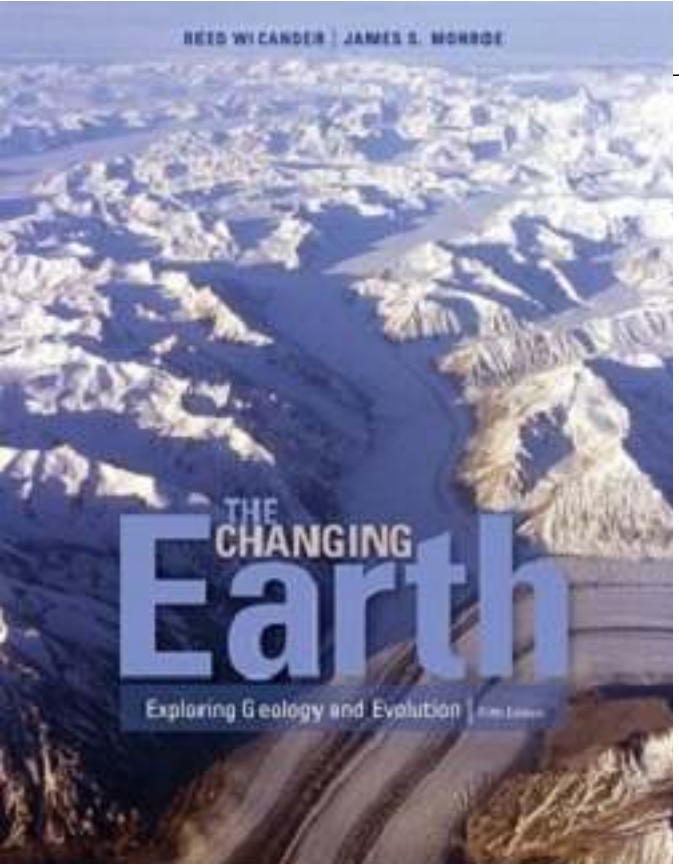
REED WICANDER | JAMES S. MONROE
THE CHANGING
Earth
Exploring Geology and Evolution

The Changing Earth

FIFTH EDITION

Exploring Geology and Evolution

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Aerial view of Arctic glaciers belonging to the Canadian 'Queen Elizabeth Islands', near Northwestern Greenland. The dark lines represent a system of lateral and medial moraines caused by transportation of rock debris and merging of strands of glaciers as they move downslope.

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PREFACE

Earth is a dynamic planet that has changed continuously during its 4.6 billion years of existence. The size, shape, and geographic distribution of the continents and ocean basins have changed through time, as have the atmosphere and biota. As scientists and concerned citizens, we have become increasingly aware of how fragile our planet is and, more importantly, how interdependent all of its various systems and subsystems are.

We have also learned that we cannot continually pollute our environment and that our natural resources are limited and, in most cases, nonrenewable. Furthermore, we are coming to realize how central geology is to our everyday lives. For example, a 9.0-magnitude earthquake in the Indian Ocean on December 26, 2004, generated a tsunami that killed more than 220,000 people in Indonesia, Sri Lanka, India, Thailand, Somalia, Myanmar, Malaysia, and the Maldives, and caused billions of dollars in damage. Two hurricanes in 2005, Katrina and Rita, damaged many offshore oil platforms and oil refineries in Texas and Louisiana, demonstrating how fragile our energy network, from production to the finished refined product, is and how dependent we are on petroleum to run our economy. For these and other reasons, geology is one of the most important college or university courses that a student can take.

The Changing Earth: Exploring Geology and Evolution, Fifth Edition, is designed for an introductory course in geology that can serve both majors and nonmajors in geology and the earth sciences. One of the problems with any introductory science course is that students are overwhelmed by the amount of material that must be learned. Furthermore, most of the material does not seem to be linked by any unifying theme and does not always appear to be relevant to their lives. This book, however, is written to address that problem in that it shows, in its easy-to-read style, that geology is an exciting and ever-changing science, and one in which new discoveries and insights are continually being made.

