CHAPTER 11

Geobiology: Life Interacts with Earth

Chapter Summary

- This chapter reveals the Earth as an enormously complex system, made up of quite complex, interacting subsystems. Living systems (organisms like plants, animals, and microbes) are in constant interaction with nonliving Earth systems.
- Geobiology is the study of how organisms interact with the Earth system.
- Earth’s biosphere consists of all its living organisms (the three domains of life—bacteria, archaea, and eukarya). The biosphere acts as a system because of numerous processes that convert inputs to outputs. Many outputs of the biosphere affect the Earth system’s climate and rock cycle.
- Ecosystems are the organizing units of the biosphere. The organisms of a biosphere can be subdivided into producers (autotrophs) or consumers (heterotrophs) according to the way they obtain their food. At a basic chemical level all foodstuffs of organisms contain the same six elements: carbon, hydrogen, oxygen, nitrogen, phosphorus, and sulfur.
- Extremophiles are microorganisms that live in some of the most extreme ecosystems on Earth.
- Metabolism is the process that all organisms use to convert inputs (energy and nutrients) to outputs (stored energy such as carbohydrates or fat or waste products). For example, a photosynthetic plant uses sunlight, carbon dioxide, and water to produce carbohydrates and oxygen gas byproducts (see Table 11.2). As their metabolic processes operate, organisms continuously exchange energy and matter with their environment. Biochemical cycles are pathways that describe this exchange or flow. Important biochemical cycles include the carbon cycle (see Figure 11.3 and Table 11.2), the phosphate cycle (see Figure 11.4), and the sulfur cycle (see Figure 11.10).
- Microbes are the most abundant and diverse organisms on Earth, and their metabolic processes have long been significant in the creation and regulation of Earth systems. For much of the first four billion years of Earth’s history all living creatures were microbes. The original ancestor was a microbe (see Figure 11.5). Extremophiles are microbes that live in environments that would kill other organisms, especially humans (see Table 11.3). Increasingly, humans are employing extremophiles to clean up our toxic wastes. Microbes play a critical role in many geologic processes, such as mineral precipitation, mineral dissolution, and the flow of important elements through Earth’s crust.
• The origin of life has been explored scientifically mostly through laboratory experiments. Best known is the Stanley Miller experiment (see Figure 11.13) but this is only one of a large pack. The fundamental issue that must be addressed in any theory of the origin of life is exactly how the molecules of life learned to reproduce themselves via the universal genetic code. Field evidence of early life is difficult to find since most sedimentary rocks of the early Earth have been recycled by plate tectonics. While the processes that formed early life are still in dispute, the rock record does show that life was in existence by the end of the first billion years of Earth’s history (see Figure 11.14). This fact supports the theory of evolution by supplying a luxurious three billion years for single-celled microorganisms to evolve into multicelled organisms. Studies of meteorites (see Figure 11.23) and modern organisms (see Figure 11.15) are slowly filling in the pieces of the puzzle of life’s origin.

• Earth’s atmosphere is thought to have been oxygenated in the middle of the Archean eon by cyanobacteria that gave off oxygen gas as a byproduct of photosynthesis. The fossils and the occurrences of banded iron formations and red beds in the geologic record provide evidence for this important milepost in the history of interactions between life and environment. An oxygen-rich surface environment sets the stage for the evolution of Eukarya, including all multicellular animals. Today, the vast net of input–output processes of the biosphere continue to provide a delicate control mechanism that insures a stable percentage of oxygen in Earth’s atmosphere.

• Radiation is the relatively rapid development of new types of organisms that derive from a common ancestor. The Cambrian explosion (see Figure 11.19), which marks the origination of all major animal groups, is the best-known example of a major radiation.

• Extinction occurs when groups of organisms are no longer able to adapt to changing environmental conditions, or compete with a superior group of organisms. When many groups of organisms become extinct at the same time it is called a mass extinction. Figure 11.17 plots the major radiation and extinction events since the onset of multicelled life (Phanerozoic eon).

