LABORATORY 1

Thinking Like a Geologist

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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.

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)?

ACTIVITY 1.1 Geologic Inquiry *(p. 3)*

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

ACTIVITY 1.2 Spheres of Matter, Energy, and Change *(p. 9)*

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

ACTIVITY 1.3 Modeling Earth Materials and Processes *(p. 14)*

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

ACTIVITY 1.4 Measuring and Determining Relationships *(p. 14)*

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

ACTIVITY 1.5 Density, Gravity, and Isostasy *(p. 20)*

ACTIVITY 1.6 Isostasy and Earth's Global Topography *(p. 22)*

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 About It | **How and why do geologists observe 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

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

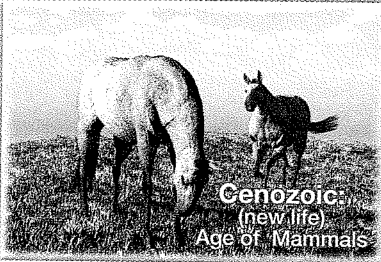
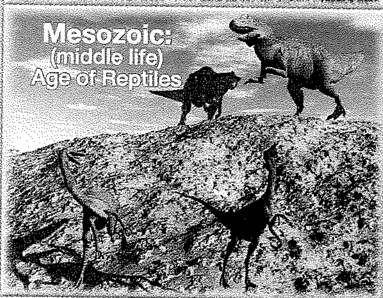
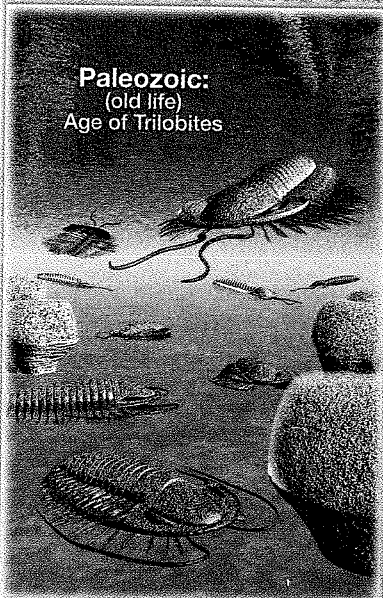
The most reliable information about Earth is obtained by direct observation, investigation, and measurement in the field (out of doors, in natural context) and laboratory. Most geologists study *outcrops*—field sites where rocks *crop out* (stick out of the ground). The outcrops are made of rocks, and 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	2.6	
		Tertiary — Neogene (N)	Pliocene	5.3	First humans (Hominidae), 15–70% extant mollusks+
			Miocene	23	
		Tertiary — Paleogene (P_G)	Oligocene	34	More mammals than reptiles, <15% extant mollusks+
			Eocene	56	
			Paleocene	66	
	 Mesozoic: (middle life) Age of Reptiles	Cretaceous (K)		145	Last dinosaur fossils: including *Tyrannosaurus rex*
		Jurassic (J)		201	First bird fossil: *Archaeopteryx*
		Triassic (Ŧ)		252	First dinosaur, mammal, turtle, and crocodile fossils
	 Paleozoic: (old life) Age of Trilobites	Permian (P)		299	Last (youngest) trilobite fossils
		Carboniferous (C)* — Pennsylvanian (ℙ)		323	First reptile fossils
		Carboniferous (C)* — Mississippian (M)		359	First fossil conifer trees
		Devonian (D)		419	First amphibian, insect, tree, and shark fossils
		Silurian (S)		443	First true land plant fossils
		Ordovician (O)		485	First fossils of coral and fish
		Cambrian (Ꞓ)		541	First trilobite fossils First abundant visible fossils
Proterozoic	Precambrian: An informal name for all of this time and rock.			2500	Oldest fossils: mostly microscopic life, visible fossils rare
Archean		Oldest fossils of visible life (stromatolites)		3500	
				4000	
Hadean		Acasta Gneiss, northwestern Canada		4030	
		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.

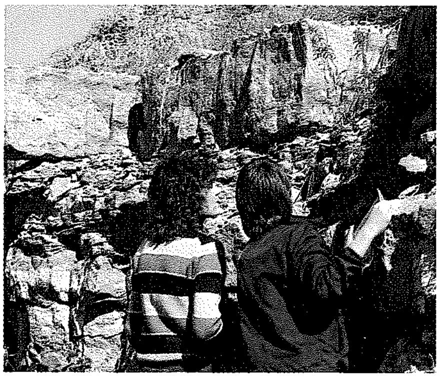
FIGURE 1.3 The geologic time scale. Absolute ages in millions of years ago (Ma) follow the International Commission on Stratigraphy, 2013. See their website for more detailed versions and recent updates of the international geological time scale (**http://www.stratigraphy.org/index.php/ics-chart-timescale**).

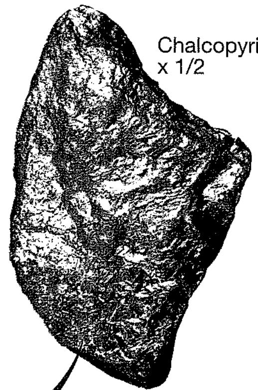
Example of Geologic Field and Laboratory Investigation

OBSERVATION 1: Earth's geosphere crops out in surface exposures called *outcrops*.

→ **OBSERVATION 2**: Outcrops are composed of *rocks*.

→ **OBSERVATION 3**: Rocks are composed of *mineral crystals*. Chalcopyrite is a kind of mineral crystal found in some rocks.





QUESTION: What is chalcopyrite comprised of?

↓

Multiple working hypotheses

HYPOTHESIS 1: Chalcopyrite could be a native element—a pure, natural occurrence of an element. An *element* is a chemical substance that cannot be separated into simpler chemical substances by processes such as heating, leaching (dissolving) with acid, or electrolysis. There are 92 naturally occurring elements, which scientists refer to by name or symbol: e.g., hydrogen (H), oxygen (O), carbon (C), copper (Cu), iron (Fe), sulfur (S), gold (Au).

HYPOTHESIS 2: Chalcopyrite could be a *compound*—a chemical substance that can be separated (decomposed or dissociated, into its constituent elements by processes such as heating, leaching (dissolving) with acid, or electrolysis. Scientists represent compounds by their chemical formulas, which denote the elements and how they are chemically combined (bonded) in fixed proportions. For example: H_2O (water), CO_2 (carbon dioxide).

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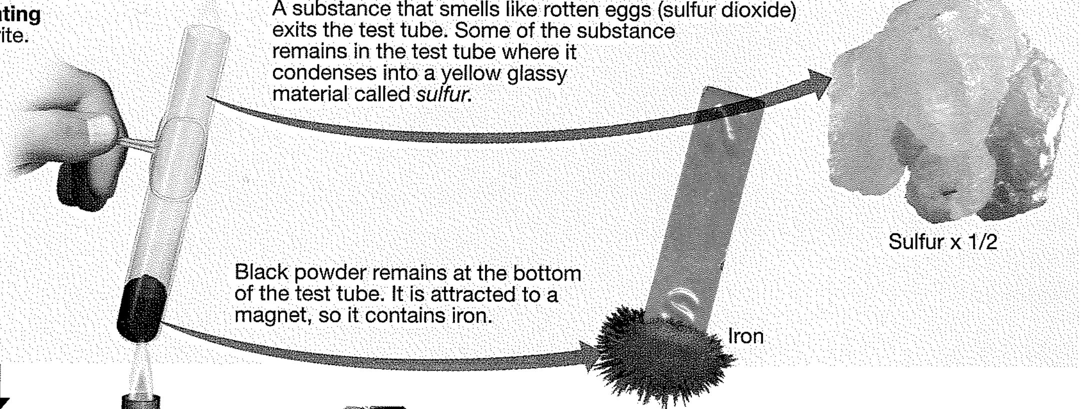
INVESTIGATION 1: Heating
Powder some chalcopyrite. Then heat it to see if it stays the same (Hypothesis 1) or separates into simpler substances (Hypothesis 2).



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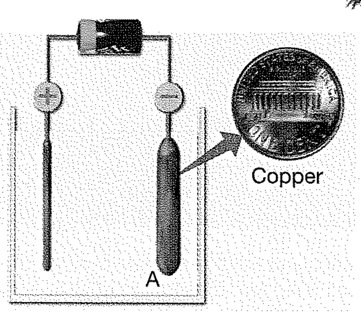
INVESTIGATION 2: Leaching and Electrolysis

A. Leaching: Dissolve soluble parts of the black powder (remaining from above) in acidic water to form solution A.
B. Electrolysis: When you pass an electric current through solution A, copper forms on one of the electrodes. Iron-rich powder is left behind.



→ **CONCLUSION**:
Chalcopyrite is a compound composed of sulfur (S), iron (Fe), and copper (Cu).

Chemists have determined in other investigations that chalcopyrite is copper-iron sulfide: $CuFeS_2$.

FIGURE 1.4 **Example of geologic field and laboratory investigation.**

logical possibilities, or **working hypotheses** (tentative ideas to investigate, test). It is always best to have more than one working hypothesis.

1. Chalcopyrite may be a pure substance, or chemical *element*. What investigating and gathering of evidence could we do to reasonably determine if this is true or false?

2. Chalcopyrite may be a *compound* composed of two or more elements. What investigating and gathering of evidence could we do to reasonably determine if this is true or false? If true, then how could we find out which elements make up chalcopyrite?

Let us conduct two **investigations** (activities planned and conducted to test hypotheses, gather and record data, make measurements, or control and explore variables). In Investigation 1, the chalcopyrite is ground to a powder and heated. This investigation reveals the presence of sulfur and at least one other substance. The remaining substance is attracted to a magnet, so it may be iron or a compound containing iron. When the powder is leached (dissolved in acidic water) and subjected to electrolysis (Investigation 2), copper separates from the powder. The remaining powder is attracted to a magnet, indicating the presence of iron. **Analysis of the results** of these two investigations leads us to the **logical conclusion** that Hypothesis 2 was correct (chalcopyrite is a compound). The results are also evidence that chalcopyrite is composed of three different elements: sulfur (S), iron (Fe), and copper (Cu). Chemists call chalcopyrite copper-iron sulfide ($CuFeS_2$). Since chalcopyrite contains a significant proportion of copper, it is also a *copper ore* (natural material from which copper can be extracted at a reasonable profit).

This same laboratory procedure is applied on a massive scale at copper mines. Because most copper-bearing rock contains only a small percentage of chalcopyrite or another copper-bearing mineral, the rock is mined, crushed, and powdered. It is then mixed with water, detergents, and air bubbles that float the chalcopyrite grains to the surface of the water. When these grains are removed, they are smelted (roasted and then melted) to separate impure copper from the other parts of the melted chalcopyrite (that cool to form *slag*). The impure copper is then leached in sulfuric acid and subjected to electrolysis, whereupon the copper is deposited as a mass of pure copper on the positive electrode (cathode).

