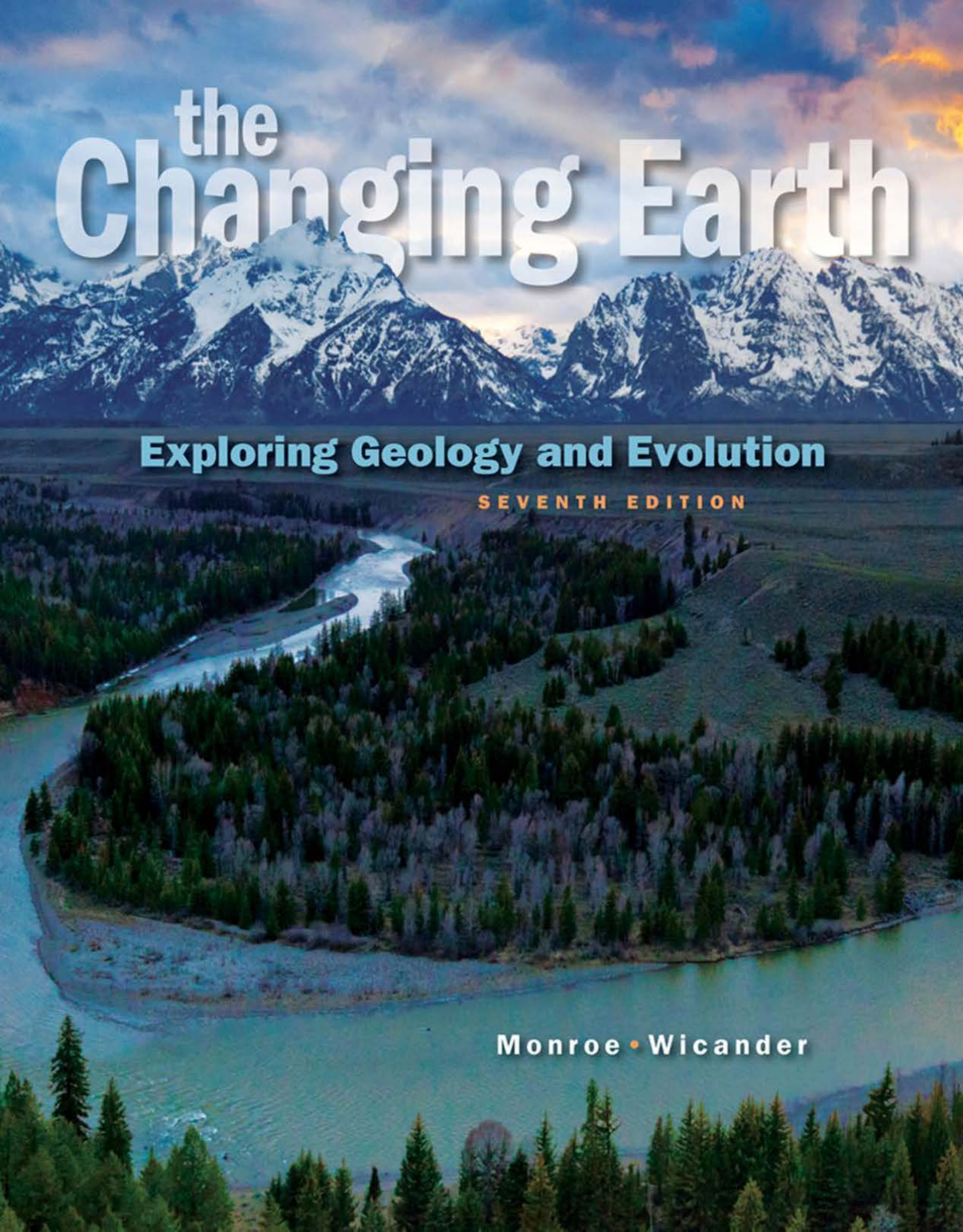
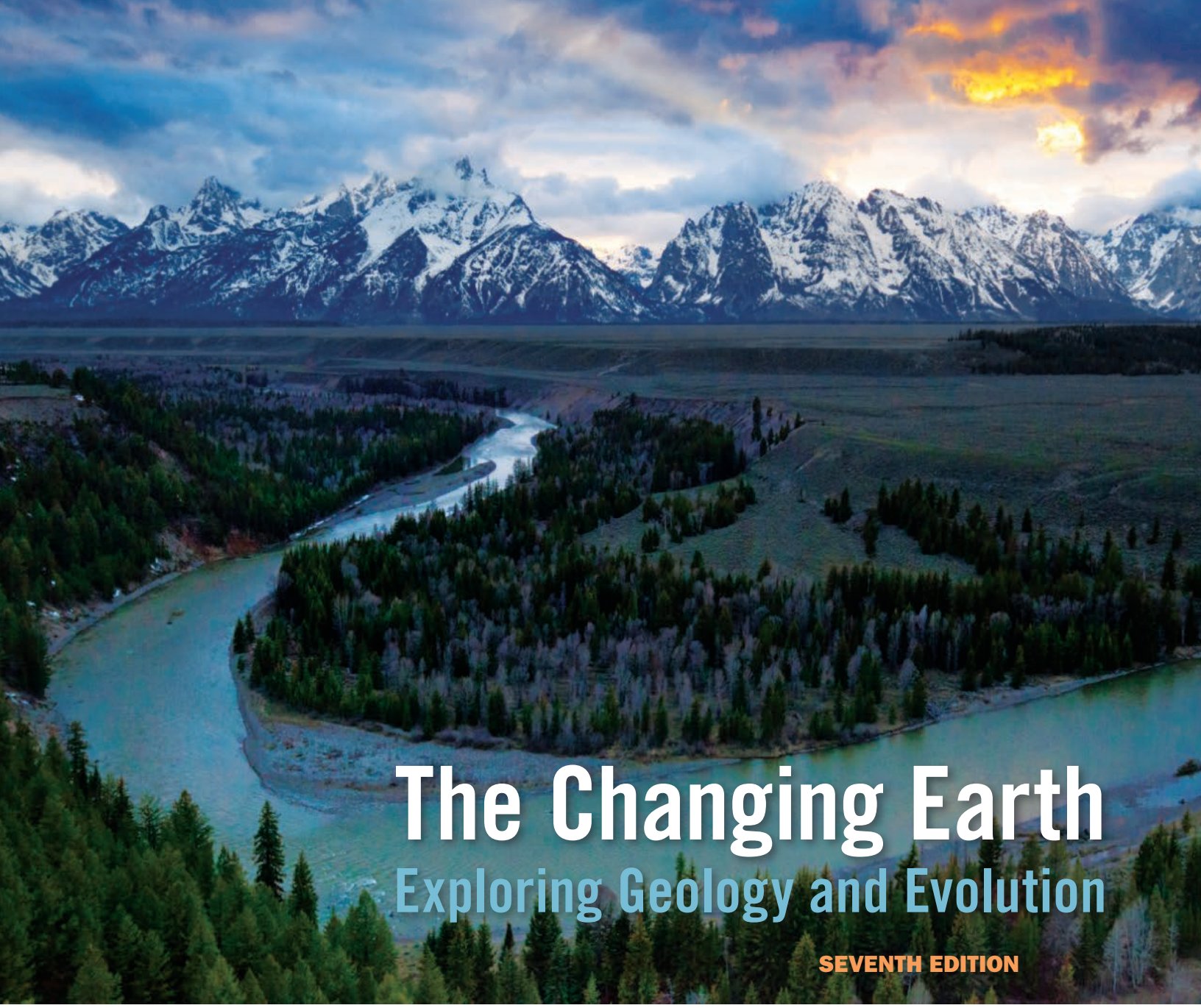

