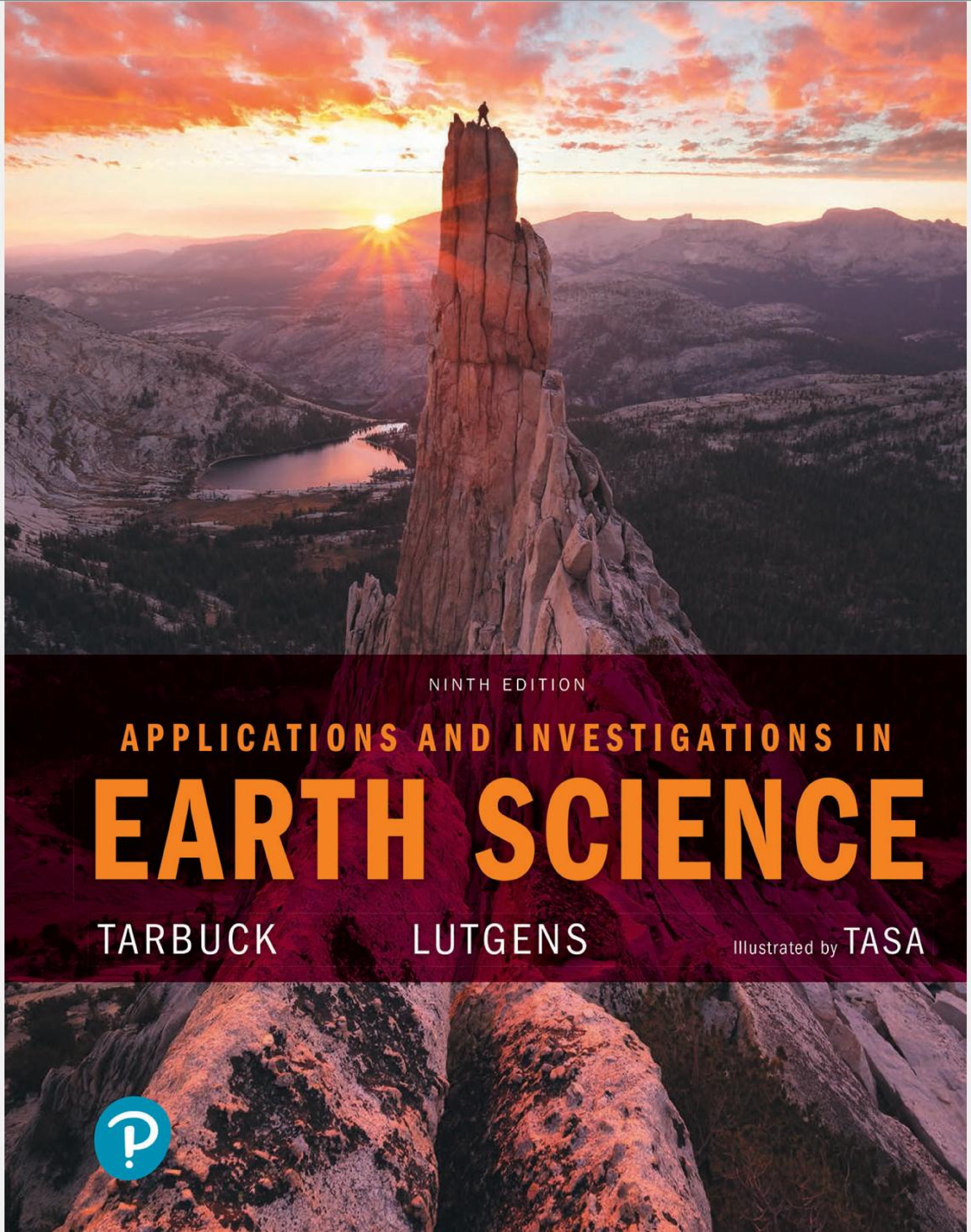

NINTH EDITION

# APPLICATIONS AND INVESTIGATIONS IN EARTH SCIENCE

TARBUCK LUTGENS Illustrated by TASA

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# Contents


**Preface** iii

## PART 1 Geology

**EXERCISE 1** The Study of Minerals 1
**EXERCISE 2** Rocks and the Rock Cycle 25
**EXERCISE 3** Plate Tectonics 47
**EXERCISE 4** Earthquakes and Earth's Interior 63
**EXERCISE 5** Volcanism and Volcanic Hazards 77
**EXERCISE 6** Geologic Maps, Block Diagrams, and Rock Structures 93
**EXERCISE 7** Aerial Photographs, Satellite Images, and Topographic Maps 111
**EXERCISE 8** Shaping Earth's Surface: Running Water and Groundwater 129
**EXERCISE 9** Shaping Earth's Surface: Arid and Glacial Landscapes 151
**EXERCISE 10** Geologic Time 167

## PART 2 Oceanography

**EXERCISE 11** Introduction to Oceanography 185
**EXERCISE 12** Waves, Currents, and Tides 199

## PART 3 Meteorology

**EXERCISE 13** Earth–Sun Relationships 219
**EXERCISE 14** Heating the Atmosphere 233
**EXERCISE 15** Atmospheric Moisture, Pressure, and Wind 247
**EXERCISE 16** Air Masses, Midlatitude Cyclones, and Weather Maps 275
**EXERCISE 17** Global Climates 289

## PART 4 Astronomy

**EXERCISE 18** Astronomical Observations 311
**EXERCISE 19** Patterns in the Solar System 321
**EXERCISE 20** Locating the Planets 335
**EXERCISE 21** Examining the Terrestrial Planets 345
**EXERCISE 22** Motions of the Earth–Moon System 361

## PART 5 Earth Science Skills

**EXERCISE 23** Location and Distance on Earth 369
**EXERCISE 24** The Metric System, Measurements, and Scientific Inquiry 385

# 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 benefit from putting the material *presented* in the classroom to *work* in the laboratory. Learning becomes more significant when accomplished by discovery.

## Ninth Edition Features

One of the goals for this ninth 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 features associated with this new edition:

- **Revised organization.** Previous users of this lab manual will see that the order of the exercises in Part I Geology has been changed. It now reflects the topic order associated with *Earth Science 15th edition*, the textbook most often used in conjunction with this lab manual. Of course, because exercises are largely self contained, they may be assigned in a different order.
- **New lab exercise on *Volcanism and Volcanic Hazards*.** At the urging of several reviewers and past users of this lab manual, a new exercise has been added. *Exercise 5: Volcanism and Volcanic Hazards* examines the nature of volcanic eruptions and the formation and characteristics of different types of volcanoes. The new exercise also explores some of the geologic hazards associated with volcanoes.
- **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 largely eliminating the need for a pre-lab lecture by the instructor.
- **A design and layout that promotes user flexibility.** Each exercise is divided into sections that include background material and one or more related activities for students to complete. This layout makes it easier for instructors to customize each exercise to fit the allotted lab period and their individual teaching preferences. The design also effectively ties figures and tables to the associated activities.
- **Mastering™ Geology.** Mastering Geology is an online homework, tutorial, and assessment program designed to work with this lab manual to engage students and improve results. Interactive, self-paced activities provide individualized coaching to help students stay on track. With a wide range of activities available, students can actively learn, understand, and retain even the most difficult Earth Science concepts. Materials in Mastering Geology include Pre-Lab Videos, Geoscience Animations, Mobile Field Trips, "Project Condor" Quadcopter videos, GIS-inspired MapMaster 2.0 interactive maps, *In the News* articles, Key Term Study Tools, 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 4-minute feature is a mini-lesson that examines the concepts illustrated by the figure. Several new SmartFigures have been added to this new edition. In addition to the Tutorials that appeared in the previous edition, there are now several SmartFigure Animations and SmartFigure Videos. SmartFigures is truly *art that teaches*.
- **Exercises that are largely 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, additional background material is provided within the exercise. Questions that rely heavily on outside material have been modified or replaced. We are confident that this approach makes exercises more useful and meaningful for students as well as instructors.
- **Inquiry-based lab experiences.** Whenever possible, the exercises provide hands-on learning. We also endeavor 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 ninth 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.

## Acknowledgments

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 Executive Editor at Pearson Education, Christian Botting. We appreciate his enthusiasm, hard work, and quest for excellence. We also want to acknowledge our conscientious Content Producer, Becca Groves for the skills she exhibited in keeping this project on track.

As always, we want to acknowledge the production team, led by Patty Donovan at SPi-Global, who turned our manuscript into a finished product. The team included copy editor Kitty Wilson, compositor SPi Global, and proofreader Linda Duarte. 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 definitely strengthened an already outstanding art program.
- We value the support of Teresa Tarbuck of Vincennes University, whose editorial assistance greatly enhanced this ninth 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 a 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 as well as many of SmartFigures that appear throughout this manual.

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

Glenn Blaylock, Laredo 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*, ninth edition, would have been far more difficult without their assistance, patience, and understanding.

Ed Tarbuck
Fred Lutgens

# 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×16.3 |
| Third order or better, recoverable mark | ×120.0 |
| Bench mark at found section corner | BM 18.6 |
| Spot elevation | ×5.3 |

| Contours | |
|---|---|
| ***Topographic*** | |
| Intermediate | |
| Index | 6000 |
| 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 | X |
| 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 | |
| Rock or coral 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 load | |
| 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 |

# Metric and English Units Compared

## Units

| | | |
|---|---|---|
| 1 kilometer (km) | = | 1000 meters (m) |
| 1 meter (m) | = | 100 centimeters (cm) |
| 1 centimeter (cm) | = | 0.39 inch (in.) |
| 1 mile (mi) | = | 5280 feet (ft) |
| 1 foot (ft) | = | 12 inches (in.) |
| 1 inch (in.) | = | 2.54 centimeters (cm) |
| 1 square mile ($mi^2$) | = | 640 acres (a) |
| 1 kilogram (kg) | = | 1000 grams (g) |
| 1 pound (lb) | = | 16 ounces (oz) |
| 1 fathom | = | 6 feet (ft) |

## Conversions

| When you want to convert: | Multiply by: | To find: |
|---|---|---|
| **Length** | | |
| inches | 2.54 | centimeters |
| centimeters | 0.39 | inches |
| feet | 0.30 | meters |
| meters | 3.28 | feet |
| yards | 0.91 | meters |
| meters | 1.09 | yards |
| miles | 1.61 | kilometers |
| kilometers | 0.62 | miles |
| **Area** | | |
| square inches | 6.45 | square centimeters |
| square centimeters | 0.15 | square inches |
| square feet | 0.09 | square meters |
| square meters | 10.76 | square feet |
| square miles | 2.59 | square kilometers |
| square kilometers | 0.39 | square miles |

| When you want to convert: | Multiply by: | To find: |
|---|---|---|
| **Volume** | | |
| cubic inches | 16.38 | cubic centimeters |
| cubic centimeters | 0.06 | cubic inches |
| cubic feet | 0.028 | cubic meters |
| cubic meters | 35.3 | cubic feet |
| cubic miles | 4.17 | cubic kilometers |
| cubic kilometers | 0.24 | cubic miles |
| liters | 1.06 | quarts |
| liters | 0.26 | gallons |
| gallons | 3.78 | liters |
| **Masses and Weights** | | |
| ounces | 20.33 | grams |
| grams | 0.035 | ounces |
| pounds | 0.45 | kilograms |
| kilograms | 2.205 | pounds |

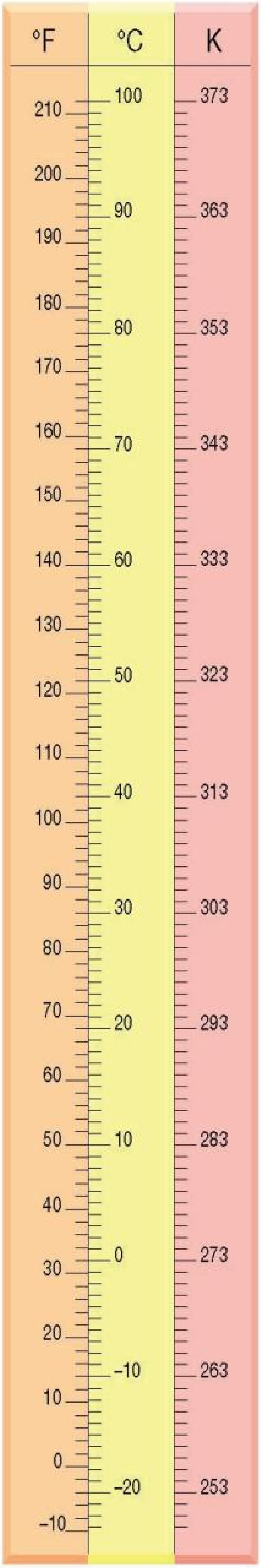
### Temperature

When you want to convert degrees Fahrenheit (°F) to degrees Celsius (°C), subtract 32 degrees and divide by 1.8.

