BIG IDEAS

Geology is the science of Earth, so geologists are Earth scientists or "geoscientists." Geologists observe, describe, and model the materials, energies, and processes of change that occur within and among Earth's spheres over time. They apply their knowledge to understand the present state of Earth, locate and manage resources, identify and mitigate hazards, predict change, and seek ways to sustain the human population.

FOCUS YOUR INQUIRY

THINK About It | How and why do geologists observe Earth materials at different scales (orders of magnitude)?

THINK About It | What materials, energies, and processes of change do geologists study?

THINK About It | How and why do geologists make models of Earth?

THINK About It | How and why do geologists measure Earth materials and graph relationships among Earth materials and processes of change?

THINK About It | How is the distribution of Earth materials related to their density?

1

LABORATORY

Thinking Like a Geologist

CONTRIBUTING AUTHORS

Cynthia Fisher • West *Chester University of Pennsylvania*
C. Gil Wiswall • *West Chester University of Pennsylvania*

Global Positioning System (GPS) devices, like this one on Mount St. Helens, are used to detect changes in the elevation of the volcano as magma moves beneath it. A rise in elevation of the volcano often precedes an eruption.

Introduction

Regardless of your educational background or interests, you probably have already done some thinking like a geologist. This lab will help you think and act even more like a geologist.

What Does It Mean to Start Thinking Like a Geologist?

You start thinking like a geologist when you focus on questions about planet Earth and try to answer them. You were thinking like a geologist if you ever observed an interesting landform, rock, or fossil, and wondered about how it formed. You were also thinking like a geologist if you ever wondered where your drinking water comes from, the possibility of earthquakes or floods where you live, where to find gold, how to vote on environmental issues, or what environmental risks may be associated with buying or building a home.

Wondering or inquiring about such things leads one to fundamental questions about Earth and how it operates. **Science** is a way of answering these questions by *gathering data* (information, evidence) based on investigations and careful observations, *thinking critically* (applying, analyzing, interpreting, and evaluating the data), *engaging in discourse* (verbal or written exchange, organization, and evaluation of information and ideas), and *communicating inferences* (conclusions justified with data and an explanation of one's critical thinking process). **Geology** is the science of Earth. Its name comes from two Greek words, *geo* = Earth and *logos* = discourse. So geologists are also Earth scientists or geoscientists.

Why Think Like a Geologist?

The products of geologic science are all around you—in the places where you live, the products you enjoy, the energy you use, and the government's environmental codes and safety policies that you must follow. For example, your home contains bricks, concrete, plaster wall boards (sheetrock), glass, metals, and asphalt roof shingles made with raw materials that were located by geologists. The safe location of your home was likely determined with the help of geologists. The wooden materials and foods in your home were processed with tools and machines containing metals that were extracted from ore minerals found by geologists. The electricity you use comes from generating plants that are fueled with coal, gas, oil, or uranium that was found by geologists. The safe location of the generating plants was evaluated by geologists, and the electricity is transported via copper wires made from copper ore minerals located by geologists. Even your trash and sewage are processed and recycled or disposed of in

accordance with government policies developed with geologists and related to surface and groundwater. So geologists are Earth detectives who try to locate and manage resources, identify and mitigate hazards, predict change, and help communities plan for the future. These things lay the foundation upon which all industrial societies are based. Yet the growing societies of the world are now testing the ability of geoscientists to provide enough materials, energy, and wisdom to sustain people's wants and needs. Now, more than ever, geologists are addressing fundamental questions about natural resources, the environment, and public policies in ways that strive to ensure the ability of Earth to sustain the human population.

How to Start Thinking and Acting Like a Geologist.

As you complete exercises in this laboratory manual, think and act like a geologist or Earth detective. **Focus on questions** about things like Earth materials and history, natural resources, processes and rates of environmental change, where and how people live in relation to the environment, and how geology contributes to sustaining the human population. **Conduct investigations and use your senses and tools to make observations** (determine and characterize the qualities and quantities of materials, energies, and changes). As you make observations, **record data** (factual information or evidence used as a basis for reasoning). **Engage in critical thinking**—apply, analyze, interpret, and evaluate the evidence to form tentative ideas or conclusions. **Engage in discourse** or collaborative inquiry with others (exchange, organization, evaluation, and debate of data and ideas). **Communicate inferences**—write down or otherwise share your conclusions and justify them with your data and critical thinking process.

These components of doing geology are often not a linear "scientific method" to be followed in steps. You may find yourself doing them all simultaneously or in odd order. For example, when you observe an object or event, you may form an initial interpretation of it or a hypothesis (tentative conclusion) about it. However, a good geologist (scientist) would also question these tentative conclusions and investigate further to see if they are valid or not. Your tentative ideas and conclusions may change as you make new observations, locate new information, or apply a different method of thinking.

How to Record Your Work.
When making observations, you should observe and record **qualitative data** by describing how things look, feel, smell, sound, taste, or behave. You should also collect and record **quantitative data** by counting, measuring or otherwise expressing in numbers what you observe. Carefully and precisely record your data in a way that others could use it.

Your instructor will not accept simple yes or no answers to questions. He or she will expect your answers to be complete inferences justified with data and an explanation of your critical thinking (in your own words). Show your work whenever you use mathematics to solve a problem so your method of thinking is obvious.

ACTIVITY

1.1 Geologic Inquiry

THINK | How and why do geologists observe
About It | Earth materials at different scales
| (orders of magnitude)?

OBJECTIVE Analyze and describe Earth materials at different scales of observation, then infer how they are related to you and thinking about geology.

PROCEDURES

1. **Before you begin**, do not look up definitions and information. Just focus on FIGURE 1.1. Use your current knowledge to start thinking like a geologist, and complete the worksheet with your current level of ability. Also, this is **what you will need** to do the activity:

   _____ Activity 1.1 Worksheets (pp. 25–26) and pencil with eraser

2. **Answer every question on the worksheets in a way that makes sense to you** and be prepared to compare your ideas with others.

3. **After you complete the worksheets**, read below about scales of observation and direct and remote observation of geology. Be prepared to discuss your observations and inferences with others.
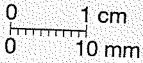
Scales of Earth Observation

The most widely known geologic feature in the United States is undoubtedly the Grand Canyon. This canyon cuts a mile deep, through millions of rock layers that are like pages of an immense stone book of geologic history called the **geologic record.** The layers vary in thickness from millimeters to meters. Each one has distinguishing features—some as tiny as microscopic fossils or grains of sand and some as large as fossil trees, dinosaur skeletons, or ancient stream channels. Yet when one measures and describes the layers, it can be done at the scale of a single page or at the scale of many pages, much the same as one might describe a single tree or the entire forest in which the tree is found. Each successive layer also represents a specific event (formation of the layer), which occurred at a specific time in Earth's long geologic history. Therefore, geologists are concerned with scales of observation and measurement in both space and time.