the Changing Earth
Exploring Geology and Evolution
SEVENTH EDITION
Monroe • Wicander



The Changing Earth

Exploring Geology and Evolution

SEVENTH EDITION

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CENGAGE Learning®

Australia • Brazil • Mexico • Singapore • United Kingdom • United States

***The Changing Earth: Exploring Geology and Evolution*, Seventh Edition**
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Cover and Text Designer: Lisa Buckley

Cover Image: © Michael Medford/National Geographic Stock

Compositor: Cenveo Publisher Services

Library of Congress Control Number: 2013940238

ISBN-13: 978-1-285-73341-8

ISBN-10: 1-285-73341-X

Cengage Learning
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About the cover image:

The Snake River and Teton Range, Wyoming The Snake River, in the foreground, meanders through Bridger-Teton National Forest, Wyoming. A large point bar (see Chapter 12) can be clearly seen in the lower left corner. The snow-covered Teton Range, including the Grand Teton (the highest peak visible) of the Rocky Mountains is dramatically set off in the background with several easily identified glacial features such as U-shaped valleys and horns (see Chapter 14). Bridger-Teton National Forest, located in western Wyoming, consists of 14,000 km^2 of forest and is part of the 81,000 km^2 Greater Yellowstone Ecosystem, one of few remaining sizeable, northern temperate zone ecosystems.

Printed in the United States of America
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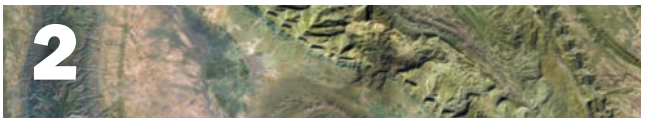

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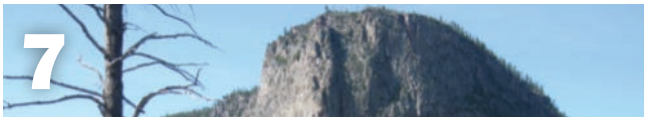

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Preface

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 also have 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, on March 11, 2011, a magnitude 9.0 earthquake struck Japan, killing more than 20,000 people and generating a tsunami that wreaked destruction along the coast of northeastern Japan, as well as damaging three nuclear power plants and causing radioactive leakage in one of them. A major oil spill in the Gulf of Mexico in 2010 resulted in much ecological damage along the shorelines of the Gulf Coast of the United States, as well as to the biota in the Gulf of Mexico. And, finally, Hurricane Sandy caused tremendous damage and major flooding along the Eastern Seaboard of the United States in October 2012.

All of these events point out how much geology affects our lives, as well as the global economy. For these and other reasons, geology is one of the most important college or university courses that a student can take.

The seventh edition of *The Changing Earth: Exploring Geology and Evolution* is designed to be 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 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, with 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 reflecting 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, and why geology is such an important course.

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, subsystems, and cycles 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 together many aspects of geology. It is a theme that is woven throughout this edition.

The economic and environmental aspects of geology are emphasized throughout the book rather than treating these topics in separate chapters. In this way, students can see, through topical and interesting examples, how geology affects our lives. Climate change is an especially relevant and important topic that currently is in the news and being discussed and debated by scientists, politicians, and citizens alike. Because of its importance, we introduce the topic in the first chapter and integrate it throughout the book as it relates to the various topics covered. Geology is unique in that it can provide the perspective of geologic time in this important debate as to what, and the possible degree to which, humans have contributed to climate change.

Another topic that has been in the news of late is hydraulic fracturing, popularly called "fracking." This controversial method of releasing oil and gas from nearly impermeable shales, is both an environmental and energy issue that elicits strong feelings from both its proponents and opponents. Because of the importance of this topic and its cross-disciplinary nature, we cover it in several chapters.

Features in the Seventh Edition

Just as Earth is dynamic and evolving, so too is *The Changing Earth: Exploring Geology and Evolution*. The seventh edition has undergone significant rewriting and updating, resulting in a volume that is still easy to read and contains a high level

of current information. Drawing on the comments and suggestions of reviewers and users of the sixth edition, we have retained those features that were both relevant and popular in the sixth edition as well as incorporated several new features into this edition.

