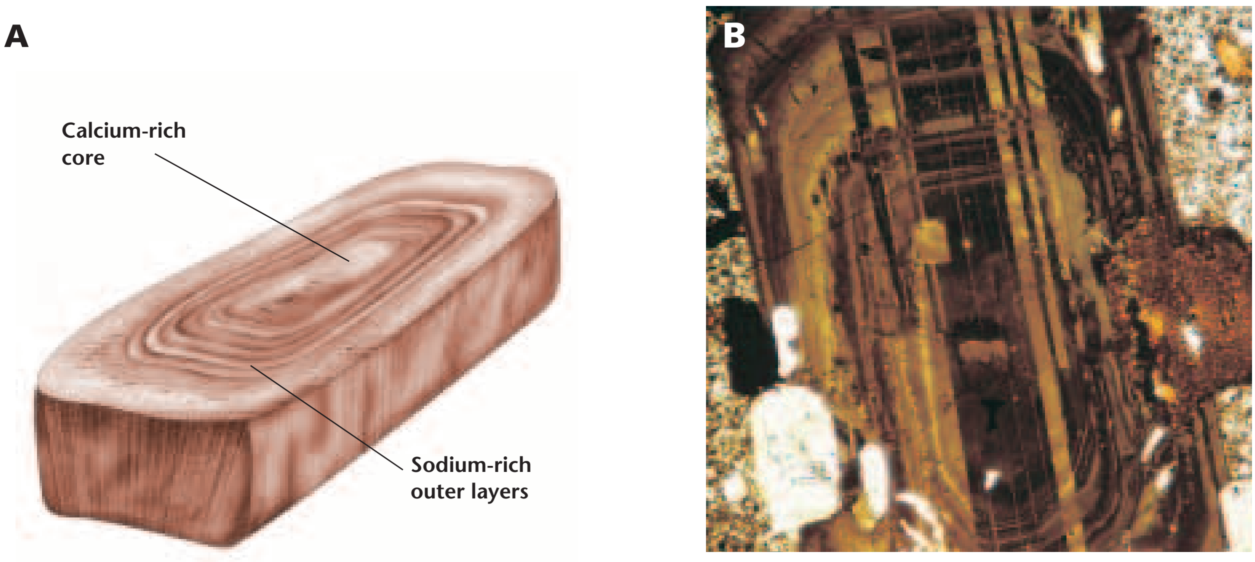


Figure 5-8 Quartz, the last mineral to crystallize, often forms in rock veins when the remaining magma is squeezed into rock fractures and cools.

magma rich in iron and magnesium cools to around 1800°C, olivine begins to crystallize. Olivine continues to form until the temperature drops to 1557°C. At that temperature, a completely new mineral, pyroxene, begins to form. All the olivine that previously formed reacts with the magma and is converted to pyroxene. Similar mineral changes have been observed in amphiboles and biotite.

As minerals form in the order shown in Bowen's reaction series, elements are removed from the remaining magma. Silica and oxygen, the most abundant elements in magma, are left over at the end of the reaction series. When the remaining melt, enriched with silica and oxygen, finally crystallizes, quartz is formed. Quartz often occurs in veins, as shown in ***Figure 5-8,*** because it crystallizes as the last liquid portion of magma is squeezed into rock fractures.

Crystal Separation As is often the case with scientific inquiry, Bowen's reaction series led to more questions. For example, if olivine converts to pyroxene during cooling, why is olivine found in rock? Geologists hypothesize that under certain conditions, newly formed crystals are separated from magma, and the chemical reactions between the magma and the minerals stop. Crystal separation can occur when crystals settle to the bottom of the magma body, and when liquid magma is squeezed from the crystal mush to form two distinct igneous bodies with different compositions.

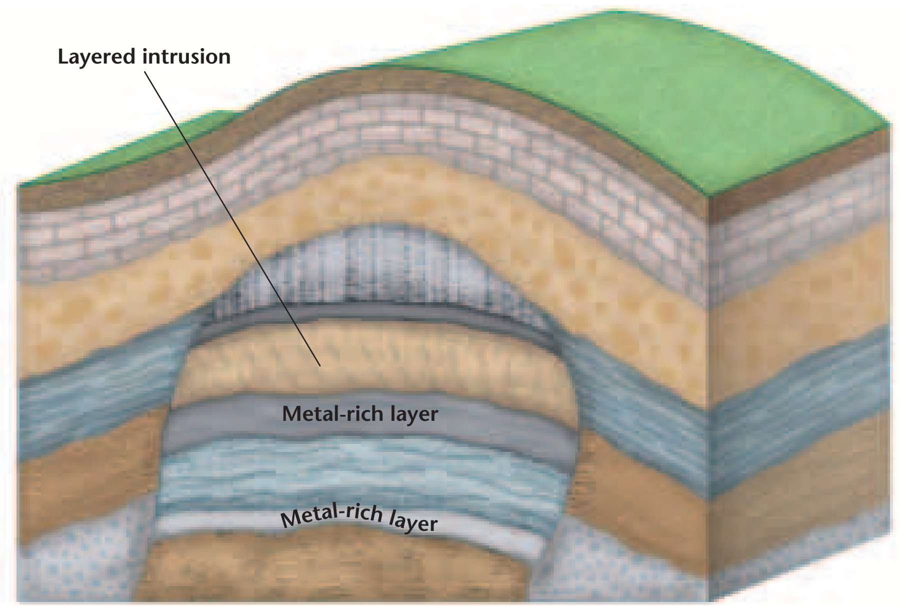
Layered Intrusions In some magma bodies, the minerals form into distinct bands in the order shown in Bowen's reaction series. The result

Earth Science Online

Topic: Bowen's Reaction
To find out more about Bowen's reaction series, visit the Earth Science Web Site at earthgeu.com

Activity: Explain which types of minerals weather more quickly than others. What unique rocks demonstrate this weathering process?

