Applications and Investigations in

Earth Science

Tarbuck • Lutgens • Pinzke

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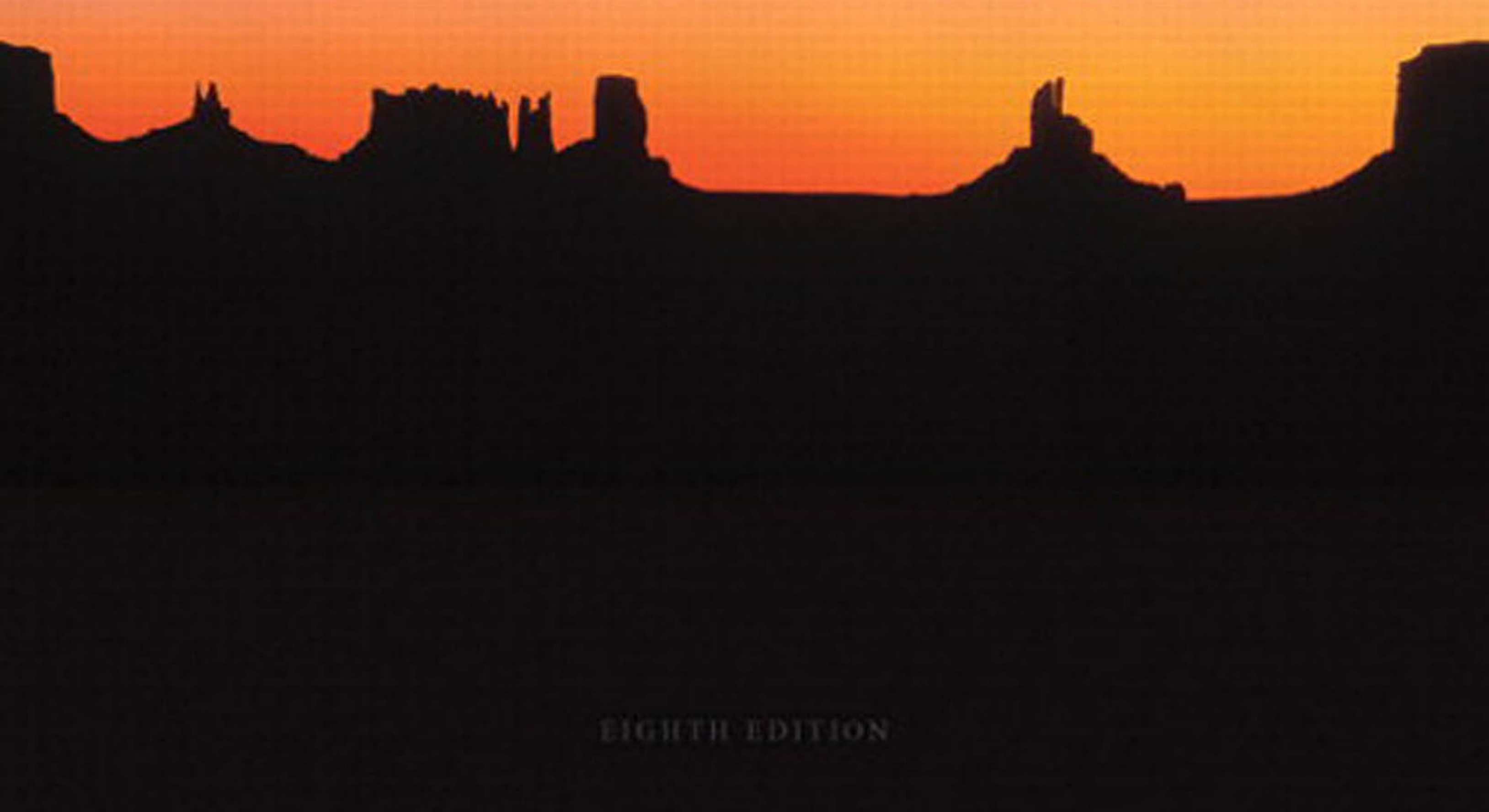

EIGHTH EDITION

Symbols used on topographic maps produced by the U.S. Geological Survey

Variations will be found on older maps.

Control data and monuments

Vertical control	
Third order or better, with tablet	BM_3 16.3
Third order or better, recoverable mark	3 120.0
Bench mark at found section corner	BM 18.6
Spot elevation	3 5.3

Contours

Topographic	
Intermediate	
Index	
Supplementary	
Depression	
Cut; fill	
Bathymetric	
Intermediate	
Index	
Primary	
Index primary	
Supplementary	

Boundaries

National	
State or territorial	
County or equivalent	
Civil township or equivalent	
Incorporated city or equivalent	
Park, reservation, or monument	

Surface features

Levee	Levee
Sand or mud area, dunes, or shifting sand	Sand
Intricate surface area	Strip mine
Gravel beach or glacial moraine	Gravel
Tailings pond	Tailings pond

Mines and caves

Quarry or open pit mine	
Gravel, sand, clay, or borrow pit	
Mine tunnel or cave entrance	
Mine shaft	
Prospect	
Mine dump	Mine dump
Tailings	Tailings

Vegetation

Woods	
Scrub	
Orchard	
Vineyard	
Mangrove	Mangrove

Glaciers and permanent snowfields

Contours and limits	
Form lines	

Marine shoreline

Topographic maps	
Approximate mean high water	
Indefinite or unsurveyed	
Topographic-bathymetric maps	
Mean high water	
Apparent (edge of vegetation)	

Submerged areas and bogs

Marsh or swamp	
Submerged marsh or swamp	
Wooded marsh or swamp	
Submerged wooded marsh or swamp	
Rice field	Rice
Land subject to inundation	Max pool 431

Coastal features

Foreshore flat	Mud
Rock or coral reef	Reef
Rock bare or awash	
Group of rocks bare or awash	
Exposed wreck	
Depth curve; sounding	3
Breakwater, pier, jetty, or wharf	
Seawall	

Rivers, lakes, and canals

Intermittent stream	
Intermittent river	
Disappearing stream	
Perennial stream	
Perennial river	
Small falls; small rapids	
Large falls; large rapids	
Masonry dam	
Dam with lock	
Dam carrying road	
Perennial lake; Intermittent lake or pond	
Dry lake	Dry lake
Narrow wash	
Wide wash	Wide wash
Canal, flume, or aquaduct with lock	
Well or spring; spring or seep	

Buildings and related features

Building	
School; church	
Urban area	
Racetrack	
Airport	
Landing strip	
Well (other than water); windmill	
Tanks	
Covered reservoir	
Gaging station	
Landmark object (feature as labeled)	
Campground; picnic area	
Cemetery: small; large	Cem

Roads and related features

Roads on Provisional edition maps are not classified as primary, secondary, or light duty. They are all symbolized as light duty roads.

Primary highway	
Secondary highway	
Light duty road	
Unimproved road	
Trail	
Dual highway	
Dual highway with median strip	

Railroads and related features

Standard gauge single track; station	
Standard gauge multiple track	
Abandoned	

Transmission lines and pipelines

Power transmission line; pole; tower	
Telephone line	Telephone
Aboveground oil or gas pipeline	
Underground oil or gas pipeline	Pipeline

Applications and Investigations in

Earth Science

Edward J. Tarbuck

Frederick K. Lutgens

Kenneth G. Pinzke

ILLUSTRATED BY DENNIS TASA

EIGHTH EDITION

PEARSON

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Dedication

Our longtime friend and colleague Ken Pinzke (1945–2009) contributed more than 40 years of professional and passionate effort to educating students in the Earth sciences. It is to his memory that we dedicate this edition.

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Preface

As with previous editions, *Applications and Investigations in Earth Science* is intended to be a supplemental tool for achieving an understanding of the basic principles of geology, oceanography, meteorology, and astronomy. While enrolled in what may be their first, and possibly only, Earth science course, students will greatly benefit from putting the material *presented* in the classroom to *work* in the laboratory. Learning, we believe, becomes significant and long-lasting when accomplished through discovery.

