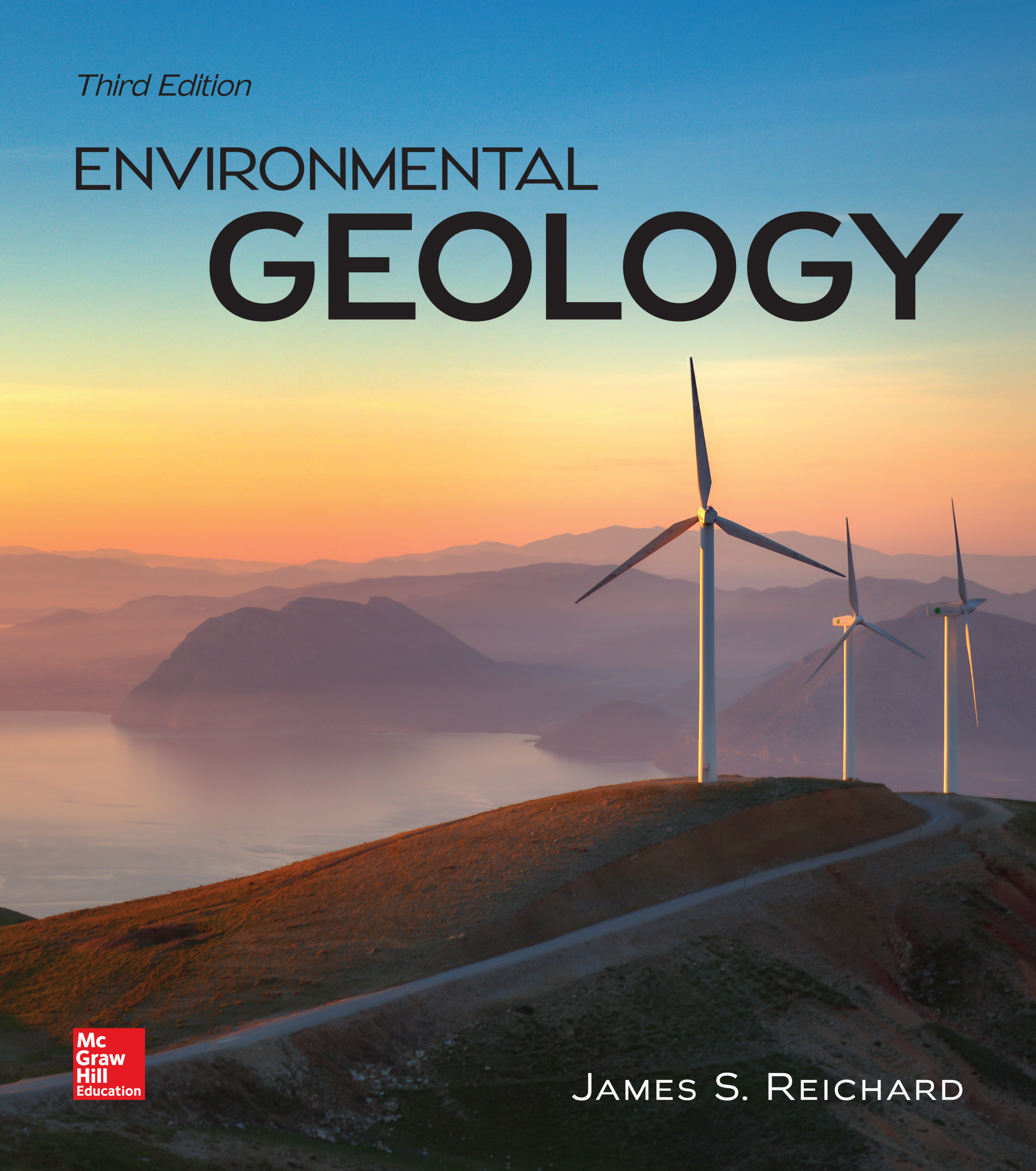


Third Edition

ENVIRONMENTAL GEOLOGY

JAMES S. REICHARD

Mc
Graw
Hill
Education

Environmental GEOLOGY

Third Edition

James S. Reichard
Georgia Southern University

Mc
Graw
Hill
Education

ENVIRONMENTAL GEOLOGY, THIRD EDITION

1 2 3 4 5 6 7 8 9 LMN 21 20 19 18 17

ISBN 978-0-07-802296-8
MHID 0-07-802296-7

Chief Product Officer, SVP Products & Markets: *G. Scott Virkler*
Vice President, General Manager, Products & Markets: *Marty Lange*
Vice President, Content Design & Delivery: *Betsy Whalen*
Managing Director: *Thomas Timp*
Director of Marketing: *Tamara Hodge*
Brand Manager: *Michael Ivanov Ph.D.*
Director, Product Development: *Rose Koos*
Product Developer: *Jodi Rhomberg*
Marketing Manager: *Noah Evans*
Digital Product Analyst: *Patrick Dillard*
Digital Product Developer: *Joan Weber*
Director, Content Design & Delivery: *Linda Avenarius*
Program Manager: *Lora Neyens*
Content Project Managers: *Sherry Kane, Rachael Hillebrand*
Buyer: *Susan K. Culbertson*
Design: *Matt Backhaus*
Content Licensing Specialists: *Lori Hancock, Jacob Sullivan*
Cover Image: © *Alexandros Maragos/Getty Images*
Compositor: *SPi Global*
Printer: *LSC Communications*

All credits appearing on page or at the end of the book are considered to be an extension of the copyright page.

Library of Congress Cataloging-in-Publication Data
Names: Reichard, James S., author.
Title: Environmental geology / James S. Reichard, Georgia Southern University.
Description: Third edition. | New York, NY : McGraw-Hill, [2017]
Identifiers: LCCN 2016030710 | ISBN 9780078022968 (alk. paper)
Subjects: LCSH: Environmental geology—Textbooks.
Classification: LCC QE38 .R45 2017 | DDC 550—dc23 LC record available at
https://lccn.loc.gov/2016030710

mheducation.com/highered

This book is dedicated to my wife Linda and children, Brett and Kristen. Their love and support has carried me through the many hours spent away from home. Words cannot express my love and gratitude.

—James Reichard

© Jim Reichard

Jim Reichard and his family on the Highline Trail in Glacier National Park, Montana. From left to right: Jim, son Brett, daughter Kristen, and wife Linda.

Brief Contents

PART ONE Fundamentals of Environmental Geology

PART TWO Hazardous Earth Processes

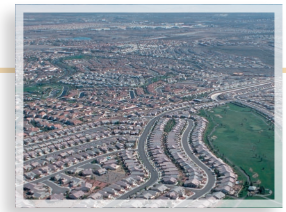
PART THREE Earth Resources

PART FOUR The Health of Our Environment

Contents

PART ONE
Fundamentals of Environmental Geology

Chapter 1



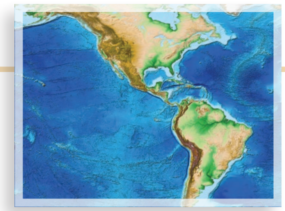
USDA, NRCS, Lynn Betts

Chapter 2

UNASA/NOAA/GSFC/Suomi NPP/VIIRS/Norman Kuring

Chapter 3

© Image Ideas/PictureQuest



Amante, C. and B. W. Eakins, ETOPO1 1 Arc-Minute Global Relief Model: Procedures, Data Sources and Analysis, NESDIS, NOAA, U.S. Dept. of Commerce

PART TWO

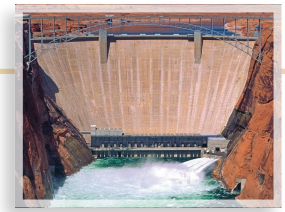
Hazardous Earth Processes

© AFLO/Mainichi Newspaper/epa/Corbis

© Image Plan/Corbis

© AP Photo/Nick Ut

Chapter 8


© Doug Sherman/Geofile

Chapter 9


Program for the Study of Developed Shorelines, Western Carolina University.