Figure 5-9 The settling of crystals, flowing currents in magma, and temperature differences may cause the formation of a layered intrusion, which sometimes has metal-rich layers.



is a layered intrusion, as shown in ***Figure 5-9.*** Geologists are uncertain how these layers form. The settling of crystals, flowing currents in the magma, and temperature gradients within the magma chamber may all play a role. Layered igneous intrusions can be valuable sources of rare metals. Some have very high concentrations of elements such as platinum, chromium, nickel, or gold. For instance, a layered intrusion in Montana called the Stillwater Complex is the only source of platinum in the United States. Platinum is a critical component in catalytic converters, which are used to reduce the amount of pollutants that vehicles emit.

Section Assessment

1. Compare and contrast magma and lava. What two types of igneous rock are formed as each cools?
2. Make a data table that lists the eight major elements found in most magma. Include the chemical symbol of each element.
3. What are the factors that affect the formation of magma?
4. Compare the ways in which iron-magnesium minerals and feldspars crystallize from magma.
5. **Thinking Critically** Geologists have found zoned pyroxene crystals that have magnesium-rich cores and iron-rich outer layers. Which has a higher melting temperature, magnesium-rich pyroxene or iron-rich pyroxene? Explain your reasoning.

Skill Review

6. **Comparing and Contrasting** Compare and contrast how partial melting and fractional crystallization can change the composition of magma. For more help, refer to the *Skill Handbook.*

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SECTION 5.2 *Classifying Igneous Rocks*

Igneous rocks are broadly classified as intrusive or extrusive. However, geologists further classify these rocks by their mineral compositions. In addition, physical properties such as grain size and texture serve as clues for the identification of various igneous rocks.

OBJECTIVES

- **Classify** *different types and textures of igneous rocks.*
- **Recognize** *the effects of cooling rates on the grain sizes of igneous rocks.*
- **Describe** *some uses of igneous rocks.*

VOCABULARY

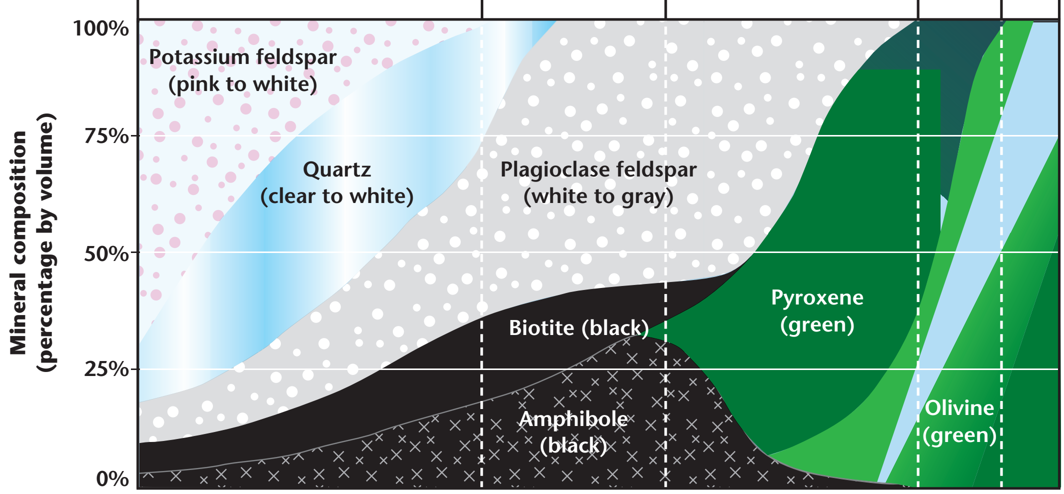
felsic
mafic
ultramafic
porphyritic
pegmatite
kimberlite

MINERAL COMPOSITION

As shown in ***Table 5-2,*** the three main groups of igneous rocks—felsic, mafic, and intermediate—are classified according to their mineral compositions. **Felsic** rocks such as granite are light-colored, have high silica contents, and contain quartz and the feldspars orthoclase and plagioclase. **Mafic** rocks such as gabbro are dark-colored, have lower silica contents, and are rich in iron and magnesium. Mafic rocks contain plagioclase, biotite, amphibole, pyroxene, and olivine. Diorite is a good example of an intermediate rock with moderate amounts of biotite, amphibole, and pyroxene.

Table 5-2 Classification of Igneous Rocks

	Felsic	Intermediate	Mafic	Ultramafic		Texture
Extrusive	Obsidian		Basaltic glass			Glassy (non-crystalline)
	Rhyolite	Andesite	Basalt			Fine-grained
Intrusive	Granite	Diorite	Gabbro	Peri-dotite	Dun-ite	Coarse-grained
	Pegmatite					Very coarse-grained



CONTENTS

MiniLab

How do igneous rocks differ?

