# AN INTRODUCTION TO GEOLOGY 1

## INTRODUCTION

*An Introduction to Geology* covers the fundamental ideas and concepts of geologic study. Fundamental concepts of historical geology, including catastrophism, uniformitarianism, and geologic time, provide a context to the study of geology. A discussion of scientific inquiry aids in understanding how geologic processes and materials are studied and understood. The chapter provides a brief discussion of Earth's spheres, including the hydrosphere, atmosphere, biosphere, and geosphere, and discusses Earth systems science as a means of understanding the interconnectedness of these spheres. The chapter then discusses the formation of the solar system, Earth, and the fundamental concepts of density and buoyancy in understanding Earth structure. This leads to a discussion of Earth's layering and the rock cycle operating at and beneath Earth's surface. The chapter ends with a discussion of the major physical features of the Earth's surface, including those of the continents and ocean basins.

## CHAPTER OUTLINE

**1.** Geology: The Science of Earth
   a. Geology is the science that pursues an understanding of planet Earth
      i. Earth is a dynamic body with many interacting parts and a complex history
      ii. Earth is continuously changing, both rapidly and slowly, and internally and externally
   b. Physical geology and historical geology
      i. Physical geology
         1. Examines the materials composing Earth
         2. Seeks to understand the many processes that operate beneath and upon its surface
      ii. Historical geology
         1. Attempts to understand the origin of Earth and its development through time
         2. Establishes an orderly chronological arrangement of changes in Earth's geologic past
      iii. Physical and historical geology is further subdivided into many areas of specialization
   c. Geology, people, and the environment
      i. The problems and issues addressed by geology are of practical value to people
      ii. Natural hazards
         1. Natural processes become hazards when people live where they occur
         2. Volcanoes, floods, tsunami, earthquakes, and landslides
         3. Urbanization makes people more vulnerable to hazards
      iii. Resources
         1. Water and soil, metallic and nonmetallic minerals, and energy
         2. Form foundation of modern civilization

iv. Processes
   1. Humans are impacted by, and have an impact on, geologic processes
   2. Example: landslides and river flooding are affected by human activities, but also pose threats to humans
v. Basic geologic knowledge and principles are needed to understand environmental problems

**2.** The Development of Geology

a. Begins with writings of Greeks, more than 2300 years ago
b. Aristotle
   i. Influential philosopher
   ii. Inaccurate explanations about the natural world
   iii. Based on keen observations and experiments
   iv. Continued to be viewed as authoritative for many centuries, inhibiting more up-to-date ideas
c. Post 1500s—Catastrophism
   i. In 1600s, James Ussher calculated that Earth was only a few thousand years old (began 4004 BC)
      1. This number earned widespread acceptance in science and religion
   ii. Led to idea that Earth's landscapes had been shaped primarily by great catastrophes
   iii. Produced by sudden and often worldwide disasters produced by unknowable causes that no longer operate
   iv. This philosophy was an attempt to fit the rates of Earth processes to the then-current ideas on the age of Earth
d. Birth of modern geology
   i. Uniformitarianism
      1. Physical, chemical, and biological laws that operate today have also operated in the geologic past
      2. Commonly stated as *the present is the key to the past*
      3. Forces and processes that we observe presently shaping our planet have been at work for a very long time
   ii. Hutton's *Theory of the Earth* persuasively argued that forces that appear small could, over long spans of time, produce effects
      1. Carefully cited verifiable observations to support his ideas
e. Geology today
   i. Present gives us insight into the past
   ii. The physical, chemical, and biological laws that govern geological processes remain unchanging through time
   iii. Does not suggest that they always had the same relative importance or that they operated at precisely the same rate
   iv. Some important geologic processes are not currently observable, but evidence that they occur is well established
   v. Grand Canyon provides a good example (Figure 1.5)

f. The magnitude of geologic time
    i. Earth has a very long and complex history
    ii. Early time scales placed the events of Earth's history in order without knowing how long ago, in years, they occurred
    iii. Today, radioactivity allows us to accurately determine numerical dates for rocks that represent important events in Earth's distant past
    iv. Today, the age of Earth is put at about 4.6 billion years

**3.** The Nature of Scientific Inquiry

a. Science is a process of making careful observations and creating explanation to produce knowledge about the natural world
    i. Assumption: the natural world behaves in a consistent and predictable manner that is comprehensible through careful, systematic study
    ii. Goal: discover the underlying patterns in nature and then use this knowledge to make predictions about what should or should not be expected, given certain facts or circumstances

b. Development of new scientific knowledge involves some basic logical processes that are universally accepted

c. Hypothesis
    i. A tentative (or untested) explanation of an observation or data
    ii. Predictions are made based on the hypothesis being considered and the predictions are tested
    iii. If a hypothesis cannot be tested, it is not scientifically useful
    iv. Those hypotheses that fail rigorous testing are ultimately discarded

d. Theory
    i. Well-tested and widely accepted view that the scientific community agrees best explains certain observable facts
    ii. Example—theory of plate tectonics