• Life on other planets? The presence of liquid water over long periods of time (hundreds of millions of years) is considered to be a prerequisite for life. On a planet too close to its star water will boil and become a gas, which can be lost to space over time. On a planet too far from its star, water will freeze into a solid. For every star, there is a habitable zone, marked by the distance away from the star to the point where water is stable as a liquid. If a planet is within the habitable zone, there is a chance that life might have originated there.

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

• Know the role of microorganisms in regard to creation of the gases of the Earth’s atmosphere.

• Know the role of microorganisms in regard to temperature regulation (greenhouse cooling and warming).

• Know the role of microorganisms in regard to the sulfur cycle.

• Know the sequence of events in the Paleocene–Eocene mass extinction event.
• Know the major evolutionary events in Earth’s history.
• Know the basic scientific assumptions that underlie efforts to discover life on distant planets.

Skills/Applications/Attitudes
• Given a specified biological process, photosynthesis and respiration we are able to specify the relevant inputs and outputs.
• Given specified environmental events, such as rise in ocean temperature, reduction, or increase of CO₂ into the atmosphere, we are able to make general predictions about one or more likely outcomes.
• In regard to maintenance of Earth systems, we are able to appreciate the significance of the role of microorganisms.

General Education Skills
• Write a short essay on one of the one of the biochemical cycles (carbon, phosphate, or sulphur) spelling out or diagramming the sequence of events and explaining the role of microorganisms.
• Write a short essay describing possible and likely impacts on the functioning of the Earth system if a specific group of microorganisms were to become extinct.
• Write a short essay on the proposition: Microorganisms should be protected under the endangered species act.
• Write a short essay on the carbon cycle and its effect on the global climate.
• Write a short essay explaining the meaning of the title of this chapter. Flesh out and develop various chapter themes to illustrate what the title means.

Freshman Survival Skills
• Distribute a chapter outline and a selection of mixed format study questions before the first lecture on Geobiology—Life Interacts with the Earth.
• Write a brief one-page summary of Chapter 11.

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 11: Geobiology—Life Interacts with Earth
Geobiology—the study of how organisms interact with the Earth system
Biosphere System
Includes all living creatures
Three domains of living creatures: Bacteria, Archaea, Eukarya
Ecosystem—the organizational unit of the biosystem:
autotrophs, heterotrophs
Extremophiles
Food chemistry—carbon, hydrogen, oxygen, nitrogen, phosphorus, and sulfur
Metabolism—the *engine* of the biosphere

- Metabolic process
  - Input $\rightarrow$ Output

Photosynthesis and respiration are key examples of a metabolic process.

Biochemical cycles—*interaction events* between the biosystem and the other Earth systems, such as the climate system and the rock cycle

- Carbon cycle
- Phosphate cycle
- Sulphur cycle

Main idea to emphasize—Metabolic processes of living organisms play an indispensable role in each biochemical cycle

Microbes—the *tiny chemists* of the biosphere

- Diverse/abundant
- Evolution
  - Original ancestor
  - Dominant on Earth for two billion years
  - Extremophiles

Biochemical cycles

- Geological processes
- Mineral precipitation and dissolution
- Flow of elements through the crust

Geobiological events in Earth’s history

- Origin of Life
  - Plate tectonics—lost fossil evidence
  - Laboratory evidence—Stanley Miller (see Figure 11.13)
  - Oldest discovered fossils (see Figure 11.14)
  - Meteorites (see Figure 11.23)
  - Hydrothermal organisms (see Figure 11.15)

Formation of Earth’s Atmosphere—photosynthesis

- Cyanobacteria $\rightarrow$ oxygen
- Banded iron formations and red beds (see Figure 11.16)
- Oxygen level increased slowly over time
- Evolution of Eukarya
- Oxygen level possibly a factor in the evolution of large multicelled Eukaryotes

