CHAPTER 5

Igneous Rocks

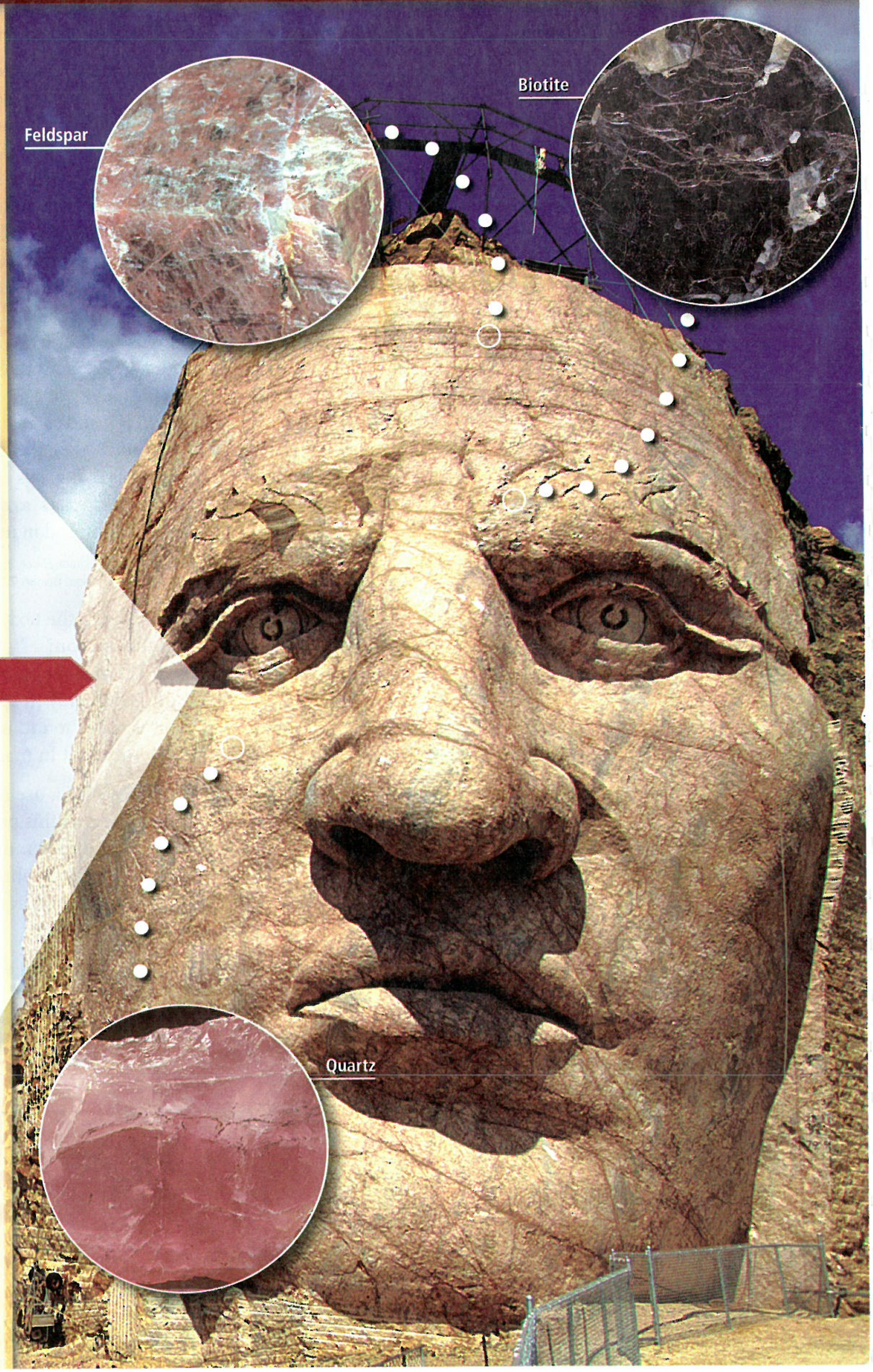
BIG Idea **Igneous rocks were the first rocks to form as Earth cooled from a molten mass to the crystalline rocks of the early crust.**

5.1 What are igneous rocks?
MAIN Idea Igneous rocks are the rocks that form when molten material cools and crystallizes.

5.2 Classification of Igneous Rocks
MAIN Idea Classification of igneous rocks is based on mineral composition, crystal size, and texture.