The goals of this book are to provide students with a basic understanding of geology and its processes and, most importantly, an understanding of how geology relates to the human experience—that is, how geology affects not only individuals, but society in general. It is also our intent to present the geologic and biologic history of Earth, not as a set of encyclopedic facts to memorize, but rather as a continuum of interrelated events that reflect the underlying geologic and biologic principles and processes that have shaped our planet and life upon it. Instead of emphasizing individual, and seemingly unrelated, events, we seek to understand the underlying causes of why things happened the way they did and how all of Earth's systems and subsystems are interrelated. Using this approach, students will gain a better understanding of how everything fits together.

With these goals in mind, we introduce the major themes of the book in the first chapter to provide students with an overview of the subject and to enable them to see how the various systems and subsystems of Earth are interrelated. We then cover the unifying theme of geology—plate tectonics, in the second chapter. Plate tectonic theory is central to the study of geology because it links many aspects of geology together. It is a theme that is woven throughout this edition. We also discuss the economic and environmental aspects of geology throughout the book rather than treating these topics in separate chapters. In this way, students can see, through relevant and interesting examples, how geology impacts our lives.

NEW AND RETAINED FEATURES IN THE FIFTH EDITION

Just as Earth is dynamic and evolving, so too is *The Changing Earth: Exploring Geology and Evolution*. The fifth edition has undergone considerable rewriting and updating, resulting in a volume that is still easy to read and has a high level of current information. Drawing on the comments and suggestions of reviewers, we have retained and incorporated a number of new features into this edition.

- The *Chapter Objectives* outline at the beginning of each chapter has been retained to alert students to the key points that the chapter will address.
- Chapter content has been rewritten to help clarify concepts and make the material more exploratory.
- Current events have been incorporated throughout the text.
- Additional content can be found throughout the book, particularly in the historical section.
- Many of the popular *Geo-Focus* features contain either new topics or have been updated.
- The successful *What Would You Do?* boxes in each chapter continue to encourage students to think critically about what they're learning by asking open-ended questions related to the chapter material. Many of these boxes are either new or have been rewritten to reflect current topics in the news.
- The two-page concept art spreads have been renamed *Geo-inSight* and redesigned to enhance students' interest in the chapter material. Furthermore, there is now a *Geo-inSight* feature in every chapter (except for Chapter 24).

- The art program has undergone revision to better illustrate the material covered in the text. In addition, the figure captions have been expanded and improved to help explain what students are seeing.
- The format of 10 multiple-choice questions and 10 short-answer questions has been retained in the *Review Questions* section at the end of each chapter. Answers to all of the multiple-choice questions, as well as two of the short-answer questions per chapter are provided at the back of the book.

It is our strong belief that the rewriting and updating done in the text, as well as the addition of new photographs and newly rendered art greatly improve the fifth edition of *The Changing Earth: Exploring Geology and Evolution*. We think that these changes and enhancements make this textbook easier to read and comprehend, as well as a more effective teaching tool.

TEXT ORGANIZATION

Plate tectonic theory is the unifying theme of geology and this book. This theory has revolutionized geology because it provides a global perspective of Earth and allows geologists to treat many seemingly unrelated geologic phenomena as part of a total planetary system.

Another theme of this book is that Earth is a complex, dynamic planet that has changed continuously since its origins some 4.6 billion years ago. We can better understand this complexity by using a systems approach to the study of Earth and emphasizing this approach throughout the book.