New to the Eighth Edition

One of the goals for this eighth edition was to minimize the need for lengthy presentations at the start of each lab session. This allows more time for student involvement in lab activities, as well as more time for instructors to interact with students individually or in small groups. Here is a list of important changes to this new edition:

- **Pre-lab videos.** Each lab is accompanied by a pre-lab video, prepared and narrated by Professor Callan Bentley. Each lesson examines and explains the key ideas explored in the exercise, thereby eliminating the need for a pre-lab lecture by the instructor.
- **Improved design and layout.** An important focus for this edition was revising the design and layout of the manual to increase ease of use and thereby promote student learning. Each exercise has been divided into sections that include background material and one or more related activities for students to complete. This new layout makes it easier for instructors to customize each exercise to fit the allotted lab period and their individual teaching preferences. This design also more effectively ties figures and tables to the associated activities.
- **MasteringGeology™.** MasteringGeology delivers engaging, dynamic learning opportunities—focused on course objectives and responsive to each student's progress—that are proven to help students understand difficult concepts. Materials in MasteringGeology include Pre-Lab Videos, Geoscience Animations, RSS Feeds, Key Term Study Tools, The Math You Need, and an optional Pearson eText.
- **SmartFigures—art that teaches.** Inside most exercises are *SmartFigures*. Students may use a mobile device to scan the Quick Response (QR) code next to a SmartFigure to view enhanced, dynamic art. Each 2- to 3-minute feature, prepared and narrated by Professor Callan Bentley, is a mini-lesson that examines and explains the concepts illustrated by the figure. It is truly *art that teaches*.
- **Exercises that are more self-contained.** Significant effort has been put into making the exercises less reliant on traditional text material and/or direct faculty instruction. In some cases, we have provided additional background material within the exercise. By contrast, we have modified or replaced questions that relied heavily on outside material. We are confident that these changes, both major and minor, make the exercises more useful and meaningful for students as well as instructors.
- **A more inquiry-based lab experience.** Whenever possible, the exercises have been modified to provide more hands-on learning. We have also endeavored to engage students in gathering and analyzing scientific data to improve their critical reasoning skills.
- **Content and illustrations revised to improve clarity.** Our many years in the classroom have made us keenly aware of the frustration that students and instructors face when instructions, illustrations, and questions are unclear. Likewise, we recognize that instructors are genuinely interested in making learning experiences meaningful for their students. With those ideas in mind, the exercises were reviewed not only by Earth science faculty but also by a support team with educational backgrounds other than

Earth science—a reflection, essentially, of the majority of the students who utilize this manual.

We sincerely hope that this eighth edition enhances the planning and implementation of instructional goals of all faculty—those who have used our materials for many years as well as those who bring fresh ideas and perspectives to the classrooms of the twenty-first century.

Acknowledgements

Writing a laboratory manual requires the talents and cooperation of many people. It is truly a team effort, and we authors are fortunate to be part of an extraordinary team at Pearson Education. In addition to being great people to work with, all are committed to producing the best textbooks possible. Special thanks to our editor, Andy Dunaway, who invested a great deal of time, energy, and effort in this project. We appreciate his enthusiasm, hard work, and quest for excellence. We also appreciate our conscientious project manager, Crissy Dudonis, whose job it was to keep track of all that was going on—and a lot was going on.

As always, we want to acknowledge the production team, led by Heidi Allgair at Cenveo® Publisher Services, who turned our manuscript into a finished product. The team included copy editor Kitty Wilson, compositor Annamarie Boley, and proofreader Heather Mann. These talented people are true professionals, with whom we are very fortunate to be associated.

We owe special thanks to a number of other people who were critical to this project:

- Working with Dennis Tasa, who creates the manual's outstanding illustrations, is always enjoyable and rewarding. We value his amazing artistic talent, imagination, and extraordinary patience with extensive revisions. Dennis and his excellent staff have made preparing this edition a pleasure.
- We value the support of Teresa Tarbuck of Franciscan University, whose editorial assistance greatly enhanced this eighth edition. She helped make the exercises more current, readable, and engaging.
- Callan Bentley has been an important contributor to this edition of *Applications and Investigations*. Callan is an assistant professor of geology at Northern Virginia Community College in Annandale, where he has been honored many times as an outstanding teacher. He is a frequent contributor to *Earth* magazine and author of the popular geology blog *Mountain Beltway*. Callan was responsible for preparing the pre-lab videos and SmartFigures that appear throughout this manual.

Appreciation also goes to our colleagues who prepared in-depth reviews. Their critical comments and thoughtful input helped guide and strengthen our efforts. Special thanks to:

Glenn Blaylock, Laredo Community College
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James Sachinelli, Atlantic Cape Community College

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Last, but certainly not least, we gratefully acknowledge the support and encouragement of our wives, Joanne Bannon and Nancy Lutgens. Preparation of *Applications and Investigations in Earth Science*, eighth edition, would have been far more difficult without their assistance, patience, and understanding.

Ed Tarbuck
Fred Lutgens

PART 1 GEOLOGY

EXERCISE 1

The Study of Minerals

LEARNING OBJECTIVES

After you complete this exercise, you should be able to:

1. Describe the physical properties commonly used to identify minerals.
2. Identify minerals using a mineral identification key.
3. Identify by sight some common rock-forming minerals.
4. List the uses of several economic minerals.

MATERIALS

set of mineral specimens
streak plate
dilute hydrochloric acid
hand lens
magnet
glass plate

PRE-LAB VIDEO

Prepare for lab! Prior to attending your laboratory session, view the pre-lab video. Each video provides valuable background that will contribute to your understanding and success in lab.

INTRODUCTION

For a student learning about our planet, identifying minerals using relatively simple techniques is an important skill. Knowledge of common minerals and their properties is basic to an understanding of rocks. This exercise introduces the physical and chemical properties of minerals and how these properties are used to identify common minerals.

(SeBuKi/Alamy)

1.1 Minerals: Building Blocks of Rock

Earth's continental and oceanic crust is home to a wide variety of useful and essential rocks and minerals. Many of them have economic value. In addition, all the processes that geologists study are in some way dependent on the properties of these basic Earth materials. Events such as volcanic eruptions, mountain building, weathering and erosion, and earthquakes involve rocks and minerals. Consequently, a basic knowledge of Earth materials is essential to understanding all geologic phenomena.

What Is a Mineral?

We begin our discussion of Earth materials with an overview of minerals—the building blocks of rocks. Geologists define **mineral** as *any naturally occurring inorganic solid that possesses an orderly crystalline structure and a definite chemical composition that allows for some variation*. Thus, Earth materials that are classified as minerals exhibit the following characteristics:

1. **Naturally occurring.** Minerals form by natural geologic processes. Synthetic materials—that is, those produced in a laboratory or by human intervention—are not considered minerals.
2. **Generally inorganic.** Inorganic crystalline solids, such as ordinary table salt (halite), that are found naturally in the ground are considered minerals. (Organic compounds, on the other hand, are generally not. Sugar, a crystalline solid that comes from sugarcane or sugar beets, is a common example of such an organic compound.)
3. **Solid substance.** Only solid crystalline substances are considered minerals. Ice (frozen water) fits this criterion and is considered a mineral, whereas liquid water and water vapor do not.
4. **Orderly crystalline structure.** Minerals are crystalline substances, which means their atoms (ions) are arranged in an orderly, repetitive manner. This orderly packing of atoms is reflected in regularly shaped objects called *crystals*. Some naturally occurring solids, such as volcanic glass (obsidian), lack a repetitive atomic structure and are not considered minerals.
5. **Definite chemical composition that allows for some variation.** Minerals are chemical compounds having compositions that can be expressed by a chemical formula. For example, the common mineral quartz has the formula SiO_2, which indicates that quartz consists of silicon (Si) and oxygen (O) atoms, in a ratio of one-to-two. This proportion of silicon to oxygen is true for any sample of pure quartz, regardless of its origin, size, or when it formed. However, the compositions of some minerals vary *within specific, well-defined limits*. This occurs because certain elements can substitute for others of similar size without changing the mineral's internal structure.

What Is a Rock?

Most minerals occur as components of rocks. Simply, a **rock** *is any solid mass of mineral, or mineral-like matter (such as volcanic glass), that occurs naturally as part of our planet*. Most rocks, like the sample of granite shown in **FIGURE 1.1**, occur as aggregates of several different minerals. The term *aggregate* implies that the minerals are joined in such a way that their individual properties are retained. Note that the different minerals that make up granite can be easily identified. However, some rocks are composed almost entirely of one mineral. A common example is the sedimentary rock *limestone*, which occurs as an impure mass of the mineral calcite.

Physical Properties of Minerals

Minerals have definite crystalline structures and chemical compositions that give them unique sets of physical and chemical properties shared by all specimens of that mineral, regardless of when or where they form. For example, if you compare two samples of the mineral quartz, they will be equally hard and equally dense, and they will break in a similar manner. However, the physical properties of individual samples may vary within specific limits due to ionic substitutions, inclusions of foreign elements (impurities), and defects in the crystalline structure.

SmartFigure 1.1 Most rocks are aggregates of minerals.

