

# Chapter 1

## An Introduction to Geology

*An Introduction to Geology* first provides a description of the science of geology including the two broad areas of physical geology and historical geology. This is followed by an explanation of the development of geology as a modern science with an explanation of uniformitarianism and an introduction to the magnitude of geologic time. Following a presentation of the nature of scientific inquiry and explanations of Earth's physical spheres relative to understanding Earth as a system is a presentation of the nebular hypothesis. This is followed by an outline of Earth's internal structure and the concept of the rock cycle. Lastly, the chapter presents the major features of Earth's surface as they occur in the ocean basins and on the continents.

### CHAPTER OUTLINE

1. Geology: The Science of Earth
  - a. Physical and Historical Geology
  - b. Geology, People, and the Environment
2. The Development of Geology
  - a. Catastrophism
  - b. The Birth of Modern Geology
  - c. Geology Today
  - d. The Magnitude of Geologic Time
3. The Nature of Scientific Inquiry
  - a. Hypothesis
  - b. Theory
  - c. Scientific Methods
  - d. Plate Tectonics and Scientific Inquiry
4. Earth as a System
  - a. Earth's Spheres
  - b. Hydrosphere
  - c. Atmosphere
  - d. Biosphere
  - e. Geosphere
  - f. Earth System Science
  - g. The Earth System
5. Origin and Early Evolution of Earth
  - a. Origin of Planet Earth
    - i. The Universe Begins
    - ii. The Solar System Forms
    - iii. The Inner Planets Form
    - iv. The Outer Planets Develop
  - b. Formation of Earth's Layered Structure
    - i. Chemical Differentiation and Earth's Layers
    - ii. An Atmosphere Develops
    - iii. Continents and Ocean Basins Evolve

6. Earth's Internal Structure
  - a. Earth's Crust
  - b. Earth's Mantle
    - i. The Upper Mantle
    - ii. The Lower Mantle
  - c. Earth's Core
7. Rocks and the Rock Cycle
  - a. The Basic Cycle
  - b. Alternative Paths
8. The Face of Earth
  - a. Major Features of the Ocean Floor
    - i. Continental Margin
    - ii. Deep-Ocean Basins
    - iii. Oceanic Ridges
  - b. Major Features of the Continents
    - i. Mountain Belts
    - ii. The Stable Interior

## FOCUS ON CONCEPTS

Each statement represents the primary learning objective for the corresponding major heading within the chapter. After you complete the chapter, you 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 a system.
- 1.5 **Outline** the stages in the formation of our solar system.
- 1.6 **Describe** Earth's internal structure.
- 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

The first chapter of the book is a good time to discuss what a geologist does, and introduce the science of geology including why it is different from other sciences. The following article, by Sarah Andrews, contains a discussion of the uniqueness of geology among the sciences.

- "Why Study Geology?": <http://www.geotimes.org/apr00/student.html>

### “Muddiest Points” – “Points for Clarification”

- Geologic time is often difficult to fully appreciate for introductory students. While most are able to learn the names and order of the components on the geologic calendar, grasping the vastness of geologic time is more difficult.
- Many students take an introductory geoscience course because it is NOT chemistry, biology, or another science. It is important to get students to think of geology as operating within the same fundamental realm of scientific inquiry as other sciences. This includes laying out the scientific inquiry process that operates within all sciences, including geology, as outlined in Figure 1.9.
- To many introductory students, the internal structure of the earth may be as foreign a concept as the outer reaches of the solar system. There are numerous myths and false beliefs that students will have about the internal structure of the earth. Be prepared with additional information from other chapters, such as Chapter 9, to provide information on HOW we substantiate our theories regarding the structure and composition of Earth’s interior.

### Teaching Tips

- 1.2** To help students appreciate how James Hutton was persuasive in his arguments that small forces, over long spans of time, can produce geologic effects, it can be helpful to bring in a little information about the state of education in post-Reformation and early Enlightenment Scotland, where Hutton lived and studied. This period of time in Scotland included an acceptance of challenges to ideas in all areas of study without fear of societal banishment.
- [https://en.wikipedia.org/wiki/Education\\_in\\_early\\_modern\\_Scotland#Reformation\\_of\\_universities](https://en.wikipedia.org/wiki/Education_in_early_modern_Scotland#Reformation_of_universities)

Helping students visualize the magnitude of the geologic time by converting the history of Earth into other scales, such as in SmartFigure 1.7, is a good tool for increasing their understanding and appreciation for the vastness of geologic time. Another conversion that is visual and somewhat kinesthetic, is to convert the time scale to the length of a soccer field and actually measure the distances out on the field itself. When students stand on one end of the soccer field and see that the last 1 million years of Earth’s history is only about two centimeters, just under one inch, of the entire 100 meter field, they can sometimes be moved from thinking a million years is impossibly long to thinking that a million years is “a blink of an eye” in the history of the Earth.