We have organized *The Changing Earth: Exploring Geology and Evolution,* Fifth Edition, into the following informal categories:

- Chapter 1 is an introduction to geology and Earth systems, geology's relevance to the human experience, and the origin of the solar system and Earth's place in it.
- Chapter 2 deals with plate tectonics in detail and sets the stage for its integration throughout the rest of the book.
- Chapters 3–7 examine Earth's materials (minerals and igneous, sedimentary, and metamorphic rocks) and the geologic processes associated with them, including the role of plate tectonics in their origin and distribution.
- Chapters 8–10 deal with the related topics of Earth's interior, the seafloor, earthquakes, and deformation and mountain building.
- Chapters 11–16 cover Earth's surface processes such as running water and mass wasting.
- Chapter 17 discusses geologic time and Chapter 18 explores fossils and evolution.
- Chapters 19–23 constitute our chronological treatment of the geologic and biologic history of Earth.
- Chapter 24 summarizes and synthesizes the concepts, themes, and major topics covered in this book.

Of particular assistance to students are the end-of-chapter summary tables found in Chapters 20–22. These tables are designed to give an overall perspective of the geologic and biologic events that occurred during the particular time interval covered in that chapter and to show how the events are interrelated.

We have found that presenting the material in the order discussed above works well for most students. We know, however, that many instructors prefer an entirely different order of topics, depending on the emphasis in their course. We have therefore written this book so that instructors can present the chapters in any order that suits the needs of a particular course.

CHAPTER ORGANIZATION

All chapters have the same organizational format as follows:

- Each chapter opens with a photograph related to the chapter material, an Outline of the topics covered, and an Objectives list that alerts students to the learning outcome objectives of the chapter.
- An *Introduction* follows that is intended to stimulate interest in the chapter and show how the chapter material fits into the larger geologic perspective.
- The text is written in a clear, informal style, making it easy for students to comprehend.
- Numerous newly rendered color diagrams and photographs complement the text and provide a visual representation of the concepts and information presented.
- Each chapter contains one *Geo-Focus* feature that presents a brief discussion of an interesting aspect of geology or geologic research.
- A *Geo-inSight* art spread is now in every chapter (except Chapter 24). These two-page features are designed to enhance students' interest in the chapter material through visual learning.
- Two *What Would You Do?* boxes per chapter encourage students to engage in critical thinking by solving hypothetical problems or issues that are related to the chapter material.
- Topics related to environmental and economic geology are discussed throughout the text. Integrating economic and environmental geology with the chapter material helps students relate the importance and relevance of geology to their lives.
- The end-of-chapter *Geo-Recap* begins with a concise review of important concepts and ideas presented in the chapter.
- The *Important Terms*, which are printed in boldface type in the chapter text, are listed at the end of each chapter for easy review, along with the page numbers on which they are first defined. A full *Glossary* of important terms appears at the end of the text.
- The *Review Questions* are another important feature of this book and include multiple-choice questions with answers, as well as short-answer questions, two of which per chapter have the answers provided at the end of the book. Many new questions have been added to each chapter of the fifth edition.

ANCILLARY MATERIALS

FOR INSTRUCTORS

We are pleased to offer a full suite of text and multimedia products to accompany *The Changing Earth: Exploring Geology and Evolution,* Fifth Edition.

Geology Resource Center academic.cengage.com/earthscience

Book Companion Website academic.cengage.com/earthscience

The Geology Resource Center and the Book Companion Website feature a rich array of learning resources for your students. The text-specific companion website includes quizzing and other web-based activities that will help students explore the concepts presented in the text.

PowerLecture with JoinIn™ on Turning Point® A complete all in one reference for instructors, the PowerLecture CD contains PowerPoint slides of images from the text, stepped art from the text, zoomable art figures from the text, Active Figures that interactively demonstrate concepts, and lectures that outline the main points of each chapter. In addition to providing you with fantastic course presentation material, the PowerLecture CD also contains electronic files of the Test Bank and Instructor's Manual as well as JoinIn, the easiest Audience Response System to use, featuring instant classroom assessment and learning. ISBN-10: 0495555029 | ISBN-13: 978-0495555025

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FOR STUDENTS

Geology Resource Center academic.cengage.com/earthscience

Book Companion Website academic.cengage.com/earthscience

This website features a rich array of learning resources, including quizzing and other web-based activities that will help you explore the concepts that are presented in the text.