GeoFacts

- In the monument pictured here, Crazy Horse's head is over 26 m tall.
- The monument, located in South Dakota, was started in 1948 and is still a work in progress. The next component created will be his arm, which will measure more than 70 m.
- When completed, the monument will be more than 170 m tall and 195 m long. Nearly 10,000,000 metric tons of rock have already been blasted away.



LAUNCH Lab

How are minerals identified?

Igneous rocks are composed of different types of minerals. It is often possible to identify the different minerals in a sample of rock.

Procedure

1. Read and complete the lab safety form.
2. Examine a **sample of granite** from a distance of about 1 m. Record your observations.
3. Use a **magnifying lens** or **microscope** to observe the granite sample. Record your observations.

Analysis

1. **Illustrate** what you saw through the magnifying glass or microscope. Include a scale for your drawing.
2. **List** the different minerals that you observed in your sample.
3. **Describe** the sizes and shapes of the mineral crystals.
4. **Describe** any evidence that suggests that these crystals formed from molten rock.

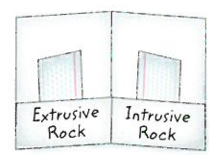
FOLDABLES™ Study Organizer

Types of Igneous Rocks Make this Foldable to compare intrusive and extrusive igneous rock.

STEP 1 Fold the bottom of a horizontal sheet of paper up about 3 cm.

STEP 2 Fold in half.

STEP 3 Unfold once, and dot with glue or staple to make two pockets. Label as shown.



FOLDABLES Use this Foldable with Section 5.1. As you read this section, use index cards or quarter sheets of paper to summarize how each type of rock forms and give examples.

Earth Science Online

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Section 5.1

Objectives

- **Summarize** igneous rock formation.
- **Describe** the composition of magma.
- **Identify** the factors that affect how rocks melt and crystallize.

Review Vocabulary

silicate: mineral that contains silicon and oxygen, and usually one or more other elements

New Vocabulary

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

What are igneous rocks?

MAIN Idea **Igneous rocks are the rocks that form when molten material cools and crystallizes.**

Real-World Reading Link At any given point in time, igneous rocks are forming somewhere on Earth. The location and the conditions that are present determine the types of igneous rocks that form.

Igneous Rock Formation

If you live near an active volcano, you can literally watch igneous rocks form. A hot, molten mass of rock can solidify into solid rock overnight. As you read in Chapter 4, magma is molten rock below Earth's surface. **Lava** is magma that flows out onto Earth's surface. **Igneous rocks** form when lava or magma cools and minerals crystallize.

In the laboratory, most rocks must be heated to temperatures of 800°C to 1200°C before they melt. In nature, these temperatures are present 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.

Composition of magma The type of igneous rock that forms depends on the composition of the magma. Magma is often a slushy mix of molten rock, dissolved gases, and mineral crystals. The common elements present in magma are the same major elements that are 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 present in magma, silica is the most abundant and has the greatest effect on magma characteristics. As summarized in **Table 5.1,** magma is classified as basaltic, andesitic, or rhyolitic, based on the amount of silica it contains. Silica content affects melting temperature and impacts how quickly magma flows.

Concepts In Motion

Interactive Table To explore more about magma composition, visit glencoe.com.

Table 5.1 Types of Magma

Group	Silica Content	Example Location
Basaltic	42–52%	Hawaiian Islands
Andesitic	52–66%	Cascade Mountains, Andes Mountains
Rhyolitic	more than 66%	Yellowstone National Park

Once magma is free of the overlying pressure of the rock layers around it, dissolved gases are able to escape into the atmosphere. Thus, the chemical composition of lava is slightly different from the chemical composition of the magma from which it developed.