e. Scientific methods
    i. Process of gathering facts through observations and formulating scientific hypotheses and theories
    ii. Not a standard recipe that scientists apply in a routine manner—An endeavor that involves creativity and insight
    iii. Many scientific investigations involve the following:
        1. A question is raised about the natural world
        2. Scientific data are collected that relate to the question
        3. Questions are posed that relate to the data and one or more working hypotheses are developed that may answer these questions
        4. Observations and experiments are developed to test the hypotheses
        5. The hypotheses are accepted, modified, or rejected based on extensive testing
        6. Data and results are shared with the scientific community for critical examination and further testing.
    iv. Best to describe the nature of scientific inquiry as the methods of science

f. Plate tectonics and scientific inquiry
    i. Early 20th century—continental drift
        1. The idea that the continents moved about the face of the planet
        2. Contradicted the established view that the continents and ocean basins are permanent and stationary features
    ii. 50 years later—plate tectonics
        1. Enough data were gathered to transform this controversial hypothesis
        2. A sound theory that wove together the basic processes known to operate on Earth
        3. Provided geologists with the first comprehensive model of Earth's internal workings

**4.** Earth as a System
  a. Earth is a dynamic body of four interacting spheres: the hydrosphere, atmosphere, geosphere, and biosphere
  b. Parts are not isolated; relate to each other in a continuously interacting whole–Earth system
  c. Earth's spheres
    i. Hydrosphere
        1. Dynamic mass of water that is continually on the move
        2. Evaporating from the oceans to the atmosphere, precipitating to the land, and running back to the ocean again
        3. Ocean—71 percent of Earth's surface, and 97 percent of Earth's water
        4. Also glaciers, streams, and groundwater
    ii. Atmosphere
        1. Earth's thin gaseous envelope
        2. Provides the air that we breathe
        3. Protects us from the Sun's intense heat and dangerous ultraviolet radiation
        4. Energy exchanges between the atmosphere and Earth's surface produce weather and climate
    iii. Biosphere
        1. All life on Earth
        2. Most life on land is also concentrated near the surface
        3. Life forms help maintain and alter the physical environment
    iv. Geosphere
        1. The solid Earth beneath the atmosphere and oceans
        2. Extends from the surface to the center of the planet, a depth of nearly 6400 kilometers

v. Examples of interactions of all spheres: soil, the thin veneer of material at Earth's surface that supports the growth of plants, may be thought of as part of all four spheres
    1. Weathered rock debris (geosphere)
    2. Organic matter from decayed plant and animal life (biosphere)
    3. Rock debris is the product of weathering processes that require air (atmosphere) and water (hydrosphere)
    4. Air and water also occupy the open spaces between the solid particles

d. Earth system science
    i. Aims to study the Earth as a system composed of numerous interacting subsystems
    ii. Integrates interdisciplinary knowledge (geology, atmospheric science, chemistry, biology, etc.)
    iii. A system is a group of interacting, or interdependent, parts that form a complex whole

e. The Earth system
    i. The Earth system has a nearly endless array of subsystems in which matter is recycled over and over again
        1. Examples: Hydrologic cycle, carbon cycle, rock cycle
        2. Parts of the Earth system are linked so that a change in one part can produce changes in any or all of the other parts
        3. Characterized by processes that vary on spatial scales from fractions of millimeters to thousands of kilometers
    ii. The Earth system is powered by energy from two sources
        1. Sun—drives weather and climate, ocean circulation, and erosional processes
        2. Earth's internal heat—powers the internal processes that produce volcanoes, earthquakes, and mountains
    iii. Humans are part of the Earth system and our actions produce changes in all of the other parts

**5.** Origin and Early Evolution of Earth

a. Origin of our solar system
    i. The universe begins
        1. Big Bang—13.7 billion years ago, formed the universe
    ii. The solar system forms
        1. Nebular theory—Solar system evolved from an enormous rotating cloud called the solar nebula
        2. Composed of hydrogen and helium atoms generated during the Big Bang, and microscopic dust grains and ejected matter of long-dead stars
        3. About 5 billion years ago, the nebula began to contract and formed a flat, disk-shape with a concentration of material around a protosun in its center

    iii. Inner planets form
        1. Formed from metallic and rocky clumps of substances with high melting points
        2. The elements of which the rock-forming minerals are composed—silicon, calcium, sodium
        3. Repeated collisions caused these masses to coalesce into larger asteroid-size bodies, called *planetesimals*
            a. Mercury, Venus, Earth, and Mars
        4. Rocky and metallic pieces that remained in orbit are called *meteorites*
    iv. Outer planets develop
        1. Larger outer planets began forming from fragments with a high percentage of ice of water, carbon dioxide, ammonia, and methane
        2. Jupiter, Saturn, Uranus, and Neptune
  b. Formation of Earth's layered structure
    i. As Earth formed, the decay of radioactive elements and heat from high-velocity impacts caused the temperature to increase
    ii. Chemical differentiation in Earth's layers
        1. Iron and nickel began to melt and sink toward the center
        2. Lighter rocky components floated outward, toward the surface
    iii. An atmosphere develops
        1. Gaseous material escaped from Earth's interior to produce the primitive atmosphere
    iv. Continents and ocean basins evolve
        1. Continents and ocean basins formed gradually over the last 4 billion years