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As the authors, we are, of course, responsible for the organization, style, and accuracy of the text, and any mistakes, omissions, or errors are our responsibility. The finished product is the culmination of many years of work during which we received numerous comments and advice from many geologists who reviewed all or parts of the text for the first three editions. They are: Kenneth Beem, Montgomery College; Patricia J. Bush, Dèlgado Community College; Paul J. Bybee, Utah Valley State College; Deborah Caskey, El Paso Community College; Renee M. Clary, University of Louisiana at Lafayette; Michael Conway, Arizona Western College; William C. Cornell, University of Texas at El Paso; Kathleen Devaney, El Paso Community College; Richard Diecchio, George Mason University; Robert Ewing, Portland Community College; David J. Fitzgerald, St. Mary's University; Dann M. Halverson, University of Southwestern Louisiana; Kristi Higginbotham, San Jacinto College; Ray Kenny, New Mexico Highlands University; Gary L. Kinsland, University of Louisiana at Lafayette; Bob Mims, Richland College; Michelle Stoklosa, Boise State University; Glenn B. Stracher, East Georgia College; Azam M. Tabrizi, Tide Water Community College; Monte D. Wilson, Boise State University; and Guy Worthey, St. Ambrose University.

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James S. Monroe
Reed Wicander

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The Changing Earth

CHAPTER 1

Understanding Earth: A Dynamic and Evolving Planet

USGS/NASA

OUTLINE

OBJECTIVES

At the end of this chapter, you will have learned that

- Geology is the study of Earth.
- Earth is a complex, 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.
- Geology plays an important role in the human experience and affects us as individuals and members of society and nation-states.
- The universe is thought to have originated approximately 14 billion years ago with a big bang. The solar system and

Satellite-based image of Earth. North America is visible in the center of this view, as well as Central America and South America. The present locations of continents and ocean basins are the result of plate movements. The interaction of plates through time has affected the physical and biological history of Earth.

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 formed during Earth's early history.
- Plate tectonics is the unifying theory of geology and this theory revolutionized the science.
- The rock cycle illustrates the interrelationships between Earth's internal and external processes and shows how and why the three major rock groups are related.
- The theory of organic evolution provides the conceptual framework for understanding the history of life.
- An appreciation of geologic time and the principle of uniformitarianism is central to understanding the evolution of Earth and its biota.
- Geology is an integral part of our lives.

INTRODUCTION

A major benefit of the space age has been the ability to look back from space and view our planet in its entirety. Every astronaut has remarked in one way or another on how Earth stands out as an inviting oasis in the otherwise black void of space (see this chapter's opening photograph). We are able to see not only the beauty of our planet, but also its fragility. We can also decipher Earth's long and frequently turbulent history by reading the clues preserved in the geologic record.

A major theme of this book is that Earth is a complex, dynamic planet that has changed continuously since its origin some 4.6 billion years ago. These changes and the present-day features we observe result from the interactions among Earth's internal and external systems, subsystems, and cycles. Earth is unique among the planets of our solar system in that it supports life and has oceans of water, a hospitable atmosphere, and a variety of climates. It is ideally suited for life as we know it because of a combination of factors, including its distance from the Sun and the evolution of its interior, crust, oceans, and atmosphere. Life processes have, over time, influenced the evolution of Earth's atmosphere, oceans, and, to some extent, its crust. In turn, these physical changes have affected the evolution of life.

By viewing Earth as a whole—that is, thinking of it as a system—we not only see how its various components are interconnected, but also better appreciate its complex and dynamic nature. The system concept makes it easier for us to study a complex subject such as Earth because it divides the whole into smaller components that we can easily understand, without losing sight of how the components fit together as a whole.