- Many new, bold, and dramatic photos open each chapter, a number of which are recent geologic events, which add relevancy to the text and emphasize the theme of how geology relates to humans.
- Chapter content has been extensively updated and rewritten to (1) help clarify concepts, (2) emphasize underlying processes, and (3) make the material more exploratory.
- *Have You Ever Wondered?* questions follow the chapter *Outline* at the beginning of each chapter. These intriguing questions are designed to spark student interest about what is covered in the chapter and motivate them to find the answers by reading the chapter.
- The *Connection Link* boxed features have been retained. These help students see the big picture of how Earth systems are interrelated and connected. In this edition, a green icon in the text refers students to the *Connection Link* box, which then refers the reader to other locations in the book where more information can be found and connections can be made with other related important topics.
- Many of the popular *Geo-Focus* and *Geo-Insight* features contain either new topics or have been updated, with an emphasis on environmental and economic topics.
- *Geo-Impact* boxed features now replace the former *What Would You Do?* These boxed features continue to encourage students to think critically about what they are learning by asking open-ended questions related to the chapter material. These features also emphasize current issues related to natural resources and the environment, and many of them have an accompanying photo to better illustrate the topic at hand.
- *Critical Thinking Questions* are part of many of the figures. These questions are designed to encourage active student learning, guide observational skill development, and deepen understanding of geologic processes.
- The *Summary* is now called *Key Concepts Review* to emphasize the important concepts covered in the chapter.
- The previous format of 10 multiple-choice questions and 10 short-answer questions in the *Review Questions* section at the end of each chapter has been reduced to five multiple-choice and five short answer questions. A number of the questions have been rewritten or are new, and answers to all of the multiple-choice questions, as well as several of the short-answer questions, are provided at the back of the book.
- The last short-answer question is now titled *Creative Thinking Visual Question* and challenges students to describe the geologic process being depicted, engage in quantitative solutions, or address an issue using the information provided in the photo or graphic. These images and questions were chosen to encourage students to develop strong observational and critical thinking skills.
- A new feature, *Global GeoScience Watch,* directs students to the Cengage Learning website, which is a one-stop site for studying Earth and the environment. The website is interactive and current, and allows users to navigate issue, country, organization, and *Global GeoScience Watch*–specific portals. A question relating to the chapter material is asked that requires students to search the website for the answer.

It is our strong belief that the rewriting and updating done in the text, as well as the new features introduced, significantly improve the seventh edition of *The Changing Earth: Exploring Geology and Evolution*. We think that these changes and the new enhancements make this textbook easier to read and comprehend, as well as making it a more effective teaching tool that engages students in the learning process, thereby fostering a better understanding of the material and how it relates to Earth in the 21st century.

Text Organization

Plate tectonic theory is the unifying theme of geology and also for 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.

A second, and equally important, theme 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 concept throughout the book.

We therefore have organized *The Changing Earth: Exploring Geology and Evolution,* seventh 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 debate about climate change and humans' possible role and effect, as well as 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. Particular emphasis is placed on the evidence substantiating plate tectonic theory, why this theory is one of the cornerstones of geology, and why plate tectonic theory serves as a unifying paradigm in explaining many apparently unrelated geologic phenomena.
- Chapters 3–8 examine Earth's materials (minerals, and igneous, sedimentary, and metamorphic rocks) and the geologic processes accounting for them, including the role of plate tectonics in their origin and distribution.
- Chapters 9–10 deal with the related topics of Earth's interior, earthquakes, and deformation and mountain building.

- Chapters 11–16 cover Earth's surface processes, including such features as mass wasting, running water, groundwater, glaciers and glaciation, the work of wind and deserts, and shorelines and shoreline processes.
- 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 allows for an integration of the major themes of this book, as well as an emphasis on the underlying principles of geology and how they relate to the human experience and in deciphering Earth's history. We also know, however, that many professors prefer an entirely different order of topics, depending on the emphasis in their course. Therefore, we have written this book so that instructors can present the chapters in whatever 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 dramatic photograph, many of which are new, followed by an *Outline* of the topics covered and a series of questions under the title *Have You Ever Wondered?* that are designed to pique student interest in the topics covered in that 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. A number of the *Introductions* have been rewritten and updated in this edition.
- The text is written in a clear, informal style, making it easy for students to comprehend.
- Within each chapter are several *Connection Link* boxes that refer the reader to other locations in the book where more information can be found, and connections are made to important concepts and topics.
- Numerous *Critical Thinking Questions* are found associated with selected figures in each chapter. These are designed to encourage active student learning and deepen understanding of geologic processes.
- Numerous color diagrams and photographs complement the text and provide a visual representation of the concepts and information presented.
- Each chapter contains at least one *Geo-Focus* or *Geo-Insight* feature that presents a brief discussion or visual representation of an interesting aspect of geology or geologic research. Several of these features are new to this edition and emphasize economic and environmental issues.
- At least one *Geo-Impact* feature per chapter encourages students to engage in critical thinking by solving hypothetical problems or issues that are related to the chapter material.
- Topics related to environmental issues, such as climate change and hydraulic fracturing, are discussed throughout the text. Integrating economic geology and environmental issues with the chapter material helps students relate the importance and relevance of geology to their lives.
- The end-of-chapter materials begin with *Key Concepts Review*, which summarizes the important concepts covered 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.
- The *Review Questions* are another important feature of this book and include multiple-choice questions with answers as well as short-answer questions, some of which have the answers provided at the end of the book. Many new questions have been added to each chapter of the seventh edition.
- The *Global GeoScience Watch* directs students to the Cengage Learning website, which is interactive, current, and allows users to navigate topics related to issue, country, and professional organizations.
- A full *Glossary* of important terms appears at the end of the text.

Ancillary Materials

For Instructors

We are pleased to offer a full suite of text and multimedia products to accompany the seventh edition of *The Changing Earth: Exploring Geology and Evolution*.

The *Earth Science CourseMate* features a rich array of study tools and learning resources for your students. This text-specific companion website includes quizzing, flashcards, and other web-based activities that will help students explore the concepts presented in the text.

The *Instructor Companion Website* contains everything you need for your course in one place! This collection of book-specific features and class tools in available online via www.cengage.com/login. Access and download PowerPoint presentations, images, instructor's manual, videos, and more.

The *Online Instructor's Manual* contains resources designed to streamline your course preparation. The Instructor's Manual includes Chapter Outlines, Learning Objectives, Chapter Summaries, Enrichment Topics, Common Misconceptions, Lecture Suggestions, "Consider This" questions, Important Terms, and Weblinks/Videos suggestions. This guide is available on the Instructor Companion Website.