Spatial Scales of Observation and Measurement

Geologists study all of Earth's materials, from the spatial scale of atoms (atomic scale) to the scale of our entire planet (global scale). At each spatial scale of observation, they identify materials and characterize relationships. Each scale is also related to the others. You should familiarize yourself with these **spatial scales of observation** as they are summarized in FIGURE 1.2 and the tables of quantitative units of measurement, symbols, abbreviations, and conversions on pages xi and xii at the front of this manual. Terms such as regional, local, hand sample, and microscopic are hierarchical *levels of scale*, not measurements. When making measurements, geologists use these kinds of scales:

- **Bar scale**—A bar scale is a small ruler printed on an image or map. You use it to measure distances on the image or map. For example, all of the images in FIGURE 1.1 are accompanied by bar scales so you can make exact measurements of features within them. If a bar scale is given in one unit of measurement, like miles, and you want to know distances in kilometers, then you must convert the measurement using the table on page xii at the front of the manual.

- **Magnification scale**—This scale tells you how many times larger or smaller an object is in a picture compared to its actual size in real life. Magnification scale can be expressed as a percentage or a multiplication factor. For example, if you take a picture of a rock and enlarge it to twice its actual (normal) size, then you should note a scale of 200%, 2x, or x2 on the picture. If you reduce the picture of the rock so it appears only half of its actual size, then you should note a scale of 50%, 0.5x, or x1/2 on the picture. It does not matter which units of measurement you magnify (multiply). For example, if you measure a distance of 6 millimeters on the image that has a scale of 200% or x2, then the distance is actually 12 millimeters in real life.

- **Fractional scale**—A fractional scale is used to indicate how much smaller something is than its actual size. It is like the magnification scale, but expressed as a fraction. Therefore, if a picture shows a rock at only half of its actual size, then you can use a fractional scale of ½ *scale* to indicate it. It does not matter which units of measure you use, the actual size would still be half of what you measure in any units.

- **Ratio scale**—A ratio scale is commonly used when making models. The scale represents the proportional ratio of a linear dimension of the model to the same feature in real life. If a toy car is 20 centimeters long and the actual car was 800 centimeters long, then the ratio scale of model to actual car is 20:800, which reduces to 1:40. (Note: this is the same as a fractional scale of 1/40.) Ratio scales are commonly provided on maps, as well as three-dimensional models.

SPATIAL SCALES OF OBSERVATION USED BY GEOLOGISTS

Scale of observation	Used to study things like...	Measured in...
Global	Entire planet and its interactive "spheres"	Thousands of kilometers (km) or miles (mi)
Regional	Portions of oceans, continents, countries, provinces, states, islands	Kilometers (km), miles (mi)
Local (outcrop or field site)	Specific locations that can be "pin-pointed" on a map	Meters (m), feet (ft)
Hand sample (field/lab. sample)	Sample of a mineral, a rock, air, water, or an organism that can be held in your hand	Centimeters (cm), millimeters (mm), inches (in.) 0 — 1 cm 0 — 10 mm
Microscopic	Features of a hand sample that can only be seen with a hand lens (magnifier) or microscope	Fractions of millimeters (mm), micrometers (μm)
Atomic (or molecular)	Arrangements of the atoms or molecules in a substance	Nanometers (nm), angstroms (Å)

Macroscopic: visible with the naked eye (spanning Regional through Local rows)

FIGURE 1.2 Spatial scales. Geologists use different scales of observation in their work.

Time Scales of Observation and Measurement

Geologists also think about **temporal scales of observation.** As geologic detectives, they analyze rock layers as stone pages of the geologic record for evidence of events and relationships. As geologic historians, they group the events and relationships into paragraphs, chapters, sections, and parts of geologic history that occurred over epochs, periods, eras, and eons of time. The index to this book of geologic history is called the **geologic time scale** (FIGURE 1.3). Notice that the geologic time scale is a chart showing named intervals of the geologic record (rock units), the sequence in which they formed (oldest at the bottom), and their ages in millions of years. The intervals have been named and dated on the basis of more than a century of cooperative work among scientists of different nations, races, religions, genders, classes, and ethnic groups from throughout the world. What all of these scientists have had in common is the ability to do science and an intense desire to decipher Earth's long and complex history based on evidence contained in the rock layers that are the natural record of geologic history.
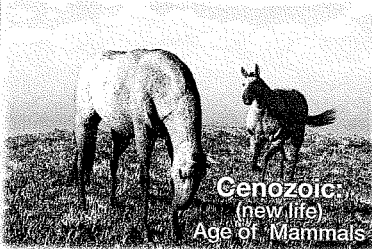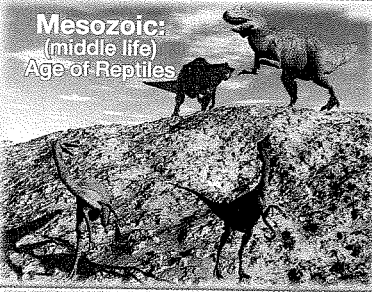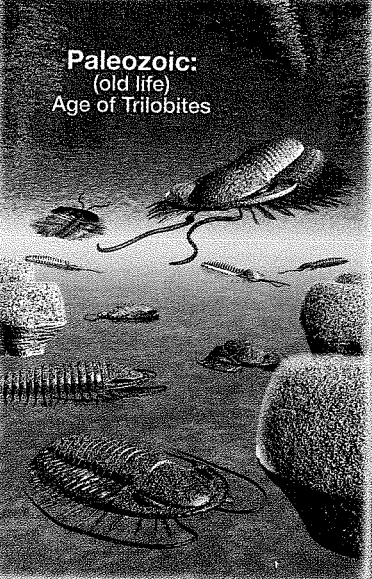
Direct and Remote Investigation of Geology

The most reliable information about Earth is obtained by direct observation, investigation, and measurement in the field (out of doors, in natural context) and laboratory. Most geologists study *outcrops*—field sites where rocks *crop out* (stick out of the ground). The outcrops are made of rocks, and rocks are made of minerals.

Samples obtained in the field (from outcrops at field sites) are often removed to the laboratory for further analysis using basic science. Careful observation (use of your senses, tactile abilities, and tools to gather information) and critical thought lead to questions and hypotheses (tentative ideas to test). Investigations are then designed and carried out to test the hypotheses and gather data (information, evidence). Results of the investigations are analyzed to answer questions and justify logical conclusions.

Refer to the example of field and laboratory analysis in FIGURE 1.4. Observation 1 (in the field) reveals that Earth's rocky geosphere crops out at the surface of the land. Observation 2 reveals that outcrops are made of rocks. Observation 3 reveals that rocks are made of mineral crystals such as the mineral *chalcopyrite*. This line of reasoning leads to the next **logical question:** *What is chalcopyrite composed of?* Let us consider the two most

THE GEOLOGIC TIME SCALE

A chart showing the sequence, names, and ages of Earth's rock layers (oldest at the bottom)

