EARTH SCIENCE

The Physical Setting

Second Edition

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In addition to this book, Amsco School Publications, Inc. publishes the following books written by Thomas McGuire: *Reviewing Earth Science: The Physical Setting, Third Edition; Laboratory and Skills Manual—Earth Science: The Physical Setting; Earth Science: Reviewing the Essentials.*

This book is dedicated to the thousands of students I have known in 32 years of teaching. I hope they have learned nearly as much from me as I have from them.

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To the Student

Earth Science: The Physical Setting, Second Edition, which follows the New York State Core Curriculum, which is based on National Standards, is an introduction to the study of Earth Science. The specific standards covered in each chapter are listed in the table of contents and next to the text to which they apply and next to each Student Activity. With this book, you can gain a firm understanding of the fundamental concepts of Earth Science—a base from which you may confidently proceed to further studies in science and enjoy a deeper appreciation of the world around you. You also will need to become familiar with the 2010 *Earth Science Reference Tables,* a document prepared by the New York State Education Department. You will find the individual tables within the appropriate chapters of this text. You can obtain a copy of the entire document from your teacher or it can be downloaded from the State Education Web site: *http://www.emsc.nysed.gov/osa/reftable/earthscience-rt/esrt2010-engw.pdf*

This book is designed to make learning easier for you. Many special features that stimulate interest, enrich understanding, encourage you to evaluate your progress, and enable you to review the concepts are provided. These features include:

1. **Carefully selected, logically organized content.** This book offers an introductory Earth Science course stripped of unnecessary details that lead to confusion. It covers the New York State Core Curriculum for the Physical Setting—Earth Science.
2. **Clear understandable presentation.** Although you will meet many new scientific terms in this book, you will find that the language is generally clear and easy to read. Each new term is carefully defined and will soon become part of your Earth Science vocabulary. The illustrations and photographs also aid in your understanding, since they, like the rest of the content, have been carefully designed to clarify concepts. Words in **boldface** are defined in place and in the Glossary. Words in *italics* are important science words you already should know.

3. **Introduction.** An introductory section at the beginning of each chapter sets the stage for the rest of the chapter. Here you will find a list of Words to Know and the learning objectives for the chapter.
4. **Step-by-step solutions to problems followed by practice.** Problem solving is presented logically, one step at a time. Sample solutions to all types of Earth Science problems are provided. These sample problems will help you approach mathematical problems logically. To enhance your newly acquired skill, you will find practice problems following most sample problems.
5. **Internet sites.** Within the chapters are the URLs, or Web addresses, of various internet sites that provide additional information or activities.
6. **End-of-chapter review questions.** The Regents-style, Part A, multiple-choice questions at the end of each chapter help you to review and assess your grasp of the content. The open-ended questions provide practice in answering questions found in Part B and Part C of the Regents exam. To answer some of these questions you may need to refer to the *Earth Science Reference Tables* or the tables found in the chapters.
7. **Appendices.** Appendix A introduces you to laboratory safety. In Appendix B, you will be presented with a format to follow when preparing laboratory reports. Appendix C reviews the International System of Units. Appendix D lists the physical constants important to Earth Science. Appendix E explores the use of graphs in science.
8. **Glossary.** This section contains all the **boldfaced** words found in the text along with their definitions.

The study of Earth Science can be both stimulating and challenging. The author sincerely hopes that this book will increase your enjoyment of this science.

Contents

UNIT 1

Earth Measures and Models

The spherical shape of Earth was proposed by Egyptian and Greek mathematicians and philosophers, as well as by learned people from other cultures, more than 3000 years ago. However, before the Age of European Exploration (the fifteenth and sixteenth centuries), most people still thought that Earth was flat. Sailors stayed close to the coast so they would not "sail over the edge." For most people living at this time, their families and the things they needed to live were close to home. Long-distance travel involved hardships and dangers, so few people traveled far from home.

The Italian explorer and navigator Christopher Columbus understood that Earth is round. However, Columbus also believed that Earth was much smaller than it really is. This led him to guess that he could reach Asia by sailing a relatively short distance west from Europe. Fortunately for him, the Americas are located where Columbus expected to find Asia. After four very hazardous voyages, Columbus thought he had found a new route to Asia. He did not realize that he had sailed only part of the way to Asia, and was very lucky to have survived his voyages. He had unknowingly reached a "new world" on his way to Asia, but died unaware of his actual discovery.

CHAPTER

1 Science and Planet Earth

WORDS TO KNOW

astronomy	geology	oceanography
coordinate system	inference	percent deviation
density	meteorology	science
Earth science	observation	scientific (exponential) notation
ecology		

This chapter will help you answer the following questions:

1. What do we mean by Earth science?
2. Why is Earth science important?
3. How do scientists make, use, analyze, and communicate their observations and measurements?

WHAT IS SCIENCE?

1: SCIENTIFIC INQUIRY 1, 2, 3

Science has played a central role in the advancement of civilization. The Latin origin of the word *science* (*scire*) can be translated as "to know." While some people might think of scientific conclusions as unchanging facts, our understanding of nature is never complete. As the understanding of nature grows, old ideas that no longer fit our observations are discarded. The so-called facts of science are often temporary, whereas the methods of science (observation and

FIGURE 1-1. Students and professional geoscientists investigate Earth through field work and laboratory analysis. These students are learning about rock that millions of years ago intruded into older rock. Field observations reveal that intruding material was a molten liquid that has since cooled and solidified.

analysis) are permanent. Therefore, science is a way of making and using observations. (See Figure 1-1.)

Science often attempts to answer such questions as: Why do we see the moon on some nights, but not on others? What causes clouds to form? Why are there violent storms, earthquakes, and volcanoes? How can people wisely use Earth's resources and still preserve the most valued qualities of our natural environment? What is the history of Earth and the universe? If we could see our planet from far away in space, we might be more aware of what a tiny part of the universe we occupy.

Rational thought and clear logic support the best scientific ideas. Scientists often use numbers and mathematics (data) to present their results because mathematics is considered to be straightforward, logical, and consistent. These qualities are valued in scientific work. Visit the following Web site to see "From the Sky" by Yann Arthus-Bertrand: http://www.scribd.com/doc/3914640/Yann-ArthusBertrand-From-The-Sky

Scientific discoveries need to be *verifiable.* This means that other scientists who investigate the same issues and make their own observations should arrive at similar conclusions. For example, when a climate prediction is supported by the work of many scientists and/or by computer models, the prediction is considered to be more reliable.

Science at Work

Alfred Wegener proposed his theory of continental drift in the early 1900s; it was based on indirect evidence. During his lifetime, he could not find enough evidence to convince most other Earth scientists that continents move over Earth's surface. However, new evidence gathered by other scientists working 50 years later gave renewed support to his ideas. Today, plate tectonics, as the theory is now known, is supported by precise measurements. This is a good example of how the efforts of many scientists and new observations resulted in a new way of thinking about how our planet works.

Science can therefore be defined as a universal and ongoing method of gathering, organizing, analyzing, testing, and using information about our world. Science provides a structure to investigate questions and to discover relationships and patterns and form conclusions. The reasoning behind the conclusions should be clear. Scientists will continue to evaluate and modify conclusions. The body of knowledge of science, even as presented in this book, is simply the best current understanding of how the world works.

STUDENT ACTIVITY 1-1 —GOOD SCIENCE AND BAD SCIENCE

2: INFORMATION SYSTEMS 1, 2, 3

Sometimes it is easier to understand science if you look for what is *not* science. Tabloids are newspapers that emphasize entertainment. They publish questionable stories that other media do not report. Bring your teacher a science article from a questionable news source. Your teacher will display the stories for the class to discuss. What are the qualities of these stories that make them a poor source of scientific information?

WHAT IS EARTH SCIENCE?

1: SCIENTIFIC INQUIRY 1, 2, 3

The science you study in school is often divided into four branches: life science (biology), physics, chemistry, and Earth science. (See Figure 1-2.) **Earth science** applies the tools of the other sciences to study our planet, including its rocky portion, its oceans, its atmosphere, its interior, and its surroundings in space.

Earth science can be divided into several branches. **Geology** is the study of the rocky portion of Earth, its interior and surface processes. Geologists investigate the processes that shape the land, and they study Earth materials, such as minerals and rocks. (See Figure 1-3 on page 6.) They also actively search for natural resources, including valuable minerals, ores, and fossil fuels.

Meteorology is the study of the atmosphere and how it changes. Meteorologists predict weather and help us to deal with weather-related disasters and other atmospheric events that affect our lives. They also investigate climatic (long-term weather) changes.

Oceanography is the study of the oceans that cover most of Earth's surface. Oceanographers investigate ocean currents, how the oceans affect weather and coastlines, the composition and properties of seawater, and the best ways to manage marine resources.

Astronomy is the study of Earth's motions and motions of objects beyond Earth, such as planets and stars. Astronomers consider such questions as: Is Earth the only planet of its kind? How

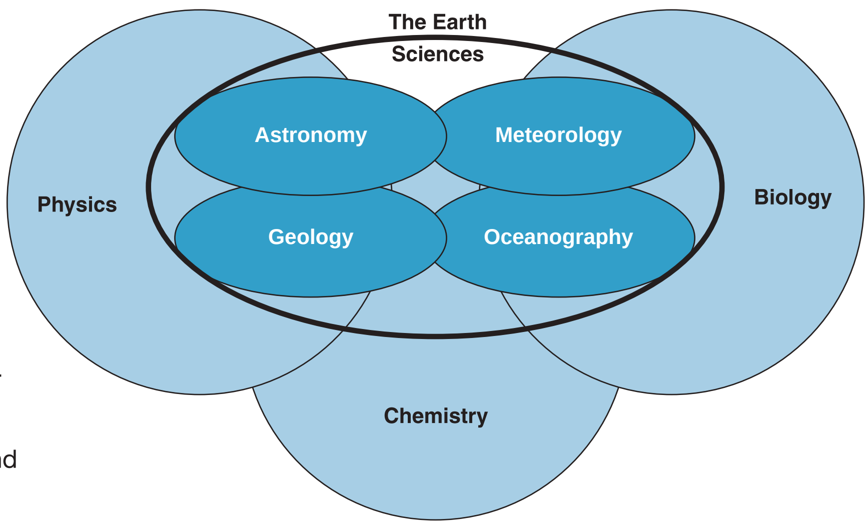


FIGURE 1-2. The four major Earth sciences draw on the fields of physics, chemistry, and biology to investigate Earth systems.

FIGURE 1-3. Dr. Frederick Vollmer, a geologist from New York, educates students onsite about the Sierra Nevada mountains.

big is the universe? When did the universe begin, and how will it end?

Many Earth scientists are involved in **ecology**, or environmental science, which seeks to understand how living things interact with their natural setting. They observe how the natural environment changes, how those changes are likely to affect living things, and how people can preserve the most important characteristics of the natural environment.

HOW IS EARTH SCIENCE RELATED TO OTHER SCIENCES?

6: SYSTEMS THINKING 1
7: CONNECTIONS 1
7: STRATEGIES 2

Earth science draws from a broad range of other sciences. This helps present a broad view of the planet and its place in the universe. Earth scientists need to understand the principles of chemistry to investigate the composition of rocks and how they form. Changes in weather are caused by the energy exchanges. By knowing the chemical properties of matter, scientists can investigate the composition of stars.

The movements of stars and planets obey the laws of physics regarding gravity and motion. Physics helps us understand how the universe formed and how stars produce such great amounts of energy. Density currents and the circulation of fluids control the atmosphere, the oceans, and even changes deep within our planet. Nuclear physics has allowed scientists to measure the age of Earth with remarkable accuracy.

The Earth sciences also make use of the principles of biology and, in turn, support the life sciences. Organic evolution helps us understand the history of Earth. At the same time, fossils found in rock are the primary evidence for evolutionary biology. The relationships between the physical (nonliving) planet and life-forms are the basis for environmental biology. Only recently, have some people understood how changes in Earth and changes in life-forms have influenced each other throughout long periods of geologic time.

WHY STUDY EARTH SCIENCE?

1: SCIENTIFIC INQUIRY 1, 2, 3
6: SYSTEMS THINKING 1
6: OPTIMIZATION 6
7: STRATEGIES 2

Although some students may become professional Earth scientists, it is more likely that you will find work in another area. No matter what career you choose, Earth science will affect your life. Everyone needs to know how to prepare for changes in weather, climate, seasons, and earth movements. We also need to become educated citizens who make important decisions in a democratic world.

Natural disasters are rare events, but when they occur they can cause great loss of life and property. To limit loss, people can prepare for hurricanes, tornadoes, floods, volcanic eruptions, earthquakes, and climate shifts. Humans can survive the effects of cold and drought if they plan ahead. However, people need to know how likely these events are and how best to avoid their devastating consequences. We need to know the answers to many questions, such as: How will humans be affected by general changes in climate? Can these changes be prevented? Will a large asteroid or comet strike Earth, and how will it affect Earth's inhabitants?

Our civilization depends on the wise use of natural resources. Freshwater, metals, and fossil fuels are among the great variety of materials that have supported a growing world economy. These resources have brought us wealth and comfort. We need to know: How much of these materials are available for use? What will happen if these materials run out? What is the environmental effect of extracting, refining, and using these resources?

These issues affect all of us regardless of our profession. As citizens and consumers, we make decisions, and as citizens, we elect governments that need to consider these issues.

Environmental Awareness

As you will read in future chapters, the natural environments of this planet have changed dramatically over the past 4.6 billion years. They continue to change, and we must expect change in the future. Humans do not control the environment; we are a part of environmental change. With or without human influences, change will occur. However, we can certainly affect how those changes occur.

For example, there has been a campaign to use paper cups rather than polystyrene foam cups. Most people think of paper as a less harmful material. However, some studies have found that the environmental effect of paper cups can be greater than that of polystyrene foam cups. Sometimes the full story is not as simple as we are led to believe. For more information visit the Web site: ***http://www.newton.dep.anl.gov/askasci/gen99/gen99498.htm***

On the other hand, it is clear that human-caused emissions of carbon dioxide are having a global effect on the environment. But, unlike the choice between paper or foam cups, the solution here is very difficult. People enjoy the convenience of using cars and the comfort of indoor heating and cooling. Alternative energy choices such as nuclear and renewable energy can be unpopular or too expensive. What can we do when people prefer to use cheaper or less controversial alternatives now rather than following long-term economic and scientific choices? Complex or potentially costly issues such as these are our most challenging problems.

There is an environmental saying, "Think globally and act locally." This is good idea. It stresses personal responsibility for environmental consequences. We currently see that rapidly developing economies throughout the world are placing new demands on Earth's limited resources and creating more waste. More than ever, nations must learn to work cooperatively to solve global environmental problems.

Working with Science

FIGURE 1-4. Cynthia Chandley

CYNTHIA CHANDLEY: Water Rights Lawyer

Cynthia Chandley is not an Earth scientist, but she knows how important it is to understand our Earth. (See Figure 1-4.) She earned a degree in geology. After several years of working in the mining industry, she attended law school and became an environmental lawyer. Ms. Chandley now works as a water rights lawyer. She says, "I constantly use my geoscience background to influence the use and preservation of an essential resource. However, these issues go well beyond my profession. Everyone needs to understand our planet's interconnected systems to determine how our resources can be most effectively managed for ourselves and for future generations."

HOW DO SCIENTISTS GATHER AND ANALYZE INFORMATION?

1: MATHEMATICAL ANALYSIS 1
1: SCIENTIFIC INQUIRY 2, 3
2: INFORMATION SYSTEMS 1, 2
6: MAGNITUDE AND SCALE 3

You receive information about your surroundings through your five senses: sight, touch, smell, taste, and hearing. To do their work, scientists must make use of information gathered using their senses. These bits of information are **observations**. Some observations are qualitative. They involve relative terms, such as long or short, bright or dim, hot or cold, loud or soft, red or blue, and they compare observations without using numbers or measurements. Other observations are quantitative. When you say that the time is 26 seconds past 10 o'clock in the morning you are being very specific. Quantitative comes from the word *quantity,* meaning "how many." Therefore, quantitative observations include numbers and units of measure.

Scientists use measurements to determine precise values that have the same meaning to everyone. Measurements often are made with instruments that extend our senses. Microscopes and telescopes allow the observation of things too small, too far away, or too dim to be visible without these instruments. (See Figure 1-5 on page 10.) Balance scales, metersticks, clocks, and thermometers allow scientists and students to make more accurate observations than they could make without the use of instruments. To use an interactive online stopwatch, visit the Web site: ***http://www.shodor.org/interactivate/activities/stopwatch/***

FIGURE 1-5. Instruments help people make better observations.

People accept many things as fact, even if they have not observed them directly. An **inference** is a conclusion based on observations. When many rocks at the bottom of a cliff are similar in composition to the rock that makes up the cliff, it is reasonable to infer the rocks probably broke away from the cliff.

Scientists often make inferences. When scientists observe geological events producing rocks in one location and find similar rocks in other locations, they make inferences about past events. Although they did not witness these events, they infer that the same processes occurred in both places. No person can see the future. Therefore, all predictions are inferences. In general, scientists prefer direct observations to inferences.

Exponential Notation

Scientists deal with data that range from the sizes of subatomic particles to the size of the universe. If you measure the universe in subatomic units you end up with a number that has about 40 zeros. How can this range of values be expressed without using numbers that are difficult to write and even more difficult to work with? Scientists use **exponential notation**, sometimes called **scientific notation**. Exponential notation uses powers of 10 to express numbers that would be more difficult to write or read using standard decimal numbers.

Numbers written in exponential notation take the form of $c \times 10^e$, where c (the coefficient) is always a number equal to or greater than

1 but less than 10 and *e* (the exponent) is the power of 10. Being able to understand and use exponential notation is very important. Any number can be expressed in exponential notation by following these two steps.

Step 1: Change the original number to a number equal to or greater than 1 but less than 10 by moving the decimal point to the right or left.

Step 2: Assign a power of 10 (exponent) equal to the number of places that the decimal point was moved.

A good way to remember whether the power of 10 will be positive or negative is to keep in mind that positive exponents mean numbers greater than 1, usually large numbers. Negative exponents mean numbers less than 1, which are sometimes called decimal numbers. Once you get used to it, it becomes easy. The following Web site may help you understand very large and small distances and the need for exponential notation: ***http://www.powersof10.com/index.php?mod=register_film***

STUDENT ACTIVITY 1-2 —EXPONENTIAL NOTATION IN THE REAL WORLD

1: MATHEMATICAL ANALYSIS 1
6: MAGNITUDE AND SCALE 3

Make a list of 5 to 10 very large or very small values, document their use, and translate them into scientific (exponential) notation. Your examples must come from printed or Internet sources, such as ***http://www.infoplease.com/ipa/A0854973.html***, outside your Earth science course materials.

For each example you present, include the following:

1. The value expressed as a standard number. (If units of measure are given, be sure to include them.)
2. What is being expressed. (For example, it might be the size of a particular kind of atom.)
3. The same value expressed in exponential notation.
4. Where you found the value. Please give enough information so that another person could find it easily.

Visit the following Web site to see the formal mathematical rules of calculation and expressing numbers: ***http://www.vendian.org/envelope/dir0/exponential_notation.html***

SAMPLE PROBLEMS

Problem 1 The age of the universe is estimated to be about 13,700,000,000 years; express this number in exponential notation.

Solution *Step 1:* Change the original number to a number equal to or greater than 1, but less than 10 by moving the decimal point to the right or left. (Zeros that appear outside nonzero digits can be left out.) In this case, you get 1.37.

Step 2: Assign a power of 10 (exponent) equal to the number of places that the decimal point was moved. This decimal point was moved to the left 10 places, making the power of 10 a positive number. So the age of our planet is 1.37×10^{10} years.

Problem 2 Light with a wavelength of 0.00004503 centimeter (cm) appears blue. Express this value in scientific notation.

Solution *Step 1:* After moving the decimal point five places to the right, the coefficient becomes 4.503. The zero before the 3 is kept because it appears between nonzero digits. This zero is needed to establish the number's value.

Step 2: When the decimal point is moved right, the exponent is a negative number. The power of 10 is −5. The number is 4.503×10^{-5} cm.

The International System of Measurement

Over the course of time, different countries developed their own systems of measurements. The inch and the pound originated in England. There were no international standards until the European nations established a system now known as the "International System of Units." This system is called "SI," based on its name in French, *System Internationale.* SI units are now used nearly everywhere in the world except the United States. SI is similar to the metric system.

In a temperature-controlled vault in France, a metal bar has been marked with two scratches that are exactly 1 meter (m) apart. In the past, it was the definition of meter, and all devices used to measure length were based on that standard. Everyone knew the length of a meter and everyone's meter was the same. Today the meter is defined as a certain number of wavelengths of light emitted by krypton-86 under specific laboratory conditions. The advantage of this change is the standard length can be created anywhere.

In everyday life, people often use a system of measures called "United States Customary Measures." Units such as the mile, the pound, and the degree Fahrenheit have been in use in this country for many years. Most Americans are familiar with them and resist change. As this country becomes part of a world economy, SI units will gradually replace the United States Customary units, as suggested in Figure 1-6. Many beverages are now sold in liters. A variety of manufactured goods created for world markets are also measured in SI units.

Scientists everywhere use SI units for several reasons:

- They are universal. Scientists do not need to translate units when they communicate with their colleagues in other countries.
- SI units are related by factors of 10. For example, there are 10 millimeters (mm) in a centimeter (cm), 10 centimeters in a decimeter (dm), and 10 decimeters in a meter (m).
- Scientific instruments sold around the world are generally marked in SI units.

You can find an on-line, Earth science related, metric conversion calculators at the following Web site: ***http://www.worldwidemetric.com/metcal.htm***

FIGURE 1-6. In some places in the United States, road signs with SI (metric) units are replacing signs with U.S. Customary Measures.

USING SI UNITS As you perform laboratory activities, you will often need to make measurements. You will be using metric rulers that measure in centimeters. In addition, you will use balances that measure mass in kilograms. You may be asked to use your measurements to find another quantity such as volume or density. To find volume, multiply the object's length by its width by its height.

SAMPLE PROBLEM

Problem A storage tank is 10 m long by 8 m wide by 3 m high. How much water can it hold?

Solution You can calculate the volume by multiplying the length by the width by the height:

$$\begin{aligned} \text{Volume} &= \text{length} \times \text{width} \times \text{height} \\ &= 10\text{ m} \times 8\text{ m} \times 3\text{ m} \\ &= 240\text{ m}^3 \end{aligned}$$

Practice Problem 1

A rectangular bar of soap measures 6.1 cm by 4.2 cm by 2.1 cm. Find the volume of the bar of soap to the nearest tenth of a cubic centimeter.

Estimation

Estimation is a valuable skill for anyone, but especially for scientists. If you want to know whether a measurement or calculation is correct, it is very helpful to estimate the value. If your estimate and the determined value are not close, you may need to give some more thought to your procedure. Suppose you wanted to guess how many people were in a particular crowd, such as the sports event shown in Figure 1-7. You could count the number of people in one section and multiply by the number of sections.

If you heard that a backpacker on the Appalachian Trail walked from Maine to Georgia in five days, it is easy to figure out that this could not be true. The distance is more than 1600 km. That would

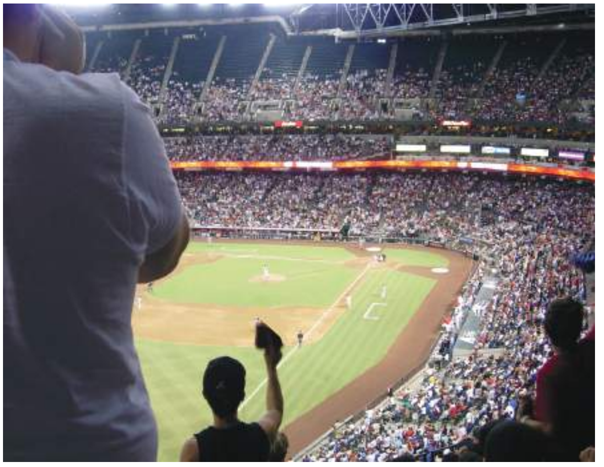


FIGURE 1-7. If you did not have access to ticket sales information, how could you estimate the number of people at a Major League sporting event?

mean walking more than 300 km a day. This is clearly not possible, especially on a mountainous trail. Most likely the walk took five months. Walking about 16 km a day is reasonable.

There are many convenient ways to make estimates. For example, you could estimate the height of a ceiling by observing that a person 1.7 m tall extends half way to the ceiling. Therefore your estimate of the ceiling height would be about 3.5 m.

STUDENT ACTIVITY 1-3 —MAKING ESTIMATIONS

1: ENGINEERING DESIGN 1
1: MATHEMATICAL ANALYSIS 3
7: STRATEGIES 2

Working in groups, estimate the volume of your classroom or your school building. Do not use any measuring instruments. Number the steps of your procedure 1, 2, 3, . . . etc. For each step, briefly explain exactly how you got your data and made your calculations. Please use only SI (metric) units.

HOW IS DENSITY DETERMINED?

1: MATHEMATICAL ANALYSIS 1, 2, 3
1: ENGINEERING DESIGN 1
6: MODELS 2
6: MAGNITUDE AND SCALE 3
6: PATTERNS OF CHANGE 5

Density is the concentration of matter, or the ratio of mass to volume. Substances such as lead or gold that are very dense are heavy for their size. Materials that we consider light, such as air or polystyrene foam, are relatively low in density. Objects made of the same solid material usually have about the same density. (Density can change with temperature or pressure as a substance expands or contracts.)

Density is an important property of matter. For example, differences in density are responsible for winds and ocean currents. Density is defined as mass per unit volume. For example, if the mass of an object is 30 grams (g) and its volume is 10 cubic centimeters (cm^3), then its density is 30 g divided by 10 cm^3, or 3 g/cm^3. The formula for calculating density is given on page 1 of the *Earth Science Reference Tables.*

Within the chapters of this book you will find the components of the *Earth Science Reference Tables:* tables, graphs, maps, physical values, and mathematical equations that you will need throughout this course. You do not need to memorize any of the information in the *Reference Tables* because this document will always be available to you for classroom work, labs, and tests. However, you should become familiar with the *Reference Tables* so you know when to use them.

Density is generally expressed in units of mass divided by units of volume:

$$\text{Density} = \frac{\text{mass}}{\text{volume}}$$

Note that the units are carried through the calculation, yielding the proper unit of density such as grams per cubic centimeter (g/cm^3). The following Sample Problem will show you how to use this equation.

SAMPLE PROBLEM

Problem What is the density of an object that has a volume of 20 cm^3 and a mass of 8 g?

Solution

$$\begin{aligned}\text{Density} &= \frac{\text{mass}}{\text{volume}}\\ &= \frac{8\text{ g}}{20\text{ cm}^3}\\ &= 0.4 g/cm^3\end{aligned}$$

Practice Problem 2

If a 135-g crystal sphere has a volume of 50 cm³, what is its density?

Water, with a density of 1 g/cm³, is used as a standard of density. Therefore, whether an object sinks or floats in water can be used to estimate density. If an object is less dense than water, the object will float in water. If the object is more dense than water, the object will sink. Most wood floats in water because it is less dense than water. Iron, glass, and most rocks sink because they are more dense than water. The idea of density will come up many times in Earth science and it will be discussed as it is applied in later chapters.

The instrument shown in Figure 1-8 is a Galileo thermometer. It is named for the Italian scientist who invented it. This thermometer is based on the principle that the density of water changes slightly with changes in temperature. As the water in the column becomes warmer and less dense, more of the glass spheres inside the tube sink to the bottom. Therefore, the number of weighted spheres that float depends on the temperature of the water. Reading the number attached to the lowest sphere that floats gives the temperature.

You can demonstrate the relative density of liquids by first pouring corn syrup, then water, followed by cooking oil, and finally alcohol into a glass cylinder. You must be careful not to mix the liquids, which will remain layered in order of density as shown in Figure 1-9.

FIGURE 1-8. This instrument is a Galileo thermometer. As the water inside becomes warmer or cooler, it changes in density. So the number of glass spheres that float changes.

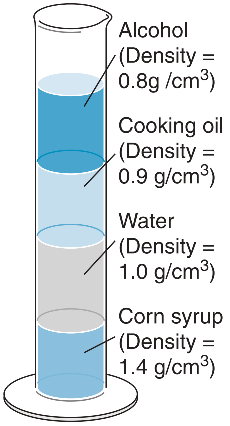


FIGURE 1-9. Liquids in graduated cylinder

If a rubber stopper with a density of 1.2 g/cm^3 were added, it would sink through the alcohol, cooking oil, and water layers. The stopper would remain suspended between the water and the corn syrup. Rubber is more dense than water, so it sinks in water. Corn syrup is more dense than rubber. Therefore, the rubber stopper would float on top of the corn syrup layer.

STUDENT ACTIVITY 1-4 —DENSITY OF SOLIDS

1: MATHEMATICAL ANALYSIS 1, 2, 3
6: MODELS 2

Density can be used to identify different substances. In general, no matter how much you have of a certain substance, its density is the same. Rather than measuring density directly, usually the mass is measured, and the volume is determined so that density (mass/volume) can be calculated. The equation volume = length × width × height is used to determine the volume of rectangular solids. There are also equations that can be used to determine the volume of other regular solids, such as spheres.

Your teacher will supply you with a variety of objects to measure. Construct a data table that lists the name, mass, volume, and density of each object. Measure the mass and determine the volume of each object, then calculate the density of each. Be sure to use SI (metric) measurements.

After you have calculated the density of each sample, place a star next to the name of those that will float in water. How can you tell that they will float?

STUDENT ACTIVITY 1-5 —THE THICKNESS OF ALUMINUM FOIL

1: MATHEMATICAL ANALYSIS 1, 2, 3
1: ENGINEERING DESIGN 1

Given the following:

1. $\text{Density} = \dfrac{\text{mass}}{\text{volume}}$
2. Volume = length × width × thickness
3. Density of aluminum = 2.7 g/cm^3

Materials: a metric ruler, a kilogram scale, a small square piece of aluminum foil (about 30 cm on each side).

Problem: Determine the thickness of the aluminum foil to the nearest ten-thousandth of a centimeter (two significant figures).

Hint: Combine the two equations above into a single equation with one unknown. Then substitute measurements, to solve for thickness. (In this problem, thickness takes the place of height as a third dimension.)

Errors in Measurement

No matter how carefully a measurement is made, it is likely that there will be some error. Using measuring instruments more carefully or using more precise instruments can reduce error, but error can never be eliminated. In general, errors are reduced to the point at which they are not important or at which it is not worth the effort to make them smaller. Sometimes measurements are used in calculations, such as the determination of density. In these cases, any errors in measurement will result in errors in the calculated value.

Percent deviation (sometimes called percent error) is a useful way to compare the size of an error with the size of what is being measured. For example, an error of 1 cm in the width of this book is a large error. But an error of 1 cm in the distance to the moon would be a very small error. They are both errors of 1 cm. However, because the book is so much smaller, this 1-cm error is far more significant. The equation for percent deviation is

$$\text{Deviation}\,(\%) = \frac{\text{difference from accepted value}}{\text{accepted value}} \times 100$$

The Sample Problem on the next page will show you how to use this equation.

SAMPLE PROBLEM

Problem A student estimated the height of a tree to be 15 m. However, careful measurement showed the true height was 20 m. What was the percent deviation?

Solution

$$\begin{aligned}\text{Deviation (\%)} &= \frac{\text{difference from accepted value}}{\text{accepted value}} \times 100 \\ &= \frac{20\text{ m} - 15\text{ m}}{20\text{ m}} \times 100 \\ &= \frac{5\text{ m}}{20\text{ m}} \times 100 \\ &= 25\%\end{aligned}$$

Notice the following features in this calculation:

1. The calculation starts with the complete algebraic equation. The only numbers that show in this first step are constants used in every application of the formula.
2. Values are substituted into the formula, including numbers and their associated units of measure.
3. The steps to the solution are organized so that they are easy to follow, leading to the answer at the end. (Be sure to include the proper units of measure.)

Practice Problem 3

A student determined the density of a stone to be 3.6 g/cm^3. The accepted value is 3.0 g/cm^3. What was the student's percent deviation?

HOW DO SCIENTISTS MAKE AND USE GRAPHS?

1: MATHEMATICAL ANALYSIS 1, 2, 3
6: MODELS 2
6: PATTERNS OF CHANGE 5
7: STRATEGIES 2

A graph is a visual way to organize and present data. Instead of reading paragraphs of information or studying columns of figures, a graph makes comparisons between variables easier because it is more visual. Unlike a data table, a graph allows the reader to see changes in data, to understand relationships between variables within the data, and to see trends or patterns.

Line Graphs

A line graph, such as the one in Figure 1-10, shows how a measured quantity changes with time, distance, or some other variable. Line graphs are constructed by plotting data on a **coordinate system**, a grid on which each location has a unique designation defined by the intersection of two lines. A coordinate system is set up on vertical and horizontal axes. The horizontal (x) axis is usually used for the independent variable. It usually indicates a uniform change, such as hours, years, or centimeters. Normally, the regular change expected in the independent variable is well understood. The vertical (y) axis is used for the dependent variable. It usually indicates the amount of the measured quantity being studied, such as temperature, height, or population. The values of the dependent variable are what you are trying to find. The graph shows how the dependent variable changes with respect to the independent variable.

The rise or fall of the line in Figure 1-10 shows the increase or decrease in the price of copper over a 5-year period. When the line on the graph moves upward and to the right, it represents a continuous increase. When the line on the graph moves downward and to the right, it indicates a continuous decrease. A horizontal line on the graph represents no change. The steeper the line segment rises

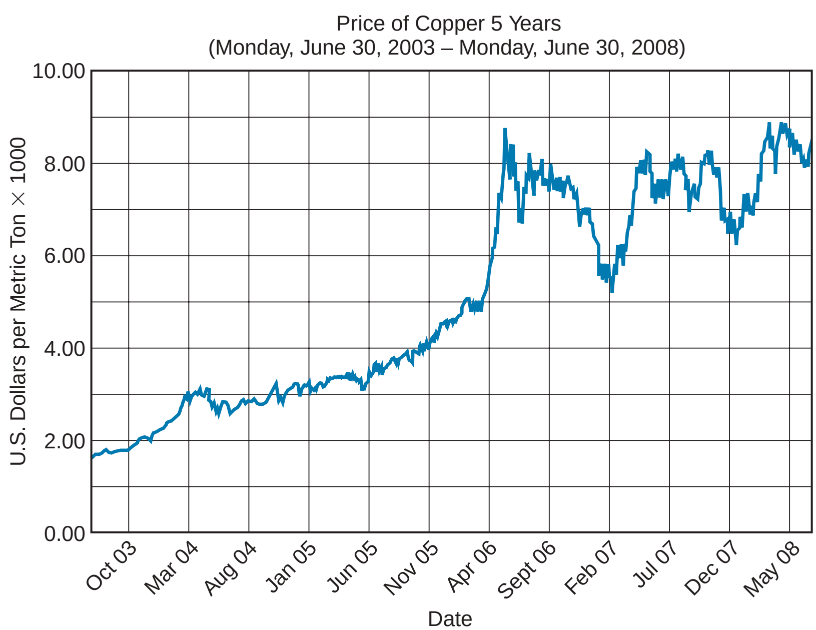


FIGURE 1-10. This line graph shows the price of copper has increased dramatically since China and India have joined the world economic markets. What was the price of copper in May 2008?

to the right, the greater the slope of the segment, and the greater the increase in price. Likewise, the steeper the line segment falls to the right, the greater the decrease in price. Some line graphs are straight lines; others are curved lines.

Pie and Bar Graphs

Sometimes, a line graph is not the best graph to use when organizing and presenting data. In Earth science, bar and pie graphs are often used. The bar graph is useful when comparing similar measurements taken at different times or in different places. For example, the bar graph in Figure 1-11, which is based on the data in Table 1-2, compares monthly rainfall, or precipitation (PPT), in millimeters (mm) over the period of 1 year.

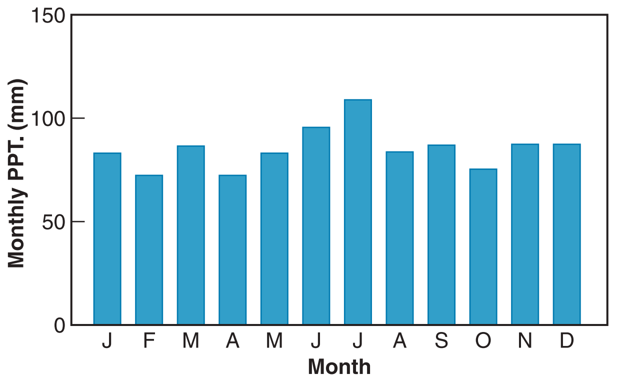


FIGURE 1-11. This bar graph represents the average monthly precipitation for Lake Placid, New York.

Table 1-2. Average Monthly Precipitation for Lake Placid, New York

Month	PPT (mm)	Month	PPT (mm)
January	81	July	107
February	71	August	84
March	86	September	86
April	71	October	74
May	81	November	86
June	94	December	86

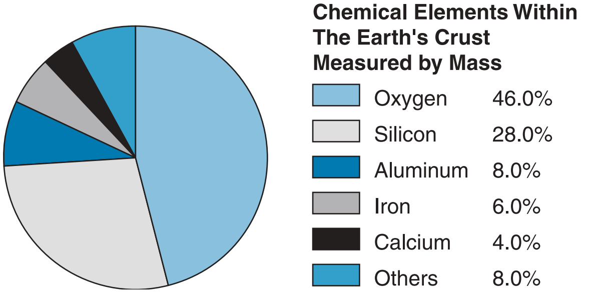


FIGURE 1-12. A pie graph shows how a quantity has been divided and the comparison between divisions.

The pie graph is used to show how a certain quantity has been divided into several parts, as well as to show the comparisons between these parts. The pie graph in Figure 1-12 shows the most abundant chemical elements in the rocks of Earth's crust by percent by mass.

Guidelines for Making Graphs

Graphs are all around us. They are especially common in news and in advertising where it is important to communicate information quickly. Sometimes, in the effort to keep the graph simple, it may contain errors. When you construct graphs in science, you should follow these guidelines:

- Keep in mind that the purpose of a graph is to provide information. The graph should have a title to explain the relationships represented. All important information should be presented as clearly and simply as possible. The axes should be labeled with quantity and units. One axis might be time in years whereas the other is human population. The graph on the next page from the United Nations gives its prediction of world population for the next several centuries. (See Figure 1-13 on page 24.)
- The independent variable should be plotted on the horizontal axis. Usually, data shows how one factor responds to changes in the other. For example, in Figure 1-13, it is clear that the human population does not determine the passage of time, but the world population depends on when (time) it is determined. In this case, time is the independent variable and population is the dependent variable. Time (the year, month, etc.) belongs on the horizontal axis.

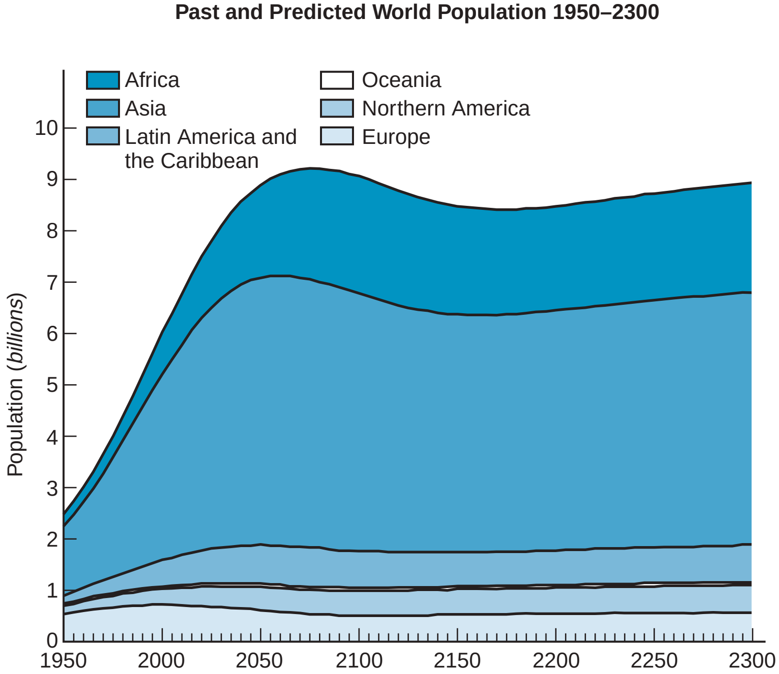


FIGURE 1-13. The United Nations predicts that the world population will stabilize as third-world countries become more economically developed.

- Fit the graph to the data. Design the vertical and horizontal axes so that the data reasonably fills the graph but does not go beyond the number scales on the two axes.

(Appendix E at the back of this book also contains a guide for constructing graphs.)

STUDENT ACTIVITY 1-6 —MAKING A GRAPH OF THE REVOLUTION OF THE PLANETS

1: MATHEMATICAL ANALYSIS 2

Does the distance of a planet from the sun affect how long it takes to make one orbit of the sun? You can investigate this question by drawing a graph.

On page 665, you will find a table "Solar System Data." Use the data in this table to graph the relationship between the distance of a planet from the sun and its period of revolution. Label each data point with the name of the object from Mercury through Neptune. (Do not include the sun or Earth's moon.)

As a follow up, you might try graphing planetary distance and other factors in this table.

HOW IS TECHNOLOGY CHANGING THE WAY SCIENTISTS WORK?

1: SCIENTIFIC INQUIRY 1, 2, 3
2: INFORMATION SYSTEMS 1

How science is "done" has always depended on the tools available. Some tools have revolutionized Earth science. Computers provide a good example. When computers are used with other devices, they can perform many functions. Computers help us analyze data from satellites, produce and edit images taken with cameras, and quickly access information on the World Wide Web. The first electronic computers filled whole rooms, and were so expensive that only a few research centers could afford them. Today, laptop computers have computing power equal to that of a supercomputer of the 1970s.

Connecting computers in networks has reached the point at which you can almost instantly access information stored in millions of computers all over the world. This is accomplished by the World Wide Web connected by the Internet. It allows all of us to communicate faster than ever before.

STUDENT ACTIVITY 1-7 —AN INTERNET SCAVENGER HUNT

2: INFORMATION SYSTEMS 1, 2

In a scavenger hunt, the goal is to collect a variety of unrelated objects. In this case, the "objects" will be bits of information. Each example will require two responses: (1) give the answer to the question, and (2) record where on the Internet you found it; that is, provide the Internet address (URL) and/or the name of the Internet site. Find answers to as many as you can.

1. What is the weather like today in Phoenix, Arizona?
2. Where and when has a very large earthquake occurred in the past 6 months?
3. Other than the sun, what is the nearest star to Earth?
4. What is the human population of New York City?
5. What is the current value of gold per ounce?
6. How many sunspots were recorded in 2007?
7. What name was given to the third tropical storm in the Atlantic Ocean last year?
8. What is the chemical composition of emeralds?

GIS and GPS are two of the most useful, recent technological advances for the Earth sciences. The Geographic Information System

FIGURE 1-14. A global positioning system receiver processes signals from satellites to determine your precise location on Earth.

(GIS) is a visual resource that allows you to plot the spatial relationships of data. Because GIS is based on information in computers all over the world, a wide variety of information can be retrieved and mapped. It also can be updated regularly. For example, GIS data can be used to make maps that show soil types, vegetation, or land ownership.

A Global Positioning System (GPS) unit is a device that receives and analyzes information sent by satellites. The information allows you to determine your location with remarkable accuracy, as shown in Figure 1-14. Installed in your car, a GPS unit can direct you to an unfamiliar location in real time. The GPS is so accurate that it has been used to measure the slow movement of continents over Earth's surface and even changes in the heights of some mountains.

Inquiry in Science

Many people would say that an inquiring mind is the most important asset humans have. Using observations, information resources, and a variety of analytical tools, people can often make important discoveries by asking the right questions and following productive leads. As long as there is the curiosity to ask questions and the will to find the answers to them, science will help find those answers.

CHAPTER REVIEW QUESTIONS

Part A

1. Some scientists estimate that age of the sun and solar system is about 4.65×10^9 years. Which choice correctly expresses this value?

(1) 465 years
(2) 465,000 years
(3) 465,000,000 years
(4) 4,650,000,000 years

2. The average diameter of the Milky Way galaxy is about 115,000 light-years. Which choice below correctly expresses this in scientific notation?

(1) 1×10^5 light-years
(2) 115×10^5 light-years
(3) 1.15×10^5 light-years
(4) 2.3×10^{10} light-years

3. A student recorded information about a rock sample. The four statements are true, which one is an observation?

(1) If placed in water, the rock will sink.
(2) The rock is billions of years old.
(3) The rock has a mass of 93.5 g.
(4) The rock formed by natural events.

4. A student made the following notes about the current weather conditions. Which statement is most likely an inference?

(1) The temperature 3 hours ago was 20°C.
(2) The current air pressure is 1000.4 millibars.
(3) The sky is completely overcast with clouds.
(4) Rain will occur in the next 6 hours.

5. An object has a mass of 46.5 g and a volume of 15.5 cm^3. What is the density of the object?

(1) 0.3 g/cm^3
(2) 46.5 g/cm^3
(3) 3.0 g/cm^3
(4) 720.8. g/cm^3

6. A student measured the mass of a rock as 20 g. But the actual mass of the rock is 30 g. What was the student's percent deviation?

(1) 25
(2) 44
(3) 33
(4) 50

7. Which is usually considered a division of Earth science?

(1) chemistry
(2) geology
(3) physics
(4) biology

Part B

8. Why do scientists use graphs to present data?

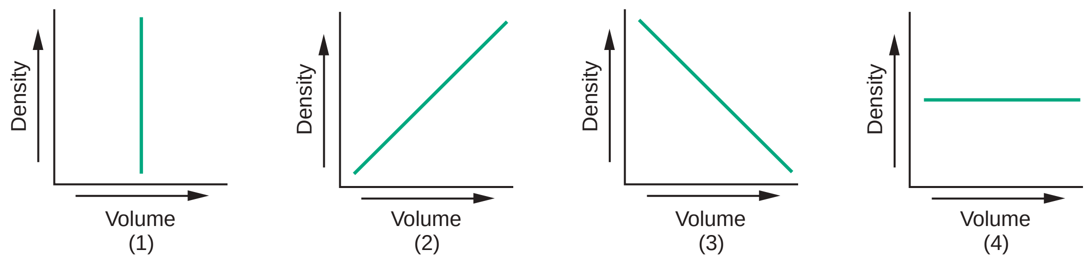
(1) Graphs do not contain errors.
(2) Graphs make data easier to understand.
(3) Graphs take less room than data tables.
(4) Graphs make papers easier to get published.

9. The data table below shows the mass and volume of three samples of the same mineral. (You may use a separate paper for your calculations.)

DATA TABLE

Sample	Mass (g)	Volume (cm^3)	Density (g/cm^3)
A	50	25	
B	100	50	
C	150	75	

Which graph best represents the relationship between the density and the volume of these mineral samples?



10. Why do we use percent deviation rather than simply expressing the size of the error itself?

(1) Percent deviation gives more information than the value of the error itself.
(2) If there is no error, percent deviation makes this clearer.
(3) Percent deviation emphasizes the importance of errors.
(4) Sometimes the value of the error itself is not known.

11. The density of quartz is 2.7 g/cm^3. If a sample of quartz has a mass of 81 g, what is its volume?

(1) 0.03 cm^3
(2) 8.1 g
(3) 11.1 g
(4) 30 cm^3

12. Gold has a density of 19.3 g/cm^3. A prospector found a gold nugget with a volume of 10 cm^3. What was the mass of the nugget?

(1) 1.93 g
(2) 193 g
(3) 19.3 g
(4) 1930 g

13. Pumice is an unusual rock because some samples float on water. What does this tell you about pumice?

(1) Pumice can be less dense than water.
(2) Pumice is most common in high mountain locations.
(3) Pumice is usually found in very small pieces.
(4) Pumice absorbs water.

14. The density of granite is 2.7 g/cm^3. If a large sample of granite is cut in half, what will be the density of each of the pieces?

(1) 1.35 g/cm^3
(2) 2.7 g/cm^3
(3) 5.4 g/cm^3
(4) 27 g/cm^3

15. If two leading scientists are investigating the same question and they reach similar conclusions, what does this show?

(1) They probably changed their results to agree.
(2) The conclusion they both made is probably in error.
(3) Their scientific work showed a lack of originality.
(4) Their conclusions have a good chance of being correct.

Part C

Base your answers to questions 16 through 19 on the following information and the data table.

The snowline is the lowest elevation at which snow remains on the ground all year. The data table on page 30 shows the elevation of the snowline at different latitudes in the Northern Hemisphere.

Latitude (°N)	Elevation of Snowline (m)	Latitude (°N)	Elevation of Snowline (m)
0	5400	50	1600
10	4900	65	500
25	3800	80	100
35	3100	90	0

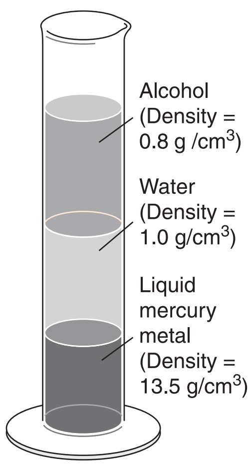
16. On a properly labeled grid, plot the latitude and elevation of the snowline for the locations in the data table. Give the graph a title. Use a dot for each point and connect the dots with a line.

17. Mt. Mitchell, in North Carolina, is located at 36°N and has a peak elevation of 2037 m. Plot the latitude and elevation of Mt. Mitchell on your graph. Use a plus sign (+) to mark this point.

18. Using your graph, determine (to the *nearest whole degree*) the lowest latitude at which a peak with the same elevation as Mt. Mitchell would have permanent snow.

19. State the relationship between latitude and elevation of the snowline.

20. The diagram below shows three liquids of different densities in a 100-mL cylinder. A sphere of oak wood about half the diameter of the cylinder and a silver sphere of the same size are dropped in the cylinder without mixing the liquids. The oak wood has a density of 0.9 g/cm^3, and the density of silver is 10.5 g/cm^3. Where will the spheres come to rest?



CHAPTER

2 Earth's Dimensions and Navigation

WORDS TO KNOW

atmosphere	latitude	prime meridian
axis	lithosphere	stratosphere
equator	longitude	terrestrial coordinate
geosphere	mesosphere	thermosphere
Greenwich Mean Time	oblate	troposphere
hydrosphere		

This chapter will help you answer the following questions:

1. How do we know that Earth is a sphere?
2. What layers of Earth do we know best?
3. How can we tell where we are on Earth when there are no familiar landmarks?

WHAT IS EARTH'S SHAPE?

Evidence of Earth's Shape

1 MATHEMATICAL ANALYSIS 1
4: 1.1c
4: 1.2c

Although Earth looks flat and endless, there were some ancient scholars who understood that Earth is a gigantic sphere. The scholars came to this conclusion because they noticed that as a ship sails away to sea, it seems to disappear from the bottom first. Ships appear to sail over and below the horizon as shown in Figure 2-1 on page 32.

FIGURE 2-1. Over the ocean, the horizon looks flat. However, as a ship sails away, it seems to disappear hull first, as it gradually dips below the horizon.

Another indication of Earth's shape comes from observing the moon. During an eclipse of the moon, Earth's shadow moves over the surface of the moon. The edge of that shadow is always a uniformly curved line. Ancient Greeks knew that the only shape that always casts a uniformly curved shadow is a sphere. The reason for their thinking is illustrated in Figure 2-2.

If you know someone who lives hundreds or thousands of miles away to the east or west, you know that person's local time is different from yours. If it is noon in New York, it is only 9 A.M. for a person in California. At the same time, people in Europe are having their evening meal. For a person in central Asia or Australia, it

FIGURE 2-2. During an eclipse of the moon, Earth's shadow gradually covers the full moon. Notice that this shadow, as always, appears as a dark circle whose diameter is about three times the diameter of the moon.

might be midnight. When time differences over the whole planet are considered, it is clear that Earth is a gigantic sphere.

There is also evidence of Earth's shape in the observation of distant objects in the night sky. A person at the North Pole sees the North Star, Polaris, directly overhead. To a person located farther south, Polaris appears lower in the sky. In fact, at the equator, Polaris is on the horizon. (See Figure 2-3.)

The **equator** is an imaginary line that circles Earth half way between the North and South poles. South of the equator, Polaris is

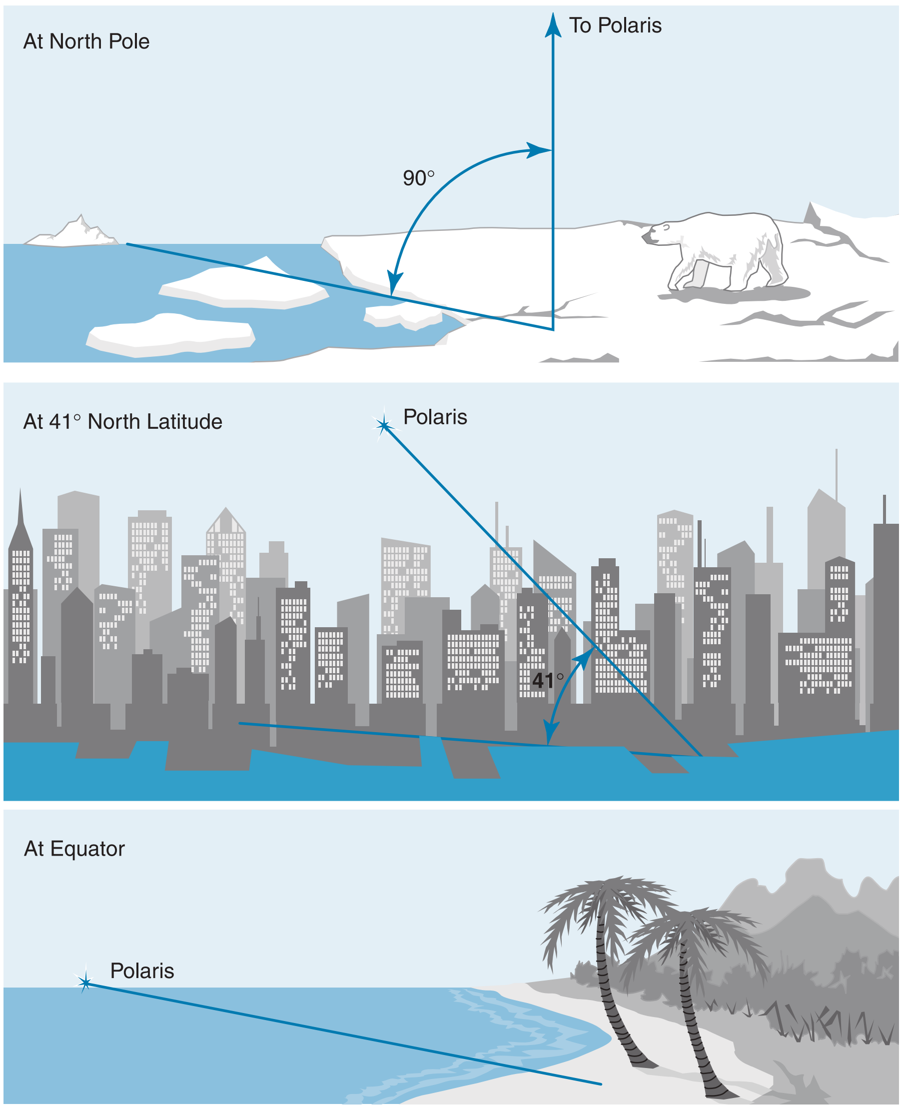


FIGURE 2-3. The altitude of Polaris in the northern sky depends on your latitude.

not visible at all. Observers south of the equator can see the stars of the Southern Cross, which is never visible in New York. These observations support the idea of a spherical planet.

The Apollo program explored the moon in the late 1960s. During these missions, astronauts flew far enough from Earth to be able to see the entire planet. The astronauts took photographs that show that our planet is a nearly spherical object orbiting in the vastness of space.

STUDENT ACTIVITY 2-1 —HOW ROUND IS EARTH?

1: MATHEMATICAL ANALYSIS 1

Careful measurements of Earth have shown that it is not a perfect sphere; its equatorial radius is 6378 km, and its polar radius is 6357 km. This is a difference of 21 km (about 13 miles). Earth's rotation on its axis causes a bulge at the equator. How much of a bulge is there? We now know that Earth's exact shape is **oblate**, or slightly flattened at the poles.

To calculate Earth's degree of flattening, use the following formula. If the result is a large number, Earth is not very round.

$$\text{Degree of flattening} = \frac{\text{difference between equatorial and polar radii}}{\text{equatorial radius}}$$

Your task is to use a drawing compass to draw two circles centered on the same point. Draw one circle proportional to the polar radius and a second circle proportional to the equatorial radius. You will need to establish and use a scale so that your drawings will fit on a sheet of paper. Compare these two circles and state how far from round Earth would appear from space.

How Large Is Earth?