New to this edition is *Cengage Learning Testing Powered by Cognero*, a flexible, online system that allows you to

- author, edit, and manage test bank content from multiple Cengage Learning solutions;
- create multiple test versions in an instant; and
- deliver tests from your Learning Management System (LMS), your classroom, or wherever you want.

Instructors can start right away. *Cengage Learning Testing Powered by Cognero* works on any operating system or browser; no special installations or downloads are needed. You'll be able to create tests from school, home, the coffee shop—anywhere with Internet access. You'll also find the following features:

- Simplicity at every step: A desktop-inspired interface features drop-down menus and familiar, intuitive tools that take you through content creation and management with ease.
- Full-featured test generator: Create ideal assessments with your choice of 15 question types, including true–false, multiple choice, opinion or Likert scale, and essay.
- Multilanguage support, an equation editor, and unlimited metadata: Ensure your tests are complete and compliant.
- Cross-compatible capability: Import and export content into other systems.

Global Geoscience Watch is an online resource center that provides access to a rich array of media resources to help you keep up with current events and highlight the concepts taught in class, as well as show the human impact on our planet. The following features are included:

- Articles
- Case studies
- Podcasts
- Videos
- World map (searchable by topic and country)
- Citation tools
- Sharing options (e-mail, Twitter, Facebook, etc.)
- Topic browsing and advanced searching
- And more!

For Students

The Changing Earth features *Earth Science CourseMate*, which helps you make the grade. *Earth Science CourseMate* includes an interactive e-book, with highlighting, note taking, and search capabilities as well as the following interactive learning tools:

- Quizzes
- Flashcards
- Video exercises
- Animations
- And more!

Go to login.cengagebrain.com to access these resources (ISBN-13: 9781285776255).

Virtual Field Trips in Geology are concept-based modules that teach you geology by using famous locations throughout the United States. Grand Canyon, Arches, and Hawaii Volcanoes National Parks are included, as well as many others. Designed to be used as homework assignments or lab work, the modules use a rich array of multimedia to demonstrate concepts. High-definition videos, images, animations, quizzes, and Google Earth activities work together in *Virtual Field Trips* to bring the concepts to life.

Global Geoscience Watch, updated several times a day, is a focused portal into GREENR—our Global Reference on the Environment, Energy, and Natural Resources—an ideal one-stop site for current events and research projects for all things geoscience. Divided into the four key course areas (geography, geology, meteorology, and oceanography), you can easily find the most relevant information for the course you are taking.

You will have access to the latest information from trusted academic journals, news outlets, and magazines. You also will receive access to statistics, primary sources, case studies, podcasts, and much more (ISBN-13: 9781111429065).

Acknowledgments

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 five editions. They are as follows: Kenneth Beem, Montgomery College; David Berry, California State Polytechnic University, Pomona; Wesley A. Brown, Stephen F. Austin State University; Patricia J. Bush, Dèlgado Community College; Paul J. Bybee, Utah Valley State College; Brian Campbell, Southwestern Oklahoma State University; Deborah Caskey, El Paso Community College; Renee M. Clary, University of Louisiana at Lafayette; Michael Conway, Arizona Western College; David Cordero, Lower Columbia 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; Yongli Gao, East Tennessee State University; Susan

Grandy, St. Clair County Community College; Ken Griffin, Tarrant County College; 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; Jorg Maletz, University at Buffalo-SUNY; James MacDonald, Florida Gulf Coast University; Kevin McCartney, University of Maine-Presque Isle; Lynn Milwood, Mountain View College; Bob Mims, Richland College; Michael O'Donnell, Lord Fairfax Community College; Clair Ossian, Tarrant County College; Joseph Sarnecki, Macomb Community College; Roger Steinberg, Del Mar College; Michelle Stoklosa, Boise State University; Glenn B. Stracher, East Georgia College; Azam M. Tabrizi, Tidewater Community College; Thomas J. Weiland, Georgia Southwestern State University; Monte D. Wilson, Boise State University; and Guy Worthey, St. Ambrose University.

We especially wish to express our sincere appreciation to the reviewers of the sixth edition who made numerous helpful and useful comments that led to many improvements and new features seen in this seventh edition. They are as follows: Joel S. Aquino, Gainesville State College; Elaine K. Alexander Fagner, McLennan Community College; Brian Lock, University of Louisiana; and Krista Syrup, Moraine Valley Community College.

We are also grateful for the generosity of the various agencies and individuals from many countries that provided photographs.

Special thanks must go to Aileen Berg at Cengage Learning, who initiated this seventh edition, and to our content developer, Jake Warde, who not only kept us on task but also superbly edited and managed the content for this edition, as well as provided a fresh perspective on this edition and gave excellent suggestions throughout the continuing gestation of this new edition. We thank Andrea Clemente and Chris Schoedel, project managers at Cenveo Publisher Services, for their excellent work in overseeing this edition, as well as Radhey Balabh, compositor, and also part of the Cenveo Publisher Services team. We are indebted to the copyeditor Maureen O'Driscoll for her attention to detail and consistency throughout the book production process. We would also like to thank Pamela Galbreath and Lisa Buckley for the fresh design. We thank Parvinder Sethi for his help in locating appropriate photographs. We would also like to recognize Carol Samet, Cengage Learning production project manager; Stefanie Beeck, media developer; Shannon Holt and Kellie Petruzzelli, content coordinators; Alexandria Brady, product development manager, for developing the media program; and Janet del Mundo, senior market development manager. As always, our families were very patient and encouraging when much of our spare time and energy were devoted to this book. We again thank them for their continued support and understanding.

James S. Monroe
Reed Wicander

The Changing Earth

True color satellite image of Asia (partly in shadow), the Arctic ice cap, and the Sun. In this book, we examine Earth as a system of interconnected components that interact with each other. The atmosphere, biosphere, hydrosphere, and lithosphere are four of Earth's major subsystems that are visible in this image. The complex interactions among these subsystems, as well as Earth's interior, results in a dynamically changing planet.

CHAPTER 1

Understanding Earth

A Dynamic and Evolving Planet

OUTLINE

HAVE YOU EVER WONDERED?