Eon of time Eonothem of rock	Era of time Erathem of rock	Period of time System of rock**		Epoch of time Series of rock	Millions of years ago (Ma)	Some notable fossils in named rock layers
Phanerozoic	Cenozoic (new life) Age of Mammals	Quaternary (Q)		Holocene	.0117	First *Homo* fossils, 70–100% extant mollusks[+]
				Pleistocene		
		Tertiary	Neogene (N)	Pliocene	2.6	First humans (Hominidae), 15–70% extant mollusks[+]
				Miocene	5.3	
					23	
			Paleogene (P$_G$)	Oligocene	34	More mammals than reptiles, <15% extant mollusks[+]
				Eocene	56	
				Paleocene		
					66	
	Mesozoic (middle life) Age of Reptiles	Cretaceous (K)				Last dinosaur fossils: including *Tyrannosaurus rex*
					145	
		Jurassic (J)				First bird fossil: *Archaeopteryx*
					201	
		Triassic (Ŧ)				First dinosaur, mammal, turtle, and crocodile fossils
					252	
	Paleozoic (old life) Age of Trilobites	Permian (P)				Last (youngest) trilobite fossils
					299	
		Carboniferous (C)*	Pennsylvanian (P)			First reptile fossils
					323	
			Mississippian (M)			First fossil conifer trees
					359	
		Devonian (D)				First amphibian, insect, tree, and shark fossils
					419	
		Silurian (S)				First true land plant fossils
					443	
		Ordovician (O)				First fossils of coral and fish
					485	
		Cambrian (Є)				First trilobite fossils First abundant visible fossils
					541	
Proterozoic						
					2500	
Archean	Precambrian: An informal name for all of this time and rock.	Oldest fossils of visible life (stromatolites)			3500	Oldest fossils: mostly microscopic life, visible fossils rare
					4000	
		Acasta Gneiss, northwestern Canada			4030	
Hadean		Nuvvuagittuq greenstone belt, Quebec, Canada			4280	
		Zircon mineral crystals in the Jack Hills Metaconglomerate, Western Australia			4400	
		Oldest meteorites			4550	

*European name
**Symbols in parentheses are abbreviations commonly used to designate the age of rock units on geologic maps.
[+]Extant mollusks are mollusks (clams, snails, squid, etc.) found as fossils and still living today.

FIGURE 1.3 **The geologic time scale.** Absolute ages in millions of years ago (Ma) follow the International Commission on Stratigraphy, 2013. See their website for more detailed versions and recent updates of the international geological time scale (**http://www.stratigraphy.org/index.php/ics-chart-timescale**).

1.3 Modeling Earth Materials and Processes

THINK | How and why do geologists make
About It | models of Earth?

OBJECTIVE Make models and use them to
understand Earth processes and the relative
proportions of Earth's physical spheres.

Geologists make models of things that are too
large or small to visualize and study. A scale model
is a physical representation of something that is
actually much larger or smaller and has the same
proportions as the actual object. For example, a toy
car is a small model of an actual car. The *ratio scale* of
the model is the ratio by which the actual object was
enlarged or reduced to make the scale model. If a toy
car is 20 centimeters long and the actual car was 800
centimeters long, then the ratio scale of model to
actual car is 20:800, which reduces to 1:40. A 1:40 scale
model has a *fractional scale* of 1/40, meaning that the
actual car is 40 times (40x) larger than the model.

Geologists also make models to study how things
work. They design laboratory experiments in which
they can control variables and test ideas before they
implement them in real life. For example, it is much
cheaper and safer to build and test many models of
earthquake-proof designs before constructing an
actual earthquake-proof building.

PROCEDURES

1. **Before you begin**, this is **what you will need**:

   ___ blue pencil or pen

   ___ calculator, ruler, drafting compass

   ___ several coins

   ___ Activity 1.3 Worksheets (pp. 30–31) and pencil
   with eraser

2. **Then follow your instructor's directions** for
   completing the worksheets.

without flames). And while some chemical reactions are
irreversible (decomposition reactions, like tooth decay),
many are reversible (under changing conditions, the
chemicals react again and recombine back into the starting
compounds). So these processes of change, powered
by energy transfer and transformation, cause chemical
materials to be endlessly cycled and recycled. One of these
cycles is the *hydrologic cycle*, or "water cycle."

The hydrologic cycle (FIGURE 1.7) involves several
processes and changes in relation to all three phases of water
and all of Earth's spheres (global subsystems). It is one of
the most important cycles that geologists routinely consider
in their work. The hydrologic cycle is generally thought to

1.4 Measuring and Determining Relationships

THINK | How and why do geologists measure
About It | Earth materials and graph relationships
| among Earth materials and processes
| of change?

OBJECTIVE Measure Earth materials using basic
scientific equipment and techniques, and determine
relationships using rates and graphs.

PROCEDURES

1. **Before you begin**, read the following background
   information on measuring Earth materials,
   determining rates, and graphing relationships.
   This is **what you will need**:

   ___ Activity 1.4 Worksheets (pp. 32–34) and pencil
   with eraser

   ___ calculator, ruler

   ___ other materials provided in the lab: 10 mL and
   500 mL or 1000 mL graduated cylinders, small
   piece of grease-based modeling clay, gram
   balance or scale, and basin of water

2. **Then follow your instructor's directions** for
   completing the worksheets.

operate like this: liquid water (hydrosphere) evaporating
from Earth's surface produces water vapor (atmospheric gas).
The water vapor eventually condenses in the atmosphere to
form aerosol water droplets (clouds). The droplets combine
to form raindrops or snowflakes (atmospheric precipitation).
Snowflakes can accumulate to form ice (cryosphere) that
sublimates back into the atmosphere or melts back into
water. Both rainwater and meltwater soak into the ground
(to form groundwater), evaporate back into the atmosphere,
drain back into the ocean, or are consumed by plants and
animals (which release the water back to the atmosphere via
the process of transpiration).

In addition to water that is moving about the Earth
system, there is also water that is stored and not circulating
at any given time. For example, a very small portion of
Earth's water (about 2% of the water volume in oceans) is
currently stored in snow and glacial ice at the poles and on
high mountaintops. Additional water (perhaps as much as
80% of the water now in oceans) is also stored in "*hydrous*"
(water-bearing) minerals inside Earth. When glaciers melt,
or rocks melt, the water can return to active circulation.

The endless exchange of energy and recycling of water
undoubtedly has occurred since the first water bodies
formed on Earth billions of years ago. Your next drink may
include water molecules that once were part of a hydrous
(water-bearing) mineral inside Earth or that once were
consumed by a thirsty dinosaur!
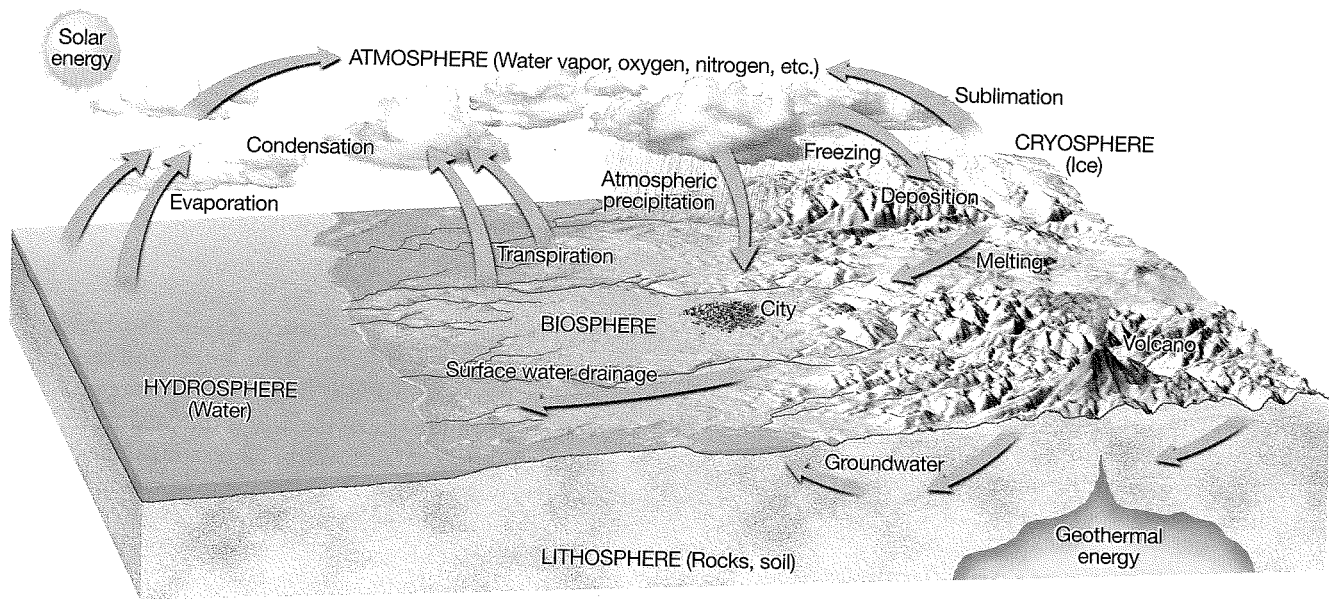
FIGURE 1.7 Hydrologic cycle (water cycle). Note the relationship of processes of change, and states of water, to Earth's spheres. Also note that the hydrologic cycle is driven (forced to operate) by energy from the Sun (solar energy), energy from Earth's interior (geothermal energy), and gravity.