**6.** Earth's Internal Structure
  a. Earth's internal layers can be defined by chemical composition, and/or physical properties
  b. The nature of Earth's interior is determined by analyzing seismic waves from earthquakes
  c. Earth's crust
    i. Thin, rocky outer skin
        1. Oceanic crust
            a. Seven kilometers (5 miles thick)
            b. Composed of dark igneous rocks called basalt
        2. Continental crust
            a. Averages 35–40 kilometers (25 miles) thick
            b. Upper crust has an average composition of a granitic rock, granodiorite, but varies from place to place
        3. Continental crust rocks are less dense and older than oceanic crust rocks
  d. Mantle
    i. More than 82 percent of Earth's volume
    ii. Solid, rocky shell, extends to a depth of 2900 kilometers (1800 miles)
    iii. Dominant rock in the uppermost mantle is peridotite
    iv. Upper mantle
        1. Crust-mantle boundary to depth of 660 kilometers (410 miles)
        2. Lithosphere—uppermost mantle, relatively cool, outer shell
            a. Thicker below continents, thinner below oceans

3. Asthenosphere—soft, relatively weak layer
    a. Small amount of melting at the top allows lithosphere to be mechanically detached from asthenosphere
    b. Lithosphere can move independently of asthenosphere
4. Strength of layers is based on composition and temperature of their environment
    a. Rocks get progressively hotter and weaker with depth in the lithosphere
5. At transition zone (660 km [410 miles]) we see a sudden increase in density
    a. Minerals in peridotite respond to increased pressure to form new minerals with closely packed atomic structures

v. Lower mantle
1. 660 kilometers (410 miles) to 2900 kilometers (1800 miles)
2. Mantle gradually strengthens with depth due to increase in pressure
3. Rocks are very hot, and capable of gradual flow
4. D'' layer is boundary between rocky mantle and hot liquid iron outer core

e. Core
i. Composed of an iron-nickel alloy with minor amounts of oxygen, silicon, and sulfur
ii. Due to the extreme pressure found in the core, the density is nearly 11 $g/cm^3$
iii. Divided into two regions with different mechanical strengths
1. Outer core is a liquid layer 2250 kilometers (1395 miles) thick
    a. Movement of metallic iron in outer core generates Earth's magnetic field
2. Inner core is a solid sphere with a radius of 1221 kilometers (757 miles)
    a. Extremely hot, but solid due to immense pressure at center of Earth

**7.** Rocks and the Rock Cycle

a. Rocks are composed of minerals
i. Minerals—chemical compounds or single elements with their own composition and physical properties
ii. Nature and appearance of a rock influenced by its minerals
iii. Texture refers to the size, shape, and arrangement of minerals in a rock
iv. Mineral composition and texture reflect the geologic processes that created the rock

b. Rocks are divided into three major groups—igneous, metamorphic, and sedimentary
i. The rock cycle helps us understand the origin of each group and the processes that form each
ii. Rocks continuously change from one form to another due to natural Earth processes

c. The basic cycle
i. Igneous rock
1. Rocks formed from cooling and solidification (crystallization) of molten material (magma)

ii. Sedimentary rock

            1. Pre-existing rocks weather and erode into pieces, called sediment
            2. When sediment is compacted and/or cemented, it turns to rock, in a process called lithification
        iii. Metamorphic rock
            1. When rocks are buried deep in the Earth, or intruded by magma, they are subjected to great heat and pressure
            2. Rock reacts to changing environment and becomes a different rock
        iv. Internal processes driven by heat from Earth's interior create igneous and metamorphic rocks
        v. External processes powered by the energy of the Sun cause the weathering and erosion that form sediment and sedimentary rocks
    d. Alternative paths
        i. Igneous rocks become metamorphic rocks if subjected to strong compressional forces and high temperatures in mountain building
        ii. Metamorphic, igneous, and sedimentary rocks can weather to become sediment
    e. Rock cycle processes take very long amounts of time, but we can observe all parts of the cycle in different locations on Earth

**8.** The Face of Earth
    a. Earth's surface—continents and ocean basins
        i. Significant difference between their relative levels, due to different thicknesses and densities
        ii. Continents are thicker, less dense
        iii. Ocean basins are thinner, more dense
        iv. As a result, continental crust floats on top of the deformable rocks of the mantle at a higher level than oceanic crust
    b. Major features of the ocean floor
        i. Ocean floor has volcanoes, deep canyons, plateaus, and flat plains
        ii. Oceanographers use depth-sounding equipment and satellite technology to understand the shape of the ocean floor
        iii. Three major regions
            1. Continental margins
                a. Continental shelf—a gently sloping platform of continental material, extends seaward from the shore
                b. Continental slope—a steep drop-off at the outer edge of the continental shelf, marks the boundary between the continents and the deep-ocean basin
                c. Continental rise—a thick wedge of sediment that moved downslope from the shelf and accumulated on the deep seafloor