Some mineral properties, called **diagnostic properties**, are particularly useful in identifying an unknown mineral. The mineral halite, for example, has a salty taste. Because so few minerals share this property, a salty taste is considered a diagnostic property of halite. Other properties of certain minerals vary among different specimens of the same mineral. These properties are referred to as **ambiguous properties**.

Next, we examine the most common physical properties used to identify minerals, which include luster, color, streak, crystal shape (or habit), hardness, cleavage, fracture, and specific gravity. We will then look at some special properties that are useful in the identification of a few specific minerals.

ACTIVITY 1.1

Minerals: Building Blocks of Rock

1. In your own words, list the five characteristics an Earth material must have in order to be considered a mineral.
   a. ______________ b. ______________
   c. ______________ d. ______________
   e. ______________

2. Use the geologic definition of a mineral to determine which of the items listed in **FIGURE 1.2** are minerals and which are not. Check the appropriate box and explain each choice.

Mineral	Yes	No	Explanations
Rain water			
Quartz			
Coal			
Silver			
Wood			
Synthetic diamonds			
Halite			

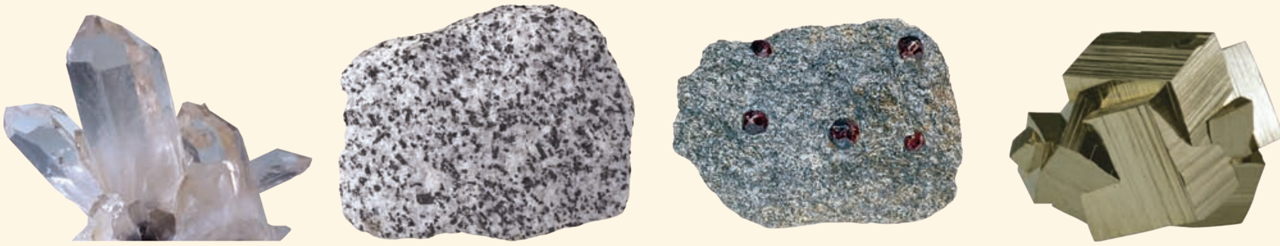
FIGURE 1.2 Which of these materials are minerals?

continued

Activity 1.1 continued

3. **FIGURE 1.3** contains images of some rocks and minerals. Which of these appear to be rocks and which are most likely minerals? (Identify the samples by letter.)

Rocks: ____________________ Minerals: ____________________



A. **B.** **C.** **D.**

FIGURE 1.3 Rock or mineral?

4. The five samples shown in **FIGURE 1.4** are all specimens of the mineral fluorite. Is color a diagnostic or ambiguous property of fluorite? Explain.

____

____

SmartFigure 1.4 Color variations exhibited by the mineral fluorite. (Photo by Dennis Tasa)

1.2 Luster

The appearance of light reflected from the surface of a mineral is known as **luster**. Minerals that have the appearance of metals, regardless of color, are said to have a **metallic luster**. Some metallic minerals, such as native copper and galena, develop a dull coating or tarnish when exposed to the atmosphere. Because they are not as shiny as samples with freshly broken surfaces, these samples exhibit a *submetallic luster.*

Most minerals have a **nonmetallic luster** and are described using various adjectives, such as *vitreous* (*glassy*), *dull* or *earthy* (a dull appearance like soil), or *pearly* (such as a pearl or the inside of a clamshell). Still others exhibit lusters that are *silky* (like silk or satin cloth) or *greasy* (as though coated in oil).

ACTIVITY 1.2
Luster

1. Examine the luster of the minerals in **FIGURE 1.5**. Place the letter A, B, C, D, or E in the space provided that corresponds to the luster exhibited. Letters may be used more than once. **A.** Metallic luster, **B.** Nonmetallic luster—glassy, **C.** Nonmetallic luster—dull, **D.** Nonmetallic luster—silky, **E.** Nonmetallic luster—greasy.

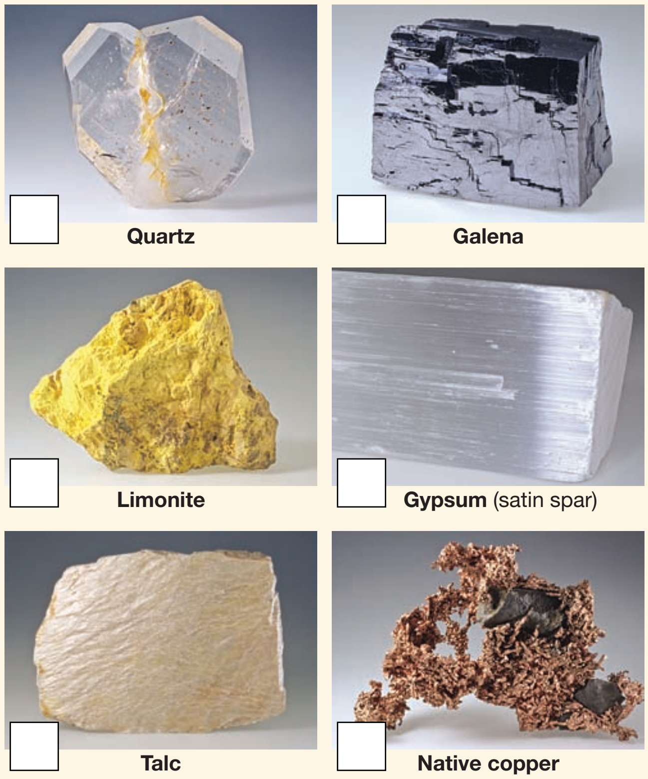


FIGURE 1.5 Various types of mineral luster.

2. Examine the mineral specimens provided by your instructor and separate them into two groups—metallic and nonmetallic.

Metallic: ______________________________

Nonmetallic: ______________________________

1.3 Color and Streak

Color is generally the most conspicuous mineral characteristic. However, because color is often variable, it usually is not a diagnostic property of most minerals. There are exceptions. For example, the mineral sulfur is usually bright yellow.

The *color* of a mineral in powdered form, called **streak**, is often useful in identification. A mineral's streak is obtained by rubbing it across a *streak plate* (a piece of unglazed porcelain) and observing the color of the mark it leaves. Although the color of a particular mineral may vary from sample to sample, the streak is usually consistent.

Streak can also help distinguish between minerals with metallic luster and those with nonmetallic luster. Minerals with a metallic luster generally have a dense, dark streak (**FIGURE 1.6**), whereas minerals with a nonmetallic luster typically have a light-colored streak.

Not all minerals produce a streak when rubbed across a streak plate. For example, the mineral quartz is harder than a streak plate and, therefore, produces no streak using this method.

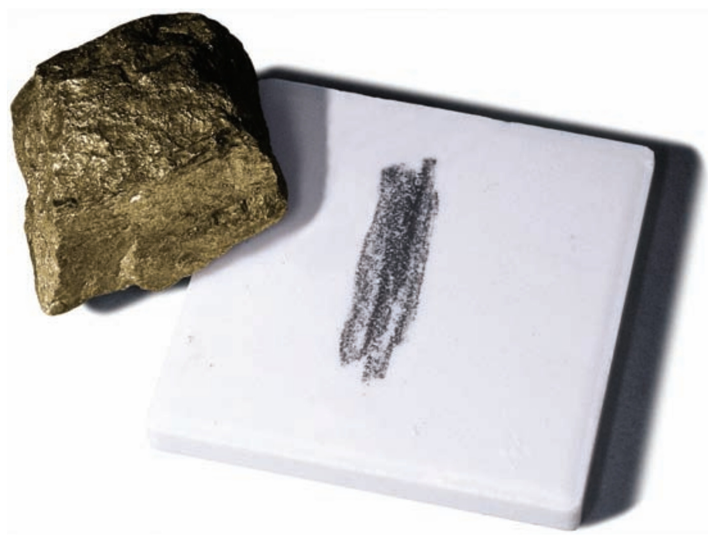


FIGURE 1.6 Using streak to help identify a mineral.

ACTIVITY 1.3

Color and Streak

1. Based on the samples of quartz in **FIGURE 1.7**, explain why color is not a diagnostic property of this mineral.

____

____

____

FIGURE 1.7 Color variations exhibited by the mineral quartz.

2. **FIGURE 1.8** shows two specimens of the mineral hematite and their corresponding streaks. For both samples, describe the color of the specimen and the streak.

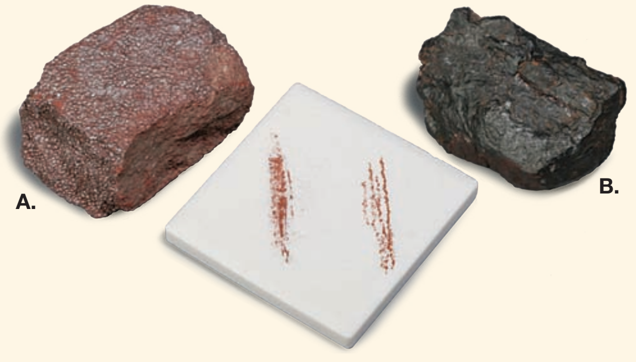


FIGURE 1.8 Hematite, an ore of iron, is found in both nonmetallic and metallic forms.