Compare and **contrast** the different characteristics of igneous rocks.

Procedure

1. Using the igneous rock samples provided by your teacher, carefully observe the following characteristics of each rock: color, grain size, texture, and, if possible, mineral composition.
2. Design a data table in your science journal to record your observations.

Analyze and Conclude

1. Classify your rock samples as extrusive or intrusive rocks.
2. What characteristics do the extrusive rocks share? How do they differ? What characteristics do the intrusive rocks share? How do they differ?
3. Classify your rock samples as felsic, intermediate, mafic, or ultramafic.

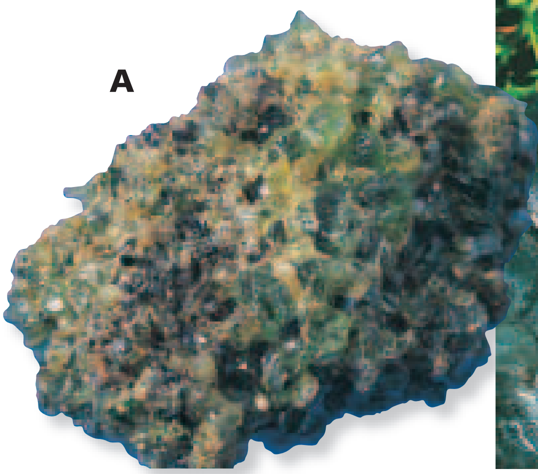
Ultramafic Rocks Two unusual igneous rocks, peridotite and dunite, have low silica contents and very high levels of iron and magnesium, and thus, they are classified as **ultramafic** rocks. Some scientists theorize these ultramafic rocks, shown in ***Figure 5-10,*** are formed by the fractional crystallization of olivine and pyroxene. The minerals may have been separated from magma and did not convert to another mineral upon reaching a particular temperature. Another hypothesis is that ultramafic rocks represent pieces of the upper mantle that have been brought close to Earth's surface. In the *MiniLab* on this page, you'll analyze the mineral compositions of various igneous rocks.

GRAIN SIZE

In addition to differences in their mineral compositions, igneous rocks differ in the sizes of their grains. ***Figure 5-11*** compares obsidian, a glassy extrusive rock, and gabbro, a coarse-grained intrusive rock. What might account for the lack of visible crystals in obsidian and the large crystals of gabbro?

Figure 5-10 Dunite **(A)** and peridotite **(B)** are ultramafic rocks. They have low silica contents and high levels of iron and magnesium.

A



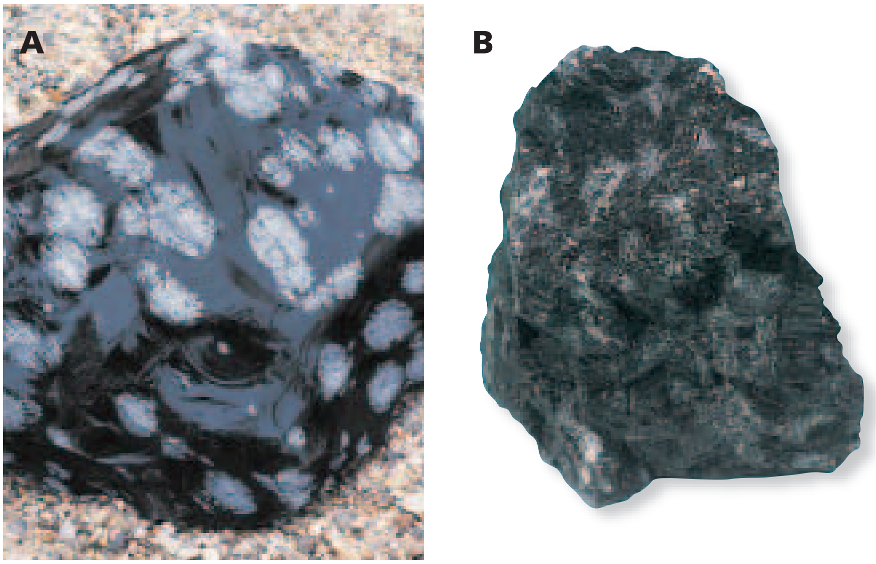


Figure 5-11 Obsidian cools quickly and has no visible mineral grains **(A).** The white patches that characterize this snowflake obsidian are mineral crystals that formed from impurities as the obsidian cooled. Gabbro cools slowly and thus large mineral grains form **(B).**

Cooling Rates When lava flows on Earth's surface, it is exposed to air and moisture. Under these conditions, the lava cools quickly, and there is not enough time for large crystals to form. Thus, extrusive igneous rocks such as obsidian have no visible mineral grains. In contrast, when magma cools slowly beneath Earth's surface, there is sufficient time for large crystals to form. Thus, intrusive igneous rocks such as gabbro may have crystals larger than 1 cm. You'll investigate the effects of cooling rate on crystal size in the *GeoLab* at the end of this chapter.