Magma formation Magma can be formed either by melting of Earth's crust or by melting within the mantle. The four main factors involved in the formation of magma are temperature, pressure, water content, and the mineral content of the crust or mantle. Temperature generally increases with depth in Earth's crust. This temperature increase, known as the geothermal gradient, is plotted in **Figure 5.1.** Oil-well drillers and miners have firsthand experience with the geothermal gradient. Drill bits, such as the one shown in **Figure 5.2,** can encounter temperatures in excess of 200°C when drilling deep oil wells.

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 that melts at 1100°C at Earth's surface will melt at 1400°C 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.

Reading Check List the main factors involved in magma formation.

Mineral content In order to better understand how the types of elements and compounds present give magma its overall character, it is helpful to discuss this fourth factor in more detail. Different minerals have different melting points. For example, rocks such as basalt, which are formed of olivine, calcium feldspar, and pyroxene (pi RAHK seen), melt at higher temperatures than rocks such as granite, which contain quartz and potassium feldspar. Granite has a melting point that is lower than basalt's melting point because granite contains more water and minerals that melt at lower temperatures. In general, rocks that are rich in iron and magnesium melt at higher temperatures than rocks that contain higher levels of silicon.

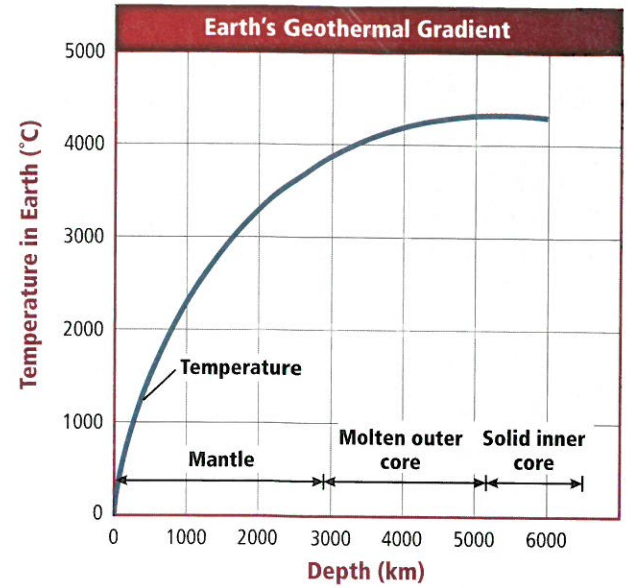


Figure 5.1 The average geothermal gradient in the crust is about 25°C/km, but scientists think that it drops sharply in the mantle to as low as 1°C/km.

Figure 5.2 The temperature of Earth's upper crust increases with depth by about 30°C for each 1 km. At a depth of 3 km, this drill bit will encounter rock that is close to the temperature of boiling water.

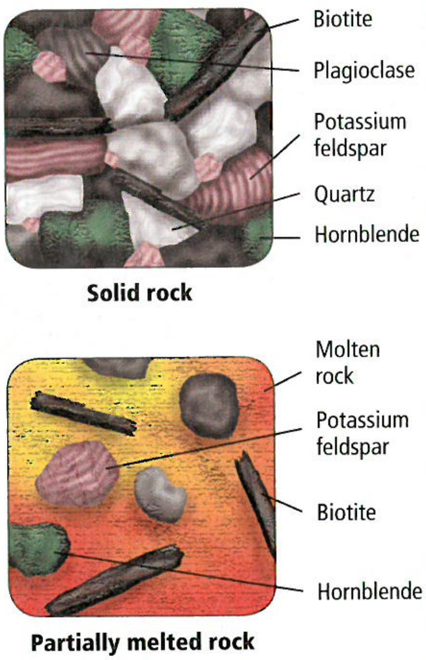


Figure 5.3 As the temperature increases in an area, minerals begin to melt.
Determine ***What can you suggest about the melting temperature of quartz based on this diagram?***