PART THREE
Earth Resources

Chapter 10


© Glow Images


Tim McCabe, USDA, NRCS


© Neil Beer/Getty Images


U.S. Coast Guard


© George Hammerstein/Corbis/ Glow Images

PART FOUR
The Health of Our Environment

Chapter 15

© Jason Hawkes/The Image Bank/Getty Images

Pollution and Waste Disposal 481

Chapter 16

© James Jordan Photography/Getty Images

Global Climate Change 517

Preface

© Steve Cole/Getty Images

Environmental Geology, 3e focuses on the fascinating interaction between humans and the geologic processes that shape Earth's environment. Because this text emphasizes how human survival is highly dependent on the natural environment, students should find the topics to be quite relevant to their own lives and, therefore, more interesting. One of the key themes of this textbook centers on a serious challenge facing modern society: the need to continue obtaining large quantities of energy, and at the same time, make the transition from fossil fuels to clean sources of energy that do not impact the climate system. *Environmental Geology* provides extensive coverage of the problems associated with our conventional fossil fuel supplies (Chapter 13), and an equally in-depth discussion of alternative energy sources (Chapter 14). The two chapters on energy are intimately linked to a comprehensive overview of global climate change (Chapter 16), which is arguably civilization's most critical environmental challenge.

Another major theme in the third edition of *Environmental Geology* is that humans are an integral part of a complex and interactive system scientists call the Earth system. Throughout the text the author explains how the Earth system responds to human activity, and how that response then affects the very environment in which we live. A key point is that our activity often produces unintended and undesirable consequences. An example from the text is how engineers have built dams and artificial levees to control flooding on the Mississippi River. This has caused unintended changes in the geologic environment. For thousands of years, the rate at which the river deposited sediment in the Mississippi Delta was approximately equal to the rate that the sediment compacted under its own weight. The land surface remained above sea level because the two rates had been similar. However, by using dams and artificial levees to confine the Mississippi River to its channel, humans disrupted the delicate balance between sediment deposition and compaction. Today large sections of the Louisiana coast, including New Orleans, are sinking below sea level, and at the same time sea level is rising due to global warming. This has not only caused severe coastal erosion, but greatly increased the chance that New Orleans will be inundated during a major hurricane.

Environmental Geology also includes a sufficient amount of background material on physical geology for students who have never taken a geology course. The author believes this additional coverage is critical. Without a basic understanding of physical geology, students would not be able to fully appreciate the interrelationships between humans and the geologic environment. To meet the needs of courses with a physical geology prerequisite, the book was organized so that instructors could easily omit the few chapters that contain mostly background material. In addition, *Environmental Geology* does more than provide a physical description of water, mineral, and energy resources; it explores the difficult problems associated with extracting the enormous quantities of resources needed to sustain modern societies. With respect to geologic hazards (e.g., earthquakes, volcanic eruptions, and floods), the textbook goes beyond the physical science and examines the societal impacts as well as the ways humans can minimize the risks. The author also highlights the

> *"My overall impression after reading Chapter 16 "Global Climate Change" was that of an excellent coverage of a still very controversial topic. Reichard has managed to cover the most fundamental societal and scientific issues related to global climate change in a format accessible to undergraduate students with or without strong science background. Reichard provides an unbiased representation of facts and does not shy away from a critical discussion of opposing arguments resulting from the interpretation of the facts."*
>
> —Thomas Boving, *University of Rhode Island*

fact that as population continues to grow, the problems related to resource depletion and hazards will become more severe.

Finally, this textbook includes learning tools designed to make it easier for students to utilize information found in the text. For example, it is unreasonable to expect students to remember everything they read. For this reason, the text often cross references topics between chapters as a reminder that additional information can be found in other parts of the book. It is hoped that cross-referencing will encourage students to make better use of the index for locating additional information.

> *“. . . I give the author credit for excelling in a very up-to-date assessment of alternative technologies, with some delightful examples of innovative systems that should interest the student reader. The author recognizes the importance of portraying the subject within the modern world that the student lives in.”*
>
> —Lee Slater, *Rutgers University–Newark*

New for the Third Edition

Readers familiar with *Environmental Geology* should find that the changes to the third edition have significantly improved the already outstanding pedagogy and photo and art program of the previous editions. Perhaps the most significant improvement is the addition of six new case studies, bringing the total to nineteen. Increasing the number of case studies was a priority for the third edition because instructors commonly have students use case studies to explore chapter concepts in more detail. In addition to the new case studies, the chapter narratives have been thoroughly revised to include recent geologic events and scientific advances. Likewise, care was taken to ensure that all of the graphs and tables include the most recently available data. Many new photos and several new graphics were added to enhance the pedagogy and increase student interest. Finally, some of the existing graphics were modified to improve student comprehension.

Although changes in the third edition are too numerous to be listed individually, some of the more significant improvements are described below. Note that the chapters with the most revisions are those on energy resources (Chapters 13 and 14) and climate change (Chapter 16).

Chapter 1—In addition to updating the chapter content for recent events and scientific advances, four of the existing photos (Figures 1.1, 1.2, 1.8, and 1.18) have been replaced to help improve visual comprehension.

Chapter 2—The opening photo has been replaced with a dramatic NASA image of Earth’s western hemisphere, which helps reinforce the theme that Earth is part of a much larger system. Perhaps the most significant change is that the case study on the search for life on Mars has been completely rewritten and now includes five new high-resolution photos. In addition to the case study, the discussion in the text on possible extraterrestrial life has been updated, and new graphics of Saturn’s moon Enceladus (Figure 2.21) and the Kepler-62 planetary system (2.23) have been added. Also, an improved graphic of Antarctic ozone concentrations (2.25) illustrates how the ozone hole has changed over time. Finally, new photos provide students with a close-up view of the iridium-rich layer at the K/T boundary (2.31) and of comet 67P/Churyumov-Gerasimenko (2.34) as it approached the Sun in 2014.

Chapter 3—The opening photo was replaced with a classic image of a sandstone butte in Monument Valley that coincides with the chapter theme of earth materials (rocks and minerals). With respect to the chapter content, a new case study with photos and graphics (Figures B3.1 and B3.2) describes how ancient zircon crystals are providing geologists with important clues as to Earth’s early history, in a period just 160 million years after the planet formed. Three photos have also been replaced (3.11, 3.17, and 3.24) to help improve student comprehension.

Chapter 4—A key graphic (Figure 4.16) showing the different types of plate boundaries has been re-labeled to improve student comprehension. Similarly, the discussion on how the movement of tectonic plates generates forces that cause buckling at convergent boundaries and rifting at divergent boundaries has been rewritten to improve clarity.