A Greek scholar named Eratosthenes (era-TOSS-then-ease) made the first recorded calculation of Earth's size about 2000 years ago. He knew that on the first day of summer the noon sun was directly overhead at the town of Syene in Egypt. In Alexandria, 5000 *stadia* (approximately 800 km, or 500 mi) to the north, the sun was 7.2° from the overhead position. (*Stadia* is the plural form of the Greek word *stadion,* a unit of distance used in Eratosthenes' time.)

Since 7.2° is $\frac{1}{50}$ of a circle, Eratosthenes reasoned that the distance around the Earth must be 50 × 5000 *stadia,* or 250,000 *stadia.* Although the exact length of a *stadion* is not known, Eratosthenes' figure appears to be remarkably close to the more accurate measurements made today. Visit this Web site to see astronomer Carl Sagan explain how Eratosthenes calculated Earth's circumference: *http://www.youtube.com/watch?v=0JHEqBLG650*

WHAT ARE EARTH'S PARTS?

2: INFORMATION SYSTEMS 1
4: 1.1i
4: 2.1j

Based on differences in composition, Earth can be divided into three parts. These parts form spheres, one inside the other, separated by differences in density. Each sphere is also a different state of matter: gas, liquid, or solid.

The **atmosphere** is the outer shell of gas that surrounds Earth. The **hydrosphere** is the water of Earth. About 99 percent of this water is contained in Earth's oceans, which cover about three-quarters of the planet. The **lithosphere** is the solid rock covering Earth. (The crust is the rocky outer layer of the lithosphere.)

Table 2-1 lists the average chemical composition of each sphere. Rocks in Earth's crust represent the lithosphere because these are

Average Chemical Composition of Earth's Crust, Hydrosphere, and Troposphere

ELEMENT (symbol)	CRUST		HYDROSPHERE	TROPOSPHERE
	Percent by mass	Percent by volume	Percent by volume	Percent by volume
Oxygen (O)	46.10	94.04	33.0	21.0
Silicon (Si)	28.20	0.88		
Aluminum (Al)	8.23	0.48		
Iron (Fe)	5.63	0.49		
Calcium (Ca)	4.15	1.18		
Sodium (Na)	2.36	1.11		
Magnesium (Mg)	2.33	0.33		
Potassium (K)	2.09	1.42		
Nitrogen (N)				78.0
Hydrogen (H)			66.0	
Other	0.91	0.07	1.0	1.0

TABLE 2-1.

the rocks that are found at and near the surface. (Deep inside Earth, denser elements, such as iron and magnesium, are more common than they are near the surface.) Notice that oxygen is among the most common elements in all three parts of Earth. Elements are shown rather than chemical compounds because the crust is composed of thousands of minerals, each with a different chemical composition. However, most minerals contain roughly the same elements. Most of the atmosphere is composed of elements in the form of gases. Only the hydrosphere is made mostly of a single compound: water. Water is composed of two parts hydrogen to one part oxygen by volume.

STUDENT ACTIVITY 2-2 —PIE GRAPHS OF EARTH'S SPHERES

2: INFORMATION SYSTEMS 1

Draw three pie graphs based on the data in Table 2-1. Make one graph of the chemical composition of the crust by mass, a second of the chemical composition of the hydrosphere by volume, and the third of the chemical composition of the crust by volume. Two of these graphs represent the composition of Earth's crust. Why do these two pie graphs look so different?

The Atmosphere

A thin layer of gas, the atmosphere, surrounds the solid earth and the oceans. Most of the mass of the atmosphere, clouds, and weather changes occur in the troposphere, the lowest layer of the atmosphere. (See Figure 2-4.) Although the atmosphere accounts for a tiny part of the total mass and volume of the planet, it is in this changing environment that people and most other lifeforms live.

Air is a mixture of gases that is about 78 percent nitrogen (N_2). Nitrogen is a stable gas that does not react easily with other elements or compounds. About 21 percent of the atmosphere is oxygen (O_2). Oxygen combines with many other elements in the processes of oxidation, combustion, and cellular respiration. Living things depend on cellular respiration to make use of the energy stored in food. The inert gas argon, which almost never reacts with other elements or compounds, makes up about 1 percent of the atmosphere.

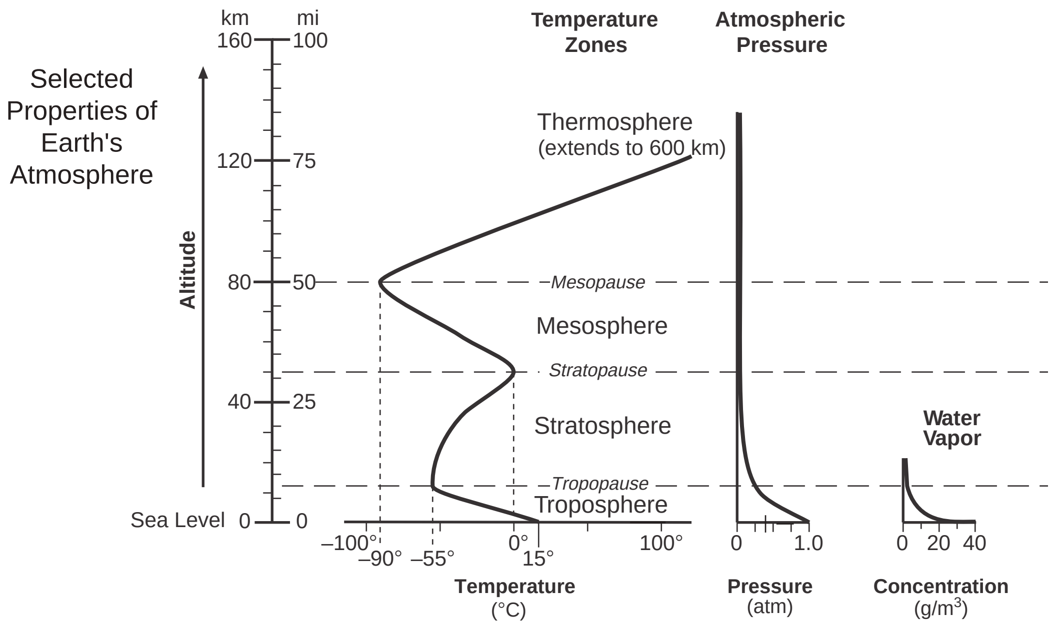


FIGURE 2-4. Selected properties of Earth's atmosphere.

The proportions of other gases in the atmosphere are not constant. The amount of water vapor, water in the form of a gas, can be as high as several percent in warm, tropical locations or a tiny fraction of a percent in deserts and cold areas. Carbon dioxide, the product of respiration and the burning of fossil fuels, makes up far less than 1 percent. However, carbon dioxide is needed by plants for photosynthesis. This gas also plays an important role in climate change, which will be explored in Chapter 25.

The paragraph above describes the composition of the atmosphere's lowest layer, the **troposphere**. Note that the names of the layers of the atmosphere end in *–sphere* because this is their shape around Earth. The names of the boundaries between layers end in *–pause,* as in stopping. Therefore, the tropopause is the place where the troposphere ends.

The atmosphere is divided into layers based on how the temperature changes with altitude, as shown in Figure 2-4. Because the layers of the atmosphere are a result of density differences, the atmosphere is most dense at the bottom of the troposphere. Actually, the troposphere contains most of the mass of the atmosphere even though it extends only about 12 km (7 mi) above Earth's surface. Nearly all the atmosphere's water vapor, clouds, and weather events occur in this lowest layer. Compared with the whole Earth, the troposphere is a very thin layer. In fact, it is the thinnest layer of our atmosphere.

Within the troposphere as altitude increases, temperature decreases. Have you ever noticed how snow lasts longer in the highest mountains than it does at lower elevations? The world's highest mountains extend nearly to the top of the troposphere. Above that height, the temperature change reverses and it actually becomes warmer with increasing altitude. The altitude at which the temperature reversal occurs is the tropopause.

The next layer of the atmosphere is the **stratosphere**, in which the temperature increases with increasing altitude. The stratosphere extends up to the stratopause, where another change in temperature trend takes place. In the **mesosphere**, the temperature falls as altitude increases. Above the mesopause, is the highest layer, the **thermosphere**, in which the air temperature rises a great deal. However, due to the atmosphere's extreme low density, the increase in temperature affects relatively few atoms. This increase in energy separates the molecules into positive and negative ions. For this reason, this layer is sometimes called the ionosphere.

The lower boundary of the atmosphere at the surface of the lithosphere or the hydrosphere is quite distinct. Because the atmosphere thins with altitude, there is no clear upper boundary of the atmosphere. The atmosphere just gets thinner and thinner as you get farther from Earth. When people refer to the atmosphere, they usually mean the relatively shallow troposphere, which actually contains about three-quarters of the atmosphere's total mass. This is layer in which we live. For information and animations about Earth's atmosphere visit the following Web site: ***http://earthguide.ucsd.edu/earthguide/diagrams/atmosphere/index.html***

STUDENT ACTIVITY 2-3 —INTERPRETING REFERENCE TABLES

2: INFORMATION SYSTEMS 1

You have probably ridden an elevator to the top of a building. What would you experience if you could ride upward in an open elevator through the atmosphere? Based on the information in Figure 2-4, write a traveler's guide to an elevator ride to a point 150 km above Earth's surface. Describe changes in temperature, air pressure, and water vapor concentration that a traveler would find on the ride. In addition, describe the protective equipment that a traveler would need to survive the various levels of the trip.

The Hydrosphere

Earth's oceans cover nearly three times as much of our planet as do the continents. People may think oceans are huge, featureless expanses of water, but oceans are not limitless and not featureless. The bottom of the oceans (the seafloor) is almost as variable as Earth's land areas. The hydrosphere is Earth's thinnest layer, averaging about 4 km (2.5 mi) in depth. Scientists think the oceans may be where life began on Earth.

The liquid hydrosphere can be divided into two parts. About 99 percent of the hydrosphere is made up of the oceans, which are salt water. Salt water is about 96.5 percent water and about 3.5 percent salt, mostly sodium chloride (common table salt). The remaining 1 percent of the hydrosphere is freshwater, which contains much smaller concentrations of dissolved solids. Freshwater is found in glaciers, streams, rivers, and lakes. However, far more liquid freshwater is in the spaces within soil and rock than on the surface. In fact, groundwater is estimated to be 25 times as abundant as the freshwater on Earth's surface.

The Lithosphere

The surface of the lithosphere, including soil and rock, is the part of Earth we see most. This natural arch shown in Figure 2-5 is part

FIGURE 2-5. Double Arch in Arches National Park near Moab, Utah, is part of the lithosphere.

of the lithosphere, Earth's rigid outer layer. The great bulk of Earth is the geosphere. We can define the **geosphere** as the mass of solid and molten rock that extends more than 6000 km from Earth's solid surface to its center. The lithosphere, the top 100 km of the geosphere, is the most rigid (unbending) part of the geosphere. Direct explorations in mines have taken humans to a depth of less than 4 km. The deepest drill hole is about 12 km deep. Everything we know about the geosphere at depths greater than 12 km comes from indirect evidence, such as the increasing temperatures with depth, the passage of seismic (earthquake) waves, examination of meteorites, and from the determination of Earth's properties, such as its density. Therefore, scientists have directly explored or penetrated only about one-fifth of 1 percent of the distance to Earth's center.

HOW IS LOCATION DETERMINED?

4: 1.1c, 1.1d, 1.1f

How can sailors far out on the ocean determine their position so they can safely return to port? With no familiar landmarks, such as roads, cities, and geographic features, they cannot describe their location in terms of surface features the way people usually do on land. Long ago, explorers solved this problem by establishing a coordinate system that covers the whole Earth.

Terrestrial Coordinates

The grid on a sheet of graph paper is a type of coordinate system. Each point on the paper has a unique address expressed in terms of numbers along the x and y axes. Many cities are laid out in a coordinate system. Much of New York City has numbered avenues that run north-south and numbered streets that run east-west. Knowing the street address of a building can help a person quickly locate it on a map or in the city itself. However, in Earth's undeveloped areas there are no roads or street signs, and there is no way to mark the oceans' surface. Because of this, explorers used their observations of the sun and stars to find their position on Earth's surface.

The coordinate system established by early sailors and explorers is Earth's system of latitude and longitude, called **terrestrial**

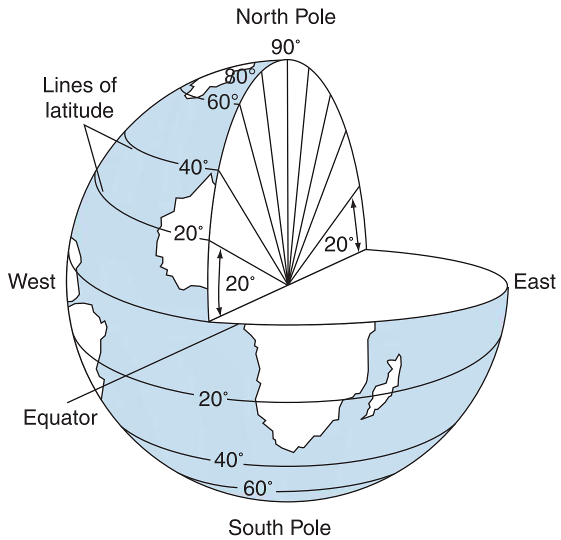


FIGURE 2-6. Latitude is your angular distance north or south of the equator. For example, this diagram shows that the angle between the equator and central north Africa is about 20°. So the latitude of this part of Africa is 20°N. It is the latitude of Mexico and India as well.

coordinates. This system is based on the spin (rotation) of Earth on its axis. The **axis** is an imaginary line that passes through Earth's North and South poles. Halfway between the poles is the equator, an imaginary line that circles Earth. The first terrestrial coordinate value is latitude. As shown in Figure 2-6, **latitude** is the angular distance north or south of the equator.

Lines of equal latitude are called parallels because they run east-west and are parallel to each other. The equator is the reference line at latitude 0°. Both north and south of the equator, latitude increases to a maximum of 90° at the poles. Parallels can be drawn at any interval of latitude from the equator (0°) to the North and South poles (90°N and S).

DIVISIONS OF ANGLES Just as meters can be divided into centimeters and millimeters, degrees of angle can be divided into smaller units. Each degree is made up of 60 minutes (60′) of angle. So, $23\frac{1}{2}$ degrees is 23 degrees and 30 minutes (23°30′). Furthermore, one minute of angle ($\frac{1}{60}$ of a degree) can further be divided into 60 seconds (60″). On Earth's surface, an accuracy of a second of latitude or longitude would establish your location to within a rectangle that measures about 30 m on each side. Visit the following Web site to convert street addresses to/from latitude/longitude in one step: ***http://www.stevemorse.org/jcal/latlon.php***

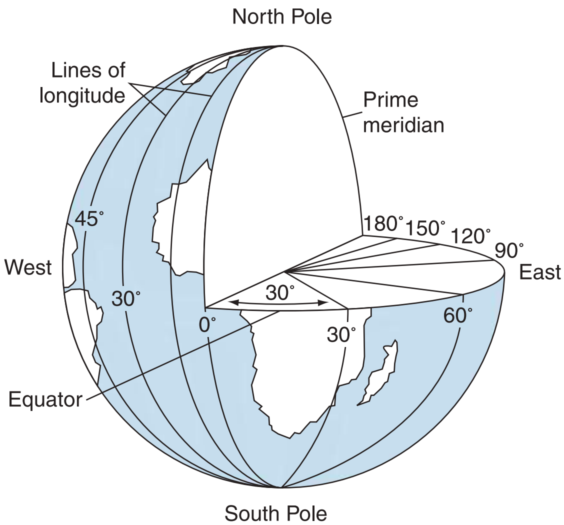


FIGURE 2-7. Longitude is your angular distance east or west of the prime meridian. At 0° longitude, the prime meridian runs through London, England, western Africa and the South Atlantic Ocean. All lines of equal longitude run from the North Pole to the South Pole.

The second terrestrial coordinate value is longitude. As shown in Figure 2-7, **longitude** measures angular distance east and west. Unlike latitude, there is no natural or logical place for longitude measurements to begin. English explorers established their reference line at the Royal Observatory in Greenwich (GREN-itch), England. Since England dominated world exploration and map-making in the 16th century, a north-south line through Greenwich became the world standard for measurements of longitude. Today, the Greenwich meridian, also known as the **prime meridian**, has become the reference line from which longitude is measured, as you can see in Figure 2-7.

Lines of equal longitude are called meridians. Meridians all run from the North Pole to the South Pole. The prime meridian has a longitude of 0°. Longitude increases to the east and west to a maximum of 180°, a line that runs down the middle of the Pacific Ocean. Meridians are not parallel because they meet at the North and South Poles. As shown in Figure 2-8, the Eastern and Western Hemispheres are the two halves of Earth bounded by the prime meridian and the north-south line of 180° longitude.

Unfortunately, some people think of latitude and longitude as only lines. For example, they confuse latitude, the angular distance from the equator, with the lines on a map that show constant latitude. If your only purpose is to read the coordinates on a map, this is not a problem. However, if you want to understand what

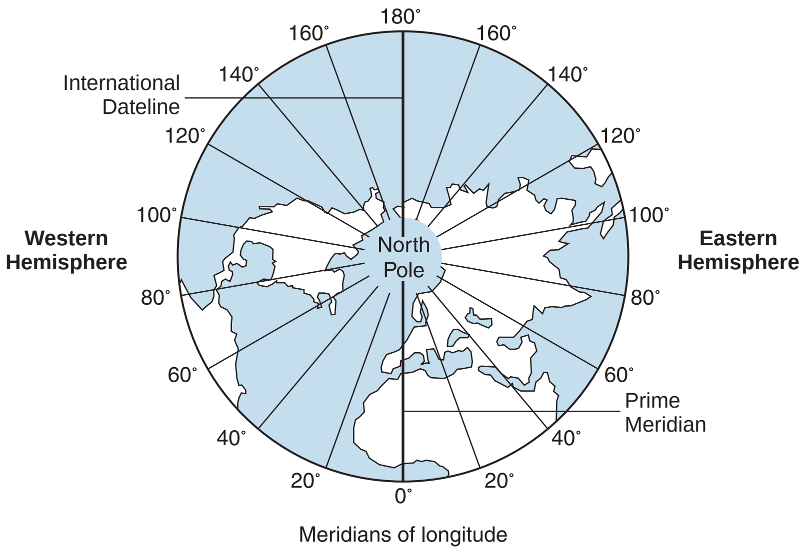


FIGURE 2-8. The prime meridian (0° longitude) and the international dateline (roughly 180°) make a circle that divides Earth into the Eastern and Western Hemispheres.

latitude and longitude are and how they are determined, you need a deeper understanding.

On a computer, Google Earth lets you "fly" anywhere on Earth to view satellite imagery, maps, terrain, 3-D buildings and even explore galaxies in the sky. Visit the following Web site to join the fun: ***http://earth.google.com/***

Finding Latitude

Earlier in this chapter you read that observations of Polaris, the North Star, were used to show that Earth is a sphere. Those observations can also be used to tell how far north a person is from the equator. Earth rotates on its axis. There is no scientific reason that Earth's axis should be pointed to any particular star. In fact, the direction in which Earth's axis points moves through a 26,000-year cycle. In our lifetime the north-south axis just happens to line up with a relatively bright star called Polaris, or the North Star. (The alignment is not perfect, since Polaris is a little less than 1 degree from the projection of Earth's axis.) A navigator can also use the Sun to determine latitude. Figure 2-9 on page 44 shows a sextant being used in celestial navigation.

An observer at the North Pole sees Polaris directly overhead in the night sky. The angle from the horizon up to Polaris is therefore 90°. That observer is also located 90° north of the equator. As the

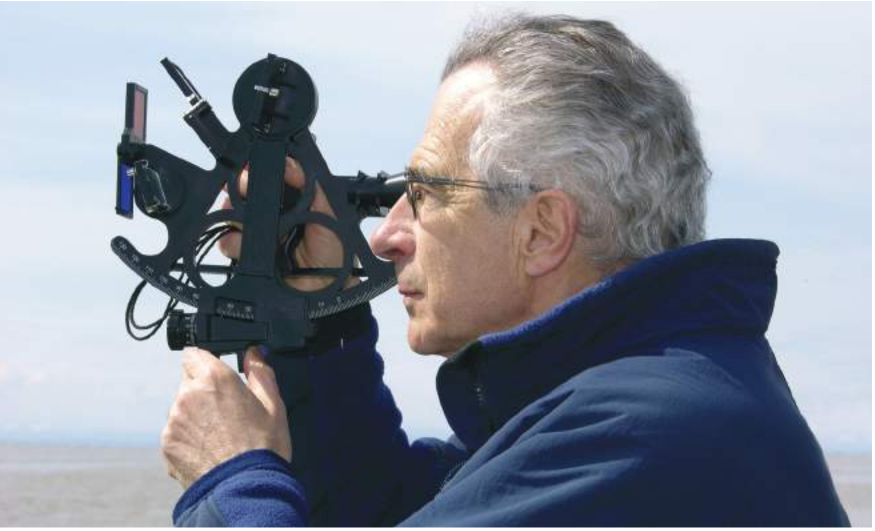


FIGURE 2-9. Precision instruments such as this mariner's sextant are used to determine latitude with remarkable accuracy.

latitude of the observer decreases, the altitude of Polaris also decreases. At the equator, Polaris is visible right on the northern horizon. Here, Polaris is 0° above the horizon, the latitude at Earth's equator is 0°. Therefore, for any observer in the Northern Hemisphere, latitude can be determined by observing the angle of Polaris above the horizon. *The altitude of Polaris equals the latitude of the observer.* Figure 2-10 illustrates how two stars in the Big Dipper can be used to find Polaris.

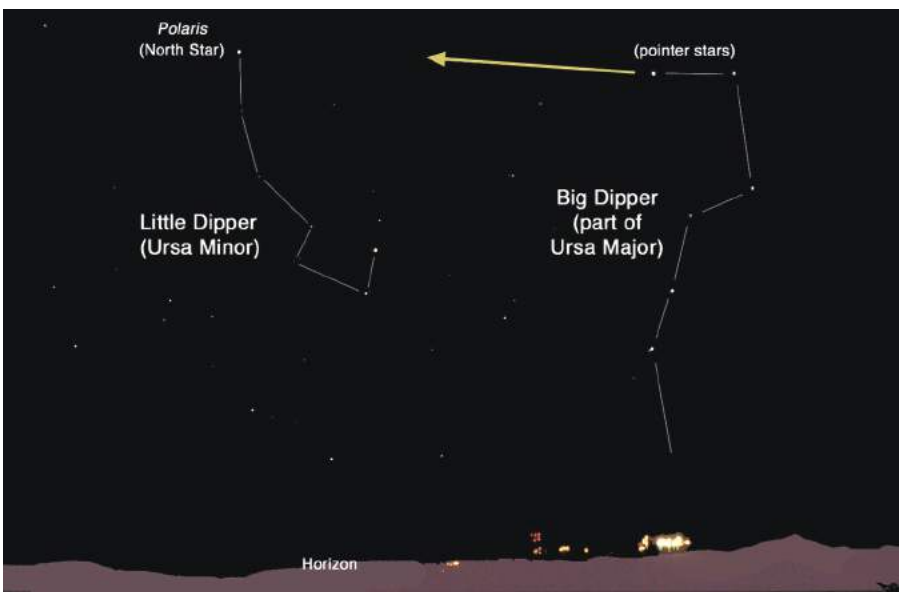


FIGURE 2-10. The "pointer stars" in the Big Dipper always line up with the North Star (Polaris). If you rotate your book through 90°, 180°, and 270°, you will see how the alignment of these two constellations changes over a 24-hour period. (Ignore the horizon.) The same rotation can be observed if you view these stars at the same clock time each night for one year.

South of the equator the North Star is not visible. However, with a star map, an observer can determine the point in the night sky that is directly above the South Pole. It is near the constellation called the Southern Cross. In a procedure similar to what is done in the Northern Hemisphere, south latitude is equal to the angle of that point in the starry sky above the horizon. For people used to sighting on Polaris, it did not take long to master finding latitude in the Southern Hemisphere.

STUDENT ACTIVITY 2-4 —DETERMINING YOUR LATITUDE

1: MATHEMATICAL ANALYSIS 1, 2, 3
6: MODELS 2
6: MAGNITUDE AND SCALE 3

You can construct an instrument to measure your latitude using the following simple materials: a protractor, a thin string, a weight, and a sighting device such as a soda straw. This instrument is similar in principle to instruments used by mariners for hundreds of years. Figure 2-11 shows this navigation device in use.

If you use a standard protractor when you sight along the horizon, the string will fall along the 90° line. Similarly, if you look straight up, the string will line up with 0°. In these cases, you will need to subtract your angle readings from 90° to find your latitude. Your latitude is equal to the angle of the star Polaris above a level horizon. Do your results agree with the latitude given for your location on maps or other references?

FIGURE 2-11. To make a simple celestial navigation instrument, use protractor, a drinking straw, and a weight on a string.

Finding Longitude

You can determine your longitude by observing the position of the sun. If it is noon where you are, it must be midnight halfway around Earth. (A full circle is 360°, so halfway around the planet is 180°.) The sun appears to move around Earth from east to west. Therefore, when it is noon where you are, in places to your east, the local time is afternoon, and in places to your west it is still morning. Because the sun appears to move around Earth in 24 hours, each difference of 1 hour of time represents $\frac{1}{24}$ of 360°, or 15°. Each 1-hour difference in time from one location to another represents 15° of longitude.

Using the time difference of 15° per hour, you can determine the numerical value of longitude. But how can you determine whether it is east or west longitude? If local time is earlier than Greenwich Time, the observer is located in the Western Hemisphere. To observers in the Eastern Hemisphere, local time is later than Greenwich Time. To make this clearer, you can look at a globe and imagine the sun at the noon position in England. Remember that Earth spins toward the east. On your globe, most of Europe and Asia, at eastern longitudes, are in the afternoon or evening. This part of Earth east of England is turning away from the sun. At the same time, to the west of England, it is still morning. These places are rotating toward the sun.

Of course, this is based on solar time. Solar noon is the time the sun reaches its highest point in the sky. Clock time may be different from solar time by half an hour—even more if daylight saving time is in effect. If people were to set their clocks to the apparent motion of the sun across the sky in their location, clock time would be different from one place to another. This was the situation before time was standardized. In those days, towns had a clock that chimed, so the citizens would know the local time. At that time, watches were difficult to make and too expensive for most people to own. Only places on a north-south line (at the same longitude) would have exactly the same clock time.

If we still used this system and you wanted to meet someone in another town at a particular time, you could not use a clock set to the time in your town because you would probably show up early or late. Radio and television programs would not necessarily begin on the hour or half-hour. To standardize time, most of the United States is divided into four time zones: Eastern, Central, Mountain, and Pacific Time. In each time zone, all clocks are set to the same time.

STUDENT ACTIVITY 2-5 —FINDING SOLAR NOON

1: MATHEMATICAL ANALYSIS 1, 2, 3
1: SCIENTIFIC INQUIRY 3

It is quite easy to measure local time by observing the sun. To determine the time of solar noon, you will need to be at a location where a tall, vertical object, such as a flagpole or the high corner of a tall building, casts a shadow onto a level surface. Throughout the middle of the day, mark the exact position of the point of the shadow, and label the positions with the accurate clock time. (To avoid making permanent marks, use a substance such as chalk that will wash away in the rain.) Call these marks the time points. Connecting the points will form a curved line north of the object casting the shadow.

The next step is to find where the curved shadow line comes closest to the base of the shadow object. (You will probably need to use a long metal tape measure to measure the distance.) Mark this point "Solar Noon." Finding the clock time of solar noon will probably require you to estimate between the marked time points to establish the precise time of "Solar Noon."

Figure 2-12 shows five positions of the sun as it travels from sunrise in the east to sunset in the west, and the solar time at each

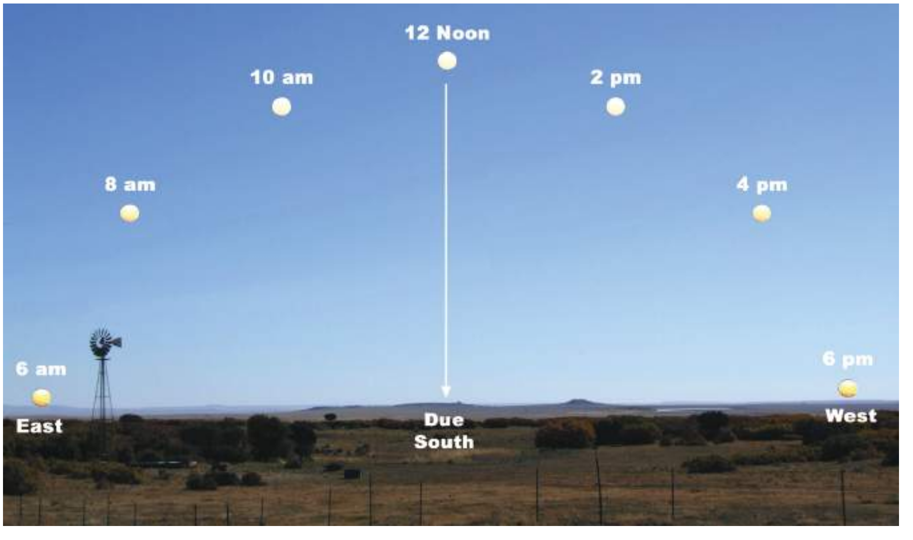


FIGURE 2-12. Solar time in spring and autumn. Solar noon in most places does not occur exactly at clock noon.

position on the first day of spring or autumn. Solar noon occurs when the sun reaches its highest point in the sky at your location. For an observer in New York State at solar noon, the sun is highest in the sky (but not directly overhead) and due (exactly) south. An added benefit of this procedure is that it allows you to draw a line that runs exactly north to south. The line from the vertical base of the shadow object to the most distant point of the noon shadow could actually be extended all the way to the North Pole.

Modern clocks have become so precise they can measure small changes in solar noon at Greenwich throughout the year. Therefore, **Greenwich Mean Time (GMT)**, which evens out these small annual changes, is used as the basis of standard time throughout the world.

In practice, measuring longitude was not easy for the early mariners. A navigator at sea needed to know the precise time noon occurred back in Greenwich. The ships carried the most accurate clocks available at that time. However, after a long sea voyage, changes in temperature and the rocking motion of the ship caused these mechanical clocks to become inaccurate. It was easy to observe local time by observing when the shadow of a vertical object pointed exactly north. Yet, comparing local time with the time back in England depended on those mechanical clocks. Until very accurate clocks could be manufactured, measurements of longitude were poor, and maps generally showed large errors in the east-west direction.

STUDENT ACTIVITY 2-6 —DETERMINING YOUR LONGITUDE

1: MATHEMATICAL ANALYSIS 1, 2, 3

Your longitude is proportional to the time difference between local solar time and Greenwich Mean Time (GMT). This difference needs to be calculated in hours and hundredths of an hour, not hours and minutes. If you performed the solar noon activity earlier in this chapter, you can use your data to determine your longitude. In that activity, you determined the difference between clock time and solar time. For example, if you determined that solar noon occurred at 11:55 A.M., the difference between clock time and solar time is −5 minutes. If solar noon occurred at 12:09 P.M., the difference between clock time and solar time is +9 minutes. (Convert your solar time from hours and minutes to hours and hundredths of an hour by dividing the minutes by 60.)

FIGURE 2-13. The world has been divided into time zones based upon Earth's rate of rotation of 15° per hour.

Earth has been divided roughly into 24 hourly time zones, as shown in Figure 2-13. Generally, for each 15° change in longitude, clock time changes by 1 hour. Thus, when it is noon on one side of the world, on the opposite side of the world the local time is midnight (180° ÷ 15°/h = 12 h).

For locations in New York State, you can find Greenwich Mean Time by adding 5 hours to your clock time. For example, if it is 1:15 P.M. clock time, Greenwich Mean Time is 6:15 P.M. (*Note:* If it is daylight saving time in New York, you would add only 4 hours.)

Once you have calculated your longitude experimentally, you can check your results with a map of New York State, such as the *Generalized Bedrock Geology of New York State* found on page 426 or in the *Earth Science Reference Tables,* that shows local latitude and longitude. (*Note:* Mean Time and solar can differ by as much as 15 minutes. This could cause an error of as much as 4° of longitude. The following Web site explains this issue, known as the Equation-of-Time: ***http://www.analemma.com/Pages/framesPage.html***)

Thanks to modern technology, finding the angle north or south of the equator (latitude) and the angle east or west of the prime meridian (longitude) has become simple and accurate. There are very accurate clocks that use the vibrations of quartz crystals to measure time. In addition, radio and telephone communications provide Greenwich Mean Time to great accuracy. Even better is the use of Global Positioning System (GPS) devices that analyze signals from orbiting satellites, allowing people to find latitude and longitude. Using a GPS device allows people to pinpoint their position to within a few meters. These devices are now small and inexpensive enough to be used by hikers and sportsmen. On land or at sea, it has become remarkably easy to find your place on the planet's terrestrial coordinates.

STUDENT ACTIVITY 2-7 —READING LATITUDE AND LONGITUDE ON MAPS

2: INFORMATION SYSTEMS 1
6: MODELS 2

The *Earth Science Reference Tables* contain three maps (one New York map and two world maps) that can be used to read latitude and longitude. However, these world maps do not show cultural features, such as cities and political boundaries. To complete this activity you will need to use an atlas or a world map.

Your teacher may ask you to make a small "*X*" at each world location on a paper copy of the Tectonic Plates world map from the *Reference Tables.*

What cities are located at the following coordinates? (Please use a sheet of notebook paper. You should not mark in this book or on any reference materials.)

(1) 34°N, 118°W
(2) 38°S, 145°E
(3) 41°N, 74°W
(4) 0°, 79°W

List the latitude and longitude coordinates of the following places on a world map. Please estimate values to the nearest degree of latitude and longitude.

(5) Albany, NY
(6) London, England
(7) São Paulo, Brazil
(8) Jakarta, Indonesia

Use the *Earth Science Reference Tables* to find the terrestrial coordinates of each of these places in New York State. Round your answers to the nearest whole degree of latitude and longitude.

(9) Utica
(10) Riverhead
(11) Mt. Marcy
(12) Binghamton

(13) What city in New York State is about half way from the equator to the North Pole?
(14) There are two locations on Earth where the clock time is undefined. At these places, a clock can be set to any convenient time. Where are they?

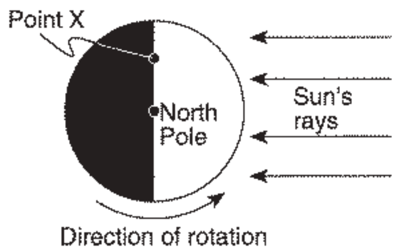
CHAPTER REVIEW QUESTIONS

Part A

1. In Earth's atmosphere, which temperature zone contains the most water vapor?

(1) mesosphere (3) thermosphere
(2) stratosphere (4) troposphere

2. The diagram below represents Earth's rotation as observed from a position directly above the North Pole. What is the approximate time at point *X* on Earth's surface?

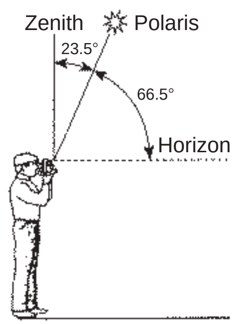


(1) 6 A.M. (2) 12 noon (3) 6 P.M. (4) 12 midnight

3. What is the approximate latitude of point *X* on the world map above?

(1) 0° (2) 45°N (3) 90°N (4) 180°

4. What is the most likely location of the observer shown below?



(1) the North Pole
(2) Northern Canada
(3) Central New York State
(4) Southern Florida

5. What two elements make up the largest percentage of Earth's crust?

(1) iron and silicon
(2) iron and oxygen
(3) oxygen and silicon
(4) aluminum and iron

6. What are the approximate terrestrial coordinates of Buffalo, NY?

(1) 79°N, 43°W
(2) 43°N, 79°W
(3) 79°N, 43°E
(4) 43°S, 79°E

7. From which New York State location would Polaris be observed to have an altitude closest to 43° above the northern horizon?

(1) Binghamton
(2) Utica
(3) Watertown
(4) New York City

8. Why do observers in New York State looking due south at the night sky see a different group of constellations from what they had seen six months earlier?

(1) Constellations revolve around Earth.
(2) Constellations revolve around the sun.
(3) The sun revolves around the center of our galaxy.
(4) Earth revolves around the sun.

9. The base of a cloud is located at an altitude of 2 km. The top of the same cloud is at an elevation of 8 km. In what part of the atmosphere is the cloud?

(1) troposphere, only
(2) stratosphere, only
(3) troposphere and stratosphere
(4) stratosphere and mesosphere

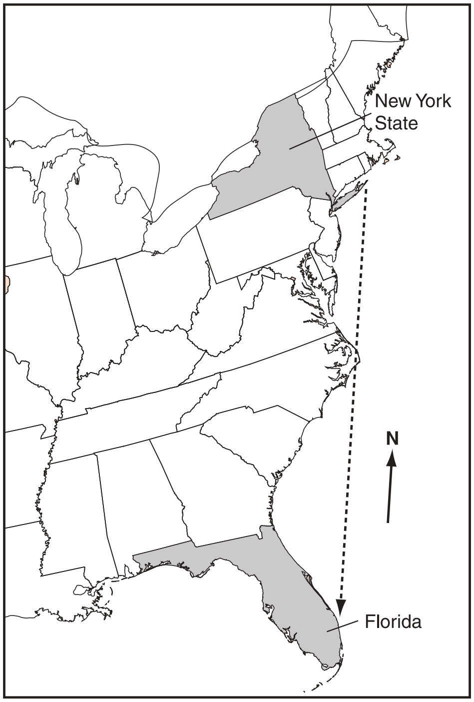
10. When the time of day for a certain ship at sea is 12 noon, the time of day at the prime meridian (0° longitude) is 5 P.M. What is the ship's longitude?

(1) 45°W
(2) 45°E
(3) 75°W
(4) 75°E

11. Approximately what percentage of Earth's surface is covered by water?

(1) 100%
(2) 75%
(3) 50%
(4) 25%

12. The arrow on the map below shows a ship's route from Long Island to Florida. As the ship travels south, the star Polaris appears lower in the sky each night.



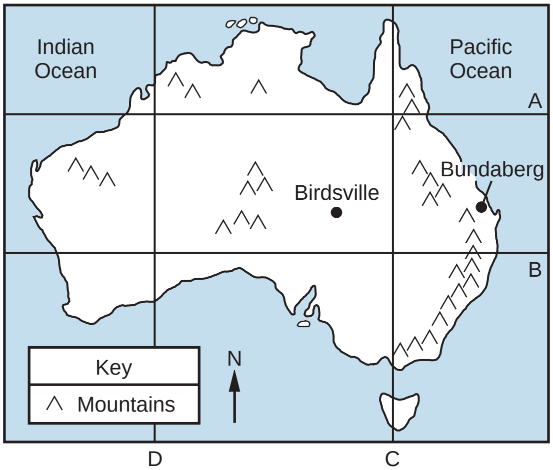
The best explanation for this observation is that Polaris

(1) rises and sets at different locations each day
(2) has an elliptical orbit around Earth
(3) is located directly over Earth's equator
(4) is located directly over Earth's North Pole

Part B

Base your answers to questions 13 and 14 on the map of Australia below.

Map of Australia



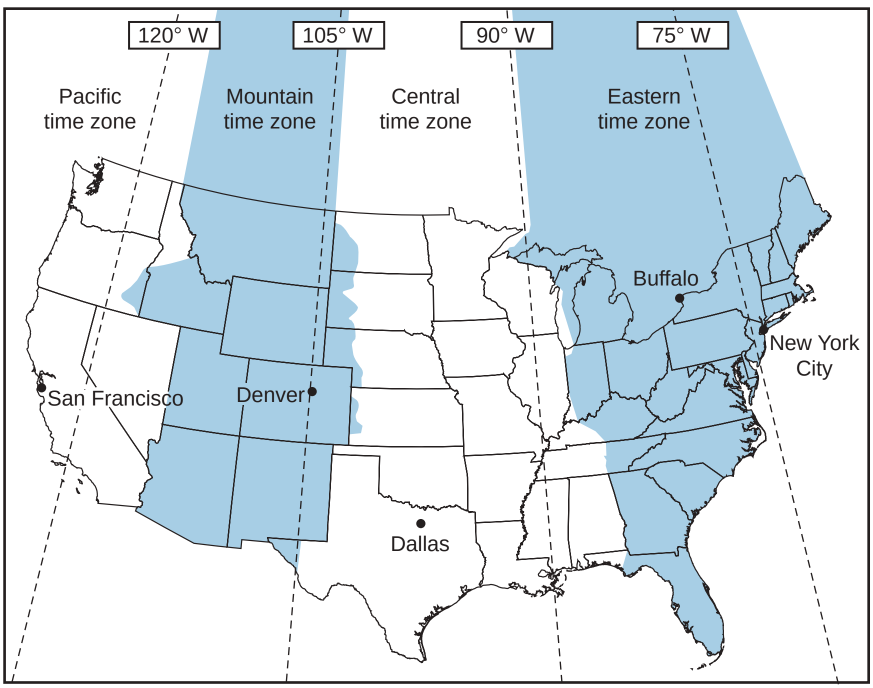
13. On the map, which straight line best represents 30° S latitude?

(1) A (3) C
(2) B (4) D

14. The map shows two cities in Australia. Explain why Bundaberg will experience solar noon before Birdsville each day.

Part C

Base your answers to questions 15 through 17 on the information and United States time zone map below. The map shows the four hourly time zones of the United States, except Alaska and Hawaii. Each time zone occupies roughly 15° of longitude. The associated lines of longitude for each time zone are shown here by dashed lines. For most locations within each, the clocks are set to the same time.

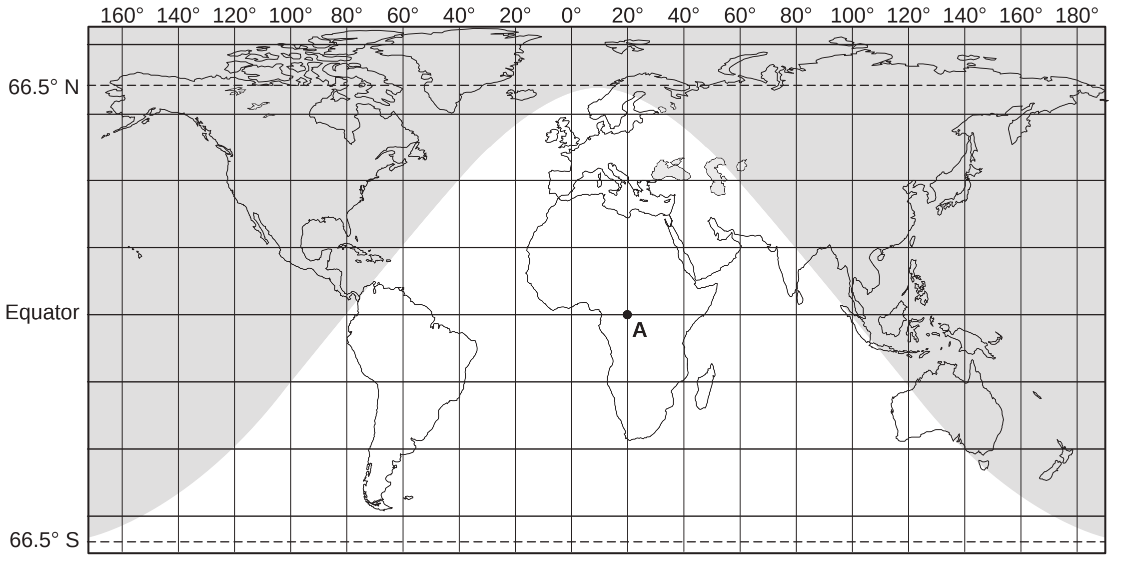


15. What is the approximate longitude of San Francisco? (Include the number, the units, and the compass direction.)

16. When it is 1:00 A.M. in New York City, what time is it in Denver?

17. Explain, in terms of Earth's rotation, why the time zones are 15° of longitude apart.

Base your answers to questions 18 and 19 on the world map below.



18. What are the latitude and longitude of the letter *A*?

19. At what rate (degrees per hour) is Earth rotating for a person located at *A*?

20. List the four layers of Earth's atmosphere in order from least dense to most dense.

CHAPTER

3 Models and Maps

WORDS TO KNOW

azimuth	gradient	model	topographic map
contour line	isoline	profile	topography
field	isotherm		

This chapter will help you answer the following questions:

1. What kinds of maps do we use to represent Earth's surface?
2. How do maps show field quantities such as surface elevations?
3. How can maps be used to make profiles?

WHAT IS A MODEL?

6: MODELS 2
6: MAGNITUDE AND SCALE 3

A **model** is anything used to represent something else. A photograph helps you remember people when they are not near. A photograph is an example of a physical model. There are also mathematical models. The formula for density you used in Chapter 1 is a mathematical model. This formula represents the relationship between mass and volume for any object made of a uniform substance. Memories and dreams are models of real or imagined events. In Chapter 2, you may have developed a mental model of the size and shape of planet Earth. Such models can be useful as you try to understand this planet.

Many physical models are scale models. They show the shape of the real object, but they are smaller or larger to make them easier to use. Toys and photographs are usually smaller than the real thing. In fact, a diagram showing the parts of an atom would need to be much larger than the original, perhaps by a factor of 1,000,000,000 (1.0×10^9, 1 billion).

A ratio is a convenient way to express scale. We often show a ratio as two numbers separated by a colon. A common scale used to make a small toy automobile is 1:64. This is read as "one to sixty-four." One centimeter (cm) on the toy car represents 64 cm on the real car. The model atom mentioned earlier would be at a scale of 1,000,000,000:1.

STUDENT ACTIVITY 3-1 —MODELS IN DAILY LIFE

6: MODELS 2
6: MAGNITUDE AND SCALE 3

Make a list of three models people use in their daily lives. Include physical models, mathematical models, and mental models. Organize your list into four columns: (1) Model (name each); (2) What It Represents; (3) Why It Is Used Instead of the Real Object (and if it is a scale model); and (4) Approximate Scale. Avoid different examples of the same kind of model.

Maps

Some maps are models of the whole Earth; other maps model just a part of its surface. Road maps help people to drive from one place to another. Political maps show the geographic limits of laws and government services. It is hard to imagine traveling without using maps.

Because Earth is a sphere, its surface is curved. The only kind of map that shows Earth's surface without distortion must also have a curved surface. Therefore, a globe is the most accurate model of Earth. Directions and distances are shown without distortion. However, flat maps are easier to carry. You can fold them for storage and open them on a flat surface. For small regions, the distortion of a flat map is not significant. Visit the following Web site to help you understand global maps and map distortion: ***http://geology.isu.edu/geostac/Field_Exercise/topomaps/distortion.htm***

When world maps are transferred to flat surfaces, they may show increasing distortion in areas far from the equator. Compromises must be made depending how the map will be used. Compare the Ocean Currents maps (Figure 3-1) with the Tectonic Plates map (Figure 3-2). Figure 3-1 shows the Scandinavian Peninsula in northern Europe as much smaller than Australia. Figure 3-2 on page 59, the Tectonic Plates map, incorrectly shows these areas to be about the same size. Although the Ocean Currents map shows less size distortion, it distorts directions. Notice how North America seems to be slanted on the Ocean Currents map. Both maps can be used to locate places by latitude and longitude.

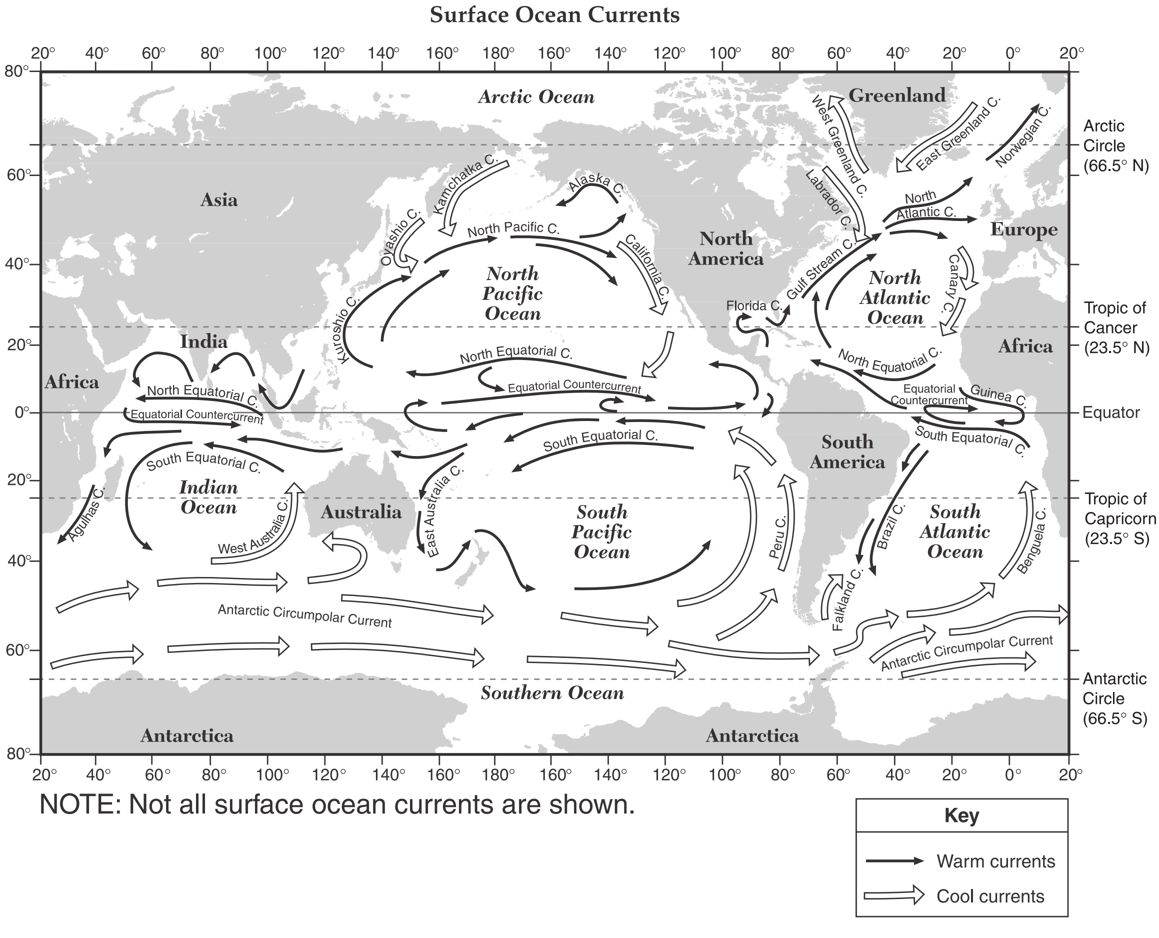


FIGURE 3-1. Major ocean currents of the world.

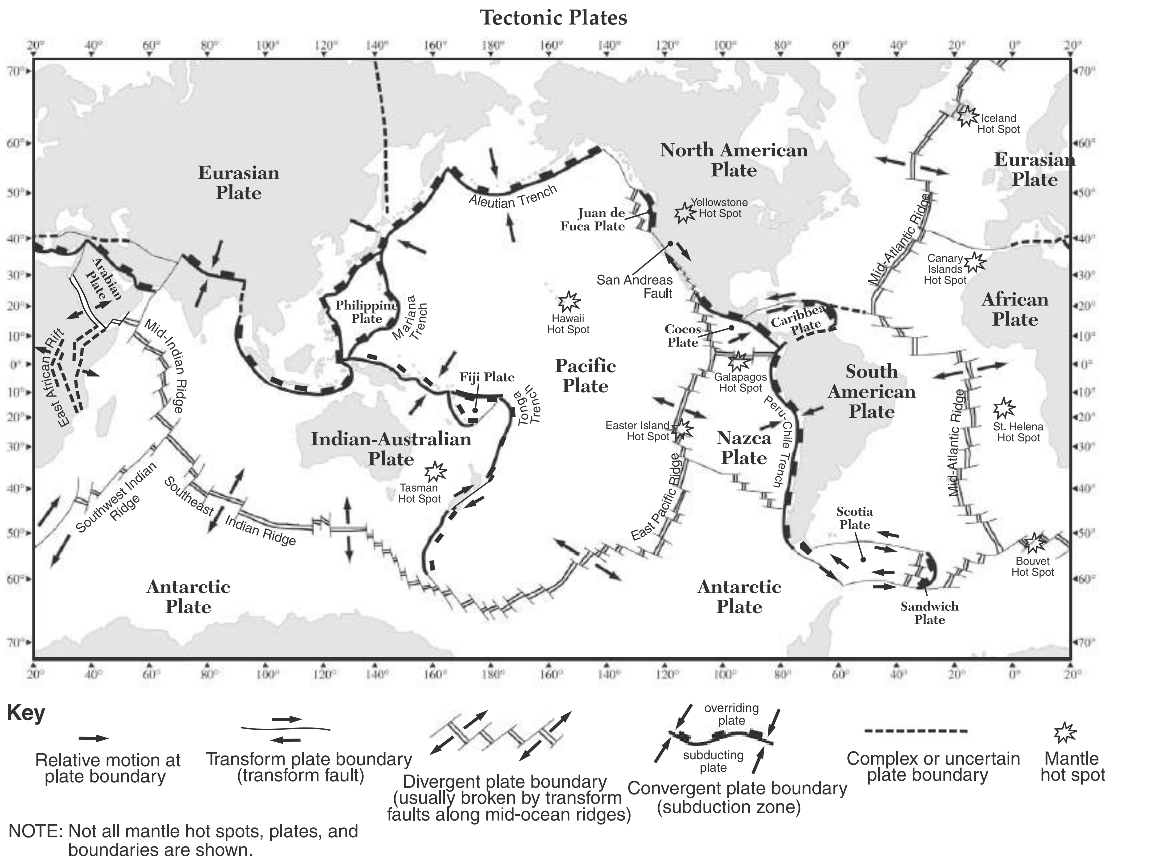


FIGURE 3-2. This map shows information about Earth's major tectonic plates. It can also be used to find latitude and longitude.

STUDENT ACTIVITY 3-2 —A MAP TO YOUR HOME

6: MODELS 2
6: MAGNITUDE AND SCALE 3

Use a sheet of $8\frac{1}{2} \times 11$ inch paper to draw a map that shows the most direct route from school to your home. You may use a computer-drawing program if it is available. Show the landmarks (buildings and natural features) that would be most useful in guiding a person who is unfamiliar with your community. Also include a scale of distance.

What Are Compass Directions?

Directions are a part of your daily life. Many people can give you directions, but Earth itself can also help you determine directions. In

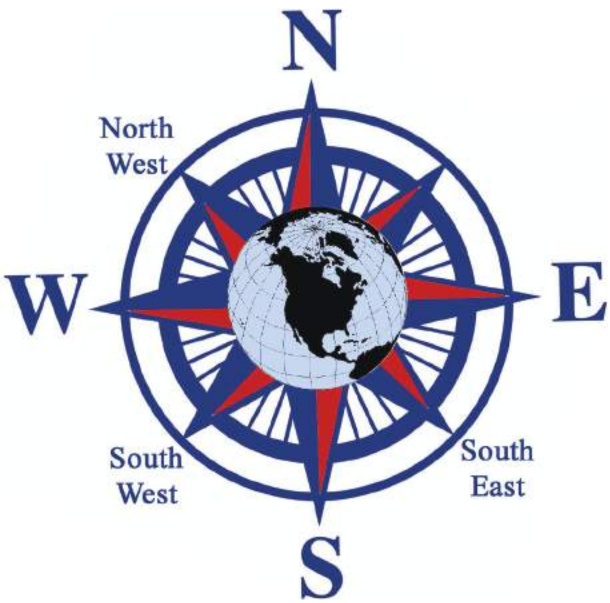


FIGURE 3-3.

general, the sun rises in the east and sets in the west. For a person in New York State, the midday sun is always in the southern part of the sky and shadows generally point north. If you want to travel to a cooler climate, head north. To avoid cold winters, travel south. In addition to the four principal directions shown on Figure 3-3, there are intermediate directions such as northeast and southwest. Compass direction can also be specified as an angle known as azimuth. **Azimuth** starts at 0°, which is directly north, and proceeds to east (90°), south (180°), west, (270°), and back to north at 360°.

Most maps are printed with north toward the top of the map. This convention helps align the map with the area it represents. However, there may be reasons to align the map in a different way. Therefore, this rule is not always followed.

Earth as a Magnet

You may have used a magnet to pick up metallic objects, such as paper clips. In ancient times, people noticed that a large piece of the iron ore magnetite, sometimes called lodestone, attracts other iron objects. They called this attractive force magnetism. Furthermore, they noticed that a piece of lodestone floating on water tends to align itself in a consistent geographic direction. (Because this kind of rock is heavier than water, it must be placed in a flotation device.) The earliest magnetic compasses were made in this way long before anyone understood magnetism.

STUDENT ACTIVITY 3-3 —MAKING A WATER COMPASS

1: ENGINEERING DESIGN 1
6: MODELS 2

You can construct a water compass by floating a strong bar magnet in a large container of water. Place the bar magnet in a shallow bowl that does not touch the sides of the large container. Be sure to try this activity well away from any magnetic metals or electric motors. Does your magnet tend to align consistently toward magnetic north as does the example in Figure 3-4?