	COLOR OF SPECIMEN	STREAK
Specimen A:	____________	____________
Specimen B:	____________	____________

3. Select three of the mineral specimens provided by your instructor. Do they exhibit a streak? If so, is the streak the same color as the mineral specimen?

	COLOR OF SPECIMEN	STREAK
Specimen A:	____________	____________
Specimen B:	____________	____________
Specimen C:	____________	____________

4. To some observers, the mineral shown in **FIGURE 1.9** exhibits a metallic luster, while others describe its luster as nonmetallic. Based on the streak of this sample, how would you describe its luster?

Luster: ____________

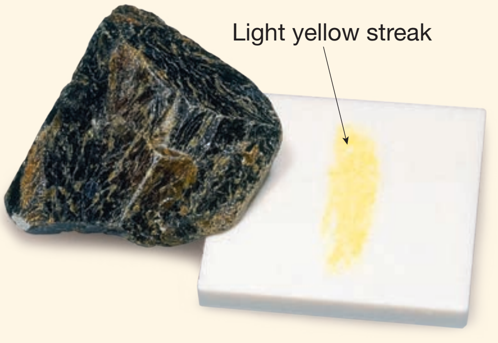


FIGURE 1.9 Using streak to assist in describing luster.

1.4 Crystal Shape, or Habit

Recall that all minerals are crystalline, and when they form in unrestricted environments, they develop **crystals** that exhibit geometric shapes. For example, well-developed quartz crystals are hexagonal, with pyramid-shaped ends, and garnet crystals are 12-sided (**FIGURE 1.10**). In addition, some crystals tend to grow and form characteristic shapes or patterns called **crystal shape**, or **habit**. Commonly used terms to describe various crystal habits include *bladed* (flat, elongated strips), *fibrous* (hairlike), *tabular* (tablet shaped), *granular* (aggregates of small crystals), *blocky* (square), and *banded* (layered).

Although crystal shape, or habit, is a diagnostic property for some specimens, many of the mineral samples you will encounter consist of crystals that are too tiny to be seen with the unaided eye or are intergrown such that their shapes cannot be determined.

A. Quartz **B. Garnet**

FIGURE 1.10 Characteristic crystal forms of **A.** quartz and **B.** garnet.

ACTIVITY 1.4
Crystal Shape, or Habit

1. Select one of the following terms to describe the crystal shape, or habit, of each specimen shown in **FIGURE 1.11**: cubic crystals, hexagonal crystals, fibrous habit, banded habit, blocky habit, bladed habit, tabular habit.

   Specimen A: ______________________

   Specimen B: ______________________

   Specimen C: ______________________

   Specimen D: ______________________

2. Use a *contact goniometer*, illustrated in **FIGURE 1.12**, to measure the angle between adjacent faces on the quartz crystals on display in the lab.
   a. Are the angles about the same for each quartz specimen, or do they vary from one sample to another?

   ____

   ____

   b. Write a generalization that describes how the angle between crystal faces relates to the size and/or shape of the sample.

   ____

   ____

   ____

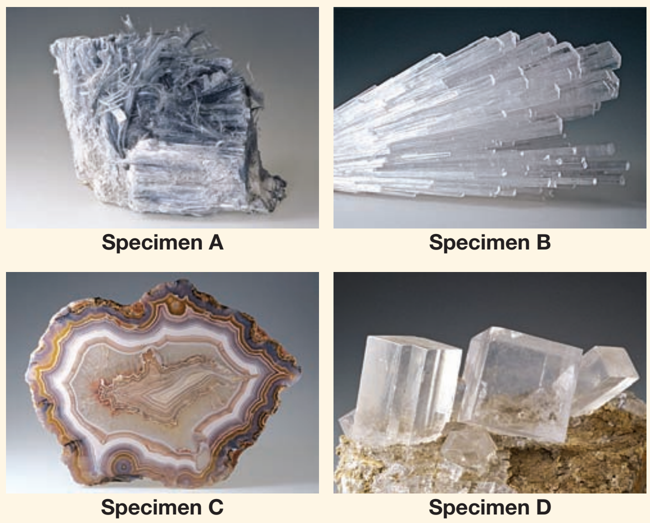


FIGURE 1.11 Crystal shapes and habits.

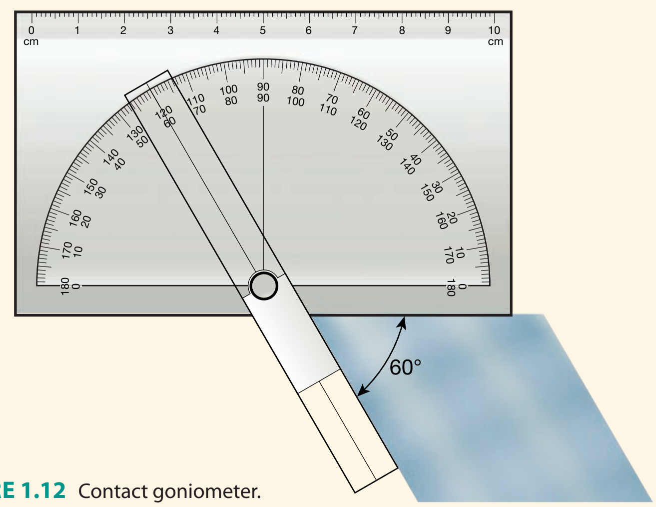
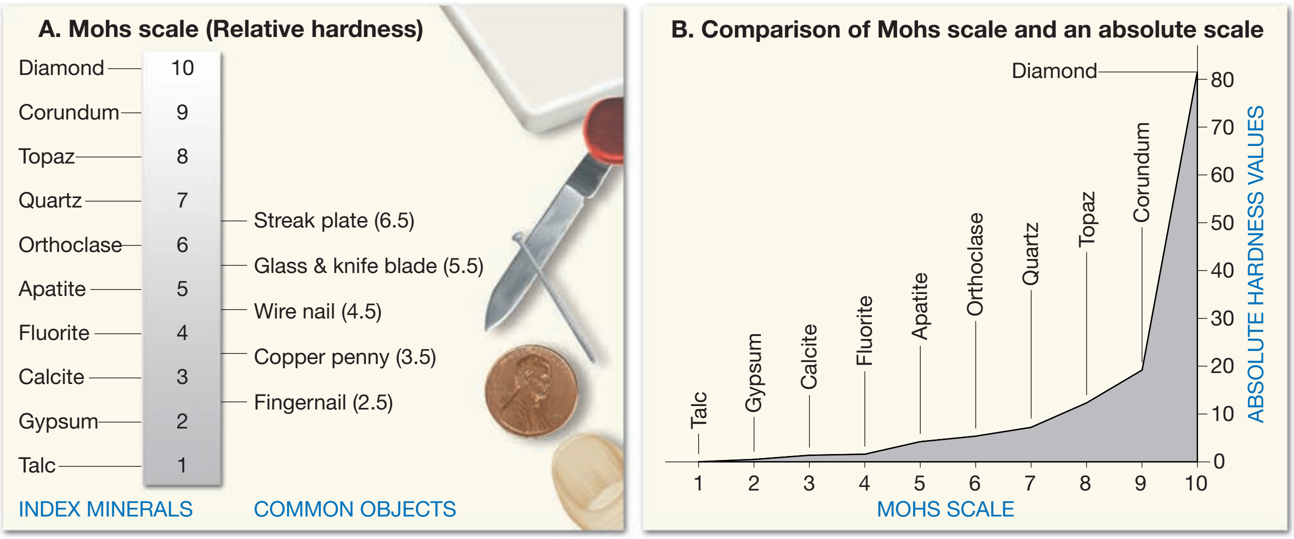


FIGURE 1.12 Contact goniometer.

1.5 Hardness

One of the most useful diagnostic properties is **hardness**, a measure of the resistance of a mineral to abrasion or scratching. This property is determined by rubbing a mineral of unknown hardness against one of known hardness or vice versa. A numerical value of hardness can be obtained by using the **Mohs scale** of hardness, which consists of 10 minerals arranged in order from 1 (softest) to 10 (hardest), as shown in **FIGURE 1.13**. It should be noted that the Mohs scale is a relative ranking; it does not imply that mineral number 2, gypsum, is twice as hard as mineral 1, talc.