Measuring Earth Materials

Every material has a *mass* that can be weighed and a *volume* of space that it occupies. An object's mass can be measured by determining its weight under the pull of Earth's gravity (using a balance). An object's volume can be calculated by determining the multiple of its linear dimensions (measured using a ruler) or directly measured by determining the volume of water that it displaces (using a graduated cylinder). In this laboratory, you will use metric balances, rulers, and graduated cylinders to analyze and evaluate the dimensions and density of Earth materials. Refer to page xiii at the front of this manual for illustrations of this basic laboratory equipment.

Metric System of Measurement

People in different parts of the world have historically used different systems of measurement. For example, people in the United States have historically used the English system of measurement based on units such as inches, feet, miles, pounds, gallons, and degrees Fahrenheit. However, for more than a century, most nations of the world have used the metric system of measurement based on units such as meters, liters, and degrees Celsius. In 1975, the U.S. Congress recognized the value of a global system of measurement and adopted the metric system as the official measurement system of the United States. This conversion is not yet complete, so Americans currently use both English and metric systems of measurement. In this laboratory we will only use the metric system.

Each kind of metric unit can be divided or multiplied by 10 and its powers to form the smaller or larger units of the metric system. Therefore, the metric system is also known as a base-10 or decimal system. The International System of Units (SI) is the modern version of metric system symbols, numbers, base-10 numerals, powers of ten, and prefixes (see page xi).

Orders of Magnitude and Scientific Notation

Differences of scale are sometimes expressed by powers (multipliers) of ten as **orders of magnitude**. For example, if object "A" is 10 times larger than object "B," then it is one order of magnitude larger (one power of ten, or 10 times larger). If object "A" is 100 times larger than object "B," then it is two orders of magnitude larger (two powers of ten, or 100 times larger).

Scientific (exponential) notation is a compact way of expressing very large or small numbers using base-ten orders of magnitude. For example, in scientific notation, three orders of magnitude larger would be "10 raised to a power of three" and written as 10^3. (This is also called "ten to the three" or "ten to the third.") The superscript "3" is called the exponent. So 3800 can be expressed in scientific notation as 3.8×10^3. For very small numbers, the exponent is negative, so 0.0038 is written 3.8×10^{-3} ("3.8 times ten to the negative three").

Scientific notation simplifies very large or small numbers by getting rid of zeros. For example, one billion is written as 1×10^9 instead of 1,000,000,000. Notice that the exponent signifies how many places to move the decimal place to the right (larger). One-millionth is written as 1×10^{-6} instead of 0.000001. In this case the exponent signifies how many places to move the decimal point to the left (smaller).

Calculators display a limited number of decimal places, so numbers with many decimal places must be entered in exponential notation. The calculators on many "smart phones" will display many decimal places when held horizontally. But if you turn the phone to a vertical position (with less space to display decimal places), then the phone will automatically change the number to exponential notion. Smart phones and most calculators use an "E" to signify the exponent, so one billion would be displayed as something like "1e+9" (representing 1×10^9).

The International System of Units (SI) is the modern version of the metric system and is based on powers of ten. See page xi at the front of this manual to learn more about it and how scientific notation is used to express large metric units.

Linear Measurements and Conversions

You must be able to use a metric ruler to make exact measurements of **length** (how long something is). This is called *linear measurement*. Most rulers in the United States are graduated in English units of length (inches) on one side and metric units of length (centimeters) on the other. For example, notice that one side of the ruler in FIGURE 1.8A is graduated in numbered inches, and each inch is subdivided into eighths and sixteenths. The other side of the ruler is graduated in numbered centimeters (hundredths of a meter), and each centimeter is subdivided into ten millimeters. The ruler provided for you in GeoTools Sheets 1 and 2 at the back of this manual are graduated in exactly the same way.

Review the examples of linear metric measurement in FIGURE 1.8A to be sure that you understand how to make *exact* metric measurements. Note that the length of an object may not coincide with a specific centimeter or millimeter mark on the ruler, so you may have to estimate the fraction of a unit as exactly as you can. The length of the red rectangle in FIGURE 1.8A is between graduation marks for 106 and 107 millimeters (mm), so the most exact measurement of this length is 106.5 mm. Also be sure that you measure lengths starting from the zero point on the ruler and *not from the end of the ruler*.

There will be times when you will need to convert a measurement from one unit of measure to another. This can be done with the aid of the mathematical conversions chart on page xii at the front of the manual. For example, to convert millimeters (mm) to meters (m), divide the measurement in mm by 1000 (because there are 1000 millimeters per meter):

$$\frac{106.5 \text{ mm}}{1000 \text{ mm/m}} = 0.1065 \text{ m}$$

Thus, 106.5 millimeters is the same as 0.1065 meters.

Unit Conversion—The Math You Need

You can learn more about unit conversion (including practice problems) at this site featuring The Math You Need, When You Need It math tutorials for students in introductory geoscience courses: **http://serc. carleton.edu/mathyouneed/units/index.html**

Area and Volume

An **area** is a two-dimensional space, such as the surface of a table. The long dimension is the *length*, and the short dimension is the *width*. If the area is square or rectangular, then the size of the area is the product of its length multiplied times its width. For example, the blue rectangular area in FIGURE 1.8A is 7.3 cm long and 3.8 cm wide. So the size of the area is 7.3 cm $\times$ 3.8 cm, which equals 27.7 cm^2. This is called 27.7 square centimeters. Using this same method, the yellow front of the box in FIGURE 1.8B has an area of 9.0 cm $\times$ 4.0 cm, which equals 36.0 cm^2. The green side of this same box has an area of 4.0 cm $\times$ 4.0 cm, which equals 16.0 cm^2.