A **system** is a combination of related parts that interact in an organized manner. An automobile is a good example of a system. Its various components or subsystems, such as the engine, transmission, steering, and brakes, are all interconnected in such a way that a change in any one of them affects the others.

We can examine Earth in the same way we view an automobile—that is, as a system of interconnected components that interact and affect each other in many ways. The principal subsystems of Earth are the *atmosphere*, *biosphere*, *hydrosphere*, *lithosphere*, *mantle*, and *core* (◗ Figure 1.1). The complex interactions among these subsystems result in a dynamically changing planet in which matter and energy is continuously recycled into different forms (Table 1.1). For example, the movement of plates has profoundly affected the formation of landscapes, the distribution of mineral resources, and atmospheric and oceanic circulation patterns, which, in turn, have affected global climate changes.

We must also not forget that humans are part of the Earth system, and our activities can produce changes with potentially wide-ranging consequences. When people discuss and debate such environmental issues as acid rain, the greenhouse effect and global warming, and the depleted ozone layer, it is important to remember that these are not isolated issues, but are part of the larger Earth system. Furthermore, remember that Earth goes through time cycles that are much longer than humans are used to. Although they may have disastrous short-term effects on the human species, global warming and cooling are also part of a longer-term cycle that has resulted in many glacial advances and retreats during the past 1.8 million years.

Accordingly, we must understand that actions we take can produce changes with wide-ranging consequences that we might not initially be aware of. For this reason, an understanding of geology, and science in general, is of paramount importance. If the human species is to survive, we must understand how the various Earth systems work and interact and, more importantly, how our actions affect the delicate balance between these systems.

As you study the various topics covered in this book, keep in mind the themes discussed in this chapter and how, like the parts of a system, they are interrelated. By relating each chapter's topic to its place in the entire Earth system, you will gain a greater appreciation of why geology is so integral to our lives.

WHAT IS GEOLOGY?

Geology, from the Greek *geo* and *logos*, is defined as the study of Earth, but now must also include the study of the planets and moons in our solar system. It is generally divided into two broad areas—physical geology and historical geology. *Physical geology* is the study of Earth materials, such as minerals and rocks, as well as the processes operating within Earth and on its surface. *Historical geology* examines the origin and evolution of Earth, its continents, oceans, atmosphere, and life.

The discipline of geology is so broad that it is subdivided into numerous fields or specialties. Table 1.2 shows many of the diverse fields of geology and their relationship to the sciences of astronomy, biology, chemistry, and physics.

Nearly every aspect of geology has some economic or environmental relevance. Many geologists are involved in