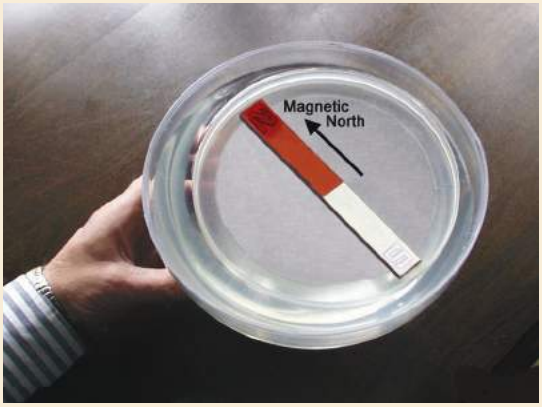


FIGURE 3-4. A simple compass can be made with a container of water and a bar magnet. Suspend the magnet on a floating object such as a lid.

A compass needle points north because Earth acts as a giant magnet. You may know that opposite magnetic poles attract each other. Then why does the north pole of a magnet tend to point toward Earth's North Pole? The reason is simple. The pole of a magnet that points north is labeled N because it is the "north-seeking pole." That end actually has a magnetic field like Earth's South Pole.

Why does Earth have a magnetic field? That question took a long time to answer. Scientists now think that Earth's outer core is made of molten liquid that circulates due to heat flow. The planet is very dense, so molten iron is a strong possibility for the major substance in the outer core. Scientists think it is this circulation guided in part by Earth's rotation (spin) that keeps the currents running generally north and south.

There are two other important things to know about Earth's magnetic field. First, the field seems to reverse itself about every 30,000 years. This is more evidence to support the outer core circulation theory. Second, the magnetic poles do not align exactly with the geographic (spin) poles. In fact, the magnetic poles wander through the Arctic and Antarctic regions.

Geographic north is determined by Earth's spin axis. There are several ways to find it. Magnetic north, which is a result of Earth's magnetic field, can be determined with a compass. Magnetic declination is the angle between geographic north and magnetic north. This angle can be measured with a protractor.

WHAT ARE FIELDS?

1: MATHEMATICAL ANALYSIS 3
6: SYSTEMS THINKING 1
6: MODELS 2
6: MAGNITUDE AND SCALE 3

A **field** is a region of space in which the same quantity can be measured everywhere. Let us look at a simple example. Have you ever noticed that when dinner is being prepared, the smell of the food drifts through the house? As you walk into the kitchen area, the smell increases. In this example, the house is the field, and smell is the field quantity that is observed.

In the previous section, you read about Earth's magnetic field. All around Earth, scientists can measure the direction and strength of Earth's magnetism in its magnetic field. Gravity is another field quantity that changes over Earth's surface. Sensitive instruments can measure very small changes in Earth's gravity from place to place. Temperature is also a field quantity. Wherever you go, you can measure or even feel the temperature and notice how it changes. Scientists often make maps to show how field quantities change over a geographic area.

Understanding Isolines

An **isoline** is a line on a field map that connects places having the same field quantity value. A weather map of the United States often shows the daily high temperatures. On some maps, there are **isotherms**, lines connecting places that have the same high temperature. These isolines generally cross the country from west to east. Other weather maps use isolines to show atmospheric pressure or the amount of precipitation.

STUDENT ACTIVITY 3-4 —CHARACTERISTICS OF ISOLINES

1: MATHEMATICAL ANALYSIS 3
6: MODELS 2
6: MAGNITUDE AND SCALE 3

Based on Figure 3-5, or a similar national isoline map, answer the following questions about isolines:

1. Do isolines ever touch or cross each other?
2. Do isolines usually have sharp angles or gentle curves? (Pick one.)
3. What does each point on an isoline have in common with all other points on the same line?
4. Do isolines ever end, except at the edge of the data area? (Note that the isolines in Figure 3-5 end at the edge of the continent.)
5. On a single map, is the change in value from one isoline to the next always the same?
6. Do isolines tend to run parallel as they extend around the map?
7. Does every isoline have one side where the values are higher and another side where the values are lower?

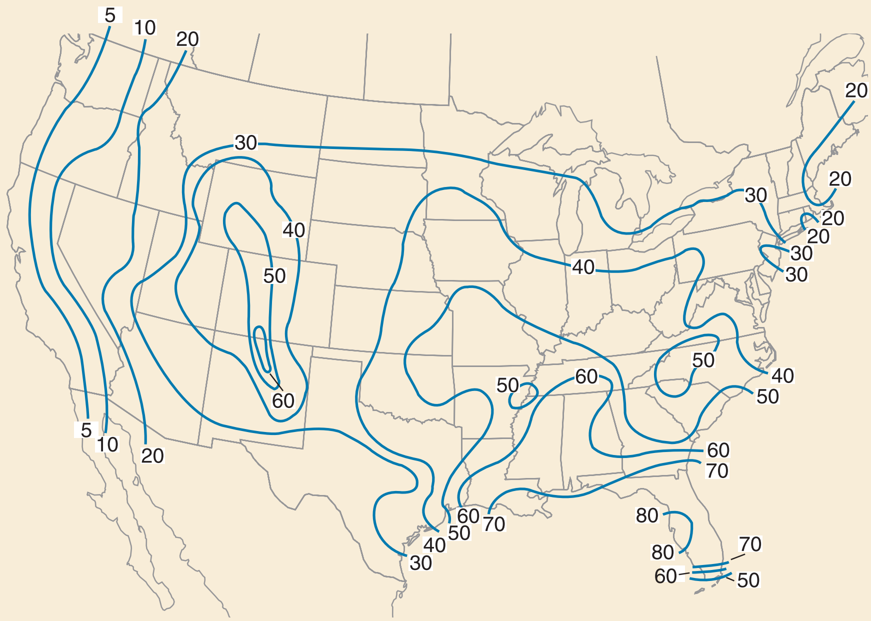


FIGURE 3-5. This isoline map shows that parts of Florida and the Gulf Coast have the largest number of thunderstorms.

To view animations that show you how to draw and check isolines, visit the following Web site: ***https://courseware.e-education.psu.edu/public/meteo/meteo101demo/Examples/Section2p03.html*** (Read through the text, and then click on the first green link within the text.)

Every isoline map is drawn at a specific interval. Many newspaper weather maps show temperatures at an interval of 10°F. That means when you move from one isotherm to the next isotherm, there is a change of 10°F. A smaller interval, such as 1°F, would make the map cluttered and hard to read. A larger interval would result in a map that does not give enough information. For every isoline map, an appropriate interval must be chosen to help viewers understand the data.

STUDENT ACTIVITY 3-5 —A TEMPERATURE FIELD

6: MODELS 2
6: MAGNITUDE AND SCALE 3

In science, you sometimes collect and analyze your own data. Gathering accurate field data can be difficult, but it is an excellent way to learn about science. For example, each student in the class can use a thermometer to read and record the air temperature at the same time throughout the classroom. Individuals or lab groups can write these numbers at the appropriate location on a floor plan of the classroom and then use the numbers to draw an isotherm map of the science room. Take simultaneous temperature readings at different levels in the classroom (floor, desk level, and 1 meter above the desks). This can be a very challenging activity, but it is a good way to learn about isolines.

WHAT IS A TOPOGRAPHIC MAP?

1: MATHEMATICAL ANALYSIS 1
4: 2.1q
6: MODELS 2
6: MAGNITUDE AND SCALE 3
7: STRATEGIES 2

A **topographic map** is a special type of field map on which the isolines are called contour lines. These maps show a three-dimensional surface on a two-dimensional page. **Contour lines** connect places that have the same elevation (height above or below sea level). Each contour line is separated from the next by the same change in elevation, called the contour interval. A common contour interval on The United States Geological Survey (USGS) topographic maps is 10 ft, which is about 3 m. As you move your finger on a map up or down a slope, each time it crosses a contour line, the elevation has changed by the amount equal to the map's contour interval. Where the contour lines are close together, the slope of the land is steep. Where there are wide spaces between contour lines, the land is more flat.

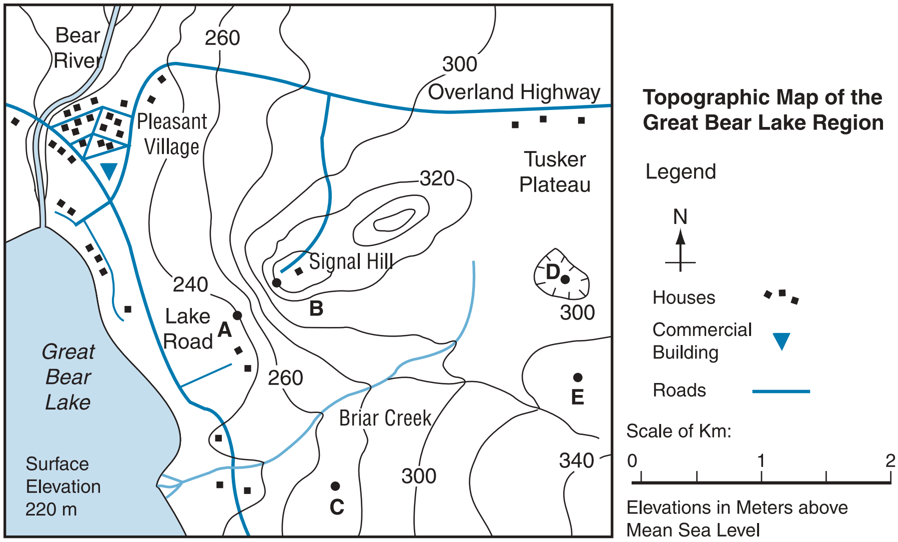


FIGURE 3-6. A topographic (contour) map of Great Bear Lake.

It may help you visualize the area represented on a topographic map if you think of each contour level as a layer on a cake. Multiple levels stack to make hills. Figure 3-6 is a topographic map of an imaginary location. Figure 3-7 is photograph of a step model constructed layer-cake style from that map. (See Activity 3-7.) A real landscape would have a more rounded shape.

Hikers and sportsmen often use topographic maps because they show the shape of the land. These maps also show where roads,

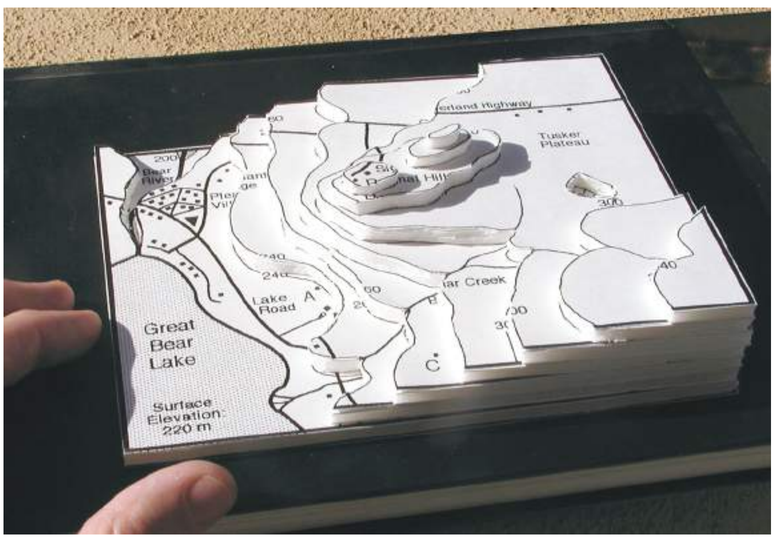


FIGURE 3-7. You can make a three-dimensional model of any topographic map or land surface using sheets of foam available at art supply stores or from supermarket food trays.

hills, lakes, and streams are, as well as a wide variety of other landmarks. Topographic maps can be used to plan the best route from one location to another. The United States Geological Survey (USGS) publishes topographic maps at various scales. Camping, sporting goods, and hardware stores often carry the local topographic maps or they can be ordered from the USGS. Visit the following Web sites to view local maps and satellite images by zip code: *http://earth.google.com*

STUDENT ACTIVITY 3-6 —MAKING A TOPOGRAPHIC MODEL

6: MODELS 2
6: MAGNITUDE AND SCALE 3

From a simple topographic contour map selected or approved by your teacher, construct a step model of the map area similar to the model in Figure 3-7. You may select your school grounds, a portion of your local USGS topographic map, or the topographic map or image of a nearby landform from which to make your model. The layers can be made of corrugated cardboard, foam board from an art supply store, or the bottoms of clean foam meat/food trays. Visit the following Web site to practice making 3-D topographic models of New York's gorgeous gorges: *http://fli.hws.edu/myplace/Directions%20to%20Make%20Modelhtm.htm#Objective*

Common Features on Topographic Maps

Topographic maps use contour lines to show the **topography**,or shape of the land. In their steeper sections, small streams often cut gullies by erosion. These distinctive features show up as a sharp bend in the contour lines, which creates a V-shape that points upstream. Figure 3-8 is a portion of the San Isabel National Forest topographic map.

Look back at Figure 3-6 on page 65. You can see that Briar Creek flows down to the west because the contour lines make V's that point upstream to the east.

Reading the elevation of a point on a contour line is easy because it is the elevation of that contour line. If you want to know the elevation of a point between contour lines, you estimate the elevation with reference to nearby contour lines. For example, point *C* on Figure 3-6 is about halfway between the 260- and

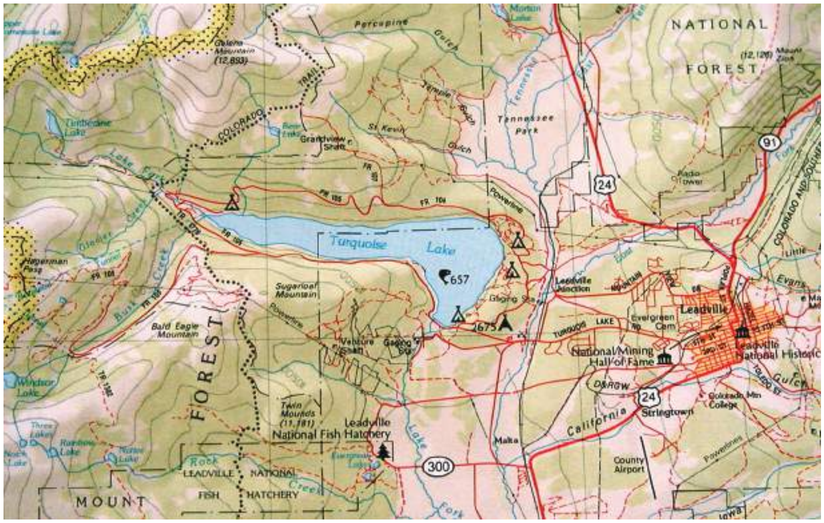


FIGURE 3-8. A topographic map of Turquoise Lake.

280-m lines. You can therefore estimate the elevation of point *C* to be 270 m.

When contour lines form an enclosed shape that is something like an irregular circle, the center of the enclosed area is usually a hill. The top of the hill is within the smallest circle. By reading the elevation of the highest contour level, you can estimate the height of the hill. A useful convention is to add half of the contour interval to the elevation of the highest contour. On Figure 3-6 the highest contour line around the house on Signal Hill is 340 m. The contour interval on this map is 20 m. So your best estimate for the elevation of the house is 350 m.

Sometimes, contour lines enclose a dip in the land surface, or a closed depression. To distinguish depressions from hills, mapmakers use contour lines with small bars that point down toward the center of the depression. Point D on Figure 3-6 is within the 300-m contour, so its elevation at the bottom of the depression is about 290 m. The first depression contour line always has the same elevation as the lower of the two adjacent contour lines.

Most maps have a legend, or key, printed outside the map area. This explains the meanings of various symbols shown on the map. The more complex the map, the greater the variety of symbols that must be explained in the legend.

As with other physical models, every topographic map has a map scale. The scale can be expressed as a ratio, such as 1:24,000.

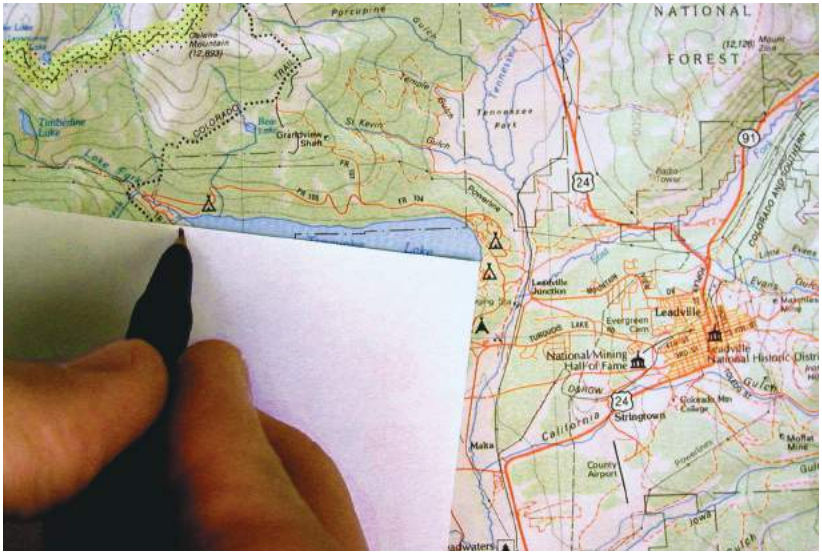


FIGURE 3-9. To determine the length of Turquoise Lake, line up the edge of the paper with the lake and clearly mark both ends on the paper.

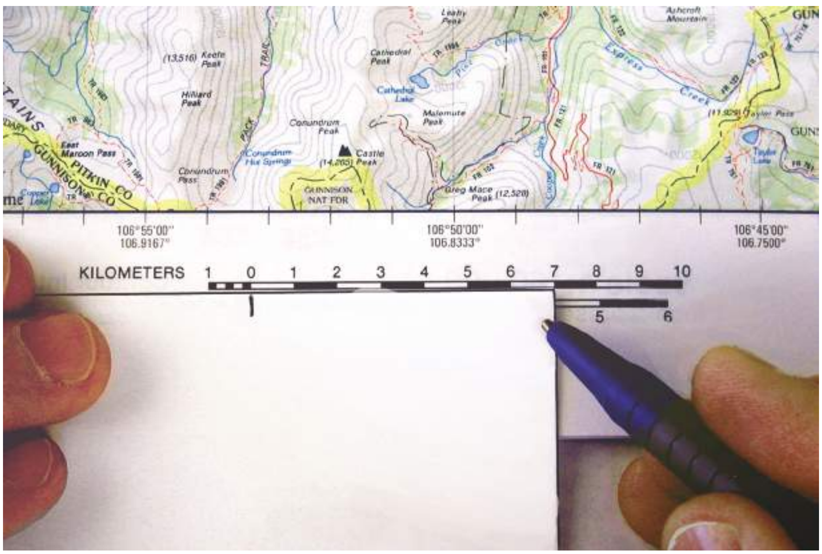


FIGURE 3-10. Holding the marked paper along the map's scale of kilometers shows that Turquoise Lake is about 7 km long.

The scale can be a translation of distances, such as 1 inch represents 2000 ft, or 1 centimeter represents 1 km. But, you will probably find the most useful scale is a line located outside the map area that is marked with divisions of distance. Figures 3-9 and 3-10 illustrate three steps in determining the distance between two map locations or the size of a geographic feature.

Step 1. To determine the length of Turquoise Lake, you will need to locate it on a topographic map.

Step 2. Hold the edge of a blank sheet of paper along the longest part of Turquoise Lake. Place the corner of the paper at one end of the lake. Make a mark along the edge of the paper where it touches the other end of the lake.

Step 3. Move the marked paper to the distance scale on the map. This indicates that Turquoise Lake is about 7 km long.

Figure 3-11 is a topographic map of a location in New York State. Bigsby Pond is located on the Minerva, New York, $7\frac{1}{2}$-minute USGS topographic map. You should be able to read the following

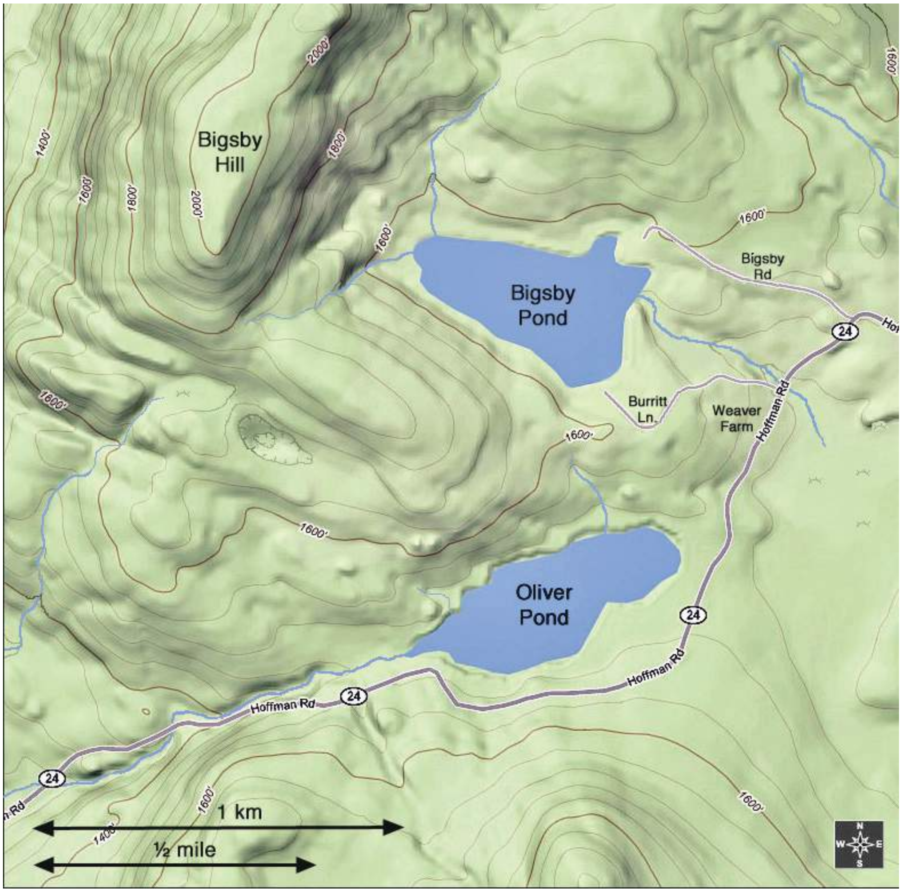


FIGURE 3-11.
Bigsby Pond map

information on this map. (1) The compass figure at the bottom right tells you that north is at the top of this map. (2) The map scales show that 1 km is a little longer than $\frac{1}{2}$ mi. (3) The scale of miles shows that both ponds are about $\frac{1}{2}$ mi long. (4) The flattest part of the map is on the eastern side, which is a swamp or bog. (5) The steepest slopes are along the eastern and western sides of Bigsby Hill and the smaller hill north of Oliver Pond. This is where the contour lines are closest together. (6) There is a closed depression (a hollow bowl shape) just to the left of the center of the map area. Note the special marks on these interior contour lines. (7) Three roads are shown on this map, Hoffman Road and two roads that lead to Bigsby Pond. (8) The contour interval is 40 feet. (9) The highest points are within small circles such as the top of Bigsby Hill and several nearby lower hills. Bigsby Hill is more than 2040 ft above sea level, but less than 2080 ft above sea level. (10) The lowest point is along the Oliver Pond outlet near the southwest corner of the map, less than 1280 ft above sea level.

This is a combination of a topographic contour map and a shaded relief map. The shading makes hills and valleys easier to see. Sometimes you can tell the direction in which a stream flows by noting where the stream flows down off the map area. But none of the three streams that meet Bigsby Pond flow to the edge of the map. However, by seeing that the contour lines make V's pointing upstream, it is clear that the stream that goes under Hoffman Road flows out of the pond to a lower elevation.

STUDENT ACTIVITY 3-7 —READING YOUR LOCAL TOPOGRAPHIC MAP

2: INFORMATION SYSTEMS 1
6: SYSTEMS THINKING 1
6: MODELS 2
6: MAGNITUDE AND SCALE 3

Download free PDF images of USGS high-resolution topographic maps. In the MAPS section of the URL below, click on "Download digital scans of topo maps," then click on "Map locator and Downloader." ***http://www.usgs.gov/pubprod***

Look at a copy of the United States Geological Survey topographic map that includes your school, town, or city. Do not make any marks on this map unless your teacher tells you to do so. Notice the locations of familiar features such as roads, buildings, and streams. Notice how hills and valleys are represented by contour lines. Find a symbol for your house or a friend's home, or identify its location.

1. What are the latitude and longitude coordinates of the bottom right corner of this map?
2. When was this map published? Has it been revised?
3. How many centimeters on the map represent 1 km of true distance?
4. What is the local magnetic declination?
5. What is the contour interval of this map?
6. Locate a place where contour lines become V-shaped as they cross a stream. Do the V's point upstream or downstream? In your notebook, make a sketch of the stream.
7. What and where are the highest and lowest elevations on this map?
8. State one or more things you learned about your area by looking at the map.
9. List several ways a person might find this map useful.

Gradient

If a hill changes quickly in elevation, it has a steep gradient. In fact, slope is often used as a synonym for gradient. At every location, a field value has a measurable gradient. If the field value is not changing in a particular area, we say that the gradient is zero. We can therefore define **gradient** as the change in field value per unit distance. (The field value on a topographic map is land elevation.)

You can tell where gradients are the steepest by looking at a field map. The places where the isolines are closest are the places with the steepest gradient. On Figure 3-6, the gradient is steep between points *A* and *B* where the contour lines run close together.

The following formula from the *Earth Science Reference Tables* can be used to calculate gradient:

$$\text{Gradient} = \frac{\text{change in field value}}{\text{distance}}$$

SAMPLE PROBLEMS

Problem 1 The temperature at the center of a town is 20°C, but 10 km west at the river it is only 15°C. What is the temperature gradient between these two locations?

Solution

$$\text{Gradient} = \frac{\text{change in field value}}{\text{distance}}$$
$$= \frac{20°\text{C} - 15°\text{C}}{10\text{ km}}$$
$$= \frac{5°\text{C}}{10\text{ km}}$$
$$= 0.5°\text{C/km}$$

Problem 2 Calculate the gradient from point *C* to point *E* on Figure 3-6

Solution Point *C*, half way between the 260- and 280-m contour lines, must be at about 270 m. Similarly, point *E* is at about 330 m. The distance between them can be determined using the scale of kilometers in the map legend as shown in Figures 3-9 and 3-10. That distance is 2 km.

$$\text{Gradient} = \frac{\text{change in field value}}{\text{distance}}$$
$$= \frac{330\text{ m} - 270\text{ m}}{2\text{ km}}$$
$$= \frac{60\text{ m}}{2\text{ km}}$$
$$= 30\text{ m/km}$$

Note the following features of both solutions.

- Each solution is started by writing the appropriate formula.
- Values including units of measure are substituted into the formula.
- Each step to the solution is clearly shown.
- The units of measure are part of the solution.

Practice Problem 1

The temperature at the floor of a classroom is 21°C. At the ceiling, 3 m above the floor, the temperature is 27°C. What is the temperature gradient between the floor and the ceiling?

Practice Problem 2

The source of a stream is at an elevation of 1000 m. The stream enters a lake at 875 m, 15 km from its source. What is the gradient of the stream?

Making Topographic Profiles

A **profile** is a cross section, or a cutaway view. If you stand between a bright light and a wall, your body will cast a shadow on the wall. When you stand with your shoulder perpendicular to the wall, your shadow will include a profile of your face with features such as your chin and nose indicated clearly. As illustrated in Figure 3-12, a topographic profile shows the elevation of the land surface along a particular route. Along the profile route, the hills show as high places and the valleys as low places. Visit the following Web site to view QuickTime VR movies about topography and topographic profiles: *http://www.scieds.com/saguaro/topo_movies.html*

A topographic map can be used to draw a profile along any straight-line route. You will need a sheet of paper that is marked with parallel lines, such as writing paper, and a blank strip of paper

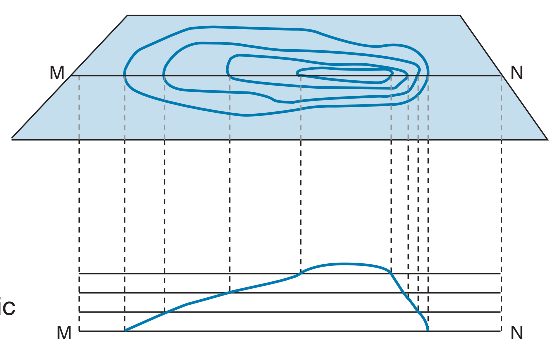


FIGURE 3-12. A profile constructed from a topographic contour map.

FIGURE 3-13. The first step in making a profile from a contour map is marking the blank strip where it crosses each contour line.

FIGURE 3-14. After labeling each mark with the elevation of the contour line it represents, the next step is to draw a dot at the correct elevation on the lined paper.

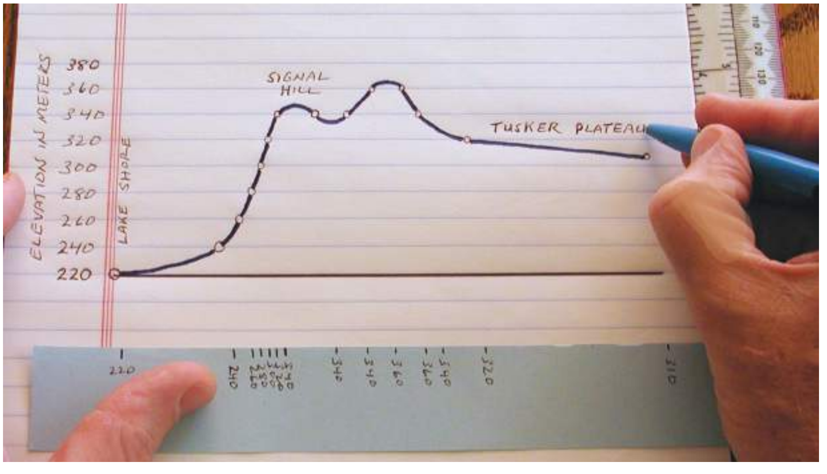


FIGURE 3-15. Complete the profile by connecting the dots with a smooth line.

a little longer than the profile route on the map. By following the steps below, you can draw a profile from a contour map.

Step 1. Place an edge of the blank strip along the profile route. Each time the edge of the blank strip crosses a contour line, make a mark at that point along the edge of the strip, as shown in Figure 3-13.
Step 2. Label each mark on the strip with the elevation of the contour line crossed. Take care with this step, because some marks will have the same elevation as others that cross the same contour line or cross another line at the same elevation.
Step 3. Along the left side of the lined paper, label the horizontal lines with the elevation of the contour lines crossed by the blank strip, as shown in Figure 3-14.
Step 4. Lay the marked blank strip along the lowest labeled horizontal line on the lined paper. Directly above the marks on the strip, make dots on the lined paper at the height indicated by the marks on the strip.
Step 5. As shown in Figure 3-15, connect the dots on the lined paper with a gently curved line. Valleys and hilltops should be rounded above the highest dots.
Step 6. Labeling features from the map line can help you visualize the curved profile. Look at Figure 3-15 again.

A similar procedure can be used to make a profile from any isoline map, such as a weather map that shows local temperatures. Some people can look at a field map and visualize its profile without following this procedure. As with making mathematical estimations, visualizing a profile is a skill that can be helpful in making accurate profiles and reading any isoline map.

STUDENT ACTIVITY 3-8 —A PROFILE ON A LOCAL TOPOGRAPHIC MAP

1: MATHEMATICAL ANALYSIS 1
6: MODELS 2
6: MAGNITUDE AND SCALE 3

Use the steps above to construct a profile from your local USGS contour map along a line selected by your teacher.

Using Isoline Maps for Practical Purposes

People have different uses for topographic maps. Developers and construction companies use maps to plan roads and the placement of buildings. Search and rescue teams use them when they look for lost or injured people and to plan rescue efforts. You, on the other hand, might want to find the best way to get to a fishing spot. Whether you will walk or travel by car will be an important consideration. Do you mind going over hills or crossing streams? How long will it take you to get to your destination? Considerations such as these can be important, depending on how and when you will travel.

STUDENT ACTIVITY 3-9 —INTERPRETING ISOLINE MAPS

6: MODELS 2
6: MAGNITUDE AND SCALE 3

The map in Figure 3-16 shows two field quantities. The thinner grey isolines show surface elevations, and the thicker red isolines show the concentrations of a toxic substance in the groundwater.

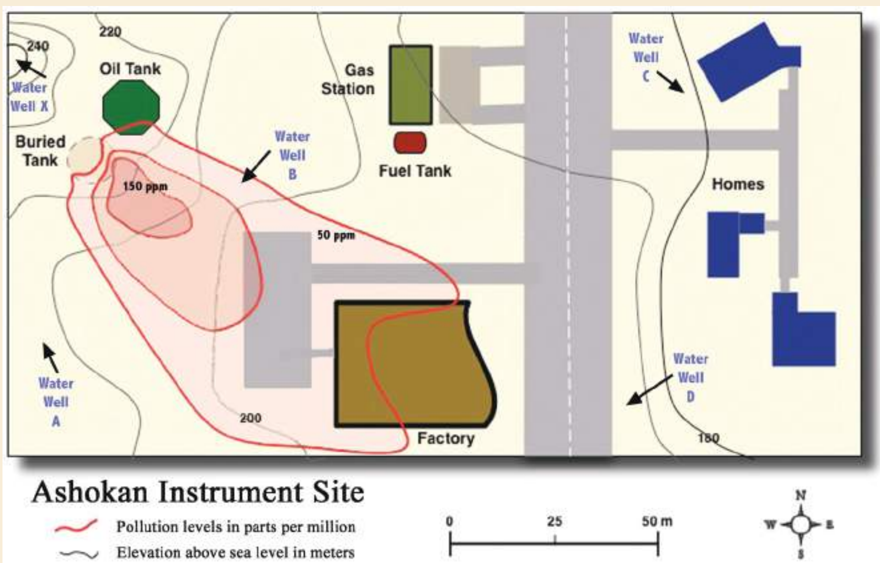


FIGURE 3-16.

1. What is the contour interval and what is the pollution interval on this map?
2. What may have caused the water pollution?

3. Which way is the contamination moving?
4. How can you tell? (There are at least two ways you can tell.)
5. Why is contamination of water well *X* unlikely?
6. In what order would you expect the remaining water wells to be contaminated?
7. If the leak occurred one month ago, at what rate has the edge of contamination (50 ppm) advanced?

STUDENT ACTIVITY 3-10 —RESCUE AND EVACUATION PLANNING

7: STRATEGIES 2

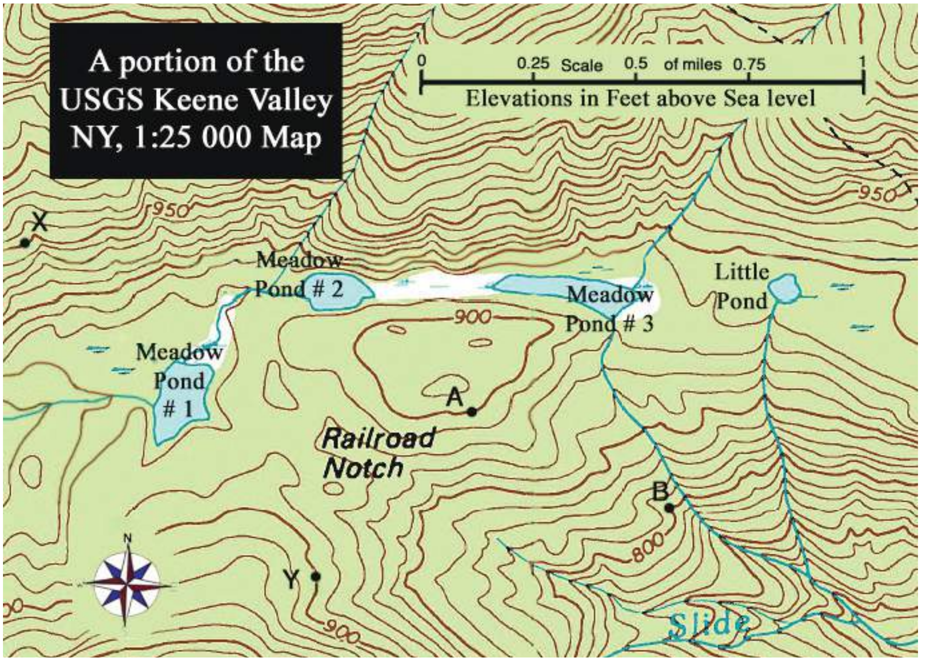
Your teacher will indicate a location on a local topographic map where a person has been injured in a fall. Figure 3-17 shows an actual rescue. Devise a detailed plan to evacuate the injured person to an ambulance waiting along a main road. In your planning, consider the cost of the evacuation and the best route to take in transporting the victim. Your plan should be written in enough detail so that the evacuation team will know how to proceed and what obstacles to avoid. Compare the plans of different groups.

FIGURE 3-17. An injured hiker in a remote area being evacuated by helicopter.

CHAPTER REVIEW QUESTIONS

Part A

Base your answers to questions 1 through 4 on the topographic map below, which shows a location in the Adirondack mountains of New York State.



1. In what direction do the streams flowing out of Meadow Pond #1 and Meadow Pond #3 flow?

   (1) The outlet to Meadow Pond #1 flows west and the outlet to Meadow Pond #3 flows north.
   (2) The outlet to Meadow Pond #1 flows west and the outlet to Meadow Pond #3 flows south.
   (3) The outlet to Meadow Pond #1 flows east and the outlet to Meadow Pond #3 flows north.
   (4) The outlet to Meadow Pond #1 flows east and the outlet to Meadow Pond #3 flows south.

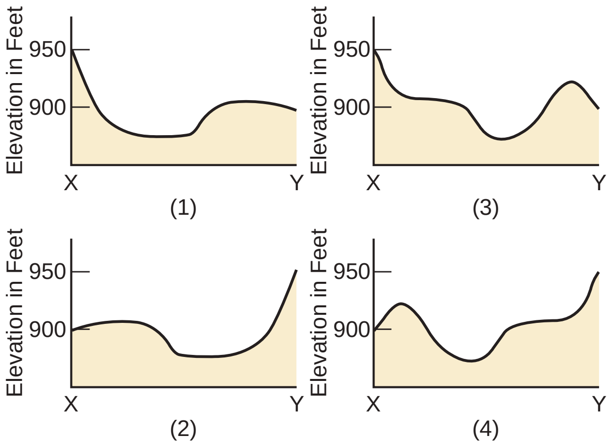
2. What is the surface elevation of Little Pond in feet?

   (1) 850 (2) 885 (3) 895 (4) 950

3. If the streams flowing out of Meadow Pond #1 and Meadow Pond #3 carry the same volume of water, which stream probably flows faster?

(1) The outlet to Meadow Pond #1 probably flows faster.
(2) The outlet to Meadow Pond #3 probably flows faster.
(3) There is no way to decide if one stream flows faster than the other.
(4) Neither Meadow Pond #1 nor Meadow Pond #3 has any stream flowing out if it.

4. Which profile below best represents the land surface from point *X* to point *Y*?



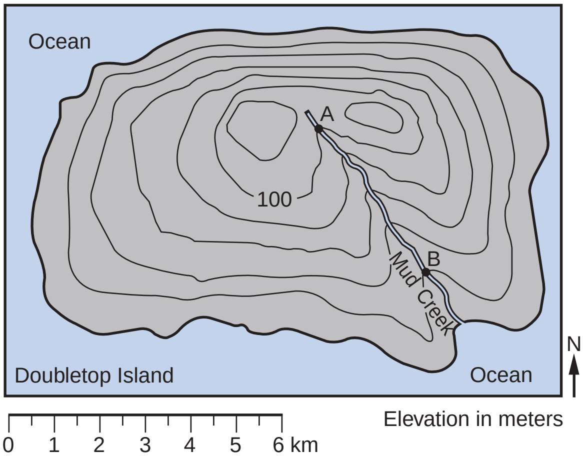
5. What is the average temperature gradient between two places in a classroom that are 10 m apart if one place has a temperature of 25°C and the other has a temperature of 23°C?

(1) 0.2°C/m
(2) 0.2 m/°C
(3) 5°C/m
(4) 5 m/°C

6. A map has a scale of 1 cm:12 km. On this map, what is the distance between two locations that are actually 30 km apart?

(1) 2.5 cm
(2) 12 cm
(3) 18 cm
(4) 30 cm

Base your answers to questions 7 through 9 on the topographic map below, which shows a small island in an ocean. Points *A* and *B* represent locations on the island.



7. In what general direction does Mud Creek flow?

(1) northeast
(2) northwest
(3) southeast
(4) southwest

8. What is the greatest elevation on Doubletop Island?

(1) 100 m
(2) 120 m
(3) 130 m
(4) 150 m

9. What is the average gradient along Mud Creek from point *A* to point *B*?

(1) 10 m/km
(2) 20 m/km
(3) 40 m/km
(4) 80 m/km

10. Which quantity is best shown by an isoline map?

(1) average annual rainfall at locations throughout North America
(2) the distance from London, England, to Paris, France

(3) the current population of Binghamton, New York
(4) the position of various stars and constellations in the night sky

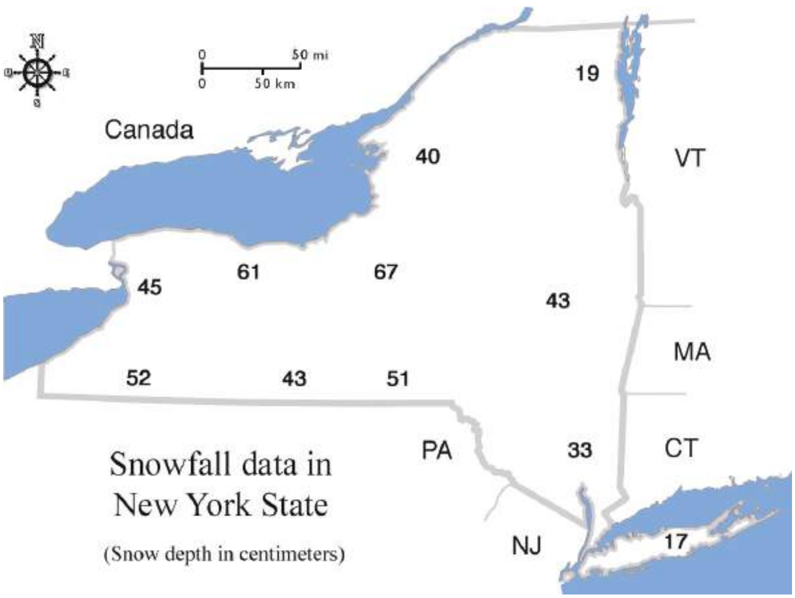
Part C

Base your answers to questions 11 and 12 on the Keene Valley—Meadow Ponds map from question 1 on page 78.

11. Calculate the straight-line topographic gradient between points A and B. Label your answer with the correct units.

12. How do you know that the slope is the least in the land near the four ponds?

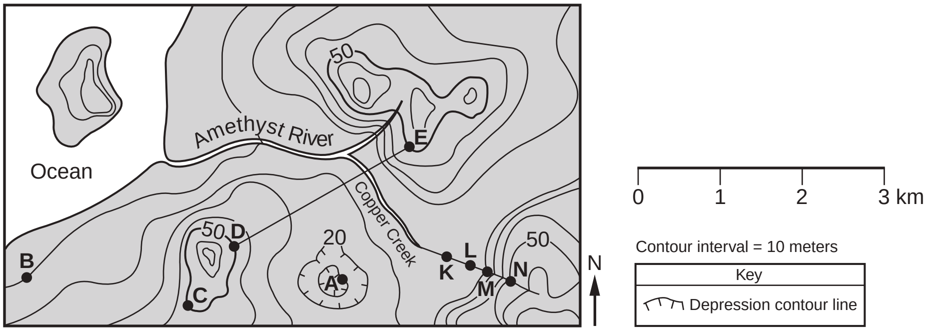
Base your answers to questions 13 and 14 on the map below, which shows students' measurements of snow depth after a major winter storm.



13. Use a copy of this map to draw isolines at an interval of 20 inches of snowfall. (Do not write in your book.)

14. What major city in New York State had the most snow at the end of this snowstorm?

Base your answers to questions 15 through 17 on the map below. Elevations are in meters.

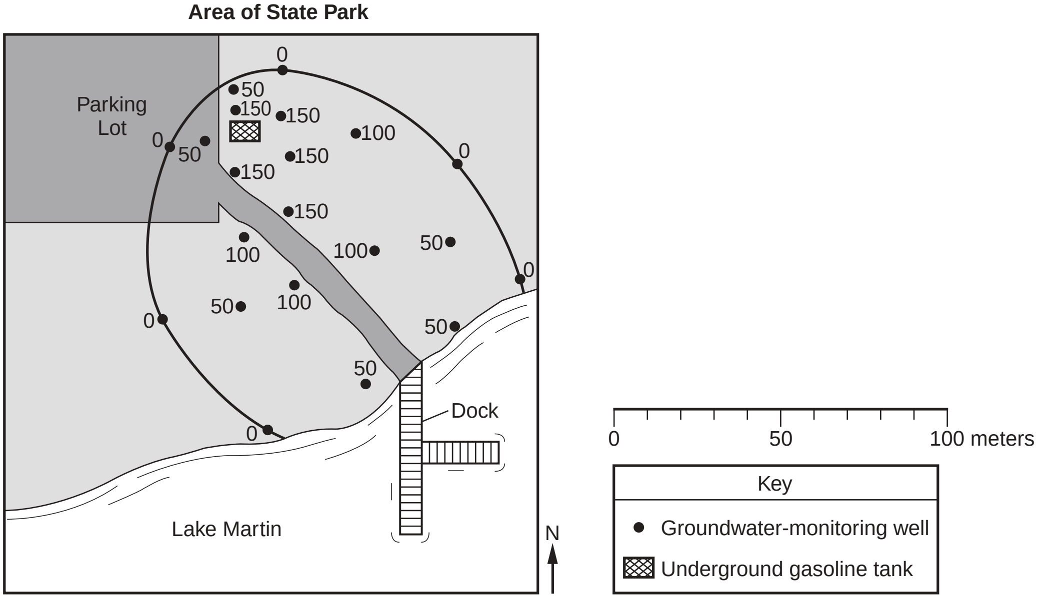


15. What is the elevation of location A?

16. Calculate the gradient between points B and C and include the correct units.

17. Use a separate piece of paper to draw a smooth, curved profile of the land surface from point D to point E.

Base your answers to questions 18 through 20 on the map below, which shows the location of an underground gasoline tank in a state park. The concentration of the gasoline shown by this field map is in parts per million (ppm) at each of the monitoring wells.



18. Use a copy of this field map to draw the 50-ppm, 100-ppm, and 150-ppm isolines. (Do not write in your book.)

19. State the general relationship between the distance from the gasoline tank and the concentration of contaminants in the groundwater.

20. State one action that park officials could take to prevent future groundwater contamination.

UNIT 2

Minerals, Rocks, and Resources

The natural resources we depend on are either grown or mined. The photo above shows an open-pit copper mine in Bagdad, Arizona. On average, Americans use over 100 pounds of mineral resources each day. Our homes and highways are built from Earth materials. Some of our natural resources are changed into metals and plastics. Other resources are used to provide energy for our homes and transportation. Fertilizers, mostly produced from fossil fuels, are critical to growing our food. Many medicines are made from mineral resources. There are even minerals, such as salt, that we eat.

The supplies of our natural resources are decreasing. Most mineral resources are nonrenewable. Each kilogram of natural resources we use reduces the amount left in the environment. The growing economies of the population giants China and India place even greater strain on Earth's limited resources.

The cost of a commodity such as oil is a function of supply and demand. In the 1950s, geoscientist M. King Hubbert proposed that the United States' oil supply would peak about 1970, leading to a need for more imported oil. Now, in the early part of the twenty-first century, many geoscientists think that we have reached a world peak oil production, and that future production will decrease. The slowing pace of new discoveries supports this prediction. When supply decreases while demand increases, the price of the commodity will rise dramatically. How will the decrease in oil production affect our lives? Will we face a global economic crisis? Or will we find new technologies to extract oil or otherwise meet our needs? Perhaps you will play a role in finding solutions to this growing crisis.

CHAPTER

4 Investigating Minerals

WORDS TO KNOW

compound	**element**	**hardness**	**mineral**	**silicate**
cleavage	**fracture**	**luster**	**Mohs scale**	**streak**

This chapter will help you answer the following questions:

1. What are minerals?
2. What are the properties of minerals?
3. What are the most common minerals?

WHAT ARE MINERALS?

4: 3.1a; 4: 3.1b

If you look around the natural environment, you will probably see two kinds of things: living and nonliving. Plants and animals are parts of the living environment. The living environment is sometimes called the biosphere. The objects studied in the Earth sciences are usually nonliving things. Much of the nonliving part of the natural environment is made up of rock and soil. Just as a house is made of a variety of building materials (for example, wood, nails, concrete, and brick) so are soil and rock made primarily of minerals.

Some rocks such as granite are composed of crystals of different colored substances. (See Figure 4-1 on page 86.) The differences in the properties of the crystals identify them as different minerals.

FIGURE 4-1. Most rocks are made of a number of minerals. In granite, these five minerals are often visible.

What is a mineral? Defining minerals as the substances of which rocks are made could be acceptable in some situations, but as you will read below, there are a few exceptions to this idea. A more exact way is needed to define what a mineral is and what it is not.

Geologists have identified thousands of minerals. In fact, new minerals are discovered and named all the time. Most of the newly discovered minerals are rare and have no practical use. The wide variety of minerals makes it difficult to define exactly what a mineral is. However, geologists do have certain characteristics that identify minerals. Visit the mineral and molecule museum at the following Web site: ***http://www.soils.wisc.edu/virtual_museum/displays.html***

Mineral Characteristics

Although artificial substances, such as steel or plastic, have some characteristics of minerals, they are not minerals. Synthetic diamonds, sapphires and rubies, while chemically the same as the natural gems, are not minerals either because they were not made by a natural process. The first property that characterizes all minerals is that they formed naturally.

In addition, all minerals are inorganic. This means that they were made by physical processes, and are not the result of biological activities. You have probably heard of and perhaps seen coal. Careful study shows that coal forms from layers of plant remains that were buried and compressed by the weight of more layers above. Since coal forms organically, it is not a mineral. The mineral olivine, which is very common deep within Earth, is not as common at the surface.

Gases, such as air, can be compressed. By applying enough pressure, a sample of a gas can be compressed to a very small volume. When the pressure is released, the gas expands nearly without limit. Therefore, gases do not have a definite volume. Gases and liquids take the shape of the container in which they are placed. Liquids and gases are called fluids. In general, a fluid is a substance that can flow and take the shape of its container. Solids have a definite shape and volume. A solid can be taken out of its container and it will keep its shape. You can measure the dimensions of a solid without the object being in a container. This is not true for gases and liquids.

All minerals are solids. Water pumped from the ground is not considered a mineral because it is a liquid. Petroleum, or crude oil, which is taken from deep underground, is a geologic resource but it is not considered a mineral for two reasons: first, petroleum is a liquid; second, like coal, it is of biological origin.

Solids maintain their shape and volume because of their atomic structure. Large crystals, such as those you might see in a museum or a mineral collection, usually have sharp corners and flat faces. Careful examination with powerful electron microscopes shows that these crystal shapes are a result of the way their atoms are arranged. An atom is the smallest part of an element. In crystalline substances, the atoms generally have a regular arrangement in rows and layers. The distance between the atoms in a solid changes very little with changes in temperature and pressure. Furthermore, the atoms in a solid cannot move over or around one another. Sometimes, enough atoms line up to make crystals that are visible, such as those in rock salt or granite. In rare occurrences, crystals can grow to the size seen in museums. The largest natural rock crystals can be several meters long. It is the internal arrangement of atoms that gives crystals their beautiful shapes. Visit the following Web site to learn about and see examples of Mexican selenite gypsum crystals from the "Crystal Cave of the Giants." http://www.crystalinks.com/mexicocrystals.html

STUDENT ACTIVITY 4-1 —SOLIDS, LIQUIDS, AND GASES

1: SCIENTIFIC INQUIRY 1

Prepare a table with three columns. Label one column "Gas," another "Liquid," and the third "Solid." List the substances you see every day under the proper category.

Definition of a Mineral

Minerals have a definite composition, or at least a specific range of composition. Some minerals are single elements. **Elements** are the basic substances that are the building blocks of matter. Gold, as do all other elements, has just one kind of atom. The number of protons in the nucleus, or center of the atom, determines which element it is. There are 92 natural elements. Copper and sulfur are also minerals that are elements. Figure 4-2 is a photograph of copper as

FIGURE 4-2. Native copper is a mineral that is also a chemical element.

it comes from the ground. This is called native copper. The minerals graphite and diamond are different crystal structures of the same element, carbon.

A second group of minerals with a definite composition are the chemical compounds. **Compounds** are substances that are made up of more than one kind of atom (element) combined chemically into larger units called molecules. Each molecule of a specific compound has the same number and kinds of atoms. For example, quartz (silicon dioxide, SiO_2) is a very common mineral compound in which each molecule has one atom of silicon (Si) and two atoms of oxygen (O). Every molecule in a compound is exactly the same. That is why compounds have a fixed composition, as shown in Figure 4-3.

The third group of minerals is made up of mineral families that have a variable composition. For example, the olivine family is a mixture of two chemical compounds. Olivines usually contain one compound of magnesium, silicon, and oxygen and another compound of iron, silicon, and oxygen. These compounds mix to form a single mineral family in which the properties of the mineral (color, hardness, density, etc.) are relatively consistent. These two compounds are not only similar in composition, but they are also similar in appearance and other physical properties.

The feldspars, the most common family of minerals, always contain the elements oxygen, silicon, and aluminum along with varying amounts of potassium, sodium, and calcium. All feldspar samples

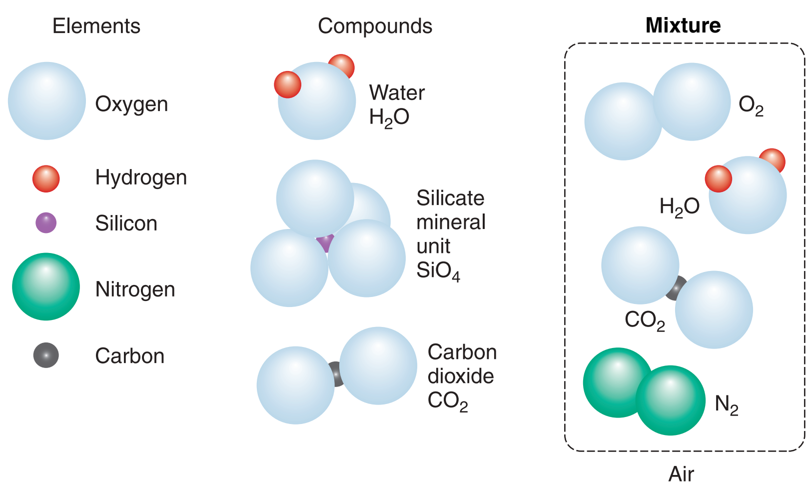


FIGURE 4-3. All matter can be characterized as elements, compounds, or mixtures. Air is a mixture of gases.

have some common properties. Feldspars are light-colored, a little harder than glass, and have a density of about 2.7 g/cm^3. Outside the laboratory, it can be very difficult to tell the different members of the feldspar family apart. For this reason, some references list feldspar as a specific mineral rather than a family of minerals.

Minerals can be defined as natural, inorganic, crystalline solids that have a specific range of composition and consistent physical properties. A surprising result of this definition is that ice is a mineral. Ice is a natural solid substance that forms crystals. Frost and snow are good examples of crystalline ice. As the solid form of water, each molecule of ice (H_2O) is composed of two atoms of hydrogen (H) and one atom of oxygen (O). But, unlike other minerals, ice has a low melting temperature, and therefore, it is not a mineral of which rocks are formed.

HOW CAN WE IDENTIFY MINERALS BY THEIR OBSERVABLE PROPERTIES?

1: SCIENTIFIC INQUIRY 1, 3
4: 3.1a

People identify things by their properties. In the identification of minerals, some properties are more useful than others. This section will concentrate on those properties that are most important in identifying minerals and putting them in groups.

Rocks and minerals change, or weather, when they are exposed to the conditions at Earth's surface. When identifying a mineral, it is important to use a fresh, unweathered sample. A fresh surface best shows the properties of the mineral. Abrasion, caused when rocks crash into each other, crushes the minerals into a powder that is much more difficult to identify than the original sample. Furthermore, as rocks are broken down, minerals are often mixed in the process.

When the minerals are broken or powdered, a greater surface area is exposed to air and water. Chemical reactions that are very slow on a fresh surface occur much more rapidly when the mineral is powdered. These chemical changes break down the mineral, transforming it into a weathering product, just as iron changes to rust. Many minerals react with moisture to form clay minerals. If you try to identify a mineral in a weathered sample, you may see the properties of a weathering product rather than the properties of the original mineral.