When you want to convert degrees Celsius (°C) to degrees Fahrenheit (°F), multiply by 1.8 and add 32 degrees.

When you want to convert degrees Celsius (°C) to kelvins (K), delete the degree symbol and add 273. When you want to convert kelvins (K) to degrees Celsius (°C), add the degree symbol and subtract 273.

## Fahrenheit, Celsius and Kelvin Units Compared




* Topographic Bathymetric maps only

EXERCISE 1

# The Study of Minerals

## LEARNING OBJECTIVES

Each statement represents an important learning objective that relates to one or more sections of this lab. After you complete this exercise you should be able to:

- **List the main characteristics that an Earth material must possess to be considered a mineral.**
- **Describe the physical properties commonly used to identify minerals.**
- **Identify minerals using a mineral identification key.**
- **Identify the most common rock-forming minerals and list the uses of several economic minerals.**

## MATERIALS

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

## PRE-LAB VIDEO https://goo.gl/8Wkho7

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.

# 1.1 Minerals: Building Blocks of Rock

- **List the main characteristics that an Earth material must possess to be considered a mineral.**

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:

- **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.
- **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.)
- **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.
- **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.
- **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


**SmartFigure 1.1** Most rocks are aggregates of minerals.

VIDEO
https://goo.gl/dLJ6f7

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.

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.** 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. For each item listed, check either Yes or No and explain your 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** provides 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)

VIDEO
https://goo.gl/qbLhc7

## 1.2 Luster

■ **Describe the physical properties commonly used to identify minerals.**

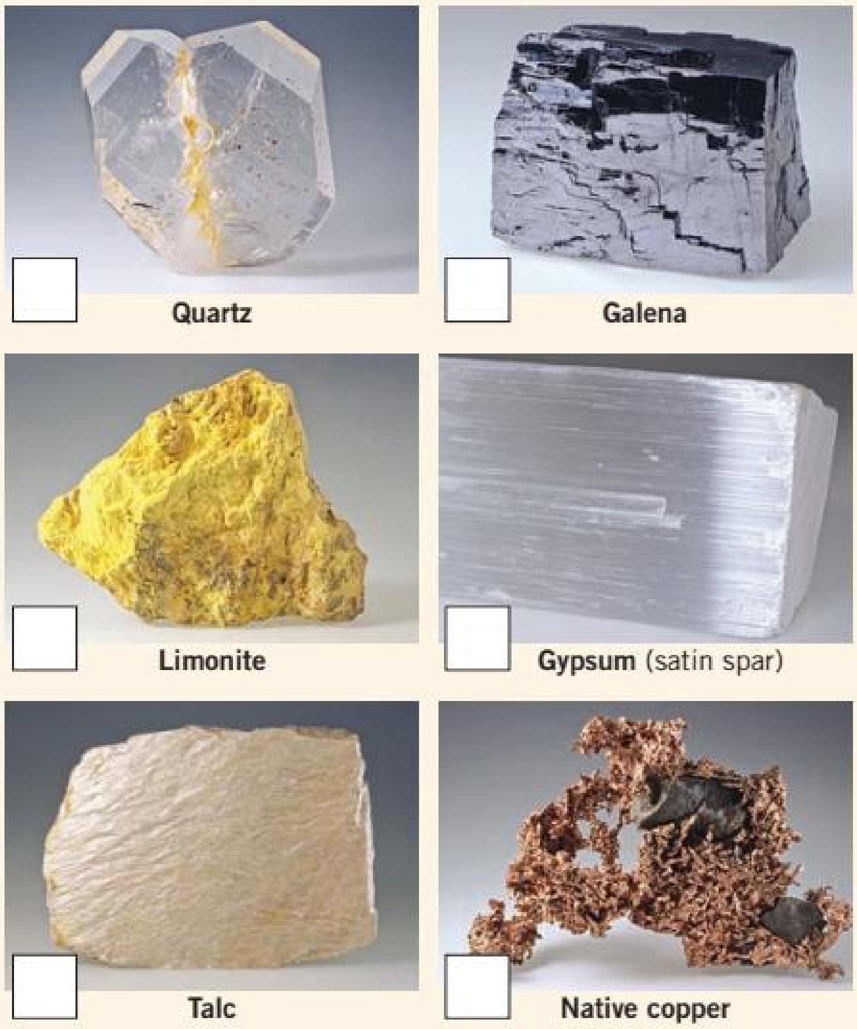
The appearance of light reflected from the surface of a mineral is known as **luster**. Minerals that have the appearance of metals, regardless of color, are said to have a **metallic luster**. Some metallic minerals, such as native copper and galena, develop a dull coating or tarnish when exposed to 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 each mineral 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

- **Describe the physical properties commonly used to identify minerals.**

**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.

▲ **SmartFigure 1.6** Using streak to help identify a mineral.

VIDEO
https://goo.gl/GzAZMk

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

- **Describe the physical properties commonly used to identify minerals.**

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.

   ______________________________

   ______________________________

   ______________________________

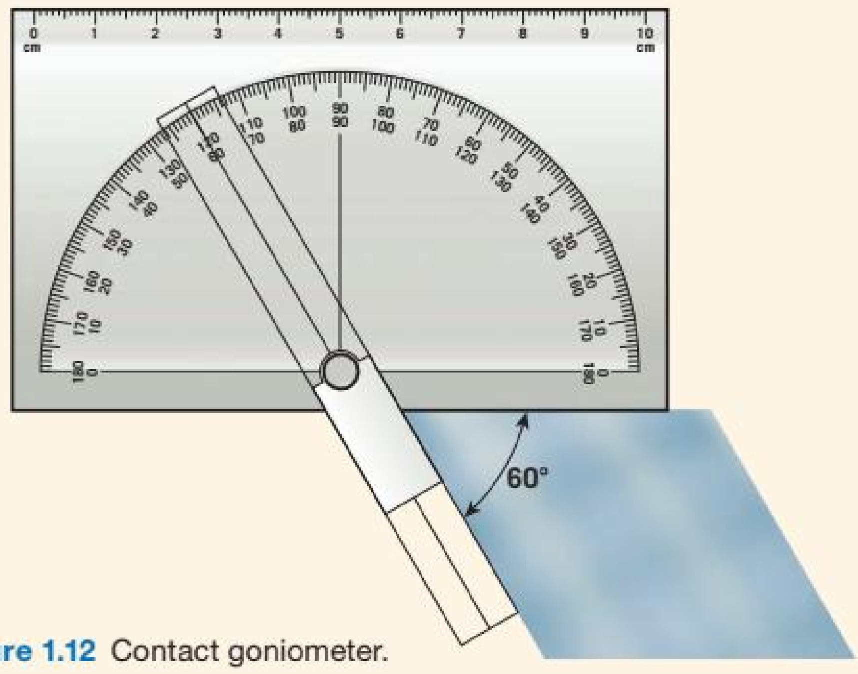
**Specimen A**

**Specimen B**

**Specimen C**

**Specimen D**

▲ **Figure 1.11** Crystal shapes and habits.




▶ **Figure 1.12** Contact goniometer.

## 1.5 Hardness

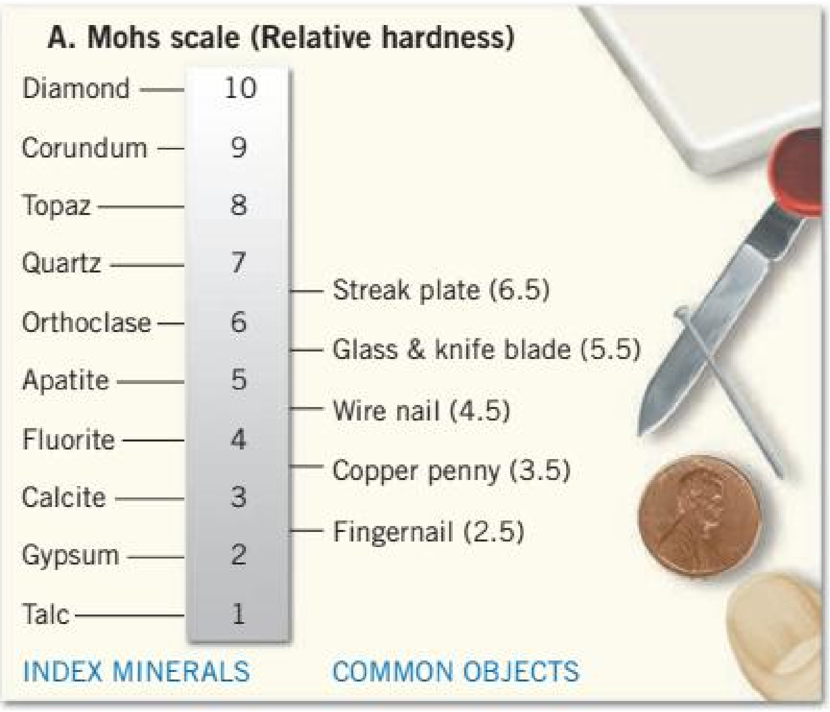
■ **Describe the physical properties commonly used to identify minerals.**

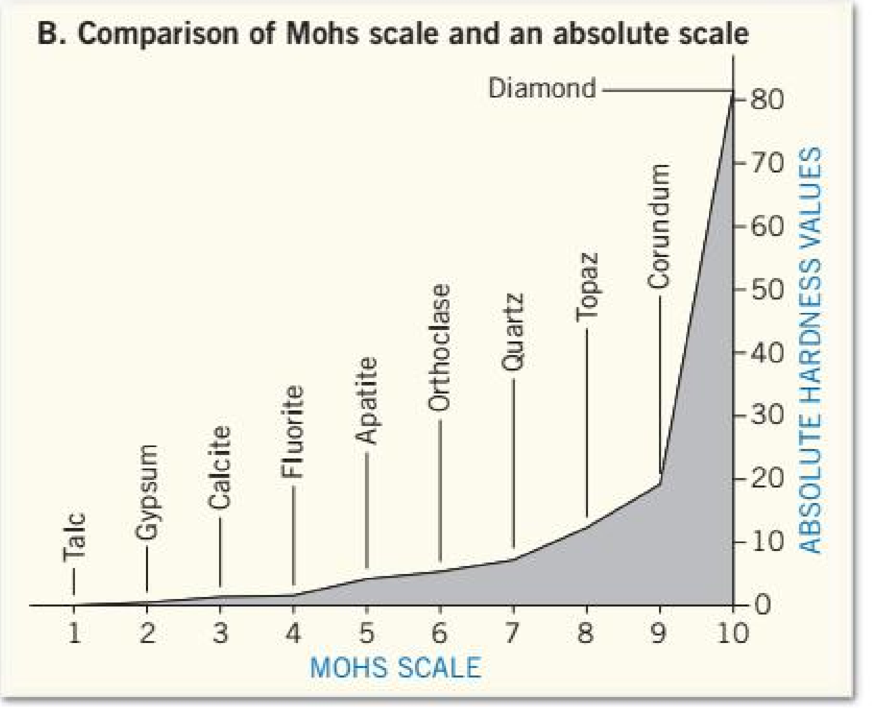
▼ **SmartFigure 1.13** Hardness scales. **A.** Mohs scale of hardness, with the hardnesses of some common objects. **B.** Relationship between the Mohs relative hardness scale and an absolute hardness scale.

VIDEO
https://goo.gl/n4U6HL

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.




## ACTIVITY 1.5
## Hardness

1. The minerals shown in **Figure 1.14** are fluorite and topaz that have been tested for hardness using a wire nail. 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.

**HARDNESS**

Specimen A: ______________________

Specimen B: ______________________

Specimen C: ______________________


▲ **Figure 1.14** Hardness test.