- How all of Earth's different components are interconnected and how the interactions among them are what make Earth a dynamic and ever-changing planet?
- Why a theory is not an unsubstantiated wild guess at explaining various natural phenomena?
- How geology relates to the human experience and affects our everyday lives?
- How environmental issues such as overpopulation, climate change, and rising sea level, to name a few, directly affect you?
- How the universe, solar system, and the planets came into being and evolved to what we now see when we look beyond our own planet Earth?
- What Earth is composed of and how its history has changed through time?
- Why you should study geology and the benefits that you will derive from a better understanding of this most important science?

Planet Observer/Universal Images Group/Getty Images

1.1 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 the chapter opening photo). We are able to see not only the beauty of our planet but also its fragility and how humans are affecting the environment. And lastly, even though we did not witness it firsthand, we can still read the story of Earth's long and turbulent 4.6-billion-year history by deciphering the clues found in the geologic record, that is, the evidence for prehistoric physical and biological events that are preserved in rocks.

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. 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 can also better appreciate its complex and dynamic nature.

The system concept makes it easier for us to study a multifaceted subject such as Earth, because it divides the whole into smaller components that we can easily understand, without losing sight of how the separate components fit together as a whole. In the same way, you can think of this book as a large, panoramic landscape painting. Each chapter fills in the details of the landscape, thereby enhancing the overall enjoyment and understanding of the entire painting.

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 one another 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 are continuously recycled into different forms. For example, the movement of plates has profoundly affected the formation and evolution of its surface features and the distribution of mineral resources, as well as atmospheric and oceanic circulation patterns, which in turn, have affected global climate changes. Examined in this manner, the continuous evolution of Earth and its life is not a series of isolated and unrelated events, but rather it is a dynamic interplay among its various subsystems.

We also must 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 pollution and global warming, it is important to remember that these are not isolated issues, but rather they are part of the larger Earth system. Furthermore, Earth goes through much longer time cycles than humans are used to. Although global warming may have deleterious short-term effects on Earth's biota, climate change is part of long-term cycles that have resulted in large-scale periods of soaring global temperature and numerous episodes of glaciation.

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.

ConnectionLink
You can learn more about climate change in the section Geologic Time and Climate Change in Chapter 17.

1.2 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. The discipline of geology 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.

Although the discipline of geology is broad and subdivided into numerous fields or specialties, nearly every aspect of geology has some economic or environmental relevance. For example, many geologists are involved in exploration for mineral and energy resources, using their specialized knowledge to locate the natural resources on which our industrial society is based. As the demand for these nonrenewable resources increases, geologists are applying the basic principles of geology in increasingly sophisticated ways, thereby enabling them to focus on areas that have the greatest chance for economic success.

Other geologists are using their expertise to address various environmental and societal issues. Not only is finding adequate sources of groundwater for the ever-burgeoning needs of communities and industries important but so too is the monitoring and prevention of surface and groundwater pollution, and when necessary, its cleanup. Geologic engineers help find safe locations for dams, waste-disposal sites, and power plants, as well as designing earthquake-resistant structures.

Geologists are increasingly asked to make short- and long-range predictions about earthquakes and volcanic eruptions and the potential destruction that may result. In fact, geologists are now more involved than ever in working with various government agencies and civil defense planners to ensure that contingency plans are in place and timely warnings are given for areas potentially affected by natural disasters, such as a tsunami.

ConnectionLink
Learn more about the connection between plate boundaries, earthquakes, and tsunami in Chapter 2, Geo-Insight 2.1.

