CHAPTER 1

## THE DYNAMIC AND EVOLVING EARTH

# OUTLINE

INTRODUCTION

WHAT IS GEOLOGY?

HISTORICAL GEOLOGY AND THE FORMULATION OF THEORIES

ORIGIN OF THE UNIVERSE AND SOLAR SYSTEM, AND EARTH’S PLACE

IN THE COSMOS

Origin of the Universe—Did It Begin With a Big Bang?

♦ Perspective *Exoplanets*

Our Solar System—Its Origin and Evolution

Earth—Its Place in Our Solar System

WHY IS EARTH A DYNAMIC AND EVOLVING PLANET?

Plate Tectonic Theory

ORGANIC EVOLUTION AND THE HISTORY OF LIFE

GEOLOGIC TIME AND UNIFORMITARIANISM

HOW DOES THE STUDY OF HISTORICAL GEOLOGY BENEFIT US?

SUMMARY

# CHAPTER OBJECTIVES

*The following content objectives are presented in Chapter 1:*

* Earth is a complex, dynamic planet that has continually evolved since its origin some 4.6 billion years ago.
* Earth can be viewed as an integrated system of interconnected components that interact and affect one another in various ways.
* Theories are based on the scientific method and can be tested by observation and/or experiment.
* The universe is thought to have originated approximately 14 billion years ago with a Big Bang, and the solar system and planets evolved from a turbulent, rotating cloud of material surrounding the embryonic Sun.
* Earth consists of three concentric layers—core, mantle, and crust—and this orderly division resulted during Earth’s early history.
* Plate tectonics is the unifying theory of geology, and it revolutionized the science.
* The theory of organic evolution provides the conceptual framework for understanding the evolution of Earth’s fauna and flora.
* An appreciation of geologic time and the principle of uniformitarianism are central to understanding the evolution of Earth and its biota.
* Geology is an integral part of our lives.

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# LEARNING OBJECTIVES

*To exhibit mastery of this chapter, students should be able to demonstrate comprehension of the following:*

* the vastness of Earth history and deep time
* the interactions of Earth systems
* the differences between physical geology and historical geology
* the scientific method and the basis of scientific theories
* the Big Bang model of the origin of the universe
* the evolution of the universe
* the general characteristics of our solar system
* the solar nebula theory for the formation of our solar system
* the characteristics that make Earth a dynamic and evolving planet
* the compositional and physical layers of Earth
* the impact of the theory of plate tectonics on the study of the Earth
* the basic concept of organic evolution, including the primary evidence and mechanisms
* the principle of uniformitarianism, and the derivation and significance of the geologic time scale

# ENRICHMENT TOPICS

### Enrichment Topic 1. Five Numbers that Explain the Universe

Michael Lemonick (2003) noted that while “cosmology is sometimes pooh-poohed as more philosophy than science,” scientists have made recent advances in quantifying the five important numbers that are needed to explain the universe. These numbers are 13.7 billion years (the age of the universe); 200 million years (the interval between the Big Bang and the first stars); 4% (the amount of the universe that is ordinary matter); 23% (the proportion of the universe that is dark matter); and 73% (the proportion of the universe that is dark energy). These numbers were calculated using a satellite known as the Wilkinson Microwave Anisotropy Probe. Discuss with your students what these numbers mean, and how they were revealed. ***Time***, Feb 24, 2003 v.61 n.8 p.45.

### Enrichment Topic 2. Scale of the Solar System

In order to convey to students the size of our solar system, and the relative proximities of the planets to the Sun, use a football field analogy:

Put the Sun on the goal line.

Mercury is on the 1-foot line

Venus is on the 2-foot line

Earth is on the 1-yard line

Mars is on the 1 1/2 yard line

Jupiter is on the 5-yard line

Saturn is on the 10-yard line

Uranus is on the 20-yard line

Neptune is on the 30-yard line

(Although Pluto is not considered a planet, it can be placed on the 40-yard line).