Three-dimensional objects are said to occupy a **volume** of space. Box shaped objects have *linear volume* because they take up three linear dimensions of space: their length (longest dimension), width (or depth), and height (or thickness). So the volume of a box shaped object is the product of its length, width, and height. For example, the box in FIGURE 1.8B has a length of 9.0 cm, a width of 4.0 cm, and a height of 4.0 cm. Its volume is 9.0 cm $\times$ 4.0 cm $\times$ 4.0 cm, which equals 144 cm^3. This is read as "144 cubic centimeters."
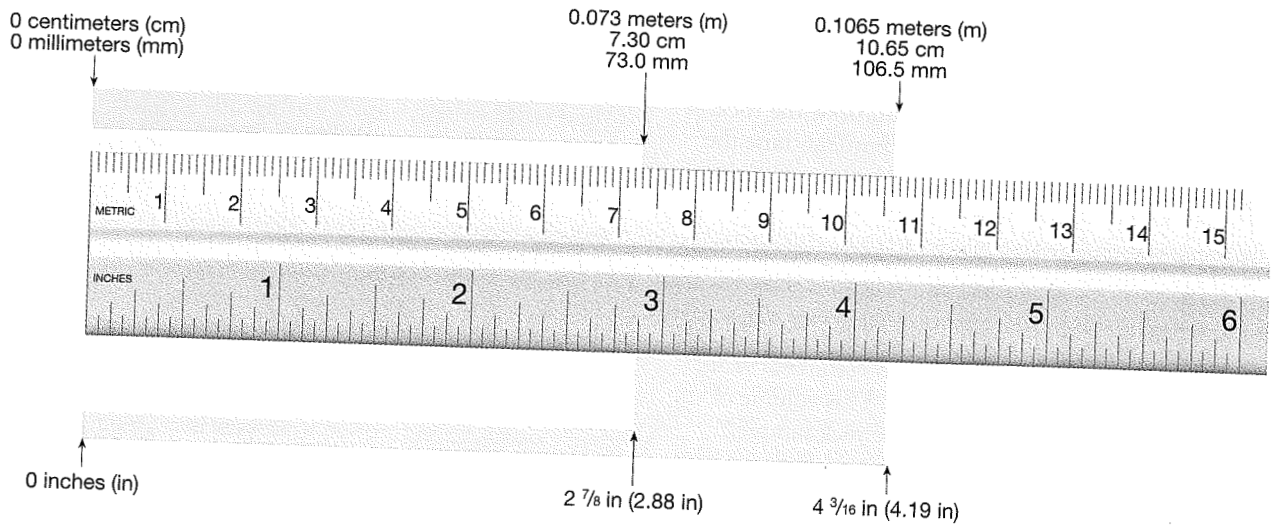
Most natural materials such as rocks do not have linear dimensions, so their volumes cannot be calculated from linear measurements. However, the volumes of these odd-shaped materials can be determined by measuring the volume of water they displace. This is often done in the laboratory with a *graduated cylinder* (FIGURE 1.8C), an instrument used to measure volumes of fluid (fluid volume). Most graduated cylinders are graduated in metric units called milliliters (mL or ml), which are thousandths of a liter. *You should also note that 1 mL of fluid volume is exactly the same as 1 cm^3 of linear volume.*

When you pour water into a graduated cylinder, the surface of the liquid is usually a curved *meniscus*, and the volume is read at the bottom of the curve (FIGURE 1.8C: middle and left-hand examples). In some plastic graduated cylinders, however, there is no meniscus. The water level is flat (FIGURE 1.8C: right-hand example).

If you drop a rock into a graduated cylinder full of water, then it takes up space previously occupied by water at the bottom of the graduated cylinder. This displaced water has nowhere to go except higher into the graduated cylinder. Therefore, the volume of an object such as a rock is exactly the same as the volume of fluid (water) that it displaces.
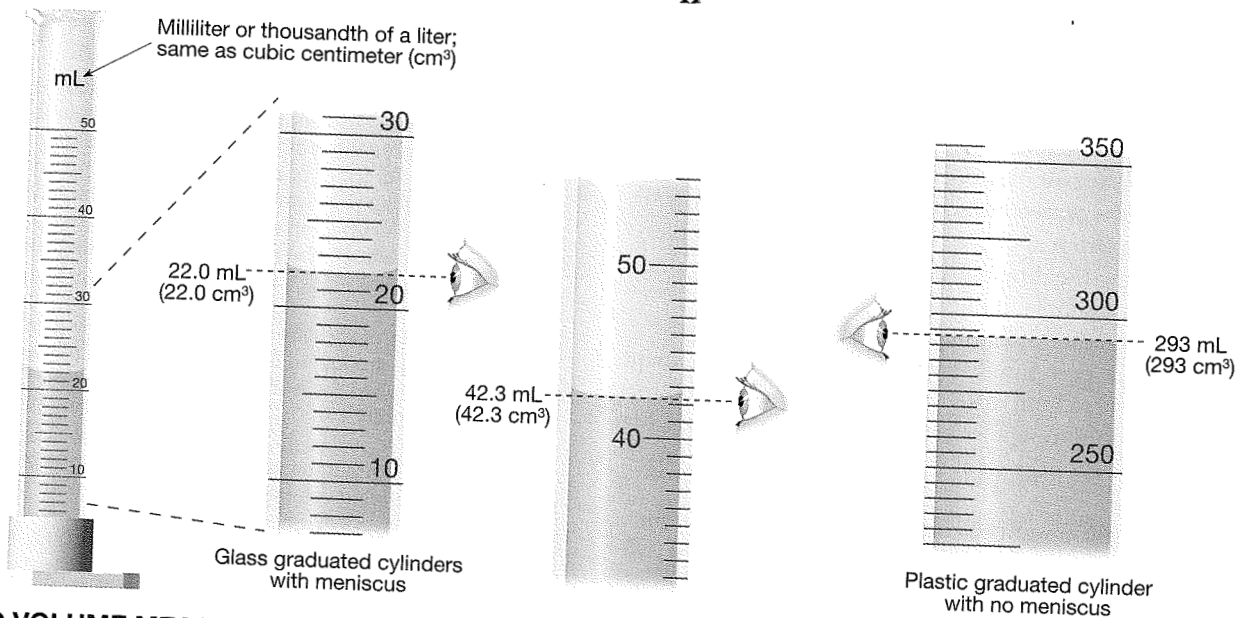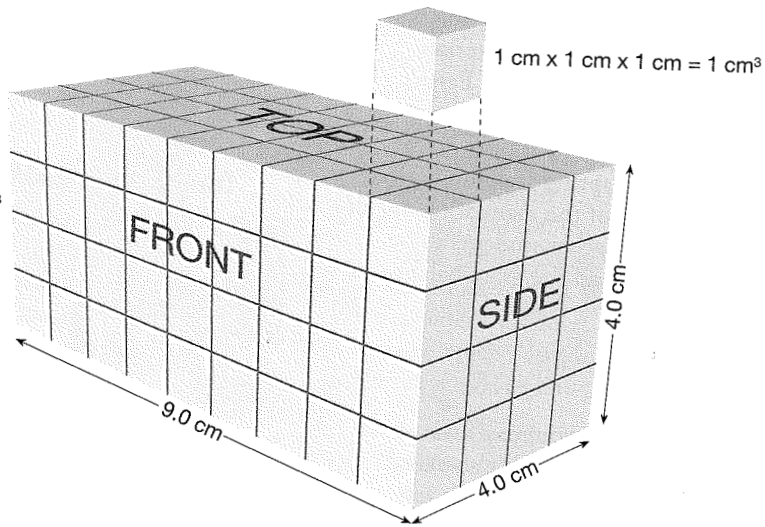
A. LINEAR MEASUREMENT USING A RULER