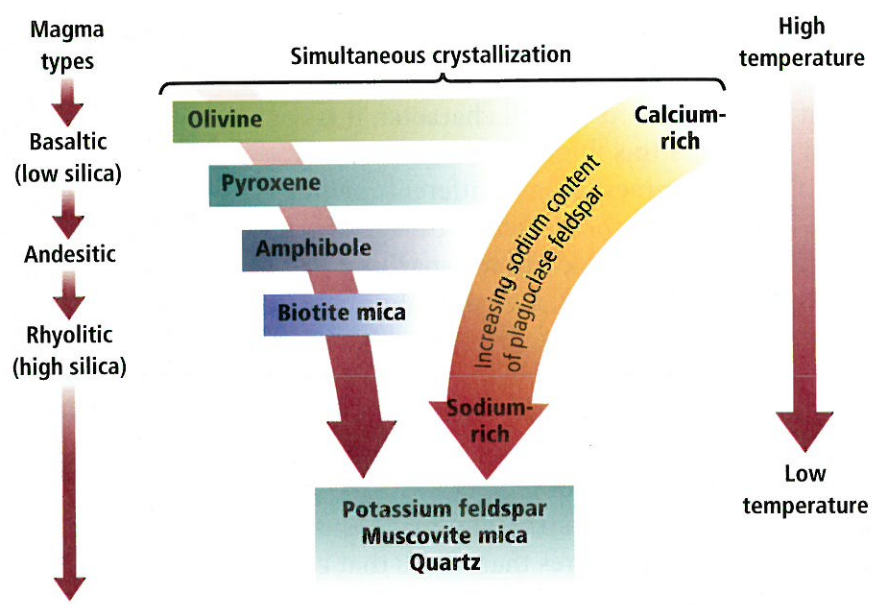
Partial melting Suppose you froze melted candle wax and water in an ice cube tray. If you took the tray out of the freezer and left it at room temperature, the ice would melt, but the candle wax would not. This is because the two substances have different melting points. Rocks melt in a similar way because the minerals they contain have different melting points. Not all parts of a rock melt at the same temperature. This explains why magma is often a slushy mix of crystals and molten rock. The process whereby some minerals melt at relatively low temperatures while other minerals remain solid is called **partial melting.** Partial melting is illustrated in **Figure 5.3.** As each group of minerals melts, different elements are added to the magma mixture thereby changing its composition. If temperatures are not high enough to melt the entire rock, the resulting magma will have a different composition than that of the original rock. This is one way in which different types of igneous rocks form.

Reading Check **Summarize** the formation of magma that has a different chemical composition from the original rock.

Bowen's Reaction Series

In the early 1900s, Canadian geologist N. L. Bowen demonstrated that as magma cools and crystallizes, minerals form in predictable patterns in a process now known as the **Bowen's reaction series.** **Figure 5.4** illustrates the relationship between cooling magma and the formation of minerals that make up igneous rock. Bowen discovered two main patterns, or branches, of crystallization. The right-hand branch is characterized by a continuous, gradual change of mineral compositions in the feldspar group. An abrupt change of mineral type in the iron-magnesium groups characterizes the left-hand branch.

Figure 5.4 On the left side of Bowen's reaction series, minerals rich in iron and magnesium change abruptly as the temperature of the magma decreases.
Compare ***How does this compare to the feldspars on the right side of the diagram?***



Iron-rich minerals The left branch of Bowen's reaction series represents the iron-rich minerals. These minerals undergo abrupt changes as magma cools and crystallizes. For example, olivine is the first mineral to crystallize when magma that is rich in iron and magnesium begins to cool. When the temperature decreases enough for a completely new mineral, pyroxene, to form, the olivine that previously formed reacts with the magma and is converted to pyroxene. As the temperature decreases further, similar reactions produce the minerals amphibole and biotite mica.