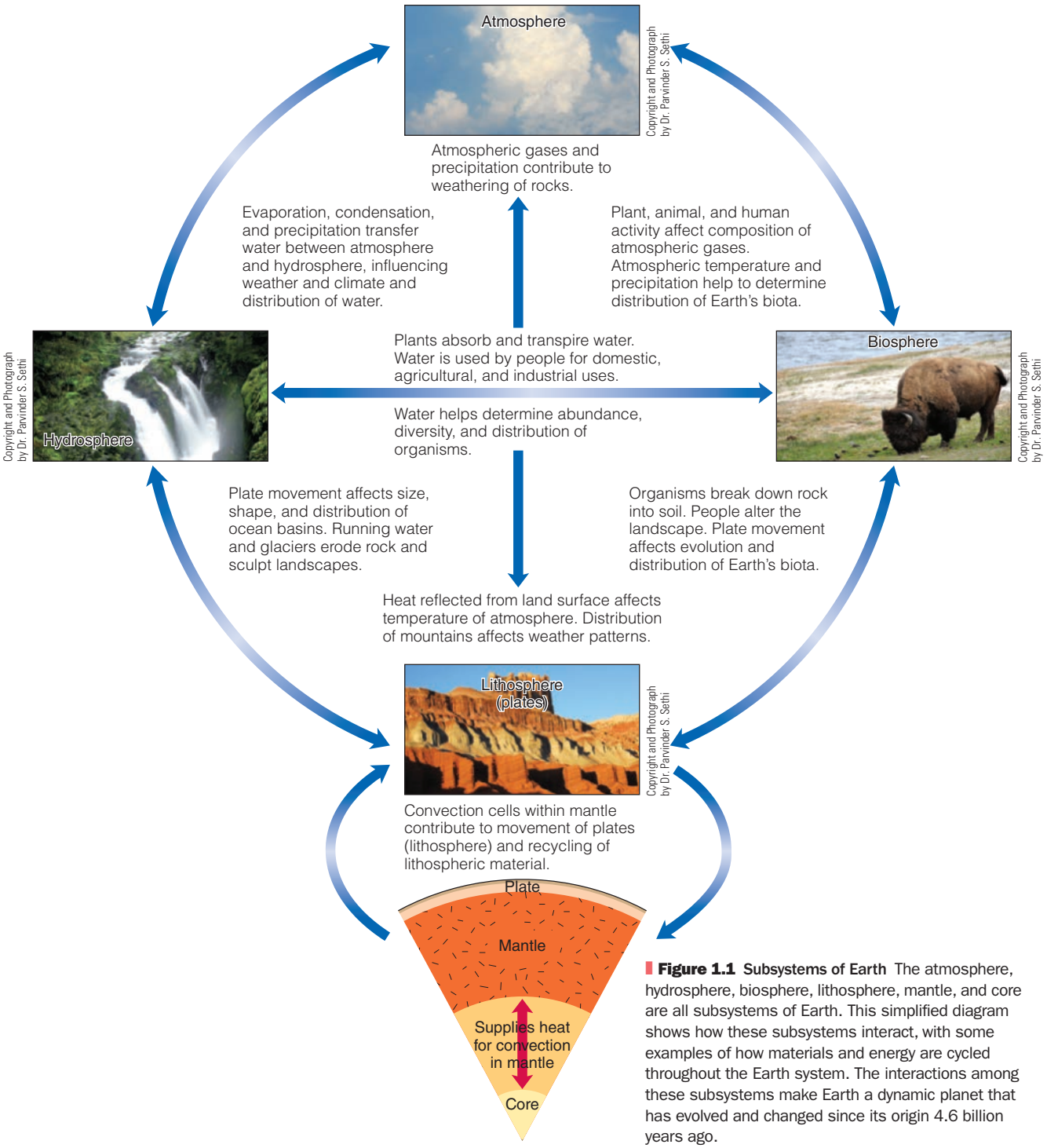


Figure 1.1 Subsystems of Earth The atmosphere, hydrosphere, biosphere, lithosphere, mantle, and core are all subsystems of Earth. This simplified diagram shows how these subsystems interact, with some examples of how materials and energy are cycled throughout the Earth system. The interactions among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

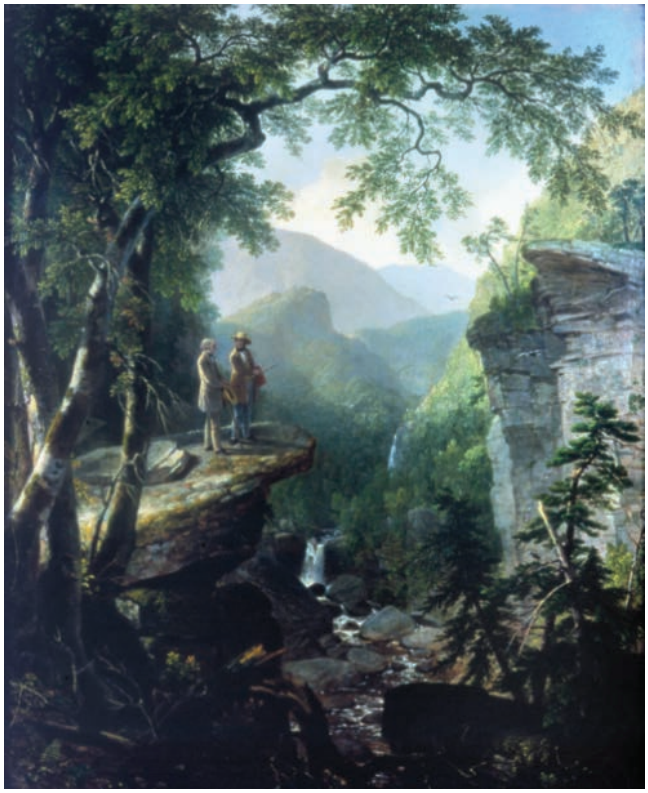
1.3 Geology and the Formulation of Theories

The term **theory** has various meanings and is frequently misunderstood and consequently misused. 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 more 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).

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 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. For example, 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.



Courtesy Crystal Bridges Museum of American Art, Bentonville, Arkansas.

Figure 1.2 Geology and Art *Kindred Spirits* by Asher Brown Durand (1849) realistically depicts the layered rocks along gorges in the Catskill Mountains of New York State. Durand was one of numerous artists of the 19th-century Hudson River School, which was known for realistic landscapes. This painting shows Durand conversing with the recently deceased Thomas Cole, the original founding force of the Hudson River School.

1.4 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 by famous painters depict rocks and landscapes realistically. Examples include 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).

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 novel *Journey to the Center of the Earth* describes an expedition into Earth's interior. The poem *Ozymandias* by Percy B. Shelley deals on one level with the fact that nothing lasts forever and even solid rock eventually disintegrates under the ravages of time and weathering. 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.

Geology has also played an important role in the history and culture of humankind. Empires have risen and fallen because mineral and energy resources are unequally distributed, thus resulting in wars to secure, for example, such critical resources as oil and gas. Natural barriers, such as mountain ranges and rivers, which are formed by geologic agents, have frequently served as political boundaries.

1.5 How Does Geology Affect Our Everyday Lives?

The most obvious connection between geology and our everyday lives is made when such natural disasters as volcanic eruptions, earthquakes, landslides, tsunami, and floods strike. Although we cannot prevent most of these natural disasters from happening, the more we learn about what causes them, the better we will be able to predict and mitigate the severity of their impact.

Less apparent, but equally significant, are the connections between geology and economic, social, and political issues. Although most readers of this book will not become professional geologists, everyone should have a basic understanding of the geologic processes that ultimately affect all of us. It is possible that at some time in the future you may become involved in geologic decisions as a member of a planning board or as a property owner with mineral rights. A perfect example is the current controversy regarding the use of hydraulic fracturing to extract oil and gas, and the environmental impact that results.

With government playing a greater role in environmental issues and regulations, members of Congress have increased the number of staff devoted to studying geology-related topics, such as climate change, energy policy, and environmental protection. It is important, therefore, to have a basic understanding of not only geology but also science, in general, to better understand these major issues that affect all of us.

ConnectionLink

You can learn more about the controversial issue of hydraulic fracturing in Chapter 13, Geo-Focus 13.1.

If such topics as nonrenewable energy resources, waste disposal, and pollution seem too far removed or too complex to be fully appreciated, consider for a moment just how dependent we are on geology in our daily routines (Figure 1.3).

Much of the electricity for our appliances comes from the burning of coal, oil, natural gas, or uranium consumed in nuclear-generating plants. Geologists locate the coal, petroleum, natural gas, and uranium. The copper and other metal wires through which electricity travels are manufactured from materials found as the result of mineral exploration. The concrete foundation (concrete is a mixture of clay, sand or gravel, and limestone), drywall (made largely from the mineral gypsum), and windows (the mineral quartz is the principal ingredient in the manufacture of glass) of the buildings we live and work in owe their very existence to geologic resources.