Chapter 5—Discussion of the recent earthquake in Nepal is accompanied by a new photo (Figure 5.20) taken after the quake that illustrates the hazards associated with masonry buildings. The chapter also includes the recently updated USGS seismic hazard map of the United States (5.34) and the newly released USGS hazard probability map for the San Francisco area (5.35). Finally, a new graphic (5.39) has been added to the section on earthquake early warning systems to complement the revised discussion of Japan’s nationwide system and California’s new *ShakeAlert* system.

Chapter 6—The opening photo has been replaced with a new, dramatic image of Mount Fuji that helps illustrate the relationship between humans and the geologic environment. Also, the discussion on the early warning system for mudflow hazards near Mount Rainier has been completely rewritten and updated.

Chapter 7—A new case study, including photos and graphics (Figures B7.3 and B7.4), describes the history behind the tragic 2014 mass wasting event that killed 43 people in Oso, Washington. In addition, the graphic that illustrates the different forces on a slope (7.4) has been relabeled to improve student comprehension, and the graphic depicting how reducing slope materials increases slope stability (7.29) has been revised for accuracy.

Chapter 8—The opening photo has been replaced with an impressive image of the Yellowstone River to help highlight the important role that streams play in the Earth system. A discussion of the thousand-year flood event in 2013 near Boulder, Colorado, has been included in the section on flash floods to help illustrate the hazards associated with these rare events.

Chapter 9—In addition to minor text changes to convey new information, the histograms showing coastal population growth (Figure 9.1) and Atlantic hurricane history (9.23) and the map of buoys and sensors in the worldwide tsunami early warning system (9.26) have all been redrawn based on the most currently available data.

Chapter 10—The opening photo has been replaced with a new image to reinforce the chapter theme—how our food supply is inextricably linked to soils. Most significant though is the addition of a new case study, including graphics (Figures B10.1 and B10.2), that describes the lessons learned regarding soil conservation practices in the aftermath of the 1930s Dust Bowl in the United States.

Chapter 11—A new case study on the Aral Sea disaster, with photos (Figure B11.1), highlights the potential problems associated with off-stream water usage. In addition, the graph showing total U.S. water withdrawals (11.4) has been updated, and the graphic illustrating saltwater intrusion of coastal aquifers (11.21) has been revised for accuracy.

Chapter 12—The opening photo has been replaced with an impressive image of a spinning bucket excavator being used to remove overburden material from a surface mine. Three data tables (Tables 12.1, 12.4, and 12.5) have been updated based on recently released USGS mineral reports. Similarly, new data from the USGS were used to update the graphs showing U.S. mineral imports (12.24) and yearly mineral consumption (12.25).

Chapter 13—Much of this chapter has undergone extensive revision that reflects recent developments with respect to conventional oil and gas resources. For example, the section on exploration and production wells now includes a discussion on deep-water oil and gas deposits along with a graphic (Figure 13.17) that includes a map of the world's deep-water fields and a diagram of a deep-water drilling operation. This section also has a new, in-depth discussion on tight oil and gas wells and a new graph (13.18) comparing depletion rates of conventional and tight gas wells. The case study on hydraulic fracturing has been updated and now includes a discussion on the significant increase in earthquake activity related to the injection of greater volumes of wastewater into deep aquifers. The map showing the location of tight oil and gas deposits (B13.1) has been updated to include deposits in Canada and Mexico. In addition, major revisions to the section on the energy crisis reflect the current volatility in oil and gas markets related to the interaction between changes in supply and demand and economic activity. Likewise, the sections on peak oil and avoiding the energy crisis have been updated based on the latest projections concerning the increase of tight oil production and the depletion of conventional oil fields. Finally, many of the graphs and charts (13.3, 13.22–13.27, 13.31, and 13.34–13.36) were updated using data from newly released reports.

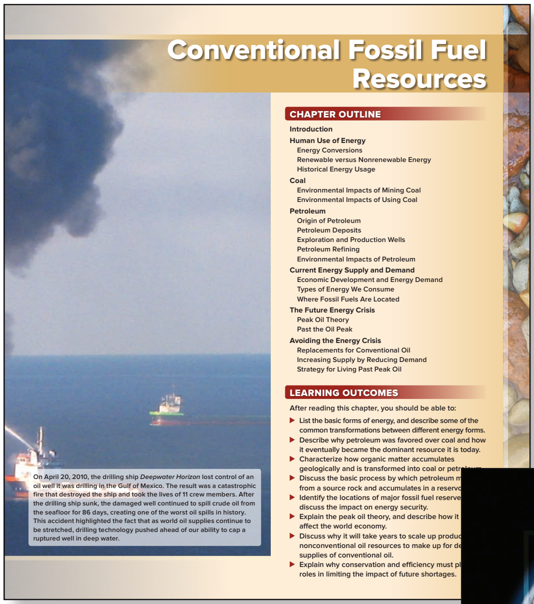
Chapter 14—To help illustrate how the world is transitioning from fossil fuels to clean and renewable energy sources, the opening photo has been replaced with one showing a new housing development with rooftop solar panels. More importantly, the chapter has been thoroughly revised to reflect both minor and major developments in a wide array of alternative energy sources. Significant revisions include updates on China's increased use of coal liquefaction for transportation fuels, changes in the EPA's renewable fuel standard (RFS) and its effect on U.S. ethanol production, new battery technology for storing electricity, and home energy conservation. Perhaps the most important change is a new case study on the next generation of nuclear power plants, which can produce carbon-free electricity and eliminate the need for long-term storage of nuclear waste. This case study complements a revised discussion on how major reductions in greenhouse gas emissions could be accomplished through a combination of increased use of nuclear power and scaled-up production of electricity from wind and solar resources. Other additions include an updated wind power map of the United States (Figure 14.21) and a graphic showing the breakdown of energy usage in the typical U.S. household (14.32). Finally, the most recently available data were used to update the table listing the cost of producing electricity from difference sources (14.1), the graph of U.S. ethanol production (14.7), and the graph of world wind power generating capacity (14.36).

Chapter 15—A new graphic (Figure 15.3) in the section on U.S. environmental laws shows the total number and status of EPA Superfund sites over time. In addition, six graphs (15.9, 15.15, 15.16, 15.17, and 15.39) were updated based on recently released EPA reports, and a new version of the acid rain deposition map (15.37) has been included. Four photos (15.6, 15.17, 15.25, and 15.32) have also been replaced to help improve student comprehension. Finally, the section on reducing anthropogenic mercury emissions underwent significant revisions based on recent EPA data, and the potential health risk from recycled tire material in athletic surfaces is described in the discussion of scrap tires.

Chapter 16—The opening photo has been replaced with an impressive image of combustion gases being released from a coal-burning power plant, highlighting the connection between society's use of fossil fuels and global climate change. In addition, numerous small changes have been made throughout the chapter to reflect the results and conclusions from the most recent United Nations report (IPCC) on climate change. Perhaps the single most significant change is a new case study describing how Miami and South Florida are at severe risk from accelerated sea level rise. Also new is a NASA image (Figure 16.1) showing the dramatic loss of ice from Greenland's Jakobshavn Glacier, a graphic (16.11) illustrating the albedo effect, a photo (16.27) showing the devastating effects of pine-beetle infestations on conifer forests, a pair of photos (16.28) illustrating the effect of a long-term drought on California's water supply, and a graph (16.39) of worldwide carbon dioxide emissions over time. In addition, eight graphs (16.2, 16.19, 16.25, 16.26, 16.32, 16.37, 16.39 and 16.40) were updated based on recently released data. Finally, a detailed discussion on the recent Paris Climate Agreement has been included in the section on mitigation of climate change.