Feldspars In Bowen's reaction series, the right branch represents the plagioclase feldspars, which undergo a continuous change of composition. 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, such as when magma cools rapidly, the calcium-rich cores are unable to react completely with the magma. The result is a zoned crystal, as shown in **Figure 5.5.**

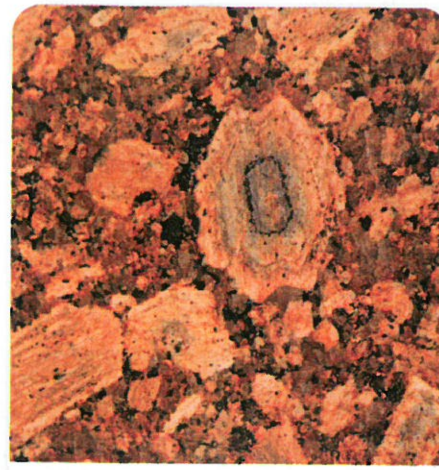


Figure 5.5 When magma cools quickly, a feldspar crystal might not have time to react completely with the magma and might retain a calcium-rich core. The result is a crystal with distinct calcium-rich and sodium-rich zones.

FOLDABLES

Incorporate information from this section into your Foldable.

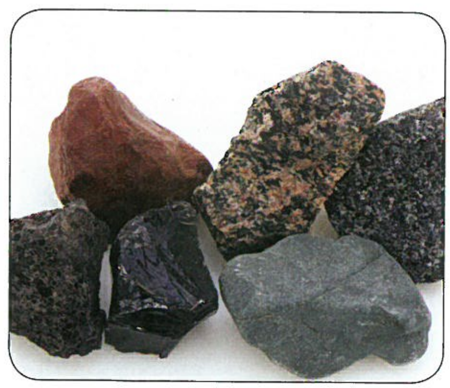
Fractional Crystallization

When magma cools, it crystallizes in the reverse order of partial melting. That is, the first minerals that crystallize from magma are the last minerals that melted during partial melting. This process, called **fractional crystallization,** is similar to partial melting in that the composition of magma can change. In this case, however, early formed crystals are removed from the magma and cannot react with it. As minerals form and their elements are removed from the remaining magma, it becomes concentrated in silica.

MiniLab

Compare Igneous Rocks

How do igneous rocks differ? Igneous rocks have many different characteristics. Color and crystal size are some of the features that differentiate igneous rocks.



Procedure

1. Read and complete the lab safety form.
2. Obtain a set of **igneous rock samples** from your teacher.
3. Carefully observe the following characteristics of each rock: overall color, crystal size, and, if possible, mineral composition.
4. Design a data table to record your observations.

Analysis

1. **Classify** your samples as either basaltic, andesitic, or rhyolitic. [Hint: The more silica in the rock, the lighter it is in color.]
2. **Compare and contrast** your samples using the data from the data table. How do they differ? What characteristics do each of the groups share?
3. **Speculate** in which order the samples crystallized. [Hint: Use Bowen's reaction series as a guide.]