Satellite Remote Sensing of Geology

There are times when geologists cannot make direct observations of Earth and must rely on a technology to acquire and record information remotely (from a distance, without direct contact). This is called *remote sensing*. One of the most common kinds of remote sensing used by geologists is satellite remote sensing.

Electromagnetic (EM) Radiation. The electromagnetic (EM) spectrum of radiation is a spectrum of electric and magnetic waves that travel at the speed of light (300,000,000 meters/second, or 3×10^8 m/s). The spectrum is subdivided into **bands**—parts of the EM spectrum that are defined and named according to their wavelength (distance between two adjacent wave crests or troughs).

Instruments aboard satellites scan information from not only the visible bands of the electromagnetic spectrum, but also parts of the spectrum that are not visible to humans (e.g., infrared).The ASTER instrument scans 14 bands of electromagnetic radiation. Bands 1, 2, and 3 are visible (blue-green, red) bands (left side, FIGURE 1.1). Bands 4–9 are short wave infrared bands (SWIR) that are invisible to humans (right side, FIGURE 1.1). Bands 10–14 are thermal infrared (TIR) bands that are also invisible to humans.

True Color and False Color Images. Data from environmental satellite instruments must be rendered into an image that humans can see, either by giving objects in the image their true color or a false color. **True color** photographs and satellite images show objects in the colors that they would appear to be if viewed by the human eye However, since many bands of radiation detected by satellites are not visible to humans, the bands are given a **false color** in satellite images (right side of FIGURE 1.1).

ACTIVITY 1.2 Spheres of Matter, Energy, and Change

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

OBJECTIVE Analyze and describe the materials, energies, and processes of change within and among Earth's spheres.

PROCEDURES

1. **Before you begin**, read the following background information on matter and spheres, energy sources and sinks, and processes and cycles of change. This is **what you will need:**
   ___ Activity 1.2 Worksheets (pp. 27–29) and pencil with eraser
2. Then, **follow your instructor's directions** for completing the worksheets.

Matter and Spheres

Everything on Earth is made of matter and energy. Matter is anything that takes up space and has a mass that can be weighed. It is tangible materials and substances. At the global scale of observation, geologists conceptualize Earth as a dynamic planetary system composed of interacting *spheres* (subsystems) of living and nonliving materials.

Geosphere

The **geosphere** is Earth's rocky body (FIGURE 1.5). The inner core has a radius of 1196 km and is composed mostly of iron (Fe) in a solid state. The outer core is 2250 km thick and is composed mostly of iron (Fe) and nickel (Ni) in a liquid state. The mantle is 2900 km thick and is composed mostly of oxygen (O), silicon (Si), magnesium (Mg), and iron (Fe) in a solid state. The crust has an average thickness of about 25 km and is composed mostly of oxygen (O), silicon (Si), aluminum (Al), and iron (Fe) in a solid state. Some people consider the cryosphere as a sub-sphere of the geosphere. The **cryosphere** is composed of snow crystals and ice that form from freezing parts of the hydrosphere or atmosphere. Ice is a rock made of mineral crystals (like snowflakes), so the cryosphere is actually a sub-sphere of the geosphere. Most of it exists in the polar ice sheets (continental glaciers), permafrost (permanently frozen moisture in the ground), and sea ice (ice on the oceans).

Hydrosphere

The **hydrosphere** is all of the liquid water on Earth's surface and in the ground (groundwater). Most of the hydrosphere is salt water in the world ocean, which has an average depth (thickness) of 3.7 km. However, the hydrosphere also includes liquid water in lakes, streams, and the ground (called *groundwater*).

Atmosphere

The **atmosphere** is the gaseous envelope that surrounds Earth. It consists of about 78% nitrogen (Ni), 21% oxygen (O), 0.9% argon (Ar) and trace amounts of other gases like carbon dioxide, water vapor, and methane. About 80% of these gases (including nearly all of the water vapor) occur in the lowest layer of the atmosphere (troposphere), which has an average thickness of about 16 km (10 miles). From there, the atmosphere thins and eventually ends (no air) at about 1000 km above sea level.

Biosphere

The **biosphere** is the living part of Earth, the part that is organic and self-replicating. It includes all bacteria, plants, and animals, so you are a member of the biosphere.

Magnetosphere

Earth's **magnetosphere** is its magnetic force field; not a material. It is generated from the core of the planet, and it is important because it shields Earth from the solar wind (a radiation of energy and particles from the Sun) that would otherwise make our planet lifeless.

Energy Sources and Sinks

Energy is the capacity to be active or do work, so matter does not move unless it has energy.

Earth's spheres would never change without their energy.

Forms of Energy

Here are some of the forms of energy that power you and the Earth system around you.

- *Thermal (heat) energy* is the energy of moving or vibrating atoms in matter related to its temperature. The higher the temperature, the greater the vibration or motion of its molecules. A hot cup of tea has a lot of thermal energy, but a cup of iced tea has less thermal energy. Cups of tea at the same temperature have equal thermal energy. One of Earth's two main sources of energy is the heat energy of its core (called **geothermal energy**).
- *Electromagnetic energy* is light, an oscillating (wave) form of energy perpetuated by coupled electronic and magnetic fields emitted from and reflected by objects. The distance between two crests in the waves of electromagnetic energy is called *wavelength*. Humans can only see a small part of the spectrum of electromagnetic wavelengths that exist in nature. Electromagnetic energy from our Sun is called **solar energy** and is the other primary source of Earth's energy (other than geothermal energy).
- **Nuclear energy** is energy stored in the nuclei (plural of nucleus) of atoms. Inside the Sun, hydrogen atoms are heated and energized so much that collisions among hydrogen atoms can fuse their nuclei together (*nuclear fusion*). This thermonuclear reaction creates one larger helium atom from every four hydrogen atoms, but it also converts some of the nuclear energy into electromagnetic energy (sunlight). Thus, the sunlight warming Earth's surface was transformed from nuclear energy in atoms of the Sun. In Earth's core, nuclei of abundant unstable atoms eventually decay (split apart into smaller nuclei, a process called nuclear fission). This transforms energy from the atomic nuclei into thermal energy. So the two main sources of energy that power Earth (solar energy, geothermal energy) have actually been transformed from nuclear energy.
- **Potential energy** is energy stored in an object because of its position in a force field. A force is a push or a pull, and the most dominant force field affecting Earth materials is Earth's gravity. Think of a small rock perched on the edge of a cliff. The rock has energy stored within it as a result of the fact that it is being pulled by Earth's gravitational force field. Gravity will cause the rock to fall if it happens to drop off the edge of the cliff (whereupon the potential energy is converted to kinetic energy).

Sometimes, objects change shape (i.e., they experience elastic strain) as potential energy builds up within them, and their potential energy can also be called elastic energy (instead of just potential energy). For example, if you bend a ruler, the ruler has energy stored within it because of the

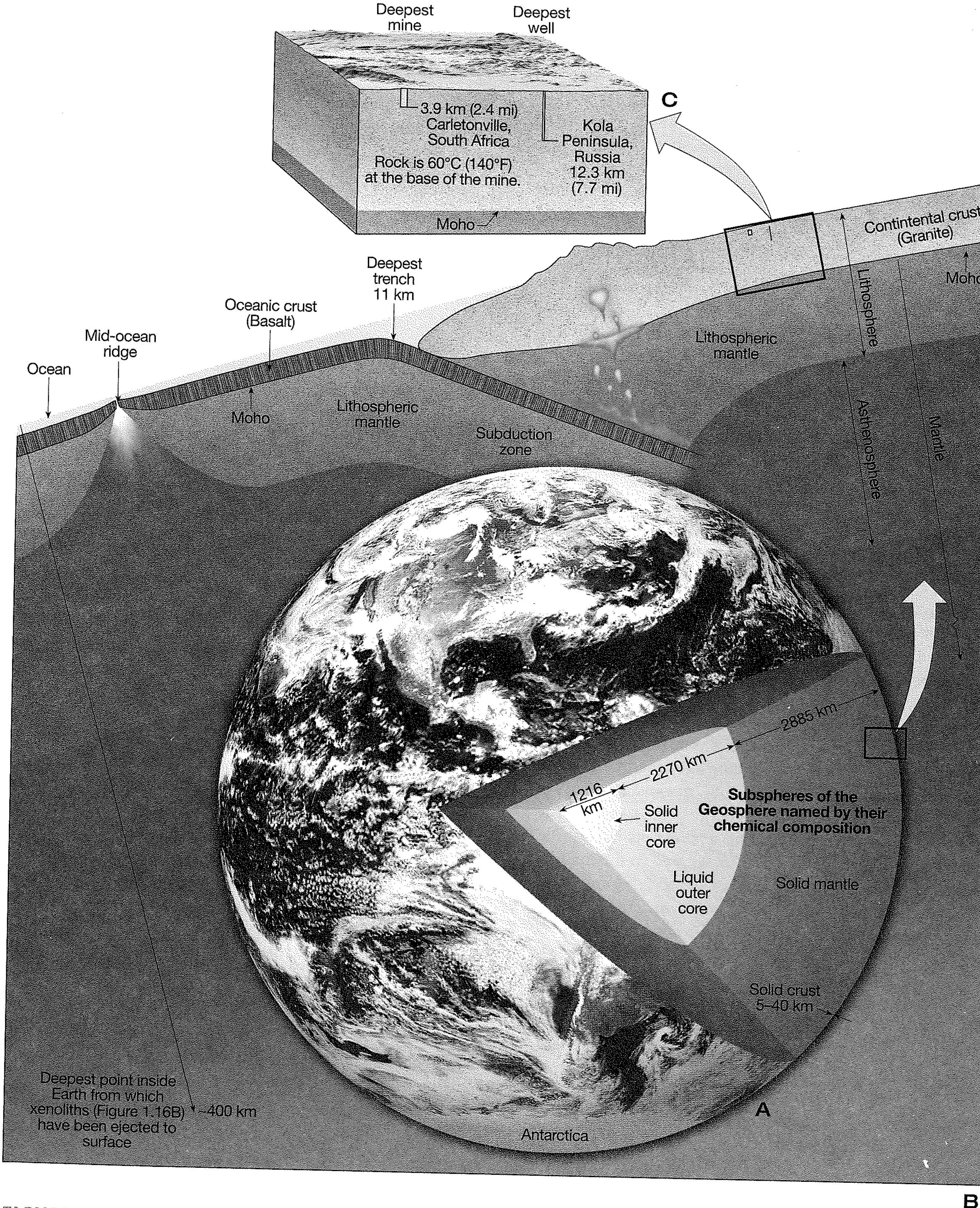


FIGURE 1.5 Global perspective of Earth. A. Earth photographed by Apollo 17 astronauts from about 37,000 km (23,000 mi) away in 1972. **(Courtesy of NASA)** Note compositional subspheres of the geosphere (rocky body of Earth) in the cutaway view: solid inner core, liquid outer core, solid mantle, and crust. B. Hypothetical cross section of the edge of the geosphere. Note the locations of thick continental crust, thin oceanic crust, Moho (base of the crust), lithosphere (crust + lithospheric mantle), and asthenosphere. C. Depths of the deepest mine and well ever drilled into Earth.

force that you physically exerted on the ruler. The amount of energy stored in the ruler is the same as the amount of energy that you exerted to bend the ruler.