Texture

Often, it's easier to observe the sizes of mineral grains than it is to observe their shapes. Geologists solve this problem by making thin sections, which are slices of rock so thin that light can pass through them. As shown in the thin section in ***Figure 5-12,*** many mineral grains have interlocking edges. As the grains crystallize from magma, they grow together and form these irregular edges. Although irregular crystal shapes are characteristic of many igneous rocks, well-shaped crystals can form under certain conditions. During fractional crystallization, the minerals that form early in the process float in a liquid and have space in which to grow distinct crystal shapes.

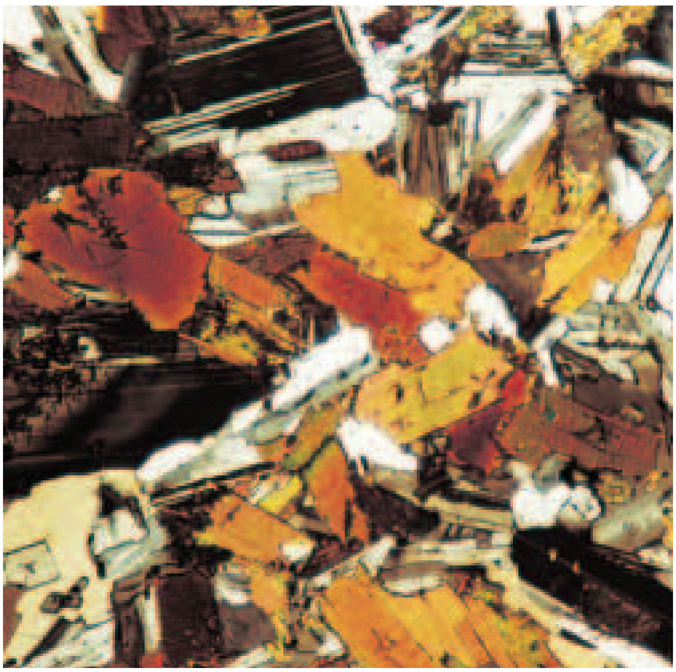
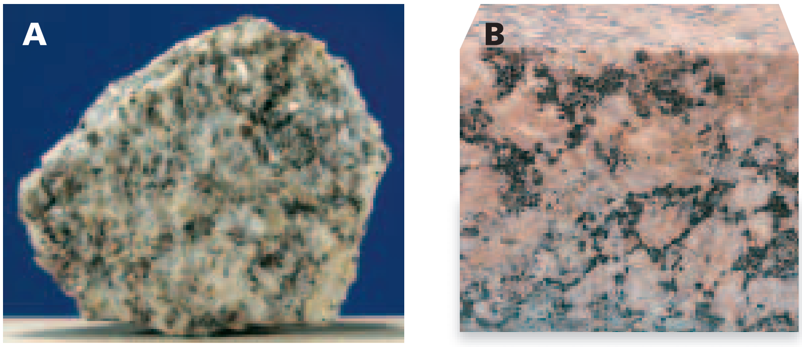


Figure 5-12 The interlocking edges of mineral grains are evident in this thin section of diorite.

Figure 5-13 The sample of granite has crystals of the same size **(A).** In contrast, the other granite sample has a porphyritic texture with crystals of different sizes **(B).**



Porphyritic Texture Compare the crystal textures of the rocks shown in ***Figure 5-13.*** One of the rocks has grains of two different sizes. This rock has a **porphyritic** texture, which is characterized by large, well-formed crystals surrounded by finer-grained crystals of the same mineral or different minerals.

What causes minerals to form both large and small crystals in the same rock? Porphyritic textures indicate a complex cooling history wherein a slowly cooling magma suddenly began cooling rapidly. Imagine a magma body cooling slowly deep in Earth's crust. As it cools, the resulting crystals grow large. If this magma were to be

Problem-Solving Lab

Interpreting Scientific Illustrations

Estimate mineral composition

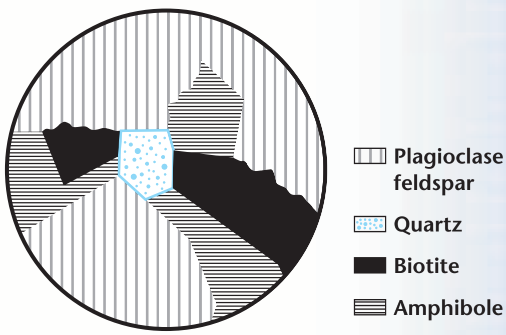
Igneous rocks are classified by their mineral compositions. In this activity, you'll estimate the different percentages of minerals in an igneous sample, then use your results to classify the rock.

Analysis

1. Using the diagram of the thin section shown here, design a method to estimate the percentages of the minerals in the rock sample.
2. Make a data table that lists the minerals and their estimated percentages.

Thinking Critically

3. Use ***Table 5-2*** to determine which type of igneous rock the thin section represents.
4. Compare your estimates of the percentages of minerals in the rock with those of your classmates. Hypothesize why the estimates vary. What are some possible sources of error?
5. What could you do to improve the accuracy of your estimate?



suddenly intruded higher in the crust, or if it erupted onto Earth's surface, the remaining magma would cool quickly and form smaller crystals. You'll explore other characteristics of igneous rocks in the *Problem-Solving Lab* on the previous page.