Visualizing Fractional Crystallization and Crystal Settling

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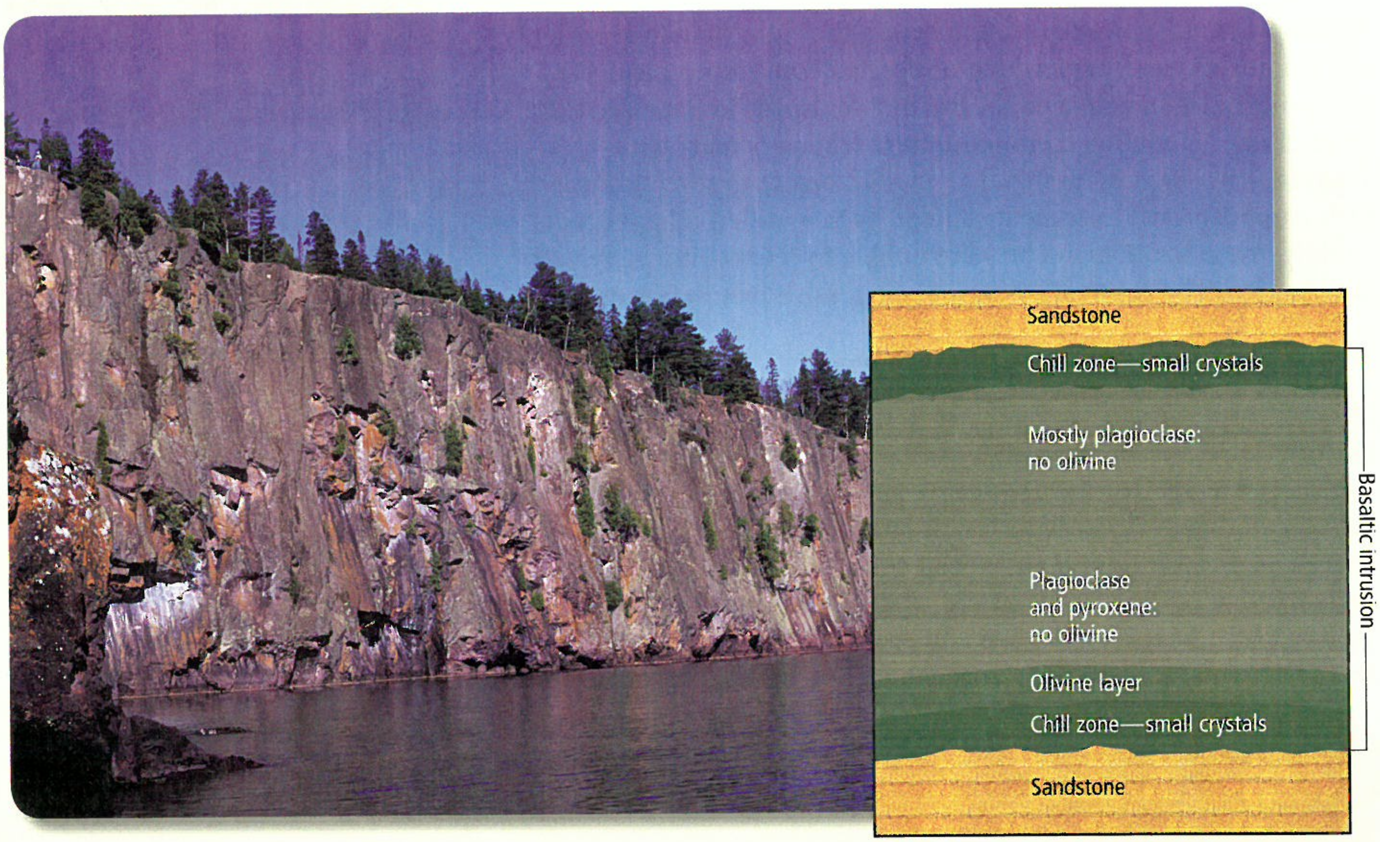
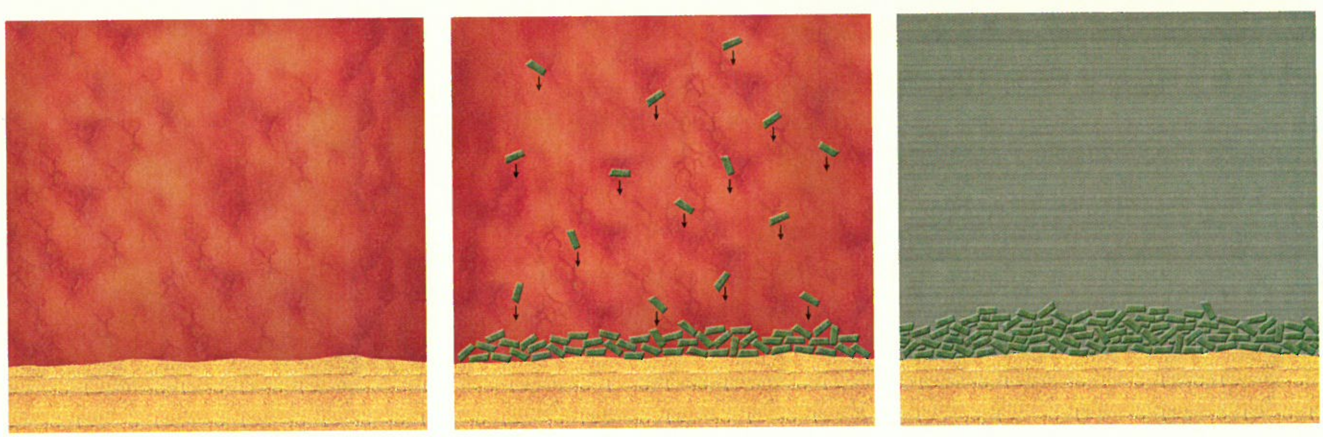
Figure 5.6 The Palisades Sill in the Hudson River valley of New York and New Jersey is a classic example of fractional crystallization and crystal settling. In the basaltic intrusion, small crystals formed in the chill zone as the outer areas of the intrusion cooled more quickly than the interior.