In the laboratory, common objects are often used to determine the hardness of a mineral. These objects include a human fingernail, which has a hardness of about 2.5, a copper penny (3.5), and a piece of glass (5.5). The mineral gypsum, which has a hardness of 2, can be easily scratched with a fingernail. On the other hand, the mineral calcite, which has a hardness of 3, will scratch a fingernail but will not scratch glass. Quartz, one of the hardest common minerals, will easily scratch glass. Diamonds, hardest of all, scratch anything, including other diamonds.



SmartFigure 1.13 Hardness scales. **A.** Mohs scale of hardness, with the hardness of some common objects. **B.** Relationship between the Mohs relative hardness scale and an absolute hardness scale.

ACTIVITY 1.5
Hardness

1. The minerals shown in **FIGURE 1.14** are fluorite and topaz that have been tested for hardness. Use the Mohs scale in Figure 1.13 to identify which is fluorite and which is topaz.

   MINERAL NAME

   Specimen A: ____________________

   Specimen B: ____________________

2. Select three mineral specimens from the set provided by your instructor. Determine the hardness of each mineral, using **TABLE 1.1** as a guide.

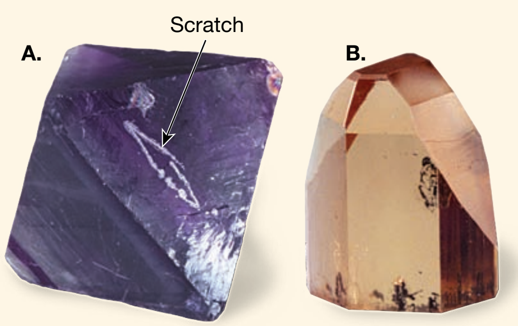


FIGURE 1.14 Hardness test.

HARDNESS

Specimen A: ____________________

Specimen B: ____________________

Specimen C: ____________________

TABLE 1.1 Hardness Guide

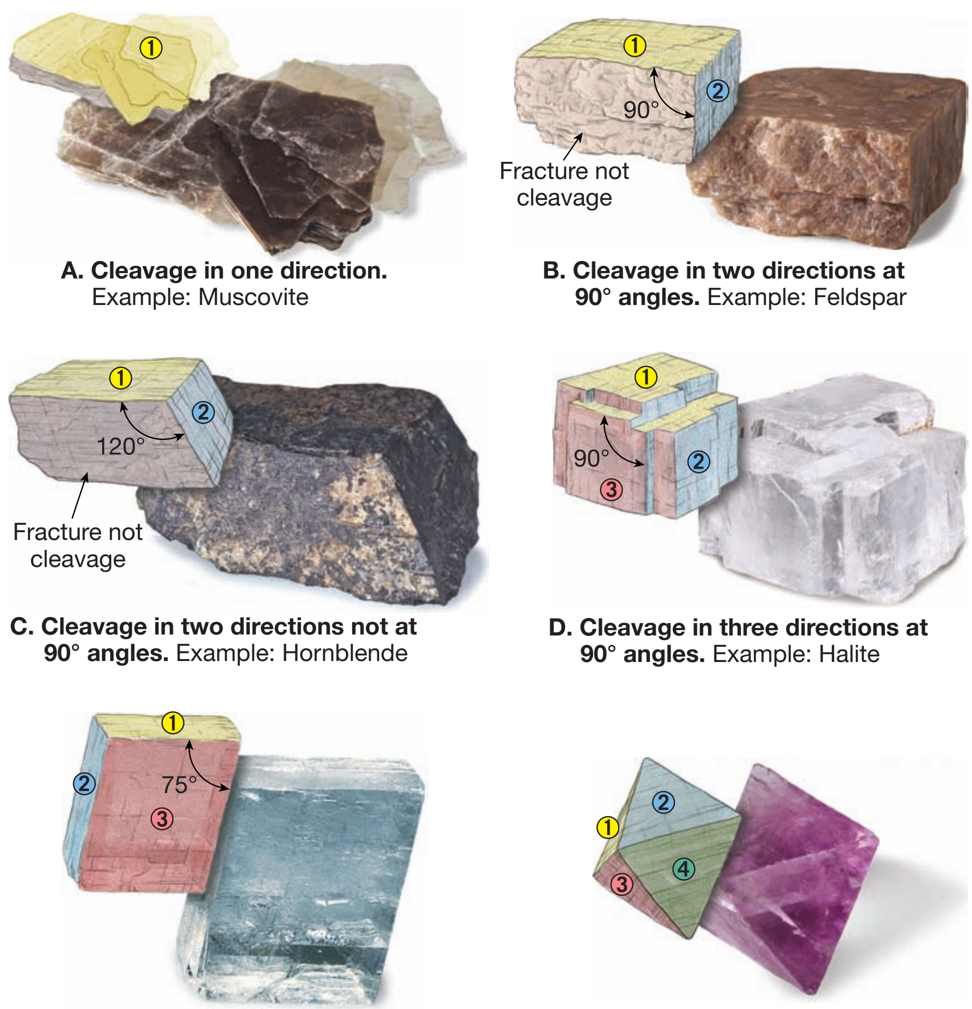
HARDNESS	DESCRIPTION
Less than 2.5	A mineral that can be scratched by your fingernail (hardness = 2.5)
2.5 to 5.5	A mineral that cannot be scratched by your fingernail (hardness = 2.5) and cannot scratch glass (hardness = 5.5)
Greater than 5.5	A mineral that scratches glass (hardness = 5.5)

1.6 Cleavage and Fracture

In the crystalline structure of many minerals, some chemical bonds are weaker than others. When minerals are stressed, they tend to break (cleave) along these planes of weak bonding, a property called **cleavage**. When broken, minerals that exhibit cleavage have smooth, flat surfaces, called **cleavage planes**, or **cleavage surfaces**.

Cleavage is described by first identifying the number of **directions of cleavage**, which is the number of different sets of cleavage planes that form on the surfaces of a mineral when it cleaves. Each cleavage surface of a mineral that has a different orientation is counted as a *different direction* of cleavage. However, when cleavage planes are parallel, they are counted only *once*, as one direction of cleavage.

Minerals may have one, two, three, four, or more directions of cleavage (**FIGURE 1.15**). For minerals with two or more directions of cleavage, you may also determine the



A. Cleavage in one direction. Example: Muscovite

B. Cleavage in two directions at 90° angles. Example: Feldspar

C. Cleavage in two directions not at 90° angles. Example: Hornblende

D. Cleavage in three directions at 90° angles. Example: Halite

E. Cleavage in three directions not at 90° angles. Example: Calcite

F. Cleavage in four directions. Example: Fluorite

SmartFigure 1.15 Common cleavage directions of minerals. **A.** Basal cleavage produces flat sheets. **B.** This type of prismatic cleavage produces an elongated form with a rectangular cross section. **C.** This type of prismatic cleavage produces an elongated form with a parallelogram cross section. **D.** Cubic cleavage produces cubes or parts of cubes. **E.** Rhombic cleavage produces rhombohedrons. **F.** Octahedral cleavage produces octahedrons.

angle(s) at which the directions of cleavage meet. The most common angles of cleavage are 60, 75, 90, and 120 degrees.

When minerals such as muscovite, calcite, halite, and fluorite are broken, they display cleavage surfaces that are easily detected. However, other minerals exhibit cleavage planes that consist of multiple offset surfaces that are not as obvious. A reliable way to determine whether a specimen exhibits cleavage is to rotate it in bright light and look for flat surfaces that reflect light.

Do not confuse cleavage with crystal shape. When a mineral exhibits cleavage, it will break into pieces that all have the same geometry. By contrast, the smooth-sided quartz crystals shown in Figure 1.10A illustrate crystal shape rather than cleavage. If broken, quartz crystals fracture into shapes that do not resemble one another or the original crystals.

Minerals that do not exhibit cleavage when broken are said to **fracture** (**FIGURE 1.16**). Fractures are described using terms such as *irregular*, *splintery*, and *conchoidal* (smooth, curved surfaces resembling broken glass). Some minerals may cleave in one or two directions but fracture in another.

A. Irregular fracture **B. Conchoidal fracture**

FIGURE 1.16 Minerals that do not exhibit cleavage are said to fracture.

ACTIVITY 1.6

Cleavage and Fracture

1. Describe the cleavage of the mineral shown in **FIGURE 1.17**.

____

____

____

FIGURE 1.17 Identifying cleavage of muscovite.

2. Refer to **FIGURE 1.18**, which shows a mineral that has several smooth, flat cleavage surfaces, to complete the following:

a. How many *cleavage surfaces* are present on the specimen?

____

b. How many *directions of cleavage* are present on the specimen?