- **Kinetic energy** is the energy that an object has due to its motion. Because the object is moving, it has the ability to do work (when it hits another object). You can tell that a moving car has kinetic energy because it is moving and has the capacity to do work when it hits something.
- **Mechanical energy** is the sum of energy associated with the motion (kinetic energy) and position (potential energy) of an object.
- **Chemical energy** is the energy stored in bonds of molecules and chemical compounds. The glucose sugar in your body stores energy that is released when its bonds are broken during respiration.
- **Electrical energy** is the energy carried by a flow of electrons, as in lightning and electrical currents flowing through wires and circuit boards in your electrical devices.

Energy Transfer and Equilibrium

Energy cannot be destroyed or used up, but it can be transferred from a *source* (place with more energy) to a *sink* (place with less energy). For example, energy from the Sun (a source) is transferred to Earth (the sink) by *radiation* (transfer of energy through space; not via materials), just as you can feel heat energy radiating from a hot stove. Energy from Earth's core (source) is transferred to the mantle above it (the sink) by *conduction* (energy transferred by direct contact between molecules of two stationary materials), just as you feel heat energy being conducted into your hand when you pick up a pan by its hot handle. Energy from Earth's core is also transferred to the mantle by *convection* (energy transferred or conveyed in moving molecules of flowing materials), just as you can see energy being transferred by convection in the motion of boiling water or in the hot globs of lava moving in a lava lamp. If energy of the source equals energy of the sink, then energy transfer stops, and the relationship is said to be in *equilibrium*. For example, if you turn off a boiling pot of water, its thermal energy will be dispersed into the materials around it until the pot of water and everything else in the room reach the same temperature (room temperature). When they reach room temperature, they are in thermal equilibrium.

Energy Transformation

When you sit in sunlight, you feel the Sun's energy being transformed into heat. Plants transform the Sun's electromagnetic energy into chemical energy to make their food. The plants apply the chemical energy when they use it to do work (cause an action; use it in photosynthesis to transform water and carbon dioxide into their food: $C_6H_{12}O_6$, glucose sugar). Energy is stored as chemical bonds (chemical energy) within the sugar molecules. When you eat sugar, your body breaks the chemical bonds so the energy can be transformed into heat energy, electrical energy, and other forms of chemical energy used to energize, grow, and repair cells. In an earthquake, potential energy stored in rocks is transformed into kinetic energy, which leads to the quaking motion of pushes and pulls that you feel and call an earthquake. Many energy transformations are associated with pushes and pulls (also called forces).

Energy, Matter, and Force

A *force* is a push or a pull. For example, the force of gravity (the mutual attraction between two objects) pulls us towards the center of Earth. Magnetic force has polarity. Unlike poles attract (pull the magnets together), and like poles repel (push the magnets apart). As a force pushes or pulls, it causes objects to build up potential energy, start moving, change direction of movement, or stop moving. Unlike matter, which you can see and feel, you cannot see a force. But you can feel the push or pull of a force, and you can see how it affects the motion or change in shape (deformation) of objects. When a force acts on matter, the matter has potential energy (energy stored in an object because of its position in a force field) or kinetic energy (the capacity to work as a function of its motion). So when we say that energy is the capacity to do work, it means that energy is the potential to exert a force. The force is what does the moving. The force also transfers energy and transforms energy.

When you push a heavy object, some of your chemical energy is converted to mechanical energy, which powers the force. During the force, the mechanical energy is transformed into potential energy until the object moves (whereupon it is transformed into kinetic energy). When you stop pushing, there is no more force (the force is destroyed), but the energy was transformed and conserved (not created or destroyed). This is a basic *law* (fundamental principle) of nature. Of course, matter cannot be created or destroyed either, so the two concepts are combined into one law. The Law of Conservation of Matter and Energy is that matter and energy can be transferred and transformed but cannot be created or destroyed.

Processes and Cycles of Change

Earth is characterized by the transfer (flow) of matter (materials) and energy during processes of change (FIGURE 1.6) at every spatial and temporal scale of observation. Most of these processes involve organic (biological; parts of living or once living organisms) and inorganic (non-biological) materials in solid, liquid, and gaseous states, or *phases*. Note that many of the processes have opposites depending on the flow of energy to or from a material: melting and freezing, evaporation and condensation, sublimation and deposition, dissolution and chemical precipitation, photosynthesis (food energy storage) and respiration (food energy release or "burning"

COMMON PROCESSES OF CHANGE

Process	Kind of Change	Example
Melting	Solid phase changes to liquid phase.	Water ice turns to water.
Freezing	Liquid phase changes to solid phase.	Water turns to water ice.
Evaporation	Liquid phase changes to gas (vapor) phase.	Water turns to water vapor or steam (hot water vapor).
Condensation	Gas (vapor) phase changes to liquid phase.	Water vapor turns to water droplets.
Sublimation	Solid phase changes directly to a gas (vapor) phase.	Dry ice (carbon dioxide ice) turns to carbon dioxide gas.
Deposition	The laying down of solid material as when a gas phase changes into a solid phase or solid particles settle out of a fluid.	Frost is the deposition of ice (solid phase) from water vapor (gas). There is deposition of sand and gravel on beaches.
Dissolution	A substance becomes evenly dipersed into a liquid (or gas). The dispersed substance is called a solute, and the liquid (or gas) that causes the dissolution is called a solvent.	Table salt (solute) dissolves in water (solvent).
Vaporization	Solid or liquid changes into a gas (vapor), due to evaporation or sublimation.	Water turns to water vapor or water ice turns directly to water vapor.
Reaction	Any change that results in formation of a new chemical substance (by combining two or more different substances).	Sulfur dioxide (gas) combines with water vapor in the atmosphere to form sulfuric acid, one of the acids in rain.
Decomposition reaction	An irreversible reaction. The different elements in a chemical compound are irreversibly split apart from one another to form new compounds.	Feldspar mineral crystals decompose to clay minerals and metal oxides (rust).
Dissociation	A reversible reaction in which some of the elements in a chemical compound are temporarily split up. They can combine again under the right conditions to form back into the starting compound.	The mineral gypsum dissociates into water and calcium sulfate, which can recombine to form gypsum again.
Chemical precipitation	A solid that forms when a liquid solution evaporates or reacts with another substance.	Salt forms as ocean water evaporates. Table salt forms when hydrochloric acid and sodium hydroxide solutions are mixed.
Photosynthesis	Sugar (glucose) and oxygen are produced from the reaction of carbon dioxide and water in the presence of sunlight (solar energy).	Plants produce glucose sugar and oxygen.
Respiration	Sugar (glucose) and oxygen undergo combustion (burning) without flames and change to carbon dioxide, water, and heat energy.	Plants and animals obtain their energy from respiration.
Transpiration	Water vapor is produced by the biological processes of animals and plants (respiration, photosynthesis).	Plants release water vapor to the atmosphere through their pores.
Evolution	Change over time (gradually or in stages).	Biological evolution, change in the shape of Earth's landforms over time.
Crystallization	Atoms, ions, or molecules arrange themselves into a regular repeating 3-dimensional pattern. The formation of a crystal.	Water vapor freezes into snowflakes. Liquid magma cools into a solid mass of crystals.
Weathering	Materials are fragmented, worn, or chemically decomposed.	Rocks break apart, get worn into pebbles or sand, dissolve, rust, or decompose to mud.
Transportation	Materials are pushed, bounced, or carried by water, wind, ice, or organisms.	Sand and soil are blown away. Streams push, bounce, and carry materials downstream.
Radiation	Transfer of energy through space; not via materials.	Sunlight radiates from the Sun to Earth.
Conduction	Transfer of energy by direct contact between molecules of two stationary materials.	A pan conducts heat from the hot stove top that it sits on.
Convection	Transfer of energy in moving molecules of flowing materials.	Thermal energy in lava is transferred as the lava flows from a volcano.
Convection cycling	Cyclic current motion (and heat transfer) within a flowing body of matter due to unequal heating and cooling. As part of the material is heated and rises, a cooler part of the material descends to replace it (whereupon it is reheated and rises again to form a convection cell.	Warm air in the atmosphere rises and cooler air descends to replace it; water boiling in a pot.

FIGURE 1.6 Some common processes of change on Earth.

ACTIVITY

1.3 Modeling Earth Materials and Processes

THINK About It | **How and why do geologists make 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.

ACTIVITY

1.4 Measuring and Determining Relationships

THINK About It | **How and why do geologists measure 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.

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 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!

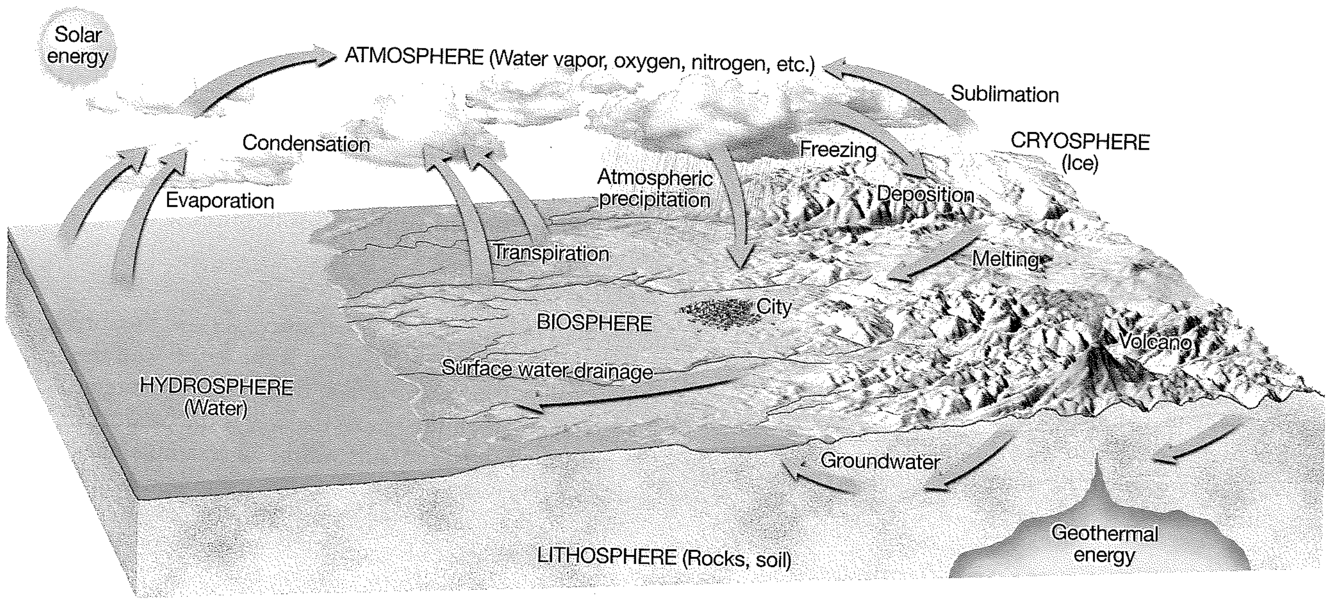


FIGURE 1.7 Hydrologic cycle (water cycle). Note the relationship of processes of change, and states of water, to Earth's spheres. Also note that the hydrologic cycle is driven (forced to operate) by energy from the Sun (solar energy), energy from Earth's interior (geothermal energy), and gravity.