Cambrian multicellular organisms

Radiation and extinction is a pattern in the Phanerozoic

- Extinction events of the Phanerozoic eon
- Five most major extinctions (see Figures 8.11 and 11.17)
  - Ordovician
  - Permian—largest (95 percent of all species)
  - Triassic
  - Cretaceous—meteorite

Two additional extinctions of interest

- Paleocene–Eocene—global warming-induced methane burp
- Holocene extinction of North American Mammals—human predation most likely cause

Anthropocene extinction rate—see discussion of the controversy concerning present day extinction rates and overall human impact on pages 574–575 in the text.

Extraterrestrial Life—Astrobiology

- Water—prerequisite for life
- Habitual zone
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.

Coop Exercise 1: How Organisms and the Earth Interact

Exercise from the Student Study Guide for Understanding Earth (available in the Understanding Earth e-Book), Chapter 11, Practice Exercises and Review Questions (note that this exercise is included below as a sample exercise) could be used as a basis for an in-class exercise. Pair students with the person sitting next to them. Have them work together to complete the chart in Exercise 1. Hint: It may be helpful to have them sketch a flow model for each process in the second column of the table. Drawing a flow model may help students understand the nature process of these organism × Earth interactions.

<table>
<thead>
<tr>
<th>Process</th>
<th>Input → Output</th>
</tr>
</thead>
</table>

If time is limited you could fill in the chart as part of your lecture, asking students to stop and draw the flow models as each row is complete.

Coop Exercise 2: 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.

Sample Exercise

The following would make a good homework assignment or in-class cooperative learning exercise.

Exercise 1: How Organisms and the Earth Interact

From the Student Study Guide for Understanding Earth, Chapter 11, Practice Exercises and Review Questions

Life processes influence weathering, precipitate minerals, and modify the composition of the atmosphere and oceans. Review some ways life processes impact the Earth by filling in the blanks in the table below.

<table>
<thead>
<tr>
<th>Life’s Impact on Earth</th>
<th>Life Process(es) Generating the Impact</th>
<th>Description of the Interaction and Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>( O_2 ) in Earth’s Atmosphere</td>
<td>Extraction of carbon from oceans and atmosphere by shell-producing and photosynthetic organisms</td>
<td></td>
</tr>
<tr>
<td>Greenhouse Effect: Cooling</td>
<td>Respiration; refer to Table 11.2</td>
<td></td>
</tr>
<tr>
<td>Mineral Precipitation</td>
<td>Sulfate “eating” microbes</td>
<td>Hydrogen, hydrogen sulfide, and methane gases may be produced</td>
</tr>
</tbody>
</table>
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 require 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.

- To encourage students to preview this chapter announce there will be a preview quiz at the beginning of the lecture for Geobiology—Life Interacts with Earth. Tell them you will ask one or two of the preview questions and will accept for full credit brief answers similar to those found in the student guide. Explain that your purpose will not be to test for complete mastery of the material but rather for a degree of familiarity that will improve their understanding of your lecture. See Part I, Chapter 3 of the Student Study Guide for additional information about previewing.

- A review of student note taking can be very helpful. There many ways to accomplish this. For this lecture it might be useful to lecture 10 or 15 minutes on a process such as the sulfur cycle. Then stop. Have students partner up with the person next to them and check their notes. Put a checklist on the board showing items you consider crucial. Suggest techniques that might help them take notes on a process (e.g., sketching a flow model of the process into their notes, being careful to label inputs and outputs of the process).

Topics for Class Discussion

For helpful ideas on generating productive in-class discussion see Chapters 2, 3, and 4 (active learning, discussion, and cooperative learning) in the Instructional Design section of this manual.