Key Features

As with all college textbooks, there are differences among the various environmental geology books currently being offered. These are some of the more significant and noticeable differences you will find in *Environmental Geology*:



Conventional Fossil Fuel Resources

CHAPTER OUTLINE

Introduction
Human Use of Energy
  Energy Conversions
  Renewable versus Nonrenewable Energy
  Historical Energy Usage
Coal
  Environmental Impacts of Mining Coal
  Environmental Impacts of Using Coal
Petroleum
  Origin of Petroleum
  Petroleum Deposits
  Exploration and Production Wells
  Petroleum Refining
  Environmental Impacts of Petroleum
Current Energy Supply and Demand
  Economic Development and Energy Demand
  Types of Energy We Consume
  Where Fossil Fuels Are Located
The Future Energy Crisis
  Peak Oil Theory
  Past the Oil Peak
Avoiding the Energy Crisis
  Replacements for Conventional Oil
  Increasing Supply by Reducing Demand
  Strategy for Living Past Peak Oil

LEARNING OUTCOMES

After reading this chapter, you should be able to:

- List the basic forms of energy, and describe some of the common transformations between different energy forms.
- Describe why petroleum was favored over coal and how it eventually became the dominant resource it is today.
- Characterize how organic matter accumulates geologically and is transformed into coal or petr
- Discuss the basic process by which petroleum m from a source rock and accumulates in a reservo
- Identify the locations of major fossil fuel reserve discuss the impact on energy security.
- Explain the peak oil theory, and describe how it affect the world economy.
- Discuss why it will take years to scale up produc nonconventional oil resources to make up for de supplies of conventional oil.
- Explain why conservation and efficiency must pl roles in limiting the impact of future shortages.

On April 20, 2010, the drilling ship *Deepwater Horizon* lost control of an oil well it was drilling in the Gulf of Mexico. The result was a catastrophic fire that destroyed the ship and took the lives of 11 crew members. After the drilling ship sunk, the damaged well continued to spill crude oil from the seafloor for 86 days, creating one of the worst oil spills in history. This accident highlighted the fact that as world oil supplies continue to be stretched, drilling technology pushed ahead of our ability to cap a ruptured well in deep water.

- **Learning Outcomes.** Each chapter is introduced with a list that provides valuable student guidance by stating key chapter concepts. This encourages students to be "active" learners as they complete the tasks and activities that require them to use critical thinking skills.
- **Chapter 2 Is Unique.** "Earth from a Larger Perspective" describes Earth's relationship to the solar system and universe, which helps give students the broadest possible perspective on our environment. Here students learn how the Earth system is part of even larger systems before moving on to the remaining chapters that focus on our planet. Chapter 2 also gives instructors the opportunity to discuss some of the external forces that influence Earth's environment, such as solar radiation, asteroid impacts, and the effect of the Moon on our tides and climate. In addition, this chapter helps explain why Earth supports a diverse array of complex life, and why humans are so dependent on its unique and fragile environment. This sets the stage for a theme that is woven throughout the entire text—that human survival is intimately linked to the environment. Students can then see how being better stewards of the Earth is in our own best interest.

Chapter 2

Earth from a Larger Perspective

CHAPTER OUTLINE

Introduction
Our Solar System
  The Sun
  The Planets
  Comets and Asteroids
  The Moon
Origin of the Solar System
  The Nebular Hypothesis
  How Reliable Is the Nebular Hypothesis?
Other Stars in the Universe
Does Life Exist Beyond Earth?
  Life on Earth
  Habitable Zones
  Possible Intelligent Life
Solar System Hazards
  Electromagnetic Radiation
  Asteroid and Comet Impacts

LEARNING OUTCOMES

After reading this chapter, you should be able to:

- Understand how the nebular hypothesis explains the formation of the solar system and how it accounts for the orbital characteristics of the planets and moons.
- Describe our solar system and the size of the Earth relative to the size of the solar system as well as to the size of our galaxy and the universe.
- Explain how extremophile bacteria are related to the origin of life on Earth and how they relate to the extraterrestrial search for life.
- Understand the concept of habitable zones and why complex animal life that may exist elsewhere will likely be restricted to such zones.
- Explain what mass extinctions are and be able to name some of their possible triggering mechanisms.
- Understand how scientists came to appreciate the serious nature of comet and asteroid impacts, and describe the steps being taken to reduce the risk.

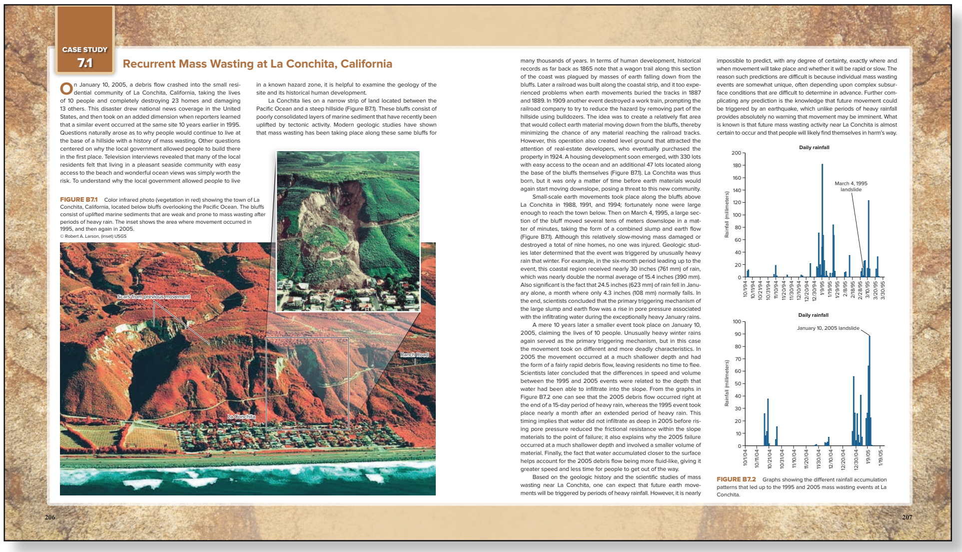
In modern times humans have sent machines into space in order to study the Earth as well as the solar system and universe. This knowledge helps us to better understand the Earth system and gives us a larger perspective from which to view environmental problems. The image shown here is centered over Mexico in North America and was taken by NASA's polar-orbiting satellite called VIIRS.

NASA/NOAA/GSFC/Suomi NPP/VIIRS/Norman Kuring

34

35

- **Case Studies.** Nearly every chapter includes a case study that is designed to give students a more in-depth look at an environmental issue. A good example is Chapter 7, where the case study examines the recurring mass wasting problems at La Conchita, California. Here students are asked to consider why some people willingly live in a hazardous area, even when the risk is well understood. In Chapter 13, the case study explores the controversy over hydraulic fracturing and the development of tight oil and gas. Students are given an objective overview of both the science and policy sides of the issue, and are then expected to draw their own conclusion as to which side of the policy debate they would support.