On this same scale, the nearest star would be 500 miles away.

**Enrichment Topic 3. Hypothesis for the Formation of the Moon**

Although the debate continues about the formation of the Earth’s one natural satellite, many scientists agree that the Earth was probably hit by a large planetesimal in its early history. Material ejected from the Earth during impact coalesced and cooled into the various lunar layers. What data support this hypothesis? Have students investigate the mineralogical composition of the Moon, and compare it with the Earth’s core, mantle and crust. Can students propose alternative hypotheses for the formation of the Moon? Students can further investigate the various geographic features of the Moon, and discuss their formations.

### Enrichment Topic 4. Enormity of Geologic Time

In order to have students begin to examine the enormity of the 4.6 billion year old history of the Earth, use an analogy that one year equals one second. Choose a few student volunteers, and have each student clap the number of years that s/he has lived (Example: 18 years = 18 seconds = 18 claps). Ask students if any of them has existed 4.6 billion *seconds*. Calculate the amount of time needed for 4.6 billion seconds:

4.6 x 109 s x 1 min/60 s x 1 hr/60 min x 1 day/24 hr x 1 yr/365.25 days = 145.8 YRS!

# LECTURE SUGGESTIONS

#### Earth as a System

Students should begin thinking about Earth as a system. Lead them into an interactive discussion of these or related topics:

**1.** Where is the energy stored within the planet? How is this energy released?

**2.** How is energy transferred from one subsystem to another? What are the effects of this transfer of energy?

1. How can the changes made in one subsystem affect another? For example, how might the warming of the atmosphere affect the hydrosphere and biosphere? How might human-induced changes—such as emissions from factories—affect the atmosphere and biosphere? Students may also come up with their own examples of interactions between subsystems.
2. Have your students investigate the “cyclical” processes of the Earth. Most students are familiar with the hydrologic cycle, but they may be less familiar with the “nitrogen cycle” and “carbon cycle” of our planet. The discussion of the carbon cycle can also be used to springboard to discussions on climate change, and proposed mechanisms of carbon sequestering.

#### Historical Geology and the Formulation of Theories

Understanding the differences between theory, hypothesis, law, and principle is extremely important for students of science. It is even more important that they comprehend the scientific method to understand the basis for and significance of theories, especially those that may be controversial.

Have students read "Method of the Multiple Working Hypothesis" by T.C. Chamberlin and discuss the following questions. Even though Chamberlin wrote this in 1893, are his thoughts on the workings of science still valid? (This is available online at <http://www.auburn.edu/~tds0009/Articles/Chamberlain%201965.pdf>)

**1.** What is the method of multiple working hypotheses? Can you construct an example, real or imagined, of this method?

**2.** What is the rationale for this approach to science? How might this method be considered good science? How might other approaches to understanding the world be considered bad science?

**3.** Have the students use their personal experiences with the Earth to describe how they have used this procedure. Alternately, they could explain how using this procedure might have gained better results.

#### Origin of the Universe, Solar System, and Earth

1. What is the solar nebula theory? What does it indicate about the formation of our solar system? Have students read the section of the chapter explaining this theory. Encourage them to undertake supplementary research on the formation of the early solar system. Students should be able to explain the concept to each other.
2. What is life? Have students suggest possible definitions for life using the textbook and their personal experiences. Where in our solar system would we be most likely to find extraterrestrial life? How would extraterrestrial life differ from life on Earth? What type of evidence should we seek in searching for extraterrestrial life? Students can investigate planets beyond our solar system on Planet Quest, <http://planetquest.jpl.nasa.gov/>.
3. Students can investigate the latest planetary discoveries through research on the Internet. The NASA website provides a wealth of resources and new information (<http://pds.jpl.nasa.gov/planets/>). Have students compare and contrast compositions, atmospheres, surface temperatures, and tectonic activity among the planets of the solar system. What patterns are revealed among terrestrial planets? What patterns are revealed among Jovian planets?