**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

■ **Describe the physical properties commonly used to identify minerals.**

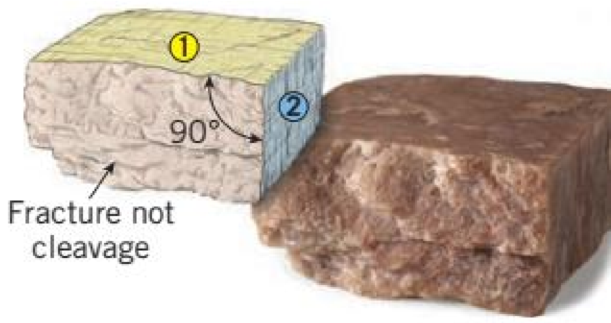
In the crystalline structure of many minerals, some chemical bonds are weaker than others. When minerals are stressed, they tend to break (cleave) along these planes of weak bonding, a property called **cleavage**. When broken, minerals that exhibit cleavage have smooth, flat surfaces, called **cleavage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

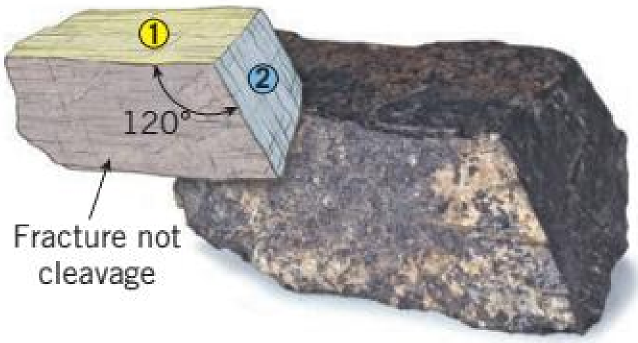
Minerals may have one, two, three, four, or more directions of cleavage (**Figure 1.15**). For minerals with two or more directions of cleavage, you may also determine the **angle(s)** at which the directions of cleavage meet. The most common angles of cleavage are 60, 75, 90, and 120 degrees.

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. Cleavage in one direction.** Example: Muscovite

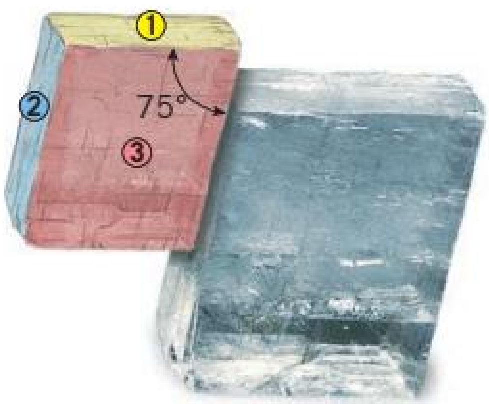


**B. Cleavage in two directions at 90° angles.** Example: Feldspar



**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.

**VIDEO**
https://goo.gl/iw3QPn

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**.

______________________________________________

______________________________________________

______________________________________________

▲ **SmartFigure 1.17** Identifying cleavage of muscovite.

ANIMATION
https://goo.gl/3ocvZJ

**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: ____________________

Cleavage angles: ______________________ degrees

## 1.7 Specific Gravity

■ **Describe the physical properties commonly used to identify minerals.**

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 24, "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 luster or a nonmetallic luster?

______________________________________________

# 1.8 Other Properties of Minerals

■ **Describe the physical properties commonly used to identify 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.

**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.

**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**).


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

▲ **SmartFigure 1.21** Calcite reacting to dilute hydrochloric acid. (Photo by Chip Clark/Fundamental Photographs)

**VIDEO**
https://goo.gl/UNQV3A

**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

■ **Identify minerals using a mineral identification key.**

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 in **Figure 1.23** and the mineral identification key in **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 the following activity, remember that the objective is to learn the *procedure* for identifying minerals through *observation* and *data collection* rather than simply to name the minerals.

## 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 |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
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Refer to the section on "Mineral Groups" to complete this part



▲ **Figure 1.23** Mineral data sheet.

## 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 |
| | | | | | | | | |
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| | | | | | | | | |

▲ **Figure 1.23** Mineral data sheet. (*continued*)

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

| | | 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

| | 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*)

*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

- **Identify the most common rock-forming minerals and list the uses of several economic minerals.**

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 (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


**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.

**A. Smoky quartz** **B. Rose quartz** **C. Milky quartz** **D. Jasper**

quite hard (7 on 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.

**A. Muscovite** **B. Biotite**

▶ **Figure 1.28** Kaolinite, a common clay mineral. (Photo by Dennis Tasa)

**Kaolinite**

**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 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 |

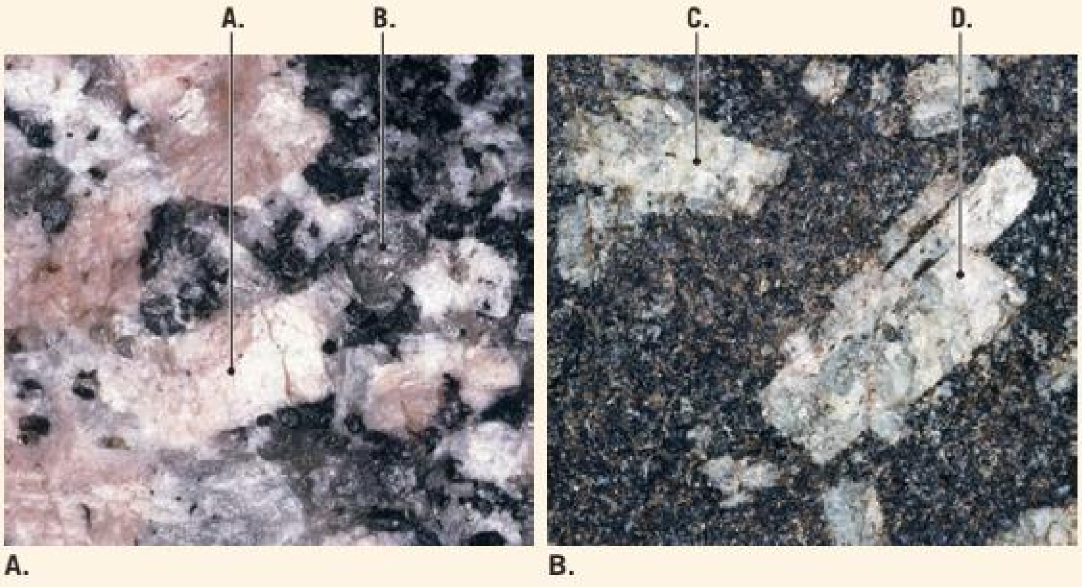
ACTIVITY 1.10

# 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?

   ____________________ ____________________

PART 1 GEOLOGY

# The Study of Minerals

LAB REPORT 1

Name ______________________ Course/Section ______________________

Date ______________________ Due Date ______________________

1. Name the physical property (hardness, color, streak, etc.) described by each of the following statements.

   DESCRIPTION — PHYSICAL PROPERTY

   Breaks along smooth planes: ______________

   Scratches glass: ______________

   Shines like a metal: ______________

   Scratching produces a red powder: ______________

   Looks like broken glass: ______________

2. What term is used to describe the shape of a mineral that has three directions of cleavage that intersect at 90–degree angles?

   ______________

3. Describe the cleavage of the minerals listed below. Include the number of directions and degrees of cleavage angles (if appropriate).

   MINERAL — CLEAVAGE

   Muscovite: ______________

   Calcite: ______________

   Halite: ______________

   Feldspar: ______________

4. What physical feature most distinguishes biotite mica from muscovite mica?

5. Name a mineral that exhibits the physical properties listed below. (Use the photos in this exercise, if needed.)

   PROPERTY — MINERAL

   One direction of cleavage: ______________

   Striations: ______________

   Multiple colors: ______________

   Cubic cleavage: ______________

   Nonmetallic, vitreous luster: ______________

   Fracture: ______________

   Metallic luster: ______________

6. **Figure 1.32** illustrates the common crystal form of the mineral fluorite and the characteristic shape of a cleaved sample of fluorite. Identify each specimen (A *or* B) next to its appropriate description below.

   Crystal form of fluorite: ______________

   Cleavage specimen of fluorite: ______________


▲ **Figure 1.32** Comparing crystal shape and cleavage.

7. Refer to the photo in **Figure 1.33** to complete the following.

   a. Describe the crystal form (habit) of this specimen.

   ______________

   b. What term is applied to the lines on this sample?

   ______________

   c. Based on what you can determine from this photo, use the mineral identification key (see Figure 1.24) to identify this mineral.

   ______________

▲ **Figure 1.33** Visually identifying mineral properties. (Photo by Dennis Tasa)

8. A photo of *agate*, a variety of quartz composed of microscopically small crystals, is provided in **Figure 1.34**. Based on this image, describe the habit of this sample.

_______________________________________

_______________________________________

▲ **Figure 1.34** Agate, a microcrystalline variety of quartz. (Photo by Dennis Tasa)

9. If a mineral can be scratched by a penny but not by a human fingernail, what is its hardness on the Mohs scale?

_______________________________________

10. What term is used to describe the tenacity of muscovite?

_______________________________________

11. Use the mineral identification key (see Figure 1.24) to identify a mineral that is nonmetallic, dark colored, harder than glass, lacking cleavage, and green in color.

_______________________________________

12. For each mineral listed below, list at least one diagnostic property that could be used to help distinguish this mineral from the others described in this exercise. (Refer to Figure 1.23 and Figure 1.24, if necessary.)

MINERAL NAME DIAGNOSTIC PROPERTY

Halite: _______________________________

Galena: _______________________________

Magnetite: _______________________________

Muscovite: _______________________________

Hematite: _______________________________

Fluorite: _______________________________

Talc: _______________________________

Graphite: _______________________________

Calcite: _______________________________

13. List the two most common rock-forming mineral groups.

_______________________________________

_______________________________________

14. Provide an economic use for each mineral listed below.

Galena: _______________________________

Hematite: _______________________________

Graphite: _______________________________

Sphalerite: _______________________________

Gypsum: _______________________________

Calcite: _______________________________

EXERCISE 2

# Rocks and the Rock Cycle

## LEARNING OBJECTIVES

Each statement represents an important learning objective that relates to one or more sections of this lab. After you complete this exercise you should be able to:

- **Distinguish among igneous, sedimentary, and metamorphic rocks and the processes by which they are formed through the rock cycle.**
- **Describe the major igneous textures.**
- **List the dominant mineral(s) found in the four groups of igneous rocks: felsic (granitic), mafic (basaltic), intermediate (andesitic), and ultramafic.**
- **Use an identification key to identify igneous rocks based on their texture and mineral composition.**
- **Compare detrital and chemical sedimentary rocks and list the major constituents of sedimentary rocks.**
- **Use an identification key to identify sedimentary rocks based on their texture and mineral composition.**
- **List the environments in which sediments tend to be deposited.**
- **Use an identification key to identify metamorphic rocks based on their texture and mineral composition.**

## MATERIALS

metric ruler
glass plate
iron nail
igneous rocks
sedimentary rocks
metamorphic rocks
hand lens
dilute hydrochloric acid

## PRE-LAB VIDEO https://goo.gl/QmmSoz

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

Why study rocks? You have already learned that some rocks and minerals have great economic value. In addition, all Earth processes depend in some way on the properties of these basic Earth materials. Events such as volcanic eruptions, mountain building, weathering, erosion, and even earthquakes involve rocks and minerals. Consequently, a basic knowledge of Earth materials is essential to understanding most geologic phenomena.

## 2.1 Rock Groups and the Rock Cycle

- **Distinguish among igneous, sedimentary, and metamorphic rocks and the processes by which they are formed through the rock cycle.**

Most **rocks** are aggregates (mixtures) of mineral crystals or fragments (gravel, sand, and silt) of preexisting rocks. However, there are some important exceptions, including *obsidian*, a rock made of volcanic glass (a non-crystalline substance), and *coal*, a rock made of decayed plant material (an organic substance). Rocks are classified into three groups—igneous, sedimentary, and metamorphic—based on the processes by which they were formed.