2. Deep-ocean basins
    a. Located between the continental margins and oceanic ridges
    b. Features
        i. Abyssal plain—flat, featureless areas
        ii. Trenches are long, narrow canyons on the ocean floor
        iii. Some trenches are located adjacent to young mountains that flank the continents while others parallel linear island chains called volcanic arcs
        iv. Seamounts—submerged volcanic structures on the ocean floor
            1. Volcanic activity also produces lava plateaus
3. Oceanic ridges
    a. The most prominent topographic feature on the seafloor
    b. Continuous belt that winds for more than 70,000 kilometers around the globe
    c. Composed of layered igneous rock that has been fractured and uplifted

c. Major features of the continents
    i. Mountain belts
        1. Uplifted regions of deformed rocks
        2. Two major zones
            a. Circum-Pacific belt surrounding the Pacific Ocean
                i. Mountains of the western Americas and western Pacific volcanic island arcs
            b. Area eastward from the Alps through Iran and the Himalayas, and southward into Indonesia
                i. Thick sequences of rocks have been squeezed and highly deformed, as if placed in a gigantic vise
    ii. The stable interior
        1. Cratons—relatively stable interior of continents; undisturbed for the past 600 million years or longer
        2. Shields—expansive, flat regions on the craton composed of deformed igneous and metamorphic rocks
        3. Stable platforms—flat areas where the shields are covered by a thin veneer of sedimentary rocks

d. Understanding the topographic features of Earth helps us to better understand the mechanisms that shaped the planet in the geologic past, and will shape the planet in the future

## Learning Objectives/Focus on Concepts

Each statement represents the primary learning objective for the corresponding major heading within the chapter. After completing the chapter, students should be able to:

**1.1 Distinguish** between physical and historical geology and describe the connections between people and geology.

**1.2 Summarize** early and modern views on how change occurs on Earth and relate them to the prevailing ideas about the age of Earth.

**1.3 Discuss** the nature of scientific inquiry, including the construction of hypotheses and the development of theories.

**1.4 List and describe** Earth's four major spheres. **Define** *system* and explain why Earth is considered to be a system.

**1.5 Outline** the stages in the formation of our solar system.

**1.6 Sketch** Earth's internal structure and label and describe the main subdivisions.

**1.7 Sketch, label, and explain** the rock cycle.

**1.8 List and describe** the major features of the continents and ocean basins.

## TEACHING STRATEGIES

**Introduce the Science of Geology:** The first chapter of the book is a good time to discuss what a geologist does, and the science of geology. This activity helps students to know their own role and interest in geology, while allowing the instructor to review writing styles of the class.

- Calibrated Peer Review Activity—"Why Study Geology": http://serc.carleton.edu/introgeo/peerreview/examples/why_study_geo.html

**Muddiest Point:** In the last 5 minutes of class, have students jot down the points that were most confusing from the day's lecture, and what questions they still have. Or provide a "self-guided" muddiest point exercise, using the "CRS" PowerPoints, textbook Concepts in Review, and website questions for this chapter. Review the answers, and cover the unclear topics in a podcast to the class or at the beginning of the next lecture.

The following are fundamental ideas from this chapter that students have the most difficulty grasping.

**A. Nature of Science**

a. Students come to an intro-level science course thinking that science is the objective accumulation of facts and science is always done following the exact steps of the scientific method. Getting students to think of science as an inquiry process is difficult, and should be reiterated throughout the semester. The fundamental concept of scientific inquiry can be explained to your students with this chapter, as the foundation of the remaining chapters. Urge your students to continuously think about "How do we know what we know?"

b. Guided Reading of a Scientific Article: http://serc.carleton.edu/NAGTWorkshops/structure/activities/47021.html

c. How many sand grains on a beach? http://serc.carleton.edu/quantskills/activities/14846.html

d. Thinking Scientifically: http://serc.carleton.edu/introgeo/indoorlabs/examples/21805.html

**B. Geologic Time**

a. Geologic time is difficult for a student to understand. Ask students to think about what is "old" to them. They will say things like grandma, the United States, a car, and so on. Ask them what is "ancient." They will likely think of things like redwood trees, Indian artifacts, the Bible, and so on. This can lead into a discussion of what is young and old to geologists. Cite specific Earth events and geologic events from your own region. Then, have students calculate how long it would take to count to 4.6 billion (the answer is in the text, but this is a useful exercise in unit conversion).

b. Big Numbers and Scientific Notation: http://serc.carleton.edu/quantskills/methods/quantlit/BigNumbers.html

c. How big is a billion? http://serc.carleton.edu/quantskills/activities/UndBigNos.html