#### Geologic Time and Uniformitarianism

**1.** *Uniformitarianism:* When discussing the principle of uniformitarianism, have the students give examples from their life experiences. (For example, students living in flood-prone areas may discuss various flooding events that are precipitated by record rainfall.) Discuss how difficult deciphering the history of the Earth would be if we did not accept uniformitarianism.

**2.** *Geologic Time:* Understanding the depth of geologic time requires an understanding of "Big Numbers" as well as the complexity of the 3rd and 4th dimensions. Students can use a variety of media to represent geologic time (adding machine tape, yarn, a football field, or the face of a clock). Describing large numbers in terms of familiar items may help students to understand that our human time scale—or even the existence of *Homo sapiens* on Earth—is miniscule.

1. *The Geologic Time Scale*: To help students familiarize themselves with the time scale, ask them to “brainstorm” a mnemonic for the time divisions you are requiring them to learn. Investigate with them the origin of the names of the eons and Phanerozoic eras (and smaller divisions as appropriate to your class). Students should learn these divisions from the oldest to the youngest in order to emphasize the order of events. The simple task of starting each class by writing the basic time divisions on a chalkboard or overhead slide (with the aid of your students) will familiarize them with the geologic time scale—without forcing them to initially memorize the eons, eras, and periods.
2. Emphasize that the geologic time scale is a human-made scale that helps scientists organize the Earth’s history and events. Students may create their own portions of the geologic time scale throughout this course by using the TimeScale Creator at <http://www.tscreator.com>.

#### What Is Geology?

Many students do not understand the myriad ways geology directly and indirectly affects their daily lives. This understanding is central to cultivating an interest in the science.

**1.** Lead a classroom discussion about what students perceive geology is. Write all responses on board and ask students if they notice any broad trends in responses (i.e. Can they be classified as physical, historical, or economic geology?)

**2.** Ask students how geology benefits them. It is helpful to make three columns on the board with the headings Environment, Energy, and Engineering. Explain how environmental geologists test soil, air, and water for pollution and develop and implement remediation strategies. Explain how engineering geologists collaborate with others to plan and build roads, dams, landfills, buildings and other structures. Explain how economic geologists search and mine natural resources such as coal, petroleum, and metals. After a brief explanation, students should be able to provide additional ways geology affects their daily lives within each category, and possibly identify new categories such as political implications of geology.

**3.** Have students explore the minerals they use on a daily basis and over their lifetimes at <http://minerals.usgs.gov/granted.html>.

#### CONSIDER THIS

**1.** What is the difference between a theory and a fact? Why do geologists consider “plate tectonics” a theory? Can you list any facts that support the theory of plate tectonics?

**2.** Why is plate tectonics called the unifying theory of geology? Can the distribution of volcanoes, earthquakes, mountain ranges, and mineral deposits be explained without this theory?

1. Why is organic evolution via the mechanism of natural selection called a theory? Does the use of the word “theory” indicate a lack of confidence in this important concept?
2. How do scientists differ in their use of the word “theory” from the general population, including social scientists?

#### IMPORTANT TERMS

|  |  |  |
| --- | --- | --- |
| asthenosphere | hypothesis | principle of uniformitarianism |
| Big Bang | Jovian planets | scientific method |
| core | lithosphere | solar nebula theory |
| crust | mantle | system |
| fossil | organic evolution | terrestrial planets |
| geologic time scale | plate | theory |
| geology | plate tectonic theory |  |

#### SUGGESTED MEDIA

### Videos/DVDs

1. Stephen Hawking’s Universe, PBS Home Video
2. The Creation of the Universe, PBS Home Video
3. NOVA- Physics: The Elegant Universe and Beyond, PBS Home Video
4. Down to Earth, Earth Revealed #1, Annenberg/CPB
5. Earth’s Interior, Earth Revealed #3,Annenberg/CPB
6. NOVA –Origins, Nova, Discovery Channel
7. The Universe – The Complete Season One (History Channel)
8. The Universe – The Complete Season Two (History Channel)
9. Cosmic Collisions, American Museum of Natural History