There are two types of mineral identification tests: those that leave the sample unchanged and those that change the sample. Observing the color of a mineral, or testing to see if it is attracted by a magnet does not change the mineral. You can get an idea of how a mineral has been broken by looking at surfaces where it broke apart. So far you have not done anything that makes the mineral more difficult to identify by the next person who sees it.

Other tests are destructive; they change the sample. If you actually break the mineral into smaller pieces to observe its properties, you have performed a destructive procedure. Although breaking the mineral may help you identify the mineral sample, this destructive procedure makes it more difficult for the next person observing the sample. Unfortunately, some useful tests are destructive. For example, to observe a mineral reacting with acid, the mineral must take part in a chemical reaction. That reaction degrades a part of the mineral into a weathering product. (You must take appropriate safety measures whenever you perform potentially hazardous tests such as this.)

When working with classroom samples, you should not perform destructive tests unless you are told to by your teacher. Rough handling or destructive procedures can change a beautiful and valuable mineral sample into useless fragments.

Color

Color is perhaps the first thing you notice about a mineral. For some minerals, color is very useful in their identification. For example, the brassy golden color of pyrite is very distinctive. No other common mineral has this color. Sulfur is one of the few yellow minerals. Almandine garnet is often identified by its red color. However, many minerals can be the same color. A black mineral might be magnetite, biotite, amphibole, pyroxene, or a number of other less common minerals.

Many minerals are colorless or white, including pure samples of quartz, halite, gypsum, and calcite. However, the color of these light-colored minerals can be changed by impurities. Impurities are small amounts of other substances that occur in the mineral. Smoky quartz is gray to black. Rose quartz is pink. Other impurities can make quartz orange, purple, or green. Agate is a banded, or striped, form of quartz in which white layers alternate with

FIGURE 4-4. Quartz is an extremely common mineral. Citrine, amethyst, rose quartz, and smoky quartz are among the colored varieties of quartz. (Note the penny for scale.)

brown or other colors. As with many other light-colored minerals, identifying quartz by its color alone can be unreliable. Dark-colored minerals are less likely to show variations in color from sample to sample because impurities usually do not cause them to change color. (See Figure 4-4.)

Streak

A different way of looking at color is **streak**, the color of the powdered form of a mineral. Figure 4-5 shows the method used to test for streak. It involves rubbing a corner of a mineral sample across an unglazed, white porcelain tile, called a streak plate. (A glaze is the glassy covering on plates, cups, and other porcelain kitchenware.) An unglazed surface is used because mineral particles do

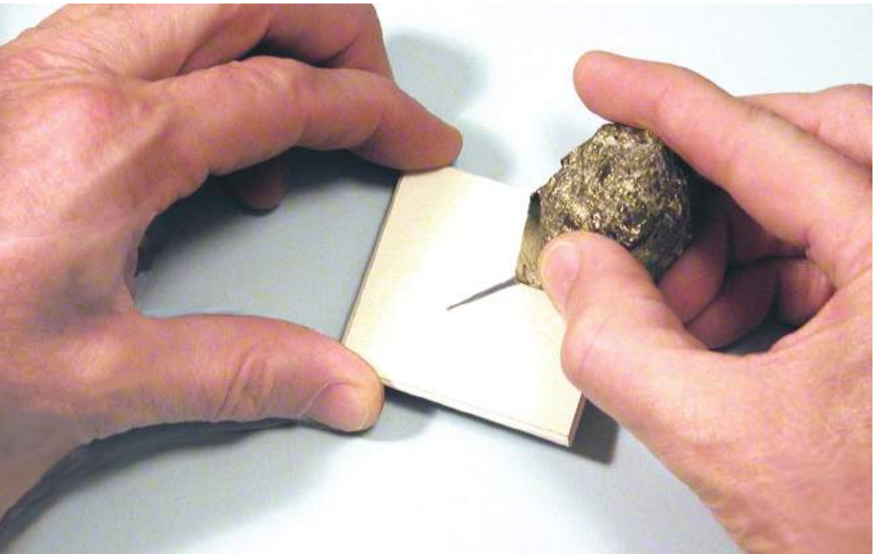


FIGURE 4-5. The streak test reveals the color of the powder of a mineral. For many metallic minerals, the streak color is different from the color of the sample.

not rub off on a surface that is smooth. The purpose of the streak test is to identify the color of the powdered form of the mineral.

For some minerals, the color of the streak is very different from the color of a fresh surface. For example, galena, a very dense ore of lead, has a shiny gray, bright metallic surface. When galena is drawn across a streak plate, the powder that is left behind is dark gray to black. Samples of hematite, an ore of iron, can vary in color, depending upon how and where they formed. Sometimes hematite is red or brown and sometimes it is dark metallic silver. However, the streak color of hematite is always reddish-brown. Pyrite, or fool's gold, is a metallic, brassy, yellow mineral that has a green to black streak.

The streak test is most useful with minerals that have a metallic luster. These are the minerals most likely to show one color on the surface of the sample and a different color streak. Most nonmetallic minerals leave a streak that is the same color as the sample itself. A few minerals are too hard for the streak test. Samples of topaz, corundum, and diamond will scratch the streak plate rather than leaving behind a powder. (Obviously, this would damage the streak plate.)

Testing for streak is a destructive procedure. Each time you rub a mineral sample on a streak plate a little bit of the sample is lost and some of the powder remains on the mineral sample. If the streak test is done carefully, the damage to the sample is small and acceptable.

Luster

Luster can be one of the more difficult observations. However, luster is a very useful property.

Shine is a part of luster, but luster is more than how shiny a mineral appears. Luster also includes how light penetrates a fresh surface. **Luster** is defined as the way light is reflected and/or absorbed by the surface of a mineral. Is all of the light reflected? Does some of the light penetrate and some reflect? Is most of the light absorbed? The answers to these questions describe the characteristics of a mineral that determine its luster.

Luster is divided into two main categories: metallic and nonmetallic. Minerals with a metallic luster reflect light only from their outer surface. These minerals may have the hard look of a polished metal surface. Silver, copper, gold, galena, and pyrite have metallic luster. Light does not penetrate their surfaces, and you cannot see anything below the surface. Please note that luster is independent of other properties. For example, most metals are also relatively dense, but a mineral can have a metallic luster and have a density lower than most metals. Minerals that have metallic luster can be hard or soft. Like color, the only way to observe luster is with your eyes.

Minerals with nonmetallic luster can be sorted into several groups. Some minerals, such as quartz and feldspar, have a glassy luster. You have probably observed that although glass is shiny, light penetrates glass. If this were not true, windows would not let light into a room.

Few people would see a piece of glass and think that it is a metal. They just do not look the same. Metal and glass are shiny, but the glass surface does not have the hard look of a metallic surface. A porcelain dinner plate has a shiny finish, but it does not appear to be made of metal. Porcelain has a glassy luster that gives it a softer look. Figure 4-6 shows minerals with a glassy and metallic luster.

Luster can also be dull. Clay has a dull, or earthy, luster because it is not shiny at all. Dull luster is obviously nonmetallic. You would never mistake clay for a metal.

There are a few other terms used to describe nonmetallic luster. Talc has a pearly luster. Garnet has a waxy luster. These terms

FIGURE 4-6. Selenite gypsum has a glassy luster because it is translucent. Pyrite has a nontransparent metallic luster.

are used to bring to mind substances that reflect and transmit light in the same way as the mineral sample.

STUDENT ACTIVITY 4-2 —LUSTER OF COMMON OBJECTS

1: SCIENTIFIC INQUIRY 3
4: 3.1a

Make a list of objects in and around the classroom that can be described by the different categories of luster. For each object, record why it fits into that category of luster.

Aluminum foil is a good example. Notice how one side is more reflective than the other is. Also notice how the side that is dull still does not allow light to penetrate below its surface.

Hardness

The **hardness** of a mineral is its resistance to being scratched. The sharp corner of any mineral will scratch a substance that is softer. However, a mineral can be scratched only by a substance that has a greater hardness. The mineralogist Friedrich Mohs developed a special scale of hardness used to identify minerals.

This scale is known as **Mohs scale** of hardness. (See Figure 4-7.) The scale lists 10 relatively common minerals in order from soft to hard. The softest mineral on Mohs scale is talc. Assigned a hardness of 1, talc is so soft that any other mineral on the Mohs

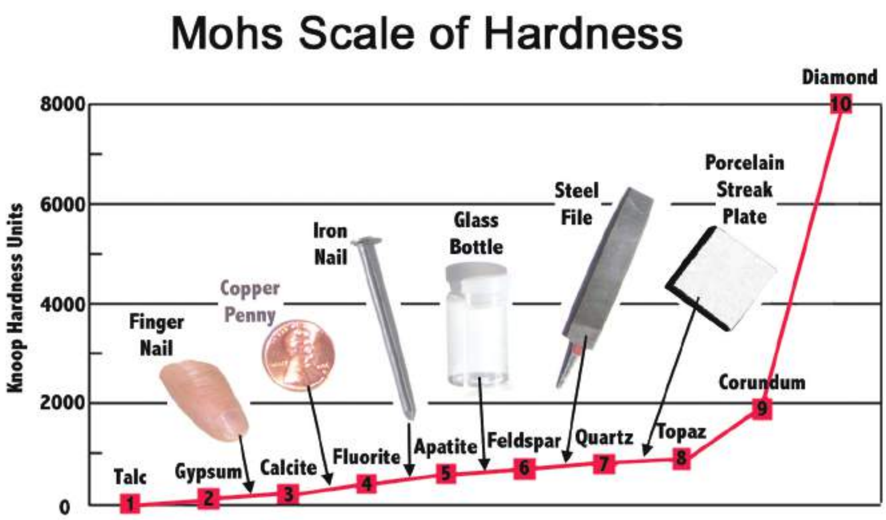


FIGURE 4-7. This graphic image of Mohs scale includes the 10 minerals selected as the standards of hardness and six common objects that can also serve as standards of hardness.

scale can scratch it. A streak plate has a hardness of about 7.5 on the scale. The hardest mineral on Mohs scale is diamond, which was assigned a hardness of 10. Diamond is the hardest known natural substance. A diamond can scratch every other mineral, but no other mineral can scratch a diamond.

Feldspar and quartz are among the most common minerals. Feldspar has a Mohs hardness of 6. The hardness of quartz is 7. This means that both minerals are relatively hard to scratch. However, quartz will scratch feldspar. On the other hand, feldspar will not scratch quartz even when a fresh edge is used because quartz is harder than feldspar. If two mineral samples have the same hardness, for example two pieces of the same mineral, each will be able to scratch the other.

Consider an example of how the hardness test works. Suppose you found a mineral that can scratch samples of talc, gypsum, and calcite. But the sample will not scratch fluorite or other minerals harder than fluorite. The hardness of the sample must be between 3 and 4 on Mohs scale. If the sample scratched fluorite and fluorite scratched the sample, the sample's hardness is 4. Perhaps the mineral you are trying to identify is fluorite.

Unfortunately, testing for hardness is a destructive test. After an object has been scratched many times, new scratches can be difficult to see. One way to make the test less destructive is to observe whether a fresh edge of the mineral will scratch a transparent glass plate. Glass is inexpensive and easy to replace. Most glass has a hardness of 5.5 on Mohs scale. Therefore, this is a good way to distinguish harder minerals from softer minerals with relatively little damage to the mineral sample.

Please note that hardness does not mean that a mineral will not break. Steel is a tough material because it does not break easily. Many of our most durable products are made from steel. Steel is not shattered by hard impacts. Diamonds are much harder than steel, but a hit that might dent or bend steel could shatter the diamond. The diamond is hard, but it is very brittle. That is why hardness is determined by the scratch test, not by any kind of collision.

Crystal Shape

You have learned that matter is composed of particles, including atoms and molecules. What evidence can you observe that solid matter is actually made of these little particles? Crystals provide visible evidence of the atomic nature of matter. The variety of crystal shapes we see is the result of the internal arrangements of atoms in different minerals.

Mineral crystals form in several different environments. Cubic crystals of halite (the mineral in rock salt) are left behind when a salty lake or lagoon evaporates. Other crystals form when water at Earth's surface or circulating underground, deposits the minerals. If the process is slow enough, layer upon layer of atoms and molecules build up to form visible crystals. Some crystals grow when molten rock cools slowly. Slow cooling allows a mineral to form large networks of ordered atoms and molecules. When lava or magma (hot liquid rock) comes to Earth's surface, dissolved gases expand and leave holes in the rock. Holes that are connected may allow water, especially heated water, to circulate through the rock. This hot water can dissolve a mineral from the large mass of rock and deposit it in the holes as crystals. Natural quartz crystals sold in some science, gift, and rock shops were formed in this way. If a large mass of magma that contains dissolved water cools slowly enough, the whole rock can be made of intergrown crystals several centimeters or more in length. Water is not required for crystal growth, but it helps form large crystals such as those shown in Figure 4-4 on page 92.

Minerals can be identified by their characteristic crystal shape. Quartz and calcite are colorless, white, or light-colored minerals with a glassy luster. Both minerals are very common. Unless you look beyond these similarities, you might get quartz and calcite confused. Quartz forms six-sided, hexagonal crystals. In cross section, they are shaped like a wooden pencil. Calcite crystals are usually four-sided with very different angles between the crystal faces. Visit the following Web site to watch snow crystal grow: ***http://www.its.caltech.edu/~atomic/snowcrystals/movies/movies.htm***

Cleavage and Fracture

When minerals break, they tend to break in characteristic patterns. The term **cleavage** refers to the tendency of some minerals to break along smooth, flat planes. Minerals that display obvious cleavage break along planes (areas) of weakness where the bonding of molecules is weaker than in other directions. Cleavage surfaces can be recognized because they reflect light like a flat sheet of glass.

FIGURE 4-8. Muscovite, like other minerals in the mica family, has perfect cleavage in one direction. That is, all mica minerals split into very thin, flexible sheets.

The number of cleavage directions and the angles between them are the most important features of cleavage. Minerals in the mica family, such as biotite and muscovite, show perfect cleavage in only one direction. Large crystals of mica are sometimes called books of mica because they can be split again and again into very thin sheets, as you can see in Figure 4-8.

The feldspars have two cleavage directions that meet at nearly a right angle. Feldspar samples break into pieces that have a rectangular cross section. The ends of the pieces are not cleavage surfaces, so they are not as smooth and do not reflect light like the two cleavage planes.

Some minerals show three cleavage directions. When they break, the pieces have shiny surfaces all around. Halite, the primary mineral in rock salt, and galena, a silvery metallic mineral, split into little cubes. These minerals show three cleavage planes that meet at right angles, as you can see in Figure 4-9. Calcite is the primary mineral in limestone. When calcite crystals break, we see three cleavage directions. However, calcite's cleavage planes do not meet at right angles. Calcite breaks into rhombohedrons, which look like rectangular solids that have been pushed to one side.

Not all minerals break along definite cleavage directions. Minerals that break along curved surfaces or surfaces that are not parallel are said to show **fracture**. Natural quartz crystals have six flat sides. But when quartz crystals break, they break like window glass

FIGURE 4-9. Halite, also known as rock salt, forms cubic crystals that also break (cleave) into rectangular solids.

along curved surfaces that are not parallel to the flat sides. This is known as conchoidal fracture. Garnet breaks smoothly, and the pieces have shiny surfaces; but the surfaces are not flat and parallel. Therefore, garnet shows fracture not cleavage.

Some substances break into fragments or a powder that shows neither cleavage nor fracture. For example, dry clay disintegrates into a fine powder. Clay is among the minerals that show neither cleavage nor fracture.

To test a mineral for cleavage or fracture you must break it. Crystals are rare and beautiful. Breaking these samples destroys them. It may be better to observe the natural breakage surfaces and the angles at which they meet rather than actually testing a mineral in a destructive procedure.

STUDENT ACTIVITY 4-3 —CLEAVAGE AND FRACTURE IN HOUSEHOLD SUBSTANCES

1: SCIENTIFIC INQUIRY 3
4: 3.1a

For this activity you will need a simple magnifying lens made of glass or plastic.

Use the magnifier to observe a variety of granular substances in your home such as sugar, salt, baking soda, and granulated laundry detergent. Check with your parents to determine which substances are safe to handle and to help you avoid making a mess.

Make a list of the substances you looked at, and tell why you think each shows cleavage, fracture, or neither.

Density

In Chapter 1, you learned that the density of an object could be calculated by dividing its mass by its volume. When mass is measured in grams and volume is measured in cubic centimeters, the unit for density is grams per cubic centimeter (g/cm^3). For example, the density of water is 1 g/cm^3. The density of the most common minerals falls between 2.5–3.5 g/cm^3. Many minerals have about the same density. Identifying a mineral by its density is helpful if the mineral is unusually dense.

Magnetite and galena are about twice as dense as the more common minerals. As mentioned previously, gold is the densest mineral substance you are likely to encounter. Gold is roughly six or seven times as dense as the most common minerals. Visit the following Web site to learn how to pan for gold: ***http://www.youtube.com/watch?v=dnkg4b6EIxc***

Special Properties

Some minerals have special properties that are relatively rare. These properties can be useful in identifying these minerals. For example, graphite and talc are unusual because they feel greasy or slippery. Graphite is used as a lubricant and is the "lead" in pencils. Talc is used to make talcum powder. Minerals in the mica family (muscovite and biotite) cleave into thin, flexible sheets. Magnetite is an ore of iron that is attracted to a magnet. Sulfur has a distinctive odor and melts at a low temperature. Some minerals fluoresce (give off visible light) under invisible ultraviolet light.

It is a good rule not to taste or eat anything in a science lab. This is especially true of laboratory chemicals. (Your teacher will tell you if it is safe to taste a substance.) However, halite (the principal mineral in rock salt) can be identified by its salty taste.

Laboratory acids can be dangerous substances. If you are allowed to use them, handle them with great care because a strong acid can burn your skin and make holes in clothing. When a drop of acid is placed on calcite or a rock that contains calcite, a chemical reaction occurs that gives off bubbles of gas. A weaker acid, such as vinegar, may react visibly with powdered calcite.

A fresh surface of plagioclase feldspar may have what looks like small, parallel scratches on its surface. These scratches are striations. You are unlikely to find uranium in an Earth science lab because it is radioactive, which means that it gives off invisible rays and particles called ionizing radiation. (Ionizing radiation is a high-energy form that can damage living cells.) This radiation can be detected with special instruments such as the Geiger counter, and it is a strong indication of the presence of minerals that contain uranium or several related elements. Visit the following Web sites to learn about mineral identification data and see photographs of minerals: *http://www.minerals.net* or *http://mineral.galleries.com/default.htm*

WHAT ARE THE MOST COMMON MINERALS?

4: 3.1a
6: MODELS 2

In this chapter, you have learned about the properties used to identify a variety of minerals. Of the thousands of known minerals, just five make up about 85 percent of Earth's crust. These are the minerals that you are most likely to see.

The two most abundant elements in Earth's crust are oxygen and silicon. The group of minerals that contains both oxygen and silicon is known as the **silicate** minerals. As you might expect, silicates are the most abundant minerals in Earth's crust. Of the following minerals, only calcite is not a silicate. Figure 4-10 illustrates that the

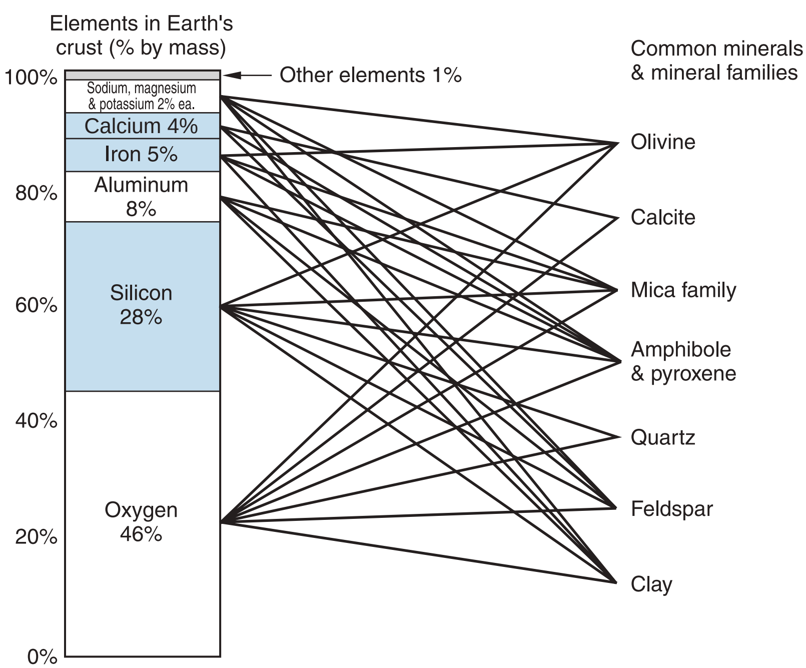


FIGURE 4-10. The most common minerals are primarily composed of oxygen, silicon, and only about a half dozen other chemical elements. These few elements make up more than 99 percent of Earth's crust.

most common minerals in Earth's crust are composed of many of the same chemical elements.

Feldspars

The feldspar family of silicate minerals makes up more than half of Earth's crust. In fact, the name feldspar comes from the Swedish words for field and mineral. The name refers to the fact that Swedish farmers had to move large amounts of feldspar-rich rocks before they could plant crops in their fields. The feldspar family of minerals is divided into groups according to composition. Plagioclase feldspars, also called Na-Ca feldspar, contain, in addition to silicon and oxygen, sodium and calcium in variable proportions. Potassium feldspar, also called orthoclase feldspar, contains potassium instead of sodium or calcium along with silicon and oxygen. Figure 4-11 shows both feldspars. Distinguishing between these groups can be difficult. In this book, they will be described by their common properties. The feldspar minerals are generally white to pink in color and cleave in two directions at nearly right angles. Feldspars have a glassy luster. With a hardness of 6 on Mohs scale, the feldspar minerals will scratch glass but will not scratch quartz.

FIGURE 4-11. Plagioclase and potassium feldspar are extremely common, both gave a glassy luster and show cleavage at nearly 90°.

Quartz

Quartz, another silicate, is second only to the feldspar minerals in abundance. If pure, quartz contains only silicon and oxygen; it has the chemical formula SiO_2. It is usually colorless or light in color and sometimes transparent. Quartz is often translucent, which means light can pass through but you cannot see objects on the other side as you could through a window. Figure 4-6 on page 94 illustrates a variety of quartz samples. Impurities can make quartz almost any color. The semiprecious gems amethyst, agate, and onyx are examples of quartz that is colored by small amounts of impurities. Like the feldspars, quartz has a glassy luster. With a Mohs hardness of 7, quartz can scratch most other minerals. Although most samples of quartz are not crystals, when quartz does form crystals, they are hexagonal, or six-sided, and can be pointed on one or both ends.

Micas

Minerals in the mica family are easy to identify because they are the only common minerals that can be split into thin, flexible sheets. We say that mica has perfect cleavage in one direction. Like quartz and feldspar, the mica minerals have a glassy luster but they are relatively soft, with a hardness of only 2.5 on Mohs hardness scale. Muscovite mica is rich in potassium and aluminum, which give it a light color. Biotite mica is dark in color due to the presence of iron and magnesium. Rocks that are rich in mica can have a reflective sheen on fresh surfaces. Figure 4-8 on page 98 is a photograph of "books" of mica surrounded by quartz.

Amphiboles and Pyroxenes

The silicates amphibole and pyroxene are the most common dark-colored minerals. Both have a Mohs hardness value between 5 and 6. They cleave into stubby splinters. Amphibole minerals, such as hornblende, can be distinguished from the pyroxene minerals, such as augite, by the angle at which their two cleavage surfaces meet. In the amphibole minerals, cleavage surfaces meet at 60° and 120° angles. The angle between cleavage surfaces in the pyroxene family is perpendicular, or 90°.

Calcite

Although calcite is not as common throughout Earth's crust as the minerals described above, it is relatively common at the surface. Calcite is also the only mineral in this section that is not a silicate. By chemical composition, calcite is calcium carbonate ($CaCO_3$). This means that calcite contains carbon and oxygen rather than the silicon and oxygen combination that defines the silicate minerals. Calcite is the most common mineral in the carbonate group. In very pure form, calcite may look transparent and colorless, but like quartz, it can have a variety of colors due to impurities. A soft mineral, calcite has a hardness of only 3. In very pure samples, breakage along cleavage directions can result in a rhombohedral shape, which looks like a rectangular solid that has been pushed toward one side, as you can see in Figure 4-12.

Olivine

Olivine is extremely common within Earth. However, it is not usually visible at the surface because it quickly weathers into clay. Olivine can often be observed in unweathered igneous rocks and it is readily identified by its olive-green color, glassy luster, and granular texture.

Clay

Clay is a family of soft, earthy minerals. Clay is the decomposition product of a wide range of other minerals, including feldspar and mica. It forms when these minerals combine chemically with water

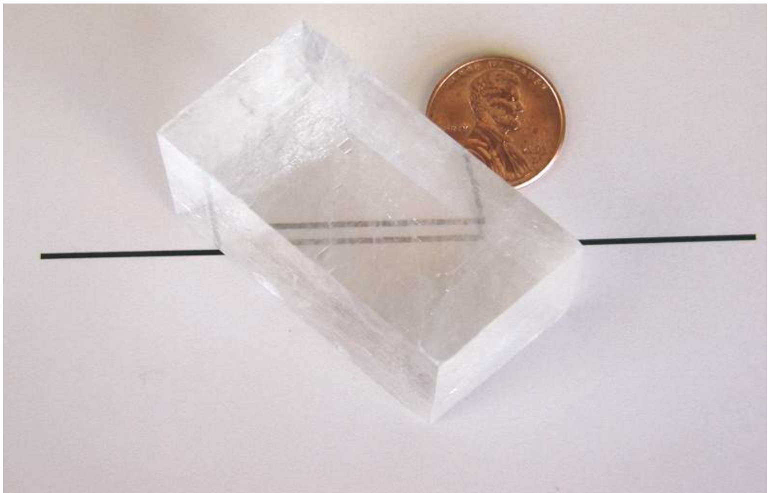


FIGURE 4-12. Calcite crystals are easily identified by their glassy luster and rhombohedral cleavage. In addition, a transparent sample can make a single line behind the crystal look like two lines (double refraction).

in the weathering process. Clay is a major component of soil and the primary mineral in shale. The very fine particles in clay become sticky and flexible when mixed with a small amount of water. Clay often has an earthy odor.

Using a Flowchart to Identify Minerals

The simplified flowchart in Figure 4-13 can help you identify seven of the most common minerals. In this chart, you start on the left and proceed through the chart to the right. For example, if your sample is light in color, at the first branch you would take the top choice. Your sample is too soft to scratch glass so you move to the top of the next division. Your sample cleaves in three directions, which takes you to the lower portion of the final division. Finally you know that your sample bubbles when tested with acid.

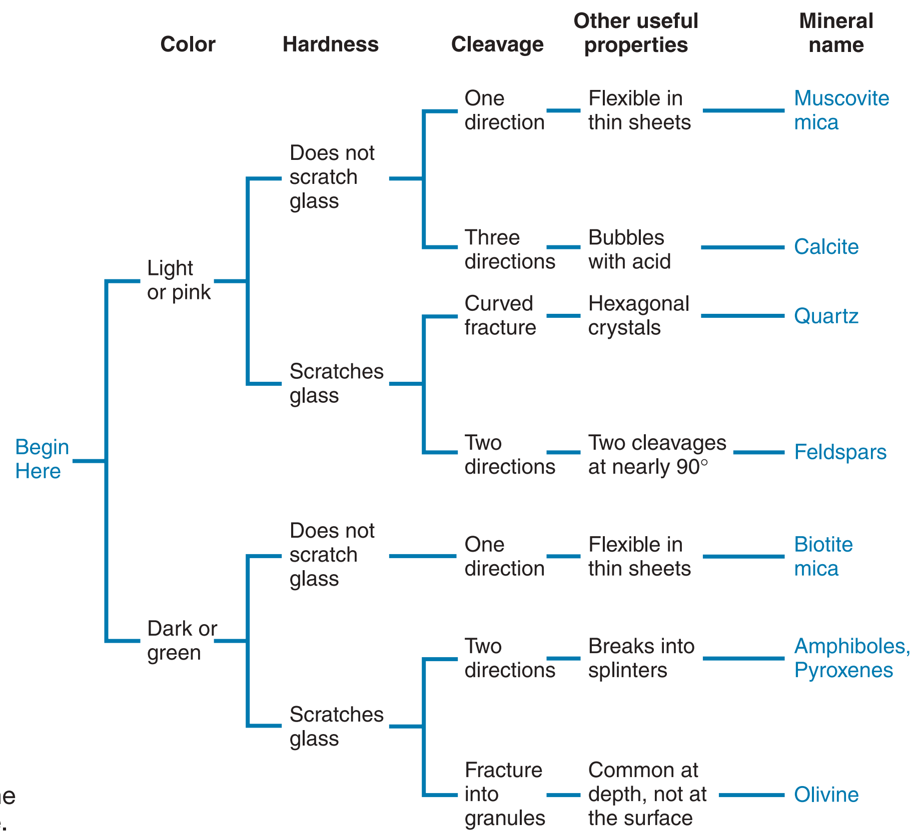


FIGURE 4-13. This mineral identification flowchart can help you identify seven of the most common minerals. Start at the left side and move to the right through the properties of the sample to arrive at the correct mineral name.

Calcite is the only common mineral that has this combination of properties.

Using the Reference Tables

The most useful properties in mineral identification are incorporated in the "Properties of Common Minerals," Figure 4-14, also found in the *Earth Science Reference Tables*. You should be able to use this chart to identify fresh samples of any of the 21 minerals listed in the "Mineral Name" column. Among the thousands of known minerals, these are the minerals you are most likely to see in the natural environment and in the science lab.

To use this table, start on the left side by identifying the luster of the sample in question. Then work your way to the right checking each property listed (hardness, cleavage or fracture, color, etc.). This table contains more than information to help you identify mineral specimens. It also includes information about the chemical composition and the principal uses of each mineral.

STUDENT ACTIVITY 4-4 —MINERAL IDENTIFICATION

1: SCIENTIFIC INQUIRY 3
6 MODELS 2

Suggested materials: set of minerals, small magnifier, streak plate, small glass plate, magnet.

Your teacher will provide you with a kit containing several minerals. Use the "Properties of Common Minerals" chart to identify each of the samples. Record all the information you used to help you identify each mineral. But record only what you actually observed. For example, you probably have only a glass plate to determine the hardness of the minerals. Therefore, you will not be able to record the specific Mohs hardness number as listed on the chart. However, you can record whether the mineral could scratch glass.

Please handle the minerals with care and avoid damaging the samples when you perform destructive procedures. For example, rather than breaking the sample to observe fracture or cleavage, look at the surface of the sample to see how it broke when the mineral sample was prepared for the kit. Visit the following Web site to identify minerals from their properties: ***http://facweb.bhc.edu/academics/science/harwoodr/GEOL101/Labs/Minerals***

Properties of Common Minerals

LUSTER	HARDNESS	CLEAVAGE	FRACTURE	COMMON COLORS	DISTINGUISHING CHARACTERISTICS	USE(S)	COMPOSITION*	MINERAL NAME
Metallic luster	1–2	✔		silver to gray	black streak, greasy feel	pencil lead, lubricants	C	**Graphite**
	2.5	✔		metallic silver	gray-black streak, cubic cleavage, density = 7.6 g/cm³	ore of lead, batteries	PbS	**Galena**
	5.5–6.5		✔	black to silver	black streak, magnetic	ore of iron, steel	Fe_3O_4	**Magnetite**
	6.5		✔	brassy yellow	green-black streak, (fool's gold)	ore of sulfur	FeS_2	**Pyrite**
Either	5.5 – 6.5 or 1		✔	metallic silver or earthy red	red-brown streak	ore of iron, jewelry	Fe_2O_3	**Hematite**
Nonmetallic luster	1	✔		white to green	greasy feel	ceramics, paper	$Mg_3Si_4O_{10}(OH)_2$	**Talc**
	2		✔	yellow to amber	white-yellow streak	sulfuric acid	S	**Sulfur**
	2	✔		white to pink or gray	easily scratched by fingernail	plaster of paris, drywall	$CaSO_4 \cdot 2H_2O$	**Selenite gypsum**
	2–2.5	✔		colorless to yellow	flexible in thin sheets	paint, roofing	$KAl_3Si_3O_{10}(OH)_2$	**Muscovite mica**
	2.5	✔		colorless to white	cubic cleavage, salty taste	food additive, melts ice	$NaCl$	**Halite**
	2.5–3	✔		black to dark brown	flexible in thin sheets	construction materials	$K(Mg,Fe)_3 AlSi_3O_{10}(OH)_2$	**Biotite mica**
	3	✔		colorless or variable	bubbles with acid, rhombohedral cleavage	cement, lime	$CaCO_3$	**Calcite**
	3.5	✔		colorless or variable	bubbles with acid when powdered	building stones	$CaMg(CO_3)_2$	**Dolomite**
	4	✔		colorless or variable	cleaves in 4 directions	hydrofluoric acid	CaF_2	**Fluorite**
	5–6	✔		black to dark green	cleaves in 2 directions at 90°	mineral collections, jewelry	$(Ca,Na)(Mg,Fe,Al)(Si,Al)_2O_6$	**Pyroxene** (commonly augite)
	5.5	✔		black to dark green	cleaves at 56° and 124°	mineral collections, jewelry	$CaNa(Mg,Fe)_4(Al,Fe,Ti)_3Si_6O_{22}(O,OH)_2$	**Amphibole** (commonly hornblende)
	6	✔		white to pink	cleaves in 2 directions at 90°	ceramics, glass	$KAlSi_3O_8$	**Potassium feldspar** (commonly orthoclase)
	6	✔		white to gray	cleaves in 2 directions, striations visible	ceramics, glass	$(Na,Ca)AlSi_3O_8$	**Plagioclase feldspar**
	6.5		✔	green to gray or brown	commonly light green and granular	furnace bricks, jewelry	$(Fe,Mg)_2SiO_4$	**Olivine**
	7		✔	colorless or variable	glassy luster, may form hexagonal crystals	glass, jewelry, electronics	SiO_2	**Quartz**
	6.5–7.5		✔	dark red to green	often seen as red glassy grains in NYS metamorphic rocks	jewelry (NYS gem), abrasives	$Fe_3Al_2Si_3O_{12}$	**Garnet**

*Chemical symbols:

Al = aluminum	Cl = chlorine	H = hydrogen	Na = sodium	S = sulfur	
C = carbon	F = fluorine	K = potassium	O = oxygen	Si = silicon	
Ca = calcium	Fe = iron	Mg = magnesium	Pb = lead	Ti = titanium	

✔ = dominant form of breakage

FIGURE 4-14.

CHAPTER REVIEW QUESTIONS

Part A

1. Which mineral has a metallic luster, a black streak, and is an ore of iron?

(1) galena (3) pyroxene
(2) magnetite (4) graphite

2. The table below shows the density of four minerals.

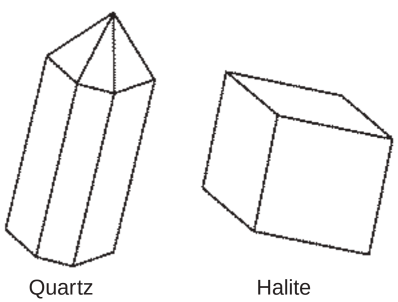
Data Table

Mineral	Density (g/cm^3)
Corundum	4.0
Galena	7.6
Hematite	5.3
Quartz	2.7

A student accurately measured the mass of a sample of one of these minerals to be 294.4 g. Its volume was 73.6 cm^3. Which mineral sample did the student measure?

(1) corundum (3) hematite
(2) galena (4) quartz

3. The diagram below shows the crystal shape of two minerals.



Why do quartz and halite have different crystal shapes?

(1) Light reflects from crystal surfaces.
(2) Energy is released during crystallization.

(3) Impurities produce surface variations.
(4) The internal arrangement of atoms is different.

4. Which is a common use of the mineral graphite?
(1) a lubricant
(2) an abrasive
(3) a source of iron
(4) a cementing material

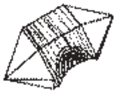
5. According to the table, which statement best describes the hardness of dolomite?

Hardness of Four Materials

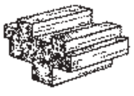
Material	Hardness
Human fingernail	2.5
Copper penny	3.0
Window glass	4.5
Steel nail	6.5

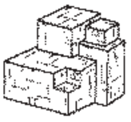
(1) Dolomite can scratch window glass, but it cannot be scratched by a fingernail.
(2) Dolomite can scratch window glass, but it cannot be scratched by a steel nail.
(3) Dolomite can scratch a copper penny, but it cannot be scratched by a fingernail.
(4) Dolomite can scratch a copper penny, but it cannot be scratched by a steel nail.

6. If the four minerals shown below were placed together in a closed, dry container and shaken vigorously for 10 minutes, which material would be scratched and abraded the most?


Quartz


Amphibole


Pyroxene


Galena

(1) quartz
(2) amphibole
(3) galena
(4) pyroxene

7. The table below shows some observed physical properties of a mineral.

Physical Property	Observation
Color	White
Hardness	Scratched by the mineral calcite
Distinguishing characteristic	Feels greasy
Cleavage/fracture	Shows some definite flat surfaces

Based on these observations, the elements that make up this mineral's composition are

(1) sulfur and lead
(2) sulfur, oxygen, and hydrogen
(3) oxygen, silicon, hydrogen, and magnesium
(4) oxygen, silicon, aluminum, and iron

8. Looking at a mineral sample on a table without touching or moving it, what property could you observe?

(1) hardness
(2) atomic structure
(3) density
(4) luster

9. Which mineral is white or colorless, has a hardness of 2.5, and splits with cubic cleavage?

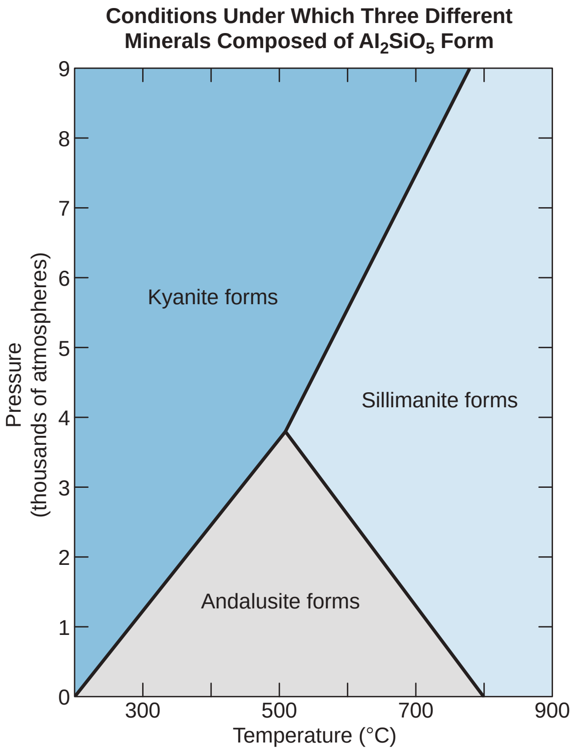
(1) calcite
(2) halite
(3) pyrite
(4) biotite

10. What property do nearly all minerals have in common?

(1) They are composed of a single element.
(2) They fell to Earth in the past century.
(3) They were organically formed.
(4) They are natural, inorganic, crystalline solids.

Part B

11. Base your answers to questions 11 and 12 on the graph below, which shows the conditions at which the same chemical elements crystallize to form one of three different minerals.



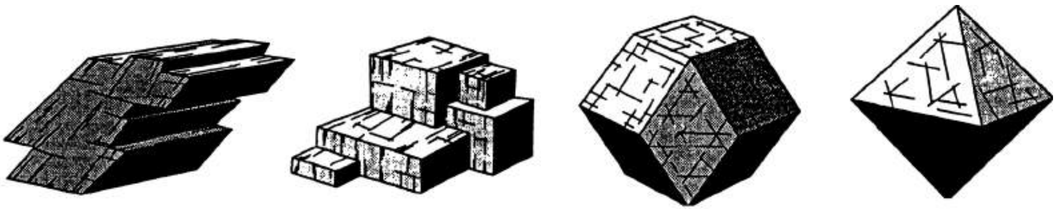
Under what pressure and temperature conditions will andalusite form?

(1) 300°C and 6000 atmospheres
(2) 500°C and 2000 atmospheres
(3) 600°C and 4000 atmospheres
(4) 700°C and 3000 atmospheres

12. Which mineral has a chemical composition most similar to andalusite, sillimanite, and kyanite?

(1) pyrite
(2) gypsum
(3) dolomite
(4) potassium feldspar

13. Halite has three cleavage directions at 90° to each other. Which model best represents the shape of a broken sample of halite?



(1) (2) (3) (4)

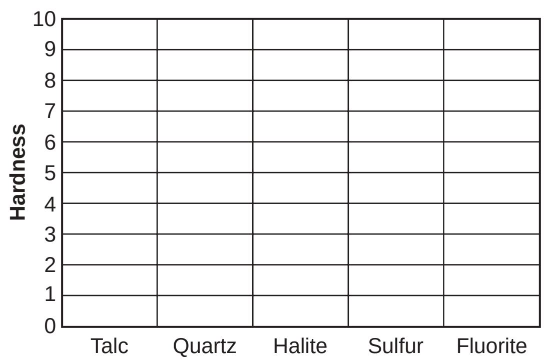
14. Quartz and calcite are both very common minerals. In what property are quartz and calcite similar?

(1) surface luster
(2) cleavage directions
(3) Mohs hardness
(4) reaction with acid

Part C

Base your answers to questions 15 through 17 on the information below.

15. Use a copy of the grid below to construct a bar graph of the hardness of these five minerals. (Do not write in this book.)

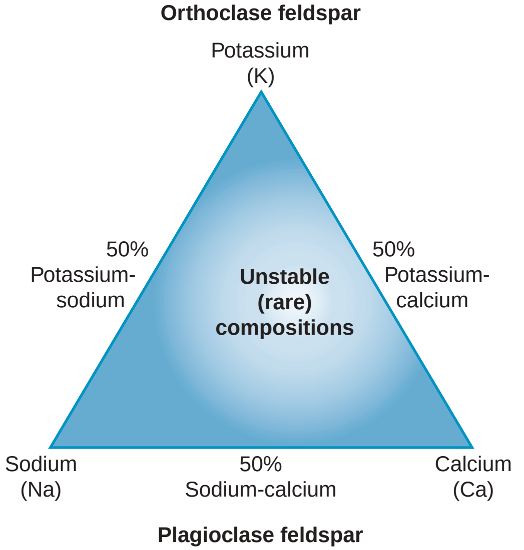


16. Which of the five minerals in the graph above would be the best abrasive? State one reason for your choice.

17. How many of these minerals could be scratched by almandine garnet?

Base your answers to questions 18 and 19 on the following information.

18. All minerals in the feldspar family contain silicon, oxygen, aluminum, and one other element. The diagram below shows the range of feldspars that contain potassium, sodium, and calcium as that last element. It is the final element or elements that determine the specific kind of feldspar mineral.



What is the most common element found in orthoclase feldspar but not in plagioclase feldspar?

19. Use a copy of this diagram to place an *X* to represent the position of a feldspar that has no potassium, but an equal amount of sodium and calcium atoms.

20. Based on the position of diamond on Mohs scale, state one way that a diamond can be identified if it is in a group of other similar-looking minerals.

CHAPTER

5 The Formation of Rocks

WORDS TO KNOW

banding
bioclastic rock
classification
clastic
contact metamorphism
crystalline sedimentary rock
extrusion
felsic
foliation
fossil
fragmental
igneous rock
intrusion
lava
mafic
magma
metamorphic rock
origin
plutonic
precipitation
regional metamorphism
rock
rock cycle
sediment
sedimentary rock
texture
vesicular
volcanic

This chapter will help you answer the following questions:

1. What are rocks?
2. How do we identify and classify igneous rocks?
3. How do we identify and classify sedimentary rocks?
4. How do we identify and classify metamorphic rocks?
5. What is the rock cycle?

WHAT ARE ROCKS?

1: SCIENTIFIC INQUIRY 3
4: 2.1m; 4: 2.1w
4: 3.1b
6: PATTERNS OF CHANGE 5

A **rock** is a substance that is or was a natural part of the solid earth, or lithosphere. Rocks come in many varieties. Some rocks are unusual enough for geologists and people interested in geology to collect them. Rocks can also be colorful or attractive. Landscapers often use rocks to beautify homes or parks.

Most rocks are composed of a variety of minerals. In some rocks, you can recognize the minerals as variations in color or other mineral properties within the rock. Granite is a good example. If you look carefully at a sample of granite with a hand lens, you will probably observe some parts of the rock that are transparent. This is probably the mineral quartz. Other parts are white or pink with angular cleavage. These are properties of plagioclase feldspar and potassium feldspar. Dark mineral grains that occur in thin sheets are biotite mica. Dark minerals that occur in stubby crystals are probably hornblende, the most common mineral in the amphibole family. Other minerals can occur in granite, but they are not as common as these four. (Look at Figure 4-1 on page 86.)

Other rocks are composed of a single mineral. Some varieties of sandstone, particularly if they are very light in color, can be nearly 100 percent quartz. Very pure limestone is nearly all calcite. Rock salt can be nearly pure halite.

Coal is mined in many areas of the United States, and is often used as a fuel. If we define a rock as a natural solid part of the lithosphere, coal is a rock. Many samples of coal show beautiful plant impressions.

While coal is a kind of rock, it was formed from living materials. Therefore coal is an example of a rock that is not made of minerals. (Impure coal does contain some mineral material.) Another example of a rock that is not composed of minerals is fossil limestone. This kind of limestone is the result of the accumulation of shells or coral. Coral is a colony of tiny marine animals that live in a hard external skeleton. These skeletons can be several inches or more in length and take unusual shapes. Because fossil limestone is made of the hard remains of coral, shells, and other living tissue cemented together grains of organic calcite, it is not composed of minerals. Minerals must be of inorganic origin.

STUDENT ACTIVITY 5-1 —MAKING A ROCK COLLECTION

1: SCIENTIFIC INQUIRY1

As you read through this chapter, collect small rock samples from around your community. If you wish, you can add rocks from your travels or rocks that you have gotten elsewhere. You may recall that when you worked with minerals you tried to use fresh, unweathered samples. It is important to follow the same rule in collecting rocks. Weathered rocks tend to crumble, and they are also harder to identify than fresh samples.

This rock collection will have two purposes. First, it should help you discover the variety of rocks around you. The second purpose is to use what you learn from this chapter to classify your rocks.

Your samples should be divided into the three categories you will learn about in this chapter: igneous, sedimentary, and metamorphic rocks. You may collect as many rocks as you wish, but the final submission will consist of six small rocks, two from each category, each of which shows a property of its category. Therefore, for each rock submitted, classify it as igneous, metamorphic, or sedimentary and tell why each sample fits into its group. Your samples may be placed in a half-dozen egg carton.

You may check your progress on this assignment with your teacher. In addition, carefully observe the rock samples you use in class to identify the properties used to classify rocks. Your teacher will collect your samples after the class has completed this chapter.

Three Rock Categories

In the previous chapter, you learned that minerals are classified on the basis of their observable properties such as luster, hardness, color, and cleavage. Geologists have found it more useful to separate rocks into three groups based on how they formed. The way rocks form is their **origin**.

Igneous rocks form from hot, molten (liquid) rock material that came from deep within Earth. Only igneous rocks have this origin. Hot, liquid rock is called **magma**. At Earth's surface magma is known as **lava**. Figure 5-1 shows a geologist taking samples of molten lava. In Chapter 2 you learned that Earth's temperature increases as you go deeper within the planet. In some places within Earth, it is hot enough to melt rock. This molten rock, which is less

FIGURE 5-1. When this lava cooled, it turned to an igneous rock like the solid rock the geologist is standing on.

dense, rises to or near Earth's surface. At the surface, it is cooler, and the liquid rock material changes to solid rock. Igneous rocks are especially common around volcanoes and in places where large bodies of rock that have melted and then solidified underground have been pushed to the surface. Visit the following Web site to see a concept map that explains rock origins: ***http://igs.indiana.edu/Geology/rocks/rockcycleactivities/cycleconceptmap.swf***

In Chapter 7 you will learn that most of Earth's interior is in the solid state. If temperatures underground are hot enough to melt rock, why is the interior not mostly liquid? The reason that Earth is mostly solid is the increase of pressure with depth. While the increasing temperature tends to melt the rock, the increase in pressure prevents melting.

Rocks weather and break down when they are exposed at Earth's surface. Eventually the weathered material collects as layers of **sediment**. Compression and cementing of weathered rock fragments or the shells of once living creatures is the origin of most **sedimentary rocks**, the second group of rocks.

If sedimentary or igneous rocks are buried so deeply that heat and pressure distort their structures and form new minerals, the result is **metamorphic rocks**. Metamorphic rocks are the only

FIGURE 5-2. The distortion of these pebbles shows how rock changes when exposed to the conditions that exist several kilometers within Earth.

group that forms directly from other rocks (usually igneous or sedimentary). Figure 5-2 shows a sedimentary rock that originally contained round pebbles, which forces within Earth have squashed and elongated.

But, if most metamorphic rocks form within Earth, why can they be found at the surface? The answer to this question involves two important Earth-changing processes. The first is uplift. Earth contains a great deal of heat energy. As heat escapes from the interior of the planet, it sometimes pushes up the crust to form mountains. The second process is weathering and erosion. Weathering and erosion wear down the mountains, exposing rocks at the surface that formed at depths of 10 km or more underground. Wherever you find a large mass of metamorphic rock at the surface, you are probably looking at the core of an ancient mountain range.

Classification is the organization of objects, ideas, or information according to their properties. Not all rocks fit easily into one of these three categories. Some volcanoes throw great quantities of ash into the air. The ash falls, settles in layers, and hardens. The settling part of ash layers' origin is similar to the processes that form sedimentary rock. However, because the material came from a volcano, volcanic ash is classified as an igneous rock. Another example is the gradual change from igneous or sedimentary rock to metamorphic rock. It may not be clear at what point the rock should no longer be classified as its original parent rock and when it should be called a metamorphic rock. In spite of these occasional difficulties, the classification of rocks by their origin has served geologists and Earth science students well. Figure 5-3 illustrates the way to classify rocks as igneous, sedimentary, or metamorphic by their appearance. Rocks can be classified by their appearance because the way they look offers clues to their formation. View online movies of Kilauea volcanic eruptions in Hawaii at the Web site *http://hvo.wr.usgs.gov/gallery/kilauea/volcanomovies/*

STUDENT ACTIVITY 5-2 —CLASSIFICATION

6: SYSTEMS THINKING 1
6: MODELS 2

Your teacher will give you about a dozen objects to classify. Divide the objects into groups based on the properties you can see. Start by listing all the objects. Each time you divide the objects into groups, state one property that allows you to clearly decide to which group an object belongs. As you divide each group into smaller groups, limit the number of subgroups to two or three. Continue the process until each object is alone in a group. Create a flowchart that will allow someone else to separate and/or identify all the objects. Figure 4-13 on page 105 (Mineral Identification Flowchart) shows a relatively simple system for classifying minerals.

Because **igneous rocks** have formed from molten magma or lava, they are composed of intergrown crystals. Rapid cooling, however, can make the crystals too small to be visible. Igneous rocks are usually quite hard and dense, and layering is rare. Gas bubbles may give igneous rocks a frothy texture.

Granite

Basalt

Most **sedimentary rocks** are composed of rounded fragments cemented in layers. In fine-grained rocks, the individual grains may be too small to be readily visible. Rocks made by chemical precipitation are composed of intergrown crystals, although these crystals are relatively soft. A rock that contains fossils is almost certainly a sedimentary rock.

Limestone

Conglomerate

Metamorphic rocks, like igneous rocks, are usually composed of intergrown crystals. But, like sedimentary rocks, they often show layering, banding, or foliation. The layers may be bent, or distorted.

FIGURE 5-3. The appearance of a rock is often a good indicator of its origin.

HOW ARE IGNEOUS ROCKS CLASSIFIED?

4: 3.1b; 3.1c
6: MODELS 2

Igneous rocks are classified by their color and texture. The colors in rocks come from the minerals that make up the rocks. Minerals rich in aluminum (chemical symbol Al) are commonly light-colored, sometimes pink. These minerals are called **felsic** because the feldspars are the most common light-colored minerals. The word "felsic" comes from *fel*dspar and *si*li*c*on. Minerals rich in magnesium (chemical symbol Mg) and iron (chemical symbol Fe) such as olivine and pyroxene families are called **mafic** (MA-fic). The word "mafic" comes from a combination of *ma*gnesium and *f*err*ic,* a Latin word used to describe iron. Mafic minerals are often dark-colored.

The next characteristic used to classify igneous rocks is their texture. **Texture** describes the size and shape of the grains and how they are arranged in the rock. Texture answers the following questions. Is the rock composed of different kinds of grains? How large are these grains, and what shape are they? Do they show any kind of organization?

In igneous rocks, the size of the crystals is generally a result of how quickly the rock solidified. If the magma cooled slowly, the atoms and molecules had enough time to form crystals that are visible without magnification. Granite is a good example of a rock that cooled slowly. Granite is a popular building stone because it resists wear and weathering and because it is attractive. Granite has a speckled appearance, as you can see in Figure 4-1 on page 86. The different colors in granite come from the different minerals of which it is composed. Crystals from 0.25- to 1.0-cm long are common in granite. If the granite is pink, it probably contains a large amount of potassium feldspar, which can be pink or white.

Most granite forms in large masses within Earth. The movement of magma to a new position within Earth's crust is called **intrusion**. Intrusion occurs underground, or inside Earth. Sometimes a large quantity of hot magma rises to a place near the surface where it slowly cools to form solid rock.

In other cases, granite originates from a mass of rock buried deeply enough to melt. As the mass cools and crystallizes, it slowly forms granite. Because coarse-grained igneous rocks such as granite form deep underground, they are classified by origin as intrusive or **plutonic** rocks. (The term plutonic comes from the name of Pluto, the Roman god of the underworld.)

Basalt is also a common igneous rock, especially under the oceans. The ways that basalt differs from granite can help you understand how igneous rocks are classified. Basalt usually forms from magma that rises to or very near the surface. **Extrusion** is the movement of magma onto Earth's surface. At the surface, lava cools quickly, and the resulting crystals may be too small to see without magnification. Fine-grained igneous rocks such as basalt are therefore called extrusive or **volcanic** rocks. Basalt is rich in mafic minerals that give it a dark color, generally dark gray to black.

Figure 5-4 is a chart from the *Earth Science Reference Tables* that can help you understand and classify igneous rocks primarily by color

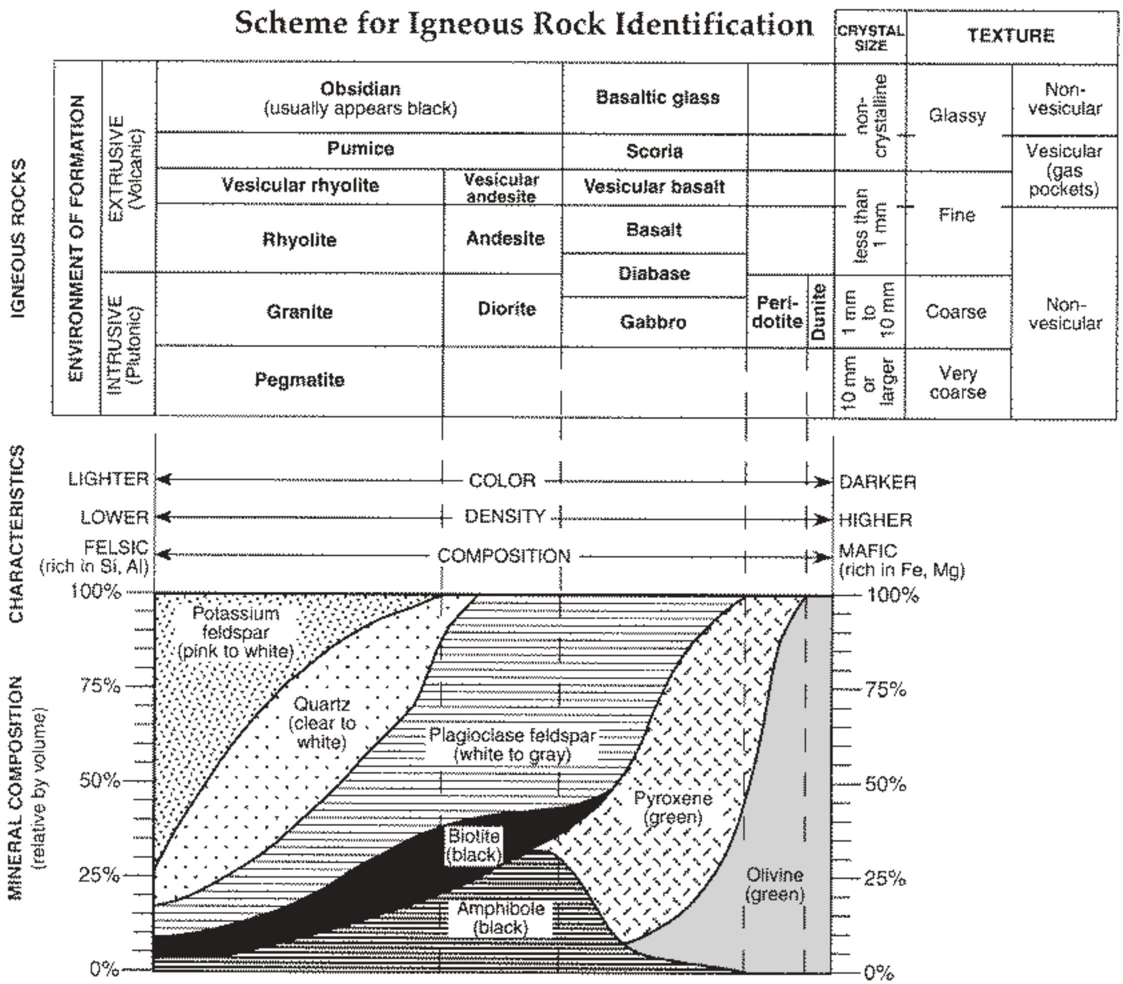


FIGURE 5-4. You can use this chart to identify the most common igneous rocks and to estimate their mineral composition.