- 1.6** Students benefit from some explanation of how the structure of Earth’s interior is determined by analyzing seismic waves. Though a protracted explanation should be postponed until Chapter 9, one simple demonstration of how seismic waves move using the classic “slinky” demonstration is appropriate (see Figure 9.10).

## MasteringGeology and LearningCatalytics resources/ideas/activities

**MasteringGeology** activities that utilize video, interactive animations, and gigapans (high-resolution panoramic images) are effective in giving students preparatory opportunities that are directly correlated with the chapter content. Have students complete Mastering activities in advance of class time to help them learn the material.

- All of the Concept Check type items are excellent preparatory questions. In addition, especially focus on the following additional items for this chapter:

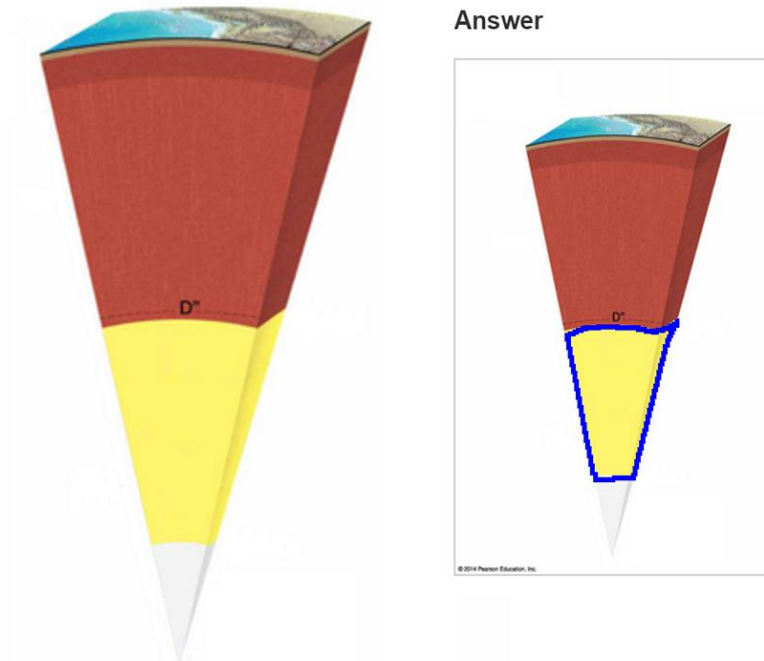
Section	Item Type	Title
1.1	Coaching Activities	Mobile Field Trip Video Quiz - A Geologist's Grand Canyon
1.2	Coaching Activities	SmartFigure: Geologic Time
1.3	Coaching Activities	Give It Some Thought: The Scientific Method—Observation, Hypothesis, and Theory
1.5	Coaching Activities	SmartFigure: The Nebular Theory
1.6	Coaching Activities	SmartFigure: Earth's Layers
1.7	Coaching Activities	Give It Some Thought: The Rock Cycle
	Coaching Activities	SmartFigure: The Rock Cycle

**LearningCatalytics** activities can provide an assessment of students' understanding in real-time to allow opportunities for review or discussion (either in small groups or the entire class).

- Using images from the text, query students' understanding of the internal structure of Earth. In the Learning Catalytics activities shown below, students answer by selecting a region on their mobile device, tablet, or laptop. These could also be sketch-type items where students sketch their own picture of the internal Earth structure:
  - General Internal Structure of Earth:

### Question

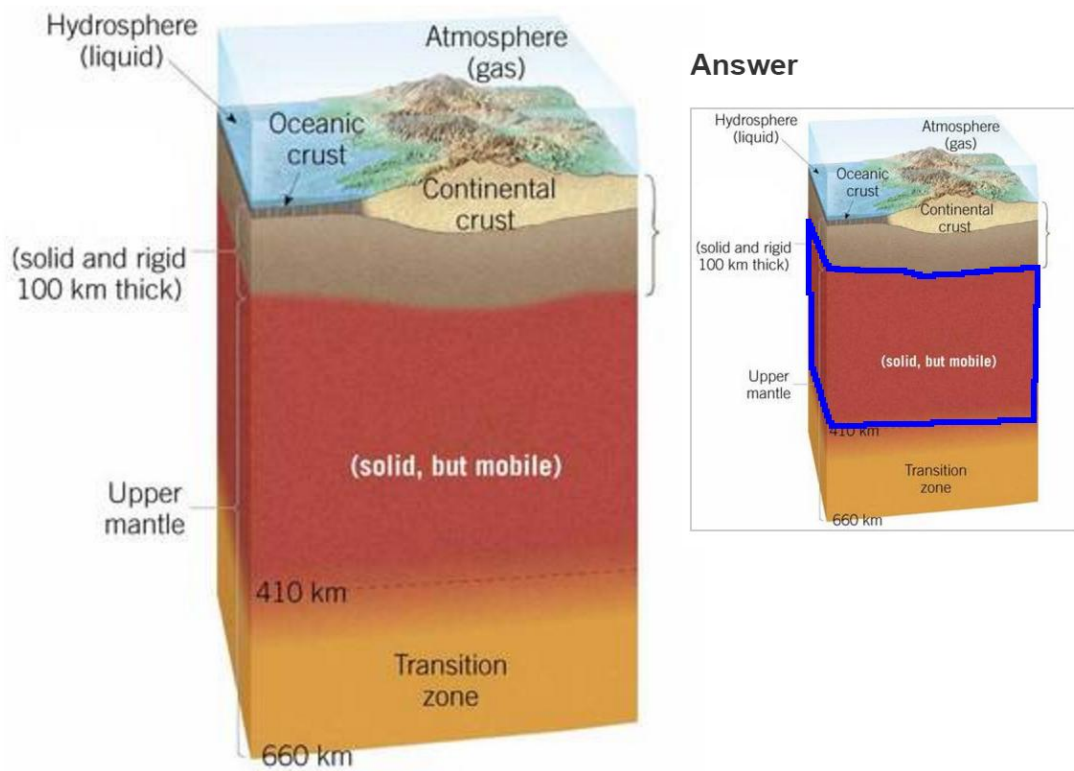
Mark where you would find liquid material in the Earth.



- o Detailed structure of the upper mantle and crust:

### Question

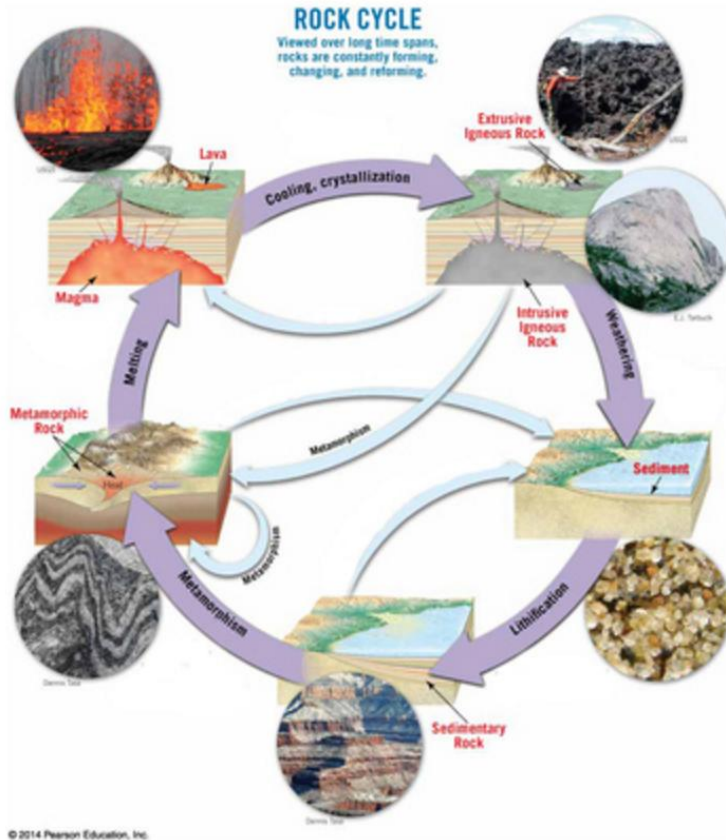
Identify (select) the region called the "asthenosphere":