The car or public transportation we use to go to work is powered and lubricated by some type of petroleum byproduct and is constructed of metal alloys and plastics. And the roads or rails we ride over come from geologic materials, such as gravel, asphalt, concrete, or steel. All of these items are the result of processing geologic resources.

As individuals and societies, we enjoy a standard of living that obviously directly depends on the consumption of geologic materials. We therefore need to be aware of how our use and misuse of geologic resources may affect the environment and thus develop policies that not only encourage management of our natural resources but also allow for continuing economic development among all the world's nations.

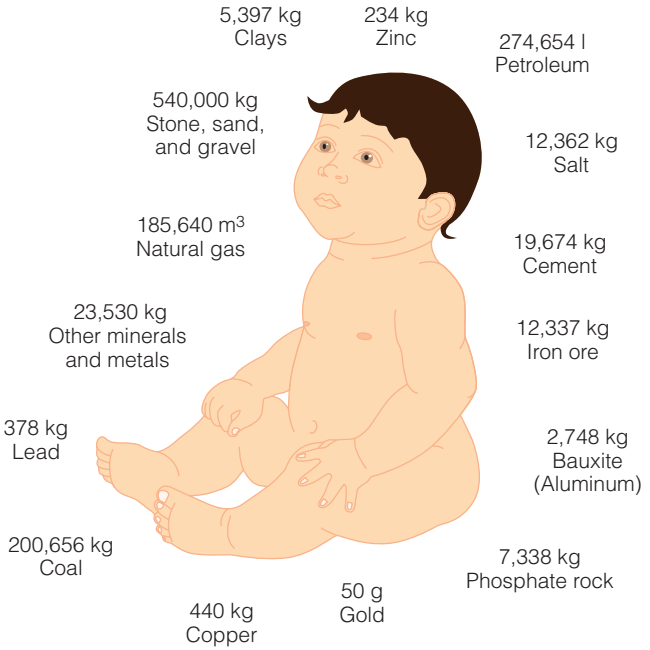


Figure 1.3 Lifetime Mineral Usage According to the Minerals Education Coalition, the average American born in 2012 has a life expectancy of 78.7 years and will need 1,350,000 kg of minerals, metals, and fuels to sustain his or her standard of living over a lifetime. That is an average of 17,154 kg of mineral and energy resources per year for every man, woman, and child in the United States. Data from the Minerals Education Coalition, The Society for Mining, Metallurgy and Exploration Foundation. http://www.mineralseducationcoalition.org/.

Critical Thinking Question Every year the life expectancy of the average American increases as well as our usage of minerals, metals, and fuels needed over a lifetime to maintain our standard of living. Is this increase sustainable, and is there anything that can be done to balance the depletion of natural resources but still maintain a high standard of living? How does our increasing consumption of these natural resources impact the rest of the world's population?

1.6 Global Geologic and Environmental Issues Facing Humankind

Most scientists would argue that overpopulation is the greatest environmental problem facing the world today. The world's population was slightly more than 7 billion at the end of 2012, and projections indicate that this number will reach between 8.0 and 10.5 billion people by 2050. Although this may not seem to be a geologic problem, remember that these people must be fed, housed, and clothed, and all with a minimal impact on the environment. Much of this population growth will be in areas that are already at risk from such hazards as earthquakes, tsunami, volcanic eruptions, and floods. Adequate water supplies must be found and protected from pollution. Additional energy resources will be needed to help fuel the economies of nations with ever-increasing populations. New techniques must be developed to reduce the use of our

GEO IMPACT

Hydraulic Fracturing and Its Impact on a Community

The county commission for zoning regulations, of which you are a member, has been asked to pass an ordinance banning hydraulic fracturing or "fracking" as it popularly is called. You have been put into a difficult position because on the one hand, the county needs the taxes and revenues generated by active exploration for, and production of, the natural gas known to exist in this region, but it is equally important to protect the environment from potential contamination. Located in a rural area of the state in which the main economic activity is farming, which uses large amounts of groundwater for irrigation, you do not want to risk polluting that resource. The recession and a stagnant economy, however, greatly reduced taxes on which the schools, social services, and infrastructure of the county depend.

In researching the topic of "fracking," you discover that it is a technique in which fluids are injected under very high pressure into organic-rich shales to create a network of fractures into which trapped natural gas can flow and ultimately be recovered. Proponents of "fracking" are quick to point out the economic benefits, whereby formerly inaccessible hydrocarbons, usually natural gas, can now be extracted.

The opponents of "fracking," however, point to the possible problems of environmental contamination, especially to groundwater reservoirs, which can be polluted by the migration of hydraulic fluids and other chemicals.

Jim West/Alamy

Protestors at an anti-fracking rally.

At the various public hearings held, there has been passionate debate about this issue by both proponents and opponents of "fracking." As these hearings will soon be coming to a close, you will be asked to vote on whether to allow or ban "fracking" in your county. How will you vote and what will be your reasons for that vote?

dwindling nonrenewable resource base and to increase our recycling efforts so that we can decrease our dependence on new sources of these materials.

