CHAPTER 1

The Earth System

Chapter Summary

- The human creative process, field and lab observations, and experiments help geoscientists formulate testable hypotheses (models) for how the Earth works and its history. A hypothesis is a tentative explanation focusing attention on plausible features and relationships of a working model. If a testable hypothesis is confirmed by a large body of data, it may be elevated to a theory. Theories are abandoned when subsequent investigations show them to be false. Confidence grows in those theories that withstand repeated tests and successfully predict the results of new experiments.
- A set of hypothesis and theories may become the basis of a scientific model that represents an entire system too complicated to replicate in the laboratory. Often models are tested and revised in a series of computer simulations. Confidence in such a model grows as it successfully predicts the behavior of the system.
- The elevations of Earth topography averages 1–2 kilometers above sea level for land features and 4–5 kilometers below sea level for features of the deep ocean.
- The **principle of uniformitarianism** states that geological processes have worked in the same way throughout time.
- Earth's interior is divided into concentric layers (crust, mantle, core) of sharply different chemical composition and density. The layered composition of the Earth is driven by gravity. Only eight of the 100 or so elements account for 99 percent of Earth's mass. The lightest element (oxygen) is most abundant in the surface crust and mantle, while the densest (iron) makes up most of what is found deep in the core.
- Earth's major interacting systems are the climate system, the plate tectonic system, and the geodynamic system. The climate system involves interactions among the atmosphere, hydrosphere, and biosphere. The plate tectonic system involves interactions among the lithosphere, asthenosphere, and deep mantle. The geodynamic system involves interactions within the central core that produce occasional reversals of Earth's magnetic field.
- As the Earth cooled, an outer relatively rigid shell, called the lithosphere, formed. Dynamic processes driven by heat transfer, density differences, and gravity broke the outer shell into plates that move around the Earth at rates of centimeters per year. Major components (atmosphere, hydrosphere, biosphere) of Earth's surface systems are driven mostly by solar energy. Earth's internal

heat energizes the lithosphere, asthenosphere, deep mantle, and outer and inner core.

- The oldest known rocks found on the Earth's surface are 4 billion years old.
- Earth's geodynamic system was functioning 3.5 billion years ago.
- The composition of Earth's atmosphere, oceans, and life history was profoundly changed by the addition of oxygen when photosynthetic life evolved more than 2 billion years ago.
- Multicelled life became markedly evident in the fossil record, beginning one half billion years ago. Following that, the evolution of life was interrupted periodically by large mass extinctions.

Learning Objectives

Focus your instruction on clear learning objectives. In this section we provide a sampling of possible objectives for this chapter. No class could or should try to accomplish all of these objectives. Choose objectives based on your analysis of your class. Refer to Chapter 1: Learning Objectives—How to Define Your Goals for Your Course in the Instructional Design section of this manual for thoughts and ideas about how to go about such an analysis.

Knowledge

At the end of this unit the student should:

- Know the distinction between hypothesis, theory, and model.
- Know the principle of uniformitarianism.
- Know the basics of plate tectonics.
- Enumerate some of the major events in geological time.

Skills/Applications/Attitudes

At the end of this unit the student should:

- Discuss the consequences of the early Earth becoming partially molten.
- Appreciate the role of the scientific method in problem solving.
- Distinguish the difference between a scientific theory, and theory as it is used in informal discussion between friends.
- Appreciate the vastness of the geological time scale in relation to the history of humans.
- Appreciate the idea that Earth is our spaceship, and therefore it makes sense for us to understand the basics of how the Earth operates.
- Appreciate the concept of Earth as a system of interacting surface and internal components, e.g., hydrosphere, atmosphere, biosphere, lithosphere, asthenosphere.

General Education Skills

- Write a summary of the idea that the movement of tectonic plates is the surface manifestation of convection in the mantle from the point of view of a skeptic. (writing/critical thinking) Use this exercise to identify questions and confusion students have regarding Earth's internal systems. This will help students assimilate the information on plate tectonics in Chapter 2.

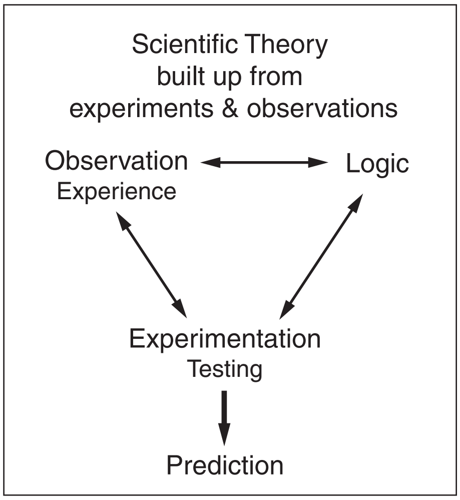
Freshman Survival Skills

- Encourage students to read the three introductory chapters of the *Student Study Guide for Understanding Earth*, available in the e-Book. These chapters explain how to use the study guide and provide helpful guidelines for reading a science text like *Understanding Earth* and studying geology. The most effective way to encourage this activity is to make it an extra credit assignment. (textbook reading, note taking, time management, exam preparation)

- Encourage students to preview Chapter 1 before lecture by awarding credit for restating in their own words acceptable answers to the **Chapter Preview Questions** in the *Student Study Guide for Understanding Earth.* (previewing/ textbook reading)
- Distribute a chapter outline and a selection of mixed format study questions before the first lecture on The Earth System. (note taking)

Sample Lecture Outline

Sample lecture outlines highlight the important topics and concepts covered in the text. We suggest that you customize it to your own lecture before handing it out to students. At the end of each chapter outline consider adding a selection of review questions that represent a range of thinking levels.