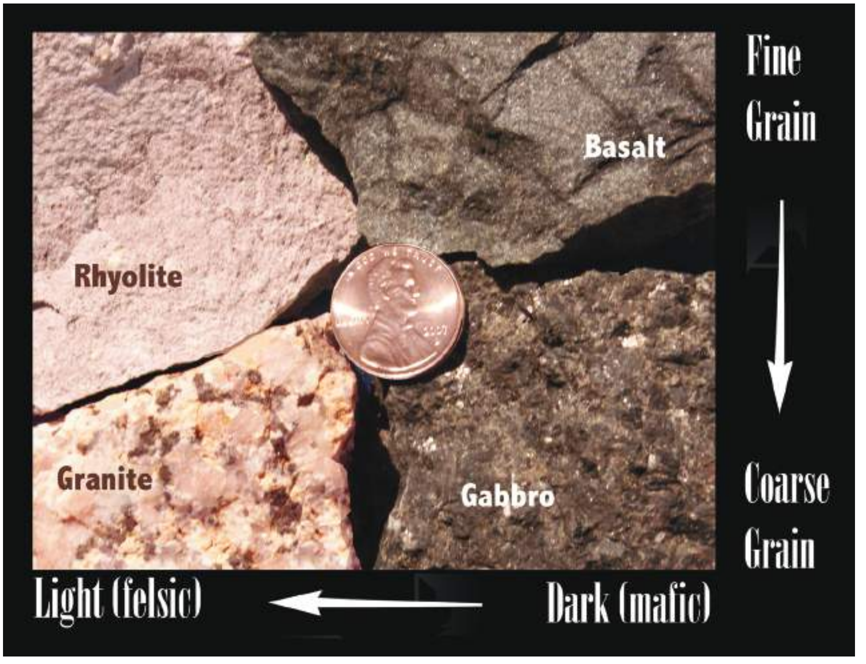


FIGURE 5-5. Notice that these four common igneous rocks correspond to rocks identified in Figure 5-4.

and texture. The rocks with the smallest crystals (fine-grained, extrusive rocks) are at the top of this chart. In these rocks, the grains of the different minerals are too small to be seen easily without magnification. Below them are the coarse igneous rocks in which it is easy to see the different minerals. Compare this chart with images of the four major igneous rock types in Figure 5-5. This image may help you understand the variables in the *Reference Table* chart.

There are major differences in composition between the light-colored (felsic) rocks, such as granite and rhyolite on the left side of the chart, and the dark-colored (mafic) rocks, such as basalt and gabbro on the right side. Along with this change in composition (felsic to mafic) the chart shows a change in color (light to dark) and a change in density. You may not be able to feel that a mafic rock is heavier than a felsic rock of the same size, but the difference is measurable. The difference in density will become important when we consider the interior of our planet in Chapter 14.

You will find the term "vesicular" on the chart. A **vesicular** texture refers to the gas pockets, called vesicles, that are common in extrusive igneous rocks. When magma rises, the decrease in pressure causes trapped gases to form bubbles. This is similar to what happens when you open a bottle of carbonated water. These bubbles are trapped carbon dioxide. But the gas bubbles that form in

FIGURE 5-6. Pumice (right) and scoria (left) are vesicular (contain small air pockets), igneous rocks. Sometimes they have so many vesicles that these rocks will float on water.

lava are mostly water vapor, which escapes into the atmosphere. Scoria has large vesicles, and may look like cinders from a fire. Pumice has smaller gas bubbles, and it can be so light it may float on water. (See Figure 5-6.) Pumice is sometimes sold as an abrasive used to scrape the gratings of barbecue grills. If you forget what vesicular means, look at the top right portion of the chart where you will find the word "vesicular" just above the two words "gas pockets" in parentheses.

At the top of the chart is a texture called glassy. Sometimes lava cools so quickly it forms a rock that looks like a shiny, dark, glass material. This is obsidian. If obsidian (also known as volcanic glass) contains crystals, they are too small to be seen even under a microscope. The properties of the other igneous rocks listed in the Scheme for Igneous Rock Identification can be determined from the rock's position on the chart. For example, pegmatite appears at the bottom left of the chart. Like other igneous rocks on the left, pegmatite is relatively light in color. Its position at the bottom means that pegmatite is composed of very large crystals.

The bottom section of the Scheme for Igneous Rock Identification on page 121 is called Mineral Composition. This section shows the minerals that are common in igneous rocks. For example, granite usually contains potassium feldspar, quartz, plagioclase feldspar, biotite, and amphibole. If you imagine a vertical line running directly below the word granite and into this section, you will see that quartz and potassium feldspar make up about 66 percent of the volume of granite. The percent of each mineral is indicated by

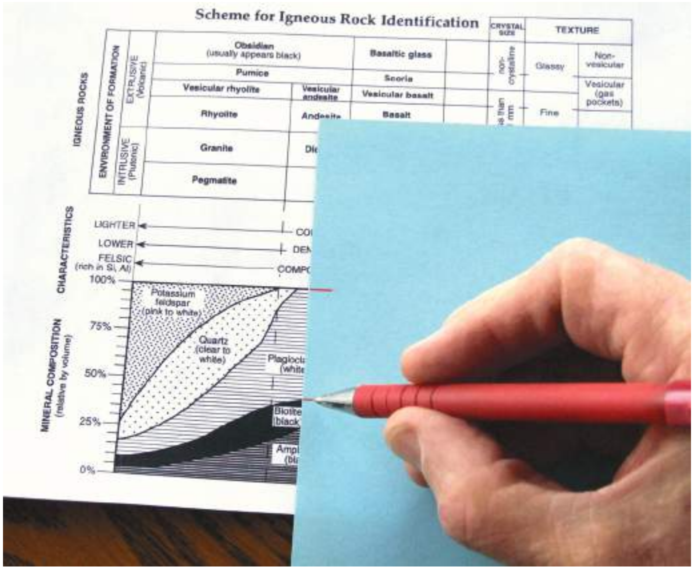


FIGURE 5-7. To determine the percentage mineral composition of a common igneous rock, mark an edge of a sheet of paper with the upper and lower limits of the proper section of the graph. (You probably will want to center the vertical edge of the paper at the center of the mineral name.) Then slide the paper over to the percent composition scale. This person is marking the limits of the plagioclase feldspar section below basalt and gabbro.

the scale that appears on each side of the Mineral Composition section of the chart. The composition of basalt is under the word "Basalt" near the other side of the chart. Basalt is mostly plagioclase and pyroxene. However, the mineral composition of igneous rocks is variable. The various compositions of each rock are enclosed by the dotted lines. Figure 5-7 shows how you can line up a sheet of paper with the mineral composition part of the chart to determine the percentage composition of various common igneous rocks.

Common Igneous Rocks

Of all the igneous rocks named on the Scheme for Igneous Rock Identification in the *Earth Science Reference Tables,* or Figure 5-4 on page 121, you are most likely to encounter just seven in your Earth science course. These seven igneous rocks are very easy to tell apart, and they show the range of properties of igneous rock.

Granite is a coarse-grained, felsic (light-colored) igneous rock. Its overall color is likely to be light gray or pink. Because of slow cooling the mineral crystals are large enough to be visible without magnification.

Rhyolite is the fine-grained equivalent of granite. Rhyolite is light-colored and felsic in composition. Rapid cooling of the magma has resulted in very small mineral grains that are unlikely to be readily visible.

Gabbro, like granite, is composed of large crystals because of slow cooling of the magma. (It is coarse-grained.) Unlike granite, gabbro is mafic in composition, which means that it is composed primarily of the dark minerals rich in iron and magnesium.

Basalt has a mineral composition similar to gabbro's, so it is also relatively dark in color. However, basalt cooled so quickly that, as in rhyolite, the individual mineral grains might be too small to see without magnification.

The next two igneous rocks share an unusual feature. Scoria and pumice are full of air pockets. This indicates that they probably formed from magma rich in dissolved gases, such as water vapor, and were ejected from a volcano during a violent eruption. The pockets in pumice are small enough that individual pockets are not obvious. Scoria has larger pockets and looks like cinders.

Volcanic glass is also called obsidian. The term "glass" describes its smooth texture, which results from rapid cooling of lava that had little dissolved water or gases. Obsidian usually breaks along curved surfaces (conchoidal fracture). It is usually black due to the even distribution of dark minerals, even though the mineral composition of volcanic glass is most often felsic. Visit the following Web site to work with a dynamic clickable igneous rocks chart: ***http://csmres.jmu.edu/geollab/Fichter/IgnRx/IgnRx.html***

STUDENT ACTIVITY 5-3 —IDENTIFICATION OF IGNEOUS ROCKS

1: SCIENTIFIC INQUIRY 1
6: MODELS 2

Obtain a set of igneous rocks from your teacher. Handle them carefully and let your teacher know if any samples are missing or damaged.

Use the information you learned in this chapter and the appropriate chart in the *Earth Science Reference Tables* to identify each of the igneous rocks in your set. List the name of each rock, such as granite or scoria, along with the characteristics you observed that helped you to identify it.

HOW DO SEDIMENTARY ROCKS FORM?

4: 2.1W
4: 3.1C

Within Earth's crust, igneous rock is the most common rock type. However, most of the surface of our planet is covered with a relatively thin layer of sedimentary rocks. Unlike igneous rocks, it is difficult to give a precise definition of sedimentary rocks. Most sedimentary rocks are made of the weathered remains of other rocks that have been eroded and later deposited as sediment in layers. Over time, the sediments are compressed by the weight of the layers above them. In addition, the layers may be cemented by mineral material left by water circulating through the sediments. The cementing material is usually silica (fine-grained quartz), clay, or calcite. All sedimentary rocks are formed at or near Earth's surface. Although this description applies only to the clastic, or fragmental, group of sedimentary rocks, these are the most common rocks of sedimentary origin. **Fossils** are any remains or impressions of prehistoric life. If fossils are present in a rock, the rock is almost certainly a sedimentary rock. The processes that create igneous and metamorphic rocks usually destroy any fossil remains.

You can recognize sedimentary rocks because they are usually composed of particles, often rounded particles, compressed and cemented into layers, called bedding planes. Shale, the most common rock on Earth's surface, is made of particles of sediment too small to be visible without magnification. Shale breaks easily into thin layers.

Clastic (Fragmental) Rocks

Clastic and **fragmental** are terms applied to the group of sedimentary rocks that are made up of the weathered remains of other rocks. These are the most common sedimentary rocks. Clastic rocks are formed by the processes of deposition, compression, and cementation of sediments. Although some sediments are deposited by wind, glaciers, or even rockfalls, most are the result of deposition in water. Seas or parts of the ocean once covered most parts of the continents. Streams and rivers carry sediments from the surrounding land into these bodies of water. The particles of sediment settle to the bottom of the water, forming fine-grained sedimentary rocks. Where deposition is rapid or currents are fast, the particles of sediment deposited are larger. Clastic, or fragmental, rocks are classified by the size of the sedimentary particles from which they are formed.

Information about the range of sizes of the various particles in sedimentary rocks is found in the sedimentary rock chart in the *Earth Science Reference Tables* and also in Figure 5-8. For example, according to this chart, sand can be defined as particles of sediment that range between 0.006 cm and 0.2 cm in size.

Conglomerate is the coarsest grained clastic rock. It is dominated by particles that are easily seen: about 0.2 cm or larger. Conglomerate sometimes looks like artificial cement with rounded pebbles embedded in it. Silica (very fine quartz), clay, and calcite (the mineral in limestone) are common cements that hold the larger particles together. There is no upper limit to the size of the particles in conglomerate, but cemented pebbles are the most common texture of conglomerate. If the particles are angular (a sign that they have not been transported very far before deposition) the term breccia (BRETCH-ee-a) is used instead of conglomerate.

Scheme for Sedimentary Rock Identification

INORGANIC LAND-DERIVED SEDIMENTARY ROCKS					
TEXTURE	**GRAIN SIZE**	**COMPOSITION**	**COMMENTS**	**ROCK NAME**	**MAP SYMBOL**
Clastic (fragmental)	Pebbles, cobbles, and/or boulders embedded in sand, silt, and/or clay	Mostly quartz, feldspar, and clay minerals; may contain fragments of other rocks and minerals	Rounded fragments	**Conglomerate**	
			Angular fragments	**Breccia**	
	Sand (0.006 to 0.2 cm)		Fine to coarse	**Sandstone**	
	Silt (0.0004 to 0.006 cm)		Very fine grain	**Siltstone**	
	Clay (less than 0.0004 cm)		Compact; may split easily	**Shale**	
CHEMICALLY AND/OR ORGANICALLY FORMED SEDIMENTARY ROCKS					
TEXTURE	**GRAIN SIZE**	**COMPOSITION**	**COMMENTS**	**ROCK NAME**	**MAP SYMBOL**
Crystalline	Fine to coarse crystals	Halite	Crystals from chemical precipitates and evaporites	**Rock salt**	
		Gypsum		**Rock gypsum**	
		Dolomite		**Dolostone**	
Crystalline or bioclastic	Microscopic to very coarse	Calcite	Precipitates of biologic origin or cemented shell fragments	**Limestone**	
Bioclastic		Carbon	Compacted plant remains	**Bituminous coal**	

FIGURE 5-8. This table can be used to identify the most common sedimentary rocks.

FIGURE 5-9. Fossils and rounded particles are common characteristics of sedimentary rocks. The rock on the left is a fossiliferous limestone, which contains shells. The rock on the right is a conglomerate.

Figure 5-9 is a sample of conglomerate that shows obvious characteristics of a sedimentary rock.

Although sandstone is defined by a precise limit of particle sizes (0.2–0.006 cm), you can identify it by its gritty feel, like sandpaper. Figure 5-10 shows a layered sandstone. Shale feels smooth because the clay particles of which it is composed are so tiny they are invisible without strong magnification. Rocks made of particles larger than those in smooth shale but smaller than those in gritty sandstone are classified as siltstone.

Unlike igneous rocks, clastic sedimentary rocks are not classified by their mineral composition. Any clastic sedimentary rock

FIGURE 5-10. Sandstone is composed of particles that feel gritty and are usually deposited in layers.

can contain quartz, feldspar, or clay, all of which are the remains of the weathering of other rocks. Nor does color help to tell them apart. The mineral content of the rocks influences their color. Pure quartz is usually light in color, whereas clay generally makes the rocks gray or black. Iron staining is common in sedimentary rocks, giving many of these rocks a red to brown color.

Chemical Precipitates

The next group of sedimentary rocks listed in the Scheme for Sedimentary Rock Identification is not as common as clastic rocks. This group forms as the water evaporates, leaving dissolved solids behind. When evaporation occurs, the compounds left behind become too concentrated to remain in solution. Therefore, the solids deposit as mineral crystals. This process is called chemical **precipitation**. Precipitation forms rocks known as the **crystalline sedimentary rocks**. Thick layers of underground rock salt are mined in Western New York State to be used as food additives and to melt ice on roads. These deposits as well as similar salt layers found worldwide identify places where large quantities of salt water have evaporated.

Rock gypsum and dolostone form in a similar process. However, the minerals gypsum and dolomite form from salt water with a different composition of dissolved mineral. Unlike clastic sedimentary rocks, which are classified by grain size, the chemical precipitates are classified by their chemical or mineral composition.

In general, rocks composed of crystals are not sedimentary. However, the chemical precipitates are the only sedimentary rocks made of intergrown crystals. Sedimentary rocks of chemical origin are made up of crystals that are relatively soft and often white in color. Furthermore, they are found among other layers of sedimentary rock. For these reasons, the chemical precipitates are seldom mistaken for igneous or metamorphic rocks, which are also composed of intergrown crystals. Sedimentary precipitates, such as rock salt, are usually made up of a single mineral.

Organic Rocks

Bioclastic rocks form from material made from or by living organisms. When you find a seam (layer) of coal, you are probably looking at the remains of an ancient swamp environment. This is a place where plants grew, died, accumulated layer upon layer, and were compressed and turned to stone. The green color of living plants is due to chlorophyll. But chlorophyll quickly breaks down when plants die. The carbon content of the plant remains. This gives coal its black color. Coal is mined as a fuel. In addition, it is used in making a variety of plastics and medicines. Fossil remains of extinct plants are especially common in coal, which preserves plant impressions in great detail.

A second bioclastic sedimentary rock is limestone. Limestone is usually formed by the accumulation and cementation of the hard parts of marine animals, such as the external skeletons of coral colonies and seashells. (See Figure 5-9 on page 128.) This organic material can be transformed into the mineral calcite, the primary mineral in limestone. Layers of limestone indicate the long-term presence of an active biological community in shallow seawater. This kind of active biological environment cannot be found in deep water because these ecosystems need sunlight. Sunlight cannot penetrate to the bottom in a deep-water environment. The bioclastic rocks are sometimes known as the organic group of sedimentary rocks.

STUDENT ACTIVITY 5-4 —IDENTIFICATION OF SEDIMENTARY ROCKS

1: SCIENTIFIC INQUIRY 1, 2
4: 2.1w

Obtain a set of sedimentary rocks from your teacher. Handle them carefully and let your teacher know if any samples are missing or damaged.

Use the information you learned in this chapter and the appropriate chart in the *Earth Science Reference Tables* to identify each of the sedimentary rocks in your set. List the name of each rock, such as shale or rock salt, along with the characteristics you observed that helped you to identify it.

HOW DO METAMORPHIC ROCKS FORM?

4: 2.1m

Have you ever baked cookies? You may know that the cookie dough you put into the oven has very different properties from the baked cookies that come out. In a similar way, rocks subjected to conditions of heat and pressure within Earth are changed to metamorphic rocks. In fact, the term metamorphism means "changed in form." Metamorphic rocks are the only kind of rocks that begins as other rocks, as you can see in Figure 5-11. Heat and pressure cause changes that transform rocks from one rock type to another. This usually happens either deep underground where both the temperature and the pressure are high, or close to an intrusion of hot magma at or near the surface. It is important to remember, however, that if the heating melts the rock, cooling and solidification will form an igneous rock. Metamorphic rocks do not form from magma.

The metamorphic process causes visible changes. Minerals that are stable at the surface undergo chemical changes when they are subjected to intense heat and pressure. Figure 5-12 shows a progression of rock types that occur when clay or shale is subjected to increasing heat and pressure by being buried deeper and deeper within Earth where both temperature and pressure increase.

You learned in the last section that shale is formed by the compaction of clay-sized particles under the weight of overlying layers.

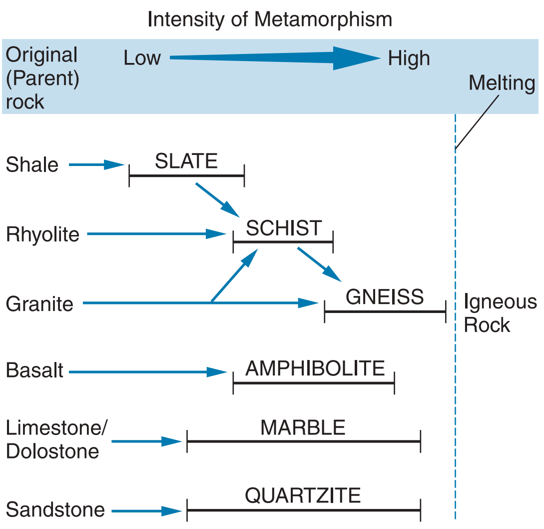
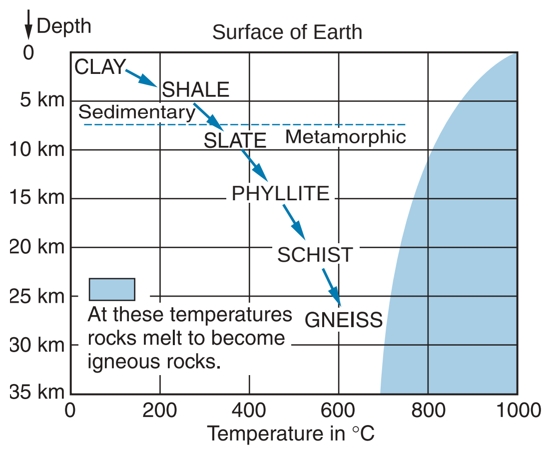


FIGURE 5-11. Metamorphic rocks are a result of changes in other kinds of rock. The black lines show the range of change in the parent rock. Metamorphism may be low or high.



Conditions necessary to make various kinds of metamorphic rocks, or to make magma, which will cool to become igneous rock.

FIGURE 5-12. This diagram represents the transformation of clay or shale into different kinds of metamorphic rock as the rock is buried deeper and deeper within Earth. The scales of depth and temperature show the conditions at which four of the most common metamorphic rocks originate.

With deeper burial, chemical changes begin that transform shale through a series of metamorphic rocks. The clay minerals begin to change to mica, as the rock becomes harder and denser, forming the metamorphic rock slate.

At this point, a new feature of the rock starts to develop. In most slate, you can see the original bedding planes of the sedimentary rock. The parent rock, shale, usually breaks along these sedimentary bedding planes. However, the growth of mica crystals is likely to be in a direction different from that of the original layers. Mica crystals grow in response to the forces on the rock. Even though these mineral crystals may be too small to be visible, they do affect the way that slate breaks. Breakage in a direction that crosses the original bedding planes signals that mineral changes happened. This alignment of mineral crystals is called **foliation**. Foliation is a textural feature common to many metamorphic rocks.

Continued burial produces a rock called phyllite (FILL-ite). The growth of mica crystals gives phyllite a silklike sheen and may destroy the original sedimentary layering. Although the mica crystals are still too small to be visible without magnification, the shiny appearance of the rock and the even more noticeable breakage along the foliation direction indicates that mineral changes continued. Schist, the next rock to form, has mica crystals that can be seen without magnification. Continued growth of mica crystals in a single direction adds to the foliation.

The final metamorphic product is gneiss (NICE). Not only can you see evidence of parallel crystal growth (foliation) in gneiss, but also the minerals may have separated into light- and dark-colored layers, parallel to the foliation. This is a property called **banding**. The light-colored bands are mostly quartz and feldspar. Feldspar is a new mineral that may not be seen in schist. The dark bands are mostly biotite, amphibole, and pyroxene. Figure 5-13 shows banding in gneiss. Some samples of gneiss do not show banding. Gneiss may also look like granite with a lot of feldspar, but without banding. However, even these samples will show a parallel alignment of mineral crystals.

The change from clay to mica and then to feldspar is not an isolated progression. Other minerals, many of them unique to metamorphic rocks, form and disappear along the way. Red garnet is a

FIGURE 5-13. Gneiss is a metamorphic rock that is often composed of minerals separated into light- and dark-colored bands. The light bands are rich in feldspar and quartz. Amphibole and pyroxene are the primary minerals in the dark bands.

good example. Garnet can often be seen as little pods in schist or gneiss.

Red garnet (almandine) is a result of mineral changes in formerly sedimentary or igneous rocks that contain both iron and aluminum. Due to the garnet mines in the Adirondack Mountains, this is the official New York State mineral by an act of the legislature.

Changes during the formation of a metamorphic rock destroy original structures in a rock, such as sedimentary layering and fossils. Gradually, these features are eliminated by foliation and crystal growth as the rock is subjected to more heat, more pressure, and more time.

The series of metamorphic rocks explained above presents the most common examples of the foliated metamorphic rocks. Yet some kinds of metamorphic rocks do not show foliation. When limestone is subjected to intense heat and pressure, calcite crystals grow and the rock changes from limestone to marble. The growth direction of calcite crystals is not affected by the force of the overlying rock or by movements of Earth's crust. This is why foliation does not occur in marble. Sometimes marble shows a swirled layering, but this is probably due to differences in composition of the original limestone layers. When sandstone changes to quartzite, and conglomerate to metaconglomerate, these metamorphic products do not show parallel crystal alignment. Therefore, marble,

FIGURE 5-14. Marble is a light-colored metamorphic rock composed mostly of calcite. Marble forms when limestone is subjected to intense heat and pressure. Both marble, on the left, and metaconglomerate, on the right, are nonfoliated metamorphic rocks.

quartzite, and metaconglomerate are commonly *nonfoliated* metamorphic rocks, as seen in Figure 5-14.

Regional and Contact Metamorphism

Metamorphic rocks can be separated into two groups by their origin. Sometimes, large-scale movements of Earth's crust cause a huge region of rock to sink into Earth. When this occurs, a large mass of rock is changed by heat and pressure. This process is called **regional metamorphism**. As the rock is drawn deeper into Earth, chemical changes in the minerals, crystal growth, and compaction cause the original parent rock to be metamorphosed. Regional metamorphism often creates rocks that are both foliated and highly distorted, or folded, as in Figure 5-15.

If metamorphic rocks form deep within Earth, why do we find them at the surface? In Chapter 14, you will learn that large-scale movements of Earth's crust are related to heat flow from deep within the planet. Forces push rock to the depths where metamorphism occurs. Forces can also uplift metamorphic rocks and the rocks covering them to form mountain ranges. After uplift, weathering and erosion wear down the mountains to expose the

FIGURE 5-15. The complicated folding of this banded gneiss was caused by intense pressure, temperature, and mountain-building forces deep within Earth.

regional metamorphic rocks. This process may take millions of years.

The next group of metamorphic rocks occurs over a smaller area. An intrusion of hot, molten magma will change the rock with which it comes in contact. This process is called **contact metamorphism**. In this environment, rocks are not exposed to the intense pressure that is found deeper within Earth. Therefore, rocks that have undergone contact metamorphism do not show foliation. The farther you go from the heat source (intrusion), the less the parent rock has changed. In fact, it is common to find metamorphic rock grading into the original sedimentary or igneous rock within a few meters of the heat source. This change can sometimes be observed as a decrease in crystal size as you move from the intensely baked rock next to the intrusion into rock that has been altered less by the heat. Hornfels is a name often applied to contact metamorphic rock of various mineral compositions.

The *Earth Science Reference Tables* contains the Scheme for Metamorphic Rock Identification. (Figure 5-16 on page 136.) The four rock types at the right in the top half of the chart are the four foliated metamorphic rocks. They are listed in order of increasing

Scheme for Metamorphic Rock Identification

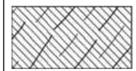
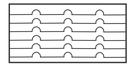
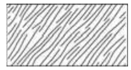
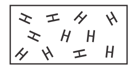
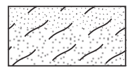
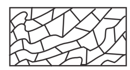
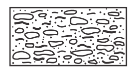
<table>
<tr><th colspan="2">TEXTURE</th><th>GRAIN SIZE</th><th>COMPOSITION</th><th>TYPE OF METAMORPHISM</th><th>COMMENTS</th><th>ROCK NAME</th><th>MAP SYMBOL</th></tr>
<tr><td rowspan="4">FOLIATED</td><td rowspan="3">MINERAL ALIGNMENT</td><td>Fine</td><td rowspan="4">MICA
QUARTZ
FELDSPAR
AMPHIBOLE
GARNET
PYROXENE</td><td rowspan="4">Regional
(Heat and pressure increases)</td><td>Low-grade metamorphism of shale</td><td>Slate</td><td></td></tr>
<tr><td rowspan="2">Fine to medium</td><td>Foliation surfaces shiny from microscopic mica crystals</td><td>Phyllite</td><td></td></tr>
<tr><td>Platy mica crystals visible from metamorphism of clay or feldspars</td><td>Schist</td><td></td></tr>
<tr><td>BAND-ING</td><td>Medium to coarse</td><td>High-grade metamorphism; mineral types segregated into bands</td><td>Gneiss</td><td></td></tr>
<tr><td rowspan="5" colspan="2">NONFOLIATED</td><td>Fine</td><td>Carbon</td><td>Regional</td><td>Metamorphism of bituminous coal</td><td>Anthracite coal</td><td></td></tr>
<tr><td>Fine</td><td>Various minerals</td><td>Contact (heat)</td><td>Various rocks changed by heat from nearby magma/lava</td><td>Hornfels</td><td></td></tr>
<tr><td rowspan="2">Fine to coarse</td><td>Quartz</td><td rowspan="3">Regional
or
contact</td><td>Metamorphism of quartz sandstone</td><td>Quartzite</td><td></td></tr>
<tr><td>Calcite and/or dolomite</td><td>Metamorphism of limestone or dolostone</td><td>Marble</td><td></td></tr>
<tr><td>Coarse</td><td>Various minerals</td><td>Pebbles may be distorted or stretched</td><td>Metaconglomerate</td><td></td></tr>
</table>

FIGURE 5-16.

metamorphic change and increasing grain size. These four rocks show the progressive metamorphism of shale that was explained earlier in this section. In the "composition" column, note the shaded bars that indicate the mineral makeup of these rocks. These bars show that minerals in the mica family are found in all four foliated metamorphic rock types. Quartz, feldspar, amphibole, and garnet are not common in slate, but are common in the three foliated rock types below slate. Of the six minerals shown here, pyroxene is the best indicator of extreme conditions of heat and pressure.

Unlike the rocks in the top half of this chart, the four rocks named at the right in the bottom half of the chart do not represent a progressive change. Each has a different mineral and chemical composition. These are the four most common metamorphic rocks that do not show foliation.

STUDENT ACTIVITY 5-5 —IDENTIFICATION OF METAMORPHIC ROCKS

1: SCIENTIFIC INQUIRY 1
6: MODELS 2

Obtain a set of metamorphic rocks from your teacher. Handle them carefully and let your teacher know if any samples are missing or damaged.

Use the information in this chapter and the appropriate chart in the *Earth Science Reference Tables* to identify each of the metamorphic rocks in your set. List the name of each rock, such as schist or marble, along with the characteristics you observed that helped you to identify it.

WHAT IS THE ROCK CYCLE?

4: 2.1m
6: MODELS 2

There is a popular saying, "The only thing constant is change." This saying reminds us that everything around us is changing. Many geological changes occur so slowly that they are difficult to observe. Nearly everywhere, rocks are slowly changing as they adjust to the conditions and environment in which they are found. These changes are shown in a model of Earth environments and materials called the **rock cycle**. (See Figure 5-17 on page 138.)

Planet Earth receives only a very small amount of matter from outer space in the form of meteorites. At the same time, a small amount of Earth's atmosphere escapes. Therefore, in terms of mass, the planet is nearly a closed system. (A closed system is one that has no exchange with the environment outside itself.) Rocks change from one form to another.

In Figure 5-17, within the rectangles are the three major categories of rocks: sedimentary, metamorphic, and igneous. Sediments and magma are shown in ovals because, although they are important substances within the rock cycle, they are not actually kinds of rock. The lines and arrows show the processes that change materials as they go through the rock cycle. The terms printed along these lines tell you what changes are represented and the order in which they occur.

For example, magma can change to a different substance in only one way: it forms igneous rock by the process of solidification, or crystallization. However, igneous rock can change to another

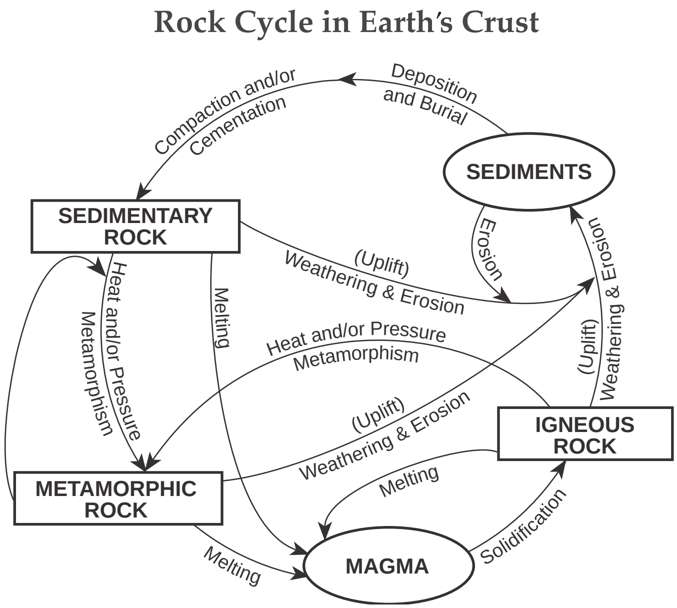


FIGURE 5-17. This diagram from the *Earth Science Reference Tables* shows that nearly all rocks are a result of geologic processes operating on other rocks. (Bioclastic and crystalline sedimentary rocks are exceptions.)

substance by any of three paths. If it is heated and melts, it can turn back into molten magma. If the igneous rock undergoes intense heating and possibly pressure, but does not melt, metamorphism will transform the igneous rock into a metamorphic rock. In the third possible path, the igneous rock is exposed to the atmosphere, probably by being pushed up to the surface. There air, water, and weather break it down and carry it away as sediments. The term "uplift" appears in parenthesis because uplift to expose the rock at the surface is likely, but it is not necessary. In the case of a lava flow onto the surface, no uplift is needed to expose the rock to weathering and erosion.

The rock-cycle diagram illustrates that nearly all rocks are made from the remains of other rocks. In the rock cycle, as you follow the arrows that show changes, notice that each begins and ends with Earth materials. None of the arrows comes in from outside the diagram. None of them take Earth materials out of the system. It is basically a closed system. To watch an animation of the rock cycle, visit the following Web site: ***http://www.geolsoc.org.uk/rockcycle***

There is one group of sedimentary rocks that does not fit into this rock cycle. The organic sedimentary rocks, such as limestone and coal, are formed from the remains of plants and animals, not other rocks.

Some rocks show a complex origin. You may remember that conglomerate is made from pebbles that are held together by a cementing material, such as silica (very fine quartz), clay, or calcite. If the conglomerate contains pebbles of gneiss, granite, and sandstone, each component of the conglomerate shows a different process of rock formation found in the rock cycle.

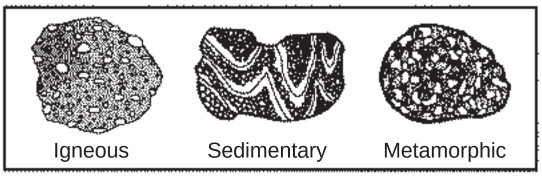
CHAPTER REVIEW QUESTIONS

PART A

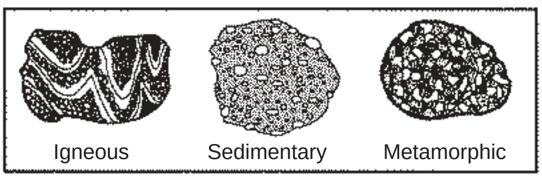
1. Which igneous rock has a vesicular texture and contains the minerals potassium feldspar and quartz?

   (1) andesite
   (2) pegmatite
   (3) pumice
   (4) scoria

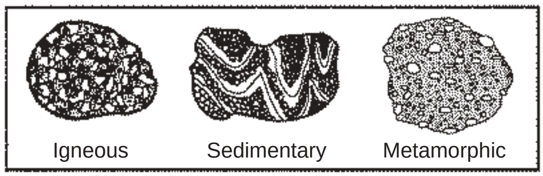
2. Which set of rock drawings below is correctly labeled?



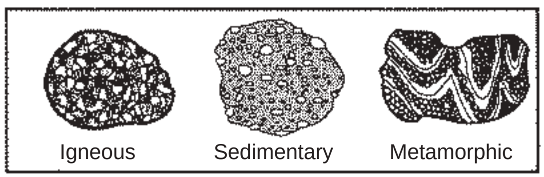
(1)



(2)



(3)



(4)

3. Dolostone is classified as which type of rock?

   (1) land-derived sedimentary rock
   (2) chemically formed sedimentary rock
   (3) foliated metamorphic rock
   (4) nonfoliated metamorphic rock

4. What is the origin of fine-grained igneous rock?

(1) lava that cooled slowly at Earth's surface
(2) lava that cooled quickly at Earth's surface
(3) silt that settled slowly in ocean water
(4) silt that settled quickly in ocean water

5. Which kind of metamorphic rock often forms from sandstone adjacent to an intrusion of magma near Earth's surface?

(1) quartzite
(2) marble
(3) phyllite
(4) slate

6. Which rock was formed organically and sometimes contains plant impressions?

(1) rock gypsum
(2) phyllite
(3) breccia
(4) coal

7. Wavy bands of dark minerals visible in gneiss bedrock probably formed from the

(1) cementing together of individual mineral grains
(2) cooling and crystallization of magma
(3) evaporation of an ancient ocean
(4) heat and pressure during metamorphism

8. Rita collected a cup of quartz sand at the beach. She poured a saltwater solution into the sand and allowed it to evaporate. The mineral residue from the salt water cemented the grains together, forming a material that is most similar to

(1) an extrusive igneous rock
(2) an intrusive igneous rock
(3) a clastic sedimentary rock
(4) a foliated metamorphic rock

9. Fossils of sea shells are found in a natural bedrock exposure. How did this rock probably form?

(1) intense metamorphism of sedimentary rock
(2) compaction and cementing of sediments
(3) crystallization of magma deep underground
(4) crystallization of lava at Earth's surface

10. What is the most common mineral in andesite?

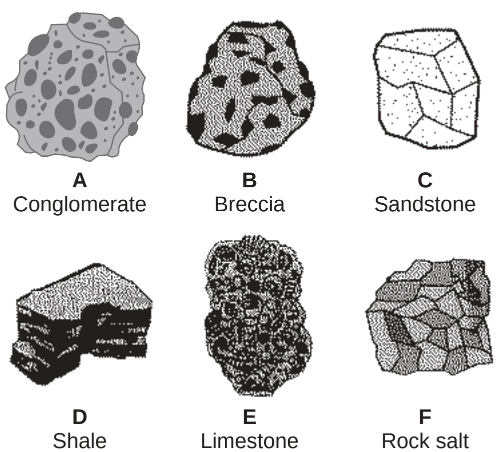
(1) quartz (3) plagioclase feldspar
(2) biotite (4) potassium feldspar

11. What kind of rock is likely to form from lava extruded by a volcano?

(1) light-colored metamorphic
(2) dark-colored metamorphic
(3) fine-grained igneous
(4) coarse-grained igneous

PART B

Base your answers to questions 12 through 14 on the drawings below of six sedimentary rocks labeled A through F.



12. Most of the rocks shown were formed by

(1) volcanic eruptions and crystallization
(2) compaction and/or cementation
(3) crystal growth deep underground
(4) melting and/or solidification

13. Which two rocks are composed primarily of quartz, feldspar, and clay minerals?

(1) rock salt and conglomerate
(2) rock salt and breccia
(3) sandstone and shale
(4) sandstone and limestone

14. Which table below shows the rocks correctly classified by texture?

Texture	Clastic	Bioclastic	Crystalline
Rock	A, B, C, D	E	F

(1)

Texture	Clastic	Bioclastic	Crystalline
Rock	A, B, C	D	E, F

(2)

Texture	Clastic	Bioclastic	Crystalline
Rock	A, C	B, E	D, F

(3)

Texture	Clastic	Bioclastic	Crystalline
Rock	A, B, F	E	C, D

(4)

PART C

Base your answers to questions 15 through 17 on the table below. Some information has been left blank.

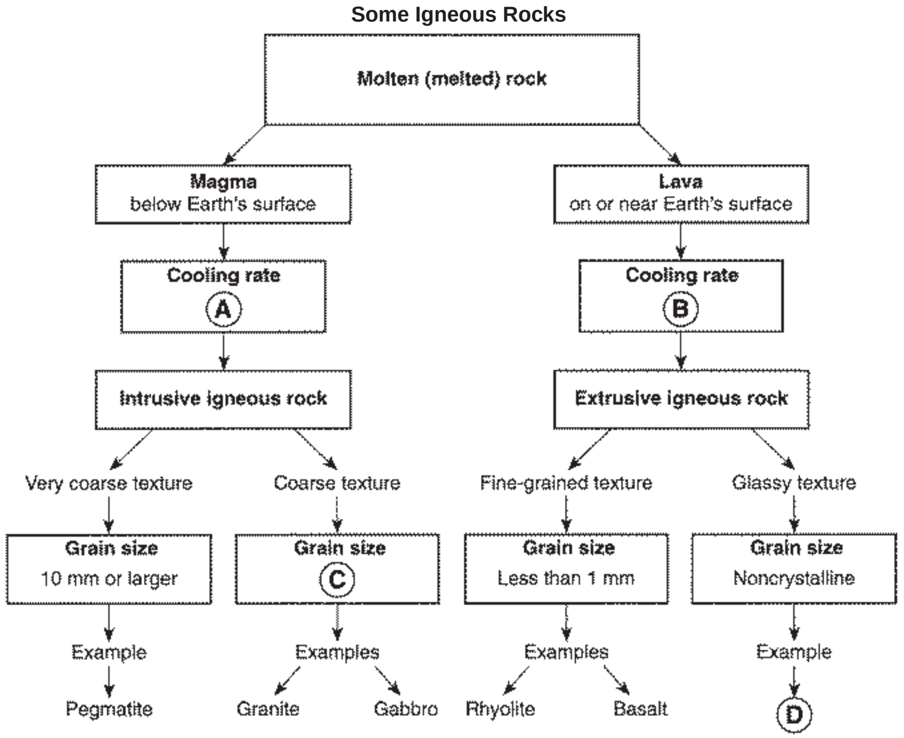
Rock Sample Number	Composition	Grain Size	Texture	Rock Name
1	Mostly clay minerals		Clastic	Shale
2	All mica	Microscopic, fine	Foliated with mineral alignment	
3	Mica, quartz, feldspar, amphibole, garnet, pyroxene	Medium to coarse	Foliated with banding	Gneiss
4	Potassium feldspar, quartz, biotite, plagioclase feldspar, amphibole	5 mm		Granite

15. State a possible grain size, in centimeters, for most of the particles found in sample 1.

16. What is the rock name of sample 2?

17. Write a term or phrase that describes the texture of sample 4.

Base your answers to questions 18 through 20 on the flowchart below, which shows the formation of selected igneous rocks.



18. Compare the cooling rate at A with the cooling rate at B.

19. What is the numerical grain size at C?

20. Name one igneous rock that could be placed at D.

CHAPTER

6 Managing Natural Resources

WORDS TO KNOW

conservation	nonrenewable resource	pollution
global warming	ore	renewable resource
natural resource		

This chapter will help you answer the following questions:

1. What are renewable and nonrenewable natural resources?
2. What are our most useful geological resources?
3. How can we conserve our natural resources?
4. What are the environmental consequences of using our natural resources?

HOW DOES THE GLOBAL MARKETPLACE WORK?

6: SYSTEMS THINKING 1
6: EQUILIBRIUM AND STABILITY 4
7: CONNECTIONS 1

A number of important changes in the world have dramatically changed commerce and the use of natural resources. The rise of civilization allowed individuals to work together for common goals: most notably food, shelter, security, and wealth. The Industrial Revolution added large-scale technology and mass production, allowing individuals to produce more goods. Continued progress has allowed people and products to travel worldwide. Globalization has joined national economies into a single worldwide economy, connecting humans as never before.

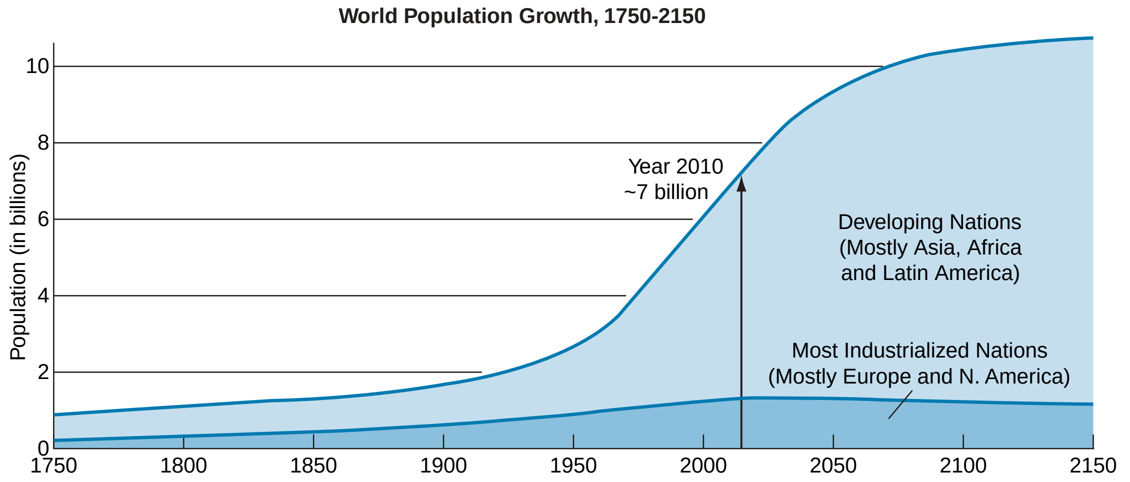


FIGURE 6-1. Demand for natural resources in recent years has been accelerated by the growth of strong economies in Asia and other parts of the developing world that have human populations much larger than the present economic powers.

But how do these changes affect you? While your great-grandparents probably got food and other needs from local suppliers, the world is very different today. For example, a car bought in your home town may be made with metals mined in Brazil or China. The car may be designed in Japan or Europe and built in the United States. Your fuel may come from Canada, Mexico, or Venezuela.

Managing our natural resources must take into account the global economy. Figure 6-1 shows that the greatest growth in world population is in the developing world. As these nations develop strong economies, they will use increasing amounts of natural resources. Visit the following Web site to see how the world population is changing and how other statistics change: ***http://www.poodwaddle.com/worldclock.swf***

What is a Natural Resource?

The food you eat, the products you buy, and the clothes you wear are all produced by technology from Earth's natural resources. A **natural resource** is any material from the environment that is used to maintain people's lives and lifestyles. The word *resource* comes from an old French word that means "to arise in a new form." It is the responsibility of all people to make the best use of our natural resources, while conserving them for future generations and protecting the environment. At every step, we must make important decisions and compromises. How much will be used now and how much will be conserved? How can these resources be extracted while maintaining a clean and beautiful environment? Not everyone will agree with the decisions that are made. But people can all make better decisions if they understand the issues involved in using and conserving resources. Earth's natural resources can be divided into two groups; nonrenewable and renewable. Visit the following Web site and go to the second page to learn about the Earth materials in an automobile: ***http://www.geosociety.org/educate/LessonPlans/Earth_Materials_in_Subaru.pdf***

WHAT ARE NONRENEWABLE RESOURCES?

4: 3.1c
6: SYSTEMS THINKING 1
6: EQUILIBRIUM AND STABILITY 4
7: CONNECTIONS 1

Nonrenewable resources exist in a fixed amount, or if they are formed in nature, the rate of formation is so slow that the use of these resources will decrease their availability. Rocks, minerals, and fossil fuels are the primary nonrenewable resources. In nearly every case, the use of these resources is increasing while the natural supply (reserves) is decreasing. This situation forces us to look for lower-quality reserves to meet our growing demands. Copper, which is mined from the ground, is a nonrenewable resource.

Metal Ores

Many of the minerals and rocks you studied in Chapters 4 and 5 are important resources. Rocks that are used to supply natural resources are called **ores**. The resources must be extracted, or separated, from their ores. Economically important metallic elements are obtained from minerals. Some elements, such as gold, silver, and copper, occur as native metals, that is, uncombined with other elements.

COPPER The element copper is used in electrical wiring, plumbing, coins, and a wide variety of other applications. Gold is a better electrical conductor than is copper. However, copper is much cheaper than gold because it is more plentiful. Copper can be drawn into wire (ductile) and pressed into thin sheets (malleable). When copper is mixed with other metals such as zinc and tin, it forms alloys (mixtures of metals). These alloys, brass and bronze, are relatively hard, resist being deformed, and resist weathering.

Like most other geological resources, copper is extracted from rocks that have unusually high concentrations of copper. In some places such as northern Michigan, small amounts of native copper are found. (See Figure 4-2 on page 88) Most copper is obtained from minerals that were deposited by hot water circulating deep underground. In the early years of mining, some locations produced ores with as much as 10 percent copper. However, as the most concentrated ores were used up, new technologies were developed along with large-scale mining operations. Now, refiners can profitably extract copper from ores that contain less than 1 percent copper.

Most copper today is produced from open pit mines where giant machines scoop up tons of copper ore with each bite. The ore is transported to refineries where it is concentrated and purified.

GOLD Gold is sometimes found in sand and gravel deposits in streams and along shorelines. Due to its high density, gold transported by running water settles in places where the water slows. The pieces of gold get caught in cracks in the bedrock. (Bedrock is the solid rock that can be found everywhere under the soil and sediments.) Gold is also found in solid rock where it has been brought by hot water. Gold is valued mostly because of its mechanical and electrical properties. Gold is also attractive and does not corrode. Therefore, gold is often used in jewelry. Of the estimated 100,000 tons of gold that have ever been produced, nearly all of it is still in circulation.

IRON Today, iron is the principal metal of construction and technology. It is used in making frames for buildings, for automobiles, and even in eating utensils. Iron is found worldwide, and this metallic element is second only to aluminum in abundance in Earth's crust. Iron ore is easy to find and is inexpensive to extract.

Combining iron with small amounts of other metals makes steel. Steel is harder and more resistant to breakage and corrosion than iron. The most important iron ore deposits are the banded

FIGURE 6-2. Banded iron ore is nonrenewable because it formed long ago when oxygen was just beginning to enter Earth's atmosphere.

iron formations that settled out of ancient seas early in Earth's history (Figure 6-2). At that time, the atmosphere contained very little oxygen. As oxygen in the atmosphere became abundant, bacteria extracted iron from the rocks and deposited concentrated iron oxide. While there are great quantities of iron ores, the fact that almost no new ores are being formed makes iron a nonrenewable resource.

Using Mineral Resources

Geologists locate ore deposits and estimate the amounts of metal that can still be extracted. Aluminum and iron are so abundant in Earth's crust that geologists are not concerned about running out of them. However, the best reserves of copper and gold in the United States have already been used up. For this reason, the amount of gold and copper we import is increasing. These rare metals are often recycled. About 25 percent of the copper produced in the United States is the product of recycling. The amount of a mineral resource that is recycled depends on its cost. The more it is worth, the more is recycled. Because of gold's high price, people do not toss away a gold object the way they discard aluminum soda cans and iron objects. Visit the following Web site to see a mineral resources map of the United States: ***http://minerals.usgs.gov/minerals/pubs/mapdata/minesmap.gif***

STUDENT ACTIVITY 6-1 —ADOPT A RESOURCE

2: INFORMATION SYSTEMS 1, 2, 3

Select a specific nonrenewable resource. Then ask your teacher for permission to prepare a report on that resource. Your report should include where the resource is found, how it is refined or changed for use, and what the resource is used for. How can this resource be recycled profitably?

Fossil Fuels

Coal, petroleum, and natural gas are used for the production of electricity, for heating, and for transportation. The energy stored in these substances began as sunlight absorbed by prehistoric plants.

PETROLEUM While the United States is the world's largest user of petroleum (oil), it has only about 3 percent of the world's oil reserves. A serious interruption of the flow of foreign oil would have a devastating effect on our economy.

Petroleum formed from the remains of microscopic organisms that lived in the oceans hundreds of millions of years ago. The remains escaped complete decay when they sank to the cold, dark ocean bottom. The deposition of more layers of sediments trapped the organic remains. Over time, the organic remains changed to a complex, low-density liquid and natural gas. These substances moved upward until they were trapped by an overlying layer of fine-grained rock, such as shale. If an oil company has enough skill and luck it may drill into a layer where oil and gas are present. Then, it can pump the oil and gas out of the ground. Petroleum products are so valuable on world markets that oil is sometimes called "black gold." Figure 6-3 on page 150 predicts a decrease in petroleum production. As the world's primary source of energy, this will cause the price of petroleum products to increase rapidly.

COAL While the United States has large deposits of coal, it is used mostly in large power plants to generate electricity. In these power plants, large quantities of coal are handled efficiently and air pollution controls are used to reduce air pollution. The use of

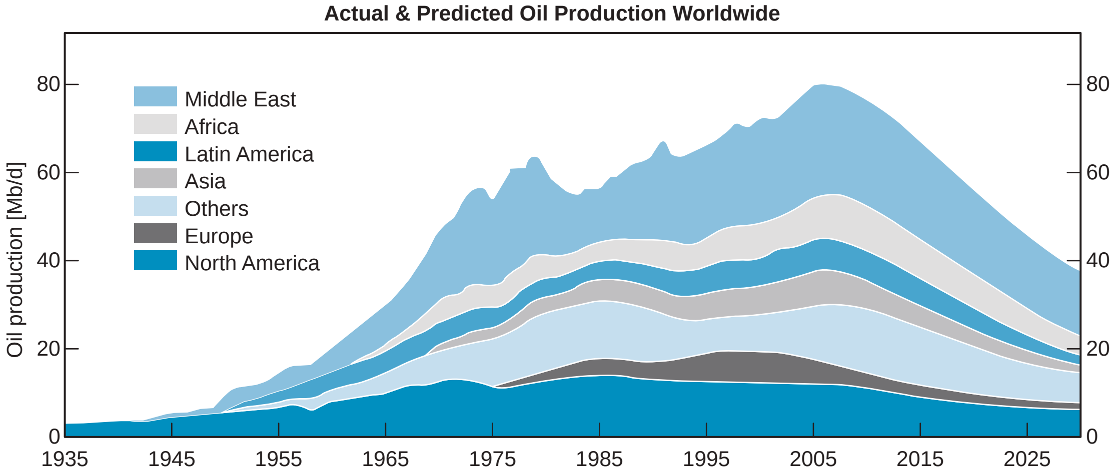


FIGURE 6-3. Some geologists predict that oil production will peak in the near future and then decline.

coal for home heating and cooking has decreased because oil, gas, and electricity are easier to use and cause less air pollution.

The fossil fuels are considered nonrenewable resources because we are using them much more quickly than natural processes can replace them. Some scientists estimate that in a few hundred years Earth could run out of fossil fuels that took 500 million years to form.

Construction Materials

By total mass, more Earth resources are used in construction than in any other application. The material used depends on the needs of the project and the materials available in the area. Sand, gravel, and crushed stone are spread as a structural base under pavements. These materials are used because they do not compress under heavy traffic, and they allow water to drain through them. A proper base layer helps the roads last longer than roads built directly on the ground. Sand and gravel are New York's most economically important mineral resources.

Concrete is made from a mixture of limestone (or dolostone) and clay that has been baked to drive off the water and carbon dioxide content of these materials. When water is added to the concrete, it "sets" to form a resistant building material. Cut stone, although it is more expensive than brick, concrete, or steel, is sometimes used for the outer facing of buildings. Like other resources, the price of concrete has been affected by economic growth in the developing countries.

WHAT ARE OUR MOST IMPORTANT RENEWABLE RESOURCES?

6: SYSTEMS THINKING 1
6: EQUILIBRIUM AND STABILITY 4
7: CONNECTIONS 1

Renewable resources are those resources that can be replaced by natural processes at a rate that is at least equal to the rate at which they are used. For example, sunlight is our planet's principal source of energy. Solar heat collectors make use of this energy. But, as fast as it is used, more solar energy arrives. Figure 6-4 is a map showing places in the United States that are most suited to harvesting solar energy. Sunlight also powers wind, another form of renewable energy. Electrical power from wind generators has become popular in several "wind farms" within New York State in recent years.