### Igneous, Sedimentary, and Metamorphic Rocks

**Igneous rocks** are the solidified products of once-molten material that was created by melting in the upper mantle or crust. Geologists call molten rock **magma** when it is found at depth and **lava** when it erupts at Earth's surface. The distinguishing feature of most igneous rocks is the interlocking arrangement of their mineral crystals that develops as the molten material cools and solidifies. *Intrusive* igneous rocks form beneath Earth's surface from magma, and *extrusive* igneous rocks form at the surface from lava

**Sedimentary rocks** form at or near Earth's surface from the products of *weathering*. This material, called **sediment**, is transported by erosional agents (water, wind, or ice) as solid particles or ions in solution to their site of deposition. The process of **lithification** (meaning "to turn to stone") transforms the sediment into solid rock. Sedimentary rocks cover much of Earth's surface and may contain organic matter (oil, gas, and coal) and fossils. The layering that develops when sediment is deposited is the most recognizable feature of sedimentary rocks. These layers, called **strata**, or **beds**, usually accumulate in nearly horizontal sheets that can be as thin as a piece of paper or tens of meters thick (**Figure 2.1**).

**Metamorphic rocks** are produced from preexisting igneous, sedimentary, or other metamorphic rocks that have been subjected to conditions within Earth that are significantly different from those under which the parent rock originally formed. *Metamorphism*, the process that causes the transformation, generally occurs at depths where both temperatures and pressures are much higher than at Earth's surface.

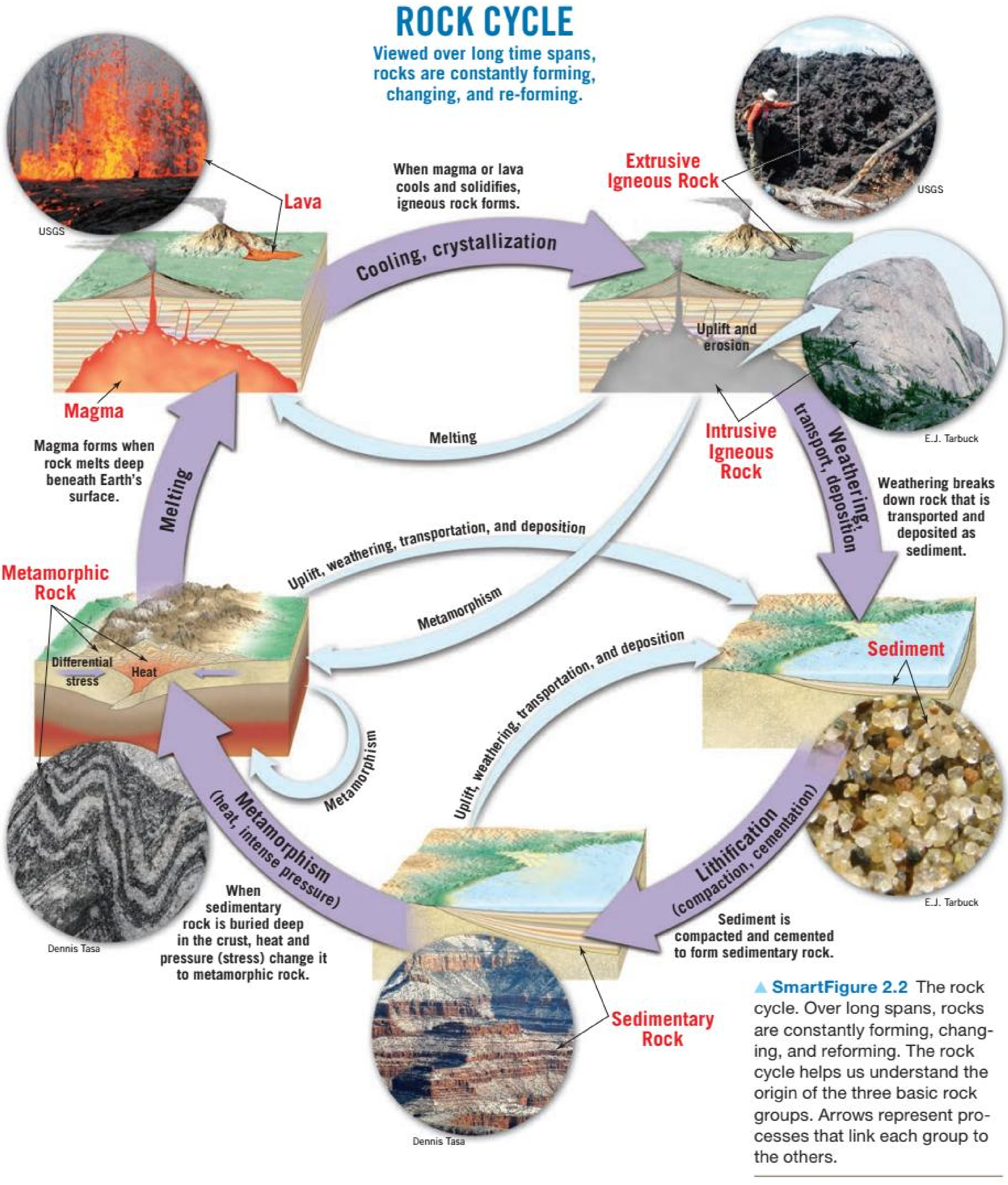
### The Rock Cycle

One very useful device for understanding rock groups and the geologic processes that transform one rock type into another is the **rock cycle** (**Figure 2.2**). We will begin with magma, molten rock that forms deep beneath Earth's surface. Over time, magma cools and solidifies. This process, called *crystallization*, may occur either beneath the surface or, following a volcanic eruption, at the surface. In either situation, the resulting rocks are called *igneous rocks*.

If igneous rocks are exposed at the surface, they will undergo *weathering*, in which the day-in and day-out influences of the atmosphere slowly disintegrate and decompose rocks. The materials that result are often moved downslope by gravity before being picked up and transported by any of a number of erosional agents, such as running water, glaciers, wind, or waves. Eventually these particles and dissolved substances, called *sediment*, are deposited. Although most sediment ultimately comes to rest in the ocean, other sites of deposition include river floodplains, desert basins, swamps, and sand dunes.

Next, the sediments undergo *lithification*, a term meaning "to turn to stone." Sediment is usually lithified into *sedimentary rock* when compacted by the weight of overlying layers or when cemented as percolating groundwater fills the pores with mineral matter.

▼ **Figure 2.1** Sedimentary layers, called strata, or beds in Canyonlands National Park, Utah. (Photo by SeBuKi/Alamy)




▲ **SmartFigure 2.2** The rock cycle. Over long spans, rocks are constantly forming, changing, and reforming. The rock cycle helps us understand the origin of the three basic rock groups. Arrows represent processes that link each group to the others.

**VIDEO** https://goo.gl/y1Xs9G

If the resulting sedimentary rock is buried deep within Earth and involved in the dynamics of mountain building or intruded by a mass of magma, it will be subjected to great pressures and/or intense heat. The sedimentary rock will react to the changing environment and turn into the third rock type, *metamorphic rock*. When metamorphic rock is subjected to additional pressure changes or to still higher temperatures, it will melt, creating magma, which will eventually crystallize into igneous rock, starting the cycle all over again.

The paths described in the preceding section are not the only ones that are possible. To the contrary, other paths are just as likely to be followed. These alternatives are indicated by the light blue arrows in Figure 2.2.

## Rock Textures and Compositions

The task of distinguishing among the three rock groups and naming individual samples relies heavily on the ability to recognize their *textures* and *compositions*. A rock's mineral composition and texture, in turn, are a reflection of the geologic processes that created it.

**Texture** A rock's **texture** refers to the size, shape, and/or arrangement of its mineral grains. The shape and arrangement of mineral grains has a significant effect on a rock's appearance and therefore provides clues to whether a rock is igneous, sedimentary, or metamorphic.

**Composition** The **composition** of a rock refers to the abundance and type of minerals it contains. Large mineral grains can often be identified by sight or by their physical properties, while a hand lens or microscope may be needed to identify small mineral grains. In addition, a few minerals can be identified based on a particular diagnostic property. For example, rocks composed of the mineral calcite fizz when a drop of dilute hydrochloric acid (HCl) is applied, and rocks composed of the mineral quartz are hard and will easily scratch glass.

ACTIVITY 2.1

## Rock Groups and the Rock Cycle

1. Label the rock cycle diagram in **Figure 2.3**.

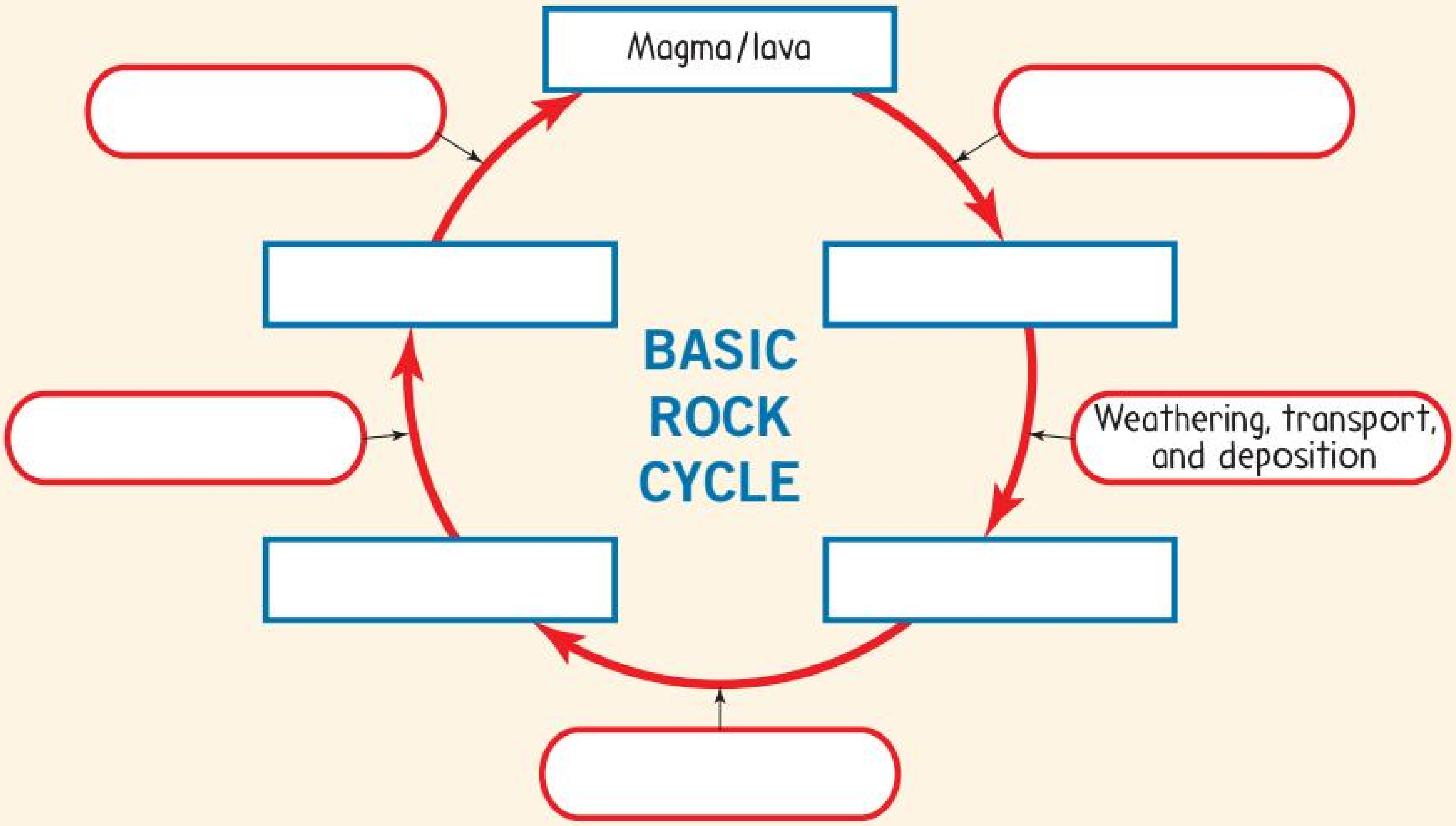



**Figure 2.3** Rock cycle diagram.

2. What is magma? How does magma differ from lava?

_______________________________________________

3. The terms *intrusive* and *extrusive* are used to describe which one of the three rock groups?

_______________________________________________

4. In your own words, write a definition of *rock texture*.

_______________________________________________

5. Name the process by which sediment is transformed into sedimentary rocks.

_______________________________________________

6. What is the most characteristic feature of sedimentary rocks?

_______________________________________________

7. What type of rock is generated when rocks that formed near the surface become deeply buried and exposed to intense pressures and/or heat?