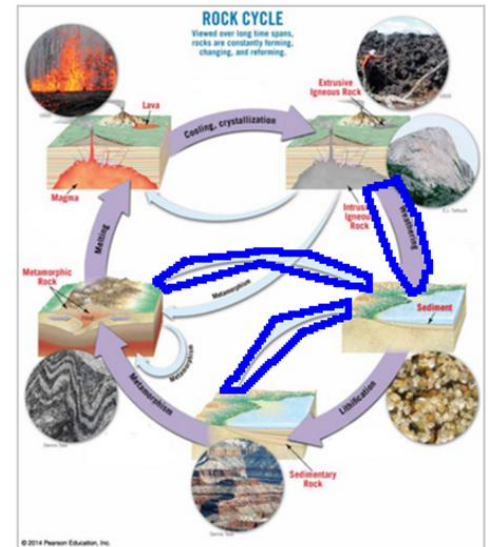
- Using images from the text, query students' understanding of the Rock Cycle. In the Learning Catalytics activity shown below, students answer by selecting a region on their mobile device, tablet, or laptop. These could also be sketch-type items where students sketch their own version of the Rock Cycle:
  - Select "uplift" portions of the Rock Cycle

## Question

Which path of the rock cycle (any color arrow) would require "uplift"? (select ALL that Apply)



## Answer



## TEACHER RESOURCES

### Web Resources:

#### Teaching 100-level Geoscience Courses

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

#### Geologic Time

- Visual Conversion:**
  - <http://pubs.usgs.gov/gip/geotime/time.html>
  - [http://www.actionbioscience.org/education/lewis\\_lampe\\_lloyd.html](http://www.actionbioscience.org/education/lewis_lampe_lloyd.html)
  - [http://www.fossils-facts-and-finds.com/clock\\_of\\_eras.html](http://www.fossils-facts-and-finds.com/clock_of_eras.html)
  - <http://www.geologyclass.org/Geologic%20Time%20Scale%20Activity.htm>

- **Other Visualizations:**  
[http://serc.carleton.edu/NAGTWorkshops/time/teaching\\_visualizations.html](http://serc.carleton.edu/NAGTWorkshops/time/teaching_visualizations.html)
- **Geological Society of America Geologic Time Scale:**  
<http://www.geosociety.org/science/timescale/>
- **ChronoZoom: A Timeline for Big History:**  
<http://eps.berkeley.edu/~saekow/chronozoom/>

#### Cycles on Earth:

- **Rock Cycle:**  
[http://ansatte.uit.no/kku000/webgeology/webgeology\\_files/english/rocks.html](http://ansatte.uit.no/kku000/webgeology/webgeology_files/english/rocks.html)
- **Plate Tectonics:**  
<http://www2.nature.nps.gov/geology/usgsnps/animate/pltecan.html>

## CONCEPT CHECKS

### 1.1 Geology: The Science of Earth

1. The two subdivisions of geology are *Physical Geology* and *Historical Geology*. Physical geology focuses on the materials that Earth is made of and the processes that operate on the surface and inside Earth. Historical geology focuses on the origin of Earth and how Earth and life on it have changed through time.
2. Several geologic hazards would include volcanic activity, floods, and earthquakes.
3. Aside from geologic hazards, describe another important connection between people and geology. An important connection between geology and people includes the resources from Earth that we exploit and depend upon. These resources include groundwater, hydrocarbons for energy, and various base and precious metals as well as industrial and agricultural mineral resources.

### 1.2 The Development of Geology

1. Because of Aristotle's influential reputation as an authority on many subjects, his non-scientific and arbitrary descriptions about the natural world remained accepted which inhibited other investigations into questions about Earth until after the Renaissance.
2. Catastrophism holds that Earth's features were formed by sudden and unrelated catastrophes. Uniformitarianism holds that Earth's geologic processes operate based on a *uniform* set of physical laws that operate today and throughout Earth's history. Catastrophists view the age of Earth as very young and align with biblical doctrine established by Bishop Usher. Uniformitarianists recognize that the processes shaping Earth operate slowly and so must operate over long periods of time to achieve the geologic change that we observe.
3. The current estimate for the age of Earth is 4.6 billion years old.
4.
  - a. Eon: Phanerozoic
  - b. Era: Cenozoic
  - c. Period: Quaternary
  - d. Epoch: Holocene

### 1.3 The Nature of Scientific Inquiry

1. A scientific hypothesis is simply an untested explanation for a set of observations. Once a hypothetical explanation is subjected to many tests and scrutiny and is not eliminated as a viable explanation, it can be considered a theory.
2. A scientific investigation starts by asking a question and collecting data related to the question. From the data collected, one or more hypotheses are formulated to explain the data, and then experiments are conducted to test the hypotheses. The tests serve to accept, modify, or reject a hypothesis. Finally, the data and results with the surviving hypotheses undergo peer examination in the scientific community.