As magma in an intrusion begins to cool, crystals form and settle to the bottom. This layering of crystals is fractional crystallization.

Concepts In Motion To explore more about the Palisade Sill, visit glencoe.com.

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As is often the case with scientific inquiry, the discovery of 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. This 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. **Figure 5.6** illustrates this process and the concept of fractional crystallization with an example from the Hudson River valley in New York and New Jersey. This is one way in which the magmas listed in **Table 5.1** are formed.

As fractional crystallization continues and more magma is separated from the crystals, the magma becomes more concentrated in silica, aluminum, and potassium. This is why the last two minerals to form are potassium feldspar and quartz. Potassium feldspar is one of the most common feldspars in Earth's crust. Quartz often occurs in veins, as shown in **Figure 5.7,** because it crystallizes while the last liquid portion of magma is squeezed into rock fractures.

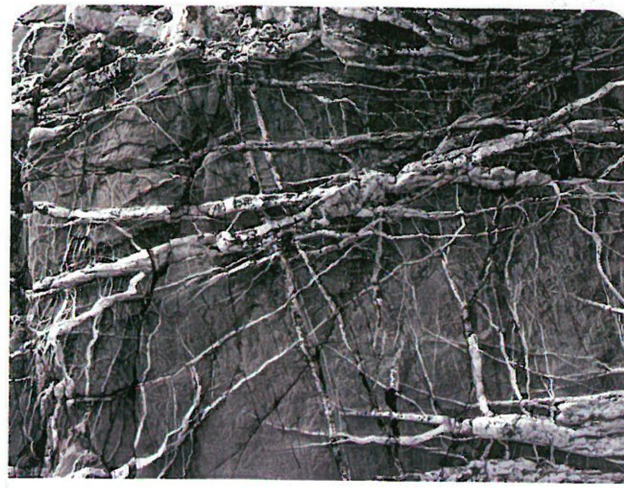

Figure 5.7 These quartz veins represent the last remnants of a magma body that cooled and crystallized.

Section 5.1 Assessment

Section Summary

- Magma consists of molten rock, dissolved gases, and mineral crystals.
- Magma is classified as basaltic, andesitic, or rhyolitic, based on the amount of silica it contains.
- Different minerals melt and crystallize at different temperatures.
- Bowen's reaction series defines the order in which minerals crystallize from magma.

Understand Main Ideas

1. MAIN Idea **Predict** the appearance of an igneous rock that formed as magma cooled quickly and then more slowly.
2. **List** the eight major elements present in most magmas. Include the chemical symbol of each element.
3. **Summarize** the factors that affect the formation of magma.
4. **Compare and contrast** magma and lava.

Think Critically

5. **Predict** If the temperature increases toward the center of Earth, why does the inner core become solid?
6. **Infer** the silica content of magma derived from partial melting of an igneous rock. Would it be higher, lower, or about the same as the rock itself? Explain.

WRITING in Earth Science

7. A local rock collector claims that she has found the first example of pyroxene and sodium-rich feldspar in the same rock. Write a commentary about her claim for publication in a rock collector society newsletter.

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