IGNEOUS ROCKS AS RESOURCES

Igneous rocks have several characteristics that make them especially useful as building materials. The interlocking grain textures of igneous rocks help to give them strength. In addition, many of the minerals found in igneous rocks are resistant to weathering. Granite is among the most durable of igneous rocks. Some common construction uses of granite are shown in ***Figure 5-14.*** You'll learn more about uses of other igneous rocks in the *Science & Technology* feature at the end of this chapter.

ENVIRONMENTAL CONNECTION

ORE DEPOSITS

As you learned in Chapter 4, ores are minerals that contain a useful substance that can be mined at a profit. Valuable ore deposits are often associated with igneous intrusions. Sometimes, these ore deposits are found within igneous rock, such as the layered intrusions mentioned earlier. Other times, ore minerals are found in the rocks surrounding intrusions. These type of deposits sometimes occur as veins.

Veins Recall from Bowen's reaction series that the fluid left during magma crystallization contains high levels of silica and water. This fluid also contains any leftover elements that

Figure 5-14 The columns in the Rhodes Memorial in Cape Town, South Africa **(A);** the kitchen tiles **(B);** and the Vietnam Memorial in Washington, D.C. **(C)** are all made of granite.

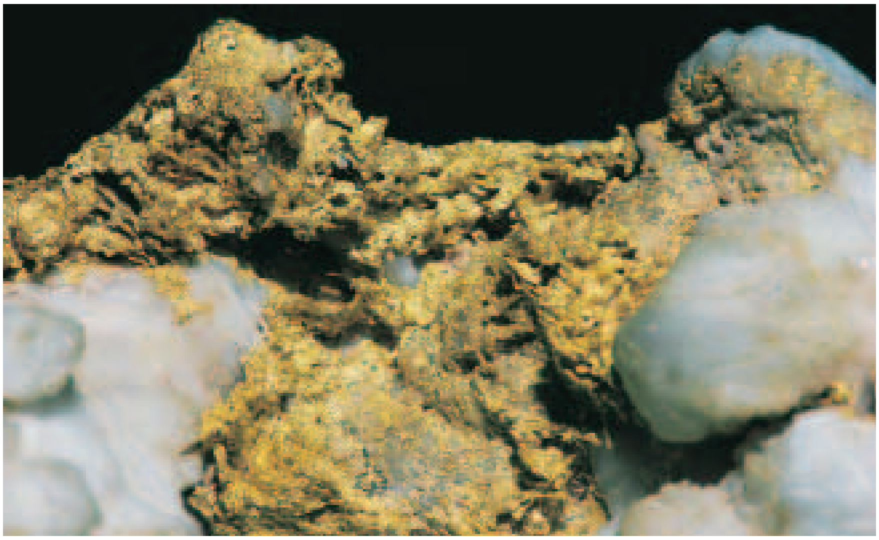


Figure 5-15 This sample of gold-bearing quartz came from El Dorado County, California.

Using Math

Using Numbers
A granite slab has a density of 2.7 g/cm^3. What is the mass of a 2-cm thick countertop that is 0.6 m x 2.5 m? How many pounds is this?

were not incorporated into the common igneous minerals. Some important metallic elements that are not included in common minerals are gold, silver, lead, and copper. These elements, along with the dissolved silica, are released at the end of magma crystallization in a hot, mineral-rich fluid that fills cracks and voids in the surrounding rock. This fluid solidifies to form metal-rich quartz veins, such as the gold-bearing veins found in the Sierra Nevada mountains of California. An example of gold-bearing quartz is shown in ***Figure 5-15.***

Pegmatites Vein deposits may contain other valuable resources in addition to metals. Veins of extremely large-grained minerals, such as the one shown in ***Figure 5-16A,*** are called **pegmatites.** Ores of rare elements such as lithium and beryllium are found in pegmatites. In addition to ores, pegmatites can produce beautiful crystals. Because these veins fill cavities and fractures in rock, minerals grow into voids and retain their shapes. Some of the world's most beautiful minerals have been found in pegmatites. An example is shown in ***Figure 5-16B.***

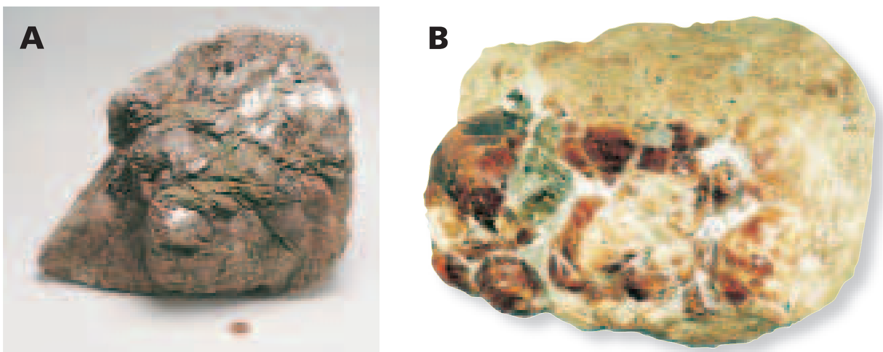


Figure 5-16 Pegmatites are veins of extremely large-grained minerals **(A).** Stunning crystals such as this garnet are often found in pegmatites **(B).**

