**The Earth Through Time**

# Chapter 1—The Science of Historical Geology

**I. Geology**

**A. Physical versus Historical Geology**

1. Physical geology – origin, classification, and composition of Earth materials and Earth’s internal and surficial processes

2. Historical geology – Earth’s evolution, changes in lands and seas, mountain building and destruction, fossil succession through time, history of the solar system

**B. Scientific Method in Geology**

1. Questions

2. Collection of data (observations)

3. Development of hypothesis (explanation)

4. Further testing of hypothesis

5. Possible development of theories and laws

**II. Three Grand Themes in Earth History**

**A. Deep Time**

1. Recognition of the immensity of geologic time

2. Relative ages of rocks and fossils

3. Absolute ages of rocks and fossils

**B. Plate Tectonics**

1. Grand unifying concept of Earth’s outer layer

2. Tectonics = large-scale deformation; Plate = large slab of Earth’s lithosphere

a. Asthenosphere – plastic layer upon which plates move

b. Plate boundaries

(1) Convergent (closing)

(2) Divergent (spreading)

(3) Transform (sliding)

**C. Evolution of Life**

1. Grand unifying concept in biology

2. Working mechanism: natural selection

**Answers to Discussion Questions**

1. When a hypothesis survives repeated challenges and is supported by accumulating favorable evidence, it may be elevated to the status of a theory. This generally takes a long time and requires the work of many people.

2. The lithosphere is the rigid outer layer of Earth – roughly 100 km thick – that includes the crust as well as the uppermost part of the mantle. The crust is a part of the lithosphere, the uppermost part.

3. Plate tectonics is the grand unifying concept that explains movement of large slabs of Earth’s lithosphere and the effect of this movement in forming Earth’s crustal features. Divergent boundaries are places where plates move apart. Convergent boundaries are places where plates move together. Transform boundaries are places where plates glide past one another without converging or diverging. Plate tectonics affects our daily lives through processes associated with plate tectonics such as earthquakes and volcanic eruptions and their associated local and global effects.

4. Fossils are the record of natural change (organic evolution) through time. Fossils are valuable indicators of age of rocks and help us understand past conditions on Earth.

5. Fossils, taken from progressively younger strata, may show a detailed record of progressive change in the structure of an organism. This is an important basis for understanding adaptation and natural selection through time.

6. The age of the Earth is about 4.6 billion years. The oldest rocks known at the Earth’s surface are about 4.2 billion years. It is unlikely that older rocks will be found because Earth’s earliest history has been destroyed by the recycling of plate tectonics and the processes of rock weathering.

7. There is strong evidence, as presented in this chapter that the Mediterranean Sea evaporated and was refilled several million years ago. This event would have had a profound effect upon the plant and animal species of the area, both on land nearby and in the Mediterranean Sea. As this happened over a long time, some species may have been able to adapt or change to the changing conditions and thus there was organic evolution.

8. Meteorites are thought to be debris from shattered planets or left over material from the formation of the solar system. They must have formed about the same time as the Earth, therefore their age reveals Earth’s age.

9. Events of the geologic past will eventually happen again, so a better understanding of the cause and effects of ancient episodes of global warming may help us predict the effects of and prepare for future global warming.

10. The three grand themes are: deep time; plate tectonics; and biologic evolution.

11. The absolute age of a rock body is expressed in years. Very often, absolute ages are given in thousands, millions, or even billions of years. This is fundamentally different from relative ages, which refer only to the relative age order of events without reference to numbers of years.

12. d

13. b

14. a

15. d

**CHAPTER ACTIVITIES**

**Student activities for in-depth learning:**

1. Take a look at a web page that discusses the steps of the scientific method, for example, http://www.sciencebuddies.org/science-fair-projects/project\_scientific\_ method. shtml. Make note of the steps in the scientific method and what happens when the validation of a hypothesis does not work out. Then, consider a geological problem in the area of historical geology. Describe the steps of the scientific method in terms of that problem. If you want ideas on possible problems for research in historical geology, be sure to read this chapter and pick one or two other chapters in the book and look at those for ideas. Or, you can ask your instructor for some ideas.

2. Using web pages at the University of California’s Museum of Paleontology (http://evolution.berkeley.edu/), take a look at the concept of evolution from a paleontological point of view. After reviewing what this web page has to offer, use the resources there to prepare a brief summary of one of the following topics, or something very similar: What is evolution and how does it work?; How does evolution impact my life?; What is the evidence for evolution?; or What is the history of thought on evolution?

**CHAPTER OVERVIEW**

This chapter *gives you* an introduction to the science of geology from both physical and historical perspectives. Physical geology examines the structure, composition, and processes that affect the Earth today. Historical geology considers all the past events on Earth. This chapter discusses the scientific method and shows how it can be used to establish a scientific theory. The three prevailing themes in the history of the Earth are also discussed: the immensity of geologic time, plate tectonics, and organic evolution.