### Software and Demonstration Aids

1. Explore the Planets, Tasa Graphics Arts, Inc.
2. Illustrated Dictionary of Earth Science, Tasa Graphics Arts, Inc.
3. Satellite Imagery – Earth from Space, Educational Images, Ltd.
4. Explore Deep Time: Geological Time and Beyond, Geological Society of America

# CHAPTER 1 – ANSWERS TO QUESTIONS IN TEXT

#### Multiple Choice Review Questions

|  |  |  |
| --- | --- | --- |
| **1.** b | **5.** c |  |
| **2.** d |  |  |
| **3.** b |  |  |
| **4.** e |  |  |

#### Short Answer Essay Review Questions

**6.** The solar nebula theory describes the origin of our solar system through the collapse and condensation of interstellar material in a spiral arm of the Milky Way Galaxy. The terrestrial planets formed nearer the Sun by accretion of rocky material and metallic elements, while the Jovian planets formed farther from the Sun from the condensation of gases. The solar nebula theory accounts for most of the characteristics of the planets and their moons, the differences in composition between the terrestrial and Jovian planets, and the presence of the asteroid belt, which was prevented from accreting into a planet by Jupiter’s tremendous gravitational field.

**7.** Uniformitarianism states that the natural processes operating in today’s world are the same processes, with the same underlying physical principles, that have operated throughout Earth’s history. Catastrophic, short-term events like volcano eruptions, earthquakes, tsunamis, landslides, and floods are integral to shaping our world. Uniformitarianism does not require the rate or intensity of a geologic process to be constant.

**8.**  Earth is made of interconnected components that interact and affect each other in many ways. For example, it is impossible to study sedimentary rocks without knowing something about the atmospheric processes that weather, erode, transport and deposit rock materials or about the biological processes that lead to life and fossils. To truly understand Earth, we must learn about it as a system.

Humans are an integral to the Earth system as part of the biosphere. Although humans are relative newcomers in Earth’s history, *Homo* *sapiens* have arguably affected the Earth more than any other species. Examples of human effects on the Earth system are visible within the lithosphere (mining, farming activities), atmosphere (acid rain, greenhouse gas emission), biosphere (monoculture, human-extinction of species), and hydrosphere (levees on river systems, pumping of groundwater).

**9.** Plate tectonic theory is the concept that lithospheric plates are in motion relative to one another, driven by convection cells in the mantle. The theory accounts for the distribution of mountain chains, major fault systems, volcanoes, and earthquake epicenters. It is the underlying set of processes for the rock cycle, and explains the biogeography of fossil and living organisms.

Plate tectonic theory is important to geology because it is a unifying theory, and the theory has provided a framework for interpreting the composition, structure, and internal processes of the Earth on a global scale. It has also led scientists to the realization that the continents and ocean basins are part of a lithosphere-atmosphere-hydrosphere that evolved together with the Earth’s interior. Therefore, the movement of the plates has affected not only the lithosphere, but also other subsystems of the Earth.

1. Scientists who examine global temperature changes during the past need to accurately record the temperature differences within a standard time scale. Then, these scientists can examine the time intervals between global temperature fluctuations of the past, and perhaps search for clues within Earth’s history to determine if there were specific causes for these fluctuations.

The geologic time scale is extremely important in the current debate on global warming. We know that the Earth’s climate has gone through cycles of long and short duration, and that global warming and cooling are completely natural processes in Earth history. However, if humans are affecting climate on an extremely short timescale, over a period of decades or centuries, this may not be part of one of the Earth’s natural cycles. It is imperative that we understand the geological time scale in order to detect the potential disastrous consequences of human-induced global warming, such as the loss of habitat and species.