_______________________________________________

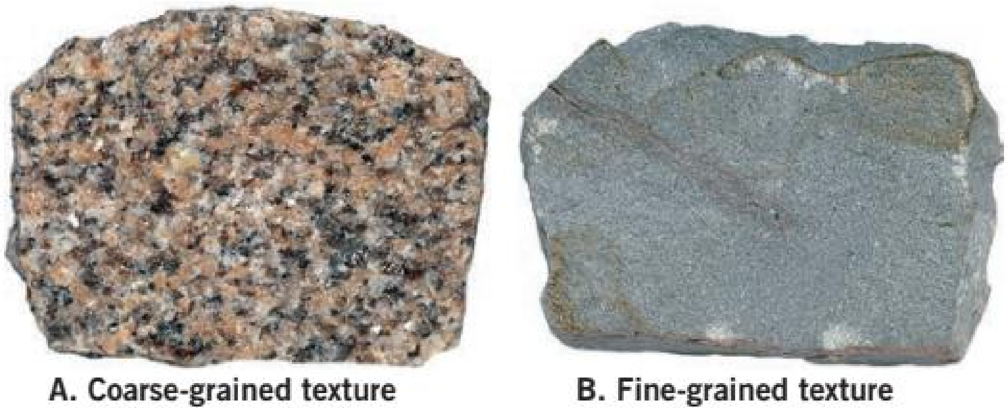
8. When determining rock composition, describe the test that can be used to determine whether it contains the mineral calcite.

_______________________________________________

## 2.2 Igneous Rock Textures

■ **Describe the major igneous textures.**

Igneous rocks form when molten rock cools and crystallizes. The interlocking assemblage of silicate minerals that develop as the molten material cools gives most igneous rocks their distinctive crystalline appearance. The rate at which magma cools determines the size of the interlocking crystals in igneous rocks. The slower the cooling rate, the larger the mineral crystals.




▲ **Figure 2.4** Coarse-grained and fine-grained igneous textures.

Molten rock may solidify at Earth's surface, or it may solidify at depth. When molten rock solidifies *at the surface*, the resulting igneous rocks are classified as **extrusive rocks**, or **volcanic rocks** (after Vulcan, the Roman fire god). When magma solidifies at depth, it forms igneous rocks known as **intrusive rocks**, or **plutonic rocks** (after Pluto, the god of the underworld in classical mythology). Intrusive igneous rocks remain at depth unless portions of the crust are uplifted and the overlying rocks are stripped away by erosion.

### Coarse-Grained (Phaneritic) Texture

When a large mass of magma solidifies at depth, it cools slowly and forms *intrusive igneous rocks* that exhibit **coarse-grained texture** (**Figure 2.4A**). These rocks have intergrown crystals that are roughly equal in size and large enough that the individual minerals within can be identified with the unaided eye. A hand lens or binocular microscope can greatly assist in mineral identification.

### Fine-Grained (Aphanitic) Texture

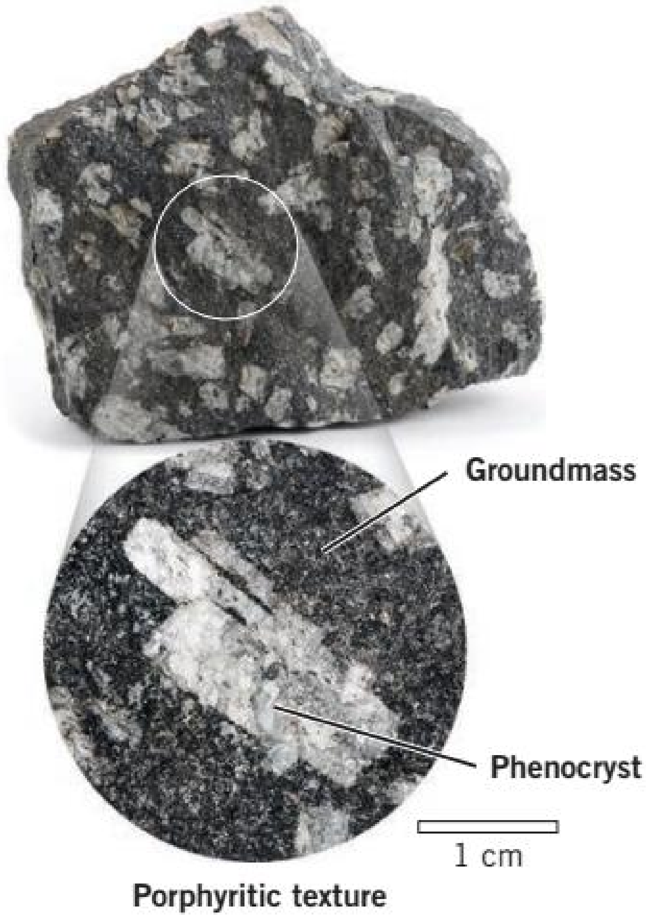
Igneous rocks that form when molten material cools rapidly at the surface, called extrusive igneous rock, or as small masses within the upper crust exhibit **fine-grained texture** (**Figure 2.4B**). Fine-grained igneous rocks are composed of individual crystals that are too small to be identified without strong magnification.

### Porphyritic Texture

**Porphyritic texture** results when molten rock cools in two different environments. The resulting rock consists of larger crystals embedded in a matrix of smaller crystals (**Figure 2.5**). The larger crystals are termed *phenocrysts*, and the smaller, surrounding crystals are called *groundmass*, or *matrix*.

### Glassy Texture

During explosive volcanic eruptions, molten rock is ejected into the atmosphere, where it is quenched (cooled to a solid state) very quickly. When the material solidifies before the atoms arrange themselves into an orderly crystalline structure, the rocks exhibit **glassy texture** that may resemble manufactured glass or fibers of spun glass (**Figure 2.6**).




▲ **Figure 2.5** The large crystals in a porphyritic rock are called *phenocrysts*, and the matrix of smaller crystals is called *groundmass*.

Glassy texture

▲ **Figure 2.6** Rocks with a glassy texture are composed of unordered atoms and often resemble manufactured glass.

Vesicular texture

▲ **Figure 2.7** This extrusive igneous rock consists of glassy fibers and contains voids left by gas bubbles that escaped as lava solidified.

Fragmental (pyroclastic) texture

▲ **Figure 2.8** Fragmental texture results from the consolidation of fragments that may include ash, once molten blobs, or angular blocks that were ejected during an explosive volcanic eruption.

## Vesicular Texture

Common features of some fine-grained and glassy extrusive igneous rocks are the voids left by gas bubbles that escape as lava solidifies. These somewhat spherical openings are called *vesicles*, and the rocks that contain them have **vesicular texture** (**Figure 2.7**).

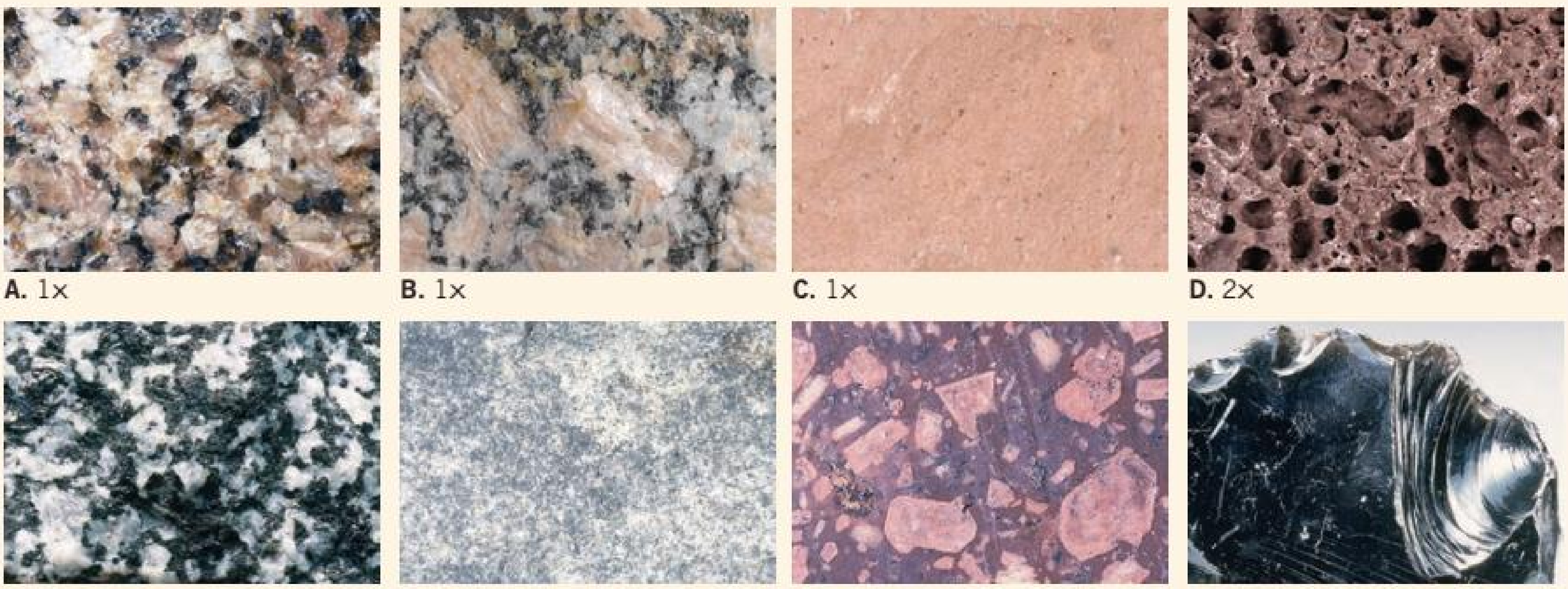
## Fragmental (Pyroclastic) Texture

Volcanoes sometimes blast fine ash, molten blobs, and/or angular blocks torn from the walls of the vent into the air during eruptions. Igneous rocks composed of these rock fragments have **fragmental (pyroclastic) texture** (**Figure 2.8**).

ACTIVITY 2.2

# Igneous Textures

Use the close-up photos of igneous rocks in **Figure 2.9** to answer the following questions.




▲ **Figure 2.9** Identifying igneous textures.

1. Which sample(s) (A–H) exhibit(s) porphyritic texture?

_______________________________________________

2. For the sample(s) you listed in Question 1, what terms are used to describe the larger crystals and the surrounding smaller crystals? Label the larger and smaller crystals on the photo(s).

   Larger crystals: _______________________________________________

   Smaller crystals: _______________________________________________

3. Which sample(s) in Figure 2.9 exhibit(s) coarse-grained texture?

_______________________________________________

4. Complete the description of the environment in which *coarse-grained igneous rocks* form by choosing the appropriate terms: (1. at great depth *or* on the surface) (2. slowly *or* rapidly) (3. extrusive *or* intrusive).

   When molten rock solidifies (1) ____________________, it cools (2) ____________________ and produces an (3) ____________________ igneous rock.

5. Which of the sample(s) in Figure 2.9 exhibit(s) fine-grained texture?

_______________________________________________

6. Complete the description of the environment in which *fine-grained igneous rocks* form by choosing the appropriate terms: (1. at great depth *or* on/near the surface) (2. slowly *or* rapidly) (3. extrusive *or* intrusive).

   When molten rock solidifies (1) ____________________, it cools (2) ____________________ and produces an (3) ____________________ igneous rock.

7. Which of the sample(s) in Figure 2.9 exhibit(s) vesicular texture?

_______________________________________________

8. Which sample(s) in Figure 2.9 exhibit(s) glassy texture?

_______________________________________________

9. Although Samples A and C in Figure 2.9 appear different, they have very similar mineral compositions. Briefly explain what accounts for their different appearances.

_______________________________________________

## 2.3 Composition of Igneous Rocks

- **List the dominant mineral(s) found in the four groups of igneous rocks: felsic (granitic), mafic (basaltic), intermediate (andesitic), and ultramafic.**

Despite their significant compositional diversity, igneous rocks (and the magmas from which they form) can be divided into four groups, based on the proportions of light and dark silicate minerals (**Figure 2.10**).