Chapter 1: The Earth System

The Scientific Method
- Testable hypothesis—working model
- Theory
- Model

Earth's Shape and Surface (topography)

The Geologic Record—principle of uniformitarianism

Earth's concentric layers
- Earth's Density (calculated density exceeds that possible for a planet made of solid rock)
- Wiechert Hypothesis:
  - Gravity drop of iron/nickel to the core
  - Therefore: dense core surrounded by a light silicate mantle
- Boundaries: crust, upper mantle, transition zone, lower mantle, outer core, inner core
- Chemical Composition (see Figure 1.12)
  - Ninety percent of Earth is iron, oxygen, silicon, and magnesium
  - Gravity has drawn the iron to the core
  - Crust and Mantle—mostly oxygen and silicon (silicate enriched)
  - Core—mostly iron
- Climate System (atmosphere, hydrosphere, biosphere)
- Plate Tectonics System (lithosphere, asthenosphere, deep mantle)
- Geodynamo System (core)

Plate tectonics system
- Key components—plate tectonic theory
  - Plates: lithosphere moving on soft asthenosphere
  - Convection/gravity help to explain how plates move

Geologic Time
- Oldest known rocks are 4 billion years old
- Chemical and biological evolution of life
- Earth's geodynamo system produces a magnetic field
- Oxygen becomes a major gas in the atmosphere
- Life's "Big Bang" 600 million years ago is marked by the appearance of a great diversity of multicelled plant and animal life in the fossil record. Since then, evolution has been characterized by periodic mass extinctions followed by new radiations of diversity.

Teaching Tips

Cooperative/Collaborative Exercises and In-Class Activities

Refer to Chapter 4: Cooperative Learning Teaching Strategies in the Instructional Design section of this manual for general ideas about conducting cooperative learning exercises in your classroom.

Five-Minute Write

1. What questions do you have about this lecture?
2. What did you find most interesting about this lecture?
3. How was this lecture relevant to you?

Coop Exercise 1: Five-Minute Write

The Five-Minute Write is done during the last five minutes of lecture. Ask students to put their names on a sheet of paper and then address the three questions per the overhead; see adjacent sample. Start the next lecture by discussing the answers to some of the questions students had about the previous lecture.

Freshman Survival Skills Assignment

In the beginning of your course it is prudent to include a few exercises to help the freshmen in your class learn how to learn and reinforce mastery of the basics of good preparation for college-level lectures. Learning skills are like critical thinking skills—they tend to be mastered slowly, over time, and with lots of practice. Even upper division students and graduate students sometimes need coaching about how to learn. (See Part I, Instructional Design for a discussion of why this is so and ideas about how to do it.) Chapter 1 discusses freshman survival as a national educational priority. Chapters 5 and 6 discuss how to develop credit assignments to encourage students to learn how to learn.

The assignment to **Preview a Textbook Chapter** is highly recommended. It may help your students develop the good habit of coming to lecture prepared. You will find this assignment in Chapter 6 of the Instructional Design section of this manual (see Part I, Chapter 6: Control the Incentives—Assign Credit to Study Skills Assignments). Making this an assignment early in the course will help to set the tone that you expect students to come to lecture prepared.

Topics for Class Discussion

- One-page articles listed below provide an excellent basis for class discussion and homework on the scientific method. They are also referred to in the *Geology in Practice* exercises.

  Shermer, M. (February, 2003). "Psychic Drift—Why most scientists do not believe in ESP and psi phenomena," *Scientific American*, p. 31.

  Shermer, M. (October, 2002). "The Physicist and the Abalone Diver—The difference between the creators of two new theories of science reveals the social nature of the scientific process," *Scientific American*, p. 42.

  Shermer, M. (April, 2002). "Skepticism as a Virtue—An inquiry into the original meaning of the word 'skeptic,'" *Scientific American*, p. 37.

  Shermer, M. (April, 2001). "Colorful Pebbles and Darwin's Dictum—Science is an exquisite blend of data and theory," *Scientific American*, p. 38.

- One hears the comment, "It's only a theory" in regard to scientific theories such as the age of the Earth, climate change, the theory of evolution, the theory of plate tectonics, etc. After reading Chapter 1, how would you respond to such a comment. Is there a fallacy? What is it? How is a scientific theory different than the way we use the word theory in casual conversation?
- A comparison of the relative volume and mass for each of the major layers within the Earth provides a useful perspective.