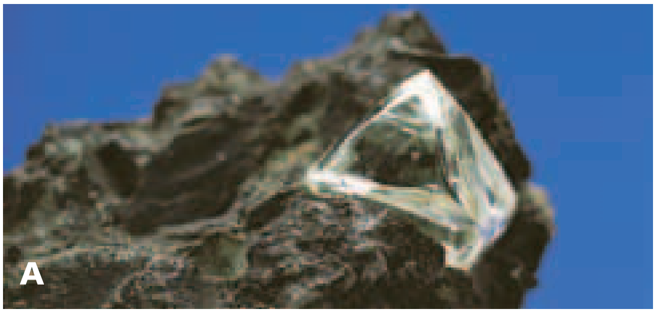


Figure 5-17 Diamonds are found in kimberlites **(A),** such as those in the Kimberly Diamond Mine in South Africa **(B).**

Kimberlites Diamond is a valuable mineral found in rare, ultramafic rocks known as **kimberlites,** named after Kimberly, South Africa, where the intrusions were first identified. These unusual rocks are a variety of peridotite. They likely form deep in the crust at depths of 150 to 300 km or in the mantle because diamond and other minerals found in kimberlites can form only under very high pressures.

Geologists hypothesize that kimberlite magma is intruded rapidly upwards towards Earth's surface, where it forms long, narrow, pipelike structures. These structures extend several kilometers into the crust, but they are only 100 to 300 m in diameter. Most of the world's diamonds come from South African mines, such as the one shown in ***Figure 5-17.***

Section Assessment

1. Describe the three major groups of igneous rocks. What are ultramafic rocks?
2. Why does rhyolite have smaller crystals than granite?
3. What chemical property is most commonly used to classify igneous rocks? List two physical properties that you could use to identify igneous rocks.
4. Why is gold often found in veins of quartz that are in and around igneous intrusions?
5. **Thinking Critically** Would quartz or plagioclase be more likely to form a well-shaped crystal in an igneous rock? Explain.

Skill Review

6. **Concept Mapping** Use the following terms to construct a concept map about igneous rock classification. For more help, refer to the *Skill Handbook.*

granite	ultramafic	diorite
types of igneous rocks	peridotite	intermediate
mafic	felsic	gabbro

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GeoLab

Modeling Crystal Formation

The rate at which magma cools has an effect on the grain size of the resulting igneous rock. Observing the crystallization of magma is difficult because molten rock is very hot and the crystallization process is sometimes very slow. Other materials, however, crystallize at lower temperatures. These materials can be used to model crystal formation.

Preparation

Problem

Model the crystallization of minerals from magma.

Materials

clean, plastic petri dishes
saturated alum solution
200-mL glass beaker
magnifying glass
piece of dark-colored construction paper
thermometer
paper towels
water
hot plate

Objectives

In this GeoLab, you will:

- **Determine** the relationship between cooling rate and crystal size.
- **Compare** and **contrast** different crystal shapes.

Safety Precautions

The alum mixture can cause skin irritation and will be hot when it is first poured into the petri dishes. If splattering occurs, wash skin with cold water. Always wear safety goggles and an apron in the lab.

Procedure

1. As a group, plan how you could change the cooling rate of a hot solution poured into a petri dish. For instance, you may want to put one sample in a freezer or refrigerator for a designated period of time. Assign each group member a petri dish to observe during the experiment.

2. Place a piece of dark-colored construction paper on a level surface where it won't be disturbed. Place the petri dishes on top of the paper.

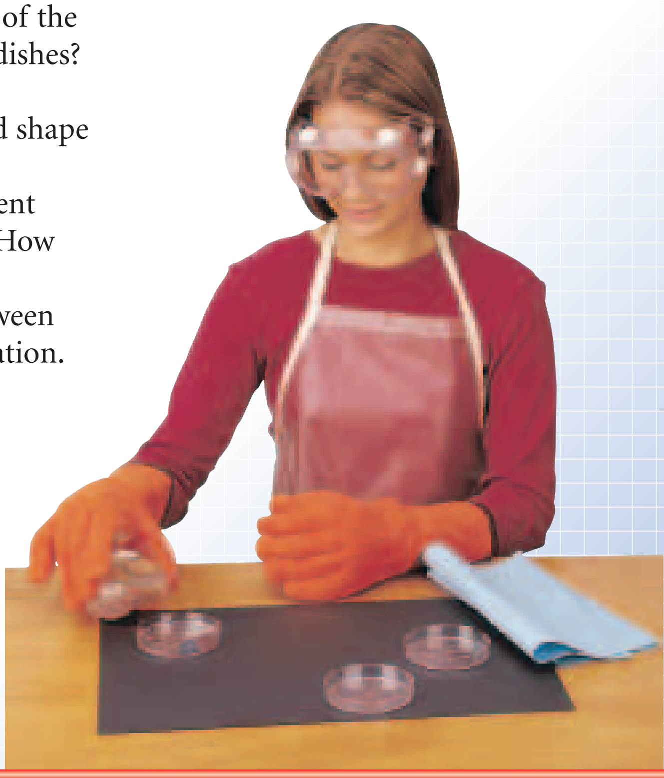
3. Carefully pour a saturated alum solution that is about 95°C to 98°C, or just below boiling temperature, into each petri dish so that it is half-full. Use caution when pouring the hot liquid to avoid splatters and burns.
4. Observe the petri dishes. Record your observations in your science journal. Draw what you observe happening in the petri dish assigned to you.
5. Every 5 minutes for 30 minutes, record your observations of your petri dish. Make accurate, full-sized drawings of any crystals that begin to form.