- Why can’t we find the fossil evidence that would answer questions about the very earliest moments of life on Earth? Where have most of the Archean sedimentary rocks gone? What other problems might you anticipate in investigations of the Archean and early life?
- What sort of environment do you think would favor the production of sulfur by microorganisms? Where would such an environment likely exist?
- How does the biosphere act as a “Thermostat” for our planet? What are the specific inputs, processes, and outputs that regulate Earth’s temperature?
- How do we know (what is the nature of the evidence) that pumping carbon into the air will produce a rise in Earth’s temperature?
- Why do you think it took three billion years for single-celled organisms to evolve into multicelled organisms? Some items to consider would be the nature of Earth’s atmosphere during this time, the difficulties inherent in building an embryo that works, the size of single-celled versus multicelled organisms.
- What is the nature of the evidence that life began during the first billion years of Earth’s existence? How convincing do you find this evidence?
• What determines the habitable zone around stars?
• What has accompanied the major cooling and warming events in late Cenozoic time?
• One extinction has been linked to a period of global warming. What were the key biological and physical processes and events that triggered the warming. Could this happen again? How?
• Are we in the midst of a major mass extinction at present? (material on Mass Extinctions is available below)
• The following exercise could be used for in-class discussion, or a structured debate where students are randomly assigned to defend or attack Lovelock’s proposition, or it could be the basis of a short critical thinking type of writing assignment.

— In the early 1980s one scientist (James Lovelock) advanced the controversial Gaia hypothesis, postulating that it might be useful to think of the Earth as a living system. Based on your reading of Chapter 11 take a position and defend or attack Lovelock’s hypothesis.

Note to instructor: It may facilitate discussion to show a slide outlining the commonly accepted criteria put forward by biologists for considering something, a living organism, and a second slide outlining Lovelock’s basic arguments that Earth is alive.

Sample Exercises
The following assignments will help students explore some of the topics in Chapter 11 in greater depth. The questions and materials could also be useful for in-class discussion and in-class explorations of some of the above topics for discussion.

Sample Assignment: Mass Extinctions

Note to instructor: Following the advancement of the crater hypothesis: the controversy over the cause of the KT extinction event was one of geology’s “hot topics.” Because of human fascination with the dinosaurs and the origins of our own species, the topic continues to appeal to students. The following exercise has been used in introductory geology courses, and you may find it useful as a model for your own exercise that involves students in this classic controversy.

We recommend you tune the questions as you think appropriate. You may also want to add your favorite recent reference to some of the classic KT impact/extinction articles on the included reading list. Hint: During the past several years there have been some very interesting and readable articles on this topic.

Suggested introduction for students: The emergence of multicelled life marked the beginning of the division of geological time, known as the Phanerozoic eon, and the periods of the Phanerozoic (Cambrian through Cenozoic) are named on the basis of radiation and extinction events which indicated major changes in the patterns of life on the planet (see Figures 11.17, 8.11, and 8.15).
The K/T is the most recent and best known extinction event. It occurred approximately 60 million years ago. It is called the K/T event because it marks the boundary between the cretaceous and tertiary periods. Most scientists agree this extinction was caused by an asteroid that crashed into the Earth in the vicinity of the Yucatan Peninsula. For the dinosaurs and about 78 percent of all other species alive at the time, the arrival of the meteorite spelled the end of existence. You can read a very interesting and chilling account of the horror that would have accompanied the arrival of the meteor in the section “Tail of the Devil” on page 305 of your text, as well as an artist’s rendering of the scene (see Figure 11.22).

While a tragedy for most creatures who lived at the time, for our ancestors, the early mammals, the K/T meteor opened a sixty-million-year window of opportunity. Without the K2 extinction it is possible that none of us humans would even be here.

The following reserve readings and associated questions in this exercise explore the subject of mass extinctions during the K/T boundary and today.