**C. Earth Structure**

a. Many students believe the entire Earth is molten beneath the surface (or even hollow—thanks, Hollywood!). Students have difficulty visualizing the interior structure of the Earth, so animations are helpful in helping them make these visualizations. Also provide alternative readings on HOW we know the structure and composition of the inside of the Earth.
   i. USGS "The Interior of the Earth": http://pubs.usgs.gov/gip/interior/
   ii. Scientific Evidence for Structure of Earth's Interior: http://www.columbia.edu/~vjd1/earth_int.htmhttp://www.columbia.edu/~vjd1/earth_int.htm

b. Good Imagery and Models: http://crack.seismo.unr.edu/ftp/pub/louie/class/100/interior.html

**D. Humans and Earth**

a. Students often think that humans cannot affect Earth processes, and therefore our actions are insignificant when thinking about Earth as a system. This concept should be addressed throughout the course, and in more detail in an Environmental Geology course. Here, when discussing Earth as a system, it is important to provide a few examples of how humans affect Earth processes.

b. A few articles to help you think about this:
   i. http://geology.geoscienceworld.org/content/33/3/161.abstract
   ii. http://www.sciencemag.org/content/277/5325/494.abstract

c. And, a fun debate for class: Have humans created a new geologic age?
   i. http://www.newscientist.com/blog/environment/2008/01/have-humans-created-new-geological.html
   ii. http://www.livescience.com/25332-anthropocene-humans-geologic-era.html
   iii. http://www.smithsonianmag.com/science-nature/what-is-the-anthropocene-and-are-we-in-it-164801414/?no-ist

## TEACHER RESOURCES

### Teaching 100-level Geoscience Courses

- The SWERC Carleton website offers many resources to help you with teaching introductory science courses: http://serc.carleton.edu/NAGTWorkshops/intro/index.html

### Scientific Inquiry and Geosciences

- McLelland, Christine V., "The Nature of Science and the Scientific Method," The Geological Society of America, August 2006. http://www.geosociety.org/educate/NatureScience.pdf
- What do geoscientists do?
  - http://www.agiweb.org/workforce/brochure.html
  - http://geology.com/articles/what-is-geology.shtml
  - http://www.bls.gov/ooh/Life-Physical-and-Social-Science/Geoscientists.htm

### Geologic Time

- Graphical Representation: http://pubs.usgs.gov/gip/geotime/time.html
- Clock of Eras: http://www.fossils-facts-and-finds.com/clock_of_eras.html
- USGS and NPS "What is?": http://www2.nature.nps.gov/geology/usgsnps/gtime/gtime1.html
- Other Visualizations: http://serc.carleton.edu/NAGTWorkshops/time/teaching_visualizations.html
- This activity can help students visualize the span of geologic time: http://www.geologyclass.org/Geologic%20Time%20Scale%20Activity.htm
- This website gives you specific information, pictures, and histories of each geologic time period: http://www.ucmp.berkeley.edu/help/timeform.html
- Geological Society of America Geologic Time Scale: http://www.geosociety.org/science/timescale/

### Cycles on Earth:

- Rock Cycle: http://ansatte.uit.no/kku000/webgeology/webgeology_files/english/rocks.html
- Water Cycle: http://www.montereyinstitute.org/noaa/lesson07.html
- Carbon Cycle: http://earthobservatory.nasa.gov/Features/CarbonCycle/
- Plate Tectonics: http://www2.nature.nps.gov/geology/usgsnps/animate/pltecan.html
  A kid's website, but a good introduction to cycles covered later: http://www.eo.ucar.edu/kids/green/cycles1.htm

## Answers to Questions in the Chapter:

### Concept Checks

**1.1**

1. ***Name and distinguish between the two broad subdivisions of geology.*** *Physical geology is the study of materials composing the Earth (minerals, rocks, water, etc.) and the processes that operate upon and below Earth's surface (plate tectonics, rock formation, deformation, erosion, etc.). Historical geology aims to understand the origin of the Earth and its development through time. This study establishes an orderly chronological arrangement of events and changes of the geologic past by study of the origin of rocks, the movements of plates over time, and the occurrence of ancient environments and life forms as displayed in the geologic record. These two areas of study are subdivided into many more areas of specialization.*
2. ***List at least three different geologic hazards.*** *Geologic hazards are natural Earth processes that adversely affect humans. Examples of geologic hazards include earthquakes, volcanic eruptions, floods, tsunami, and landslides. Humans can also exacerbate natural Earth processes, creating hazards, by interfering with natural processes. Examples include the increased flooding hazards created by the clearing of forests, building cities, and constructing dams.*
3. ***Aside from geologic hazards, describe another important connection between people and geology.*** *Earth resources, formed by Earth processes, have tremendous value to humans. These resources include water, soil, metallic and nonmetallic minerals, and energy. The extraction and use of these resources have many environmental impacts.*