Analyze

1. How did you vary the cooling rate of the solutions in the petri dishes? Compare your methods with those of other groups. Did one method appear to work better than others? Explain.
2. Use a magnifying glass or binocular microscope to observe your alum crystals. What do the crystals look like? Are all the crystals the same size?
3. Compare your drawings and petri dish with those of other students in your group. Which petri dish had the smallest average crystal size? Describe the conditions under which that petri dish cooled.
4. Do all the crystals have the same shape? Draw the most common shape. Share your drawings with other groups. Describe any patterns that you see.

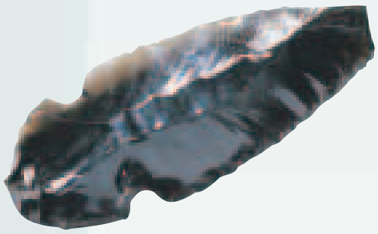
Conclude & Apply

1. What factors affected the size of the crystals in the different petri dishes? How do you know?
2. Infer why the crystals changed shape as they grew.
3. How is this experiment different from magma crystallization? How is it the same?
4. Describe the relationship between cooling rate and crystal formation.



Science & Technology

Cutting-Edge Surgery



When we hear the word technology, *we often envision complicated gadgets. But one of the earliest forms of technology centered around common rocks. To better hunt their prey, for instance, our early ancestors created razor-sharp arrowheads and spears from the igneous rock obsidian. Today, there's a new use for this old rock: plastic surgery.*

Knapping

Knapping is the process of shaping a rock by using a mallet-like instrument to break off pieces of the rock. For thousands of years, this technique has been used to shape obsidian into tools and decorative pieces. This fast-cooling, extrusive rock has a conchoidal fracture, which allows the rock to break in predictable ways. Knappers use three techniques, sometimes in combination, to shape obsidian. Percussion flaking involves using a hammer or mallet to shape the rock. Pressure flaking involves using specially designed tools to pry off flakes of the rock. Lastly, in indirect percussion, a tool called a punch is placed on the edge of the rock. Flaking results when the punch is struck by a hammer or mallet.

Obsidian Scalpels

Knapping is carried on today by skilled artisans. Some of these modern knappers have taken their craft into the medical field, and are creating scalpels made from obsidian. Because obsidian scalpels are handmade, their surfaces look somewhat rough compared with traditional stainless steel scalpels. However, obsidian scalpels actually have a much sharper, smoother edge than stainless steel scalpels. When viewed under an electron microscope, the edges of an obsidian scalpel meet at a single point, which gives the scalpel its fine, sharp edge. This sharpness allows the scalpel to "divide" rather than tear flesh. Unlike the stainless steel scalpel, the obsidian scalpel creates such a small incision it barely leaves a scar. For this reason, obsidian scalpels are particularly well-suited to plastic surgery.

Disadvantages

At present, only a few doctors use obsidian scalpels, largely because these handmade-tools are relatively expensive. The price of the scalpels is high because only a few knappers are producing the scalpels, and each scalpel takes days or even weeks to complete. The average obsidian scalpel may cost $20. In contrast, stainless steel scalpels, which can be mass-produced, cost approximately $2 each.

Reading Analysis

In addition to scalpels, obsidian is used to make knives. Other igneous rocks, such as granite, are used in the construction industry. Go to the Earth Science Web Site at earthgeu.com to research and write a report about some common uses for igneous rocks.

CHAPTER 5

Study Guide

Summary

SECTION 5.1

What are igneous rocks?

Main Ideas

- Igneous rocks are formed by the cooling and crystallization of magma. Intrusive rocks form inside Earth's crust, and extrusive rocks form on Earth's surface. Extrusive rocks, which cool more rapidly than intrusive rocks, are generally more fine grained.
- Magma is a slushy mix of molten rock, gases, and mineral crystals. The elements found in magma are the same major elements found in Earth's crust: oxygen (O), silicon (Si), aluminum (Al), iron (Fe), magnesium (Mg), calcium (Ca), potassium (K), and sodium (Na).
- Silica (SiO_2) is the most abundant compound in magma. Magmas are classified as basaltic, andesitic, and rhyolitic, based on the amount of SiO_2 they contain.
- Different minerals melt and crystallize at different temperatures in the processes of partial melting and fractional crystallization. Minerals crystallize from magma in a sequential pattern known as Bowen's reaction series.

Vocabulary

Bowen's reaction series (p. 103)
extrusive (p. 99)
fractional crystallization (p. 103)
igneous rock (p. 99)
intrusive (p. 99)
lava (p. 99)
partial melting (p. 102)

SECTION 5.2

Classifying Igneous Rocks

Main Ideas

- Igneous rocks are classified as felsic, mafic, intermediate, and ultramafic, depending upon their mineral compositions. Felsic rocks such as granite are light-colored, have high silica contents, and contain quartz and feldspars. Mafic rocks such as gabbro are dark-colored, have lower silica contents, and are rich in iron and magnesium. Intermediate rocks have moderate silica levels. Ultramafic rocks have low silica contents and very high levels of iron and magnesium. Igneous groups can be further identified by crystal size and texture.
- Early forming minerals may have well-shaped crystals, while later-forming minerals have irregular shapes. Porphyritic textures contain both large and small crystals.
- Igneous rocks such as granite are often used as building materials because of their strength, durability, and beauty.
- Valuable ore deposits and gems are often associated with igneous intrusions. Ores of rare elements such as lithium and beryllium are found in veins of extremely large-grained minerals called pegmatites. Diamonds are found in rare types of igneous intrusions known as kimberlites.