Volume and Mass of Earth's Layers

<table>
<tr><th>Layer</th><th>Volume (% of total)</th><th>Mass (% of total)</th></tr>
<tr><td>Atmosphere</td><td>————</td><td>0.02</td></tr>
<tr><td>Continental crust</td><td>0.44</td><td rowspan="2">0.42 (continental and ocean)</td></tr>
<tr><td>Ocean crust</td><td>0.16</td></tr>
<tr><td>Mantle</td><td>83.02</td><td>67.77</td></tr>
<tr><td>Outer core</td><td>15.68</td><td rowspan="2">31.79 (outer and inner core)</td></tr>
<tr><td>Inner core</td><td>0.70</td></tr>
</table>

Teaching Resources

Student Study Guide Highlights (part of the *Understanding Earth* e-Book)

In Part I, chapters provide strategies for learning geology. Ideally, students would read these chapters early in the course.

Chapter 1: Brief Preview of the *Student Study Guide for Understanding Earth*

Chapter 2: Meet the Authors

Chapter 3: How to Be Successful in Geology

In Part II, Chapter 1: *The Earth System*

Before Lecture: Preview Questions and Brief Answers

During Lecture: Learning Warm-up Tip (s)

After Lecture:

- Check Your Notes

Exam Prep:

- Chapter Summary
- Review Questions

Sample Exercises

Sense of Geologic Time

1. The oldest rock yet to be found on Earth is from Canada and is radiometrically dated at four billion years. Radiometric dates usually measure the interval of time that has elapsed since the igneous rock solidified from a molten state. Various lines of evidence, including radiometric dates on meteorites and lunar samples, suggests that the Earth and our solar system is about 4.5 to 5 billion years old. Over this interval of time, staggering compared to human standards, the atmosphere and hydrosphere of the Earth evolved.

A billion years is an immense length of time! To gain a sense of the magnitude of geologic time, figure out how many years it would take for you to count to one billion, assuming that each count takes one second. In other words, how many years in one billion seconds?

Show your work and keep track of the units!

Answer ________________________________

Sense of Scale

This exercise is designed to get students thinking about the scale of major planetary features, a sense for the vastness of geologic time, and a sense for the rates of geologic processes.

2. Air is our most precious resource. Without food, we can live for weeks and without water, we can live for days, but without air to breathe we survive about four minutes. At the top of Mt. Everest at 29,028 feet, it's hard to walk without a tank of oxygen, even if you are in the best physical shape. In a commercial jet, traveling across country at 35,000 feet you would be dead in minutes without the pressurized cabin and a supply of oxygen to breathe.

Relative to the planet Earth, the atmosphere we survive in is extremely thin. Most people live at or close to sea level since most major cities of the world are along coastlines. Some cities and villages in Mexico, South America and China, for example, are at higher (8,000 to 12,000 feet) elevations. Few people live above 15,000 feet. Mt. McKinley in Alaska is about 20,320 feet high, and climbers do get to the top without oxygen tanks, but they need tremendous determination due to the thin atmosphere.

Since most people live below an elevation of 15,000 feet, let's estimate that this is the height or thickness of our atmosphere in which humans effectively live. You can survive at higher elevations, but we thrive when we are lower.

A) Calculate how many miles in 15,000 feet, round off to the nearest tenth of a mile.

Show all work.

Answer ________________________________

B) Ask students to translate the distance they calculate in part A to the distance between their campus and some well-known feature or major intersection.

Answer________________________________

"Walking" to the Center of the Earth

3. The Earth's interior is composed of three main concentric zones: the crust, mantle, and core. The outermost layer, the crust, averages about 40 km thick on the continents and is thinner (average 10 km) under the oceans. The middle layer, the mantle, is an average of 2900 km thick, and the core, the inner most layer, has an average radius of 3470 km, about the size of the planet Mars.

A) Assuming you can walk 10 miles in a day, how many days would it take you to walk to the crust–mantle interface (called the moho) if you started from the land surface? **Hint:** 1 mile = 1.6 km) Show your work and round off to the nearest whole day.

Show your work and round off to the nearest whole day.

Answer ________________________________

B) How many more days would it take you to get to the center of the Earth?

Answer ______________________________

C) How many months would the whole trek take?

Answer ______________________________

Rates at Which Geologic Processes Operate

4. Some geologic processes like volcanism and earthquakes occur intermittently but can cause significant and sometimes catastrophic change very quickly. Others processes like weathering and erosion tend to act continuously but gradually and may seem to be imperceptibly slow. Regardless of whether we can notice changes or not, geologic processes, acting over long periods of time (thousands and millions of years) produce significant changes to the Earth's surface

If you were to occasionally visit the Grand Canyon over a period of many years, you would most likely notice no change. Even the details in the cliffs would probably seem "forever" frozen. Yet the Colorado River is continuously, albeit somewhat slowly, cutting into and eroding the Colorado Plateau. The Grand Canyon is gradually getting deeper and wider.

Some geologists find evidence to suggest that this mile deep canyon may have formed within the last 4 million years. Assuming a uniform rate of erosion and without considering canyon widening due to slope retreat, calculate how fast (in millimeters per year) the Colorado River would have to downcut per year to form the mile deep Grand Canyon in 4 million years.

Show all your calculations.

Answer ______________________________