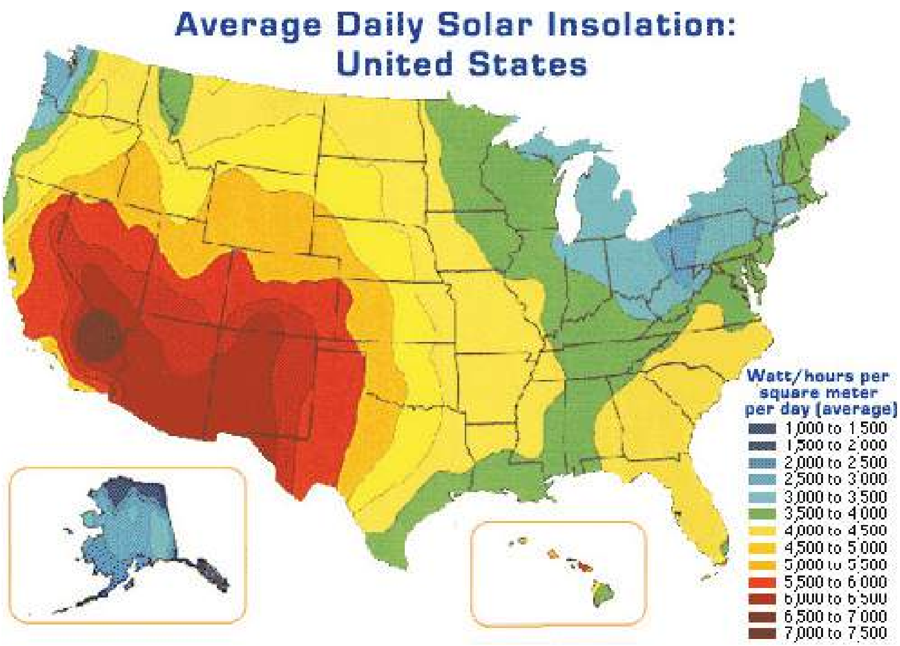


FIGURE 6-4. In the United States, solar energy is most concentrated in the desert of the Southwest. Here the sun is highest in the sky and the weather is often clear. Unfortunately, collecting solar energy is limited by high installation costs and its low concentration, requiring very large collection areas.

Although renewable resources may never run out, our use of these resources is sometimes limited by how quickly they are replaced. If your community uses a nearby river for its water supply, the amount of water used cannot be greater than the total amount of water flowing in the river.

Wood

Before people made extensive use of fossil fuels, wood was the fuel of choice. In most areas, wood could be cut locally. Even now, people burn wood to heat homes, prepare hot water, and cook food. Wood is a renewable resource. Once the trees are cut, new trees can grow back in as little as 10 years, or perhaps as long as a century. As long as usage and replacement are in balance, the supply could be unlimited.

Soil

For now, soil will be considered as the loose material at Earth's surface that can support plant growth. Later in the book, you learn a definition that is related to how soil is formed. Biological productivity is an essential feature of soil as a resource. If you look at a food chain, it begins with the organisms called producers (green plants). Plants are the only organisms that can live in an environment without needing other organisms for food. The producers use the substances they get from soil, along with air, water, and sunlight to create living tissue. All animals (including humans) depend on producers to transform the resources of the physical environment into food.

In some places, the best soil has been carried away by running water or by dust storms. This is often the result of careless farming practices. When a farmer plows up and down the slopes of hills, this allows runoff to carry away large amounts of soil. To avoid this, farmers plow the land along the contours of the hills. This makes each ridge of soil act as a dam to hold back the water and its load of sediments. Another careless procedure is leaving land without any plant cover. Without plants and their roots to slow runoff and hold soil in place, soil can be quickly washed or blown away.

The processes of weathering, infiltration of groundwater, and biological activity can restore soil, but the process could easily take hundreds of years. Although some people consider soil to be a renewable resource, the best practice is to protect soil through conservation.

Water

Water is another essential natural resource. All living things need water or they depend upon other organisms that need water. Plants use water during photosynthesis. People use water for drinking, transportation, waste disposal, industrial development, and a habitat for our food sources. Of Earth's water, 97 percent is salt water. Salt water is in the oceans and in several landlocked bodies of water, such as the Great Salt Lake in Utah. However, this water cannot be used for drinking and agriculture.

Only about 3 percent of Earth's water is freshwater. Glaciers and the polar ice caps hold 2 percent of Earth's freshwater. Of the remaining 1 percent, most is in the ground where it is not as easy to tap as are sources at the surface. Most of our water needs are fulfilled by the 0.008 percent of the total that is found as surface water in streams and lakes.

The Colorado River flows from the Rocky Mountains southwest through the desert toward the Pacific Ocean. Parts of seven states depend on Colorado River water. Through a series of agreements the states of Colorado, Utah, New Mexico, Wyoming, Arizona, Nevada, and California, as well as Mexico, have tapped into the river. Their residential, agricultural, and industrial use of the water uses the total volume of water flowing in the river. Unless there is a flood, none of the water from the Colorado River reaches the ocean. This area is the fastest-growing region in the country. How will this area find more water to support population and economic growth?

Water is usually considered a renewable resource. As water is drawn from surface sources, such as streams and lakes, more water flows in to replace it. There is an assumption here that once water is used, the water cycle replaces it. It is not always that simple.

In the 1920s, the federal government encouraged people to move into the Great Plains of the United States. People were offered loans and inexpensive land. Rich soil and good precipitation made this region seem to be a natural location for agricultural development. However, in the 1930s, there was a drought.

Meanwhile the new farm owners had plowed the land and it was exposed to wind erosion. The dust storms of the 1930s blew away much of the most productive soil. Some farmers drilled wells to bring water to the surface. That part of the United States is over a natural groundwater reservoir called the Ogallala aquifer. While farming continues today, it often depends on irrigation water drawn from the aquifer. Each year, the water level in the aquifer goes down because more water is withdrawn than nature can restore.

Lack of freshwater is a problem in parts of Africa and other arid (dry) regions of developing countries. Temporarily, new wells will help these people find clean water for drinking and household use. But what will happen when their aquifers are depleted?

HOW CAN WE CONSERVE RESOURCES?

6: SYSTEMS THINKING 1
6: EQUILIBRIUM AND STABILITY 4
6: OPTIMIZATION 6
7: CONNECTIONS 1

Conservation is the careful use, protection, and restoration of our natural resources. To practice conservation, people need to estimate their resources and forecast their needs. Only then can they decide what needs to be done. For example, although the use of aluminum is increasing, Earth's crust contains so much aluminum that there seems little danger of running short. However, the future for gasoline and other petroleum products is not as bright. Some people estimate that petroleum will start to run short in just a few decades. There is a popular saying "Necessity is the mother of invention." Necessity to replace petroleum fuels may be getting close. But it is not clear what "inventions" will carry us through this crisis. Conservation generally involves one or more of the three "R's" of ecology: reduce, recycle, and replace.

Reduction

If you were to find a soda can that was made 50 years ago, you might be surprised at how heavy it would be. Changes in the manufacturing process and the shape of soda cans have allowed beverage companies to use much less metal, generally aluminum, than ever before. People who carpool, drive small cars or drive hybrids not only save money, but they also use less gasoline. This helps to extend our limited and petroleum reserves.

Recycling

A large fraction of the copper we use has been recovered from old buildings, automobiles, and electrical parts. If you grew tired of a piece of gold jewelry, you would probably not put it into the trash. More likely, you would sell it for its value in gold. While aluminum is plentiful, it is costly to extract and purify from its ore. This has contributed to programs to recycle aluminum cans. (Recycling programs also help the environment by making it less likely that people will throw empty soda cans along highways.) Each time we use recycled metals we delay the inevitable time when these resources will run out.

Replacement

Replacement is often the long-term solution to decreasing resources. In the past, most people heated their homes and cooked their food by burning wood. Wood is a renewable resource. However, as the human population grew and people moved into cities, nearby wood sources could not keep up with the growing need for fuel. Coal and then petroleum fuels replaced wood as the fuel of choice. In many applications, plastics are replacing wood and leather. Necessity will certainly continue to bring about new solutions to our problems.

STUDENT ACTIVITY 6-2 —WATER USE IN THE HOME

6: OPTIMIZATION 6

Measure or estimate the amount of water that your family uses at home on a typical day. To do this you will need to identify all the household devices and activities that use water. You must also find ways to determine how much water these uses require. (You may find useful information in reference sources, on the Internet, on your water bill, or from your water meter.) After you have determined your family's daily water usage, suggest ways to reduce your water consumption.

WHAT ARE THE EFFECTS OF ENVIRONMENTAL POLLUTION?

6: SYSTEMS THINKING 1
6: EQUILIBRIUM AND STABILITY 4
6: OPTIMIZATION 6
7: CONNECTIONS 1

Pollution is any material or form of energy in the environment that harms humans or the plants and animals on which they depend. Pollution can be classified according to the part of the environment that has been affected: ground, water, and/or air.

Ground Pollution

The city of Niagara Falls, New York, became an industrial area because of the availability of inexpensive hydroelectric power. Chemical plants were built in the area to take advantage of this local resource. Unfortunately, the local government did not monitor or regulate the industry and its disposal of chemical wastes. When a local waterway called Love Canal was filled in, drums of toxic chemicals were buried. Eventually the land was given to the city of Niagara Falls. The city allowed low-cost housing and an elementary school to be built on the land.

Toxic liquids began to seep out of the ground. People, especially children, developed health problems. The toxic chemicals were linked to these health problems in the 1970s. The residents were shocked and angry. They did not want their families, especially the children, to be exposed to these chemical waste products.

As the tragedy became news, the value of homes in the area decreased dramatically. People could not sell their homes and they could not afford to buy homes in another area. The homeowners felt let down by their local government, which should have informed them about the chemical danger at Love Canal.

Another example of ground pollution can be found in agricultural areas. Insecticides have been sprayed to protect crops from insect damage. Over the years, these chemicals may remain in the soil and make the soil unfit for other crops. Furthermore, windblown dust can be a hazard to farm workers. In addition, dust can carry the chemicals to nearby residential areas. Children and senior citizens are especially sensitive to diseases caused by exposure to dangerous substances.

Weapons production, nuclear power generation, health services and a wide variety of other important uses have created tons of radioactive waste. Much of it is mildly radioactive and can be buried in special landfills. However, high-level radioactive waste can be isolated in places such as deep mine tunnels where it will still be very dangerous for centuries. How to dispose of or store these radioactive materials has been in debate for decades, and the debate is likely to continue for many more years.

Water Pollution

It is more efficient to send electrical power over long distances if the voltage is stepped up to levels that would be dangerous in homes. The General Electric Company (GE) needed to build transformers to change the high-voltage current sent over transmission lines into ordinary household current. Transformers will overheat if they are not cooled by a liquid that carries away excess heat. Water is a good absorber of heat, but it can evaporate or boil away. In the mid-1950s, GE began to use liquids called polychlorinated biphenyls (PCBs) in transformers. PCBs are good absorbers of heat and are less likely to boil away than is water. Because PCBs are chemically stable, the company felt that there was little danger when these substances leaked into the environment. Two manufacturing plants along the Hudson River north of Albany, New York, used the chemicals. Neither GE nor the state knew that PCB pollution would become a serious environmental issue.

After PCBs had been used for several decades, scientists discovered that PCBs could cause serious health problems if they were in drinking water. Scientists found that fish in the Hudson River had absorbed PCBs when they ate plants or other fish containing PCBs. The chemicals built up in the bodies of the fish. People learned that PCBs were not as safe as they at first appeared to be. Meanwhile, dangerous amounts of PCBs had washed into the Hudson River at the two manufacturing plants. The government warned people about the danger of eating fish from the river and looked for a long-term solution.

GE and environmental groups have disagreed on what to do about the contamination. Environmentalists (and the courts) have said that GE should remove the PCBs by dredging the most contaminated mud and dumping it on land. GE wants to leave the sediments where they are. The company says that the PCBs will eventually wash out of the river. Like many environmental controversies, all solutions have some disadvantages. The current settlement calls for GE to pay for dredging that began in 2009.

Contamination of water supplies is a problem in parts of the world where manufacturing is growing. In their efforts to compete in the world market with low-priced goods, factories may be built without adequate methods to prevent environmental pollution.

Air Pollution

Air pollution is a concern in most urban areas. Exhaust gases from cars and airborne discharge from homes, businesses, and industries can produce high levels of ozone and oxides of nitrogen. Even wind-blown dust can be a health hazard. Serious air pollution events have occurred in many cities. The response to rising air pollution is the use of cleaner fuels and pollution control devices on motor vehicles and electrical power plants that burn fossil fuels. Some dust pollution in the United States has been traced back to Asia as its source. (China is experiencing its own "Dust Bowl.")

Some air pollution issues have been dealt with quickly while other forms of pollution are more difficult to address. Scientists discovered that chlorofluorocarbon gases (CFCs) given off by some spray cans and air conditioners were weakening Earth's protective ozone layer. (Ozone is needed in the upper atmosphere because it helps protect Earth from harmful shortwave solar energy.) Government and businesses have found other chemicals to use in air conditioning systems and spray cans. These chemicals do not break down ozone in the upper atmosphere.

Our planet faces more difficult issues. By burning fossil fuels, humans have increased the carbon dioxide content of Earth's atmosphere by about 25 percent. Most of that increase has occurred in the last 50 years. The concern is that carbon dioxide absorbs heat energy that might otherwise escape into space. The increase in carbon dioxide concentration in the air is likely to cause **global warming**, an increase in the average temperature on Earth. While some locations might benefit from a warmer climate, productive farmland could be changed into desert. Another consequence could be the melting of polar ice caps and a rise in sea level, which would drown coastal cities. Unfortunately, our society depends primarily on fossil fuels for heating, electrical power, and transportation.

As the price of fossil fuels increases and the effects of global warming encourage conservation, there will be a shift to other sources of energy such as nuclear power, solar, and wind energy. Uranium for nuclear power is easily available. Nuclear energy sources do not create greenhouse gases such as carbon dioxide However, critics worry about releases of radiation and secure storage of radioactive waste products. Rising prices will also pressure consumers to use less energy. We can use less energy by constructing more efficient buildings, using smaller cars and mass transportation, and changing other habits to more carefully use heating and air conditioning.

CHAPTER REVIEW QUESTIONS

PART A

1. What is Earth's most important renewable energy source?

(1) coal (3) sunlight
(2) natural gas (4) uranium

2. Which metal is most common in Earth's crust?

(1) iron (3) aluminum
(2) copper (4) magnesium

3. Which of the following is a fossil fuel?

(1) wood (3) uranium
(2) coal (4) solar energy

4. Limestone and calcite are valuable natural resources. Which product is made from these raw materials?

(1) gasoline (3) cement
(2) lubricants (4) electrical insulators

5. Why do products made from metal ores become more expensive through time?

(1) These resources are quickly replaced by natural processes.
(2) Ores that are easy to mine are used first.
(3) Exploration and manufacturing technologies do not change.
(4) Alternative products quickly replace refined metals.

6. What property of gold is often used to separate it from other natural Earth materials?

   (1) Gold is an electrical insulator.
   (2) Gold has a glassy luster.
   (3) Gold one of the most abundant common minerals.
   (4) Gold is more dense than other minerals.

7. Which lists energy resources in the historical order of their use by humans?

   (1) wood, coal, petroleum, uranium
   (2) uranium, petroleum, coal, wood
   (3) coal, petroleum, uranium, wood
   (4) petroleum, uranium, wood, coal

Base your answers to questions 8 and 9 on the satellite image of the New York City area below.

8. Which feature highlighted on the satellite image is the greatest potential source of water pollution?

(1) Central Park
(2) North River Sewage Treatment Plant
(3) Verrazano Narrows Bridge
(4) Kennedy Airport

9. As the distance from the center of New York City increases, measurable air pollution most likely

(1) decreases
(2) increases
(3) does not change

10. What mineral that is common in New York State could be used as a source of the element magnesium?

(1) coal
(2) quartz
(3) dolomite
(4) magnetite

11. Which is the most logical first step in a long-term plan to reduce the amount of water that your family uses in the home?

(1) Turn off the main supply of water to your home.
(2) Measure how much water you use for various purposes.
(3) Install an irrigation system for your lawn and gardens.
(4) Purchase a new water softener and water heater.

12. Which group of materials does not come directly from the lithosphere?

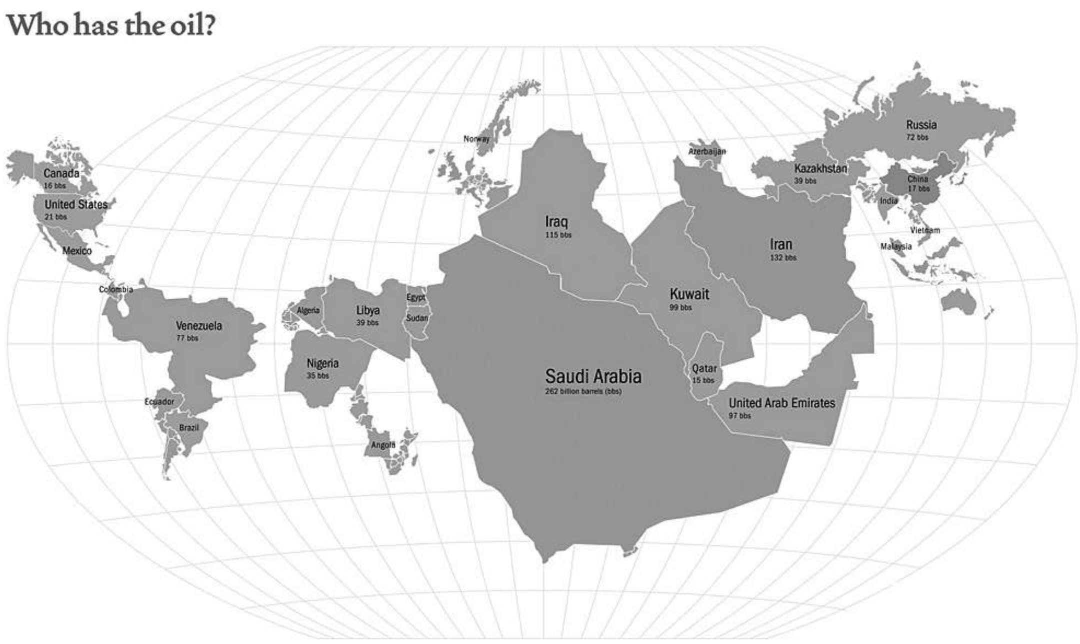
(1) metals such as iron and copper
(2) fuel, including coal and oil
(3) jewelry, including gold and silver
(4) food, including meat and fish

13. Why is ocean water generally unfit for most human uses?

(1) Ocean water is generally poisonous.
(2) Ocean water has a high concentration of mineral salts.
(3) Ocean water is a very limited water supply.
(4) Ocean water is very expensive.

PART B

Base your answers to questions 14 through 16 on the world map below, in which the size of the nations represents their reserves of petroleum.



14. What part of the world can supply the most oil to world markets?

(1) Western Europe
(2) The Middle East
(3) South America
(4) The United States

15. If this map were to show by size the major users of petroleum, rather than the major sources, what part of the map would most likely increase in size the most?

(1) Africa
(2) The Middle East
(3) South America
(4) The United States

16. How could the United States most effectively reduce its use of imported oil?

(1) Use government money to reduce the price of gasoline.
(2) Conserve energy by using more fuel-efficient vehicles.

(3) Impose new environmental restrictions on mining and oil drilling in the United States.
(4) Eliminate all government money to mass transit projects.

PART C

17. If gold is a better conductor than copper, why do we use more copper than gold in electrical devices?

18. The fossil fuels are considered geological resources, but not mineral resources. Why?

19. Why is wood considered to be a renewable resource?

20. Why might there be public opposition to starting a coal mine in your community?

UNIT 3

Weathering and Erosion

There is a saying, "Nothing is permanent but change." This means that change is the natural state of our world. As you learned earlier, science changes. As a result of new observations, scientists come to new understandings about how the world works. A similar change occurs in your own outlook. As you grow older, not only does your world change, but your way of looking at things changes.

Even without humans or any other life forms, change is the natural state of Earth. Many geological changes occur deep within Earth or at such a slow rate that is hard to for anyone to observe them. Even natural landmarks will change. The photo on this page was taken in 1973. At the bottom of page 183, you will find another that was taken in 2000, 27 years later. Look carefully at the images. Are they identical? No. In 1975, the balanced rock in the background fell during a thunderstorm. In just a few seconds, this landmark was changed forever. How long do you think it will continue to look as it does now?

CHAPTER

7 Weathering and Soils

WORDS TO KNOW

abrasion	frost wedging	residual soil
bedrock	infiltration	soil
biological activity	mechanical weathering	soil horizon
chemical change	organic matter	transported soil
chemical weathering	physical weathering	weathering
exfoliation		

This chapter will help you answer the following questions:

1. Why do rocks change when they are exposed at Earth's surface?
2. What are the two major classes of weathering?
3. How does chemical weathering differ from physical weathering?
4. What factors affect the rate at which rocks weather?
5. How do soils form?

WHY DOES WEATHERING OCCUR?

4: 2.1s
6: PATTERNS OF CHANGE 5

In Unit 2 you learned about the solid materials that make up our planet. You were introduced to rocks, minerals, and the rock cycle. The rock cycle is a model of how these materials change. Many geological changes occur deep within Earth. Others occur at such a slow rate that is hard for a person to observe them. For example, Niagara Falls has been eroding upstream at the rate of 1 meter per year. (In recent years this upstream movement has been slowed by water diversion above the falls.) However, some geological changes occur quickly. If you look at a stream before and after a flood, the whole path of the stream may have changed. In 2003, many years of weathering and frost action led to the collapse of the Old Man of the Mountain, one of New Hampshire's most famous landmarks.

When exposed to conditions at Earth's surface rocks change. This change is called **weathering**. Weathering is influenced by exposure to wind, water, oxygen, plants, and animals. All these agents contribute to breaking down **bedrock**, the solid, or continuous, rock that extends into Earth's interior. The weathering of rock creates a loose substance known as *sediment*.

What is Physical Weathering?

Weathering processes can be classified as physical changes or chemical changes. **Physical weathering**, also known as **mechanical weathering**, breaks rocks into smaller particles. However, the chemical (mineral) composition of the particles does not change from the composition of the original rock.

ABRASION The grinding away of rock by friction with other rocks is **abrasion**. Abrasion is a form of physical, or mechanical, weathering that occurs when pieces of rock collide or rub against one another and against the underlying bedrock. Consider a large rock that breaks off bedrock near the head of a stream. It is likely that the rock will fall into the stream and begin its journey downstream. Repeated collisions with other rocks gradually wear down the rock, grinding off any corners as it travels downstream. The farther the fragments (pieces) travel, the smaller and more rounded they become. (See Figure 7-1.) What began as a large piece of rock near the head of a stream is changed into small bits of sediment as it travels downstream. These rounded pieces are called river rocks.

FROST WEDGING Have you ever seen the damage caused by frozen pipes in your home? Or have you left a bottle of water in

FIGURE 7-1. The three rounded river rocks may have begun their journey as larger, more angular fragments like the rock behind them.

the freezer, only to find it cracked the next day because the water inside expanded as it froze?

Water is one of the few substances that expands when it forms a solid (freezes). If this were not true, ice would sink in water. Rivers and lakes would freeze from the bottom up, killing fish and other organisms that can survive only in liquid water. Water is sometimes trapped in cracks in rock. **Frost wedging** is a kind of weathering that occurs in moist places when the temperature alternates between day temperatures above the freezing point of water and night temperatures that are below freezing. With repeated cycles of freezing and thawing, frost wedging widens the cracks, gradually forcing the rock apart. The force created when water freezes can also open new cracks for water to enter. In this way, solid rock is broken into smaller fragments.

Water can weather rocks in other ways. Figure 7-2 on page 168 is a close-up of beach sand from the island of Hawaii compared with pebbles from a beach in California. On Hawaii, molten lava flows into the ocean. The lava is cooled very quickly by contact with the sea water. The rapid temperature change causes the rock to shatter into tiny, angular fragments. Most beach sand is composed of rounded particles shaped by abrasion. But this "shatter sand" is as sharp as broken glass.

EXFOLIATION Granite forms by slow cooling and crystallization well below Earth's surface. When granite solidifies, the rock

FIGURE 7-2. Unlike the rounded pebbles found on a California beach, shatter sand is angular.

is under great pressure caused by the weight of rocks above it. When thousands of years of uplift and weathering expose granite at Earth's surface, there is a great reduction in pressure on the rock. In addition, changing temperatures in daily and annual cycles weaken the surface layer of the granite rock. The result is **exfoliation** as granite near the surface expands and cracks into slabs that break away from the solid bedrock.

There is no change in composition involved in this process, so it is a physical change. Figure 7-3 is a rock that was apparently abraded (worn down by collisions) into a rounded "river rock" before it weathered by exfoliation and was broken on one end.

BIOLOGICAL ACTIVITY Rocks are also broken apart by **biological activity**. When the roots of a tree or other plant grow into a

FIGURE 7-3. A rock that was most likely shaped by stream abrasion, exfoliation, and angular breakage.

FIGURE 7-4. Lichens live on solid rock surfaces and help break down the rock.

crack in solid rock, the roots apply a constant pressure that can help break the rock apart. Lichens and mosses sometimes grow on rock surfaces, as you can see in Figure 7-4. These tiny plant-like organisms also help break the rock apart. Burrowing animals such as earthworms, ants, woodchucks, and rabbits create passages through soil and allow water and air to come into contact with unweathered or partially weathered rock.

Why Do Some Rocks Last Longer Than Others?

Not all rocks wear away at the same rate. The harder a rock is, the more resistant it is to physical, or mechanical, weathering. Resistance to abrasion depends on which minerals make up the rock and how the rock is held together. For example, quartz is a relatively hard mineral (Mohs scale hardness = 7). A rock of solid quartz is likely to wear away very slowly. Although sandstone is often composed of quartz grains, sandstone will weather quickly when the quartz grains are not securely cemented. Limestone is made primarily of calcite (Mohs hardness = 3). However, a solid layer of limestone can be more resistant to abrasion and other forms of physical weathering than poorly cemented sandstone. In general, the softer parts of a rock weather more quickly than the harder parts. This differential weathering may result in a texture of harder layers sticking out more than softer layers, as you can see in Figure 7-5 on page 170.

FIGURE 7-5. In general, the softer layers of rock weather more than the harder layers, leaving the harder layers sticking out.

The Grand Canyon in Arizona is 1.5 km deep. The walls of the canyon expose more than a dozen major rock formations. The most resistant layers form the steepest rock faces because they wear away slowly and have the most strength. The weaker layers tend to form terraces because soft rocks do not have the strength to hold up as cliffs. Weak rocks can also be found as indentations or notches protected above and below by stronger rocks.

STUDENT ACTIVITY 7-1 —ROCK ABRASION

1: SCIENTIFIC INQUIRY 1, 2, 3
6: PATTERNS OF CHANGE 5

Materials: rock chips, mass scale, wide-mouth plastic jar with lid, sieve or strainer, plastic bucket

You can model the conditions in a fast-moving stream by placing rock chips and water in a wide-mouth plastic jar and shaking the jar. Before beginning the activity, your teacher will have soaked the rock chips in water for an hour or more. Measure out a mass of approximately 100 g of rock chips to the nearest 0.1 g. Place a few centimeters of water in the plastic jar, add the rock chips, and screw the top on tightly. (Be sure the jar does not leak.) Shake the jar vigorously for 4 minutes. Using a strainer to catch the rock chips, pour the water into a bucket. Find the mass of rock remaining after shaking and record it.

Repeat the procedure with the same rock fragments, shaking them for two additional 4-minute intervals. Record the mass of rock remaining after each 4 minutes of shaking. Create a graph that shows the initial mass and the mass after each 4 minutes of shaking. [Label abrasion time on the horizontal (x) axis, and mass remaining on the vertical (y) axis.] If different groups use different kinds of rock, compare the data to decide which kind or kinds of rock are abraded more quickly.

What Is Chemical Weathering?

Sometimes the weathering process does more than simply break the rocks into smaller pieces. If you find a steel nail that has been exposed to the weather for a long time, it will probably be rusted. Rusting is a **chemical change**, which results in the formation of a new substance. Iron, the major ingredient in steel, can combine chemically with oxygen in the atmosphere to form rust (iron oxide). The presence of moisture (water) speeds up the rusting process.

Chemical weathering is a natural process that occurs under conditions at Earth's surface, forming new compounds. Rusting is a form of chemical weathering because a new substance (rust) is formed. Although steel is not found in nature, many minerals do contain iron. Iron is often one of the first parts of a rock to weather. When iron combines with oxygen in the atmosphere it usually forms iron oxide, which gives rock a rusty red to brown color. The chemical equation for this change is below. (As you can see on page 16 of the *Earth Science Reference Tables,* Fe is the chemical symbol for iron.)

$$\begin{array}{ccccc} 4Fe & + & 3O_2 & \rightarrow & 2Fe_2O_3 \\ \text{iron} & + & \text{oxygen} & \rightarrow & \text{iron oxide} \end{array}$$

Calcite, the principal mineral in limestone and marble, is chemically weathered by water that is acidic. The chemical formula for limestone is $CaCO_3$ (calcium carbonate). Rainwater absorbs carbon dioxide as it falls through the atmosphere, making rain a weak acid (carbonic acid, H_2CO_3). This is not strong enough to hurt you or your clothing, but it can slowly break down limestone. When rainwater enters the ground, it picks up more carbon dioxide from decaying plant remains. The acid (represented by H^+) can then react with limestone. The chemical equation for this change is written as

$$\begin{array}{ccccccccc} CaCO_3 & + & 2H^+ & \rightarrow & Ca^{2+} & + & H_2O & + & CO_2 \\ \text{calcium carbonate} & + & \text{acid} & \rightarrow & \text{calcium ions} & + & \text{water} & + & \text{carbon dioxide} \end{array}$$

This process forms limestone caverns, such as Howe Caverns and Secret Caverns near Cobleskill, New York. Although the longest limestone caverns in New York State have been explored to about 10 km, Mammoth Caves in Kentucky have more than 500 km of connected underground passages. Visit the following Web site to search a database of the longest and deepest caves of the world: ***http://www-sop.inria.fr/agos-sophia/sis/DB/database.html***

Limestone and marble make excellent building stones, although the calcite in them has a hardness of only 3 on the Mohs scale. These rocks are soft enough to be cut into blocks but strong enough to support the weight of a large building. Limestone and marble are also relatively easy to shape into sculptures and ornaments.

The burning of fossil fuels adds sulfur dioxide to the atmosphere. This gas forms sulfuric acid when it combines with moisture in the atmosphere. Nitrogen oxides from motor vehicles and electrical power plants form nitric acid when combined with moisture in the atmosphere. When acid precipitation (rain or snow) falls on limestone and marble it changes the mineral calcite into a chalky powder. Many historic buildings and outdoor statues are built with limestone and marble. In Europe and North America many old buildings have been damaged by acid weathering. This is a major reason there are laws to limit acid pollution. Although these measures cannot repair damaged structures, they have slowed the further chemical weathering of buildings and monuments made of limestone and marble.

SURFACE AREA Figure 7-6 shows that breaking a rock into smaller fragments increases the surface area of the material. Weathering occurs on surfaces. Breaking up a rock exposes more surface area and accelerates the rate of weathering. Visit the following Web site to learn about sand: ***http://www.paccd.cc.ca.us/SAND/SANDHP.htm***

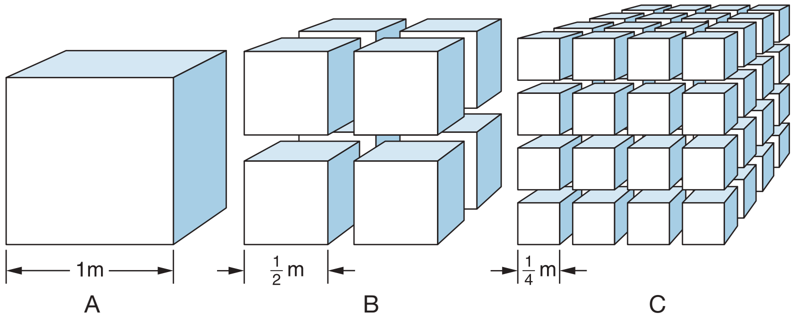


FIGURE 7-6. As solid rock is broken into smaller pieces, its total surface area increases. Additional surface area generally increases the rate of weathering.

STUDENT ACTIVITY 7-2 —CALCULATING SURFACE AREA

1: MATHEMATICAL ANALYSIS 1, 2, 3

Figure 7-6 shows a single cube of rock 1 meter on each side (A) that is divided into smaller and smaller pieces. Calculate the total surface area of the samples in parts A, B, and C of the diagram. Show your work. Start with an algebraic equation, substitute numbers and units, and show the mathematical steps to each solution.

Feldspar is the most common mineral in rocks at or near Earth's surface. But feldspar is not stable when it is exposed to the atmosphere over very long periods of time. Feldspar weathers to a softer material composed primarily of clay and silica.

Figure 7-7 shows how the mineral composition of granite changes as chemical weathering takes place. The unweathered rock is composed mostly of quartz and feldspar. After a long period of weathering, the sediments are mostly clay, quartz, and iron oxide. Of the original minerals, the amount of quartz changes the least.

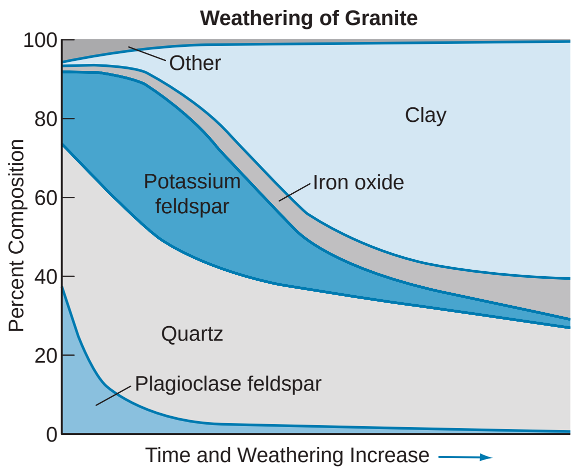


FIGURE 7-7. The graph shows how mineral change as granite weathers. Granite is usually composed mostly of feldspar and quartz. Exposure to Earth's atmosphere causes the minerals to change until clay, quartz, and iron oxide are the dominant minerals.

This shows that quartz is stable over a wide range of environmental conditions.

STUDENT ACTIVITY 7-3 —CHEMICAL WEATHERING AND TEMPERATURE

1: SCIENTIFIC INQUIRY 1, 2, 3
1: ENGINEERING DESIGN 1

Materials: small beakers (100–250 mL), hot and cold running water, thermometers, three or four small pieces of antacid tablets, stopwatch.

In this activity, you will develop your own laboratory procedure. The objective is to find out how temperature affects the rate of a chemical reaction. Once you have planned and written down your procedure, check it with your teacher. When your procedure is approved, perform the experiment and create a data table. Finally, record your conclusion about the effect of temperature on this chemical reaction. Visit the following Web site to learn about more science experiments with antacid tablets: ***http://www.alkaseltzer.com/as/student_experiment.html***

What Environmental Factors Affect Weathering?

The amount and kind of weathering that takes place depends on three factors. You have read that the harder a rock is, the more it resists physical weathering. The more chemically stable its minerals are the better a rock resists chemical weathering. The final factor is climate. Figure 7-8 shows that cold climates favor physical weath-

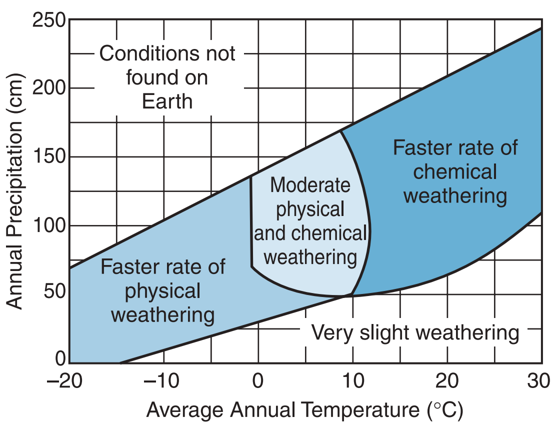


FIGURE 7-8. Cold climates favor physical weathering, especially frost action. Chemical weathering dominates under conditions of warm temperatures and abundant rainfall.

ering. Daily cycles of temperatures above and below freezing promote frost action in cold climates. Warm and moist climates accelerate chemical changes. For this reason chemical weathering is especially active in hot, humid, tropical locations.

HOW DOES SOIL FORM?

4: 2.1s

To this point in the chapter, weathering has been considered a destructive process that loosens rock and wears down the land. But weathering is responsible for one of our most important natural resources—soil. **Soil** is a mixture of weathered rock and organic matter. **Organic matter** is the remains of living organisms in which plants can grow. You may not find soil a very exciting topic. Yet, soil is a critical resource that allows us to grow and produce food. In addition, it is an absolutely critical part of the natural environment.

Figure 7-9 illustrates the development of soil on a solid rock surface. In the first column in the diagram, the bedrock is mostly unbroken, but it is exposed to the atmosphere and weather. The weathering process begins as rainwater reacts with the rock surface and water seeps into cracks in the rock. Water that seeps into crevices and fissures may change to ice and push the rock apart. Minerals soften and some minerals expand as they react with rainwater and groundwater.

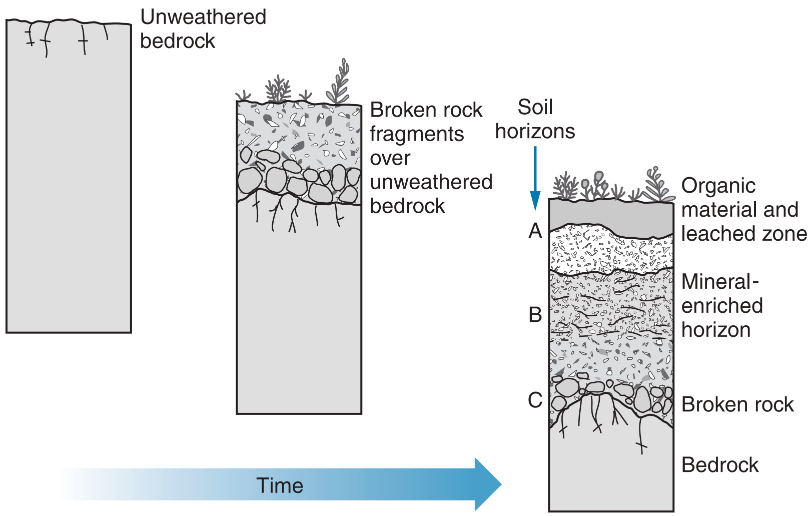


FIGURE 7-9. Weathering, water seepage, burrowing by animals, plant growth, and decay of organic remains help form soil. This process can take thousands of years.

Many years later, the second column shows fragments of broken rock covering solid bedrock. The third column shows a mature soil in which organic remains, mostly dead plant material, have been mixed into the topsoil. **Infiltration** (water seeping into the ground) has carried some water deeper into the soil. The mature soil shows layering called **soil horizons** that are typical of well-developed soils. The topsoil is usually enriched with organic remains but may lack some dissolved minerals that water carried deeper into the soil. As a result, the soil below is enriched in soluble minerals. At the bottom of the soil profile, a layer of broken rock sits on the solid bedrock from which the soil may have formed.

The soil formed at any location depends on the composition of local bedrock, the climate, and the time for development. Warm and moist climates favor chemical weathering and usually produce thick soils, although the movement of groundwater through the soil may wash away important nutrients. Polar locations more often have thin, rocky soils with little chemical weathering.

Animals take part in soil formation as they burrow by mixing the components of soil (minerals in various states of weathering and organic remains), by loosening soil, and by allowing air and water to circulate. Figure 7-10 is a profile of soil horizons in glacial sediments along the Atlantic coast of Cape Cod, Massachusetts.

FIGURE 7-10. Soil horizons in this natural exposure range from the dark, organic rich topsoil to the less developed subsoil.

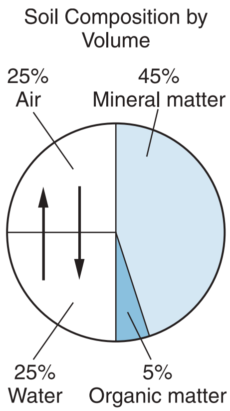


FIGURE 7-11. The best soils for the growth of most plants contain a mixture of weathered minerals and organic remains. The amount of air and water in the soil depend upon the location and recent weather conditions.

Active volcanoes can be dangerous, but the soils that result from the weathering of volcanic rocks are usually very fertile. At least two cities were destroyed by the eruption of Mount Vesuvius in southern Italy in 79 CE. In spite of the danger, people soon moved back to the slopes of Vesuvius. The volcano is still active, and another major eruption is possible at any time. In spite of this, farmers are drawn back to the slopes of the mountain by the rich soil.

Figure 7-11 shows that the best soils contain air and moisture within a mix of weathered rock and organic remains. The water and air are in the pores (openings between particles) in the soil. Soil provides support for plants and the minerals provide important nutrients. Organic material holds water in the soil and holds the soil together. Water is essential for plant growth, but air is also important. Many plants cannot thrive if their roots are covered in water all the time.

Soil that is formed in place and remains there is called **residual soil**. Residual soils develop through the processes of weathering over hundreds or even thousands of years. **Transported soil** is formed in one location and moved to another location. In most areas, including New York State, transported soils, mostly by streams and glaciers, are more common than residual soils. Visit the following Web site to learn more about classification of soil types: *http://www.answers.com/topic/soil-classification?cat=technology*

Continental glaciers that repeatedly formed in Canada and moved southward pushed, carried, and dragged most of our sediment and soil from the place where it formed in Canada to New York State. The absence of a layer of broken bedrock that gradually changes with depth into solid rock in most New York locations is evidence of this transportation of soil. The soil shown in Figure 7-10 is a soil formed in a thick deposit of transported glacial debris.

CHAPTER REVIEW QUESTIONS

Part A

1. Which is a weathering process most common in a cold, moist climate?

(1) abrasion (3) frost action
(2) deposition (4) cementation

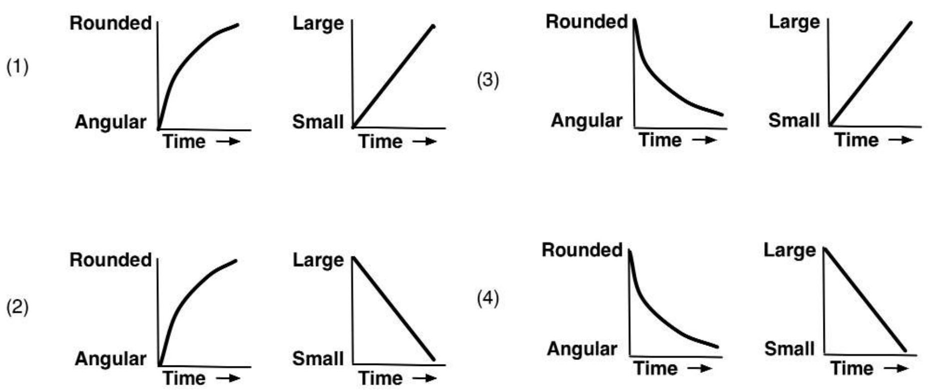
2. How does weathering usually affect rocks?

   (1) Weathering causes the mineral fragments to become larger.
   (2) Weathering makes rock harder.
   (3) Weathering occurs when sediment changes to sedimentary rock.
   (4) Weathering weakens rock so it can be carried away.

3. Which statement best describes physical weathering that occurs when ice forms within cracks in rock?

   (1) Physical weathering occurs when new minerals form.
   (2) Cracks increase in size because water expands as it freezes.
   (3) Cracks grow only because chemical reactions between water and rock dissolve the rock.
   (4) Physical weathering is most common in regions with warm, humid climates.

4. A pile of freshly broken rocks were exposed to atmospheric conditions and surface processes for a long time. Which set of graphs below best shows how the particles changed in shape and size?



5. Which rock most quickly forms new compounds when it is exposed to air polluted with acids?

   (1) gneiss
   (2) limestone
   (3) granite
   (4) schist

6. As rock is broken apart by physical weathering processes,

(1) its soil production decreases
(2) its total surface area increases
(3) new minerals form in the rock material
(4) the mass of the rock increases

7. Marble is a metamorphic rock composed mostly of the mineral calcite. One hundred grams of marble is added to each of two identical beakers of hydrochloric acid. One marble sample is coarse marble chips. The second sample is a finely ground powder of marble. Why does the fine powder react more quickly with the acid?

(1) Grinding changes the chemical composition of marble.
(2) Fine particles of marble are less dense than coarser particles.
(3) The finely ground powder has a greater total surface area.
(4) The coarse chips have greater contact with the acid.

8. Which event is an example of chemical weathering?

(1) rocks falling off a steep cliff
(2) feldspar in granite being crushed into clay-sized particles
(3) acid rain reacting with limestone bedrock
(4) water freezing in cracks in a roadside outcrop

9. Which of the following changes does *not* directly contribute to the formation of soil?

(1) melting of rock to make molten magma
(2) plant roots growing into cracks in the ground
(3) acidic rainfall reacting with the mineral calcite
(4) rocks split apart by water freezing in cracks

10. The lowest horizon of a residual soil that formed in place is composed primarily of

(1) organic remains
(2) roots and twigs
(3) broken bedrock
(4) products of intense chemical weathering

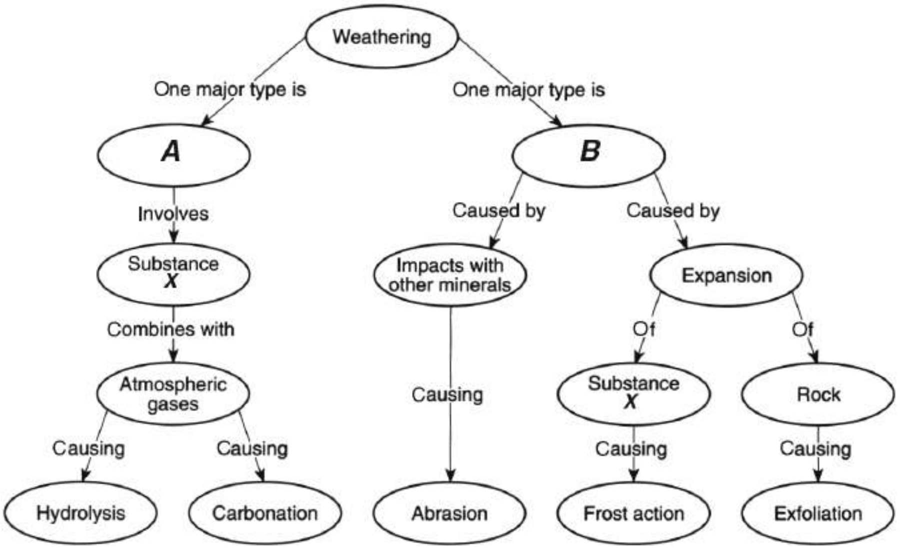
11. The image below shows several rocks weathered by wind-blown sand in a desert environment. These angular rocks are called ventifacts.

What kind of weathering process most likely shaped these rocks?

(1) physical abrasion
(2) chemical weathering
(3) biological processes
(4) melting of rock

Part B

Base your answers to questions 12 and 13 on the figure below. The flowchart below is a model of weathering. Letters *A* and *B* identify two major kinds of weathering, and substance *X* is an important part of both kinds of weathering.



Definitions
Frost action – the breakup of rocks caused by the expansion of substance ***X***
Abrasion – the wearing down of rocks or particles as they rub or bounce against other rocks
Exfoliation – the peeling away of large sheets of loosened material at the surface of a rock
Hydrolysis – the change in a material caused by contact with a substance ***X***
Carbonation – the change in material caused by contact with carbonic acid

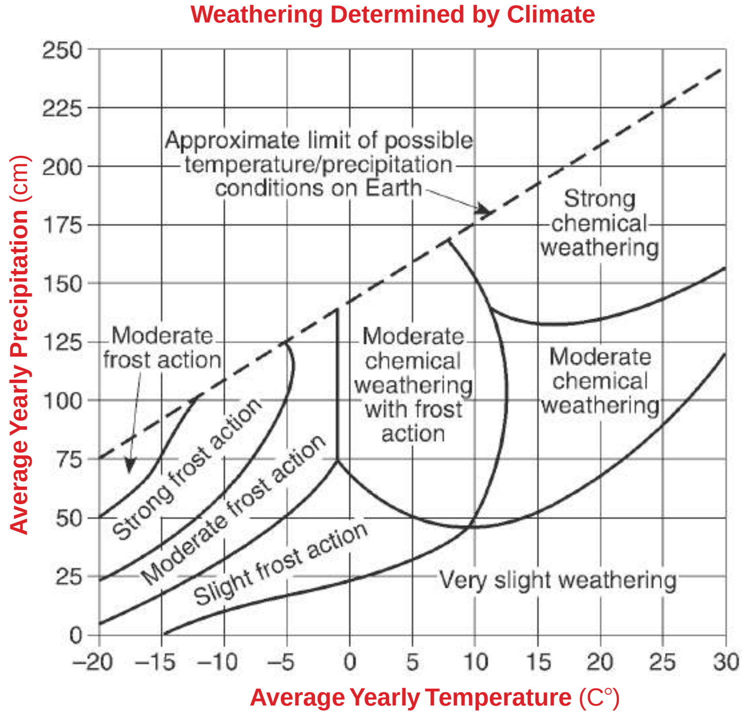
12. What kind of weathering does *A* represent?

(1) physical (3) chemical
(2) biological (4) glacial

13. What substance is best represented by *X* in the flowchart above?

(1) potassium feldspar (3) hydrochloric acid
(2) air (4) water

Base your answers to questions 14 and 15 on the diagram below, which shows how conditions of climate determine the kind of weathering that is most common in a particular location.



14. What kind of weathering is most common in an area with an average yearly temperature of 5°C and precipitation of 45 cm?

(1) moderate chemical weathering
(2) very slight weathering
(3) moderate chemical weathering with frost action
(4) slight frost action

15. The amount of chemical weathering will increase if

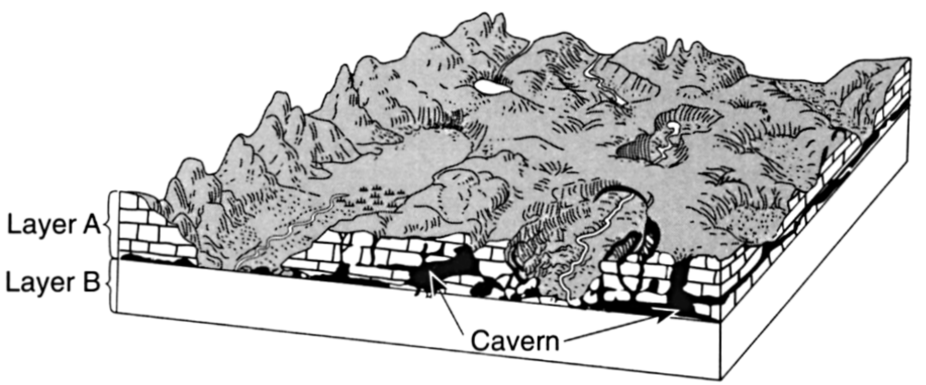
(1) air temperature decreases and precipitation decreases
(2) air temperature decreases and precipitation increases
(3) air temperature increases and precipitation decreases
(4) air temperature increases and precipitation increases

16. Look at Figure 7-10 on page 176. How did this soil form?

(1) erosion of organic material
(2) melting followed by crystallization
(3) weathering and biologic activity
(4) changes caused by heat and pressure deep within Earth

Part C

Base your answers to questions 17 and 18 on the diagram below, which represents a special kind of landscape. The symbol for rock type *A* is shown, but type *B* is not shown.



17. Name the most abundant mineral in rock layer *A*.

18. Describe how the caverns formed in rock layer *A*.

19. What is the major cause of physical weathering of big rocks transported along a large stream that has a steep gradient?

20. The image below is a fragment of broken glass found in a sand dune.

Describe the specific process that most likely changed this glass from a clear, jagged, and sharp-edged fragment to a slightly smaller object with a rounded and weathered surface.

CHAPTER

8 Erosion and Deposition

WORDS TO KNOW

agent of erosion	erosion	mass movement
bed load	flotation	solution
deposition	glacier	sorting
dune	graded bedding	striations
dynamic equilibrium	horizontal sorting	suspension
equilibrium	landslide	vertical sorting

This chapter will help you answer the following questions:

1. How is erosion different from weathering?
2. What is the primary force that causes erosion?
3. What is the most important agent of erosion?
4. What is deposition?
5. How can we recognize particles eroded by different agents of erosion?
6. What characterizes a system in which erosion and deposition are in equilibrium?

WHAT IS EROSION?

4: 2.1t; 4: 2.1u

Have you ever visited the Grand Canyon in Arizona? Each year millions of people visit this spectacular natural wonder. The canyon (see Figure 8-1) is 10 to 20 km wide and 1.5 km deep. It is one of Earth's most inspiring examples of deposition and erosion. The walls of the canyon are mostly sedimentary rocks that represent millions of years of deposition. The Colorado River eroded the canyon in about 6 million years, as tectonic forces pushed up the Colorado Plateau more than 1000 m. Visit the following Web sites to see the Utah Slot Canyons and the Grand Canyon: ***http://www.priweb.org/ed/earthtrips/s_rockies/s_rockies.htm*** and ***http://www.nps.gov/archive/grca/photos/***

New York State also has striking erosional features such as Letchworth Gorge on the Genesee River. This gorge is sometimes called the "Grand Canyon of the East." It has steep walls up to 120 m (394 ft) high on both sides. The Genesee River carved Letchworth Gorge after deposits from the most recent advance of continental glaciers blocked the river. Over the past 15,000 years, the river has cut a new route through thick layers of sedimentary rock. Watkins Glen (Figure 8-2 on page 186) and Enfield Glen in the Finger Lakes region are smaller gorges that have trails following streams with many waterfalls and potholes. Visit the following Web site to see the Gorges of the Finger Lakes region of New York: ***http://www.citrusmilo.com/fingerlakes/iloveny1.cfm***

FIGURE 8-1. Arizona's Grand Canyon is probably the most dramatic erosional feature on Earth's surface. Scientists estimate that the Colorado River took about 6 million years to make the canyon, and rapid erosion continues today.

FIGURE 8-2. Watkins Glen is one of the dozens of gorges that cut through the shales and other flat lying sedimentary rocks in Western New York State.

Erosion is the transportation (movement) of sediments by water, air, glaciers, or by gravity acting alone. If erosion did not occur, there would be no streams or valleys, no canyons, and no waterfalls. Mountains pushed up by tectonic forces within Earth would become higher and higher as long as uplift continued. Scientists know that the processes of weathering and erosion wear down mountains and the balance mountain-building forces within our planet.

Mass Movement

The force of gravity drives all erosional processes. Sometimes gravity acting alone transports (moves) earth materials. When weathering weakens rocks near the top of a cliff, the force of gravity may pull the rock off the cliff. In Chapter 16, you will read about the dangers to people and property caused by **mass movement** of rock and sediment.

The positions of rocks at the bottom of a landslide have little relationship to their position or organization before the landslide occurred. **Landslides** are most common in areas where tectonic forces within Earth are building high mountains. Figure 8-3 shows blocks of rock that have fallen to the bottom of a cliff.

FIGURE 8-3. Weathering weakens rock so that it falls under the influence of gravity.

Other forms of mass movement occur more slowly. If clay-rich sediments along a slope become saturated with rainwater or snowmelt, they may move downslope in a mudflow. Sometimes blocks of sediment slide down steep slopes along weakened layers. However, the internal structure of the blocks of sediment remains unchanged, as shown in Figure 8-4. This kind of erosion is common where streams or ocean waves cut thick layers of sediment into cliffs.

Rocks eroded by gravity without being transported by water, wind, or glaciers are usually angular and rough. Recently broken surfaces show fewer signs of weathering than parts of the rock that have been exposed to weather for a longer time.

FIGURE 8-4. Mass movement occurred along a slope that was made steeper by road construction and lubricated by water in the soil.

Erosion by Water

When water, wind, or ice causes erosion, they are called **agents of erosion**. Running water is the most important agent of erosion because it carries more sediment than any other agent of erosion. Each year streams and rivers carry millions of tons of sediment into lakes and oceans. The Mississippi River alone is estimated to carry about 6 tons of sediment per second into the Gulf of Mexico. Visit the following Web site to watch soil erosion animations: ***http://serc.carleton.edu/NAGTWorkshops/visualization/collections/soil_erosion.html***

METHODS OF TRANSPORT Streams carry sediment in several ways. The smallest sediments are dissolved in water and are carried in **solution**. For example, when a stream flows over rock or sediment rich in the mineral halite (sodium chloride, or rock salt), the halite dissolves in water, forming a solution. The sodium and chlorine enter the solution as ions (atoms with an electrical charge). These ions are so small that they cannot be seen or separated from water by filtration. Materials carried in solution can give water a color, but you can still see through the solution; it is transparent. Natural water always has some substances in solution, even if they are present in very small amounts. Visit the following Web site to see examples of river erosion, transport, and deposition: ***http://serc.carleton.edu/NAGTWorkshops/visualization/collections/erosion_deposition.html***

Sediments carried in **suspension** are small enough that they settle out of the water very slowly. Suspended sediments can be removed by passing the water through a filter. Most streams are turbulent. That is, the water does not flow smoothly downstream. When tumbling currents move faster than the speed at which suspended particles settle, the suspended load of a river can be carried indefinitely. Silt and clay in suspension give streams a muddy appearance. However, not all suspensions are in water. Clouds in the sky are actually collections of ice crystals or water droplets so small they remain suspended in atmosphere.