**Felsic (or granitic)** igneous rocks are composed mainly of the light-colored minerals quartz and potassium feldspar, with lesser amounts of plagioclase feldspar. Recall that feldspar crystals can be identified by their rectangular shapes, flat surfaces, and tendency to be pink, white, or dark gray in color. Quartz grains, on the other hand, are glassy and somewhat rounded and tend to be light gray. Dark-colored minerals account for no more than 15 percent of the minerals in rocks in this group.

**Intermediate (or andesitic)** rocks are mixtures of both light-colored minerals (mainly plagioclase feldspar) and dark-colored minerals (mainly amphibole). Dark minerals comprise between 15 percent and 45 percent of these rocks.

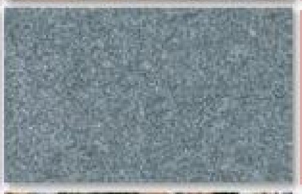
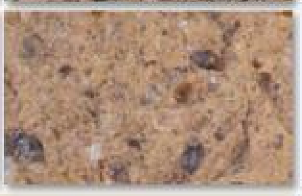
**Mafic (or basaltic)** rocks contain abundant dark-colored minerals (mainly pyroxene and olivine) that account for between 45 percent and 85 percent of their composition. Plagioclase feldspar makes up the bulk of the remainder.

**Ultramafic** rocks are composed almost entirely of the dark silicate minerals pyroxene and olivine and are seldom observed at Earth's surface. However, the ultramafic rock peridotite is a major constituent of Earth's upper mantle.

An important skill used in identifying igneous rocks is being able to classify them based on mineral composition—felsic, intermediate, mafic, or ultramafic. However, it is not possible to identify minerals in fine-grained igneous rocks without sophisticated equipment. Further, the dark silicate minerals are often difficult to differentiate—even in coarse-grained rocks. Consequently, geologists working in the field estimate mineralogy by using the **color index**, a value based on the percentage of dark silicate minerals, shown at the bottom of Figure 2.10. Rocks with a low color index (light in color) are felsic in composition, whereas those with a high color index (dark in color) are mafic or ultramafic.

It is important to note that although the dark silicate minerals are often black in color, the mineral pyroxene can be dark green, and olivine is often olive green in color. Therefore, rocks with a dark greenish color have a very high color index and are usually ultramafic in composition.

## IGNEOUS ROCK IDENTIFICATION KEY

| | | MINERAL COMPOSITION | | | |
|---|---|---|---|---|---|
| | | **Felsic** (Granitic) | **Intermediate** (Andesitic) | **Mafic** (Basaltic) | **Ultramafic** |
| **Dominant Minerals** | | Quartz Potassium feldspar | Amphibole Plagioclase feldspar | Pyroxene Plagioclase feldspar | Olivine Pyroxene |
| **Accessory Minerals** | | Plagioclase feldspar Amphibole Muscovite Biotite | Pyroxene Biotite | Amphibole Olivine | Plagioclase feldspar |
| TEXTURE: **Coarse-grained (Phaneritic)** |  | **Granite** | **Diorite** | **Gabbro** | **Peridotite** |
| TEXTURE: **Fine-grained (Aphanitic)** |  | **Rhyolite** | **Andesite** | **Basalt** | Uncommon |
| TEXTURE: **Porphyritic** (two distinct grain sizes) |  | The name "porphyry" follows the rock name if it contains appreciable phenocrysts. | | | Uncommon |
| TEXTURE: **Glassy** |  | **Obsidian** (compact glass) | | | Uncommon |
| TEXTURE: **Vesicular** (contains voids) |  | **Pumice** (frothy glass) (floats in water) | | **Scoria** (Vesicular basalt) | Uncommon |
| TEXTURE: **Pyroclastic** (fragmental) |  | **Tuff** (Most fragments less than 4 mm) **Volcanic Breccia** (Most fragments greater than 4 mm) | | | Uncommon |
| **Rock Color** (based on % of dark minerals) | | 0% to 25% | 25% to 45% | 45% to 85% | 85% to 100% |

▲ **SmartFigure 2.10** Igneous rock identification key.

VIDEO
https://goo.gl/kCdkjt

## ACTIVITY 2.3

## Using Color Index to Determine Composition

Use the color index shown at the bottom of Figure 2.10 as well as the photos of Samples A–F in **Figure 2.11** to complete the following statements.

1. Sample(s) ______________________________ has/have felsic (granitic) composition.
2. Sample(s) ______________________________ has/have intermediate (andesitic) composition.
3. Sample(s) ______________________________ has/have mafic (basaltic) or ultramafic composition.

▶ **Figure 2.11** Hand samples that illustrate igneous compositions.

A. Rhyolite
B. Gabbro
C. Andesite porphyry
D. Diorite
E. Peridotite
F. Granite

# 2.4 Identifying Igneous Rocks

- **Use an identification key to identify igneous rocks based on their texture and mineral composition.**

Igneous rocks are identified by their texture and mineral composition. The texture of an igneous rock is mainly a result of its cooling history, whereas its mineral composition is largely a result of the chemical makeup of the parent magma. Because igneous rocks are classified on the basis of both mineral composition and texture, some rocks with similar mineral constituents but that exhibit different textures are given different names.

## ACTIVITY 2.4

## Identifying Igneous Rocks

Place each of the igneous rocks supplied by your instructor on a numbered piece of paper. Then complete the igneous rock chart in **Figure 2.12** and identify each specimen. To identify an igneous rock, follow these steps:

**Step 1:** Identify the texture of the rock.

**Step 2:** Determine the mineral composition of the rock by:

**a.** Identifying the abundance of major minerals

or

**b.** Estimating the mineral composition using the color index

*continued*

*Activity 2.4 continued*

**Step 3:** Use the igneous rock identification key in Figure 2.10 to identify the rock.

| IGNEOUS ROCK CHART | | | | |
|---|---|---|---|---|
| Sample Number | Texture | Color (light- intermediate- dark) | Dominant Minerals | Rock Name |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

▲ **Figure 2.12** Igneous rock chart.

## 2.5 Classifying Sedimentary Rocks

- **Compare detrital and chemical sedimentary rocks and list the major constituents of sedimentary rocks.**

Weathering disintegrates and decomposes rock. The resulting products are transported and deposited or precipitated as sediment. Over long periods of time, compaction and cementation turn solid particles of sediment into sedimentary rock, whereas material dissolved in water may be precipitated as a crystalline rock.

Materials that accumulate as sediment have two principal sources. First, sediments may originate as solid particles from weathered rocks. These particles are called *detritus*, and the rocks they form are called *detrital sedimentary rocks*. The second major source of sediment is soluble material produced by chemical weathering.

**Detrital sedimentary rocks** consist of mineral grains or rock fragments derived from mechanical and chemical weathering that are transported and deposited as solid particles. Clay minerals are the most abundant solid products of chemical weathering. Quartz is abundant in detrital rocks because it is extremely durable. Geologists use particle size to distinguish among detrital sedimentary rocks.

**Chemical and biochemical sedimentary rocks** are products of mineral matter that were dissolved in water and later precipitated. Precipitation may occur as a result of processes such as evaporation or temperature change or as a result of life processes, such as those that result in the formation of shells. Sediment formed by life processes has a *biochemical* origin. Limestone, which is composed of calcite ($CaCO_3$), is the most common mineral in chemical sedimentary rocks and may originate either from chemical or biological processes.

## Compositions of Sedimentary Rocks

Sedimentary rocks are classified as detrital or chemical, based on the nature of the sediment of which they are composed. Determining the mineral composition of sedimentary rocks is an important step in their identification. Most sedimentary rocks contain a high percentage of one of the following:

- **Clay minerals** Rocks composed of clay minerals are very fine grained and soft, and they can be scratched with an iron nail.
- **Quartz** Sedimentary rocks composed mainly of quartz usually consist of sand-size particles that are hard and can scratch glass.
- **Calcite** Rocks composed of calcite effervesce when a drop of dilute HCl is applied. They can also be easily scratched with an iron nail.
- **Evaporite minerals** These sedimentary rocks contain salts, usually halite or gypsum, that are deposited when saltwater evaporates. They are crystalline and can be scratched by an iron nail. Gypsum is soft enough to be scratched by a fingernail.
- **Altered plant fragments** Rocks composed of organic material are usually black in color, have a low density, and are easily broken.

## Sedimentary Textures

Sedimentary rocks exhibit two basic textures: *clastic* and *nonclastic*. Rocks that display a **clastic texture** consist of discrete particles that are cemented or compacted together. Clastic textures are further divided based on particle size and shape.

Rocks that have a **nonclastic texture** are often crystalline and consist of minerals that form patterns of interlocking crystals. Although crystalline sedimentary rocks can be similar in appearance to some igneous rocks, they tend to consist of minerals—most often calcite, halite, or gypsum—that are easily distinguished from the silicate minerals found in igneous rocks.

**ACTIVITY 2.5**

## Examining Sedimentary Compositions and Textures

Carefully examine the common sedimentary rocks shown in **Figure 2.13**. Use these photos and the preceding discussion to answer the following questions.

1. What characteristic can be used to distinguish Sample A (conglomerate) from Sample B (breccia)?

   ______________________________

2. List the name(s) of the chemical sedimentary rocks that clearly exhibit(s) clastic texture.

   ______________________________

3. Samples C, O, P, and Q are all primarily composed of quartz. What property of quartz would assist you in identifying these samples?

   ______________________________

4. Samples G–L all contain calcite. What property of calcite would assist you in identifying these samples?

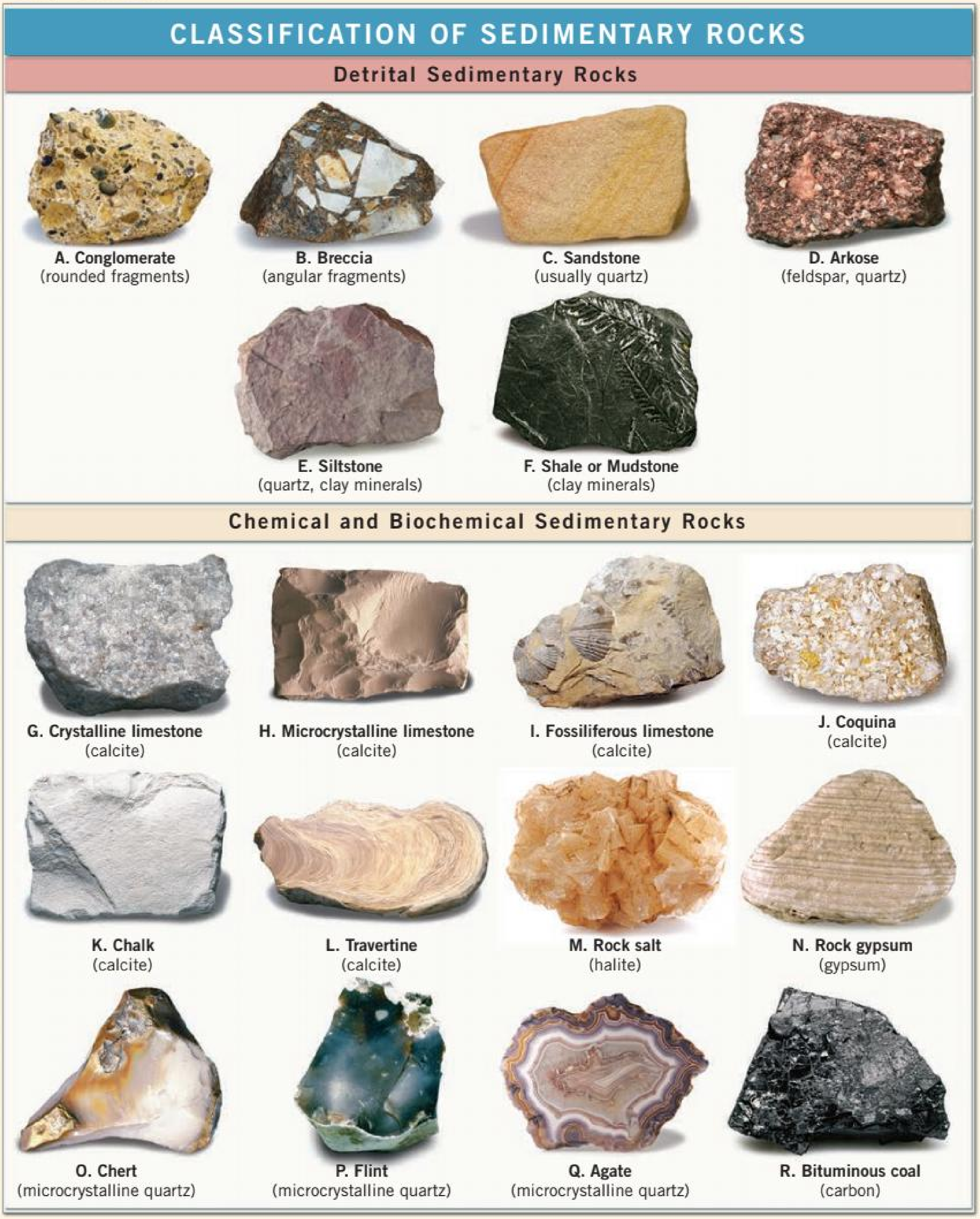
   ______________________________

5. Compare and contrast Sample I (fossiliferous limestone) and Sample J (coquina).

   ______________________________

*continued*

*Activity 2.5 continued*




▲ **Figure 2.13** Hand samples of common sedimentary rocks.