**LEARNING OBJECTIVES**

By reading and completing information within this chapter, you should gain an understanding of the following concepts:

* Describe and implement the scientific method to solve problems.
* Discuss the concept of deep geologic time and the use of radioactive dating to determine the absolute age of rock specimens.
* Discuss plate tectonics and define divergent plate boundaries, convergent plate boundaries, and transform plate boundaries.
* Discuss the general concept of evolution and differentiate organic evolution from physical evolution.
* Apply the concept of natural selection to organic evolution.

**CHAPTER OUTLINE**

1. Why Study Earth History
2. Geology Lives in the Present and the Past
3. A Way to Solve Problems: the Scientific Method
4. Three Great Themes in Earth History
   1. Deep Time
   2. Plate Tectonics
   3. Evolution of Life
5. What Lies Ahead?

**Key Terms** (*page numbers are in parentheses*)

**absolute age (7):** The geologic age of a fossil, or a geologic event or structure expressed in units of time, usually years.

**asthenosphere (8):** The zone between 50 and 250 kilometers below the surface of the Earth, where shock waves of earthquakes travel at much reduced speeds, perhaps because of less rigidity. The asthenosphere may be a zone where convective flow of material occurs.

**convergent boundary (8):** Develop when two plates move toward one another and collide. Characterized by a high frequency of earthquakes and are thought to be the zones along which folded mountain ranges or deep-sea trenches may develop.

**crust (8):** The outer part of the lithosphere; it averages about 32 kilometers in thickness. Seismically defined as all of the solid Earth above the Mohorovicic discontinuity. The thin, rocky veneer that constitutes the continents and the floors of the oceans.

**divergent boundary (8):** Develop when two plates move way from each other. May manifest themselves as *mid-oceanic ridges* complete with tensional (pull-apart) geologic structures. The rending of the crust is accompanied by earthquakes and enormous outpourings of volcanic materials that are piled high to produce the ridges itself.

**half-life (7):** The time needed for half of the original quantity of radioactive atoms to decay to daughter products.

**historical geology (2):** A branch of geology concerned with the systematic study of bedded rocks and their relations in time and the study of fossils and their locations in a sequence of bedded rocks.

**hypothesis (3):** An explanation for an observation. It is subject to testing and modification. If well supported by evidence, it then may become a theory.

**lithosphere (8):** The outer shell of the Earth, lying above the asthenosphere and comprising the crust and upper mantle.

**mantle (8):** A thick, homogeneous layer surrounding the core composed of several concentric layers. Believed to have stony, rather than metallic, composition. Oxygen and silicon probably predominate and are accompanied by iron and magnesium as the most abundant metallic ions. Probably composed of *peridotite*, an iron- and magnesium-rich rock.

**natural selection (9):** The natural process where by organisms are preserved or eliminated according to their fitness or adaptation to their environment.

**physical geology (2):** That branch of geology concerned with understanding the composition of the Earth and the physical changes occurring in it, based on the study of rocks, minerals, and sediments, their structures and formations, and their processes of origin and alteration.

**plate tectonics (8):** The theory that explains the tectonic behavior of the crust of the Earth in terms of several moving plates that are formed by volcanic activity at oceanic ridges and destroyed along great ocean trenches.

**relative age (8):** The placing of an event in a time sequence without regard to the absolute age in years.

**scientific law (5):** If a theory continues to triumph over every challenge, it can be raised to the level of a scientific law.

**scientific method (3):** A systematic way to find answers to questions, solutions to problems, and evidence to prove or disprove ideas and beliefs.

**theory (3):** A hypothesis that survives repeated challenges and is supported by accumulating favorable evidence.

**transform boundary (8):** A plate boundary along which plates slide past one another, and the crust is neither produced or destroyed. On land it is recognized as a strike-slip fault.

**The Science of Historical Geology**

**4,560,00,000 years and counting**

**Geology is the study of the Earth.**

**Two major branches of geology:**

* **Physical Geology – The study of Earth materials and processes**
* **Historical Geology – The study of origin and changes of Earth and life through time.**

**Scientific Method in Geology**

**Like all scientists, geologists use the Scientific Method.**

**The scientific method is used to find answers to questions and solutions to problems. Scientists work like detectives to gather data, to try to figure out what happened.**

**The data may be obtained through observations and/or experiments, which can be repeated and verified by others.**

**Summary of Scientific Method**

1. **A question is formulated.**
2. **Observations are made (data is collected).**
3. **Develop an hypothesis or hypotheses (idea(s) that may explain the observations).**
4. **Test the hypothesis or hypotheses by experimenting and either accept, reject, or modify original ideas.**

**The simplest explanation is always the best.**

1. **When a hypothesis has considerable experimental or observational support over time, it is accepted as the best explanation (or Theory).**