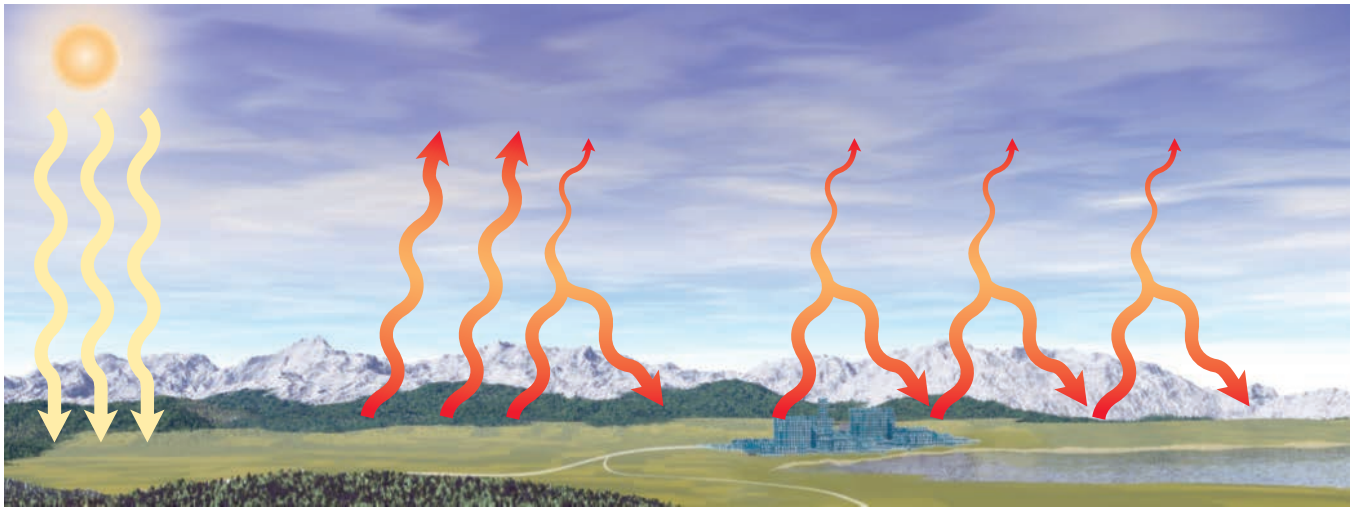
The problems of overpopulation and how it affects the global ecosystem vary from country to country. For many poor and nonindustrial countries, the problem is too many people and not enough food. For the more developed and industrial countries, the problem is too many people rapidly depleting both the nonrenewable and renewable natural resource base. And in the most industrially developed countries, it is people producing more pollutants than the environment can safely recycle on a human time scale. The common thread tying these varied situations together is an environmental imbalance created by a human population that is exceeding Earth's short-term carrying capacity.

Other global issues in the news all the time are the greenhouse effect, global warming, and climate change. These topics affect not only all of us but also the planet we live on. But just how will global warming and the resultant climate change personally affect you? Should you really be concerned about them? After all, you do have to worry about exams, graduation, and employment, let alone the everyday issues we all must deal with, not to mention your personal life. Yet, part of the college experience is examining and debating the "big picture" and issues facing society today. So what about global warming and you?

The relationship between the greenhouse effect and global warming is an excellent example of how Earth's various subsystems are interrelated. As a by-product of respiration and the burning of organic material, carbon dioxide is a component of the global ecosystem and constantly is being recycled as part of the carbon cycle. The concern in recent years over the increase in atmospheric carbon dioxide levels is related to its role in the greenhouse effect.

The recycling of carbon dioxide between Earth's crust and atmosphere is an important climate regulator because carbon dioxide and other gases, such as methane, nitrous oxide, chlorofluorocarbons, and water vapor, allow sunlight to pass through them, but they trap the heat reflected back from Earth's surface. This retention of heat is called the *greenhouse effect*. It results in an increase in the temperature of Earth's surface and, more importantly, its atmosphere, thus producing global warming (▮ Figure 1.4). The issue is not whether we have a greenhouse effect, because we do, but rather the degree to

Figure 1.4 The Greenhouse Effect and Global Warming



a Short-wavelength radiation from the Sun that is not reflected back into space penetrates the atmosphere and warms Earth's surface.

b Earth's surface radiates heat in the form of long-wavelength radiation back into the atmosphere, where some of it escapes into space. The rest is absorbed by greenhouse gases and water vapor and reradiated back toward Earth.

c Increased concentrations of greenhouse gases trap more heat near Earth's surface, causing a general increase in surface and atmospheric temperatures, which leads to global warming.

which human activity, such as the burning of fossil fuels, is increasing the greenhouse effect and thus contributing to global warming.

Because of the increase in human-produced greenhouse gases during the past 200 years, many scientists are concerned that a global warming trend has already begun and will result in severe global climatic shifts. Presently, most climate researchers use a range of scenarios for greenhouse gas emissions when predicting future warming rates. Climate model simulations published in the *2007 Fourth Intergovernmental Panel on Climate Change* show a predicted increase in global average temperature from 2000 to 2100 of 1–3°C under the best conditions, to a 2.5–6.5°C rise under "business-as-usual" conditions. These predicted increases in temperatures are based on various scenarios that explore different global development pathways. The fifth assessment by the Intergovenmental Panel on Climate Change was issued in 2013 and addressed the question of how much global warming actually results from increased carbon dioxide production.

Regardless of which scenario is followed, the global temperature change will be uneven, with the greatest warming occurring in the higher latitudes of the Northern Hemisphere. As a consequence of this warming, rainfall patterns will shift dramatically. This realignment will have a major effect on the largest grain-producing areas of the world, such as the United States Midwest. Drier and hotter conditions will intensify the severity and frequency of droughts, leading to more crop failures and higher food prices. With such shifts in climate, Earth's deserts may expand, with a resulting decrease in valuable crop and grazing land.

As climates change, diseases such as malaria are easily spreading into areas of warmer, wetter climates. Disease-carrying mosquitoes are expanding their range as climate changes allow them to survive in formerly inhospitable regions.

ConnectionLink

To learn more about desertification, which is the expansion of deserts into formerly productive lands, go to the Introduction in Chapter 15.

Higher temperature will also affect regional water supplies, creating potential water crises in the western United States within the next 20 years, as well as in other areas such as Peru and western China. Just as many regions will experience longer and hotter summers, other areas will suffer from intense and increased rainfall, which will result in severe flooding and landslides.

Moreover, continued global warming will result in a rise in mean sea level, as ice caps and glaciers melt and contribute their water to the world's oceans (Figure 1.5). It is predicted that at the current rate of glacial melting, sea level will rise 21 cm by around 2050, thus increasing the number of people at risk from flooding in coastal areas by approximately 20 million.

We would be remiss, however, if we did not point out that not all scientists are convinced that the global warming trend is the direct result of increased human activity related to industrialization. In fact, there has been much heated debate concerning the data and statistics used in the various models that are then used to make climate change predictions. These scientists indicate that although the level of