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 × 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 × 4.0 cm, which equals 36.0 cm^2. The green side of this same box has an area of 4.0 cm × 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 × 4.0 cm × 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.

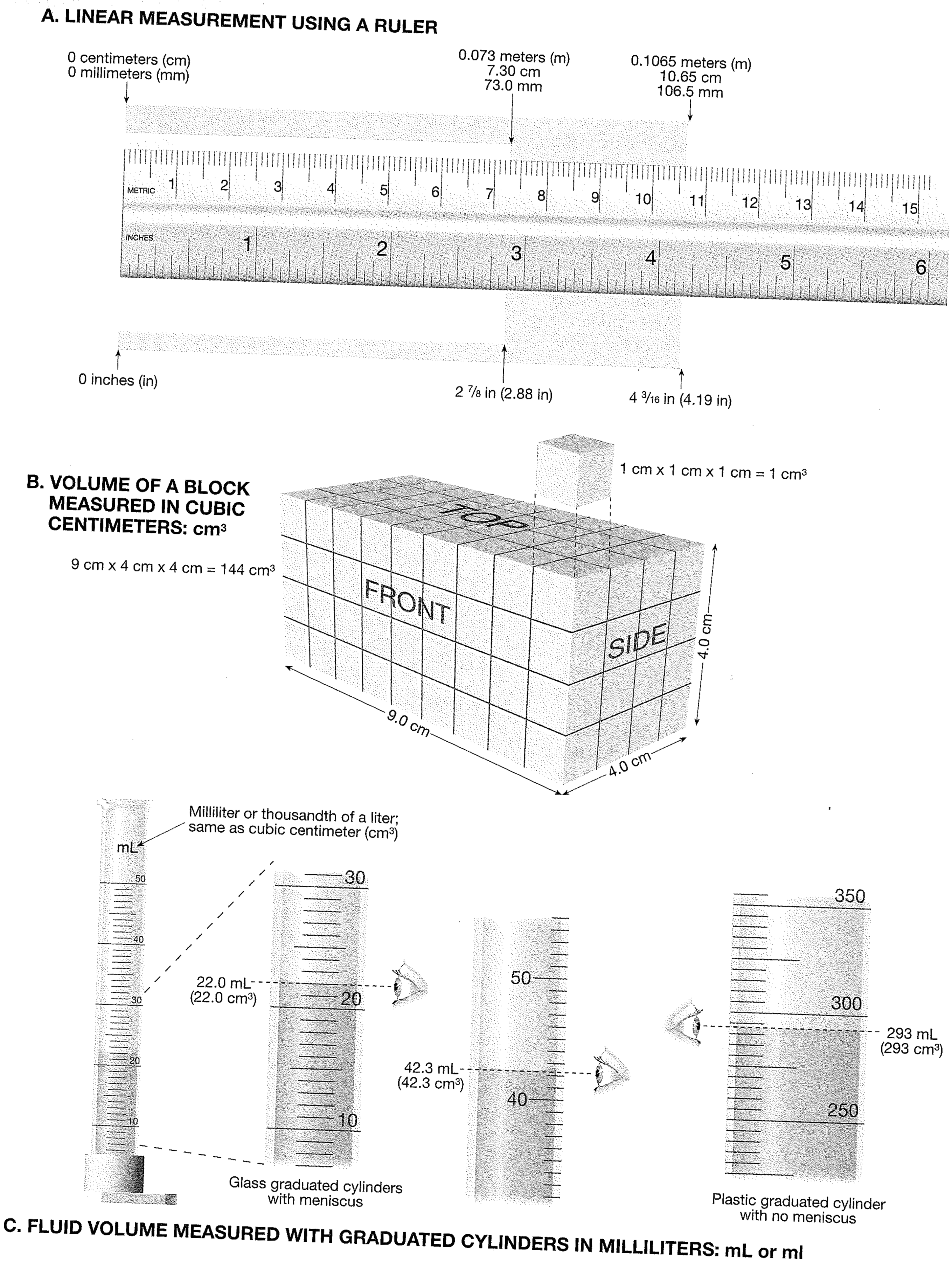


FIGURE 1.8 Tools and scales of measurement. A. Linear measurement using a ruler. B. Linear volume measured in cubic centimeters. C. Fluid volume measured with graduated cylinder (at base of meniscus). A milliliter (mL or ml) is the same as a cubic centimeter (cm^3).

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

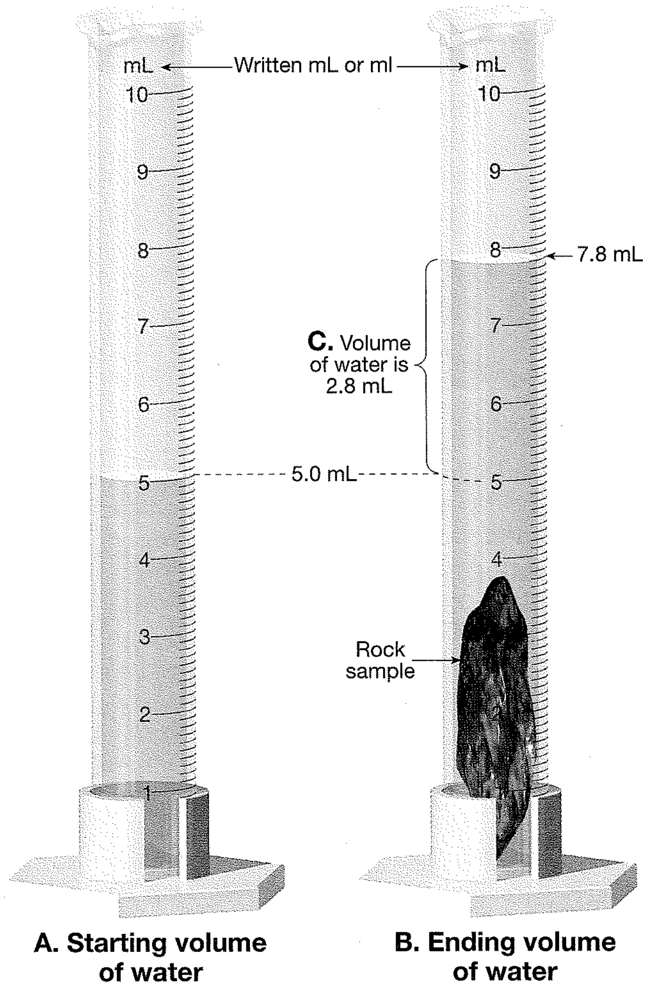
Earth materials do not just take up space (volume). They also have a mass of atoms that can be weighed. You will use a gram balance to measure the **mass** of materials (by determining their weight under the pull of Earth's gravity). The gram (g) is the basic unit of mass in the metric system, but instruments 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



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 axis (independent variable), you get two lines. So this kind of graph is called a *two-line graph*.

- **Bar graphs or histograms** use the length/height of a bar or column to show how frequently a measurement occurs. The bars are labeled according to the *class interval* of measurements that you choose (independent variable). The length/height of the bars is their *frequency*, how many times (how frequently) data values occur in each class interval. In Excel™, histograms are called bar graphs if the bars are horizontal and column graphs if the bars are vertical.

Graphing—The Math You Need

You can learn more about graphing and how to use graphs in the geosciences 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/graphing/index.html**

ACTIVITY

1.5 Density, Gravity, and Isostasy

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

OBJECTIVE Develop and test models of isostasy, measure rock densities, and calculate the isostasy of oceanic and continental crust.

PROCEDURES

1. **Before you begin**, read the following background information on density, gravity, and isostasy, and equations.This is **what you will need**:
   - ____ Activity 1.5 Worksheet (p. 35) and pencil with eraser
   - ____ calculator, ruler
   - ____ other materials provided in the lab: wood blocks (oak, pine), basin of water, gram balance or scale
2. **Then follow your instructor's directions** for completing the worksheets.

Density, Gravity, and Isostasy

Scientists have wondered for centuries about how the distribution of Earth materials is related to their density and gravity. Curious about buoyancy, the Greek scientist and mathematician, Archimedes, experimented with floating objects around 225 B.C. When he placed a block of wood in a bucket of water, he noticed that the block floated and the water level rose (FIGURE 1.10A). When he pushed down on the wood block, the water level rose even more. And when he removed his fingers from the wood block, the water pushed it back up to its original level of floating. Archimedes eventually realized that every floating object is pulled down (toward Earth's center) by gravity, so the object displaces fluid and causes the fluid level to rise. However, Archimedes also realized that every floating object is also pushed upward by a buoyant force that is equal to the weight of the displaced fluid. This is now called Archimedes' Principle.

Buoyant force (buoyancy) is caused as gravity pulls on the mass of a fluid, causing it to exert a *fluid pressure* on submerged objects that increases steadily with increasing depth in the fluid. The deeper (greater amount of) a fluid, the more it weighs, so deep water exerts greater fluid pressure than shallow fluid. Therefore, the lowest surfaces of a submerged object are squeezed more (by the fluid pressure) than the upper surfaces. This creates the wedge of buoyant force that pushes the object upward and opposes the downward pull of gravity (white arrows in FIGURE 1.10B). An object will sink if it is heavier than the fluid it displaces (is denser than the fluid it displaces). An object will rise if it is lighter than the fluid it displaces (is less dense than the fluid it displaces). But a floating object is balanced between sinking and rising. The object sinks until it displaces a volume of fluid that has the same mass as the entire floating object. When the object achieves a motionless floating condition, it is balanced between the downward pull of gravity and the upward push of the buoyant force.