CASE STUDY 7.1

Recurrent Mass Wasting at La Conchita, California

- **Photos and Illustrations.** It is well established in the field of education that most people are predominantly visual learners. Therefore, the author integrated very relevant photos and illustrations within the narrative so that abstract and complex concepts are easier to understand. The integrated use of visual examples within a narrative writing style should not only help increase student comprehension, but it should also encourage students to read more of the text.

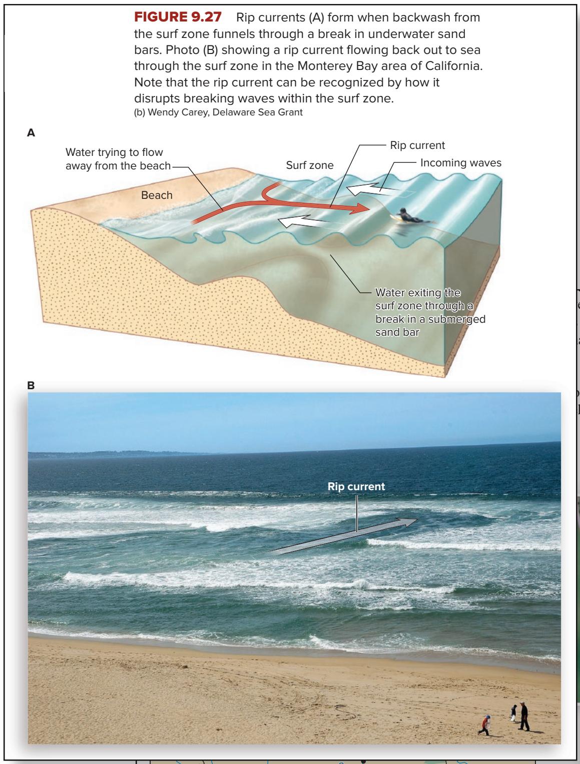


FIGURE 9.27 Rip currents (A) form when backwash from the surf zone funnels through a break in underwater sand bars. Photo (B) showing a rip current flowing back out to sea through the surf zone in the Monterey Bay area of California. Note that the rip current can be recognized by how it disrupts breaking waves within the surf zone.
(b) Wendy Carey, Delaware Sea Grant


FIGURE 14.3 Synthetic crude oil is currently being produced from oil sand deposits (A) in Alberta, Canada. The hydrocarbons are in the form of bitumen, a highly viscous substance that is separated from the sand using steam. Photo (B) shows a bitumen sample whose viscosity has been lowered by heating. Approximately 60% of Canadian production involves strip mining (C); the remainder is produced by steam injection and pumping wells.
(B) © Syncrude Canada Ltd; (C) © Photographic Services, Shell International Ltd.

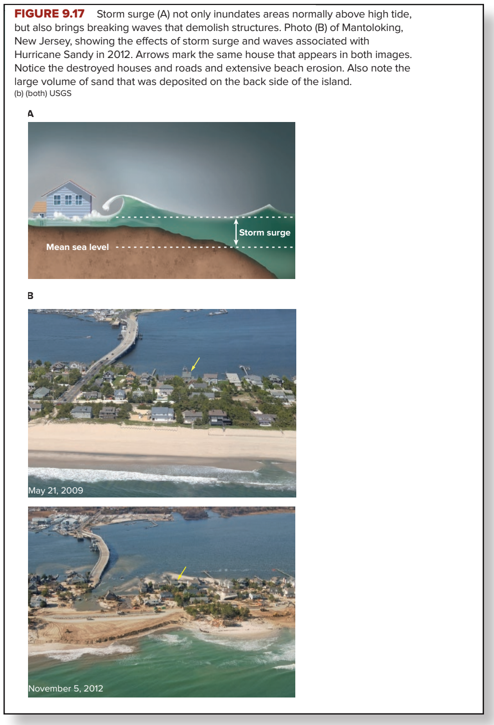


FIGURE 9.17 Storm surge (A) not only inundates areas normally above high tide, but also brings breaking waves that demolish structures. Photo (B) of Mantoloking, New Jersey, showing the effects of storm surge and waves associated with Hurricane Sandy in 2012. Arrows mark the same house that appears in both images. Notice the destroyed houses and roads and extensive beach erosion. Also note the large volume of sand that was deposited on the back side of the island.
(b) (both) USGS

- **Summary Points.** Each chapter concludes with a list of Summary Points to provide students with a list of important concepts that should be reviewed in preparation for exams.

- **Key Words.** The study of geologic processes can be daunting due to the proliferation of unfamiliar terms. Each chapter includes a list of important terms with page references, so that terms can be viewed within the context of their use. Complete definitions are also provided in the Glossary at the back of the text.

SUMMARY POINTS

1. Shorelines are unique in that they are where Earth's two most fundamental environments meet: the terrestrial (land) and marine (ocean), forming a desirable habitat for humans. Because population growth is much higher in coastal zones compared to inland areas, more people are exposed to coastal erosion and hazards such as hurricanes and tsunamis.
2. Ocean tides are caused by the gravitational pull of the Moon and Sun on Earth's oceans, whereas ocean currents move in response to winds, differences in water density, and wave action along coastlines.
3. Wave energy travels horizontally and causes water molecules to move vertically in circular paths. As a wave enters shallow water, the moving water molecules begin to drag on the bottom, causing the wave to decelerate. This causes the wave to increase in height and to become more asymmetric, eventually falling over to form a breaking wave.
4. When waves crash onto shore at an angle, water is pushed parallel to shore in a longshore current. Grains of sand in the surf zone move in a zigzagging pattern in the direction of the longshore current in the process of beach drift.
5. Irregular shorelines with more isolated beaches are commonly found in tectonically active areas and in places where sea level is rising relative to the land surface. Erosion and deposition from wave action slowly causes shorelines to evolve into ones with longer and wider beaches. At the same time, weathering and erosion of the landscape tend to produce more low-lying terrain.
6. Hurricanes are a serious coastal hazard as they generate powerful winds, storm surge, and heavy rains. Satellite early warning systems have greatly reduced the number of fatalities, but increased coastal development has caused property losses to escalate.
7. Tsunamis most commonly form during subduction zone earthquakes as water is displaced by movement of the seafloor. When a tsunami reaches shallow water, the tremendous wave energy translates into tall waves that break far beyond the normal surf zone, causing death and destruction along developed coastlines.
8. Rip currents pose a serious risk to swimmers as water from the surf funnels back out to sea through breaks in shallow sand bars. People are unable to swim back to shore against the strong currents, but can get out of the current by swimming parallel to shore.
9. The interaction between waves and a landmass can cause a shoreline to naturally retreat landward. The slow migration of a shoreline can also occur when there is a global rise in sea level or when the land itself becomes lower due to subsidence. Accelerated shoreline retreat is occurring in many areas due to human activity, increasing the hazards associated with ocean storms.
10. Humans attempt to protect their property and reduce shoreline retreat through engineering techniques such as seawalls, groins, and beach nourishment. Jetties are used to keep navigational channels free of sediment, and breakwaters provide quiet areas by keeping waves from impacting on the shoreline. Some of these techniques result in beach starvation and accelerated retreat in down-drift areas.