6. Sample G (crystalline limestone) in **Figure 2.13** and Sample F (granite) in **Figure 2.11** are both crystalline. How do these samples differ in appearance?

_______________________________________________

7. What characteristic do Sample Q (agate) and Sample L (travertine) share?

_______________________________________________

**8.** Which of these terms most accurately describes the texture of Sample N—*clastic* or *nonclastic*?

______________________________

**9.** Sample H is a microcrystalline rock composed of calcite, and Sample O is a microcrystalline rock composed of quartz. What test(s) could be used to figure out which is which?

______________________________

**10.** What mineral does Sample D contain that gives it a pinkish color?

______________________________

## 2.6 Identifying Sedimentary Rocks

- **Use an identification key to identify sedimentary rocks based on their texture and mineral composition.**

The sedimentary rock identification key in **Figure 2.14** divides sedimentary rocks into two groups: detrital and chemical. The primary subdivisions for detrital rocks are based on grain size, whereas composition is the main criterion used to subdivide the chemical sedimentary rocks.

**SEDIMENTARY ROCK IDENTIFICATION KEY**

**Detrital Sedimentary Rocks**

| Clastic Texture (particle size) | Distinctive Properties | | Rock Name |
|---|---|---|---|
| **Gravel** Coarse (over 2 mm) | Rounded rock or mineral fragments, typically poorly sorted | | **Conglomerate** |
| | Angular rock or mineral fragments, typically poorly sorted | | **Breccia** |
| **Sand** Medium (1/16 to 2 mm) | Quartz grains, typically rounded, well sorted | Sandstone | **Quartz Sandstone** |
| | At least 25% feldspar, typically poorly sorted, angular fragments | Sandstone | **Arkose** |
| | Mixture of sand and mud, typically poorly sorted | Sandstone | **Graywacke** |
| **Silt/mud** Fine (1/16 to 1/256 mm) | Mostly silt-size quartz and clay, blocky, gritty | Mudstone | **Siltstone** |
| **Clay/mud** Very fine (less than 1/256 mm) | Mostly clay, splits into layers, may contain fossils | Mudstone | **Shale** |
| | Mostly clay, crumbles easily | Mudstone | **Claystone** |

**Chemical and Organic Sedimentary Rocks**

| Composition | Texture and Distinctive Properties | | Rock Name |
|---|---|---|---|
| Calcite, $CaCO_3$ (effervesces in HCl) | Fine to coarse crystalline | Limestone | **Crystalline Limestone** |
| | No visible grains, may exhibit conchoidal fracture | Limestone | **Micrite** |
| | Visible shells and shell fragments loosely cemented | Limestone | **Coquina** |
| | Various size shells and shell fragments, well cemented | Limestone | **Fossiliferous Limestone** |
| | Microscopic shells and clay, soft | Limestone | **Chalk** |
| | Faint layering, may contain cavities or pores | Limestone | **Travertine** |
| Quartz, $SiO_2$ | Microcrystalline, may exhibit conchoidal fracture, will scratch glass | | **Chert (light colored)** |
| | | | **Flint (dark colored)** |
| | | | **Agate (banded)** |
| Gypsum $CaSO_4 \cdot 2H_2O$ | Fine to coarse crystalline, soft | | **Rock Gypsum** |
| Halite, NaCl | Fine to coarse crystalline, tastes salty | | **Rock Salt** |
| Altered plant fragments | Black brittle organic rock, may be layered | | **Bituminous Coal** |

▲ **Figure 2.14** Sedimentary rock identification key.

ACTIVITY 2.6

## Identifying Sedimentary Rocks

Place each of the sedimentary rocks supplied by your instructor on a numbered piece of paper. Then complete the sedimentary rock chart in **Figure 2.15** for each rock. Use the sedimentary rock identification key in Figure 2.14 to identify each specimen.

**SEDIMENTARY ROCK CHART**

| Specimen Number | Texture and Grain Size | Composition or Sediment Name | Detrital or Chemical (Biochemical) | Rock Name |
|---|---|---|---|---|
| | | | | |
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▲ **Figure 2.15** Sedimentary rock chart.

## 2.7 Sedimentary Environments

■ **List the environments in which sediments tend to be deposited.**

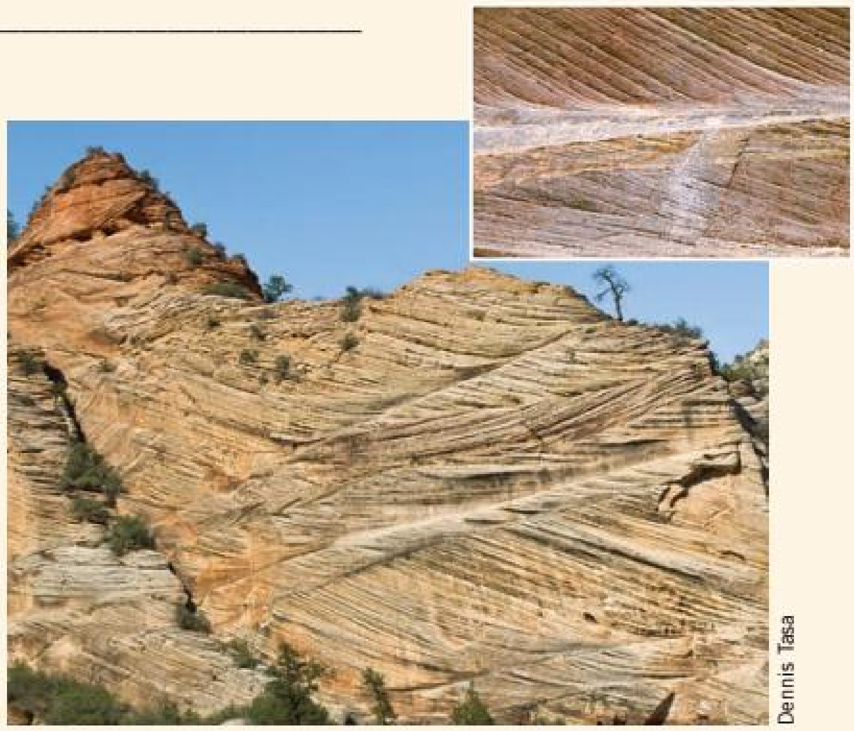
Sedimentary rocks are extremely important in the study of Earth history. The texture and mineral composition of sedimentary rocks often suggest something about the location (environment) where the sediment accumulated. For example, rock salt forms in warm, shallow seas, where the loss of water by evaporation exceeds the annual rainfall. In addition, fossils and sedimentary structures provide important clues about a rock's history. Think of each sedimentary rock as representing a "place" on Earth where sediment was deposited and later lithified. **Figure 2.16** illustrates and describes a few modern environments where sediment accumulates.


**Figure 2.16** Sedimentary environments. (Photos A and C by Michael Collier; photo B by Dennis Tasa; photo D by USGS; photo F by Mason Jar/Shutterstock; photo G by Alan Majchrowicz/AGE Fotostock; photo H by Barrett & MacKay/Glow Images; photo I by Radius/Superstock; photo J by E. J. Tarbuck; photo K by Marli Miller; photo L by Pixachi/Superstock)

ACTIVITY 2.7

## Identifying Sedimentary Environments

1. Use Figure 2.16 to identify the environment(s) (A–L) where the sediment for the following sedimentary rocks could have been deposited.
   Rock gypsum: ______
   Conglomerate: ______
   Sandstone: ______
   Shale: ______
   Bituminous coal: ______
   Travertine: ______
2. Briefly describe the environment that is associated with the formation of coral reefs.
   ______
3. The rocks in Zion National Park, Utah, consist of layers of well-sorted quartz sandstone, shown in **Figure 2.17**. Describe the environment that existed when these sediments were deposited. (*Hint:* Examine the sedimentary environments shown in Figure 2.16.)
   ______
   ______
   ______




▶ **Figure 2.17** The orange and yellow cliffs of Utah's Zion National Park.

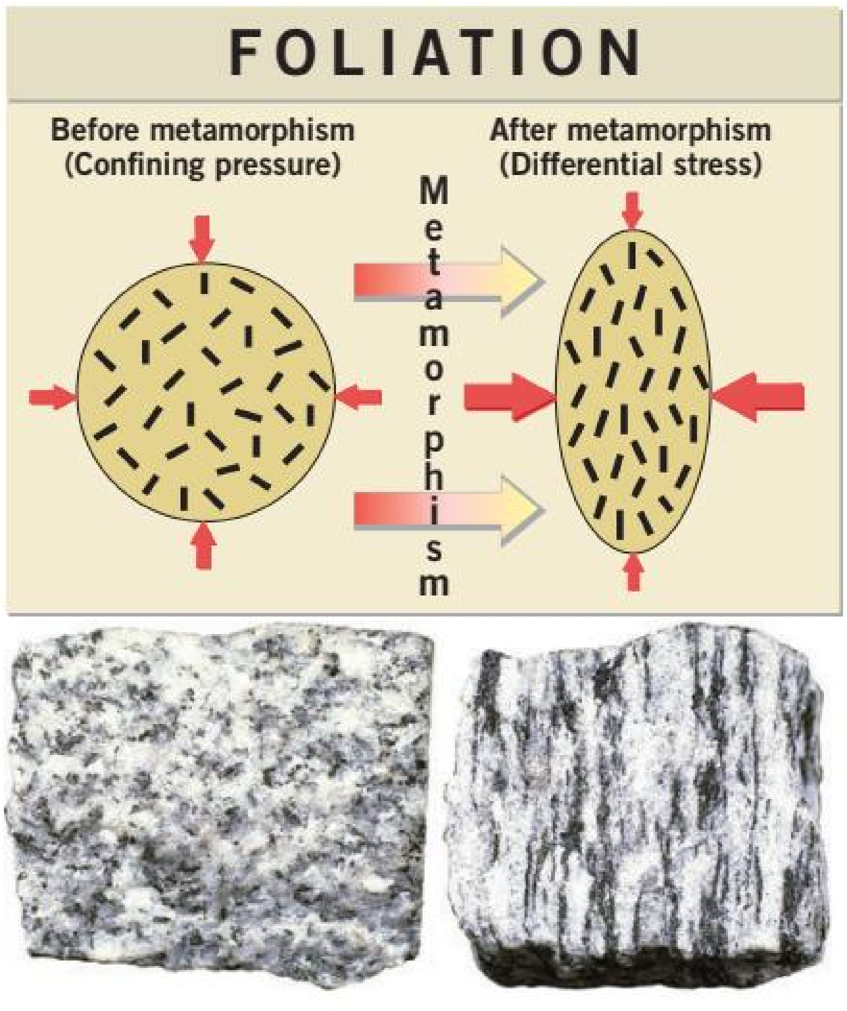
## 2.8 Identifying Metamorphic Rocks

- **Use an identification key to identify metamorphic rocks based on their texture and mineral composition.**

Extensive areas of metamorphic rocks are exposed on every continent in the relatively flat regions known as *shields*. They are also located in the cores of mountains and buried beneath sedimentary rocks on the continents.