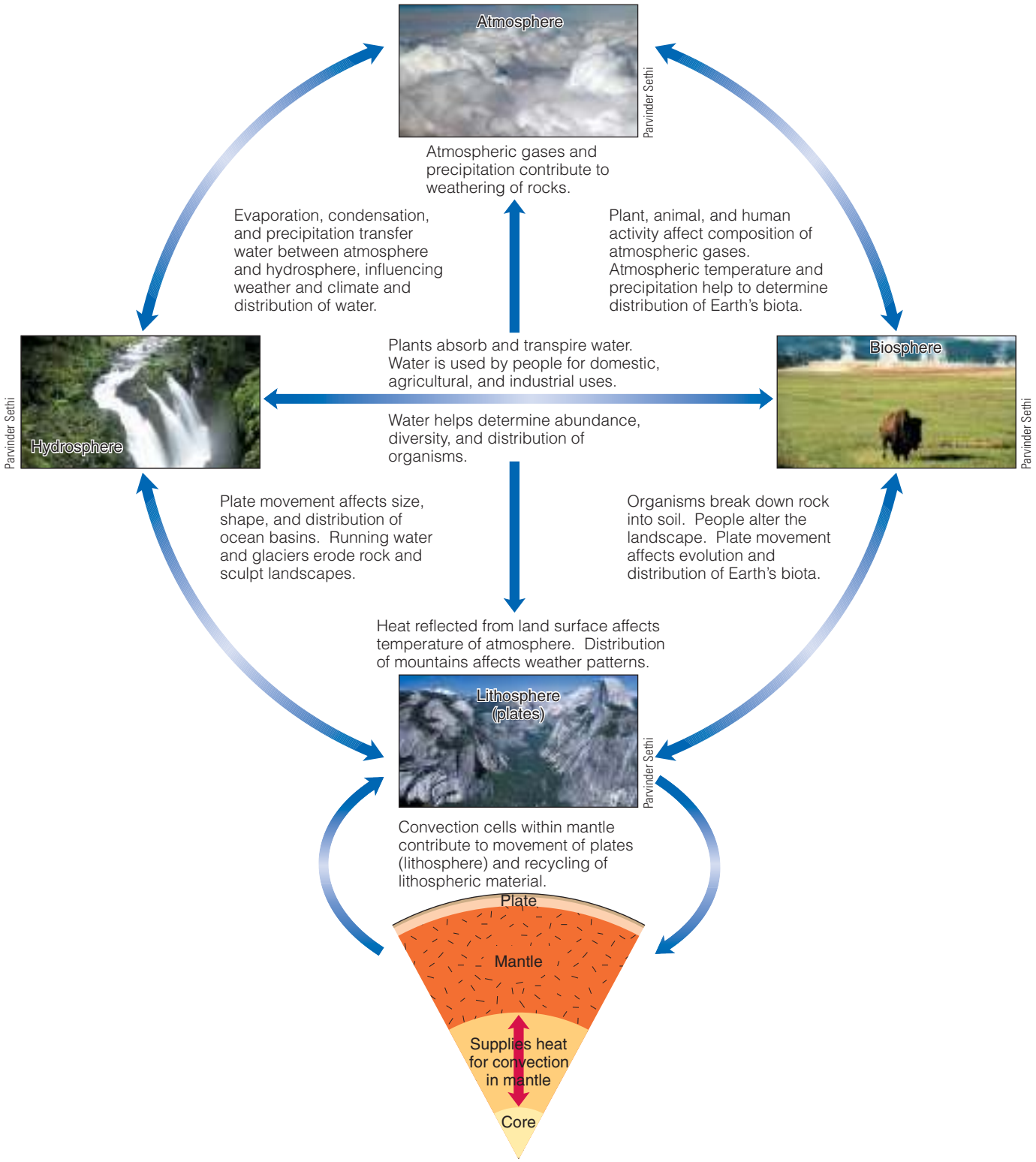


Figure 1.1 Subsystems of Earth The atmosphere, hydrosphere, biosphere, lithosphere, mantle, and core are all subsystems of Earth. This simplified diagram shows how these subsystems interact, with some examples of how materials and energy are cycled throughout the Earth system. The interactions between these subsystems make Earth a dynamic planet that has evolved and changed since its origin 4.6 billion years ago.

TABLE 1.1 Interactions Among Earth's Principal Subsystems

	Atmosphere	Hydrosphere	Biosphere	Lithosphere
Atmosphere	Interaction among various air masses	Surface currents driven by wind; evaporation	Gases for respiration; dispersal of spores, pollen, and seeds by wind	Weathering by wind erosion; transport of water vapor for precipitation of rain and snow
Hydrosphere	Input of water vapor and stored solar heat	Hydrologic cycle	Water for life	Precipitation; weathering and erosion
Biosphere	Gases from respiration	Removal of dissolved materials by organisms	Global ecosystems; food cycles	Modification of weathering and erosion processes; formation of soil
Lithosphere	Input of stored solar heat; landscapes affect air movements	Source of solid and dissolved materials	Source of mineral nutrients; modification of ecosystems by plate movements	Plate tectonics

exploration for mineral and energy resources, using their specialized knowledge to locate the natural resources on which our industrialized society is based. As the demand for these nonrenewable resources increases, geologists apply the basic principles of geology in increasingly sophisticated ways to focus their attention on areas that have a high potential for economic success.