119

4. Oceanic crust is relatively thin and composed of basalt, whereas continental crust is thicker and composed of granitic rock. The crust and upper mantle act as a single rigid layer and together are called the lithosphere. The lithosphere is broken up into rigid plates that move over the weak, semimolten layer called the asthenosphere.
5. Decay of radioactive elements within the Earth generates heat and helps create a large temperature difference between the core and the crust. This sets in motion large convection cells that transport both heat and plastic mantle material toward the surface.
9. Major surface features develop along plate boundaries and include ocean ridges, ocean trenches, rift valleys, island arcs, volcanic arcs, and complex mountain belts. The majority of earthquakes and volcanic eruptions also occur along plate boundaries.
10. In addition to geologic processes, plate tectonics plays a central role in the Earth system by affecting the atmosphere, hydrosphere, and biosphere. For humans, plate tectonics is important because it creates hazards (earthquakes, volcanic eruptions, landslides), regulates our climate, distributes natural resources, and was important in the development of life.

KEY WORDS

asthenosphere	97
compression	95
continental arc	112
convection cells	99
convergent boundary	106
crust	98
divergent boundary	106
elastic limit	95
fault	96
geothermal gradient	99
inner core	97
island arc	111
lithosphere	98
mantle	97
mid-oceanic ridges	101
ocean trenches	101
outer core	97
rift valley	109
seafloor spreading	102
shear	95
subduction	103
tectonic plates	98
tension	95
theory of plate tectonics	94
transform boundary	106

APPLICATIONS

Student Activity Go to the website of a major news organization, such as the *New York Times,* the*Wall Street Journal,* or the BBC, and make a list of all the stories you can find that are in some way related to plate tectonics. Then, briefly state how the topic relates to plate tectonics. For example, earthquakes and volcanoes are easy to relate, but if you think about it, mineral, energy, and water resources and even climate change can be linked to plate tectonics.

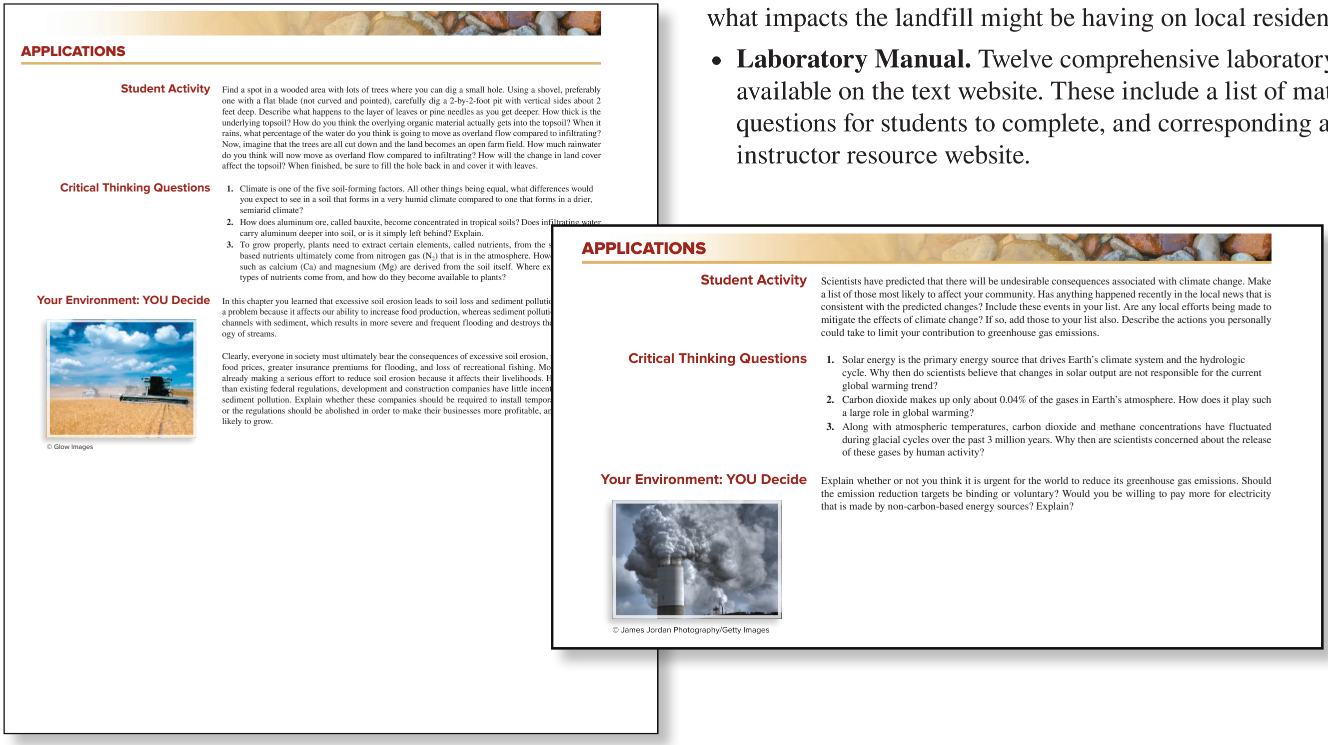
Critical Thinking Questions

1. Rocks that are brittle will deform by fracturing when they exceed their elastic limit, but if they become ductile, they will deform by flowing plastically. Can you think of an everyday material that can go from being brittle to being ductile, and thus go from fracturing to flowing plastically when deformed?
2. Large-scale convection cells develop in the mantle due to differences in density caused by Earth's internal heat. Can you think of an example of density-driven convection circulation that takes place in Earth's surface environment?
3. Some disaster movies have shown lava erupting in downtown Los Angeles, California. Given the fact that Los Angeles is situated along a transform plate boundary, is a volcanic eruption there very likely? Explain.

Your Environment: YOU Decide In this Chapter you learned how the theory of plate tectonics was finally developed in the 1960s, based on data gathered from numerous geologic studies over many years. These data include maps of the seafloor, magnetic studies, earthquake locations, and similar rock and fossil sequences on the continents.

Describe the piece of evidence you found to be most convincing in showing that tectonic plates are indeed moving on top of the asthenosphere. Be sure to explain why.

- **Applications.** At the end of each chapter, sections called **Student Activity** and **Critical Thinking Questions** and **Your Environment: YOU Decide** encourage students to think about how their own lifestyles may be playing a role in environmental issues. For example, in Chapter 12 ("Mineral and Rock Resources") they are asked to think about the social implications of buying a diamond that comes from a part of the world where illegal proceeds support violent uprisings and civil war. In Chapter 15 ("Pollution and Waste Disposal") students are asked to contact their local government to determine the location of the landfill where their trash is being sent. They are then asked to investigate whether the landfill has any reported pollution problems, and if so, to describe what impacts the landfill might be having on local residents.
- **Laboratory Manual.** Twelve comprehensive laboratory exercises are available on the text website. These include a list of materials needed, questions for students to complete, and corresponding answer keys on the instructor resource website.



APPLICATIONS

Student Activity Find a spot in a wooded area with lots of trees where you can dig a small hole. Using a shovel, preferably one with a flat blade (not curved and pointed), carefully dig a 2-by-2-foot pit with vertical sides about 2 feet deep. Describe what happens to the layer of leaves or pine needles as you get deeper. How thick is the underlying topsoil? How do you think the overlying organic material actually gets into the topsoil? When it rains, what percentage of the water do you think is going to move as overland flow compared to infiltrating? Now, imagine that the trees are all cut down and the land becomes an open farm field. How much rainwater do you think will now move as overland flow compared to infiltrating? How will the change in land cover affect the topsoil? When finished, be sure to fill the hole back in and cover it with leaves.