### 1.4 Earth's Spheres

1. a. Hydrosphere: The hydrosphere encompasses all of Earth's water. This includes water vapor in the atmosphere, all the liquid water of the oceans, the fresh water underneath the ground and in the lakes and streams as well as the solid water in the form of ice in glaciers.  
b. Atmosphere: The atmosphere is the gaseous envelope that surrounds Earth and provides the elements we call *weather* and *climate*.  
c. Biosphere: The biosphere encompasses all the life on Earth and, in a broad sense, all of the places on Earth where life can exist.  
d. Geosphere: The geosphere encompasses the entire solid, inorganic portion of Earth.
2. Compared to the thickness of the solid Earth, which is about 6400 kilometers (4000 miles), the atmosphere is very shallow with 90 percent of its mass within 16 kilometers (10 miles) of the surface.
3. Oceans cover 71 percent of Earth's surface and account for almost 97 percent of all of Earth's water.
4. 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. 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 Early Evolution of Earth

1. The solar nebular theory holds that a cloud of gas and dust, the nebula, contracted under the force of gravity, flattening into a spinning disk. The protosun forms at the nebula's center and as gas and dust condense around the protosun, planetesimals begin to collect from the matter in the spinning disk. More and more material is swept up from the disk by the planetesimals until the current configuration of planets is achieved.



2. a. Inner planets: Mercury, Venus, Earth, and Mars are the smaller planets of the solar system and contain mostly iron, nickel, and the rock-forming elements such as silicon, calcium, and sodium.  
b. Outer planets: Jupiter, Saturn, Uranus, and Neptune are the larger planets composed mostly of extremely large amounts of ice, carbon dioxide, ammonia, and methane with minor amounts of rocky material and metals.
3. As early Earth heated and metallic elements began to melt, they sank to the center of Earth due to their density. Lighter elements formed more buoyant magmas that rose closer to the surface taking other light elements and elements that were soluble in the magma with them. This created a layered structure based mostly on density or association with magmas of specific buoyancies.

### 1.6 Earth's Internal Structure

1. The three major compositional layers of Earth are the core, mantle, and crust. The core is composed mostly of an iron–nickel metal alloy and only minor amounts of lighter elements (those that readily bond with iron—oxygen, silicon, and sulfur). The mantle is composed of true *rock* containing silicate minerals that are high in iron and magnesium. The crust consists of a more varied composition than the mantle or core. That portion of the crust underneath the oceans, the *oceanic crust*, is composed of rocks containing iron- and magnesium-rich minerals, but not as much as the underlying mantle. The portion of the crust comprising the continents, the *continental crust*, has a more varied composition than ocean crust, but, in general, contains less iron- and magnesium-rich minerals giving an average density of  $2.7 \text{ g/cm}^3$  while the ocean crust is denser (about  $3.0 \text{ g/cm}^3$ ).
2. The lithosphere and asthenosphere are subdivisions of Earth's interior that are defined based on physical properties and behavior rather than chemical composition. The lithosphere consists of the entire crustal layer and the upper portion of the mantle and behaves as relatively cool, solid, rigid material. The underlying asthenosphere is hotter and behaves as a softer, weaker material than the lithosphere. Because of the property differences between the lithosphere and asthenosphere, they are able to move independently of each other.
3. The outer core is hot enough for the specific composition of iron and nickel present to melt and remain liquid at the pressures that occur there. The movement of the liquid metal alloy of the outer core is what generates Earth's magnetic field. The inner core, by contrast, is under much more pressure and, although hotter than the outer core, is not hot enough to remain molten and so is solid iron–nickel.

### 1.7 Rocks and the Rock Cycle

1. A rock's mineral composition and texture reflect the geologic processes that created it.
2. Rock cycle diagram. See SmartFigure 1.23.

### 1.8 The Face of Earth

1. The continents are composed mostly of granitic rocks with an average density of  $2.7 \text{ g/cm}^3$  while the ocean basins are composed of basaltic rocks with an average density of  $3.0 \text{ g/cm}^3$ .