Some of the sediment load of a stream is too large to be carried in solution or suspension. Larger particles that are less dense than water float to the surface. Fresh leaves and other organic remains may be carried downstream by **flotation**. Large particles that are more dense than water settle to the bottom of a stream. If the stream is flowing quickly enough, these sediments will roll or bounce along the bottom of the stream as **bed load.**

SIZE AND VELOCITY Figure 8-5, from the *Earth Science Reference Tables,* shows the relationship between the size of rock particles and the stream velocity needed to transport them. Boulders are rocks greater than 25.6 cm (almost 12 inches) in diameter. The graph shows that the smallest boulders require a stream velocity of about 300 cm/second to keep them moving.

To help you read this graph, use the corner of a sheet of paper. Carefully align one edge of the paper with the horizontal axis. Then slide the paper until the vertical edge is at the proper stream velocity. Making sure that the edge is parallel to the vertical axis, read the particle diameter from the vertical axis. (See Figure 8-6 on page 190.)

How fast must a stream be moving to keep all sand-size particles in motion? The largest sand grains are 0.2 cm in diameter.

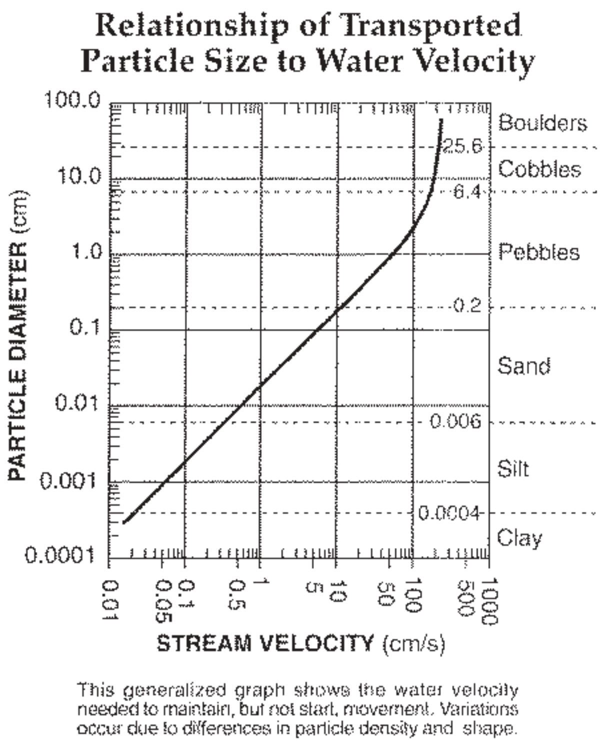


FIGURE 8-5. The faster a stream moves, the larger the particles it can move. This graph from the *Earth Science Reference Tables* shows the stream velocity needed to keep sediment of various sizes in motion. (The stream velocity needed to start motion is usually greater.)

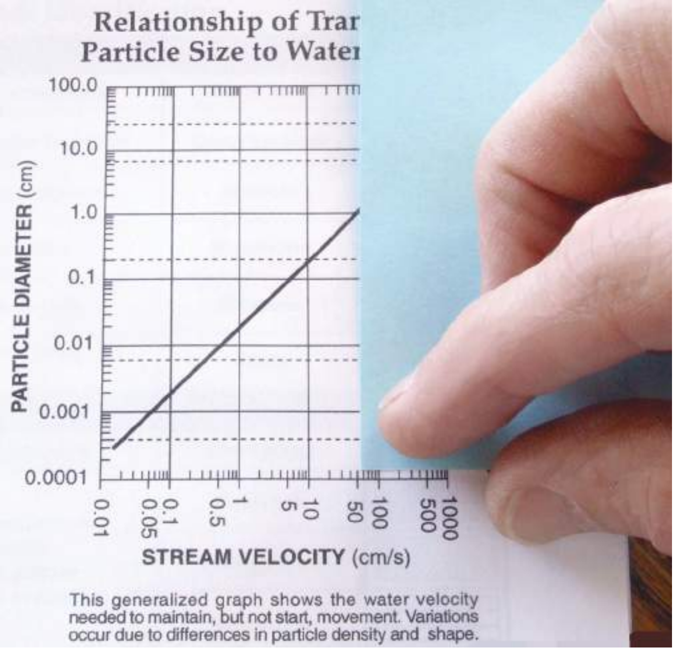


FIGURE 8-6. You can read the graph more accurately by lining up the corner and edge of a sheet of paper with the two axes of the graph.

That is the size that requires the fastest stream velocity. The line on the graph crosses the 0.2-cm sand-pebbles interface at the point where the velocity is approximately 11 or 12 cm/s.

This graph does not take into account several important factors that influence the relationship between particle size and stream velocity. For example, the stream velocity needed to start particles of sediment moving is greater than the speed needed to keep them moving. This graph applies only to particles already moving. A second issue is shape of the particles. The values from the graph apply to rocks that are neither spherical nor flat, but some average shape. Another factor is density. The denser a rock, the harder it is to move. A final factor is the nature of the bottom of the stream. The smoother and harder the bottom of the stream, the easier it is to keep sediments in motion. Therefore, this graph represents the average characteristics of shape and density of moving rock particles, as well as average conditions of the bottom of the stream.

Notice that Figure 8-5 gives the particle size for the various kinds of sediment: clay, silt, sand, pebbles, cobbles, and boulders. You can read particle size (diameter) on the vertical axis on the left side of the graph, or you can read the numbers on the dotted lines that separate each particle from larger grains above or smaller grains below. For example, sand particles are between 0.006 and 0.2 cm in diameter. Particle diameter is the typical distance across the particle. Once again, there is an assumption that the particle is partly rounded.

In this graph, clay refers to particles of sediment smaller than 0.0004 cm. Clay-sized particles are often the clay minerals, but other minerals can be reduced to the size geologists call clay.

One method to determine the relative velocity of two nearby parts of a stream is to observe the size of sediments in the stream. In the faster parts of the stream, only larger particles can settle. In the slower sections smaller particles settle out. Therefore, the speed of a stream determines the size of particles to be found in the streambed. The larger the sediments, the faster the water velocity.

Erosion by Wind

Strong winds can also transport sediments. However, because air is less dense than water, wind is generally unable to move particles larger than sand. As with stream water, the faster the wind, the larger the particles it can carry.

Wind erosion is most active in deserts and beaches. Here, there are few plants to slow the wind and hold soil in place. Wind-blown particles cause weathering by abrasion. Softer minerals in a rock are worn away, which may give wind-abraded rocks a pitted look. Ventifacts are wind-worn rocks that have flat surfaces (facets) like those of a regular geometric solid. These facets form when the rock is partly buried in sand. Abrasion by wind-blown sand wears the exposed rock face to a flat surface level with the top of the sand. Other flattened surfaces form when the rock is moved and another surface is exposed to the wind. Visit the following Web site to learn more about erosion by wind: ***http://plantandsoil.unl.edu/croptechnology2005/pages/index.jsp?what=topicsD&informationModuleId=1086025423&topicOrder=19&max=20&min=0***

Rocky deserts are more common than sandy deserts. Figure 8-7 on page 192 shows a wind-blasted desert surface in Arizona. This type of surface is called desert pavement. Without plants to hold the soil, fine sediment is blown away, leaving a surface covered by rocks that are too large to be carried away by the wind. Many of the remaining rocks have flat faces and straight edges, a shape typical of wind-eroded rocks.

FIGURE 8-7. Desert pavement is found where winds have carried away small sediments and left behind rocks too large to be blown away by wind alone.

Erosion by Glaciers

Geologists know that the climate of New York State has not always been the way it is now. Thousands of years ago, the climate was cold enough that winter snow did not melt during the brief summers. In eastern Canada, layers of snow built up and compressed the layers beneath them into ice. Eventually, the ice became thick enough that it flowed southward into New York under the influence of gravity. A **glacier** is a large mass of ice that flows over land due to gravity.

As the ice in a glacier flows downhill, it pushes, drags, and carries rocks, soil, and sediment. Rocks along the bottom of the glacier are worn down into partly rounded shapes. Glaciated rocks often have scratches known as **striations**, which are caused by a glacier dragging rocks along the surface of other rocks. Figure 8-8 shows rocks with shapes characteristic of different kinds of erosion.

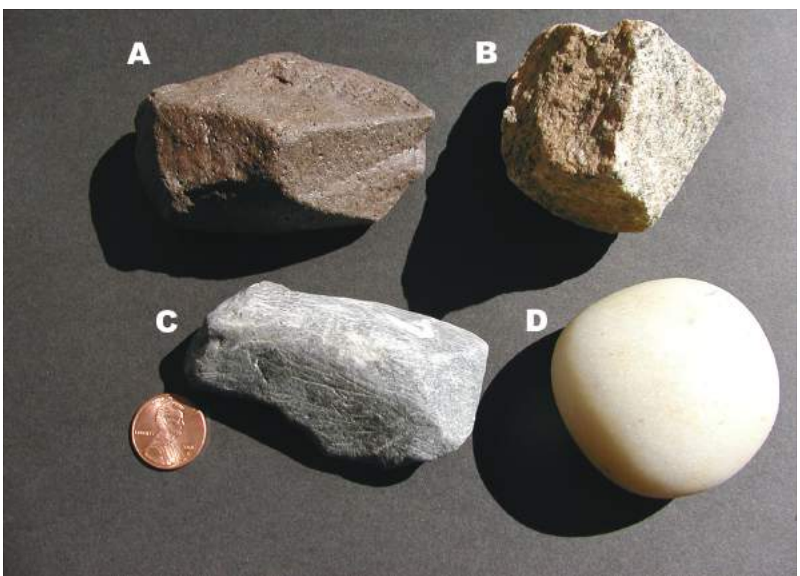


FIGURE 8-8. Each agent of weathering or erosion produces characteristic features. (A) Wind-eroded rocks tend to be angular with broad facets. (B) Rock fragments eroded and deposited by gravity acting alone are usually rough with some very fresh surfaces. (C) Glacial erosion may leave scratches, known as striations, on the rock. (D) River-worn rocks tend to be round and smooth.

WHAT IS DEPOSITION?

4:2.1t; 4: 2.1u; 4:2.1v

Agents of erosion deposit sediments. Therefore, agents of erosion are also agents of deposition. **Deposition** is the settling, or release, of sediments carried by an agent of erosion. Gravity and glaciers transport sediment without regard to the sizes of the particles. Everything gets transported and dumped together. There is no organization in sediments deposited by gravity or by glaciers. But deposition by running water and wind is more selective. The size, shape, and density of the particles of sediment affect the rate at which they are deposited.

When streams enter the relatively calm water of a pond, lake, or ocean, sediments are deposited at the end of the stream. Sometimes the depositional feature called a *delta* forms at the mouth of the river. Figure 8-9 includes satellite images of the Nile River delta in Africa and the Mississippi River delta in North America. They are two of the world's major river deltas.

FIGURE 8-9. The Nile River delta in Egypt and the Mississippi River delta in Louisiana are among the world's most important delta regions. Both support major cities and agricultural areas. The Nile delta is easy to distinguish by the triangular-shaped green area. The more complex Mississippi Delta is outlined in red.

The Effect of Particle Size on Deposition

The size of particles transported by wind or running water determines how quickly they settle out of their transporting medium. If a landslide releases a large mass of sediment into deep water or if an underwater slide occurs along a steep slope, particles in a wide range of sizes begin to settle at the same time. The largest particles will settle to the bottom first, followed by smaller and smaller particles. Each landslide results in a layer of sediment. Within the layer, the largest particles are on the bottom and the size of particles decreases toward the top.

Figure 8-10 shows a vertical cross section of layers of sediment produced in this way. Notice that within each layer there is a gradual change in sediment size from large at the bottom to small at the top showing the order in which the particles settle to the bottom. This is called **vertical sorting**, or **graded bedding**. Note that you are not looking at alternating layers of fine sediments and coarse sediments. A single layer shows both features.

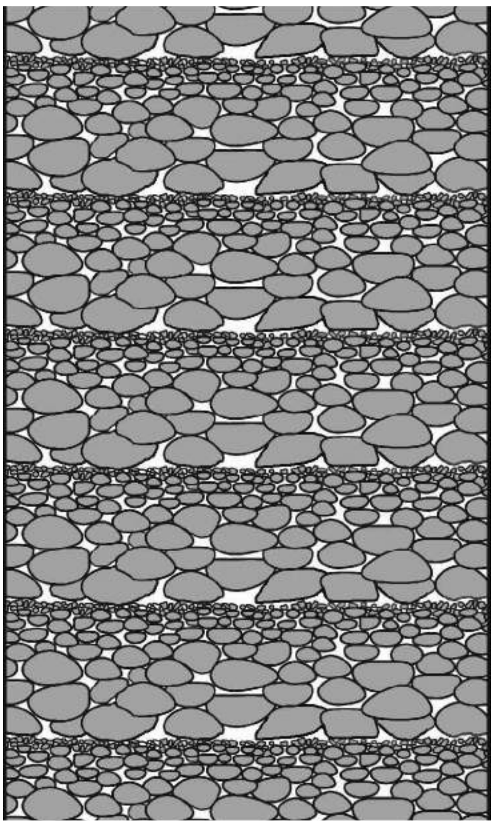


FIGURE 8-10. This diagram shows five complete layers of graded bedding. Each layer represents a single event of deposition in which the largest particles settled first. Parts of two similar layers of graded bedding are shown at the top and the bottom of the diagram.

STUDENT ACTIVITY 8-1 —WHAT IS GRADED BEDDING?

1: SCIENTIFIC INQUIRY 1, 2, 3
6: SYSTEMS THINKING 1
6: PATTERNS OF CHANGE 5

The following is a procedure you can try yourself to observe how particles are deposited. Get a sample of mixed sand with particles that range from fine to coarse sand. (Very fine particles such as silt and clay will cloud the water, making the process difficult to observe.) Quickly pour about 10 mL of mixed sand into a transparent tube about 30 cm or more tall that is about half full of water. (A tall transparent jar can be substituted if necessary.) As the sand settles, look carefully at the layer that settles out. If you repeat this procedure, each layer should show this gradual change in particle size from largest at the bottom to smaller particles toward the top. The transition to new layers will be marked by a sudden change from small particles to larger particles, as you saw in Figure 8-10.

The Effect of Particle Shape on Deposition

The shape of sediment particles affects how quickly they settle. Spherical particles settle fastest because they are streamlined. Flat and irregular particles must push more water out of the way as they settle, which slows their fall. Friction is also greater for flat and irregular particles because they have a larger surface area.

The Effect of Particle Density on Deposition

Among particles of the same size and shape, the most dense particles settle first. How quickly sediments settle depends on the balance between resistance and weight. Resistance, which is determined by size and shape of the sediments, holds them back. The force of gravity (the weight of the particles) causes them to sink. Therefore if the weight (or density) of particles increases with no change in resistance, the particles will settle more quickly.

Running Water Sorts Sediments

Sorting is the separation of sediments by their shape, density, or size. Among particles of sediment transported by streams, the shape and density of particles seldom changes enough to make separation by shape or density apparent. But sediments are often

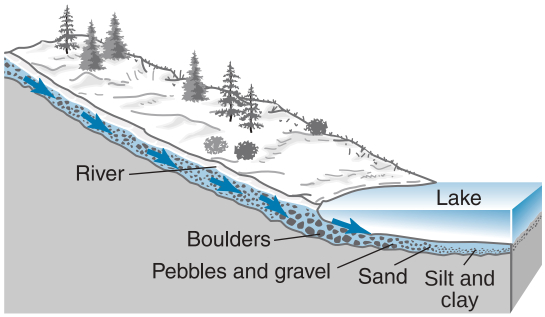


FIGURE 8-11. Horizontal sorting occurs as a fast-moving stream enters still water. The largest particles are usually deposited near shore. The finest sediments are carried the greatest distance into calm water.

sorted by their sizes. Graded bedding illustrates how water sorts sediments.

Another kind of sorting occurs when a fast-flowing river enters the relatively still water of a lake or an ocean, which causes the water to slow. The fast river current can transport sediments in a range of sizes. When the river slows, sediments are deposited. According to Figure 8-5 on page 189, the first group of sediments to settle out will be the largest particles, the boulders. By the time the current slows to about 300 cm/s, the boulder-sized particles have been deposited and cobbles will settle. If the current continues to decrease, pebbles, sand, silt, and finally, clay particles are deposited. Flatter, less dense, and smaller particles are carried farther and settle more slowly. The pattern that results from the decrease of current velocity is different from the vertical separation of graded bedding. **Horizontal sorting** is a decrease in the size of sediment particles with increasing distance from the shore that is produced as a stream enters calm water. (See Figure 8-11.)

Deposition by Wind

Like running water, wind sorts sediments. The primary difference is that wind cannot pick up large rocks. Sediments deposited by wind tend to be sand size (0.006 cm to 0.02 cm) and smaller. In areas where wind is the primary agent of erosion and deposition, wind blows sand into hills or ridges of sediment called **dunes**. The wind blows particles of sand up the gentle slope of the windward side of sand dunes and deposits them on the steeper, protected downwind face. Dunes form in some desert regions where there are few plants to hold the sand in place and some locations along lakes and oceans where sand is plentiful. Figure 8-12 shows a sand

FIGURE 8-12.
The shape of these dunes makes it clear that the wind blows left to right. Sand blows up the gentle left side of these dunes and settles on the right side where it forms a steeper slope. There are many shapes of sand dunes, but all active dunes are steeper on the lee (downwind), depositional side.

dune in a desert area of southern Utah. It is clear that the wind has been coming from the left.

Have you been to a place along the ocean where land areas are separated from the water by sand dunes? The line of dunes protects inland areas from storms and erosion by waves. There may be no plant cover on the dunes because sand lacks important nutrients, the sand is unable to hold onto water, and the sand has a loose consistency. Sand dunes are fragile ecological features that are important to the beach environment. Only recently have people become aware of the importance of protecting dunes from motor vehicle and foot traffic as well as residential or commercial development.

Deposition by Ice

In some ways, glaciers are like running water. They flow from higher areas to lower areas. Glaciers often occupy valleys that they form by erosion. The rate of flow of a glacier is usually a meter or less per day. Glaciers are not able to separate, or sort, different sizes of particles. Ice is not fluid enough to allow sediments to settle through the ice. As a result, sediments carried by moving ice are not deposited until the glacier melts. Giant boulders, fine clay, and every sediment size in between are deposited in irregular mounds with no separation or sorting. Figure 8-13 on page 198 shows glacially deposited sediments in New York State. Notice the range

FIGURE 8-13. This construction site in Westchester County, New York, contains unsorted sediments deposited by glacial ice.

of particle sizes with no layering or apparent sorting. You will learn more about glaciers in Chapter 12.

Sorted and layered sediments can be found in areas where glaciers are or were active. However, these sorted sediments were deposited by streams running out of the glaciers. Sediments deposited directly by ice are unsorted.

STUDENT ACTIVITY 8-2 —WHAT'S IN SEDIMENT?

6: SYSTEMS THINKING 1
6: PATTERNS OF CHANGE 5

Materials: containers of sand and other sediments, magnifiers, metric rulers

Your teacher will set out containers of sediments collected from a variety of locations. Compare the sediments by overall color, colors of the grains, shapes of the grains, average particle size, sorting, range of sizes, and any other unusual characteristics you may observe.

WHEN IS THERE EQUILIBRIUM BETWEEN EROSION AND DEPOSITION?

6: EQUILIBRIUM AND STABILITY 4

Consider a section of a river that is carrying sediment. You may observe that the river looks about the same over a long period of time. If the riverbed is not filling with sediment and it is not cutting deeper into its bed, the river is in equilibrium. **Equilibrium** is a state of balance. In the case of the river, the sediment washed into this stretch of river must be equal to the sediment that is carried away.

There are two ways in which this can occur. It is possible that the sediment entering this part of the river is carried along without any erosion or deposition. The particles of sediment that are carried in are the same particles that are carried out. The river does not change and the sediment that makes up the bottom of the river does not change. In this condition there is no erosion and no deposition.

It is more likely, however, that some new sediment is deposited, and some sediment from the bottom of the river channel is carried away by erosion. This is especially likely if the volume of water and the velocity of the water change through time, as they do in nearly all rivers. Flooding causes erosion of the streambed and deposition occurs when the flow is reduced. If equilibrium is reached over the course of the year, erosion and deposition are equal. However, some sediment from the bed of the river has been carried away, while some new sediment has been deposited. This is **dynamic equilibrium**. In a dynamic equilibrium, opposing processes are taking place, but they balance out because they take place at the same rate.

CHAPTER REVIEW QUESTIONS

Part A

1. The largest particles that a stream deposits as it enters a pond are 0.008 cm in diameter. What is the minimum velocity of the stream at this location?

(1) 0.1 cm/s (2) 0.5 cm/s (3) 1.0 cm/s (4) 5.0 cm/s

2. What process was primarily responsible for the formation of a delta?

(1) glacial erosion
(2) cementation of sediment
(3) deposition of sediment
(4) mass movement

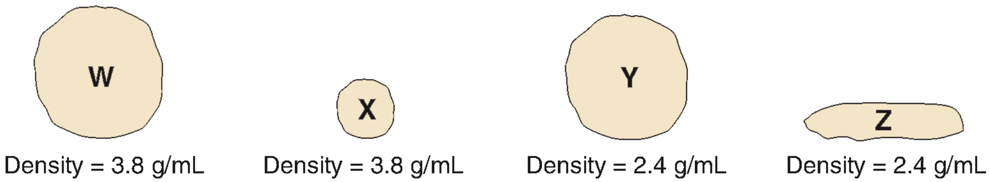
3. Which event is the best example of erosion?

(1) shale breaking apart as water freezes in its cracks
(2) dissolving of limestone to make a cave
(3) a pebble rolling along the bottom of a stream
(4) bedrock crumbling to form a residual soil

4. A stream flowing at a velocity of 75 cm/s can transport

(1) clay, only
(2) pebbles, only
(3) pebbles, sand, silt, and clay, only
(4) boulders, cobbles, pebbles, sand, silt, and clay

5. A stream transports particles *W*, *X*, *Y*, and *Z* as shown below. They are shown actual size.



Which particle is likely to settle most quickly as the velocity of the stream decreases?

(1) *W* (2) *X* (3) *Y* (4) *Z*

6. Look at the photograph of the sand dunes in Figure 8-12 on page 197. How did the dunes most likely form?

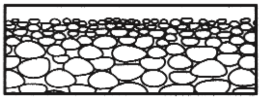
(1) water flowing from the left
(2) water flowing from the right
(3) wind blowing from the left
(4) wind blowing from the right

7. What process best describes the downward slide of some rock layers from a cliff?

(1) tidal changes (3) mass movement
(2) glacial erosion (4) lava flow

8. The diagram below is a profile of a sediment deposit. In what type of event were these sediments most likely deposited?

(1) a landslide into deep water
(2) a slowly moving glacier
(3) a delta deposited at the end of a river
(4) sand blown into a dune



(Drawn to scale)

9. When small particles settle through water faster than large particles, the small particles are probably

(1) lighter in color (3) better sorted
(2) less rounded (4) more dense

10. Which property of a mineral sample does *not* influence how quickly it settles in water?

(1) density (3) shape
(2) hardness (4) size

11. Where the stream velocity decreases from 300 to 200 cm/s, which size sediment will be deposited?

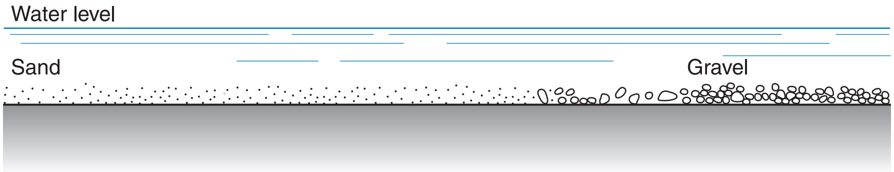
(1) cobbles (2) sand (3) silt (4) clay

12. The particles of sediment at the top of a single layer of graded bedding are usually those that are

(1) most dense, most rounded, and smallest
(2) least dense, most flattened, and smallest
(3) most dense, most rounded, and largest
(4) least dense, most flattened, and largest

Part B

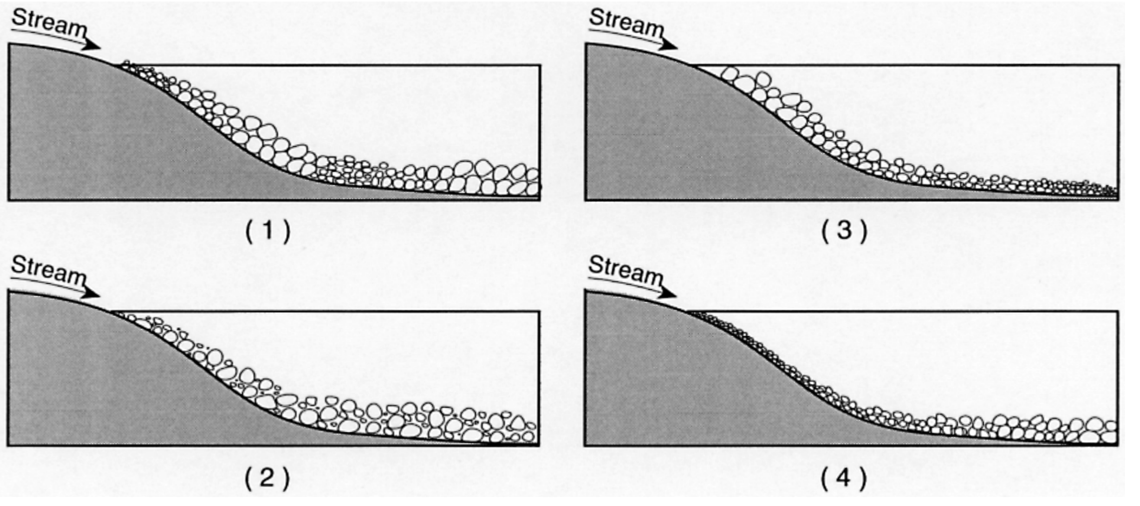
13. The diagram below shows sediments along the bottom of a stream.



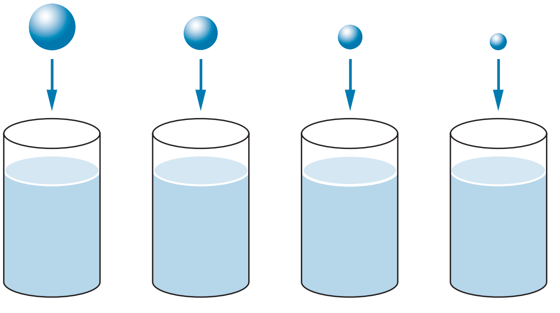
What can we say about the water velocity in this stream at the time these sediments were deposited?

(1) The stream velocity decreased to the left.
(2) The stream velocity increased to the left.
(3) The stream velocity was constant in this section of the stream.
(4) There is no relationship between sediment size and stream velocity.

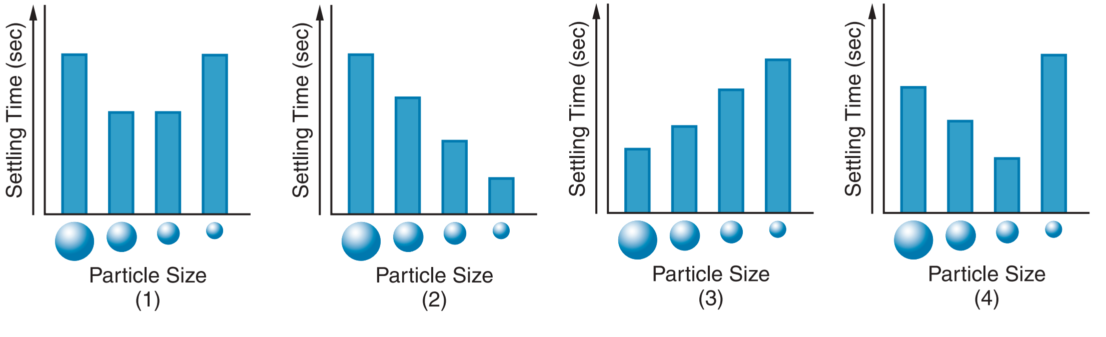
14. These diagrams represent a stream flowing into an ocean. Which diagram best shows the distribution of large and small particles?



15. The diagram below shows four identical columns of water. Four sizes of spherical object made of the same uniform material are dropped into the columns where they settle to the bottom as shown below.

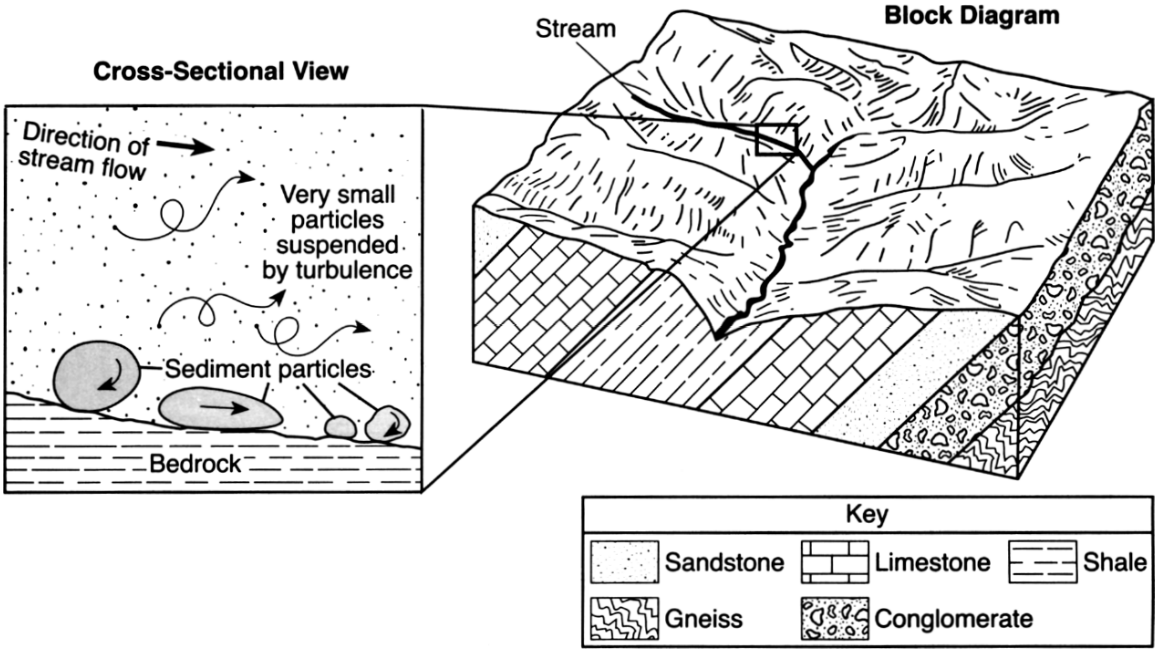


Which graph best shows the relative settling times of the four objects?



Part C

Base your answers to questions 16 through 19 on the block diagram below. The diagram shows streams flowing over bedrock. In the cross-sectional view on the left, the particles are drawn to actual size and the arrows show their motion in the water. The rock symbols match those shown in the *Earth Science Reference Tables.*



16. Measure the particles and determine the name of the largest particles in the cross section that are shown.

17. What process is responsible for the rounded shape of the large particles in the cross section?

18. What kind of rock in the diagram appears to be most easily eroded?

19. What size sediment is classified as clay?

20. At a brick factory along a river, stacks of identical bricks were left outside the building for shipment. A major flood destroyed the factory and washed away the bricks. Some bricks were carried several miles downstream; others were deposited close to the factory site. State two characteristics of the brick recovered far downstream that are likely to be different from the brick found near the factory site.

UNIT 4

Water Shapes Earth's Surface

As you learned in Chapter 8, water is a major agent of erosion. Water carries sediments and carves canyons, changing the shape of Earth's surface. Rivers also shape our history. The trade routes of Native Americans and the routes of European explorers followed rivers to reach the interior of North America. Travel by water was easier than travel by land, especially where the forests were thick and travelers were carrying food and supplies. The earliest colonial settlements were along the coastline. Here they had access to shipping and manufactured goods. From coastal cities, settlements and commerce followed the rivers to the interior of the country. Before settlers built roads, rivers were the highways they used for travel, trade, and communications.

The Colorado River of the American Southwest, while not especially large in terms of water flow, is one of the world's most important rivers in terms of its regional influence. The Colorado River starts in the Rocky Mountains and forms the boundary between Arizona and California before it enters Mexico. Due to human water use, the river has not reached the sea for many years. This picture shows a portion of the Colorado River near Page, Arizona.

CHAPTER

9 Stream Dynamics

WORDS TO KNOW

delta	levee	stream
discharge	meander	stream system
drainage divide	overland flow	tributary
drainage pattern	runoff	watershed
floodplain		

This chapter will help you answer the following questions:

1. Why are rivers important to us?
2. Why are streams sometimes called stream systems?
3. What is a drainage basin?
4. What are the common features of streams?
5. How can you measure properties of streams such as stream speed?

WHAT DOES THE HUDSON RIVER MEAN TO NEW YORK STATE?

7: CONNECTIONS 1

The Hudson and Mohawk Rivers played a crucial role in the history of New York State. The Hudson-Mohawk lowlands provided the only low-level route from New England and the Atlantic coastal colonies to the interior of the growing nation. The Hudson River is actually a sea level passage that can be traveled by oceangoing vessels all the way to Albany. It was the Hudson River and the deep-water harbor that led to New York City becoming the major center for commerce in the colonies. The Hudson River corridor played a central role in the American Revolution. The British tried to divide the colonies by taking control of this inland passage. Later, the Erie Canal was built to connect the Great Lakes to New York City and the East Coast. These valleys also provided a path for the New York State Thruway, one of the first links in the Interstate Highway System. Today, highways, railroads, and air routes have replaced streams as our primary arteries for travel, settlement, and commerce. Rivers and lakes still carry some commerce while they supply freshwater and serve as recreational areas.

WHAT IS A RIVER SYSTEM?

1: SCIENTIFIC INQUIRY 1, 3
4: 1.2g
4: 2.1 p, 2.1v
6: SYSTEMS THINKING 1

A system is a collection of components that work together to perform a function. A river system, or **stream system**, consists of all the streams that drain a particular geographic area. A **stream** is any flowing water, such as a brook, river, or even an ocean current. The function of a river is to transport water and sediments from a specific land area to an ocean or a lake.

Water and sediments have potential energy at the beginning of their journey. The amount of energy depends on how high they are above the end, or mouth, of the stream. As water and sediment flow downhill, potential energy changes to kinetic energy. At the end of the stream where water flows into the calm water of a lake or ocean, potential energy has decreased because water and sediments are at their lowest elevation. The kinetic energy also decreases as these materials stop moving. For these materials, the transporting function of the stream system has been accomplished. Figure 9-1 shows a stream that is transporting a large load of sediment.

Watersheds

The geographic area drained by a particular river or stream is its **watershed**, or drainage basin. All the rain, snow, and other precipitation that falls into the watershed and does not escape by infiltration, evaporation, or transpiration must exit the watershed through its principal river, stream, or other body of water. (Sometimes a lake or an ocean rather than a river defines a watershed.)

FIGURE 9-1. This braided river in Alaska carries so much sediment that the river breaks into many gravel-clogged channels. Much of the sediment load comes from glacier fed streams in the mountains. Visit the following Web site to see current water flow conditions in the United States: *http://waterdata.usgs.gov/nwis/rt*

Drainage divides separate one watershed from the next. These are often ridges from which water drains in opposite directions.

You can identify watershed boundaries and trace the perimeter of a watershed by drawing a line that separates all the streams draining into one watershed from streams that flow into neighboring watersheds. The Continental Divide is a geographic line that separates North America into watersheds that drain into different oceans.

Watersheds are important because they show the region drained by a particular stream system. Communities that draw water from a nearby stream or river depend on rain and snow that falls within the watershed. The availability of water for such a community depends only on the amount and the quality of precipitation in the watershed upstream from where the community takes its water. When a water-soluble form of pollution is released into the environment, it flows downhill, and is carried into the nearest stream. Salt used to melt ice on roads during the winter is a good example. As smaller streams join larger streams, the pollution affects only downstream locations in the watershed. Like water pollution, flooding is also confined to a particular watershed. Visit this Web site to see high-resolution images of rivers and watersheds compiled by the United States Geological Survey and the World Wildlife Fund: *http://hydrosheds.cr.usgs.gov*

Most of the precipitation that falls over the continents reaches solid ground. If this water does not infiltrate the ground or evaporate, it flows downhill under the influence of gravity as **overland flow,** or **runoff**. The amount of runoff depends on the slope of the land, the permeability of the surface, and the amount of precipitation. The steeper the slope, the greater the runoff. More water runs off a hard surface, such as concrete, than off a permeable surface, such as soil. Grasses and shrubs in the soil also decrease runoff because they absorb water. The greater the amount of precipitation, rain or snow, the greater the runoff. Overland flow continues until the water reaches a stream.

Names such as brook or creek are often used to label small streams that flow into larger streams such as rivers. A stream that flows into another larger stream is called a **tributary**. In large watersheds, small tributaries join to form larger tributaries which themselves may be a tributary of even larger streams. The Bedrock Geology of New York State map in the *Earth Science Reference Tables* shows some of the major rivers of New York State. Figure 9-2 shows the watershed of the Hudson River.

FIGURE 9-2. The watershed of the Hudson River lies mostly within New York State, although it also includes small areas of nearby states.

STUDENT ACTIVITY 9-1 —DRAINAGE OF THE SCHOOL GROUNDS

6: MODELS 2
6: MAGNITUDE AND SCALE 3

Make a map of your school grounds to determine how water drains off different parts of the property. On the map, identify potential sources of water pollution and show what parts of the grounds would most likely be affected by these sources of pollution. Also show where runoff could cause erosion problems and suggest ways to prevent these problems.

Features of Streams

As most streams flow from their source to their mouth, the *slope,* or *gradient,* of the stream decreases and the shape of the valley becomes wider. Streams that form steep, V-shaped valleys in mountain areas move into regions where the gradient is smaller. Here the valleys become wider with floodplains. (See Figure 9-3.)

FLOODPLAINS Most of the time, a stream is confined to a relatively narrow and winding path along the bottom of the valley. In

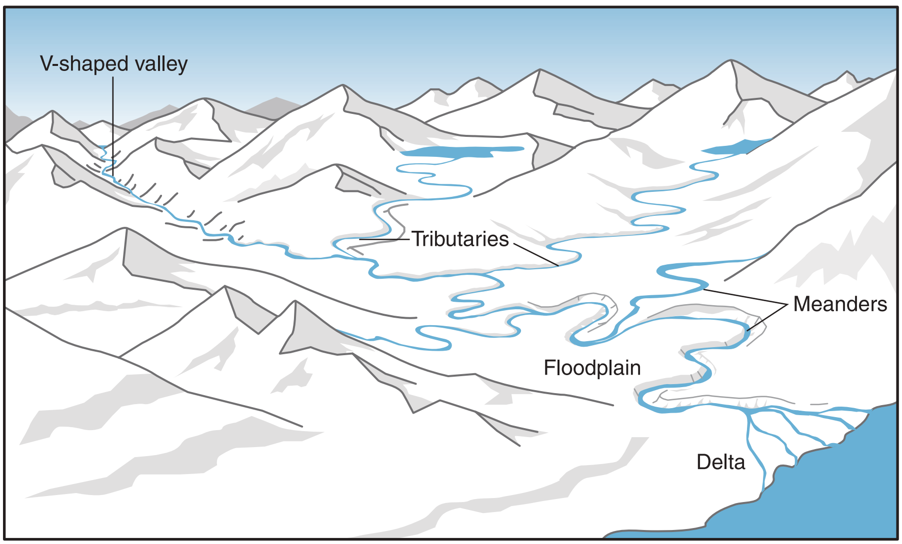


FIGURE 9-3. Many rivers start as small mountain streams in narrow V-shaped valleys. As they move into a lower gradient and are joined by tributary streams, they develop a broad floodplain and curves called meanders. Finally, the river may deposit a delta at its mouth.

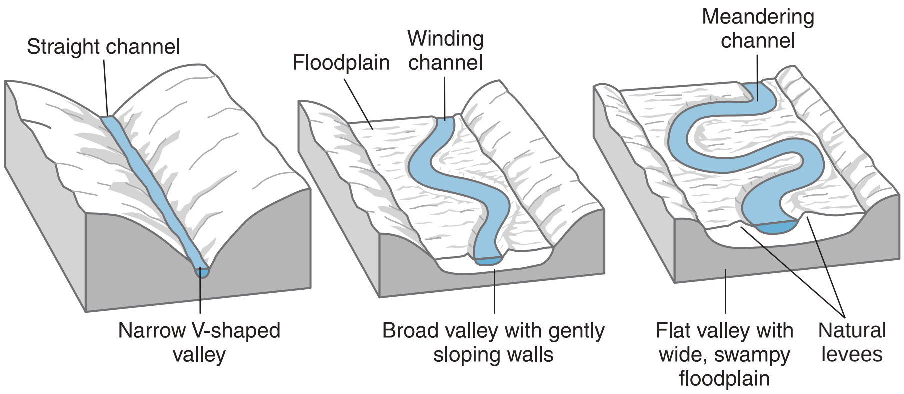


FIGURE 9-4. Over time, rivers erode their valleys, changing them from a narrow, steep-sided, V-shaped valley to a broader valley with a lower gradient and a floodplain next to the main channel.

times of flood, streams overflow their banks and spread over a floodplain. A **floodplain** is a flat region next to a stream or river that may be covered by floodwater. Floodplains are good for agricultural land because sediments brought by floods enrich the soil with important minerals and nutrients for plant growth. Figure 9-4 shows a stream as it changes through time from being in a narrow, steep-sided valley to wandering over its floodplain in a broad valley.

People may agree that the occasional flooding of farm land is an acceptable risk. However, when people build houses and other structures on floodplains, flooding can cause huge losses. This is why zoning laws are important to protect people from loss of property and loss of life during floods.

Floodplains often are developed by raising the level of the land with fill material. In these areas, streams are more restricted when they flood. Without broad areas to carry away floodwater, flood levels become higher and cause more land to be flooded.

DELTA As most rivers continue downstream, they empty into the calm water of a lake or ocean. With the decrease in velocity, the water loses its ability to carry sediment. Deposition often forms a delta at the end of the stream. A **delta** is a region at the end (mouth) of a stream or river that is made of sediments deposited as stream velocity decreases. Look again at Figure 9-3 on page 209, which shows stream features including V-shaped valleys, tributaries, a floodplain, and a delta.

MEANDERS As a stream flows over relatively flat land, its path develops curves called **meanders**. Builders of irrigation canals have discovered that when the channel has a soft streambed and little slope, the path of the canal tends to meander. Even when the path of the water is initially straight, meanders develop, through time, unless the banks are lined with a hard material such as concrete. The curves of a meandering stream are the natural shape of streams and rivers that have a low gradient and flow over a broad valley.

Where the stream is straight, the fastest current is near the center. The current at the sides and bottom is slowed by friction with the banks and river bed. When the water flows through a meander, the fastest current is at the outside of the curve, and the slowest current is at the inside of the curve.

Figure 9-5 illustrates a meandering stream highlighting where deposition occurs and where erosion occurs. These processes cause meanders to change and move downstream. The longer arrows indicate the fastest current. Notice that deposition occurs where the stream slows on the inside of the meanders. Along the outside, where the water flows fastest, is where erosion takes place. The three cross sections to the right show that where the water flows fastest (see the red circles) and near the eroding banks is where the channel is also the deepest.

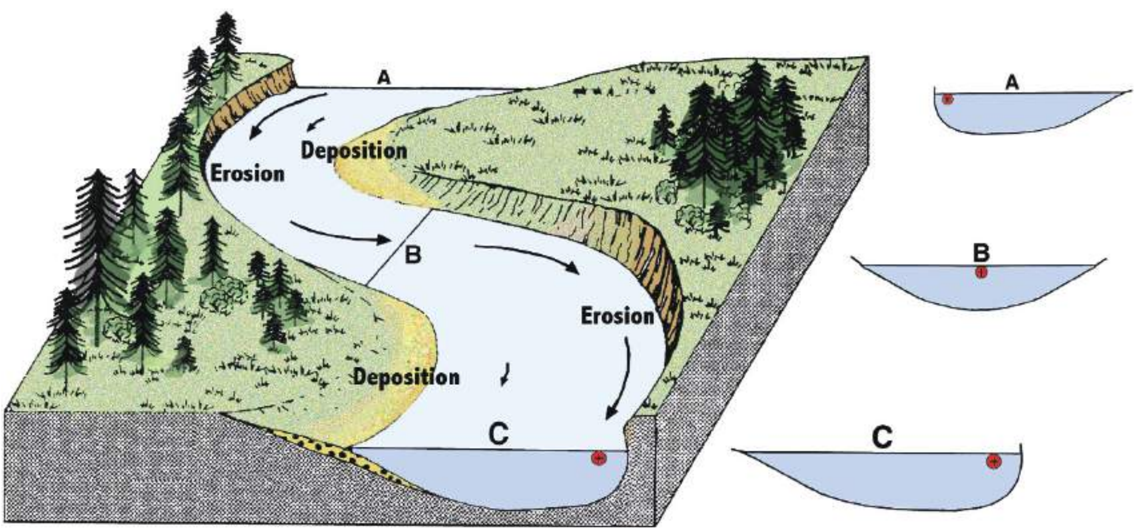


FIGURE 9-5. Erosion tends to occur where the stream velocity is highest along the outsides of meanders. On the inside of these curves, where the water slows, deposition takes place. Also notice that where the stream velocity is the greatest, the stream is deepest.

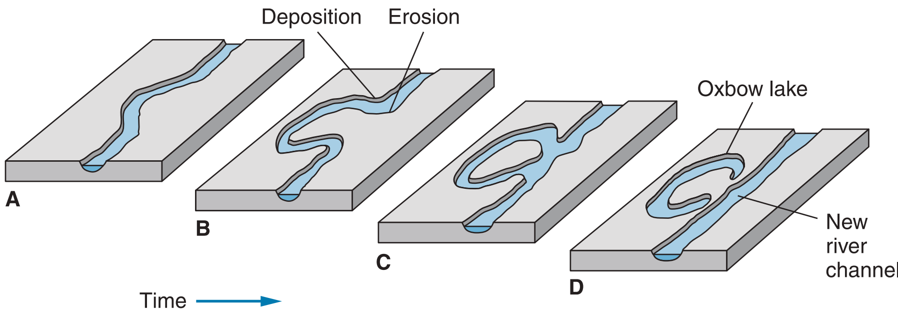


FIGURE 9-6. Meanders form where stream gradient is low and there is a broad floodplain. Diagram A shows a meander beginning to form in a stream. In B, erosion and deposition are starting to cut through the meander. In C, the cutoff is complete. In D, deposition along the edge of the river leaves the meander isolated, or cut off, as an oxbow lake.

Once meanders have formed, they do not remain in place through time. If you could see a greatly speeded-up view of a meandering stream, the meanders would shift like the slithering motion of a snake. How do they do this? Streams change their course as a result of erosion and deposition. Erosion occurs where the water flows fastest, and deposition takes place where the water slows. If a stream has a low gradient, it will tend to form meanders and then cut off its meanders as shown in Figure 9-6.

LEVEES Streams in broad valleys sometimes flood and leave deposits of sand and silt on the land next to and parallel to the streams. These ridges are called **levees**. The natural levees may be only a few feet high and hundreds of feet wide, so they may be identified by their dry land rather than their slope. In New Orleans, Louisiana, the first homes were built on the natural levees along the Mississippi River. These areas are the highest and driest locations in the flat delta region. The land away from the riverbanks is often low and swampy. The natural levees are often used as foundation for tall, artificial levees, which are built to keep the river in its channel during flooding. Figure 9-4 on page 210 shows these natural levees, although the height has been exaggerated.

When Hurricane Katrina flooded New Orleans in 2005, the older parts of the city, built on the natural levees, suffered the least flooding. Newer neighborhoods have been built on lower, drained swampland farther from the river. These areas were under as much as 5 m of water, flooding some homes to their roofs. The long-time residents understood this contradiction very well; the closer you lived to the river, the *less* likely your house was to be flooded.

When people change natural systems, we often get unintended results. Tall levees may force a river to deposit its sediment load in the river channel. In some locations, the Mississippi River is now higher than the surrounding land. This increases the danger of flooding. The artificial levees may need to be built higher and higher. However, the new and higher levees often shift the danger to older levees. They protect one area from flooding while putting another in danger.

STUDENT ACTIVITY 9-2 —MODELING A STREAM SYSTEM

6: MODELS 2

Materials: stream table, and fine sand or coarse silt

You can buy or build a table-top model including a small running stream system. Observe and list characteristics and common features of streams that develop on a stream table. How does the path of the stream change through time? Where do erosion and deposition occur?

HOW DO WE MEASURE STREAMS?

1: MATHEMATICAL ANALYSIS 1, 2, 3
6: SYSTEMS THINKING 1

Scientists measure the velocity and size of streams. Several factors affect the velocity of a stream. Size is more than just the length of the stream.

Stream Velocity

How quickly water flows in a stream is a function of three factors: shape of the stream channel, gradient (slope), and volume of water. If the stream channel is straight and smooth, water can flow quickly. However, if the stream is flowing over large rocks, the rocks slow the water as it bounces from rock to rock. Many mountain streams are filled with coarse sediment such as large cobbles and boulders, which slow the velocity of the stream.

The gradient of a stream affects how quickly water moves. The force of gravity maintains flow of water. Other factors being equal, the steeper a stream channel, the faster water will flow.

The third factor is the volume of water flowing in a stream. When the discharge (water flowing) in a stream increases, the weight of water usually increases faster than the resistance of the stream channel. Most streams are steepest at their beginning, with the gradient decreasing as they flow downstream. But many rivers flow faster as they move downstream because the increase in the volume has a larger effect on its speed than the reduction in slope.

In Figure 9-7 you see profiles along the length of the Hudson River and the Colorado River. The concave shape of these profiles is typical of many streams. These streams are steeper near their source than they are near their end.

The vertical lines on the profile of the Colorado River in Figure 9-7 represent two major dams. The lower dam is Hoover Dam. Lake Mead is the reservoir that formed behind this dam. The Hoover and the Glen Canyon dams prevent flooding on the Colorado River, provide hydroelectric power, and store several years' supply of fresh water. The water is used, for example, to grow crops, for drinking water, for laundry, and for watering lawns in the cities of the desert Southwest. Without these dams, economic development of this area would have been impossible.

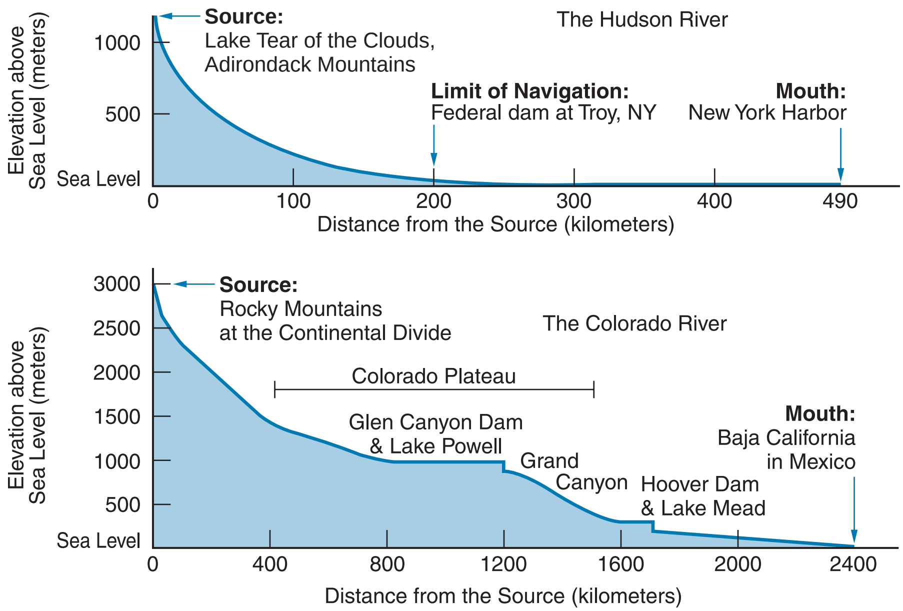


FIGURE 9-7. The longitudinal profiles of the Hudson and Colorado rivers are concave as their slope decreases downstream. The double concave shape of the Colorado River profile indicates uplift of the Colorado Plateau.

STUDENT ACTIVITY 9-3 —WATER VELOCITY

1: MATHEMATICAL ANALYSIS 2
1: SCIENTIFIC INQUIRY 3

Materials: Stream table or running water and tilted trough to represent a stream bed, meterstick, stopwatch or timer

Determine the influence of gradient and stream discharge on stream velocity. Measure the velocity of the water as the gradient and the discharge are changed. Use your data to explain how gradient and discharge affect stream velocity. (May also be a teacher demonstration.)

You can measure the speed of a stream by selecting a relatively straight section of a small stream. You will need a device to measure distance, such as a meterstick, a timing device such as a watch with a second hand, or a stopwatch, and an object to float downstream. (In case there is wind, it may be best to use an object that floats, but is mostly submerged.) Measure the length of the stream section in units such as meters. Then place the floating object in the water above the measured section and time how long it takes for the object to float through the measured distance. The stream velocity can be calculated using the following formula:

$$\text{Velocity} = \frac{\text{distance}}{\text{time}}$$

SAMPLE PROBLEM

Problem Two students stand 53 m apart along a straight portion of a small stream. One student places a floating marker in the stream and immediately begins timing it with a stopwatch. If the marker passes the second student in 50 s, what is the average velocity of this section of the stream?

Solution

$$\begin{aligned} \text{Velocity} &= \frac{\text{distance}}{\text{time}} \\ &= \frac{53\ \text{m}}{50\ \text{s}} \\ &= 1.06\ \text{m/s} \end{aligned}$$

Practice

1. A floating marker takes 30 s to travel 105 m along a straight portion of a stream. What is the average velocity of this section of the stream?
2. The average velocity of a stream is 0.4 m/s. How far will a marker travel in 1 minute?

Stream Size

The size of a stream can be measured in several ways. One measure is the area of its watershed. In general, the larger the drainage basin, the larger the stream. However, some locations receive more precipitation than others. In a dry region, a large watershed may supply water only to streams that are dry most of the year. Some watersheds receive so little rain and snow that none of the water in the stream flows out of the watershed. Streams in these areas run into bodies of water that lose their water by evaporation, such as the Great Salt Lake in Utah, or the stream water may seep into the ground before the stream reaches its lowest level.

Stream size is more often measured by finding discharge. **Discharge** is the amount of water flowing in a stream past a particular place in a specified time. For example, a small stream may have discharge of a fraction of a cubic meter per second. However, the Amazon River in South America has the greatest discharge of any river on Earth. It discharges about 200,000 m^3 of freshwater into the Atlantic Ocean each second. That's about 6 times as much water as the Mississippi and about 150 times the discharge of the Hudson River.

To measure the discharge of a stream, you can measure the area of its cross section at a particular location, then multiply that value by the velocity of the stream. You can estimate the area of the cross section by multiplying the average depth of the stream by its width at that point. Area is measured in square meters. Velocity is expressed in meters per second. The product of these values is cubic meters per second. The following formula shows how to calculate discharge volume:

$$\text{Discharge} = \text{area of cross section} \times \text{stream velocity}$$

STUDENT ACTIVITY 9-4 —MEASURING STREAM DISCHARGE

1: ENGINEERING DESIGN 1

Materials: Device to measure distance, watch, or timer

Use the method described in the text above to measure the discharge of a stream near your school or home. Devise a different method to find the discharge in order to verify the first value that you obtained.

The size of a stream determines how it responds to rainfall. As you can see in Figure 9-8, large streams are slower to respond than small streams. This is because the water in a large drainage basin has a greater distance to flow before it reaches the river. Streams in smaller watersheds generally respond quickly because the precipitation does not flow far to reach a small stream.

When land is covered by buildings and paved areas (urbanized), all streams in the area respond more quickly and dramatically to rainfall. The curve for the river may become similar to the shape to the small stream, but with a far higher curve and larger discharge volume. Therefore, cities need runoff channels that can manage much larger stream flows than their former, natural streams.

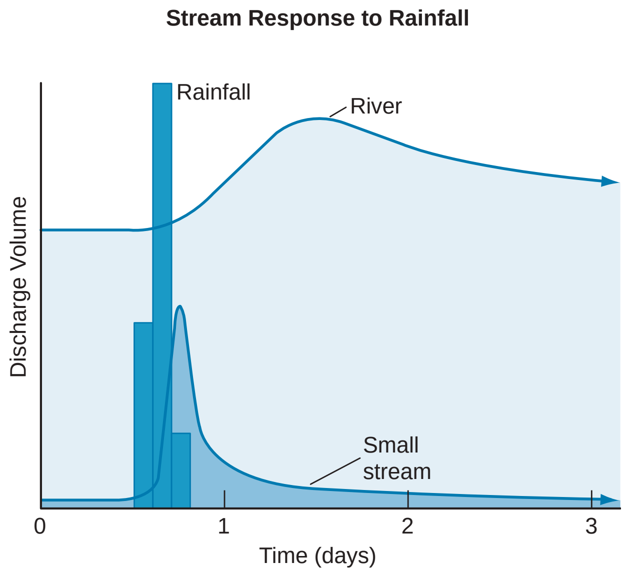


FIGURE 9-8. Hydrographs of a river and a small stream. The dark-blue bars show rainfall in a summer thunderstorm. Note that the river responds slowly and does not return to its former discharge volume even after three days. The smaller stream responds quickly, growing to many times its original discharge volume, but it also returns to its original state quickly. What is the lag time (from maximum rainfall to maximum water discharge) for each stream?