0 centimeters (cm)
0 millimeters (mm)

0.073 meters (m)
7.30 cm
73.0 mm

0.1065 meters (m)
10.65 cm
106.5 mm

METRIC 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

INCHES 1 2 3 4 5 6

0 inches (in)

2 7/8 in (2.88 in)

4 3/16 in (4.19 in)

B. VOLUME OF A BLOCK MEASURED IN CUBIC CENTIMETERS: cm³

9 cm x 4 cm x 4 cm = 144 cm³

1 cm x 1 cm x 1 cm = 1 cm³

TOP

FRONT

SIDE

4.0 cm

9.0 cm

4.0 cm

Milliliter or thousandth of a liter;
same as cubic centimeter (cm³)

mL

50

40

30

20

10

22.0 mL
(22.0 cm³)

30

20

10

Glass graduated cylinders
with meniscus

50

42.3 mL
(42.3 cm³)

40

350

300

293 mL
(293 cm³)

250

Plastic graduated cylinder
with no meniscus

C. FLUID VOLUME MEASURED WITH GRADUATED CYLINDERS IN MILLILITERS: mL or ml

FIGURE 1.8 Tools and scales of measurement. A. Linear measurement using a ruler. B. Linear volume measured in cubic centimeters.
C. Fluid volume measured with graduated cylinder (at base of meniscus). A milliliter (mL or ml) is the same as a cubic centimeter (cm³).

The water displacement procedure for determining the volume of a rock is illustrated in FIGURE 1.9. First place water in the bottom of a graduated cylinder. Choose a graduated cylinder into which the rock will fit easily, and add enough water to be able to totally immerse the rock. It is also helpful to use a dropper or wash bottle to raise the volume of water (before adding the rock) up to an exact graduation mark (5.0 mL mark in FIGURE 1.9A). Record this starting volume of water. Then carefully slide the rock sample down into the same graduated cylinder and record this ending level of the water (7.8 mL mark in FIGURE 1.9B). Subtract the starting volume of water from the ending volume of water, to obtain the displaced volume of water (2.8 mL, which is the same as 2.8 cm^3). This volume of displaced water is also the volume of the rock sample.

Mass

Earth materials do not just take up space (volume). They also have a mass of atoms that can be weighed. You will use a gram balance to measure the **mass** of materials (by determining their weight under the pull of Earth's gravity). The gram (g) is the basic unit of mass in the metric system, but instruments used to measure grams vary from triple-beam balances to spring scales to digital balances (see page xiii at the front of the manual). Consult with your laboratory instructor or other students to be sure that you understand how to read the gram balance provided in your laboratory.

Determining Rates

Geologists make many comparisons. You may find yourself comparing similar kinds of objects (a so-called *apples-to-apples* comparison) in one case, but different kinds of objects in another case (a so-called *apples-to-oranges* comparison). The same is true when comparing measurements of things (quantitative data). You may find yourself recording one kind of data in one unit of measure, but a second kind of data in another unit of measure. If the two measures are of the same class, such as two lengths or two masses, then you can simplify your comparison (from apples-to-oranges to apples-to-apples) by converting the different units of measure to one kind of unit. For example, if one distance is measured in miles and another in kilometers (an apples-to-oranges comparison), then simply convert the miles measurement to kilometers so both distances are in kilometers (and make a simpler apples-to-apples comparison). Conversion tables are provided on page xii at the front of the manual for this purpose.

What if you want to compare measures of different classes, such as how long objects are (units of length) compared to their mass (units of weight)? You are "stuck" with an apples-to-oranges comparison, so you must determine a rate. **Rate** is a mathematical expression of how much an amount determined in one unit of measure varies "per" (divided by) an amount determined in a different unit of measure.

WATER DISPLACEMENT METHOD FOR DETERMINING VOLUME OF A ROCK SAMPLE

A. Starting volume of water

B. Ending volume of water
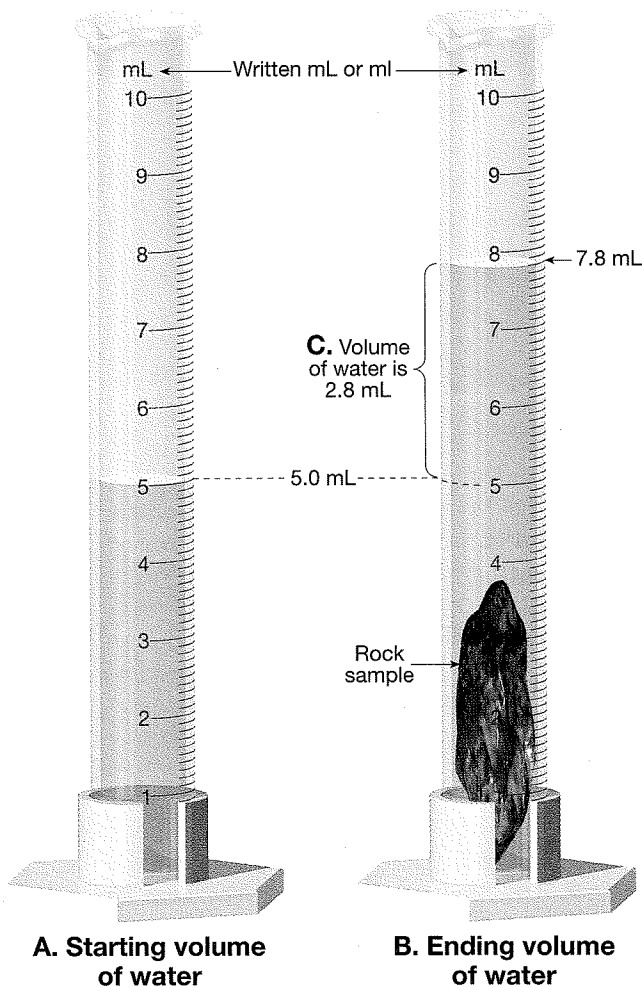
PROCEDURES

A. Place water in the bottom of a graduated cylinder. Add enough water to be able to totally immerse the rock sample. It is also helpful to use a dropper bottle or wash bottle and bring the volume of water (before adding the rock sample) up to an exact graduation mark like the 5.0 mL mark above. Record this starting volume of water.

B. Carefully slide the rock sample down into the same graduated cylinder, and record the ending volume of the water (7.8 mL in the above example).

C. Subtract the starting volume of water from the ending volume of water to obtain the displaced volume of water. In the above example: 7.8 mL – 5.0 mL = 2.8 mL (2.8 mL is the same as 2.8 cm^3). This volume of displaced water is the volume of the rock sample.

FIGURE 1.9 **Procedure for determining volume of a rock sample by water displacement.**

Rates Involving Time

The most common kind of rate is an expression of how something changes per unit of time, such as miles per hour. For example, if you drive 100 miles in 2 hours, then your rate of travel is 100 miles ÷ 2 hours, or 50 miles per hour (50 mi/h or 50 MPH).