____

c. Do the cleavage directions meet at 90-degree angles *or* angles other than 90 degrees?

____

FIGURE 1.18 Identifying cleavage of calcite.

3. Select one mineral specimen supplied by your instructor that exhibits more than one direction of cleavage. How many directions of cleavage does it have? What are the angles of its cleavage?

   Number of directions of cleavage: ______________

   Degrees of cleavage angles: ______________

1.7 Specific Gravity

You are probably familiar with the term *density*, which is defined as mass per unit volume and is expressed in grams per cubic centimeter (g/cm^3). Mineralogists use a related measure called *specific gravity* to describe the density of minerals. **Specific gravity (SG)** is a number representing the ratio of a mineral's weight to the weight of an equal volume of water. Water has a specific gravity of 1.

Most common rock-forming minerals have a specific gravity between 2 and 3. For example, quartz has a specific gravity of 2.7. By contrast, some metallic minerals such as pyrite, native copper, and magnetite are more than twice as dense as quartz and thus are considered to have high specific gravity. Galena, an ore of lead, is even denser, with a specific gravity of about 7.5.

With a little practice, you can estimate the specific gravity of a mineral by hefting it in your hand. Ask yourself whether the mineral feels about as "heavy" as similar-sized rocks you have handled. If the answer is "yes," the specific gravity of the sample is likely between 2.5 and 3. (*Note:* Exercise 23, "The Metric System, Measurements, and Scientific Inquiry," contains a simple experiment involving determining the specific gravity of a solid.)

ACTIVITY 1.7
Specific Gravity

1. Heft each specimen supplied by your instructor. Using this technique, identify the minerals from this group that exhibit high specific gravity.

   ____

2. Of those with a high specific gravity, did most of them have a metallic or nonmetallic luster?

   ____

1.8 Other Properties of Minerals

MAGNETISM Magnetism is characteristic of minerals, such as magnetite, that have a high iron content and are attracted by a magnet. One variety of magnetite, called *lodestone*, is magnetic and will pick up small objects such as pins and paper clips (**FIGURE 1.19**).

FIGURE 1.19 Lodestone, a variety of magnetite, is a weak magnet and will attract iron objects.

CAUTION Do not taste any minerals or any other materials unless you know it is *absolutely* safe to do so.

TASTE The mineral halite has a "salty" taste and is used for table salt.

ODOR A few minerals have distinctive odors. For example, minerals that are compounds of sulfur smell like rotten eggs when rubbed vigorously on a streak plate.

FEEL The mineral talc often feels "soapy," and the mineral graphite has a "greasy" feel.

STRIATIONS Striations are closely spaced, fine lines on the crystal faces of some minerals. Certain plagioclase feldspar minerals exhibit striations on one cleavage surface (**FIGURE 1.20**).

CAUTION Hydrochloric acid can discolor, decompose, and disintegrate mineral and rock samples. Use the acid only after you have received specific instructions on its use from your instructor. Never taste minerals that have had acid placed on them.

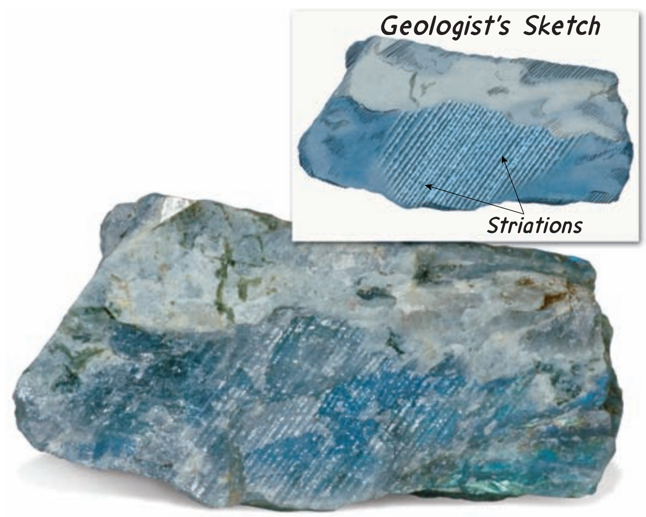


FIGURE 1.20 These parallel lines, called *striations*, are a distinguishing characteristic of the plagioclase feldspars. Some other minerals also exhibit this characteristic.

Figure 1.21 Calcite reacting with dilute hydrochloric acid.
(Photo by Chip Clark/Fundamental Photographs)

REACTION TO DILUTE HYDROCHLORIC ACID A very small drop of dilute hydrochloric acid, when placed on the surface of certain minerals, will cause them to "fizz" (effervesce) as carbon dioxide is released (**FIGURE 1.21**). The acid test is used to identify the *carbonate minerals*, especially the mineral calcite ($CaCO_3$), the most common carbonate mineral.

TENACITY The term **tenacity** describes a mineral's resistance to breaking or deforming. Some minerals, such as fluorite and halite, tend to be *brittle* and shatter into small pieces when struck. Other minerals, such as native copper, are *malleable*, or easily hammered into different shapes. Minerals, including gypsum and talc, that can be cut into thin shavings are described as *sectile*. Still others, notably the micas, are *elastic* and will bend and snap back to their original shape after the stress is released (**FIGURE 1.22**).

THE ABILITY TO TRANSMIT LIGHT Minerals are able to transmit light to different degrees. A mineral is described as **opaque** when no light is transmitted; **translucent** when light, but not an image, is transmitted; and **transparent** when both light and an image are visible through the sample (see Figure 1.22).

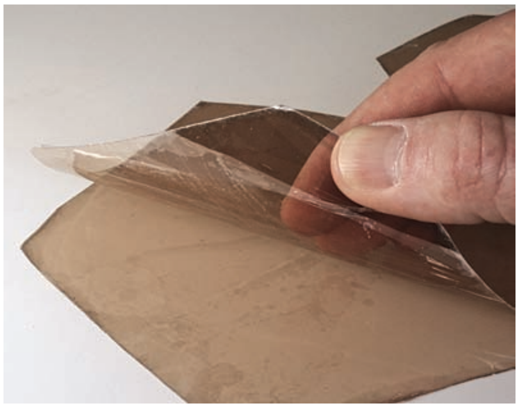


FIGURE 1.22 Sheets of elastic minerals, like muscovite, can be bent but will snap back when the stress is released. Sheets of muscovite are transparent because they transmit both light and images. (Photo by Dennis Tasa)

ACTIVITY 1.8

Other Properties of Minerals

1. What do we mean when we refer to a mineral's *tenacity*? List three terms that describe tenacity.

2. Describe the simple chemical test that is useful in the identification of the mineral calcite.

3. Compare and contrast the terms *opaque*, *translucent*, and *transparent*. Select a mineral from the set supplied by your instructor that is an example of each.

1.9 Identification of Minerals

Now that you are acquainted with the physical properties of minerals, you are ready to identify the minerals supplied by your instructor. To complete this activity, you need the mineral data sheet (**FIGURE 1.23**) and the mineral identification key (**FIGURE 1.24**).

The mineral identification key divides minerals into three primary categories: (1) those with metallic luster, (2) those with nonmetallic luster that are dark colored, (3) and those with nonmetallic luster that are light colored. Hardness is used as a secondary identifying factor. As you complete this exercise, remember that the objective is to learn the *procedure* for identifying minerals through *observation* and *data collection* rather than simply naming the minerals.

FIGURE 1.23 Mineral data sheet.

MINERAL DATA SHEET #1

Sample number	Luster	Hardness	Color	Streak	Fracture or Cleavage (number of directions and angles)	Other Properties	Name	Economic Use or Rock-forming

Refer to the section on "Mineral Groups" to complete this part

FIGURE 1.23 Mineral data sheet *(continued)*

MINERAL DATA SHEET #2

Sample number	Luster	Hardness	Color	Streak	Fracture or Cleavage (number of directions and angles)	Other Properties	Name	Economic Use or Rock-forming

Refer to the section on “Mineral Groups” to complete this part

ACTIVITY 1.9

Identification of Minerals

1. Identify the specimens supplied by your instructor, using the following steps:

Step 1: Leaving enough space for each mineral, number a piece of paper (up to the number of samples you've been assigned) and place your specimens on the paper.

Step 2: Select a specimen and determine its physical properties by using the tools provided (glass plate, streak plate, magnet, etc.).

Step 3: List the properties of that specimen on the mineral data sheet (Figure 1.23).

Step 4: Use the mineral identification key (Figure 1.24) as a resource to identify the specimen.