Vocabulary

felsic (p. 107)
kimberlite (p. 113)
mafic (p. 107)
pegmatite (p. 112)
porphyritic (p. 110)
ultramafic (p. 108)

earthgeu.com/vocabulary_puzzlemaker

CHAPTER 5

Assessment

Understanding Main Ideas

1. What term describes igneous rocks that crystallize inside Earth?
   a. magma **c.** lava
   b. intrusive **d.** extrusive

2. What magma type contains the greatest amount of SiO_2?
   a. basaltic **c.** rhyolitic
   b. andesitic **d.** peridotitic

3. What igneous rock has no visible crystals as a result of rapid cooling?
   a. gabbro **c.** obsidian
   b. andesite **d.** pegmatite

4. What type of ultramafic rock sometimes contains diamond?
   a. pegmatite **c.** granite
   b. kimberlite **d.** rhyolite

5. What minerals are associated with the right branch of Bowen's reaction series?
   a. olivine and pyroxene **c.** mica and feldspars
   b. feldspars **d.** quartz and biotite

6. What is the last mineral to crystallize from magma?
   a. biotite **c.** olivine
   b. plagioclase **d.** quartz

7. What are veins of extremely coarse-grained igneous rocks called?
   a. gabbros **c.** pegmatites
   b. layered intrusions **d.** crystals

8. What effect does a fast cooling rate have on grain size in igneous rocks?
   a. It forms fine-grained crystals.
   b. It forms large-grained crystals.
   c. It forms light crystals.
   d. It forms dark crystals.

9. What term describes magma that flows out onto Earth's surface?
   a. layered intrusion **c.** crystallization
   b. lava **d.** ultramafic

10. Which of the following affects the melting temperature of magma?
    a. ore deposits **c.** oxygen content
    b. silica content **d.** potassium content

11. Which of the following does not affect the formation of magma?
    a. temperature **c.** volume
    b. pressure **d.** mineral composition

12. What are some uses of igneous rocks in the construction industry?

13. Why do scientists theorize that kimberlites originate deep within Earth's crust or mantle?

14. What are the three main types of magma? What factor determines these classifications?

15. Describe Bowen's reaction series. Be sure to discuss the two branches of the series.

16. Why are olivine and calcium-rich plagioclase often found together in igneous rocks?

Test-Taking Tip

GET TO THE ROOT OF THINGS. If you don't know the definition of a word, you can infer its meaning by examining its roots, prefixes, and suffixes. For instance, words that start with *non-*, *un-*, *a-*, *dis-*, and *in-* generally reverse what the rest of the word means. Words that end in *-ly* are usually adverbs, and thus, are descriptive terms.

earthgeu.com/chapter_test

Applying Main Ideas

17. Why is magma usually a slushy mixture of crystals and molten rock?
18. What is unusual about peridotite and dunite?

Use the table below to answer questions 19-21.

Rock Composition

Mineral	Mineral Percentage			
	Rock 1	Rock 2	Rock 3	Rock 4
Quartz	5	35	0	0
Potassium feldspar	0	15	0	0
Plagioclase feldspar	55	25	0	55
Biotite	15	15	0	10
Amphibole	25	10	0	30
Pyroxene	0	0	40	5
Olivine	0	0	60	0

19. Which rock is most likely granite?
20. Which rock is an ultramafic rock?
21. Rock 4 is fine grained. What type of rock is it?
22. What characteristics of igneous rocks make them good building materials?

Thinking Critically

23. How is it possible for magma to have a higher silica content than the rock from which it formed?
24. Would you expect to find plagioclase feldspar or biotite in a greater variety of igneous rocks? Explain.
25. Which would make a lighter-colored kitchen counter, granite or gabbro? Why?
26. Why are mineral deposits often found around the perimeter of igneous intrusions?

Standardized Test Practice

1. Which of the following is most abundant in magma and has the greatest effect on its characteristics?
   - **a.** O
   - **b.** Ca
   - **c.** Al
   - **d.** SiO_2
2. Which process describes how different minerals form at different rates?
   - **a.** partial melting
   - **b.** Bowen's reaction series
   - **c.** fractional crystallization
   - **d.** geothermal gradient

USING TABLES Use the table to answer questions 3 and 4.

Characteristics of Rocks

	Color	Silica Content	Composition
Rock A	light	high	quartz and feldspars
Rock B	dark	low	iron and magnesium

3. Rock A is most likely what kind of rock?
   - **a.** felsic
   - **b.** mafic
   - **c.** ultramafic
   - **d.** intermediate
4. Which type of rock is rock B?
   - **a.** granite
   - **b.** diorite
   - **c.** gabbro
   - **d.** pegmatite