Isostasy

In the 1880s, geologists began to realize the abundant evidence that levels of shoreline along lakes and oceans had changed often throughout geologic time in all parts of the world. Geologists like Edward Suess hypothesized that changes in sea level can occur if *the volume of ocean water changes* in response to climate. Global atmospheric warming leads to sea level rise caused by melting of glaciers (cryosphere), and global atmospheric cooling leads to a drop in sea level as more of Earth's hydrosphere gets stored in thicker glaciers. However, an American geologist named Clarence Dutton suggested that shorelines can also change *if the level of the land changes* (and the volume of water remains the same).

Dutton reasoned that if blocks of Earth's crust are supported by the mantle beneath them (solid rock capable of a slow flow) then they must float in the mantle according to Archimedes' Principle (like wood blocks, icebergs, and boats floating in water). Therefore, he proposed that Earth's crust consists of buoyant blocks of rock that float in gravitational balance in the top of the mantle. He called this floating condition **isostasy** (Greek for "equal standing"). Loading a crustal block (by adding lava flows, sediments, glaciers, water, etc.) will decrease its buoyancy, and the block will sink (like pushing down on a

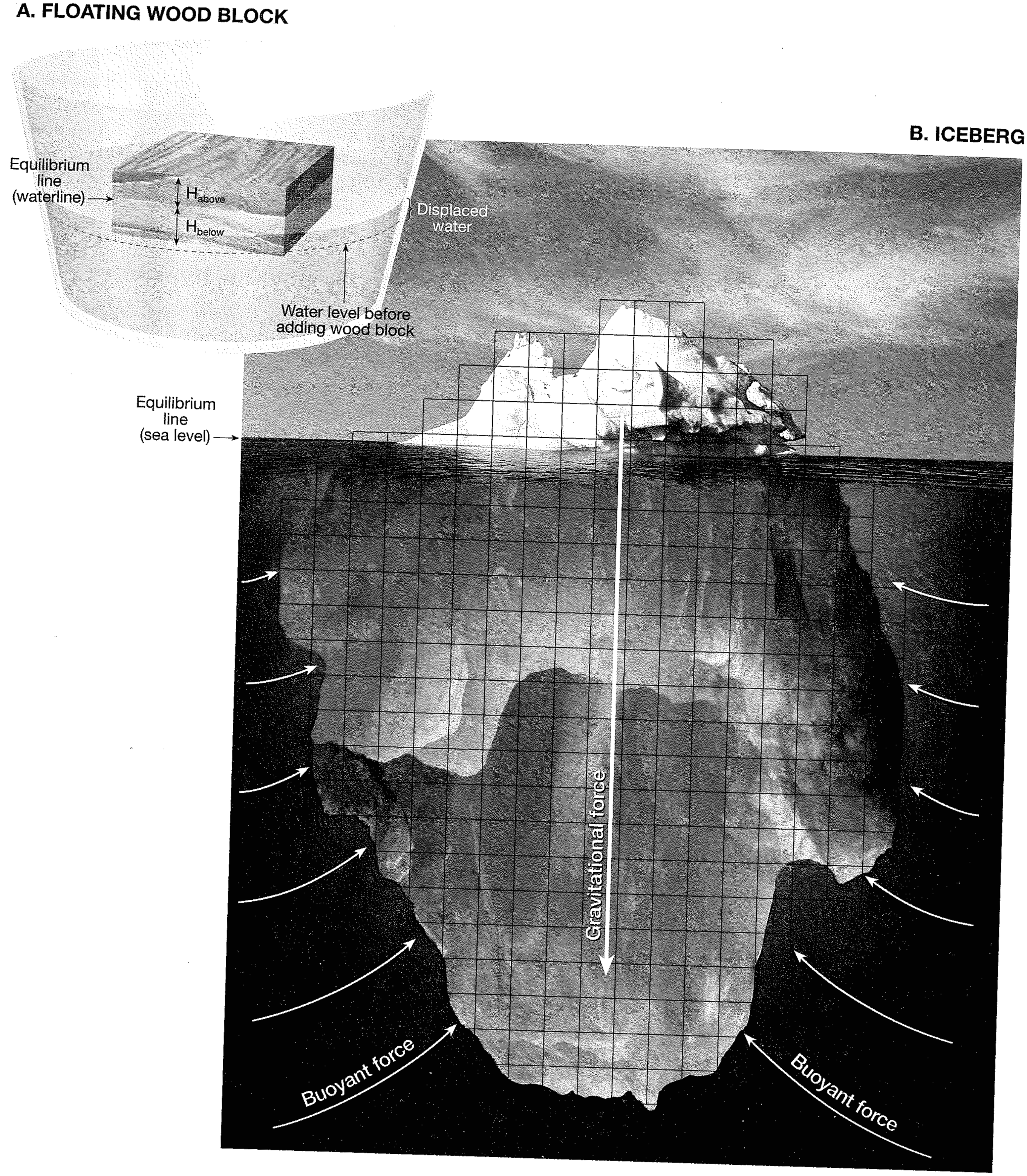


FIGURE 1.10 Isostasy relationships of a floating wood block (A) and iceberg (B). Refer to text for discussion. (Iceberg image © Ralph A. Clavenger/CORBIS. All rights reserved)

floating wood block). Unloading materials from a crustal block will increase its buoyancy, and the block will rise. Therefore, you can also think of isostasy as the equilibrium (balancing) condition between any floating object (such as the iceberg in FIGURE 1.10) and the more dense fluid in which it is floating (such as the water in FIGURE 1.10). Gravity pulls the iceberg down toward Earth's center (this is called *gravitational force*), so the submerged root of the iceberg displaces water. At the same time, gravity also tries to pull the displaced water back into its original place (now occupied by the iceberg's root). This creates fluid pressure that increases with depth along the iceberg's root, so the iceberg is squeezed and wedged (pushed) upward. This squeezing and upward-pushing force is called *buoyant force*. **Isostatic equilibrium** (balanced floating) occurs when the buoyant force equals (is in equilibrium with) the gravitational force that opposes it. An **equilibrium line** (like the waterline on a boat) separates the iceberg's submerged root from its exposed top.

Equations—The Math You Need

Activity 1.6 involves writing and rearranging equations. You can learn more about equations (including practice isostasy 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/equations/ManEqSP.html**

ACTIVITY

1.6 Isostasy and Earth's Global Topography

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

OBJECTIVE Analyze Earth's global topography and infer how the presence of continents and oceans it may be related to isostasy.

PROCEDURES

1. **Before you begin**, read the following background information on isostasy and Earth's global topography. This is **what you will need**:
   - ____ Activity 1.6 Worksheets (pp. 36–38) and pencil with eraser
   - ____ calculator
   - ____ other materials provided in the lab: 500 mL or 1000 mL graduated cylinder, small samples (about 30–50 g) of basalt and granite that fit into the graduated cylinder, a gram balance or scale, and water
2. **Then follow your instructor's directions** for completing the worksheets.

Isostasy and Earth's Global Topography

Clarence Dutton applied his isostasy hypothesis in 1889 to explain how the shorelines of lakes or oceans could be elevated by vertical motions of Earth's crust. At that time, little was known about Earth's mantle or topography of the seafloor. Modern data show that Dutton's isostasy hypothesis has broader application for understanding global topography.

Global Topography: The Hypsometric Curve

Radar and laser imaging technologies carried aboard satellites now measure Earth's topography very exactly, and the data can be used to form very precise relief images of the height of landforms and depths of ocean basins. For example, satellite data was used to construct the image in FIGURE 1.11A of Earth with ocean water removed. The seafloor is shaded blue and includes features such as shallow continental shelves, submarine mountains (mid-ocean ridges), deep abyssal plains, and even deeper trenches. Land areas (continents) are shaded green (lowlands) and brown (mountains).

The histogram (bar diagram) of Earth's topography in FIGURE 1.11B shows the percentage of Earth's surface for each depth or height class (bar) in kilometers. Notice that the histogram is bimodal (shows two levels of elevation that are most common on Earth). One of the elevation modes occurs above sea level and corresponds to the continents. The other elevation mode occurs below sea level and corresponds to the ocean floor.

FIGURE 1.11C is called a *hypsometric curve* (or *hypsographic curve*) and shows the cumulative percentage of Earth's spherical surface that occurs at specific elevations or depths in relation to sea level. This curve is not the profile of a continent, because it represents Earth's entire spherical surface. Notice that the cumulative percentage of land is only 29.2% of Earth's surface, and most of the land is lowlands. The remaining 70.8 cumulative percent of Earth's surface is covered by ocean, and most of the seafloor is more than 3 km deep.

Hypsometric Curve—The Math You Need

You can learn more about the hypsometric curve and how to read and use it 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/hypsometric/index.html**