- Knowing the rate of change per unit of time enables you to predict (calculate) how much change will occur by a future time. For example, if your rate of travel is 50 mi/h, then how far will you travel in four hours?

$$\frac{50 \text{ mi}}{1 \text{ h}} \times \frac{4 \text{ h}}{1} = 200 \text{ mi}$$

- Knowing the rate of change per unit of time also enables you to predict (calculate) how long it will take for a given amount of change to occur. If your rate of travel is 50 mi/h, then how far will it take you to travel 400 miles?

$$\frac{400 \text{ mi}}{50 \text{ mi/h}} = 8 \text{ h}$$

Calculating Rates—The Math You Need

You can learn more about calculating rates (including practice problems) at this site featuring The Math You Need, When You Need It math tutorials for students in introductory geoscience courses: **http://serc.carleton.edu/mathyouneed/rates/index.html**

Density: Mass per Volume

Every material has a *mass* that can be weighed and a *volume* of space that it occupies. However, the relationship between a material's mass and volume tends to vary from one kind of material to another. For example, a bucket of rocks has much greater mass than an equal-sized bucket of air. Therefore a useful way to describe an object is to determine its mass per unit of volume, which is a rate called **density**. *Per* refers to division (as in miles *per* hour). So, density is a measure (rate) of an object's mass divided by its volume (density = mass ÷ volume). Scientists and mathematicians use the Greek character rho (ρ) to represent density. Also, the gram (g) is the basic metric unit of mass, and the cubic centimeter is the basic unit of metric volume (cm^3), so density (ρ) is usually expressed in grams per cubic centimeter (g/cm^3).

Calculating Density—The Math You Need

You can learn more about calculating density (including practice problems) at this site featuring The Math You Need, When You Need It math tutorials for students in introductory geoscience courses: **http://serc.carleton.edu/mathyouneed/density/index.html**

Graphing Relationships

Graphs are useful for visualizing relationships in your data. So before you can make a graph, you need a set of data. Data makes more sense if you organize it into a chart. If you use Excel™, then your chart of data is called a spreadsheet. When organizing data, scientists normally have a column of data representing an independent variable. The independent variable is what you control, to see how it affects the dependent variable. The dependent variable is the variable being tested for, so you do not know what the values will be until you do an experiment. As you change the independent variable, you do a test or experiment to observe and record the dependent variable data. For example, if you want to characterize how fast a plant grows, then you may decide to measure its height every week (time here being the independent variable). When you measure and record the plant's height every week, then you are recording the dependent variable data. Geologists often want to characterize how something changes over time, so time is usually the independent variable. If you are placing your data in an Excel™ spreadsheet, then the independent variable data are entered in the first column (left-hand column, column A). The dependent variable data are entered in column B. Once you have an organized chart of data, then you can use it to construct a graph.

X-Y graphs are graphs with two axes, a horizontal X-axis and a vertical Y-axis. Scientists universally plot the independent variable along the X-axis and the dependent variable on the Y-axis. In Excel™, X-Y graphs are called scatter graphs or line graphs.

- **Scatter graphs** are X-Y graphs on which points are plotted (paced on the graph) but not joined into a line. Picture holes in a dart board. They are like the points on a scatter plot. By analyzing relationships among the points you can determine if they are widely scattered (a weak relationship to one another or no relationship at all) or closely concentrated (a strong relationship to one another). You can also look for patterns in the graph such as whether or not the points form one concentration or two or three concentrations of related points.

- **Line graphs** are X-Y graphs on which points are plotted and joined to form a line. If the points form a line that runs from lower left to upper right, then there is what is called a *positive* or *direct relationship*. This means that as the values of X (independent variable) increase, so do the values of Y. If the points form a line that runs from upper left to lower right, then there is what is called a *negative* or *inverse relationship*. This means that as the values of X (independent variable) increase, so do the values of Y. In both cases just described, the closer the points are to the line, the stronger is the relationship. Also, some line graphs compare two kinds of dependent variables to the independent variable. For example, you may want to know how plant height and number of leaves vary over the same time intervals. By plotting the data (two sets of dependent variable data) against the time

Name: _____ **Course/Section:** _____ **Date:** _____

A. Make the following unit conversions using the Mathematical Conversions chart on page xii.

1. 10 mi = _____ km   **3.** 16 km = _____ m   **5.** 25.4 mL = _____ cm^3

2. 1 ft = _____ m   **4.** 25 m = _____ cm   **6.** 1.3 liters = _____ cm^3

B. Write these numbers using scientific notation

1. 6,555,000,000 = _____   **2.** 0.000001234 = _____

C. Using a ruler, draw a line segment that has a length of exactly 1 cm (1 centimeter). A line occupies only one dimension of space, so a line that is 1 cm long is 1 cm^1.

D. Using a ruler, draw a square area that has a length of exactly 1 cm and a width of exactly 1 cm. An area occupies two dimensions of space, so a square that is 1 cm long and 1 cm wide is 1 cm^2 of area ($1 \text{ cm} \times 1 \text{ cm} = 1 \text{ cm}^2$).

E. Using a ruler, draw a cube that has a length of 1 cm, width of 1 cm, and height of 1 cm. This cube made of centimeters occupies three dimensions of space, so it is 1 cm^3 (1 cubic centimeter) of volume.

F. Explain how you could use a small graduated cylinder and a gram balance to determine the density of water (ρ_{water}) in g/cm^3. Then use your procedures to calculate the density of water as exactly as you can. Show your data and calculations.

G. Obtain a small lump of clay (grease-based modeling clay) and determine its density (ρ_{clay}) in g/cm^3. There is more than one way to do this, so develop and apply a procedure that makes the most sense to you. Explain the procedure that you use, show your data, and show your calculations.

H. Reconsider your answers to items **F** and **G** and the fact that modeling clay sinks in water.

1. Why does modeling clay sink in water?

2. What could you do to a lump of modeling clay to get it to float in water? Try your hypothesis and experiment until you get the clay to float.
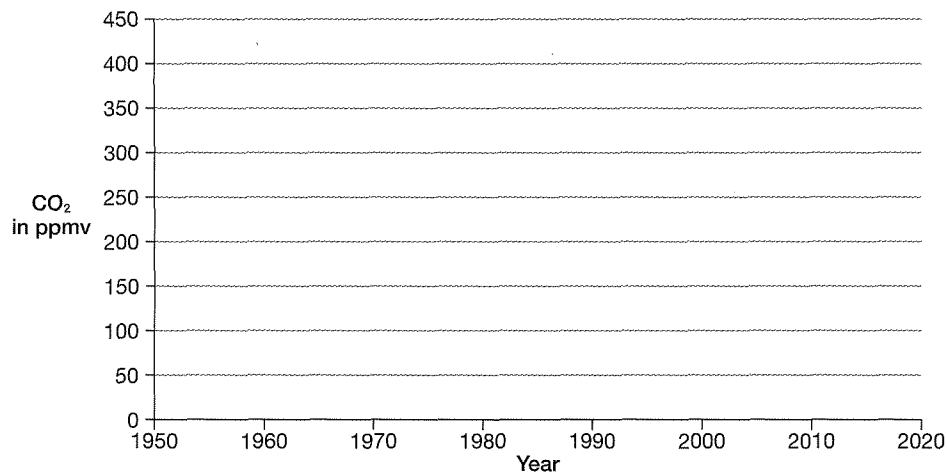
I. REFLECT & DISCUSS How is the distribution of Earth's spheres related to their relative densities? Why?