Group I METALLIC MINERALS

Luster	Hardness	Streak	Other Diagnostic Properties	Name (Chemical Composition)
METALLIC LUSTER	Harder than glass (>5.5)	Gray-black	Black; magnetic; hardness = 6; specific gravity = 5.2; often granular	**Magnetite** (Fe_3O_4)
		Greenish-black	Brass yellow; hardness = 6; specific gravity = 5.2; generally an aggregate of cubic crystals	**Pyrite** (FeS_2)-fool's gold
		Red-brown	Gray or reddish brown; hardness = 5–6; specific gravity = 5; platy appearance	**Hematite** (Fe_2O_3)
	Softer than glass but harder than a fingernail (2.5–5.5)	Gray-black	Golden yellow; hardness = 4; specific gravity = 4.2; massive	**Chalcopyrite** ($CuFeS_2$)
		Gray-black	Silvery gray; hardness = 2.5; specific gravity = 7.6 (very heavy); good cubic cleavage	**Galena** (PbS)
		Gray-black	Black to bronze; tarnishes to purples and greens; hardness = 3; specific gravity = 5; massive	**Bornite** (Cu_5FeS_4)
		Yellow-brown	Yellow brown to dark brown; hardness variable (1–6); specific gravity = 3.5–4; sometimes found in rounded masses; earthy appearance	**Limonite** ($Fe_2O_3 \cdot H_2O$)
		Copper	Generally tarnished to brown or green; hardness = 2.5; specific gravity = 9; massive	**Native copper** (Cu)
		Pale yellow	Yellow brown to black; hardness = 4; good cleavage in six directions, light yellow streak that has the smell of sulfur	**Sphalerite** (ZnS)
	Softer than a fingernail (<2.5)	Dark gray	Silvery gray; hardness = 1 (very soft); specific gravity = 2.2; massive to platy; writes on paper (pencil lead); feels greasy	**Graphite** (C)

FIGURE 1.24 Mineral identification key.

Group II NONMETALLIC MINERALS / DARK COLOR

NONMETALLIC DARK COLOR	Hardness	Cleavage	Other Diagnostic Properties	Name (Chemical Composition)
NONMETALLIC DARK COLOR	Harder than glass (>5.5)	Cleavage present	Greenish black to black; hardness = 5–6; specific gravity = 3.4; fair cleavage, two directions at nearly 90 degrees	**Augite** (Ca, Mg, Fe, Al silicate)
			Black to greenish black; hardness = 5–6; specific gravity = 3.2; fair cleavage, two directions at nearly 60 degrees and 120 degrees	**Hornblende** (Ca, Na, Mg, Fe, OH, Al silicate)
			White to dark gray; hardness = 6; specific gravity = 2.6; two directions of cleavage at nearly right angles; striations on some faces	**Plagioclase feldspar** (Na, Ca, $AlSi_3O_8$)
		Cleavage poor or absent	Red to reddish brown; hardness = 6.5–7.5; conchoidal fracture; glassy luster	**Garnet** (Fe, Mg, Ca, Al silicate)
			Gray to brown; hardness = 9; specific gravity = 4; hexagonal crystals common	**Corundum** (Al_2O_3)
			Dark brown to black; hardness = 7; conchoidal fracture; glassy luster	**Smoky quartz** (SiO_2)
			Olive green; hardness = 6.5–7; small glassy grains	**Olivine** ($(Mg, Fe)_2SiO_4$)
	Softer than glass but harder than a fingernail (2.5–5.5)	Cleavage present	Yellow brown to black; hardness = 4; good cleavage in six directions, light yellow streak that has the smell of sulfur	**Sphalerite** (ZnS)
			Dark brown to black; hardness = 2.5–3, excellent cleavage in one direction; elastic in thin sheets; black mica	**Biotite mica** (K, Mg, Fe, OH, Al silicate)
		Cleavage absent	Generally tarnished to brown or green; hardness = 2.5; specific gravity = 9; massive	**Native copper** (Cu)
	Softer than a fingernail (<2.5)	Cleavage poor or absent	Reddish brown; hardness = 1–5; specific gravity = 4–5; red streak; earthy appearance	**Hematite** (Fe_2O_3)
			Yellow brown; hardness = 1–3; specific gravity = 3.5; earthy appearance; powders easily; not a true mineral	**Limonite** ($Fe_2O_3 \cdot H_2O$)

FIGURE 1.24 Mineral identification key (*continued*)

Activity 1.9 continued

Group III NONMETALLIC MINERALS / LIGHT COLOR

NONMETALLIC LIGHT COLOR

Hardness	Cleavage	Other Diagnostic Properties	Name (Chemical Composition)
Harder than glass (>5.5)	Cleavage present	Usually pink or white; hardness = 6; specific gravity = 2.6; two directions of cleavage at nearly right angles; lacks striations	**Potassium feldspar** ($KAlSi_3O_8$)
		White to dark gray; hardness = 6; specific gravity = 2.6; two directions of cleavage at nearly right angles; striations on some faces	**Plagioclase feldspar** ($Na, Ca, AlSi_3O_8$)
	Cleavage absent	Any color; hardness = 7; specific gravity = 2.65; conchoidal fracture; glassy appearance; varieties: milky (white), rose (pink), smoky (gray), amethyst (violet)	**Quartz** (SiO_2)
Softer than glass but harder than a fingernail (2.5–5.5)	Cleavage present	White, yellowish to colorless; hardness = 3; three directions of cleavage at 75 degrees (rhombohedral); effervesces in HCl; often transparent	**Calcite** ($CaCO_3$)
		White to colorless; hardness = 2.5; three directions of cleavage at 90 degrees (cubic); salty taste	**Halite** (NaCl)
		Yellow, purple, green, colorless; hardness = 4; white streak; translucent to transparent; four directions of cleavage	**Fluorite** (CaF_2)
Softer than a fingernail (<2.5)	Cleavage present	Colorless; hardness = 2–2.5; transparent and elastic in thin sheets; excellent cleavage in one direction; light colored mica	**Muscovite mica** (K, OH, Al silicate)
		White to transparent, hardness = 2; when in sheets; is flexible but not elastic; varieties: selenite (transparent, three directions of cleavage); satin spar (fibrous, silky luster); alabaster (aggregate of small crystals)	**Gypsum** ($CaSO_4 \cdot 2H_2O$)
	Cleavage poor or absent	White, pink, green; hardness = 1–2; soapy feel; pearly luster	**Talc** (Mg silicate)
		Yellow; hardness = 1–2.5	**Sulfur** (S)
		White; hardness = 2; smooth feel; earthy odor; when moistened, has typical clay texture	**Kaolinite** (Hydrous Al silicate)
		Pale to dark reddish brown; hardness = 1–3; dull luster; earthy; often contains spherical particles; not a true mineral	**Bauxite** (Hydrous Al oxide)

FIGURE 1.24 Mineral identification key (*continued*)

Repeat steps 2 through 4 until you have identified all samples.

2. Read the following section, which examines some common rock-forming minerals and selected economic minerals. This will provide you with the information you need to complete the last column of the mineral data sheet (Figure 1.23).

1.10 Mineral Groups

More than 4000 minerals have been named, and several new ones are identified each year. Fortunately for students who are beginning to study minerals, no more than a few dozen are abundant! Collectively, these few make up most of the rocks of Earth's crust and, as such, are referred to as the **rock-forming minerals**.

Although less abundant, many other minerals are used extensively in the manufacture of products; they are called **economic minerals**. However, rock-forming minerals and economic minerals are not mutually exclusive groups. When found in large deposits, some rock-forming minerals are economically significant. For example, the mineral calcite has many uses, including the production of concrete.

Important Rock-Forming Minerals

FELDSPAR GROUP Feldspar is the most abundant mineral group and is found in many igneous, sedimentary, and metamorphic rocks (**FIGURE 1.25**). One group of feldspar minerals contains potassium ions in its crystalline structure and is referred to as *potassium feldspar*. The other group, called *plagioclase feldspar*, contains calcium and/or sodium ions. All feldspar minerals have two directions of cleavage that meet at 90-degree angles and are relatively hard (6 on the Mohs scale). The only reliable way to physically distinguish the feldspars is to look for striations that are present on some cleavage surfaces of plagioclase feldspar (see Figure 1.25D) but do not appear in potassium feldspar.