Critical Thinking Questions

1. Climate is one of the five soil-forming factors. All other things being equal, what differences would you expect to see in a soil that forms in a very humid climate compared to one that forms in a drier, semiarid climate?
2. How does aluminum ore, called bauxite, become concentrated in tropical soils? Does infiltrating water carry aluminum deeper into soil, or is it simply left behind? Explain.
3. To grow properly, plants need to extract certain elements, called nutrients, from the s
based nutrients ultimately come from nitrogen gas (N_2) that is in the atmosphere. How
such as calcium (Ca) and magnesium (Mg) are derived from the soil itself. Where ex
types of nutrients come from, and how do they become available to plants?

Your Environment: YOU Decide

In this chapter you learned that excessive soil erosion leads to soil loss and sediment pollutio
a problem because it affects our ability to increase food production, whereas sediment polluti
channels with sediment, which results in more severe and frequent flooding and destroys th
ogy of streams.

Clearly, everyone in society must ultimately bear the consequences of excessive soil erosion,
food prices, greater insurance premiums for flooding, and loss of recreational fishing. Mo
already making a serious effort to reduce soil erosion because it affects their livelihoods. H
than existing federal regulations, development and construction companies have little incent
sediment pollution. Explain whether these companies should be required to install tempor
or the regulations should be abolished in order to make their businesses more profitable, ar
likely to grow.

© Glow Images

APPLICATIONS

Student Activity Scientists have predicted that there will be undesirable consequences associated with climate change. Make a list of those most likely to affect your community. Has anything happened recently in the local news that is consistent with the predicted changes? Include these events in your list. Are any local efforts being made to mitigate the effects of climate change? If so, add those to your list also. Describe the actions you personally could take to limit your contribution to greenhouse gas emissions.

Critical Thinking Questions

1. Solar energy is the primary energy source that drives Earth's climate system and the hydrologic cycle. Why then do scientists believe that changes in solar output are not responsible for the current global warming trend?
2. Carbon dioxide makes up only about 0.04% of the gases in Earth's atmosphere. How does it play such a large role in global warming?
3. Along with atmospheric temperatures, carbon dioxide and methane concentrations have fluctuated during glacial cycles over the past 3 million years. Why then are scientists concerned about the release of these gases by human activity?

Your Environment: YOU Decide Explain whether or not you think it is urgent for the world to reduce its greenhouse gas emissions. Should the emission reduction targets be binding or voluntary? Would you be willing to pay more for electricity that is made by non-carbon-based energy sources? Explain?

© James Jordan Photography/Getty Images

Organization

In most environmental geology courses the list of topics includes some combination of geologic hazards and resources along with waste disposal and pollution. Consequently, this book is conveniently organized so instructors can pick and choose the chapters that coincide with their particular course objectives. The chapters are organized as follows:

Part One Fundamentals of Environmental Geology
Chapter 1 Humans and the Geologic Environment
Chapter 2 Earth from a Larger Perspective
Chapter 3 Earth Materials
Chapter 4 Earth's Structure and Plate Tectonics

Part Two Hazardous Earth Processes
Chapter 5 Earthquakes and Related Hazards
Chapter 6 Volcanoes and Related Hazards
Chapter 7 Mass Wasting and Related Hazards
Chapter 8 Streams and Flooding
Chapter 9 Coastal Hazards

Part Three Earth Resources
Chapter 10 Soil Resources
Chapter 11 Water Resources
Chapter 12 Mineral and Rock Resources
Chapter 13 Conventional Fossil Fuel Resources
Chapter 14 Alternative Energy Resources

Part Four The Health of Our Environment
Chapter 15 Pollution and Waste Disposal
Chapter 16 Global Climate Change

> *"I found the chapter [16] to overall be very well written, very interesting, and logically organized. I am especially impressed by the thorough summary the author provides on the Earth's climate system."*
> —John C. White, *Eastern Kentucky University*

McGraw Hill Education connect®

Required=Results


©Getty Images/iStockphoto

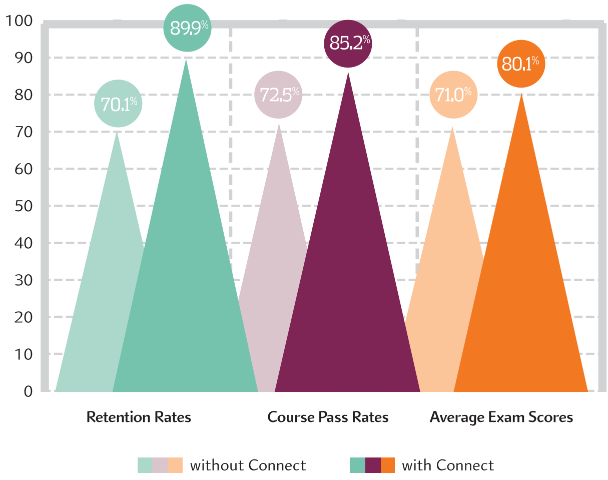
McGraw-Hill Connect®
Learn Without Limits

Connect is a teaching and learning platform that is proven to deliver better results for students and instructors.

Connect empowers students by continually adapting to deliver precisely what they need, when they need it, and how they need it, so your class time is more engaging and effective.

> 73% of instructors who use **Connect** require it; instructor satisfaction **increases** by 28% when **Connect** is required.

Connect's Impact on Retention Rates, Pass Rates, and Average Exam Scores



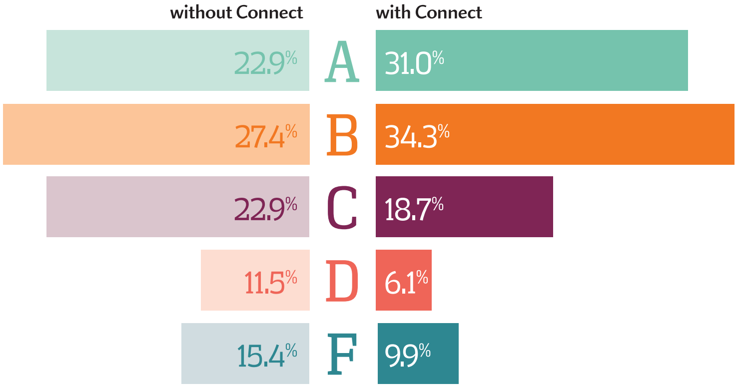
Using **Connect** improves retention rates by **19.8%**, passing rates by **12.7%**, and exam scores by **9.1%.**

Analytics

Connect Insight®

Connect Insight is Connect's new one-of-a-kind visual analytics dashboard—now available for both instructors and students—that provides at-a-glance information regarding student performance, which is immediately actionable. By presenting assignment, assessment, and topical performance results together with a time metric that is easily visible for aggregate or individual results, Connect Insight gives the user the ability to take a just-in-time approach to teaching and learning, which was never before available. Connect Insight presents data that empowers students and helps instructors improve class performance in a way that is efficient and effective.

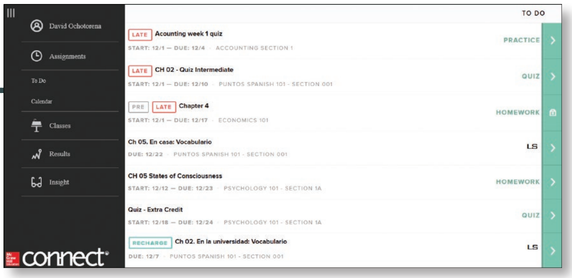
Impact on Final Course Grade Distribution



> Students can view their results for any **Connect** course.