J. RATES:

1. Some geologists infer that Grand Canyon in Arizona is about 6 million years old. Its greatest depth is 1.6 km.

   a. At what rate (in mm/year) is the canyon being cut into the geosphere? Show your work, and give your final answer in scientific notation

   b. Based on the rate of canyon cutting that you just calculated above, how many millimeters has the Grand Canyon deepened during your lifetime? Show your work.

2. The geosphere is energized mostly by geothermal heat (heat originating in Earth's core). Therefore, it is much hotter deep inside Earth than it is near the surface. The **geothermal gradient** is the rate of temperature increase with depth from Earth's surface. The deepest mine on Earth is located on the African continent (Carletonville, South Africa: FIGURE 1.5). It is 3.9 km deep, and rocks at that depth are 60°C. Assuming that rocks at the surface of the mine are 0°C, what is the geothermal gradient at the mine? Show your work.

K. SINGLE-LINE GRAPH:
The amount of CO_2 in the atmosphere has been monitored at Mauna Loa Observatory, Hawaii since 1959. Below is a chart of NOAA (U.S. National Oceanic and Atmospheric Administration) data from the observatory, showing how the concentration of CO2 in ppmv (parts per million volume) has changed per decade since 1962. Plot the data onto the graph as neatly and perfectly as possible, then draw a best fit line through the points.
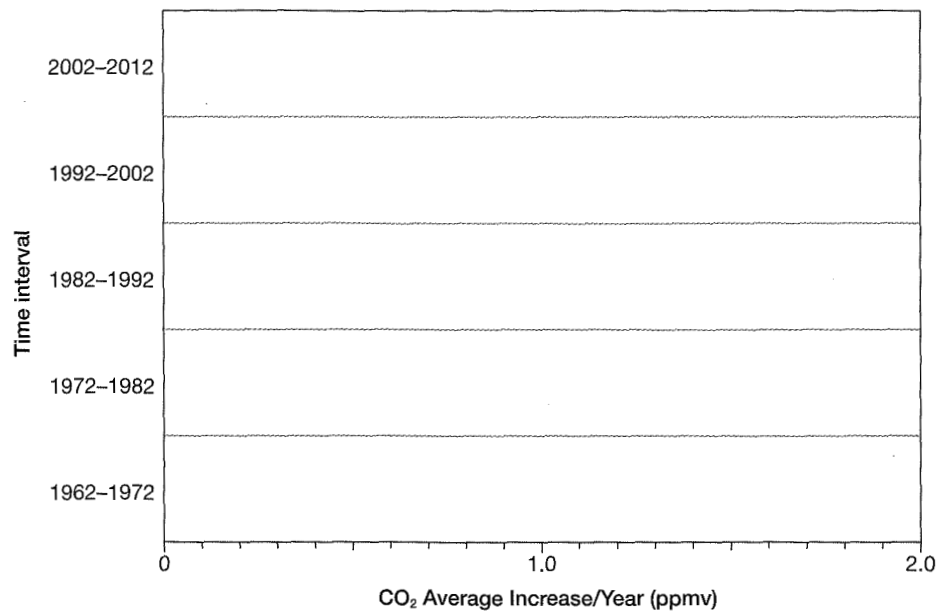
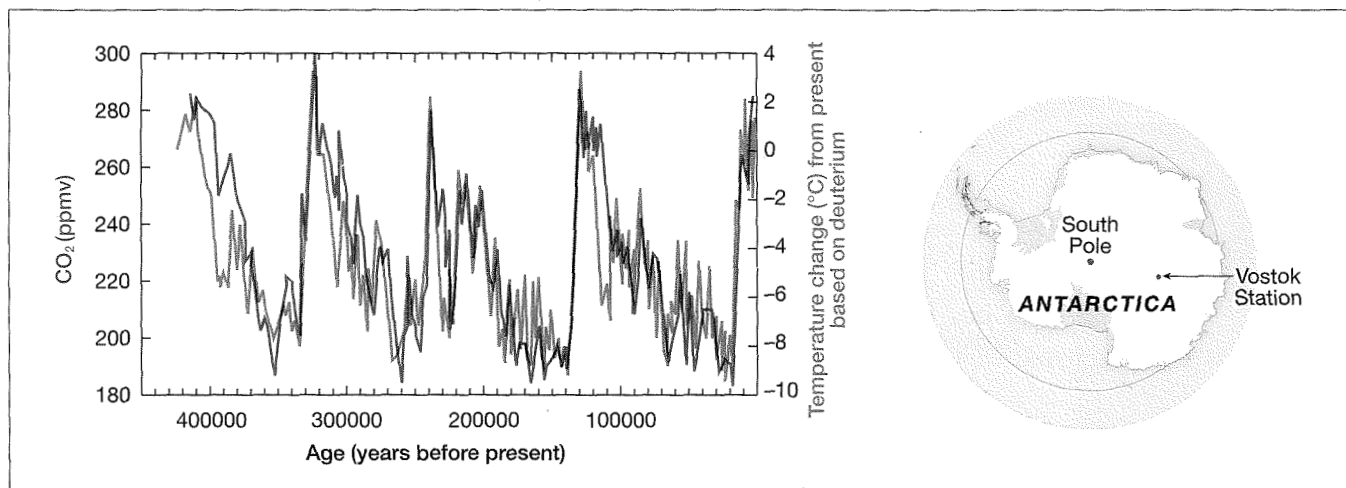| Annual Average Concentration of Atmospheric Carbon Dioxide at Mauna Loa, Hawaii	
Year	CO_2 (ppmv)
1962	318
1972	327
1982	341
1992	356
2002	373
2012	393

1. What does the graph show?

2. What are two ways you can tell from the graph that the concentration of CO_2 has increased since 1962?

L. BAR GRAPH: Using the data from part L, calculate the average rate of increase in CO_2 concentration per year for the time intervals 1962–1972, 1972–1982, 1982–1992, 1992–2002, and 2002–2012. Then plot the results as a bar graph.

Average Yearly Rate of Increase in the Concentration of Atmospheric Carbon Dioxide at Mauna Loa, Hawaii	
Time interval	Rate of increase per year
1962–1972	
1972–1982	
1982–1992	
1992–2002	
2002–2012	

(Bar graph: y-axis labeled "Time interval" with intervals 1962–1972, 1972–1982, 1982–1992, 1992–2002, 2002–2012; x-axis labeled "CO_2 Average Increase/Year (ppmv)" ranging 0 to 2.0)

M. TWO-LINE GRAPH: Two-line graph of data obtained by analysis of a core of ice from Vostok Station, Antarctica (from NOAA: U.S. National Oceanic and Atmospheric Administration). Blue line shows how temperature at Vostok has changed in degrees Celsius from present (0 is the present temperature). Red line shows how the concentration of carbon dioxide (in ppmv: parts per million volume) has changed at Vostok over the same interval of time.

(Graph: left y-axis "CO_2 (ppmv)" 180 to 300; right y-axis "Temperature change (°C) from present based on deuterium" −10 to 4; x-axis "Age (years before present)" from 400000 to near present. Map of Antarctica showing South Pole and Vostok Station.)

1. What relationship between temperature and carbon dioxide concentration is revealed by this graph?

N. REFLECT & DISCUSS What do you predict will happen to Earth's atmospheric temperature in the future? How do the graphs above (Parts K, L, and M) help you to answer this question?