This difference in density allows the continents to float higher on the underlying mantle than the ocean crust. In addition, except for a limited area of mountainous relief, the continents are rather flat features with an average elevation of 0.8 kilometers (0.5 mile) above sea level. In contrast, the ocean basins have an average depth of 3.8 kilometers (2.4 miles) below sea level.

2. The three major regions of the ocean floor are: the continental margin, the deep-ocean basin, and the oceanic ridges. The continental margin consists of the continental shelf, which is the flooded edge of the continent, and the continental slope and rise, which are the boundaries between the continents and the ocean basin. The deep-ocean basin consists of the abyssal plains, which are incredibly flat areas and extremely deep areas called the deep-ocean trenches. Other features present on the ocean basins are chains of submerged volcanic remnants called seamounts. Finally, the ocean ridges consist of layers of igneous rock that is fractured and uplifted to create this broad, elevated feature.
3. The youngest mountains of Earth are in two major belts. One, the circum-Pacific Belt, lies on the edges of the continents that enclose the Pacific Ocean. The other extends from the Alps in Europe through Iran, into the Himalayas and then southward into Indonesia where it connects with the circum-Pacific belt.
4. Cratons are the older, relatively stable interiors of continents and the shields are the exposed areas of the craton. The stable platforms are those parts of the craton that have been covered by relatively thin deposits of younger sedimentary rocks.

## CONCEPTS IN REVIEW

- 1.2 We currently live in the Holocene Epoch of the Quaternary Period of the Cenozoic Era of the Phanerozoic Eon.
- 1.4 Even though the spheres of Earth cannot be isolated and are interrelated, glaciers would be considered part of the hydrosphere because the hydrosphere includes all of Earth's resources of fresh water.
- 1.5 Mars and Jupiter will be the same age as Earth, about 4.6 billion years old. The sun is perhaps a little older, but not much.
- 1.6 The diagram show Earth's layered structure based on physical properties. Layer A identifies the asthenosphere, layer B is the lithosphere, layer C is the solid mantle below the asthenosphere, layer D is the liquid outer core, and layer E is the solid inner core.
- 1.7 In the diagram of the rock cycle, letter A represents cooling of molten material to form igneous rock, letter B represents weathering to produce sediment, letter C represents lithification of sediment to form sedimentary rock, letter D represents the addition of heat and pressure to form metamorphic rock, and letter E represents continued heating to the point of melting to create molten rock (magma).
- 1.8 The features of the ocean floor in order from shallowest to deepest are: continental shelf, continental slope, continental rise, abyssal plains, deep-ocean trenches.

## 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. Hypothesis A: The electricity to that switch is turned off.  
Hypothesis B: The light sources controlled by that switch are burned out or inoperable.  
Hypothesis C: That wall switch does not control the lights for that room. The next step is to retrieve another light source and check the light sources, and then determine if the switch is intended to control that light source or something else. Finally, check the electricity to the switch.
3. a. Since the air pressure at the top of Mt. Everest is one-third that at sea level, you have to take three breaths there to equal one breath at sea level.  
b. At an altitude of 12 kilometers, the atmospheric pressure is about 200 millibars. This means that 800 millibars of the approximately 1000 millibars of pressure at sea level are below you. That equals about 80 percent of the atmosphere.
4. Figure 1.2A shows researchers collecting data on the side of an active volcano in Africa. This type of data collection has the advantage of allowing very detailed measurements to be made first-hand, but requires the person to be in the field during acceptable field conditions and precludes collecting more data without returning to the field location. Figure 1.8 (top) shows data collected from satellite-based instruments. This data-collection method has the advantage of being able to collect data over a large area repeatedly over time.
5. The atmosphere and hydrosphere were involved in the mudslide most obviously by providing the extraordinary rainfall. The geosphere was involved by the character of the soil and the underlying earth materials as well as the steepness of the slope. The biosphere played a role in the type of vegetation that was present and how that vegetation could not hold the earth materials against the addition of water. Additionally, the biosphere is involved in the loss of life in the village and the damage to the plants and animals on the slope.
6. Within the rock cycle, many of the paths include steps that include some process that provides uplift to bring the rock to the surface where it can be weathered and deposited at the surface. For any rock to be visible to us, it must be brought to the surface by one of the paths or alternate paths.
7. The shoreline in the picture is an interface, which means it is a boundary where parts of Earth's system (atmosphere, hydrosphere, geosphere, and biosphere) interact. The shoreline is not the boundary between the ocean basin and the continent because the continent continues outward into the sea as the *continental slope*.