**1.2**

1. ***Describe Aristotle's influence on geology.*** *Aristotle was a Greek philosopher whose writings influenced early understanding of the Earth. Unfortunately, Aristotle's ideas were not based on study and observation, but simply his own opinions of how the natural world worked. These ideas were viewed as authoritative explanations for many centuries, slowing the progress of study based on observations, until Renaissance thought pushed more detailed study of the Earth.*
2. ***Contrast catastrophism and uniformitarianism. How did each view the age of Earth?*** *Catastrophism viewed the Earth as being shaped by great catastrophes—sudden and worldwide disasters produced by unknowable processes that no longer operate. Catastrophism was based on the idea that Earth formed in 4004 BC as calculated by biblical scholar James Ussher in 1660. Conversely, uniformitarianism (now a fundamental concept of geology) views Earth processes as happening over very long time periods, and those processes that we see operating today also operated in the geologic past. The common idea of uniformitarianism is "the present is the key to the past." This concept understands that Earth is much older than thought by catastrophism, and processes that operate continually on and beneath its surface created (and continue to create) the features we see.*

3. ***How old is Earth?*** *Today, the age of Earth is put at about 4.6 billion years. This age is based on scientific study of the radioactivity of rocks, as will be discussed in Chapter 9.*
4. ***Refer to Figure 1.6 and list the eon, era, period, and epoch in which we live.*** *Phanerozoic Eon, Cenozoic Era, Quaternary Period, Holocene Epoch.*
5. ***Why is an understanding of the magnitude of geologic time important for a geologist?*** *An understanding of geologic time is essential to geologic study because many processes studied are so gradual that vast spans of time must pass before noticeable and significant changes occur. For example, the rocks of the Grand Canyon (Figure 1.5) were created over millions of years, and it took many more millions of years for the Colorado River to erode down through these rocks to the display we see today.*

**1.3**

1. ***How is a scientific hypothesis different from a scientific theory?*** *A scientific hypothesis is a tentative, untested explanation of a natural phenomenon. Generally, scientists formulate more than one hypothesis to explain their observations. A fundamental caveat of a hypothesis is that it must be testable (able to pass objective testing and analysis); if it cannot be tested, it is not scientifically useful. Hypotheses may be accepted when evidence demonstrates that they are correct, but also may be rejected when they fail rigorous testing. The Earth-centered model of the universe is an example of a hypothesis that, once tested, was rejected as an explanation of the orientation of our planet in the solar system.*

   *A scientific theory is a well-tested hypothesis that has gone through extensive testing and scrutiny. It is a well-tested and widely accepted view that the scientific community agrees best explains a natural phenomenon. Theories generally include several well-tested, accepted hypotheses to explain a larger scale process or phenomenon on Earth. An example of a theory is the Theory of Plate Tectonics, which will be discussed in Chapter 2.*
2. ***Summarize the basic steps followed in many scientific investigations.*** *The scientific method is the process by which researchers gather facts through observations and formulate scientific hypotheses and theories. Although this method does not always follow a fixed path, it does involve: (1) a question about the natural world, (2) data collection related to that question, (3) formulation of one or more hypotheses to explain the question and data, (4) observation and experiments to test the hypothesis, (4) the acceptation, modification, or rejection of the hypothesis based on extensive testing, and (5) sharing data and results with the scientific community for further testing and critical examination. See Figure 1.9*.

**1.4**

1. ***List and briefly describe the four spheres that constitute the Earth system.*** *The hydrosphere is the dynamic mass of water at Earth's surface, including water in the oceans, atmosphere, lakes and rivers, glacial ice, and groundwater. Water moves about the hydrosphere via the water cycle through processes such as evaporation, transpiration, runoff, precipitation, and infiltration.*

*The atmosphere is the gaseous layer surrounding Earth's surface. This layer comprises the air we breathe, protects Earth from harmful ultraviolet radiation, and creates the weather and climate we experience at the surface.*

*The biosphere is all life on Earth. The biosphere includes plants and animals living on and above Earth's surface, within the oceans, and underground.*

*The geosphere is the solid earth extending from the surface to the center (core) of Earth including both consolidated (rock) and unconsolidated (sediment) earth material. The geosphere includes rock and sediment at the surface, bedrock beneath and at the surface, and the materials making up the layers deep within the Earth.*

2. ***Compare the height of the atmosphere to the thickness of the geosphere.*** *Ninety percent of Earth's atmosphere is located within 16 km (10 miles) of the surface. Compared to the geosphere, which comprises the entire inner Earth to a depth of 6400 km (4000 miles), the atmosphere is an extremely thin veneer on the surface of the Earth.*
3. ***How much of Earth's surface do oceans cover? What percentage of the Earth's water supply do oceans represent?*** *Earth's oceans cover 71 percent of its surface and represent 97 percent of Earth's water supply.*
4. ***What is a system? List three examples.*** *A system is a group of interacting, or interdependent, parts forming a complex whole. The Earth system is comprised of individual components such as land, water, air, and life (Earth's spheres) that are interconnected and interact to create the processes we see at the surface. Examples of systems operating on Earth include the rock cycle (the recycling of rock from one form to another), the hydrologic cycle (the movement of water about and beneath the surface), and the carbon cycle (the exchange of carbon between the air, life, and rocks).*
5. ***What are the two sources of energy for the Earth system?*** *The Earth system is powered by energy from the Sun and from heat energy generated from Earth's interior. Energy from the Sun drives processes in the atmosphere and hydrosphere such as weather, climate, ocean circulation, and erosional processes. Energy from the Earth's interior is continuously generated by radioactive decay and powers internal Earth processes such as volcanism, earthquakes, and mountain-building.*