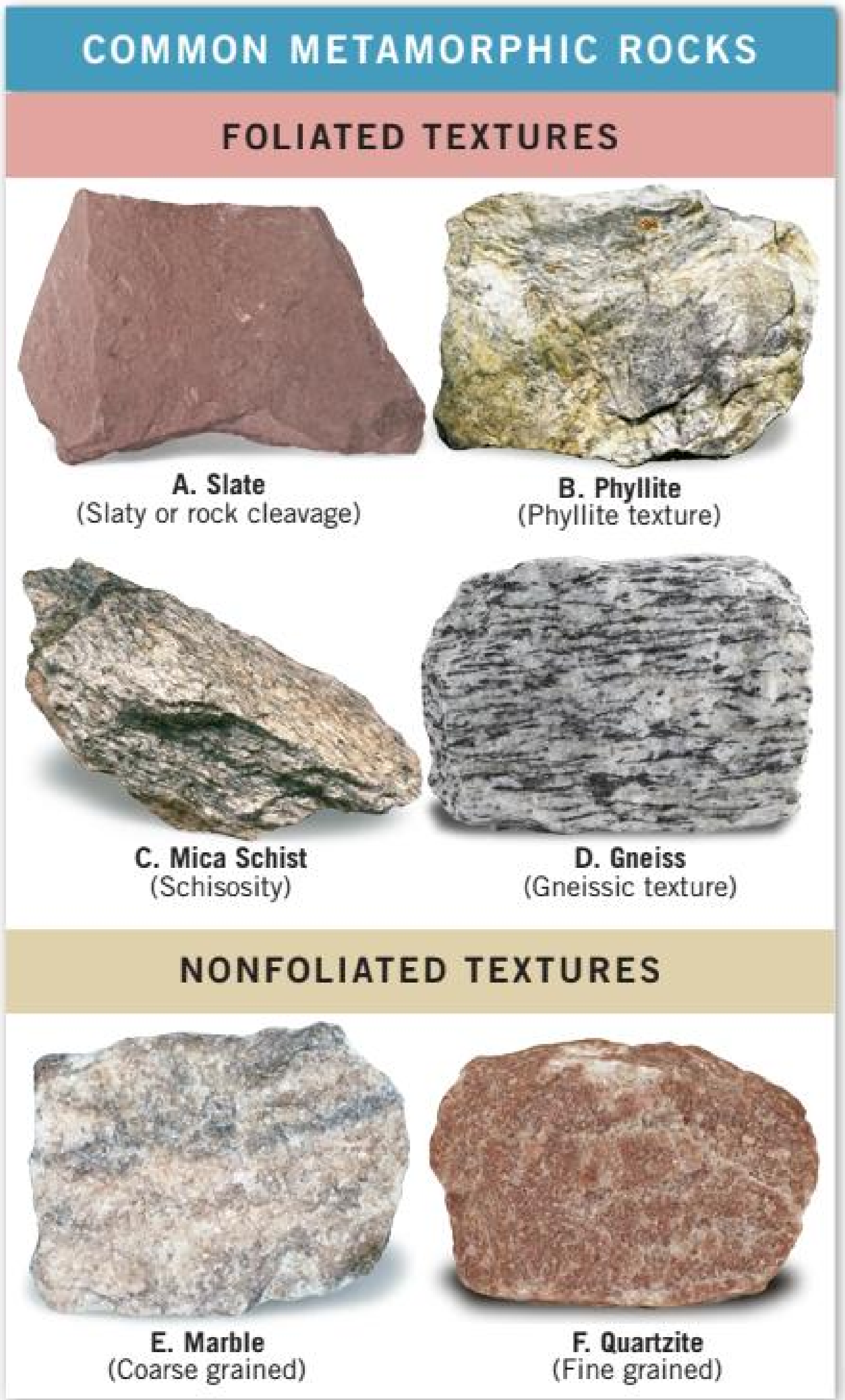
### Metamorphic Textures

During metamorphism, new minerals often form and/or existing minerals grow larger as the intensity of metamorphism increases. Frequently, mineral crystals that are elongated (such as hornblende) or have a sheet structure (for example, the micas—biotite and muscovite) become oriented perpendicular to compressional forces. The resulting parallel, linear alignment of mineral crystals is called **foliation** (**Figure 2.18**). Foliation is associated with many metamorphic rocks and gives them a layered or banded appearance.




◀ **Figure 2.18** Under directed pressure, linear or platy minerals, such as the micas, become reoriented or recrystallized so that their surfaces are aligned at right angles to the stress. The resulting planar orientation of mineral grains is called foliation.

The mineral crystals in foliated metamorphic rocks are either elongated or have thin, platy shapes and are arranged in a parallel or layered manner. During metamorphism, increased heat and pressure can cause mineral crystals to *become larger* and *foliation to become more obvious*. The various types of foliation, shown in **Figure 2.19A–D**, are described below:




▲ **Figure 2.19** Metamorphic textures.

- **Slaty or rock cleavage** refers to closely spaced, flat surfaces along which rocks split into thin slabs when struck with a hammer (Figure 2.19A).
- **Phyllite texture** develops when minute mica crystals in slate begin to increase in size. Phyllite surfaces have a shiny, somewhat metallic sheen and often have a wavy surface (Figure 2.19B).
- **Schisosity** can be identified by a scaly layering of glittery, platy minerals (mainly micas) that are often found in association with deformed quartz and feldspar grains (Figure 2.19C).
- **Gneissic texture** forms during high-grade metamorphism when ion migration results in the segregation of light and dark minerals (Figure 2.19D).

Some metamorphic rocks *do not* exhibit foliated texture. These rocks, referred to as **nonfoliated**, typically develop in environments where deformation is minimal and the parent rocks are composed of one mineral, such as quartz or calcite.

## Foliated Metamorphic Rocks

**Slate** is a very fine-grained foliated rock composed of minute mica flakes that are too small to be visible to the unaided eye (Figure 2.19A). A noteworthy characteristic of slate is its excellent rock cleavage, or tendency to break into flat slabs. Slate is usually generated by low-grade metamorphism of shale. Slate's color is variable; black slate contains organic material, red slate gets its color from iron oxide, and green slate is usually composed of chlorite, a greenish mica-like mineral.

**Phyllite** represents a degree of metamorphism between that of slate and that of schist. Its constituent platy minerals, mainly muscovite and chlorite, are larger than those in slate but not large enough to be readily identifiable with the unaided eye. Although phyllite appears similar to slate, it can be easily distinguished from slate by its glossy sheen and wavy surface (Figure 2.19B).

**Schists** are moderate to strongly foliated rocks formed by regional metamorphism (Figure 2.19C). They are platy and can be readily split into thin flakes or slabs. Many schists originate from shale parent rock. The term *schist* describes the *texture* of a rock, regardless of composition. For example, schists composed primarily of muscovite and biotite are called *mica schists*.

**Gneiss** (pronounced "nice") is the term applied to banded metamorphic rocks in which elongated and granular (as opposed to platy) minerals predominate (Figure 2.19D). The most common minerals in gneisses are quartz and feldspar, with lesser amounts of muscovite, biotite, and hornblende. Gneisses exhibit strong segregation of light and dark silicates, giving them a characteristic banded texture.

## Nonfoliated Metamorphic Rocks

Nonfoliated metamorphic rocks consist of inter-grown crystals of various size and are most often identified by determining their mineral composition. The minerals that comprise them are most often quartz or calcite. Therefore, the hardness test and/or the acid test can be used.

**Marble** is a coarse, crystalline rock whose parent rock is limestone (Figure 2.19E). Marble is composed of large interlocking calcite crystals formed from the recrystallization of smaller grains in the parent rock. White marble is particularly prized as a stone from which to carve monuments and statues. Marble can also be colored—pink, gray, green, or even black—if the parent rocks from which it formed contain impurities that color the stone.

**Quartzite** is a very hard metamorphic rock most often formed from quartz sandstone (see Figure 2.19F). Under moderate- to high-grade metamorphism, the quartz grains in sandstone fuse. Pure quartzite is white, but iron oxide may produce reddish or pinkish stains, and dark minerals may impart a gray color.

## Other Metamorphic Rocks

Numerous other metamorphic rocks exist, as shown in **Figure 2.20A–F**. During intermediate- to high-grade metamorphism, recrystallization of existing minerals often produces new minerals. These newly formed minerals, commonly referred to as *accessory minerals*, tend to form large crystals, called *porphyroblasts*. The large porphyroblast crystals are surrounded by smaller crystals of other minerals, such as muscovite and biotite. When naming a metamorphic rock that contains one or more easily recognizable accessory minerals, geologists add a prefix to the appropriate rock name. For example, Figure 2.20A shows a mica schist that contains large dark red garnet crystals embedded in a matrix of fine-grained micas; consequently, this rock is called a *garnet-mica schist*. The metamorphic rock gneiss also frequently contains accessory minerals, including garnet and staurolite—which are called *garnet gneiss* and *staurolite gneiss*, respectively.

Some metamorphic rocks exhibit stretched or deformed pebbles (Figure 2.20B). Another distinguishing characteristic of highly deformed metamorphic rocks is foliation that becomes contorted or folded, as shown in Figure 2.20C. Furthermore, some metamorphic rocks, such as *hornfels* (Figure 2.20D), form when rock surrounding a molten igneous body is baked (contact metamorphism). The metamorphic form of coal, called *anthracite*, is

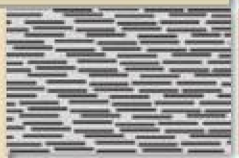
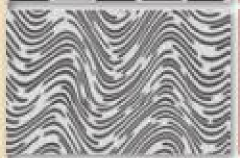
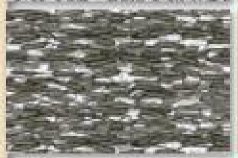
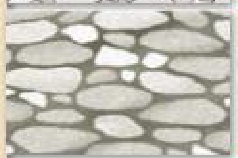
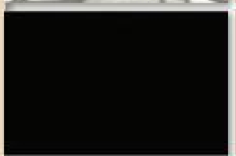

▲ **Figure 2.20** Other metamorphic rocks.

generated when deformation caused by mountain building metamorphoses bituminous coal (Figure 2.20E). *Serpentinite,* forms by the hydrothermal alteration of mafic rocks along the mid-oceanic ridge (Figure 2.20F).

## Classifying Metamorphic Rocks

Metamorphic rocks are classified according to their texture and mineral composition, as shown in the metamorphic rock identification key in **Figure 2.21**. Note that the names of medium- and coarse-grained metamorphic rocks are often modified to include the mineral composition before the name (for example, *mica schist*). Use this figure to complete the following activity.

**METAMORPHIC ROCK IDENTIFICATION KEY**

| Distinctive Properties | Grain Size | Parent Rock | Texture | | Rock Name |
|---|---|---|---|---|---|
| Excellent rock cleavage, smooth dull surfaces | Very fine | Shale, or siltstone | Foliated |  | **Slate** |
| Breaks along wavy surfaces, glossy sheen | Fine | Shale, slate, or siltstone | |  | **Phyllite** |
| Micas dominate, breaks along scaly foliation | Medium to Coarse | Shale, slate, phyllite, or siltstone | |  | **Schist** |
| Compositional banding due to segregation of dark and light minerals | Medium to Coarse | Shale, schist, granite, or volcanic rocks | |  | **Gneiss** |
| Interlocking calcite or dolomite crystals nearly the same size, soft, reacts to HCl | Medium to coarse | Limestone, dolostone | Nonfoliated |  | **Marble** |
| Fused quartz grains, massive, very hard | Medium to coarse | Quartz sandstone | |  | **Quartzite** |
| Round or stretched pebbles that have a preferred orientation | Coarse-grained | Quartz-rich conglomerate | |  | **Metaconglomerate** |
| Shiny black rock that may exhibit conchoidal fracture | Fine | Bituminous coal | |  | **Anthracite** |
| Usually, dark massive rock with dull luster | Fine | Any rock type | |  | **Hornfels** |
| Very fine grained, typically dull with a greenish color, may contain asbestos fibers | Fine | Mafic or ultramafic rocks | |  | **Serpentinite** |

▲ **Figure 2.21** Metamorphic rock identification key.