**Mass Extinction Information Packet** includes:


Earth Impact Effects Program

Easy-to-use, interactive Web site for estimating the regional environmental consequences of an impact on Earth. This program will estimate the ejecta distribution, ground shaking, atmospheric blast wave, and thermal effects of an impact as well as the size of the crater produced.
http://www.lpl.arizona.edu/impacteffects/

Spacewatch

The primary goal of Spacewatch is to explore the various populations of small objects in the solar system and study the statistics of asteroids and comets in order to investigate the dynamical evolution of the solar system.
http://spacewatch.lpl.arizona.edu/

Questions

Answer Questions 1 and 6. Then choose one other.

1. You are a speaker at a conference where scientists are debating the causes of the K/T mass extinction. You need to take a stand. Do you support (a) an impact event, (b) catastrophic volcanic eruptions, or (c) a more gradual cause of the extinction event? Pick one hypothesis and discuss three lines of evidence supporting your choice for a cause of the K/T mass extinctions. Be sure you clearly state how the evidence you cite specifically supports your hypothesis and not the others. Refer to the following articles for your reference: Alvarez, W., et al. (1984), McCartney and Loper (1989), Monastersky, R. (Jan & Feb, 1992), and Officer, et al. (1992).

2. Stephen J. Gould in his article, “The Cosmic Dance of Siva,” says that “Mass extinctions are not unswervingly destructive in the history of life. They represent a source of creation as well.” Discuss what Gould means by this.


4. Why has research on impacts and mass extinctions been “interdisciplinary to the extreme?” What are three challenges in doing interdisciplinary scientific research? What is the benefit from an interdisciplinary approach to science? Refer to Alvarez, W. (1991).

5. You and other geologists are examining stratigraphic sections in the famous Hell Creek and Tullock formations of Montana, searching for clues to explain the K/T extinctions. Suddenly, a major discovery is made: A fossil pelvic bone of a Tyrannosaurus in a fluvial sandstone fully one meter above the recognized K/T boundary. The age of this sandstone is well established based on fossils and its stratigraphic position. So this is it! Proof that some dinosaurs lived into the Tertiary! Wisely, you are a bit skeptical and want additional evidence. What is another explanation for the dinosaur bone being found in a rock layer that is seemingly “too” young?

6. The often quoted figure is that 60% of species living on Earth within the last two centuries have gone extinct. In the National Wildlife Federation special issue on endangered species various animals (mostly North American) mentioned are extinct or are currently in danger of
extinction. Pick two animals from the following list and discuss what factors have been most responsible for their decline or extinction.

- Kirtland’s Warbler
- San Joaquin Kit Fox
- Great Auk
- Desert Pup Fish
- Blacktail Prairie Dog
- Prairie Chicken
- California Condor
- Peregrine Falcon
- Ivory-billed Woodpecker
- Atlantic Green Turtle
- Black-footed Ferret
- Passenger Pigeon

7. You are a paleontologist several million years (a long time, relative to human history) into the future trying to determine the cause for extinction of the animals you picked from the above list. What evidence might be preserved in the rock record that would allow you to reconstruct the probable cause for the extinctions? Or, would this be another extinction in geologic history for which the cause will remain largely speculative? Either describe two possible lines of evidence that would be preserved in the rock record (layers, rock units, etc.) that would allow a future geologist to explain the present-day extinctions or discuss why you think the cause for the extinctions could not be determined.

**Review Article Assignment**

The following articles can be used as the basis of a writing assignment in which the student is asked to abstract and summarize evidence.

**Helpful Hints for Students**

- Start by outlining the important ideas and evidence cited by author(s) that support their ideas.
- Write the review as though you were an author of the article. Think of your review as the executive summary. There is no need to mention the authors throughout the review. Be sure the title and author(s) of the article are included in the title of your report.


**Teaching Resources**

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

In Part I, Chapters 1–3 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 11: *Geobiology—Life Interacts with Earth*

Before Lecture: Preview Questions and Brief Answers

During Lecture: Learning Warm-up Tip

After Lecture:
- Check Your Notes

Exam Prep:
- Chapter Summary
  - Practice Exercises: *How Organisms and the Earth Interact*

Review questions