**1.5**

1. ***Name and briefly outline the theory that describes the formation of our solar system.*** *The nebular theory says that the bodies of our solar system evolved from an enormous rotating cloud of microscopic dust grains and ejected matter of dead stars. This cloud of gasses, called a solar nebula, began to contract about 5 billion years ago due to gravitational interactions of the particles. As it contracted, it rotated faster and faster, and a flat disk with a central protosun formed. The gravitational energy of the rotating nebula converted to thermal energy allowing dust particles to break into molecules. When heating ceased, these molecules coalesced into the planets—with the inner planets (Mercury, Venus, Earth, and Mars) composed of the heavier elements of the cloud and the outer planets (Jupiter, Saturn, Uranus, and Neptune) of the lighter elements.*

2. ***List the inner planets and outer planets. Describe basic differences in size and composition.*** *The inner planets are Mercury, Venus, Earth, and Mars. These planets are smaller and are composed of iron, nickel, silicon, calcium, sodium, and other rock-forming minerals and metals. The outer planets are Jupiter, Saturn, Uranus, and Neptune. These planets are larger and have a high percentage of ice of water, carbon dioxide, ammonia, and methane with smaller amounts of rocky and metallic minerals.*
3. ***Explain why density and buoyancy were important in the development of Earth's layered structure.*** *Early in Earth's formation, the planet was intensely heated from impacts and radioactive decay of elements. This heating was enough to melt most of the materials of early Earth. As the Earth subsequently cooled, the higher-density materials (iron, nickel) sank toward the center of the Earth, creating the core. The lighter materials, those enriched in oxygen and oxygen-seeking elements, rose buoyantly to the surface, creating the crust.*

**1.6**

1. ***Name and describe the three major layers defined by their chemical composition.*** *The three major layers of Earth, as defined by their chemical composition, are the crust, the mantle, and the core. The crust is Earth's outer layer and is composed of relatively low density continental and oceanic crust. Continental crust is less dense than oceanic crust and is composed of many rock types, with an average composition of granitic rock. Oceanic crust is denser than continental crust and is composed of basalt. The mantle is Earth's middle layer and is composed of peridotite, a denser, magnesium- and iron-rich rock. The core is Earth's innermost layer and is thought to be composed of an iron-nickel alloy.*
2. ***Contrast the characteristics of the lithosphere and the asthenosphere.****The lithosphere is the rigid, relatively cool outermost shell of Earth and consists of the Earth's crust plus the uppermost mantle. The asthenosphere is beneath this layer, and is a soft, relatively weak layer. The upper portion of the asthenosphere has some melting, allowing the asthenosphere to be mechanically detached from the asthenosphere.*
3. ***Why is the inner core solid?*** *The outer core is a liquid layer of moving metallic iron. The inner core is a solid sphere because of the immense pressure at the center of the Earth.*

**1.7**

1. ***List two rock characteristics that are used to determine the processes that created a rock.*** *A rock's mineral composition and texture (size, shape, and arrangement of grains) reflect the geologic processes that formed it. For example, the large, inter grown crystals in a granite tell us that the rock cooled slowly from molten material deep below the surface.*
2. ***Sketch and label a basic rock cycle. Make sure to include alternate paths.*** *See Smart Figure 1.22.*

**1.8**

1. ***Compare and contrast ocean basins and continents.*** *The main difference between continents and ocean basins are their elevation. These differences in elevation are a result of differing densities and thicknesses—oceanic crust that comprises ocean basins is thinner and*

*denser than the thicker continental crust that comprises continents. Ocean basins are about 3.8 km below sea level , are about 7 km in thickness, and are composed of basalt with a density of 3.0 g/cm³.Continents are mostly flat (except for mountainous regions) and lie close to sea level. Continents average about 25 km thickness and have an average composition of granite with a density of 2.7 g/cm³.*

2. ***Name the three major regions of the ocean floor. What are some features associated with each?*** *The major features of the ocean floor are continental margins, deep-ocean basins, and oceanic ridges. Continental margins are those areas of the seafloor adjacent to major landmasses. These areas include the continental shelf, a broad gently sloping platform of material that extends seaward from the shore, the continental slope, a steep drop-off from the outer edge of the continental shelf, and the continental rise, an accumulated wedge of sediment that moved downslope from the shelf. The deep ocean basins are flat abyssal plains with some deep ocean trenches and submerged seamounts. The oceanic ridges are broad, elevated mountain belts comprised of layers of uplifted and fractured igneous rock.*

3. ***Describe the general distribution of Earth's youngest mountains.*** *Earth's youngest mountains tend to occur in two major zones. The first zone surrounds the Pacific Ocean and includes the mountains of the western Americas and the volcanic island arcs of the western Pacific. The second zone extends eastward from the Alps through Iran into the Himalayas and then southward into Indonesia.*