**Grand Themes in Earth History**

1. **Deep time**
2. **Plate tectonics**
3. **Evolution of life**

**Deep Time**

* **Segments of time longer than a average human life span are difficult to comprehend.**
* **Recognition of immensity of geologic time is geology's most important contribution to human knowledge.**
  + **If you lived 100 years your life span would be 0.000002% of the Earth’s history.**
* **The science that deals with determining the ages of rocks is called geochronology.**

**Methods of Dating Rocks**

* **Absolute age - Quantifying the age of the rock or mineral in years before the present. Methods used to determine ages involve the decay rate of radioactive isotopes and seasonal tree rings as well as others.**
  + ***Example: Your birthday***
* **Relative age - Determining the sequence of rock formation (i.e. which rocks are older and which are younger) without knowing the absolute age.**
  + **Example: Bedtime ritual you perform each night**

**Absolute Age**

**The discovery of radioactivity in 1896 provided us the tools to find the absolute age of a rock.**

**Radiometric dating involves analysis of the decay (breakdown) of radioactive “parent” elements in rocks and minerals to their stable “daughter” elements.**

**Radioactive elements decay by releasing subatomic particles from their nuclei. Through this process, the unstable radioactive element is converted to a stable "daughter" element.**

***Example:* *Uranium-235 decays to form lead-207.***

**Radioactive Decay**

**Many radioactive elements can be used as geologic clocks. Each radioactive element decays at its own nearly constant rate. The rate of decay also know as the half-life can be measured.**

**Once this rate is known, geologists can determine the length of time over which decay has been occurring by measuring the amount of radioactive parent element and the amount of stable daughter elements.**

**Relative Age**

* **Determining the sequence of events that in the Earth’s history**
* **The geologic time scale predates the development of radiometric dating and was produced through the use of relative dating techniques.**
* **Geologic time scale is a framework to place events of the geologic past.**
* **Radiometric dating has been used to add actual dates in years to the geologic time scale.**

**Major Themes in Earth History**

1. **Deep time**
2. **Plate tectonics**
3. **Evolution of life**

**Plate Tectonics**

**Plate Tectonic Theory has revolutionized the understanding of geology.**

**Plate tectonics explains many large-scale patterns in the Earth's geological record.**

***Examples: earthquakes, volcanoes, and mountain ranges***

**It is a "great unifying theory" in geology.**

**Plate Geography**

**The lithosphere is Earth’s rigid outer shell. It lies above the asthenosphere, and it includes the upper part of the mantle and both types of crust: continental and oceanic.**

**Earth's Plates**

**The lithosphere is about 100 km thick and consists of the rigid, brittle crust and uppermost mantle.**

**Rigid lithospheric or tectonic plates rest (or "float") on the asthenosphere, the easily deformed, or partially molten part of mantle below the lithosphere.**

**All the tectonic plates are moving, but their rates and directions of movement vary.**

**Plate Movements**

**Plate movement is result of the movement of heat from the Earth’s core to the surface**

**Plates move at different rates, but typically only move a few millimeters per year, about the rate at which your fingernails grow.**

**Plate Boundaries**

* **Divergent - where plates move apart from one another.**
* **Convergent - where plates move toward one another.**
* **Transform - where two plates slide past one another**

**Major Themes in Earth History**

1. **Evolution of life**

**In biology, evolution is the**

**"great unifying theory" for understanding**

**the history of life.**

**As a result of evolution, plants and animals living today are different from their ancestors. They differ in appearance, genetic characteristics, body chemistry, and in the way they function.**

**These differences appear to be a response to changes in the environment and competition for food.**

**The fossil record illustrates the changes in Earth's organisms over time.**

**Natural Selection**

**Charles Darwin and Alfred Wallace were the first scientists to assemble a large body of convincing observational evidence in support of evolution.**

**They proposed a mechanism for evolution which Darwin called natural selection.**

**Tenets**

* **Any given species produces more offspring than can survive to maturity.**
* **Many variations exist among the offspring.**
* **Offspring must compete with one another for food and habitat.**
* **Offspring with the most favorable characteristics are more likely to survive (and thus reproduce).**
* **In this way, beneficial traits are passed on to the next generation.**

**Evidence for Evolution cited   
by Darwin**

* **Fossils provide direct evidence for changes in life in rocks of different ages.**
* **Certain organs or structures are present in a variety of species, but they are modified to function differently (homologous structures).**
* **Modern organisms contain vestigial organs that appear to have little or no use. These structures had a useful function in ancestral species.**
* **Animals that are very different, had similar-looking embryos.**

**Other Lines of Evidence**

* **Genetics (DNA molecule).**
* **Biochemistry (Biochemistry of closely-related organism is similar, but very different from more distantly related organisms).**
* **Molecular biology (sequences of amino acids in proteins).**