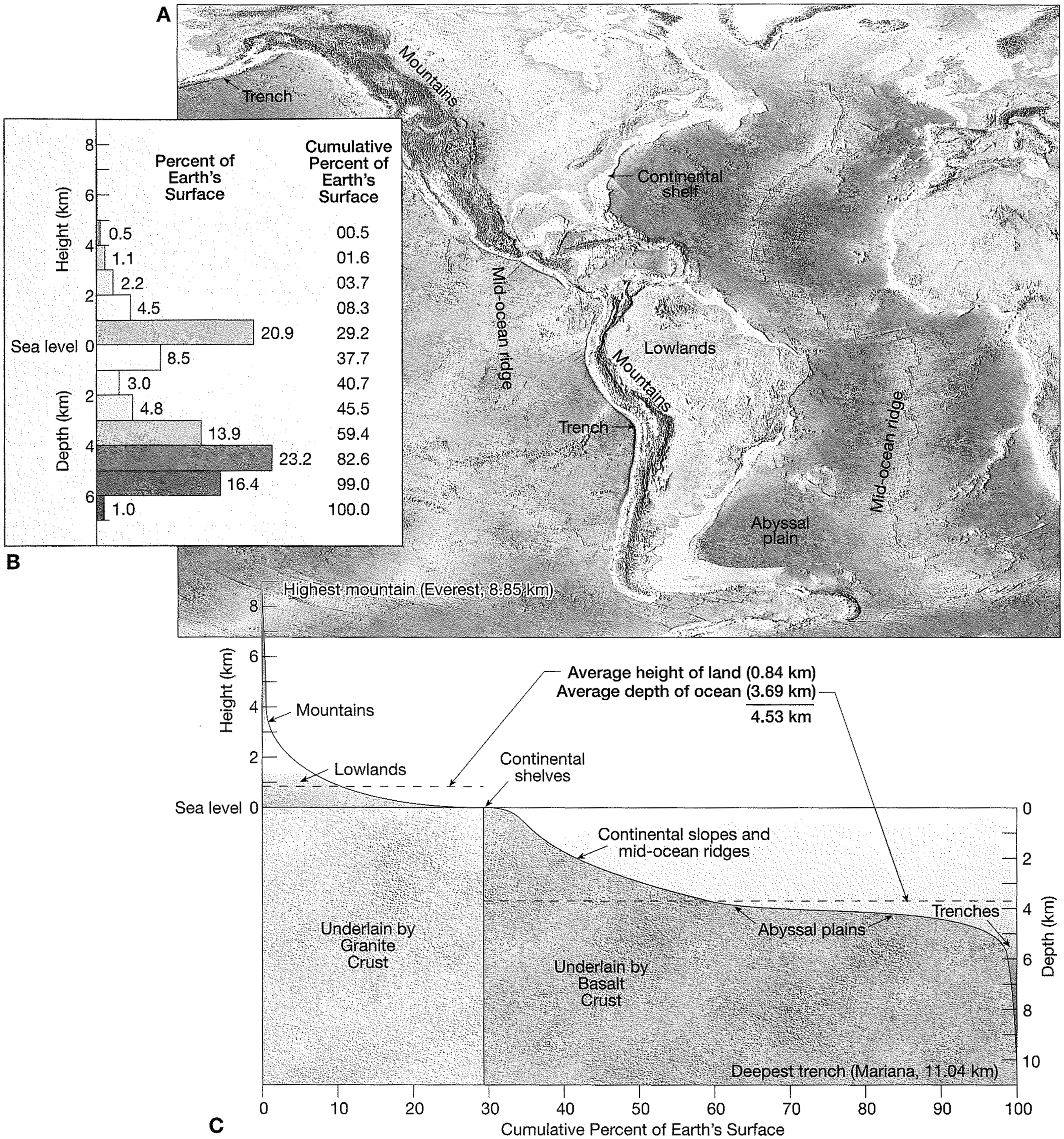


FIGURE 1.11 Global topography of Earth. A. Portion of Earth with ocean water removed, based on satellite-based radar and laser technologies. B. Histogram of global topography. C. Hypsometric curve (or hypsographic curve) of Earth's global topography. (Refer to text for discussion.)

Global Isostasy

The average elevation of the continents is about 0.84 km above sea level (+0.84 km), but the average elevation of the ocean basins is 3.87 km below sea level (−3.87 km). Therefore the difference between the average continental and ocean basin elevations is 4.71 km! If the continents did not sit so much higher than the floor of the ocean basins, then Earth would have no dry land and there would be no humans. What could account for this elevation difference? One clue may be the difference between crustal granite and basalt in relation to mantle peridotite.

Granite (light-colored, coarse-grained igneous rock) and basalt (dark-colored, fine-grained igneous rock) make up nearly all of Earth's crust. *Basaltic rocks* form the crust of the oceans, beneath a thin veneer of sediment. *Granitic rocks* form the crust of the continents, usually beneath a thin veneer of sediment and other rock types. Therefore, you can think of the continents (green and brown) in FIGURE 1.11A as granitic islands surrounded by a low sea of basaltic ocean crust (blue). All of these rocky bodies rest on mantle rock called *peridotite*. Could differences among the three rock types making up the outer edge of Earth's geosphere explain its bimodal global topography?

ACTIVITY 1.1 Geologic Inquiry

Name: ______________________ **Course/Section:** ______________________ **Date:** ____________

A. Carefully observe and analyze each part of FIGURE 1.1. Describe below what you see in each part. Be sure to record qualitative data (e.g., names, colors, shapes, textures, relationships of what you see) and quantitative data (e.g., amounts, sizes) in your descriptions. Be prepared to share your descriptions (data) with others.

1.1A: Aster satellite images of Escondida mining region, Chile:
1.1B: Ground view of Escondida open pit mine:
1.1C: Boulders in Escondida open pit mine:
1.1D: Minerals of Escondida open pit mine:
1.2E: Coin:
1.1F: Circuit board:
1.1G: Copper atoms:

B. How is everything in **FIGURE 1.1** related?

C. According to the Minerals Education Coalition, every American born in 2012 will consume 978 pounds (80.7 kg) of copper in his/her lifetime (**www.mineralseducationcoalition.org**). Analyze the three parts of **FIGURE 1.1** listed below, and do your best to answer the questions based on what you observe.

1.1A: Aster satellite images of Escondida mining region, Chile. How could geologists use these images, at this scale of observation, to find new sources of copper ore?
1.1B: Ground view of Escondida open pit mine. How can geologists and miners locate copper ore when they view the mine at this scale of observation?
1.1D: Minerals of Escondida open pit mine. What must be done with these ore minerals to provide you with the copper you need?

D. REFLECT & DISCUSS Analyze **FIGURE 1.1A**, ASTER satellite images of Chile's Escondida Mine and vicinity. This is primarily a mine for copper ore minerals, from which copper is extracted. Some silver and gold are also extracted from the same ore. The ore is mined from large open pits. Notice how these pits appear in the images.

1. Imagine that you are a geologist who has been hired by Escondida Mine to find the best location for a new pit. Which location, A, B, or C, is probably the best site for a new pit? What evidence and critical thinking process leads you to this conclusion?

2. What plan of scientific investigation would you carry out to see if the location you chose above is actually a good source for more copper ore?

ACTIVITY 1.2 Spheres of Matter, Energy, and Change

Name: ______________________ **Course/Section:** ______________ **Date:** ________

A. Complete the table below.

State of Matter	Sphere	What is the main source of energy that powers the sphere (Sun or geothermal energy)?	Give examples of named parts of this sphere that you have personally encountered.
GAS: What is a gas?	What sphere is made mostly of gases?		
LIQUID: What is a liquid?	What sphere is made mostly of liquid water?		
	What subsphere of Earth in Figure 1.8 is a mostly liquid rock?	Geothermal energy	Not encountered by humans.
SOLID: What is a solid?	What subsphere is made mostly of water ice?		
	What sphere is made mostly of solid rock (besides water ice)?		
SOLIDS, LIQUIDS, AND GASES	What sphere consists of living parts containing solids, liquids, and gases?		

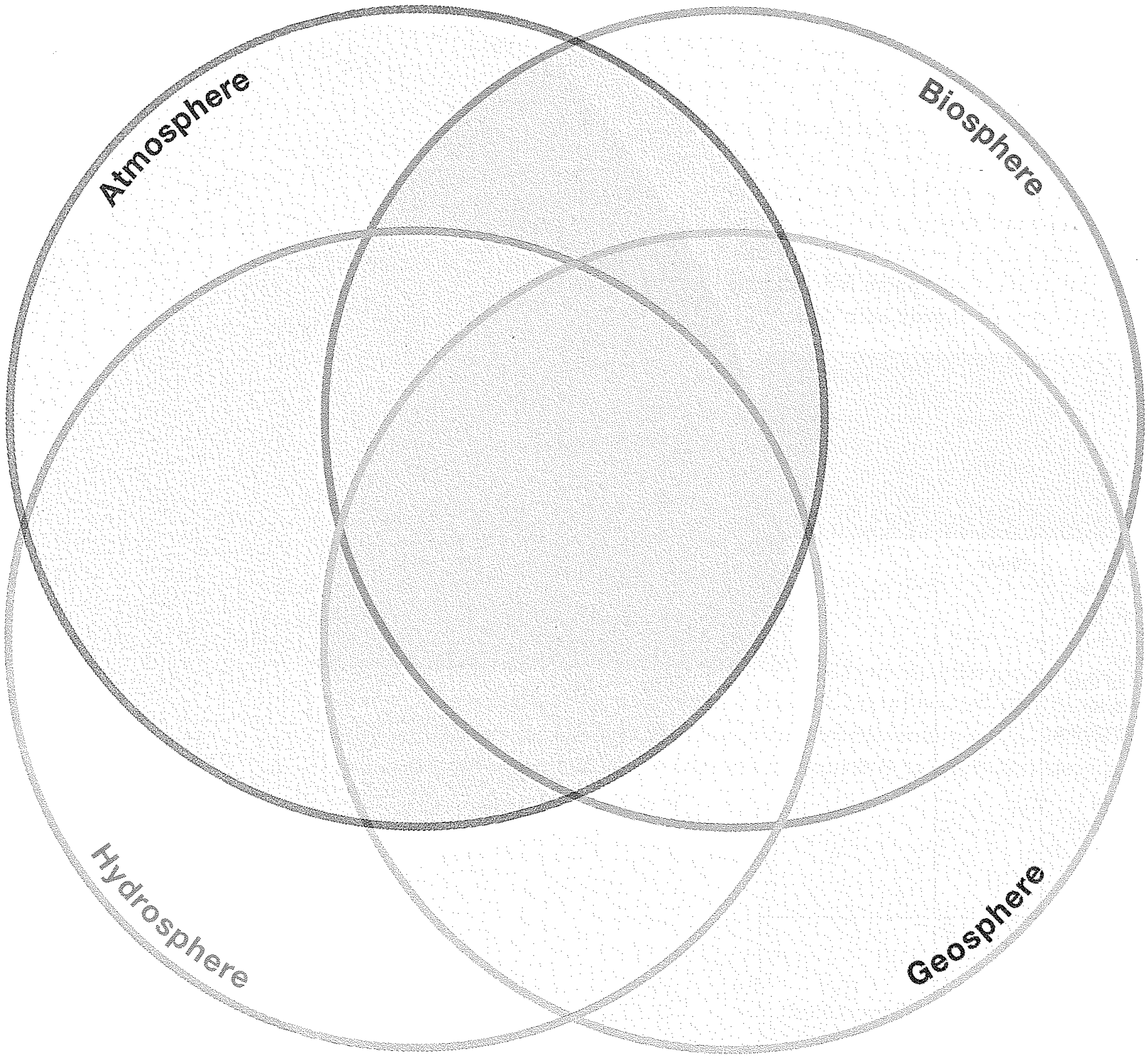
B. Study the processes of change in **FIGURE 1.6**, then complete the table below as done for deposition.

Process of Change	Sphere(s) involved in the process or product	Give an example of how you observed the process happening or how you encountered the result of the process	What caused the process to happen?
Deposition	atmosphere geosphere	I saw frost crystals on cold metal surfaces and windows of my car last winter.	The temperature of the metal was so cold that water vapor in the air formed ice crystals on contact with the metal.
	hydrosphere geosphere atmosphere	At the seashore, sand covered up my feet as waves crashed onto the beach where I was standing.	Wind caused waves. Waves carried the sand. When waves broke, they lost energy and the sand settled out.
Evaporation			
Condensation			
Decomposition reaction			
Dissolution			
Chemical precipitation			

C. Many of Earth's physical environments and ecosystems (communities of organisms and the physical environments in which they live) occur at the boundary between, or at intersection among, two or more spheres.