4. ***What is the difference between shields and stable platforms?*** *Shields are flat expanses of metamorphic and igneous rocks found near the center or cores of the continents. The crystalline rocks in shields are typically Precambrian in age and highly deformed. Stable platforms are areas of the stable interior where the highly deformed rocks of the shield are covered by a thin veneer of sedimentary rocks. The sedimentary rocks are nearly horizontal except where they have been deformed to form large basins or domes.*

## EYE ON EARTH

### EOE 1.1 ROCK LAYERS

1. ***Can you establish a relative time-scale for these rocks? That is, can you determine which one of the layers shown here is likely oldest and which is probably youngest?*** *The lowest layers are oldest, and the upper layers are youngest.*

2. ***Explain the logic you used.*** *The rocks here are made from sediments that are deposited in horizontal layers by rivers, waves, wind, and glaciers. If these rocks formed in layers, the bottom layer must have been laid down first, then the next, then the next, and so on.*

### EOE 1.2 CRUISING JET

1. ***Refer to the graph in Figure 1.13. What is the approximate air pressure at the altitude where the jet is flying?*** *Using the curved line on Figure 1.12, the air pressure at 10 km (6.2 miles) is approximately 250 mb.*

2. ***About what percentage of the atmosphere is below the jet (assuming that the pressure at the surface is 1000 millibars)?*** *To determine this answer, subtract*

*250 mb from 1000 mb and divide by 1000 mb. Multiply your answer by 100 to get a percentage: 1000 mb – 250 mb = 750 mb/1000 mb = 0.75 × 100 = 75% of the atmosphere is below the jet.*

**EOE 1.3 SHORELINE**

1. ***Does the shoreline, the line where the water meets the land, mark the outer edge of the North American continent?*** *No.*
2. ***Explain your answer to Question 1.*** *The outer edge of the North American continent is offshore, at the edge of the continental shelf. Along most coasts, the continental shelf extends seaward from the shore, and is underlain by continental crust. Thus, the shelf is a flooded extension of the continents.*

## GIVE IT SOME THOUGHT

**1.** *To determine this answer, you should divide the amount of human history by all of geologic time (rounded to 5 billion).*

$$5000 \text{ years}/5{,}000{,}000{,}000 \text{ years} = 0.000001 = 1.0 \times 10^{-6}$$

*To make this a percentage, take the answer times 100.*

$$0.000001 \times 100 = 0.0001\%$$

*Therefore, recorded human history of 5000 years is 0.0001% of all geologic time.*

**2.**

a. *One breath at sea level is 1000 mb of pressure; we can assume this means 100% atmosphere at sea level. At the top of Mount Everest, Figure 1.13 shows that pressure is 314 mb; this is roughly 31% atmosphere at the top of Mount Everest. Therefore, we would need to take about 3.2 breaths (31% × 3.2 = 99.82%) to equal one breath at sea level.*

b. *Using Figure 1.13, we see that the pressure at 12 km is 200 mb. To determine this answer, subtract 200 mb from 1000 mb and divide by 1000 mb to get the fraction of air at this altitude. Multiply your answer by 100 to get a percentage: 1000 mb – 200 mb = 800 mb/1000 mb = 0.80 × 100 = 80% of the atmosphere is below a jet traveling at 12 km altitude.*

**3.** *Figures 1.2 a and b and Figure 1.8 demonstrate ways scientific data are gathered. In Figure 1.2, scientists are in the field, directly observing and measuring Earth processes. In Figure 1.8, scientists are using remote tools to understand Earth processes.*

**4.** *In this photo, we see the interactions of the atmosphere, hydrosphere, and geospheres. The atmosphere contained the water vapor that fell to Earth as rain, thus creating an excess of water (hydrosphere) on the hillside (geosphere). This water saturated the Earth materials (geosphere) of the hillside and they were set into motion when their stabilizing forces were overcome by gravitational forces. We might also say that the biosphere was involved, as plants, animals, and humans were likely affected by this mass movement.*

**5.** *All rock types, once exposed at the surface, can undergo weathering and erosion to become sediment. The resulting sediment will eventually be transformed into sedimentary rock at the surface, thus accounting for a large percentage of all rocks.*

**6.** *An interface is a common boundary where different parts of a system come in contact and interact. Here, the hydrosphere (ocean) interacts with the geosphere (rocks and sediment of the land surface). Another common interface in the Earth system is the surface of the ocean. Here, the atmosphere and hydrosphere interact through exchange of gasses and water vapor.*

**7.** *Hypotheses for this observation include:*

a. *The switch is not working.*
b. *The bulb in the light is not working (needs to be replaced).*
c. *The electricity in the room is not working.*

*Once we have formulated our hypotheses, we should begin testing them. For our first hypothesis and our last hypothesis, we could have an electrician test the power at the switch and in the room to see if it is functioning properly. For our second hypothesis, we might try to replace the light bulb with a new one, and retry the switch.*