Whereas some geologists work on locating mineral and energy resources, other geologists use their expertise to help solve environmental problems. Finding adequate sources of groundwater for the ever-burgeoning needs of communities and industries is becoming increasingly important, as is the monitoring of surface and underground water pollution and its cleanup. Geologic engineers help find safe locations for dams, waste-disposal sites, and power plants, as well as designing earthquake-resistant buildings.

Geologists are also engaged in making short- and long-range predictions about earthquakes and volcanic eruptions, and the potential destruction that may result. Following the tragic events in Indonesia in 2004, geologists are now more involved than ever in working with various governmental agencies and civil defense planners to ensure that timely warnings are given to potentially affected regions when natural disasters such as tsunami occur, and that contingency plans are in place.

GEOLOGY AND THE FORMULATION OF THEORIES

The term **theory** has various meanings. In colloquial usage, it means a speculative or conjectural view of something—hence, the widespread belief that scientific theories are little more than unsubstantiated wild guesses. In scientific usage, however, a theory is a coherent explanation for one or several related natural phenomena supported by a large body of objective evidence. From a theory, scientists derive predictive statements that can be tested by observations and/or experiments so that their validity can be assessed. The law of universal gravitation is an example of a theory that describes the attraction between masses (an apple and Earth in the popularized account of Newton and his discovery).

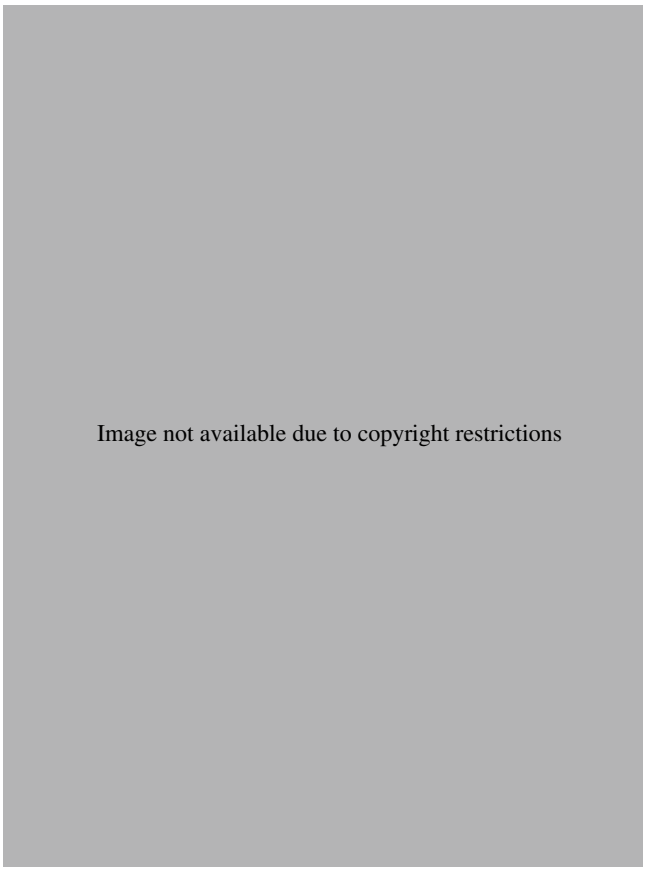
TABLE 1.2 Specialties of Geology and Their Broad Relationship to the Other Sciences

Specialty	Area of Study	Related Science
Geochronology	Time and history of Earth	Astronomy
Planetary geology	Geology of the planets	
Paleontology	Fossils	Biology
Economic geology	Mineral and energy resources	
Environmental geology	Environment	
Geochemistry	Chemistry of Earth	Chemistry
Hydrogeology	Water resources	
Mineralogy	Minerals	
Petrology	Rocks	
Geophysics	Earth's interior	Physics
Structural geology	Rock deformation	
Seismology	Earthquakes	
Geomorphology	Landforms	
Oceanography	Oceans	
Paleogeography	Ancient geographic features and locations	
Stratigraphy/sedimentology	Layered rocks and sediments	