1. Add the following environments and ecosystems to the correct field of the Venn diagram below.

Surface of a leaf	Surface of an ocean, lake, stream	Lava flowing over a forest
Beach	Moldy brick basement walls	Bottom of ocean, lake, stream
Phytoplankton floating at the surface of the ocean	Surface of a glacier	Seafloor rock with attached oysters
	Soil	



2. In the four sphere fields above (labeled atmosphere, hydrosphere, geosphere, and biosphere) add an "S" for solar energy and a "G" for geothermal energy to indicate which kind of energy *primarily* powers it. Where two of the fields overlap, write an "SS" or "SG" to indicate the sum of energies that power the field. Use the same convention with three letters to indicate the sum of energy sources where three fields overlap.

E. **REFLECT & DISCUSS** Do you think that most change on Earth occurs within individual systems, at boundaries between two systems, or at the intersections of more than two systems? Why?

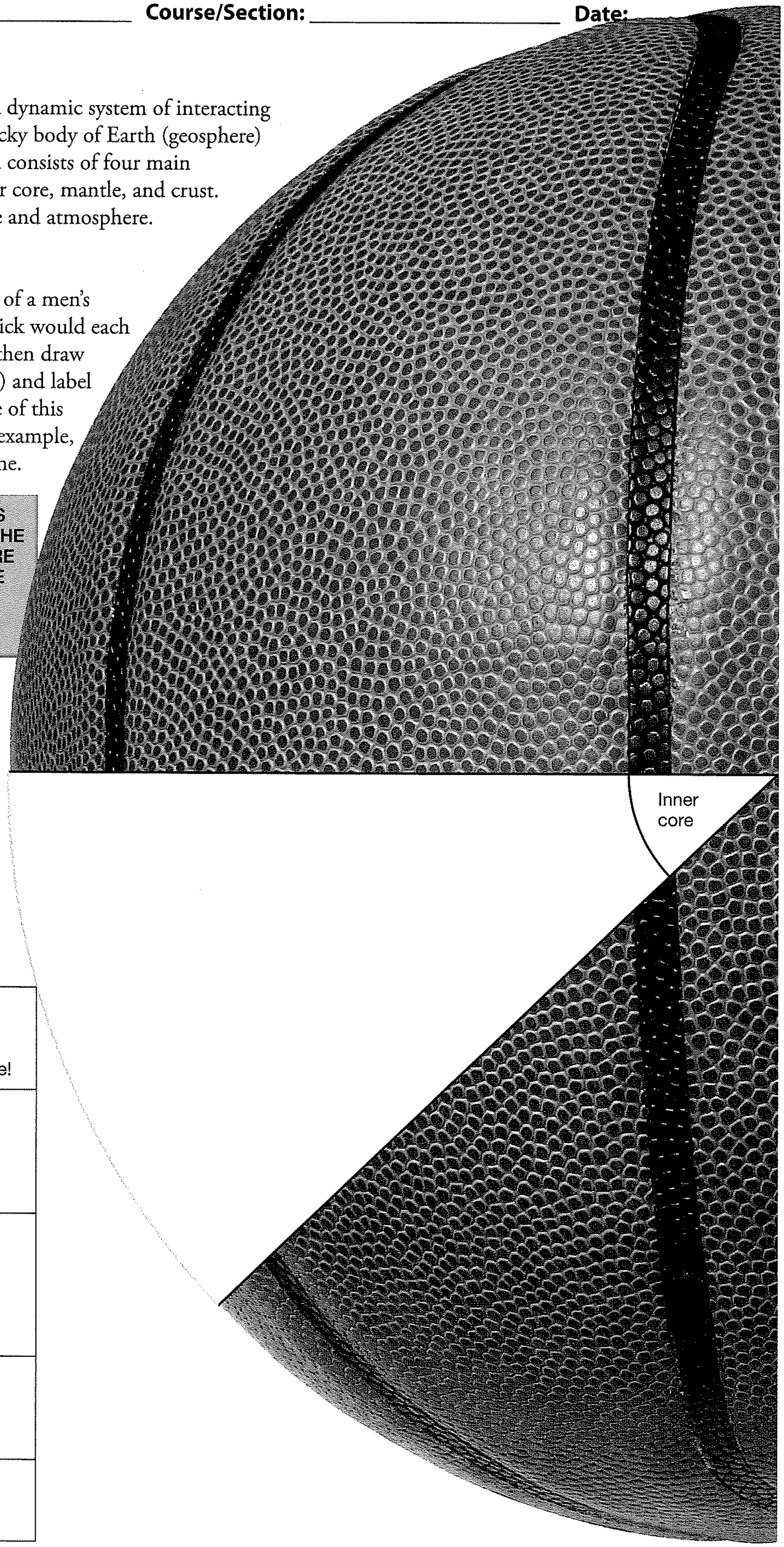
ACTIVITY 1.3 Modeling Earth Materials and Processes

Name: ______________________ **Course/Section:** ______________________ **Date:**

A. Geoscientists conceptualize Earth as a dynamic system of interacting material spheres (subsystems). The rocky body of Earth (geosphere) has an average radius of 6371 km and consists of four main compositional layers: inner core, outer core, mantle, and crust. These are overlain by the hydrosphere and atmosphere.

1. If Earth's geosphere had the radius of a men's basketball (119 mm), then how thick would each sphere be? Fill in the chart below, then draw (with a ruler and drafting compass) and label each sphere on the pie-shaped slice of this basketball. Label each sphere. For example, the inner core has already been done.

SPHERE	ACTUAL THICK-NESS	THICKNESS IN MM, IF THE GEOSPHERE IS THE SIZE OF A BASKET-BALL
Atmosphere: mostly nitrogen (N), oxygen (O), and argon (Ar) gases in air. Nearly all of the materials in air occur in a sphere just 16 km (10 mi) thick (troposphere). "Space" (no air) begins about 1000 km above sea level.	16 km	
Hydrosphere: mostly water (H_2O, ocean) in a liquid state.	3.7 km	Draw in blue!
Crust: mostly oxygen (O), silicon (Si), aluminum (Al), and iron (Fe).	25 km	
Mantle: mostly oxygen (O), silicon (Si), magnesium (Mg), and iron (Fe) in a solid state.	2900 km	
Outer Core: mostly iron (Fe) and nickel (Ni) in a liquid state.	2250 km	
Inner Core: mostly iron (Fe) in a solid state	1196 km	22.3 mm



2. Recall that Earth's actual average radius is 6371 km (6,371,000 meters) and that the radius of the basketball is only 119 mm (0.119 meters). Calculate the fractional scale (show your work) and ratio scale of the basketball model.

Fractional scale: **Ratio scale:**

B. MODELING LANDSLIDE HAZARDS

1. Place a ruler flat on a table in front of you. Place a coin in the center of the ruler. What happens if you lift one end of the ruler?

2. The coin did not slide off of the ruler at the very second you started to lift one end of the ruler. Why?

3. Why did the coin start sliding when it did?

4. **REFLECT & DISCUSS** Landslides are sudden downslope movements of rock, soil, and mud that occur in every country of the world. The U.S. Geological Survey warns that landslides are a major geologic hazard because they happen in all 50 states and U.S. territories and cause $1–2 billion in damages and more than 25 fatalities in the U.S. on average each year. Describe below how you would modify your ruler and coin model and use it to study what factors can trigger a landslide?

ACTIVITY 1.4 Measuring and Determining Relationships

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.

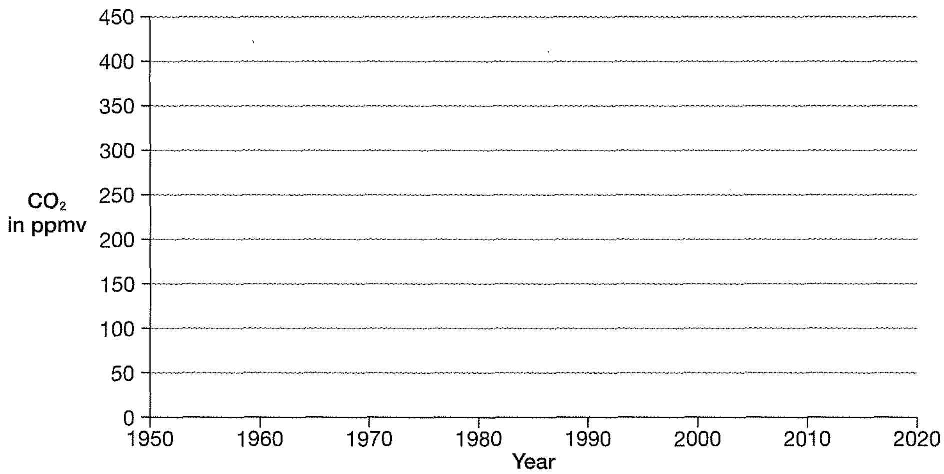
   a. At what rate (in mm/year) is the canyon being cut into the geosphere? Show your work, and give your final answer in scientific notation

   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

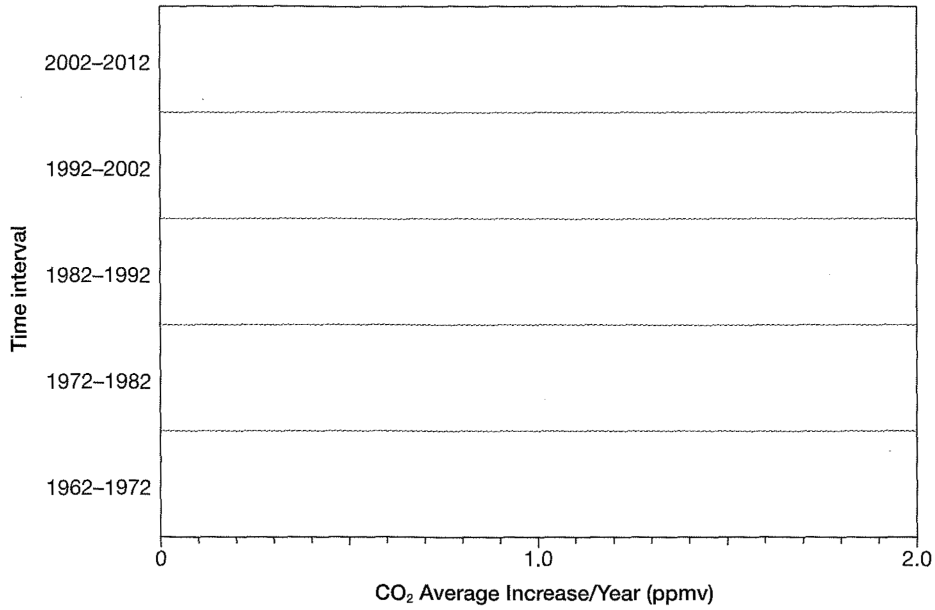


1. What does the graph show?

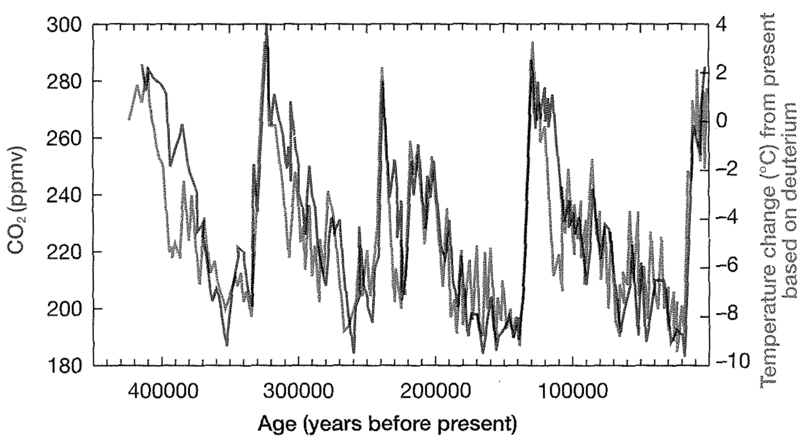
2. What are two ways you can tell from the graph that the concentration of CO_2 has increased since 1962?