WHAT IS A DRAINAGE PATTERN?

4: 2.1t, 2.1u

Streams seek the lowest path as they move downhill, and they tend to erode their beds in places where the ground is weak. Therefore, both topography and geologic structure affect the **drainage pattern**, the path a stream follows through an area. By looking at a map view of a stream, you can often infer the underlying bedrock structures. Figure 9-9 shows the relationship between stream pattern and rock structure.

The most common stream pattern is dendritic drainage (see Figure 9-9 A). Dendritic streams flow downhill in the same general direction and they join to make larger streams. As a result, they have a branching appearance. This pattern is common where the bedrock is uniform, without faults, folds, or other major structures or zones of weakness to capture the streams. Dendritic drainage is

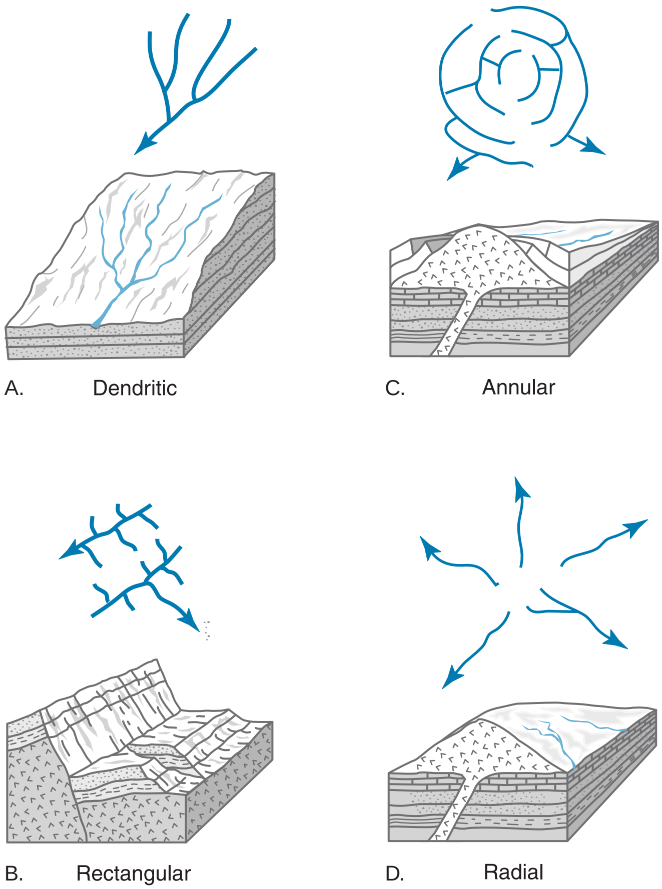


FIGURE 9-9. Underlying rock structures influence the drainage patterns we see on map views of streams. Streams follow low areas, weak rock types, and fractured rocks.

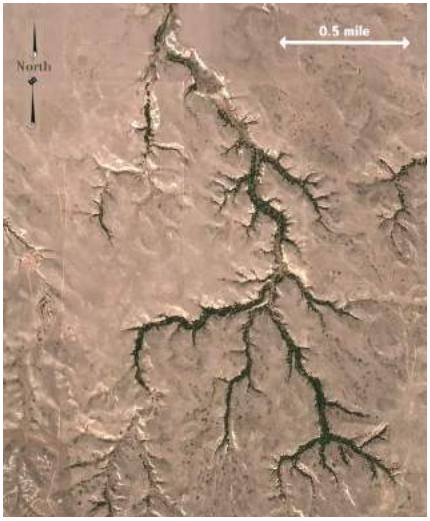


FIGURE 9-10. Dendritic drainage pattern in the flat-lying sedimentary layers of the Great Plains near Hisle, South Dakota.

also common where the rock layers are horizontal. Much of the region of western New York State north of the Pennsylvania border has dendritic drainage because rock layers are flat and there are few faults or folds to divert streams. The satellite view of stream drainage in Figure 9-10 shows dendritic drainage pattern in South Dakota.

A region that has prominent parallel and perpendicular faults, repeated folds, or a strong rectangular jointing pattern will display a rectangular drainage pattern (see Figure 9-9 B). (Joints are cracks in bedrock along which no significant movement has occurred. They may be related to expansion or regional forces acting on bedrock.) Streams run to the lowest areas of folds, fractured rocks along faults, or the weakest surface bedrock locations.

Annular drainage is a pattern of concentric circles that are connected by short radial stream segments (see Figure 9-9 C). This type of drainage occurs in an eroded dome.

A radial drainage pattern resembles the spokes of a wheel (see Figure 9-9 D). Streams flow away from a high point at the center of the pattern. Radial drainage may develop on a smooth dome or a volcanic cone. The Adirondack Mountain region of New York displays radial drainage, although rock structures such as faults and folds in the Adirondacks change the regional pattern and may make radial drainage hard to observe.

The important point is that the underlying rock types and geologic structures influence streams, and that different structural features produce different patterns of drainage.

CHAPTER REVIEW QUESTIONS

Part A

1. Which condition would cause surface runoff to increase in a particular location?

(1) covering a dirt parking area with pavement
(2) reducing the gradient of a steep hill
(3) planting grasses and shrubs on a hillside
(4) having a decrease in the annual rainfall

2. A stream bank is steeper on the outside of a meander because the water there is flowing

(1) slower, causing deposition
(2) faster, causing deposition
(3) slower, causing erosion
(4) faster, causing erosion

3. What unit is used to measure the discharge volume of the stream?

(1) kilometers per hour
(2) cubic meters per second
(3) centimeters per minute
(4) meters per square meter

4. Why are streams and rivers with the features of their watersheds called systems?

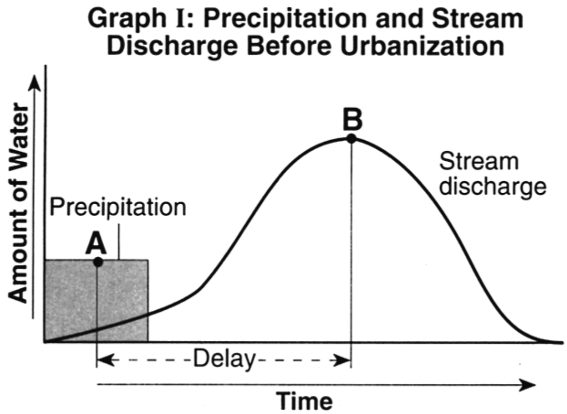
(1) All streams and rivers are the same size.
(2) Streams and rivers form straight channels.
(3) Different parts contribute to the same outcome.
(4) The features of one stream system are not found in other stream systems.

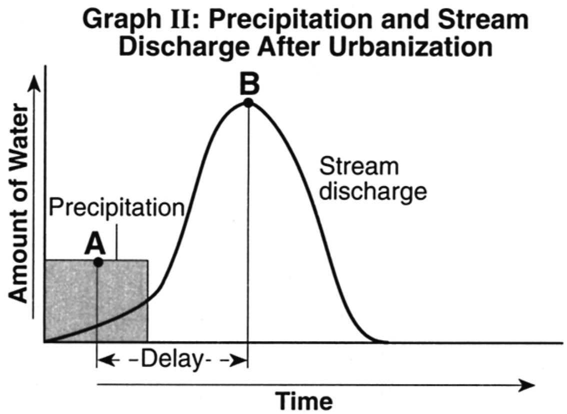
5. Which river is a tributary of the Hudson River?

(1) Mohawk River
(2) Susquehanna River
(3) Delaware River
(4) Genesee River

Part B

Base your answers to questions 6 and 7 on the two graphs below. The graphs show the discharge of storm water into a nearby stream following two equal rain events in the same urban location. Graph II was constructed from data obtained after several major construction projects.





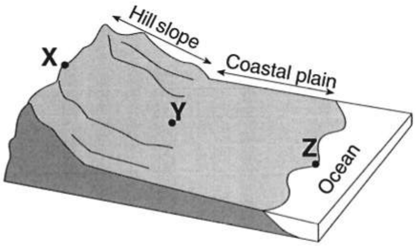
6. The delay time between A and B on both graphs is primarily due to the time needed for

(1) groundwater to evaporate
(2) precipitation water to move into the drains
(3) green plants to absorb precipitation
(4) rainfall to slow from its maximum rate

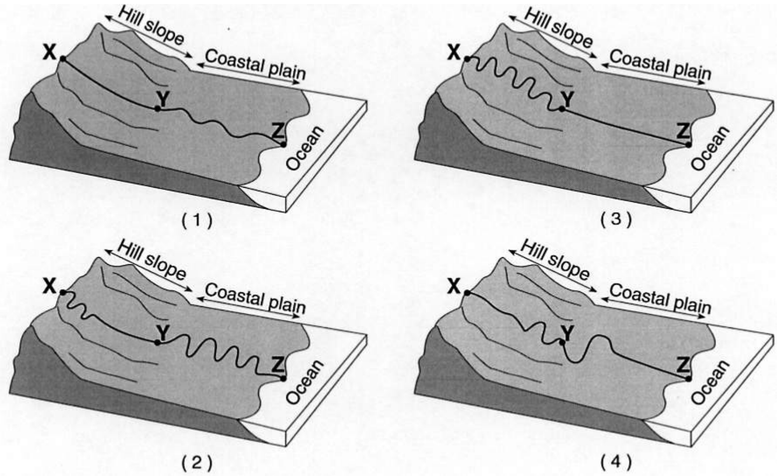
7. How did urbanization affect the maximum rate of discharge and the delay time between rainfall and stream discharge?

(1) The maximum discharge rate decreased, and the delay time decreased.
(2) The maximum discharge rate decreased, and the delay time increased.
(3) The maximum discharge rate increased, and the delay time decreased.
(4) The maximum discharge rate increased, and the delay time increased.

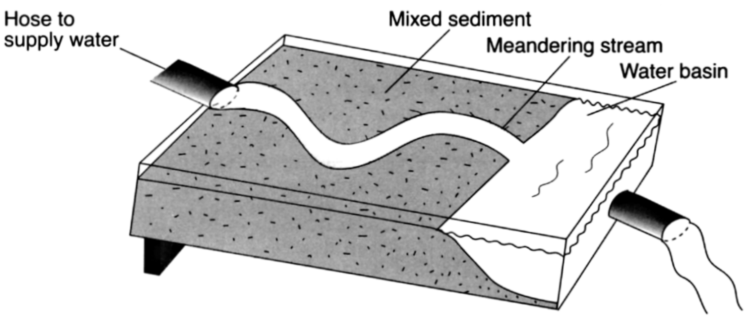
8. The diagram below shows a coastal region that is drained primarily by a single stream that flows from location *X* to *Y* and *Z*. The stream is not shown in this diagram.



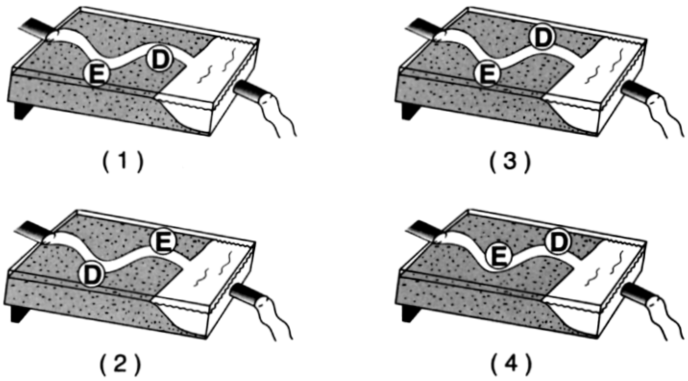
Which diagram below shows the most probable path of the stream?



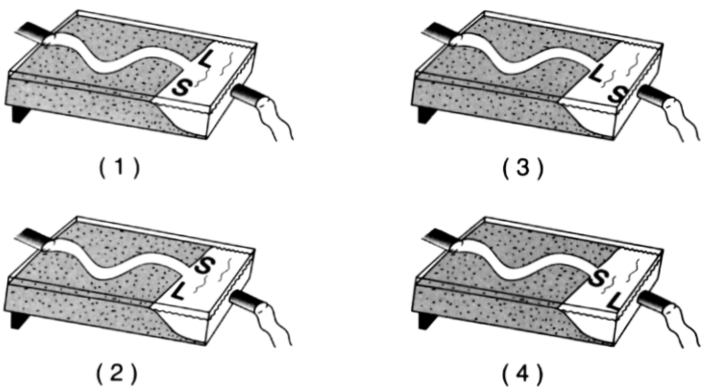
Base your answers to questions 9 through 11 on the diagram below. The stream table models a meandering stream over a land surface with a gentle slope.



9. Which diagram below best represents where erosion, *E,* and deposition, *D,* are occurring?



10. As the stream enters the still water at the bottom of the slope, where are the larger, *L,* and smaller, *S,* particles deposited?

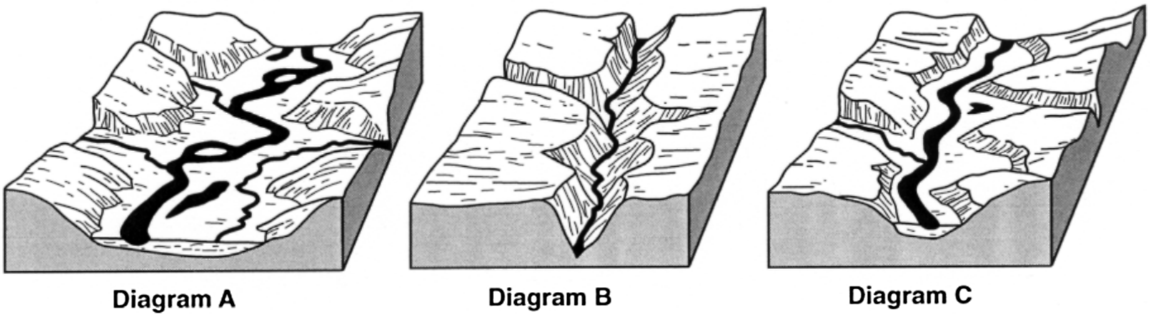


11. How can the stream table be changed to increase the amount of sediment transported by the stream?

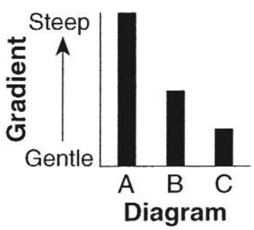
(1) decrease the temperature of the sediment
(2) decrease the slope of the stream
(3) increase the size of the sedimentary particles
(4) increase the rate of the water flow

12. For most streams, as you travel from the source of the stream toward the mouth, the

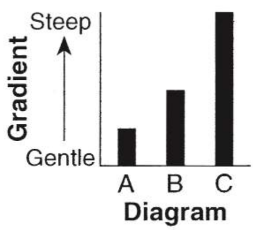
(1) gradient increases
(2) discharge volume decreases
(3) floodplain becomes wider
(4) force of gravity becomes weaker



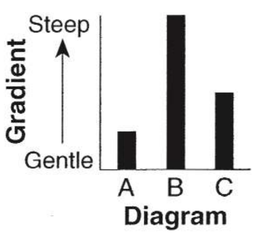
13. The block diagrams above represent three river valleys. Which bar graph below best represents the relative gradients of the principal rivers shown in diagrams *A, B,* and *C*?



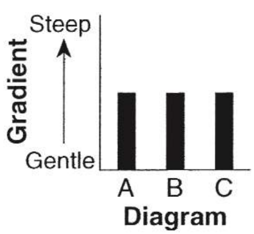
(1)



(3)



(2)



(4)

Part C

Base your answers to questions 14 and 15 on the data below. The table shows the average monthly discharge for a stream in New York State. Below the data table is a sample graph that you can use as a model to construct your own graph. (Please do not write in this book.)

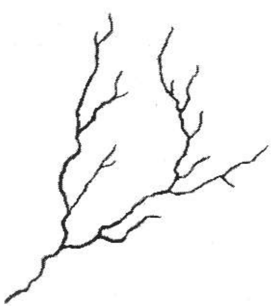
Data Table

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Discharge (ft^3/s)	48	52	59	66	62	70	72	59	55	42	47	53

14. On a piece of graph paper, construct a graph of the discharge data. Choose an appropriate scale for the *x* and *y* axes. The *x* axis is the horizontal axis, the *y* axis is the vertical axis. Write the months of the year along the *x* axis and Discharge (ft^3/s) along the *y* axis. Plot an *X* for the average stream discharge for each month shown in the data table. Then connect the *X*'s with a line.

15. Give one likely reason that the stream discharge volume in April is greater than the discharge volume is in January.

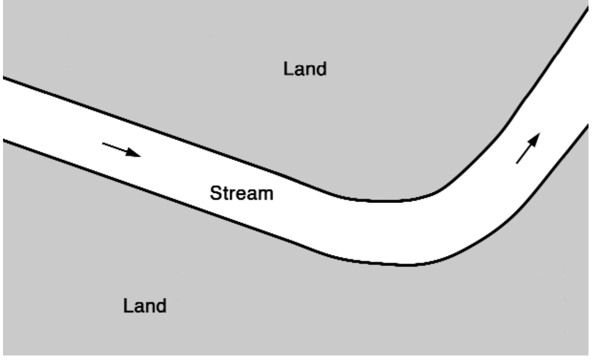
16. This is an illustration of a portion of the Susquehanna River in south-central New York State. Describe the structure of the rocks that most likely underlie this location.



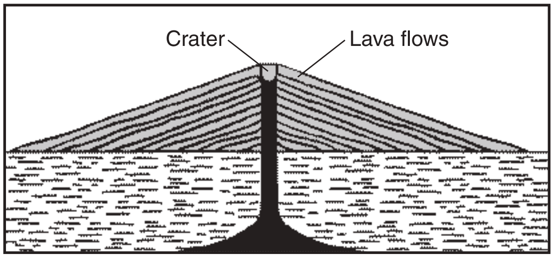
17. Why are low areas near rivers in New York State better suited for farmland and growing crops than they are for use as home sites?

18. A student decided to measure the speed of a stream by floating apples down a straight section of the stream. Describe the steps the student must take to determine the stream's rate of surface movement (speed) by using a stopwatch, a 4-m rope, and several apples. Include the equation for calculating velocity.

19. The diagram below shows a stream with a constant flow running through an area where the land around the stream is made of uniform sand and silt. Make a sketch copy of this map view. Show the future path of this stream resulting from erosion and deposition as it usually occurs along a meander by drawing two dotted lines (one on each side of the river) to show the future stream banks.



20. On a separate sheet of paper, draw a map view of water's likely drainage pattern on the landform below.



CHAPTER

10 Groundwater

WORDS TO KNOW

aquifer	groundwater	spring
capillarity	hydrologic cycle	transpiration
condensation	infiltration	water table
convection	permeability	zone of aeration
dew point	porosity	zone of saturation
evaporation	precipitation	

This chapter will help you answer the following questions:

1. Where is most of Earth's water?
2. How does water circulate through the environment?
3. How can we find water underground?
4. What are the properties of a good aquifer?
5. What problems are associated with groundwater?

WHERE DOES THE WATER IN STREAMS COME FROM?

4: 1.2g

When it rains hard or when snow melts you can see water running over the ground toward streams. This is easy to see in cities where the ground is covered by pavement and buildings. The link between precipitation and stream flow is easy to see. But there can be weeks between rainstorms, and the streams still flow. So where

FIGURE 10-1. Even when it has not rained for weeks, streams can flow because they are fed by groundwater that comes to the surface in springs. Deep within the Grand Canyon water gushes from the canyon wall at Vasey's Paradise. Note the people on the raft to the left.

does the water come from? In some places, water seeps out of the ground. These features are called **springs** such as the spring in Figure 10-1. Even in desert climates where rain is infrequent, springs can run, permanently feeding small streams.

In the desert environment, many streams run overland and then disappear into the ground. Sometimes water that seeps into the ground at one location along a stream shows up downstream as it comes back to the surface. Where water disappears and where it comes back to the surface depend on conditions underground.

WHERE IS EARTH'S WATER?

4: 1.2g

Earth is sometimes called the "water planet," or the "blue planet." After all, about 71 percent of Earth's surface is covered by oceans and another 3 percent by glacial ice. Earth is the only planet known where it is neither too hot nor too cold for liquid water to exist on the surface. In fact, water is the only common substance that exists on Earth in three states: solid, liquid, and gas. Water is necessary for life. If people were to settle on another planet, one of their most important considerations would probably be the availability of water.

Water that enters the ground filling open spaces in soil and sediment as well as openings in bedrock, including cracks and spaces between the grains, is **groundwater**. For humans, groundwater is an important part of Earth's water supply. Groundwater is usually freshwater. It is available nearly everywhere on the continents, and it is generally free of organic pollution, germs, and dangerous contaminants.

However, groundwater is endangered. Once groundwater is polluted or used up, recovery will be very slow. In some locations, it may be too late. But in most locations understanding groundwater and the *hydrologic cycle* could allow us to conserve it for future use.

The Hydrologic (Water) Cycle

Earth has a limited supply of water. However, water is considered a renewable resource because it circulates through various parts of the environment. Figure 10-2 shows that about 97 percent of Earth's supply of water is salt water in the oceans, and another 2 percent is ice, mostly in polar ice caps. The remaining 1 percent is the freshwater that supports life. As the human population has expanded and the use of water in our homes, for farming, and for industry has increased, there are growing concerns about the availability of usable water. Perhaps it is time to consider what water has in common with nonrenewable resources and plan more carefully for the present and the future. Visit the following Web site to learn more about the hydrologic cycle: ***http://ga.water.usgs.gov/edu/watercycle.html***

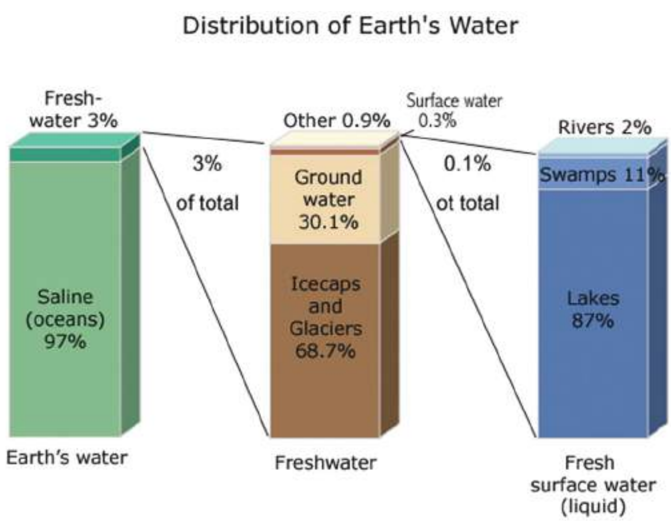


FIGURE 10-2. Most of Earth's water is in the oceans. Of the remaining (fresh) water, about a third is groundwater.

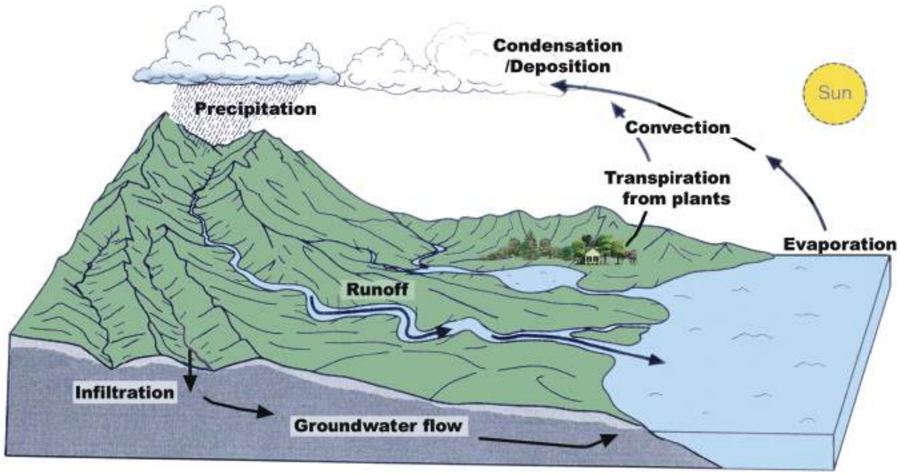


FIGURE 10-3. The hydrologic cycle illustrates how water circulates within Earth's lithosphere and atmosphere. The labels show eight processes that allow water to circulate.

EVAPORATION Water is constantly being recycled through the oceans, atmosphere, and land in the **hydrologic cycle**, as shown in Figure 10-3. As with any cycle, a description of water circulation can begin at any point in the cycle. Most of the water that enters the atmosphere comes from the oceans through evaporation. **Evaporation** is the process by which a substance changes from a liquid to a gas as the substance absorbs energy. Evaporation in nature is powered by solar energy, which lifts water into the air. On land areas, evaporation from open water and from the soil is extended by **transpiration**, which is the release of water vapor by plants.

CONDENSATION The process by which a substance changes from a gas to a liquid as the substance loses energy is **condensation.** Circulation of the atmosphere is driven by density differences that cause **convection**. Warm air is less dense than cooler air and therefore tends to rise. If convection lifts air high enough into the atmosphere, it expands and cools. As cooling continues, air reaches the **dew point**, the temperature at which air is saturated with water vapor. As the temperature falls below the dew point, water vapor condenses on tiny particles of dust, smoke, and salt from ocean spray to form droplets of water and ice crystals. Although liquid water and ice are more dense than air, the droplets and ice crystals are small enough to remain suspended in the atmosphere. We see these water droplets and ice crystals when they form a cloud.

STUDENT ACTIVITY 10-1 —OBSERVING CONDENSATION

1: MATHEMATICAL ANALYSIS 1, 2, 3
1: SCIENTIFIC INQUIRY 1

On a humid summer day, take a very cold can of soda from the refrigerator and measure its mass with an electronic balance. Allow moisture to condense on the cold can and weigh it again. Calculate the percentage increase in the mass of the soda can.

PRECIPITATION As some clouds develop, the ice crystals and water droplets grow and combine until they are too large to be held up by the air. Then they fall back to Earth as **precipitation**: rain, snow, sleet, or hail. Most precipitation falls into the ocean where it completes the water cycle. Precipitation that falls onto land can accumulate on the surface, it can run overland into streams, or it can infiltrate the ground.

Infiltration is the process by which water soaks into the ground under the influence of gravity. Whether water sits on the surface, runs off, or infiltrates depends on many factors. If the ground is saturated with water, it will not be able to hold any more water. Frozen ground also stops infiltration. Precipitation that falls as snow may remain where it fell until it melts. The ground can absorb more water when rainfall comes as a long, steady rain. Rapid, intense rainfall may be more likely to run into streams than seep into soil. Slope is also important. The steeper the surface gradient, the more likely water is to run off into streams and the less likely it is to infiltrate. Water is more likely to infiltrate a permeable soil with large pores.

Ground cover is also important. Grass, trees, and other vegetation slow runoff and give surface water more time to soak in. However, when the ground is covered with pavement and buildings, water run off is rapid and infiltration may not take place at all.

Permeability is the ability of rock, soil, or sediment to allow water to flow down through it. A loose or sandy soil is more permeable than clay or a soil with mineral deposits that block infiltration. Permeable sandstone makes an excellent aquifer to hold groundwater.

DOES GROUNDWATER OCCUR IN SPECIFIC ZONES?

4: 1.2g

Gravity pulls water into the ground until it reaches the **zone of saturation**, the part of the rock and soil where all available spaces are filled with water. Below the zone of saturation, the layers of rock or other material (such as clay) that do not have pores that water can penetrate. (These layers are impermeable.) Above this zone of saturation is the **zone of aeration**, the region in which air fills most of the available spaces in the rock and soil. As groundwater infiltrates, it moves through the zone of aeration and enters the zone of saturation.

The upper limit of the zone of saturation is the **water table**, as shown in Figure 10-4. Therefore the zone of saturation extends from impermeable layers at the bottom to the water table at the top. The height of the water table changes depending on infiltration, horizontal flow of groundwater, and usage. Sometimes there is a period of plentiful precipitation. At this time, infiltration is greater than the amount of water taken from wells or that flows out through the ground. In response, the water table will rise and groundwater will move closer to the surface. However, a dry spell is likely to result in a drop of the water table, as inflow is less than usage from wells and water that flows away.

The depth of the water table is important to anyone who uses a well to tap groundwater. Unless the well reaches below the water table, water will not flow into the well. As water is drawn from a

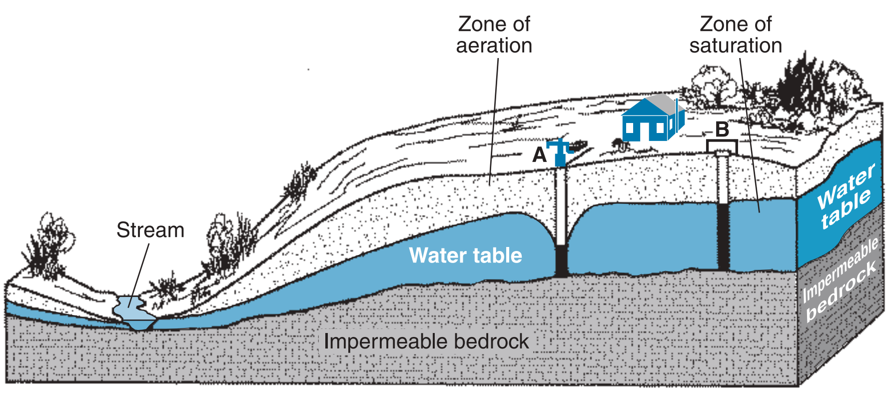


FIGURE 10-4. The zone of saturation is between impermeable layers below and the zone of aeration above. The top surface of the zone of saturation is the water table. The height of the water table depends on the balance between water entering as infiltration, water leaving as underground flow, and usage from wells. Well *A* is active and it has depressed the water table nearby. The well at *B* does not affect the water table because it is not being used.

well, the water table falls near the well, as shown in Figure 10-4. It is important to limit the usage of water from a well. The amount of water taken out should not be greater than the amount of water that can flow into the well.

If the water table falls below the bottom of the well, the well is said to run dry. Unfortunately, a well is most likely to run dry when there is a lack of surface water and the need for well water is the greatest. There are several ways to correct this problem: reduce the pumping of groundwater, allowing the water table to rise back into the well; find other sources of water to reduce the use of well water; and dig the well deeper.

The water table is often an irregular surface that has high and low places where there are hills and valleys on the land. However, the water table usually has less relief, or change in elevation. The water table is usually deeper below the surface at hilltops, and the water table may come to the surface in valleys. If the water table comes to the surface, it can feed ponds or lakes or it may flow out of the ground onto the surface.

Figure 10-5 shows two streams in different climate regions. The top stream is in a humid location where it is fed by groundwater. The other stream is in a dry area. It loses water through its bottom into the ground. Visit the following Web site, How Our Rivers Run, to learn how precipitation affects our rivers: ***http://www.bigelow.org/virtual/water_sub2.html***

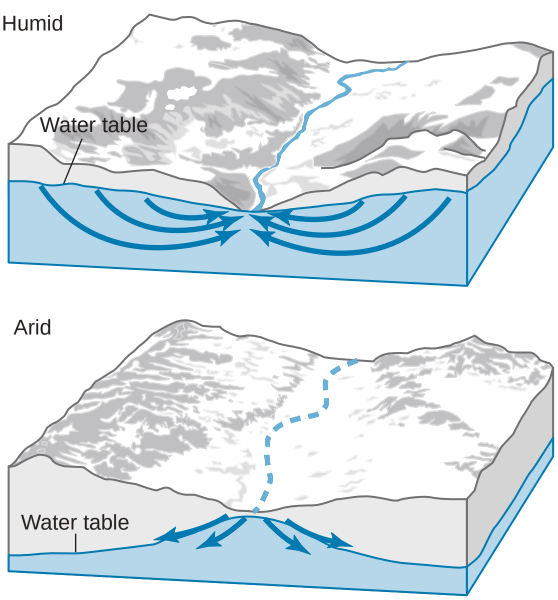


FIGURE 10-5. In humid climates, groundwater feeds into streams to maintain flow between rainstorms. But in arid climates, streams may run dry as they lose water into the ground through their streambed.

STUDENT ACTIVITY 10-2 —GROUNDWATER MODEL

1: SCIENTIFIC INQUIRY 1, 3
6: MODELS 2

You can construct a model of groundwater zones in a watertight container such as a fish tank. The bottom of the tank can represent the impermeable zone, although you may be able to place a layer of clay in the bottom of the tank to represent this layer. Well-sorted sand, such as beach sand, is a good choice to represent the part of the ground in which water can circulate. Soda straws can represent wells of various depths. Note the flow of groundwater and changes in the position of the water table. Make a list of your observations as water infiltrates the model and as water is drawn from the wells.

HOW DOES GROUNDWATER MOVE?

4: 2.1g

The ability of soil and bedrock to hold and transfer groundwater changes from place to place. In some places, groundwater is plentiful while other places have little or no groundwater. Even if there is groundwater, it is easier to remove water from some materials than from others. Several factors affect where groundwater occurs and how it moves. Visit the following Web site to learn more about groundwater: ***http://ga.water.usgs.gov/edu/mearthgw.html***

Permeability

If the ground is very permeable, infiltration will be quick, and water can flow freely within it. Therefore, permeable ground prevents or reduces flooding. Permeable soils allow water to infiltrate before it reaches streams. *Permeability* affects the recharging, or replacement, of groundwater. The more permeable the soil, sediment, and bedrock are, the more quickly water can flow down into the zone of saturation to replace groundwater lost to outflow or pumping from wells.

Large openings that are connected make rocks or soil very permeable. Even bedrock can be permeable if it is composed of particles with spaces between them, such as sandstone. Bedrock can also be permeable if it has large and connected cracks, such as a fractured granite, or limestone that has underground passageways.

Among sediments, the most permeable are well-sorted sediments with the largest, roundest particles. Soils made of uniform large particles have large spaces between the particles. This is especially true for rounded grains, which cannot be packed as tightly as flat or rectangular particles. If smaller particles are mixed with the large particles, the smaller grains fill in spaces between the large particles and reduce the permeability.

Even though a fine-grained soil may have the same total space between the grains as a coarse-grained soil, water cannot flow as quickly through these smaller spaces. Water clings to the surfaces of grains of sediment. Because fine-grained sediments have more total surface area, water cannot pass through fine-grained sediments easily. Therefore materials like silt and clay have low permeability. Compact clay can be nearly as impermeable as solid bedrock.

Porosity

Porosity is the ability of a material to hold water in open spaces, or pores. It is an important property of a soil, sediment, or bedrock because porosity determines how much water the ground can store. If the porosity is low, there cannot be much groundwater stored. Rock and sediment with a high porosity generally result in a good supply of groundwater. Porosity can be calculated using the following equation:

$$\text{Porosity} = \frac{\text{volume of pore space}}{\text{total volume of the sample}}$$

Well-sorted sediments with round grains have a high porosity because of the large spaces between the particles. Sand that is rounded and well sorted can have porosity as high as 50 percent. However, unlike permeability, the size of the particles does not affect porosity. Figure 10-6 on page 236 shows three containers of spherical particles. The container on the left holds a sample of small particles, the container in the middle holds medium particles, and the container on the right holds large particles. In each container, the particles are packed in the same way. Each sample has the same porosity.

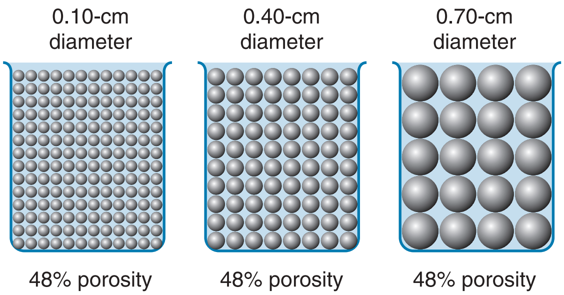


FIGURE 10-6. Changing the size of the particles does not change the porosity of a sample. This is true as long as there is no change in the sorting, shape, and packing of grains. Note that each of the samples shown has the same porosity, 48 percent.

STUDENT ACTIVITY 10-3 —COMPARING THE POROSITY OF DIFFERENT MATERIALS

1: SCIENTIFIC INQUIRY 1, 2, 3
1: ENGINEERING DESIGN 1
6: MODELS 2

Determine the porosity of several different samples of sand and gravel by comparing the volume of each sample with the volume of water needed to fill each sample to its surface with water.

To remember that the size of the particles does not affect the porosity, imagine a hollow cube that encloses the largest possible solid sphere. The solid sphere takes up about 52 percent of the volume of the cube. Therefore, the percent of open space is the remaining 48 percent. This is true of any size of cube in which the length of the side of the cube and the diameter of the enclosed sphere are equal. Although smaller particles leave smaller spaces between particles, the increase in the number of spaces balances the decrease in the sizes of the spaces.

Porosity does depend on the shape and the packing of the particles. Flat or rectangular particles can pack more closely than spherical particles. Figure 10-7 shows how tighter packing can even reduce the porosity of sediment composed of identical spherical particles.

Two other factors affect the porosity of a soil. In a mixture of sediment sizes, small particles fit into pore spaces between larger particles. Figure 10-8 illustrates how mixing different particle sizes

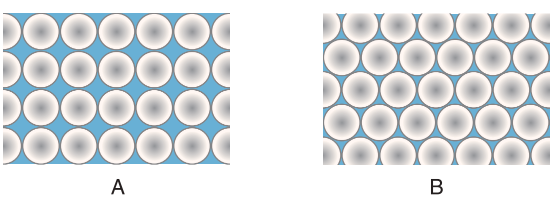


FIGURE 10-7. Sample *A* has a greater porosity than sample *B* because the particles are more tightly packed in sample *B.* Tighter packing reduces the porosity.

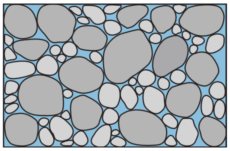


FIGURE 10-8. The porosity of a soil sample is reduced when small particles occupy spaces between the larger particles.

reduces porosity. A final factor is mineral cement. When particles are held together by a substance such as calcite, clay, or silica cement, the cementing substance reduces the porosity of material.

Capillarity

The property of adhesion causes water to stick to surfaces. Adhesion is related to the surface tension of water, which can be a remarkably strong force. This force draws water up into tiny spaces; this is called **capillarity**, or capillary action. Sometimes, this action can pull water from the water table upward to where it reaches the roots of plants. Capillarity also allows trees to draw water from the soil into their leaves tens of meters above the ground. Tree trunks contain narrow passageways that draw water toward the leaves. Capillarity is also the way that a towel soaks up water or the way wax moves up through a wick to vaporize and serve as fuel for the flame of a candle. Figure 10-9 illustrates capillary action in small openings in glass tubes.

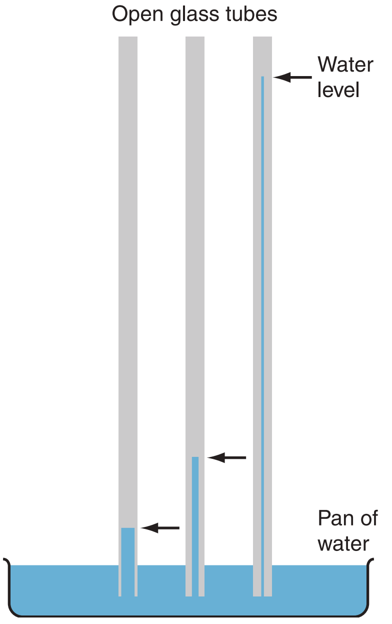


FIGURE 10-9. Water rises into narrow tubes due to capillarity. Water rises highest in the tube with the smallest opening. This is how water rises tens of meters through small natural channels in tall trees.

STUDENT ACTIVITY 10-4 —CAPILLARITY OF SEDIMENTS

6: MODELS 2

Find several transparent plastic or glass tubes that are about 0.5 cm in internal diameter. (Transparent drinking straws may work.) Cover the bottom of each tube with cotton fabric held in place by a rubber band. The fabric will allow water to pass through the opening but prevent the sediments from falling out. Fill each tube with a different size of sediment from sand to silt. Place the tubes of sediment in a pan of water. Observe how high the water rises into each sample of sediment.

Capillary action occurs only in rock or sediments with very small, connected pore spaces. When openings become wider, the weight of water in the openings increases without a corresponding increase in the surface area of the openings. Adhesion cannot hold or draw water into large openings.

WHERE IS GROUNDWATER AVAILABLE?

4: 1.2g

In places where surface water evaporates, especially in the summer, groundwater may be the only reliable supply of freshwater. Unless there is a source of freshwater in an area, people cannot live there. People need freshwater to drink and prepare food, to clean and for other household purposes, and to grow food. In most places, groundwater is more reliable and cleaner than surface water.

In most places, groundwater can be found within 100 m of Earth's surface, but the depth of solid, impermeable rock varies greatly from place to place. In some places, solid rock without open spaces is exposed at the surface, and the impermeable rock extends into Earth's interior. In other places, water can be brought to the surface from many kilometers underground. Digging or drilling wells can be a major expense for a property owner. The deeper the well goes, the greater the cost. Knowing where to place a well, how deep to dig, and when to stop drilling can be difficult decisions.

About 98 percent of Earth's supply of freshwater is within the ground. Lakes, rivers, and streams are more visible than groundwater. However, there is far more freshwater stored in the ground than on the surface. The best supplies of groundwater are in underground aquifers. An **aquifer** is a zone of porous material that contains useful quantities of groundwater. Farming in the western United States depends on well water drawn from aquifers. The circular patterns familiar to people who have flown over the Great Plains are created by center-pivot irrigation systems. In some cases, water has been taken out of the aquifers so much faster than it can be replenished by rainfall and infiltration that there is danger of completely depleting the aquifer. This is sometimes called "mining" water because farmers are taking water that has been in the ground for hundreds of years. Although scientists usually consider freshwater a renewable resource, the rate of usage of some aquifers far exceeds the rate at which they receive new water.

In some places, groundwater is trapped between impermeable layers. If the recharge area is higher than the outlet of an aquifer, spring water can gush quickly out of the ground. Artesian flow can be started by drilling a well through an impermeable layer and into an aquifer under pressure. In some cases, the well water just rises above the level of the surrounding groundwater. In other cases, water may flow out of the well without being pumped.

WHAT ARE SOME GROUNDWATER PROBLEMS?

7: CONNECTIONS 1
7: STRATEGIES 2

Just as many streams have been contaminated by careless disposal of wastes, some aquifers are also being seriously polluted. Wherever soluble waste materials are left on or in the ground, infiltration can carry them to an aquifer. Several factors make the contamination of groundwater even more difficult to deal with than the pollution of surface waters. People cannot see or smell buried wastes. They cannot see them contaminating an aquifer. In addition, it may take a long time for waste materials to reach the aquifer. By the time scientists know an aquifer is becoming polluted it might be impossible to prevent a very serious problem. It will also take far more time to rid an aquifer of contamination than it would to flush surface water of organic or inorganic toxic materials.

Sewage

Many people use septic systems to dispose of waste water and human waste. In a septic system, liquid wastes and water seep into the ground from an underground tank. Solid wastes remain in the tank. There are nutrients in sewage; organisms that live in the ground use these nutrients. As a result they clean sewage-filled water. However, this cleaning is effective only as long as nutrients are not present in amounts too large to be consumed by the organisms in the ground. When communities conclude that increasing population and density of housing threaten to create a health problem, they install public sewage systems. These systems pipe sewage to a central location and treat it to speed up the rate at which organisms use and therefore remove toxic substances. Keeping waste materials out of the ground helps preserve the quality of groundwater. Visit the following Web site to learn more about how septic and sewer systems work: ***http://home.howstuffworks.com/sewer3.htm***

Saltwater Invasion

The increasing use of groundwater in coastal locations has allowed salt water from the ocean to invade some aquifers. Because salt water is more dense than groundwater, the salt water flows in and under the freshwater. This has occurred in eastern Long Island, New York, as shown in Figure 10-10. The problem has been dealt with in several ways. Some parts of Long Island use water piped in from upstate rivers to reduce groundwater withdrawal. Returning treated wastewater to the aquifer has also been used to reduce salt-

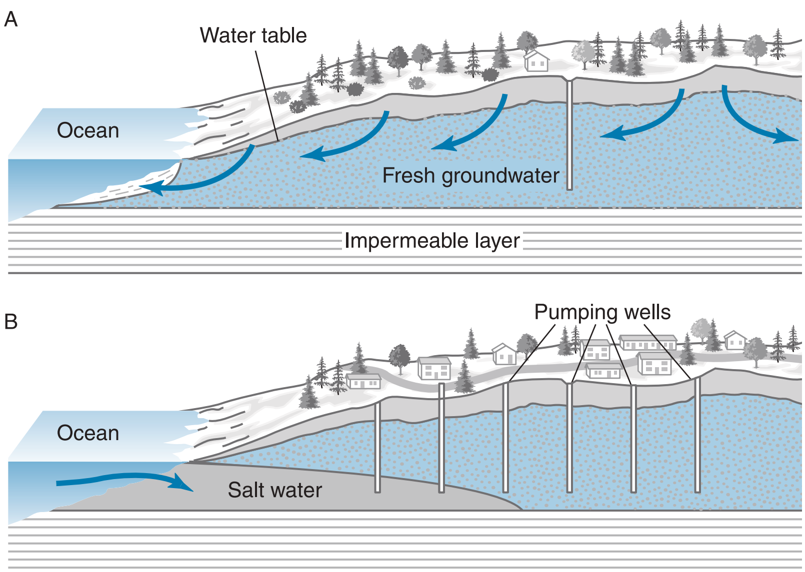


FIGURE 10-10. Pumping groundwater from an aquifer in a coastal region such as Long Island, New York, can let salt water flow into the aquifer and contaminate wells. Part *A* is a profile before extensive pumping from the aquifer. Part *B* shows salt water invading the emptied aquifer.

water invasion. Visit the following Web site to learn more about the endangered Long Island, New York, aquifer. (You must sign up for a password to access the *New York Times* archives.) ***http://www.nytimes.com/2006/12/02/nyregion/02water.html?fta=y***

A related problem occurs in arid parts of the United States. In these areas, the soil is often salty. Irrigation of salty soil carries the salt deeper into the ground where it pollutes underground water supplies.

Subsidence

Taking water from the ground can cause the land to sink, or subside. Figure 10-11 shows a crack in the ground created by the use of groundwater. Usually, the sinking is a slow process that is not noticeable. However, cracks sometimes appear near the edge of the valley where deep sediments meet shallow bedrock. Sediments held up by bedrock are unable to sink with the central parts of the valley. This causes cracks to open. While the movement itself is not a danger, it can cause problems in the foundations of buildings and it can damage roads. The sinking ground level can also increase the danger of flooding when rivers run full. Perhaps more important, this is a sign that water is being mined too quickly. In a location such as this, groundwater is a nonrenewable resource.

FIGURE 10-11. In Arizona, this crack opened in the ground in a matter of days. Water taken out of the ground nearby caused the land level to sink several meters.

CHAPTER REVIEW QUESTIONS

Part A

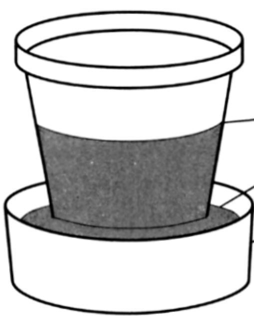
1. The water table usually rises when there is a(n)

(1) decrease in the amount of infiltration
(2) decrease in the amount of surface covered by vegetation
(3) increase in the amount of precipitation
(4) increase in the slope of the land

2. By which process do plants add water vapor to the atmosphere?

(1) precipitation (3) condensation
(2) transpiration (4) absorption

3. Water was poured into the container under a clay flowerpot. The water level in the bottom container dropped to level *A* as the wet part of the clay pot moved upward to *B*.



Water level *B* is higher than the water at *A* because water

(1) is less dense than the clay pot
(2) is more dense than the clay pot
(3) traveled upward in the clay pot by capillary action
(4) traveled downward in the clay pot by capillary action

4. Which sediment size would allow water to flow through at the fastest rate?

(1) clay (3) sand
(2) silt (4) pebbles

5. Why is much of Earth's water unfit for use by humans?

(1) Most of Earth's water is frozen.
(2) Most of Earth's water contains natural salt.
(3) Most of Earth's water is contaminated with sewage.
(4) Most of Earth's water is too deep underground to pump out.

6. How deep must a well be dug to yield a constant supply of freshwater?

(1) to the bottom of the soil
(2) to the top of the zone of aeration
(3) below the water table
(4) several meters into the bedrock

7. During a heavy rainstorm, runoff is most likely to occur if the surface of the soil is

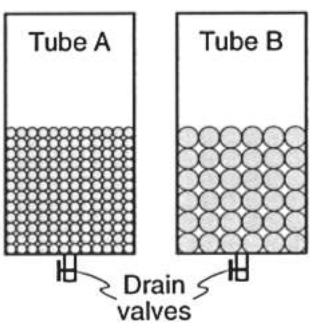
(1) firmly packed clay-sized particles
(2) loosely packed sand-sized particles
(3) covered by trees, shrubs, and grasses
(4) unsaturated and has a gentle slope

Part B

8. Which soil type has the slowest permeability rate and is most likely to cause flooding?

(1) clay (2) silt (3) sand (4) pebbles

9. Tubes *A* and *B* below with their drain valves are identical. Both are partly filled with spherical plastic beads of uniform size. However, the beads in *A* are smaller than in *B*. Each tube was filled with water to the same level; to the top of the beads. The information in the data table was recorded for tube *A* only.



Data Table 1: Tube A	
Water required to fill pore spaces	124 mL
Time required for draining	2.1 sec
Water that remained around the beads after draining	36 mL

If the same experiment was performed with tube *B*, which data table below best represents the expected results?

Data Table 2: Tube B	
Water required to fill pore spaces	124 mL
Time required for draining	1.4 sec
Water that remained around the beads after draining	26 mL

(1)

Data Table 2: Tube B	
Water required to fill pore spaces	124 mL
Time required for draining	3.2 sec
Water that remained around the beads after draining	36 mL

(3)

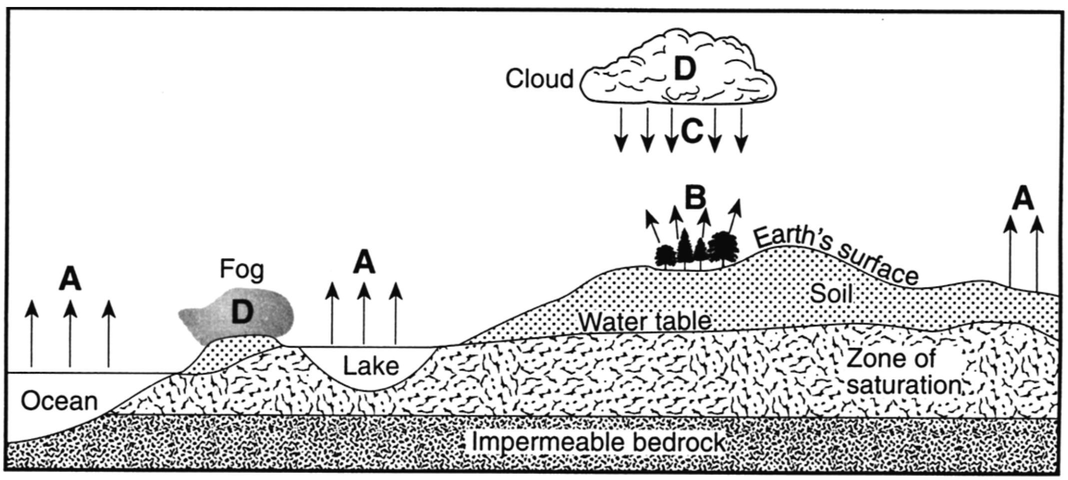
Data Table 2: Tube B	
Water required to fill pore spaces	168 mL
Time required for draining	3.2 sec
Water that remained around the beads after draining	46 mL

(2)

Data Table 2: Tube B	
Water required to fill pore spaces	168 mL
Time required for draining	1.4 sec
Water that remained around the beads after draining	36 mL

(4)

Base your answers to questions 10 through 12 on the diagram below, which shows selected processes of the hydrologic cycle.



10. Which two letters represent processes in the water cycle that usually cause a lowering of the water table?

(1) A and B
(2) A and C
(3) B and D
(4) C and D

11. What are two water-cycle processes *not* represented by arrows in this diagram?

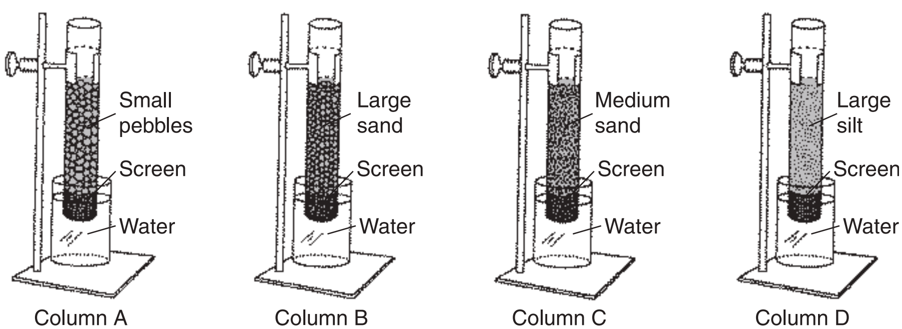
(1) transpiration and condensation
(2) evaporation and melting
(3) precipitation and freezing
(4) runoff and infiltration

12. What change in state is represented by *D* and how does this change affect the temperature of the air?

13. Which of the following events will upset people who use well water in their homes?

(1) building a community park
(2) constructing a gas station
(3) installing pipes under the roads to carry away storm water
(4) passing a law to prevent real estate development

14. Columns *A, B, C,* and *D* below are partly filled with different sediments. Each column contains particles of a uniform size. A fine wire-mesh screen covers the bottom of each column to prevent the sediment from falling out. The lower part of each column has just been placed in a beaker of water.

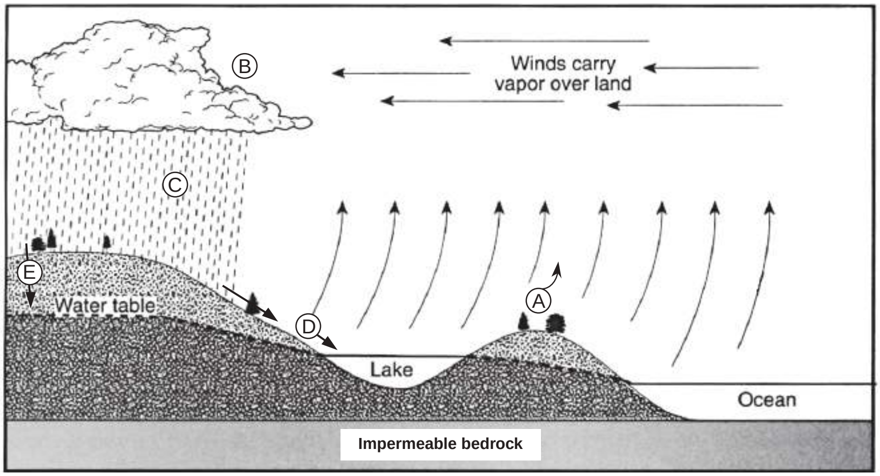


In which column would capillary action cause the water from the beaker to rise the highest?

(1) *A* (3) *C*
(2) *B* (4) *D*

Part C

15. Base your answer to question 15 on the diagram below. Name the process of the hydrologic cycle that occurs at each of the letters on the diagram: *A, B, C, D,* and *E.*

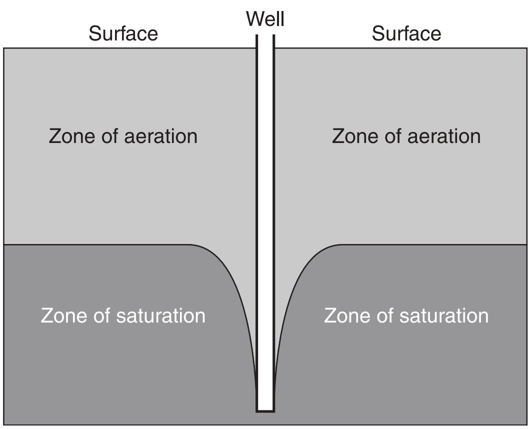


16. Describe the process of evaporation.

17. State one land-surface condition that would allow runoff to occur.

18. Explain one role of plants in the water cycle.

19. The diagram below is a profile view of a working water well. If the owner stopped using the well for many weeks, the position of the water table would probably change. On a sketch or a copy of this diagram, draw a dotted line to show the most likely new water level after this long period of no withdrawal of groundwater.



20. By what process do plants affect the moisture content of the atmosphere?