Theories are formulated through the process known as the **scientific method**. This method is an orderly, logical approach that involves gathering and analyzing facts or data about the problem under consideration. Tentative explanations, or **hypotheses**, are then formulated to explain the observed phenomena. Next, the hypotheses are tested to see whether what was predicted actually occurs in a given situation. Finally, if one of the hypotheses is found, after repeated tests, to explain the phenomena, then the hypothesis is proposed as a theory. Remember, however, that in science, even a theory is still subject to further testing and refinement as new data become available.

The fact that a scientific theory can be tested and is subject to such testing separates it from other forms of human inquiry. Because scientific theories can be tested, they have the potential for being supported or even proven wrong. Accordingly, science must proceed without any appeal to beliefs or supernatural explanations, not because such beliefs or explanations are necessarily untrue, but because we have no way to investigate them. For this reason, science makes no claim about the existence or nonexistence of a supernatural or spiritual realm.

Each scientific discipline has certain theories that are of particular importance. In geology, the formulation of plate tectonic theory has changed the way geologists view Earth. Geologists now view Earth from a global perspective in which all of its subsystems and cycles are interconnected, and Earth history is seen to be a continuum of interrelated events that are part of a global pattern of change.



HOW DOES GEOLOGY RELATE TO THE HUMAN EXPERIENCE?

You would probably be surprised at the extent to which geology pervades our everyday lives and the numerous references to geology in the arts, music, and literature. Many sketches and paintings depict rocks and landscapes realistically. Leonardo da Vinci's *Virgin of the Rocks* and *Virgin and Child with Saint Anne*, Giovanni Bellini's *Saint Francis in Ecstasy* and *Saint Jerome*, and Asher Brown Durand's *Kindred Spirits* (◗ Figure 1.2) are just a few examples by famous painters.

In the field of music, Ferde Grofé's *Grand Canyon Suite* was no doubt inspired by the grandeur and timelessness of Arizona's Grand Canyon and its vast rock exposures. The rocks on the Island of Staffa in the Inner Hebrides provided the inspiration for Felix Mendelssohn's famous *Hebrides Overture.*

References to geology abound in *The German Legends of the Brothers Grimm.* Jules Verne's *Journey to the Center of the Earth* describes an expedition into Earth's interior. There is even a series of mystery books by Sarah Andrews that features the fictional geologist Em Hansen, who uses her knowledge of geology to solve crimes. On one level, the poem "Ozymandias" by Percy B. Shelley deals with the fact that nothing lasts forever and even solid rock eventually disintegrates under the ravages of time and weathering. Even comics contain references to geology. One of the best known is *The Far Side* by Gary Larson, which, over the years, has had many cartoons with a geological theme.

Geology has also played an important role in the history and culture of humankind. Empires throughout history have risen and fallen on the distribution and exploitation of natural resources. Wars have been fought for the control of such natural resources as oil and gas, and valuable minerals such as gold, silver, and diamonds. The configuration of Earth's surface, or its topography, which is shaped by geologic agents, played a critical role in military tactics. For example, Napoleon included two geologists in his expeditionary forces when he invaded Egypt in 1798, and the Russians used geologists as advisors in selecting fortification sites during the Russo-Japanese war of 1904–1905. Natural barriers such as mountain ranges and rivers have frequently served as political boundaries, and the shifting of river channels has sparked numerous border disputes. Deserts, which most people think of as inhospitable areas, have been the home to many people, such as the Bedouin, throughout history.

HOW DOES GEOLOGY AFFECT OUR EVERYDAY LIVES?

The most obvious connection between geology and our everyday lives is when natural disasters strike. Less apparent,