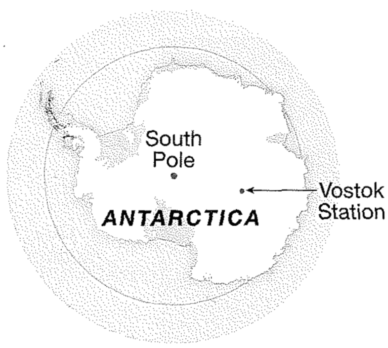
L. BAR GRAPH: Using the data from part L, calculate the average rate of increase in CO_2 concentration per year for the time intervals 1962–1972, 1972–1982, 1982–1992, 1992–2002, and 2002–2012. Then plot the results as a bar graph.

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	



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.





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?

ACTIVITY 1.5 Density, Gravity, and Isostasy

Name: ______________________ **Course/Section:** ______________________ **Date:** ____________

A. Obtain one of the wood blocks provided at your table. Determine the density of the wood block (ρ_{wood}) in g/cm^3. Show your calculations.

B. Float the same wood block in a bowl of water (like FIGURE 1.10A) and mark the equilibrium line (waterline).

1. Measure and record H_{block} (total height of the wood block) in cm: ______________ cm
2. Measure and record H_{below} (height of the wood block that is submerged below the water line) in cm: ______________ cm
3. Measure and record H_{above} (height of the wood block that is above the water line) in cm: ______________ cm

C. Write an isostasy equation (mathematical model) that expresses how the density of the wood block (ρ_{wood}) compared to the density of the water (ρ_{water}) is related to the height of the wood block that floats *below* the equilibrium line (H_{below}). [*Hint:* Recall that the wood block achieves isostatic equilibrium (motionless balanced floating) when it displaces a volume of water that has the same mass as the entire wood block. For example, if the wood block is 80% as dense as the water, then only 80% of the wood block will be below the equilibrium line (water line). Therefore, the portion of the wood block's height that is below the equilibrium line (H_{below}) is equal to the total height of the wood block (H_{block}) times the ratio of the density of the wood block (ρ_{wood}) to the density of water (ρ_{water}).

D. Change your answer in Part C to an equation (mathematical model) that expresses how the density of the wood block (ρ_{wood}) compared to the density of the water (ρ_{water}) is related to the height of the wood block that floats *above* the equilibrium line (H_{above}).

E. The density of water ice (in icebergs) is 0.917 g/cm^3. The average density of (salty) ocean water is 1.025 g/cm^3.

1. Use your isostasy equation for (H_{below}) (Question C) to calculate how much of an iceberg is submerged below sea level. Show your work.
2. Use your isostasy equation for (H_{above}) (Question D) to calculate how much of an iceberg is exposed above sea level. Show your work.
3. Notice the graph paper grid overlay on the picture of an iceberg in FIGURE 1.10B. Use this grid to determine and record the cross-sectional area of this iceberg that is below sea level and the cross-sectional area that is above sea level (by adding together all of the whole boxes and fractions of boxes that overlay the root of the iceberg or the exposed top of the iceberg). Use this data to calculate what proportion of the iceberg is below sea level (the equilibrium line) and what proportion is above sea level. How do your results compare to your calculations in Questions E1 and E2?
4. What will happen as the top of the iceberg melts?

F. **REFLECT & DISCUSS** Clarence Dutton proposed his isostasy hypothesis to explain how some ancient shorelines have been elevated to where they now occur on the slopes of adjacent mountains. Use *your* understanding of isostasy and icebergs to explain how this may happen.

ACTIVITY 1.6 Isostasy and Earth's Global Topography

Name: ______________________ **Course/Section:** ______________ **Date:** ________

A. *As exactly as you can*, weigh (grams) and determine the volume (by water displacement, FIGURE 1.9) of a sample of basalt. Add your data to the basalt density chart below. Calculate the density of your sample of basalt to tenths of a g/cm^3. Then determine the average density of basalt using all ten lines of sample data in the basalt density chart.

B. *As exactly as you can*, weigh (grams) and determine the volume (by water displacement, FIGURE 1.9) of a sample of granite. Add your data to the granite density chart below. Calculate the density of your sample of granite to tenths of a g/cm^3. Then determine the average density of granite using all ten lines of sample data in the granite density chart.

A. BASALT DENSITY CHART

Basalt Sample Number	Sample Weight (g)	Sample Volume (cm^3)	Sample Density (g/cm^3)
1	40.5	13	3.1
2	29.5	10	3.0
3	46.6	15	3.0
4	31.5	10	3.2
5	37.6	12	3.1
6	34.3	11	3.1
7	78.3	25	3.1
8	28.2	9	3.1
9	55.6	18	3.1
10			

Average density of basalt = ____________________

B. GRANITE DENSITY CHART

Granite Sample Number	Sample Weight (g)	Sample Volume (cm^3)	Sample Density (g/cm^3)
1	32.1	12	2.7
2	27.8	10	2.8
3	27.6	10	2.8
4	31.1	11	2.8
5	58.6	20	2.9
6	62.1	22	2.8
7	28.8	10	2.9
8	82.8	30	2.8
9	52.2	20	2.6
10			

Average density of granite = ____________________

C. Seismology (the study of Earth's structure and composition using earthquake waves), mantle xenoliths, and laboratory experiments indicate that the upper mantle is peridotite rock. The peridotite has an average density of about 3.3 g/cm^3 and is capable of slow flow. Seismology also reveals the thicknesses of crust and mantle layers.

1. Seismology indicates that the average thickness of basaltic ocean crust is about 5.0 km. Use the average density of basalt (from part A above) and your isostasy equation (Activity 1.5, item D) to calculate how high (in kilometers) basalt floats in the mantle. Show your work.

2. Seismology indicates that the average thickness of granitic continental crust is about 30.0 kilometers. Use the average density of granite (from part B above) and your isostasy equation (Activity 1.5, item D) to calculate how high (in kilometers) granite floats in the mantle. Show your work.

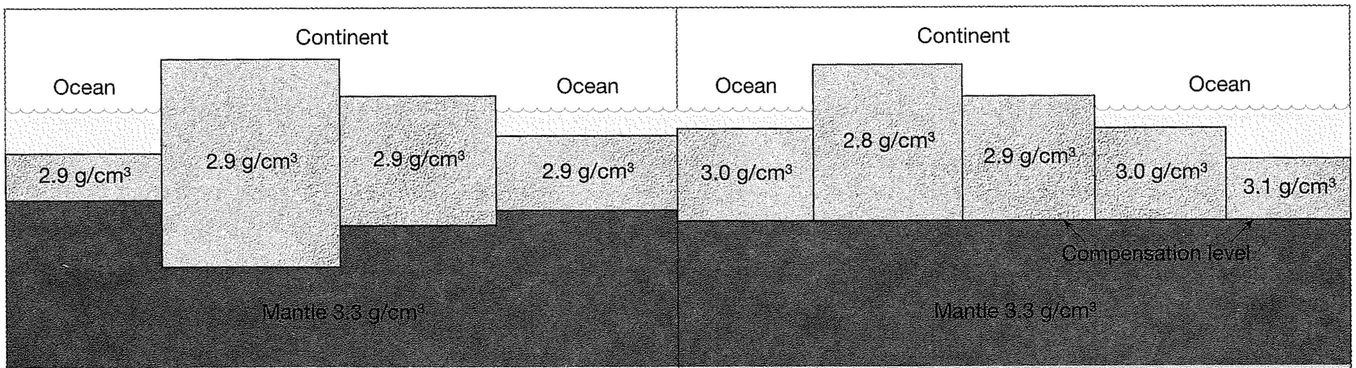
3. What is the difference (in km) between your answers in C1 and C2?

4. How does this difference between C1 and C2 compare to the actual difference between the average height of continents and average depth of oceans on the hypsographic curve (**FIGURE 1.11C**)?

D. **REFLECT & DISCUSS** Reflect on all of your work in this laboratory. Explain why Earth has a bimodal global topography.

E. **REFLECT & DISCUSS** How is a mountain like the iceberg in **FIGURE 1.10B**?

F. **REFLECT & DISCUSS** Clarence Dutton was not the first person to develop the concept of a floating crust in equilibrium balance with the mantle, which he called *isostasy* in 1889. Two other people proposed floating crust (isostasy) hypotheses in 1855 (See illustration below). John Pratt (a British physicist and Archdeacon of Calcutta) studied the Himalaya Mountains and hypothesized that floating blocks of Earth's crust have different densities, but they all sink to the same *compensation level* within the mantle. The continental blocks are higher because they are less dense. George Airy (a British astronomer and mathematician) hypothesized that floating blocks of Earth's crust have the same density but different thicknesses. The continental blocks are higher because they are thicker. Do you think that one of these two hypotheses (Pratt vs. Airy) is correct, or would you propose a compromise between them? Explain.



Airy Hypothesis:
- Blocks of crust have the same density.
- Blocks of crust have different thicknesses.
- Continental blocks are higher than ocean blocks because they are thicker than the ocean blocks.

Pratt Hypothesis:
- Blocks of crust have different densities.
- All blocks of crust sink to the same level (compensation level).
- Continental blocks are higher than ocean blocks because they are less dense than the ocean blocks.