QUARTZ *Quartz* is a major constituent of many igneous, sedimentary, and metamorphic rocks. Quartz is found in a wide variety of colors (caused by impurities), is quite hard (7 on

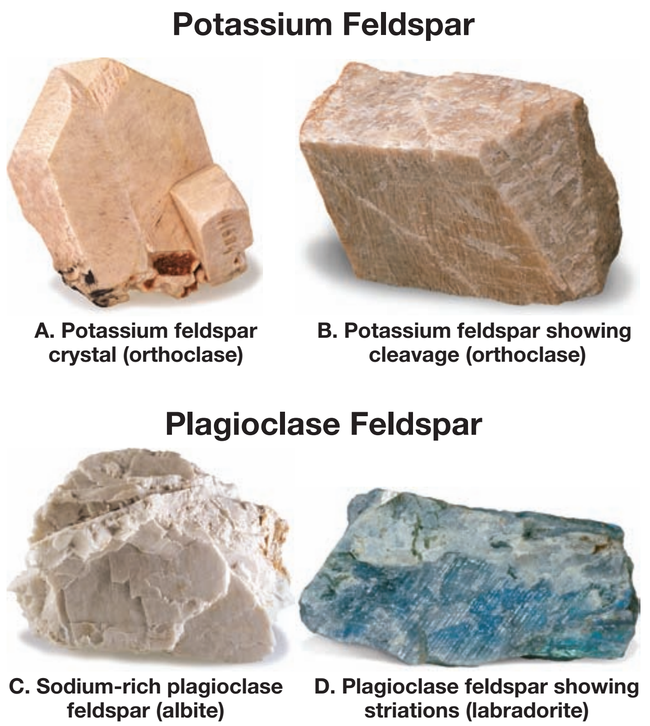


FIGURE 1.25 Feldspar group. **A.** Characteristic crystal form of potassium feldspar. **B.** Like this sample, most pink feldspar belongs to the potassium feldspar subgroup. **C.** Most sodium-rich plagioclase feldspar is light colored and has a porcelain luster. **D.** Calcium-rich plagioclase feldspar tends to be gray, blue-gray, or black in color. Labradorite, the variety shown here, exhibits striations.

FIGURE 1.26 Quartz is one of the most common minerals and has many varieties. **A.** Smoky quartz is commonly found in coarse-grained igneous rocks. **B.** Rose quartz owes its color to small amounts of titanium. **C.** Milky quartz often occurs in veins that occasionally contain gold. **D.** Jasper is a variety of quartz composed of microscopically small crystals.

the Mohs scale), and often exhibits conchoidal fracture when broken (**FIGURE 1.26**). Pure quartz is clear, and if allowed to grow without interference, it will develop hexagonal crystals with pyramid-shaped ends (see Figure 1.10A).

MICA *Muscovite* and *biotite* are the two most abundant members of the mica family. Both have excellent cleavage in one direction and are relatively soft (2.5 to 3 on the Mohs scale) (**FIGURE 1.27**).

CLAY MINERALS Most clay minerals originate as products of chemical weathering and make up much of the surface material we call soil. Clay minerals also account for nearly half of the volume of sedimentary rocks (**FIGURE 1.28**).

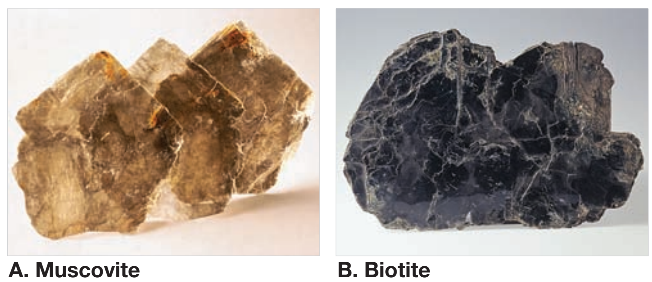
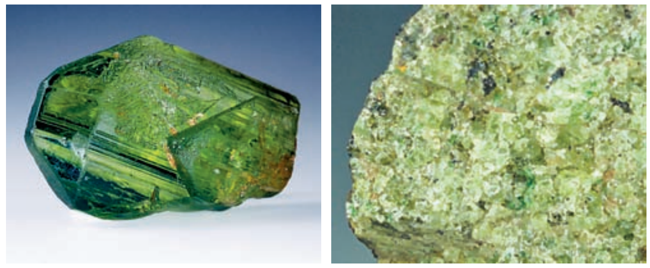


FIGURE 1.27 Two common micas: **A.** muscovite and **B.** biotite.

FIGURE 1.28 Kaolinite, a common clay mineral. (Photo by Dennis Tasa)

OLIVINE Olivine is an important group of minerals that are major constituents of dark-colored igneous rocks and make up much of Earth's upper mantle. Olivine is black to olive green in color, has a glassy luster, and exhibits conchoidal fracture (**FIGURE 1.29**).



A. B.

FIGURE 1.29 Olivine. **A.** Solitary olivine crystal. **B.** Numerous olivine crystals in the igneous rock called dunite. (Photos by Dennis Tasa)

PYROXENE GROUP The *pyroxenes* are a group of silicate minerals that are important components of dark-colored igneous rocks. The most common member, *augite*, is a black or greenish, opaque mineral with two directions of cleavage that meet at nearly 90-degree angles (**FIGURE 1.30A**).

AMPHIBOLE GROUP *Hornblende* is the most common member of the amphibole group and is usually dark green to black in color (**FIGURE 1.30B**). Except for its cleavage angles, which are about 60 degrees and 120 degrees, it is very similar in appearance to augite. Found in igneous rocks, hornblende makes up the dark portion of otherwise light-colored rocks.

CALCITE *Calcite*, a very abundant mineral, is the primary constituent in the sedimentary rock limestone and the metamorphic rock marble. A relatively soft mineral (3 on the Mohs scale), calcite has three directions of cleavage that meet at 75-degree angles (see Figure 1.18).

A. Augite

B. Hornblende

FIGURE 1.30 These dark-colored silicate minerals are common constituents of igneous rocks: **A.** Augite and **B.** Hornblende. (Photos by Dennis Tasa)

Economic Minerals

Many of the minerals selected for this exercise are metallic minerals that are mined to support our modern society. In addition, nonmetallic minerals such as fluorite, halite, and gypsum have economic value. **TABLE 1.2** provides a list of some economic minerals and their industrial and commercial uses.

TABLE 1.2 Economic Minerals

MINERAL	INDUSTRIAL AND COMMERCIAL USES
Calcite	Cement; soil conditioning
Chalcopyrite	Major ore of copper
Corundum	Gemstones; sandpaper
Diamond	Gemstones; drill bits
Fluorite	Used in steel manufacturing, toothpaste
Galena	Major ore of lead
Graphite	Pencil lead; lubricant
Gypsum	Wallboard; plaster
Halite	Table salt; road salt
Hematite	Ore of iron; pigment
Kaolinite	Ceramics; porcelain
Magnetite	Ore of iron
Muscovite	Insulator in electrical applications
Quartz	Primary ingredient in glass
Sphalerite	Major ore of zinc
Sulfur	Sulfa drugs; sulfuric acid
Sylvite	Potassium fertilizers
Talc	Paint; cosmetics

ACTIVITY 1.10

Mineral Groups

1. When feldspar minerals are found in igneous rocks, they tend to occur as elongated, rectangular crystals. By contrast, quartz (most commonly the smoky and milky varieties) usually occurs as irregular or rounded grains that have a glassy appearance. Which of the crystals (A, B, C, or D) in the igneous rocks shown in **FIGURE 1.31** are feldspar crystals, and which are quartz?

Feldspar: ____________________________

Quartz: ____________________________

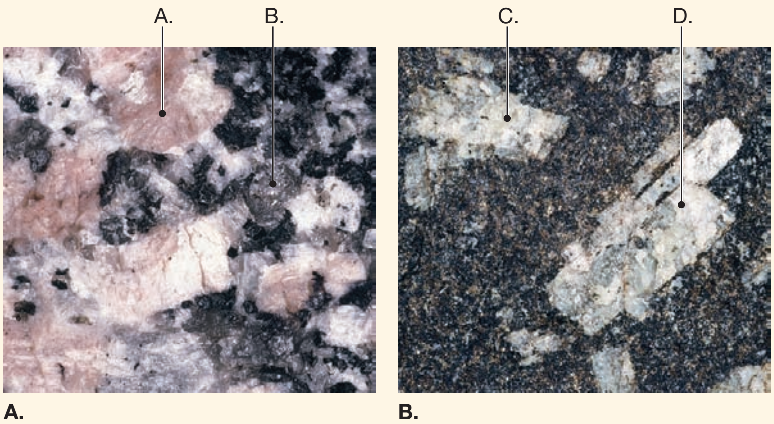


FIGURE 1.31 Identifying crystals of feldspar and quartz in coarse-grained igneous rocks.

2. Complete the last column in the mineral data sheet (see Figure 1.23) by indicating ″rock-forming″ or by listing the economic use of the samples used in this exercise (see Table 1.2). Which, if any, of the minerals you identified are *both* rock forming and economic?

____________________________ ____________________________