Mobile

Connect's new, intuitive mobile interface gives students and instructors flexible and convenient, anytime–anywhere access to all components of the Connect platform.



LATE Acounting week 1 quiz
START: 12/1 — DUE: 12/4 · ACCOUNTING SECTION 1

LATE CH 02 - Quiz Intermediate
START: 12/1 — DUE: 12/10 · PUNTOS SPANISH 101 - SECTION 001

PRE LATE Chapter 4
START: 12/1 — DUE: 12/17 · ECONOMICS 101

Ch 05. En casa: Vocabulario
DUE: 12/22 · PUNTOS SPANISH 101 - SECTION 001

CH 05 States of Consciousness
START: 12/12 — DUE: 12/23 · PSYCHOLOGY 101 - SECTION 1A

Quiz - Extra Credit
START: 12/18 — DUE: 12/24 · PSYCHOLOGY 101 - SECTION 1A

RECHARGE Ch 02. En la universidad: Vocabulario
DUE: 12/7 · PUNTOS SPANISH 101 - SECTION 001

Adaptive

THE **ADAPTIVE READING EXPERIENCE** DESIGNED TO TRANSFORM THE WAY STUDENTS READ

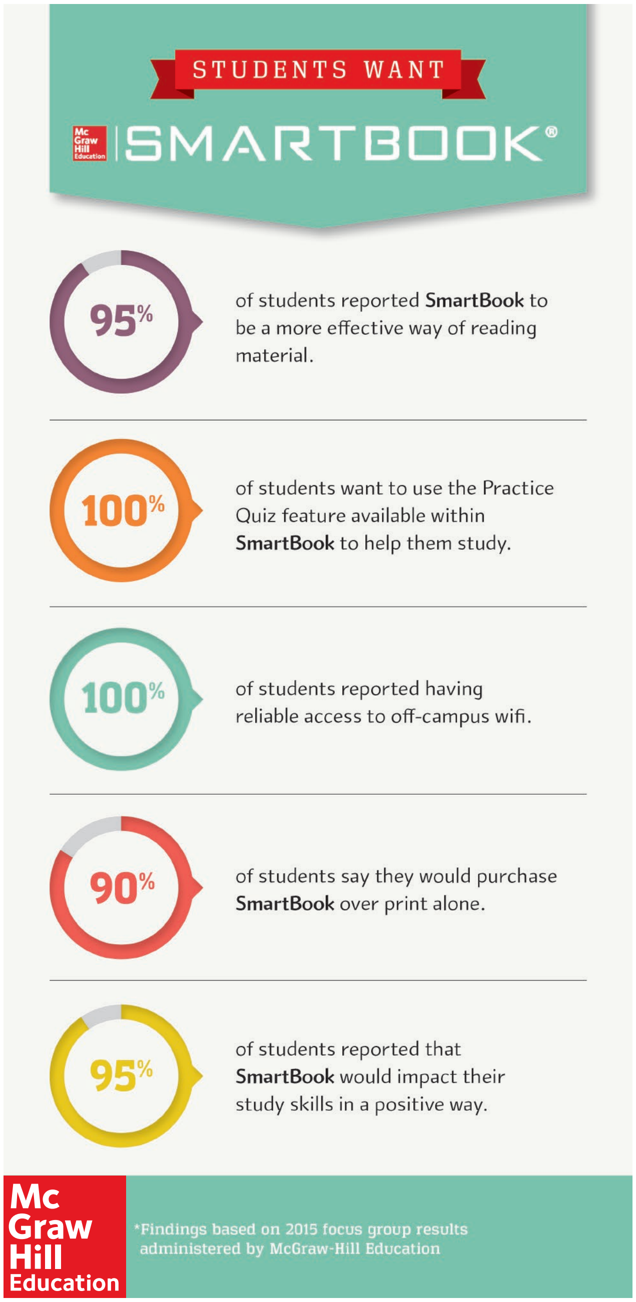
> More students earn **A's** and **B's** when they use McGraw-Hill Education **Adaptive** products.

SmartBook®

Proven to help students improve grades and study more efficiently, SmartBook contains the same content within the print book, but actively tailors that content to the needs of the individual. SmartBook's adaptive technology provides precise, personalized instruction on what the student should do next, guiding the student to master and remember key concepts, targeting gaps in knowledge and offering customized feedback, and driving the student toward comprehension and retention of the subject matter. Available on tablets, SmartBook puts learning at the student's fingertips—anywhere, anytime.

> Over **8 billion questions** have been answered, making McGraw-Hill Education products more intelligent, reliable, and precise.

www.mheducation.com



STUDENTS WANT

SMARTBOOK®

95% of students reported **SmartBook** to be a more effective way of reading material.

100% of students want to use the Practice Quiz feature available within **SmartBook** to help them study.

100% of students reported having reliable access to off-campus wifi.

90% of students say they would purchase **SmartBook** over print alone.

95% of students reported that **SmartBook** would impact their study skills in a positive way.

*Findings based on 2015 focus group results administered by McGraw-Hill Education

Acknowledgments

The third edition of *Environmental Geology* allowed me to improve upon the outstanding features of the original text. This required the help of many different people. In particular, I would like to thank the McGraw-Hill team that worked on this project, including Jodi Rhomberg (Senior Product Developer), Sherry Kane (Content Project Manager), Matt Backhaus (designer), Lori Hancock (Lead Content Licensing Specialist), Noah Evans (Associate Marketing Manager), Michael Ivanov Ph.D. (Brand Manager) and Thomas Timp (Managing Director). In addition to the publishing team, a special thanks goes to my wife, Linda. The demands placed on me by publishing deadlines, teaching schedules, and research commitments were at times overwhelming. Linda not only took on nearly all of the family responsibilities, giving me the time I needed, but her unwavering support and encouragement helped me get through it all. I can never thank her enough.

I would also like to thank the many individuals, companies, and government agencies who generously supplied the noncommercial photos. In many cases, this involved people taking time from their busy schedules to search photo archives and retrieve the high-resolution photos that I wanted to use. Because far too many people contributed to this effort for me to acknowledge here, their contributions are listed in the photo credits within the book. However, I do want to recognize the following individuals for producing special photos and graphics for this textbook:

James Bunn *National Oceanic and Atmospheric Administration*
Eleanor Camann *Red Rocks Community College*
Chris Daly *Oregon State University*
Carolyn Donlin *U.S. Geological Survey*
Lundy Gammon *IntraSearch*
Robert Gilliom *U.S. Geological Survey*
Bob Larson *University of Illinois*
Jake Crouch *National Oceanic and Atmospheric Administration*
Naomi Nakagaki *U.S. Geological Survey*
Matt Sares *Colorado Geological Survey*
Christie St. Clair *U.S. Environmental Protection Agency*
Cindy Starr *National Aeronautics and Space Administration*
Jeremy Weiss *University of Arizona*

I would also like to acknowledge different government agencies for supporting programs that address important environmental issues around the globe. This textbook made use of publically available reports, data, and photographs from the following agencies:

Australian Commonwealth Scientific and Industrial Research Organization
Environment Canada
Geological Survey of Canada, Natural Resources Canada
National Aeronautics and Space Administration (NASA), U.S. Government
National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Commerce
Natural Resources Conservation Service, U.S. Department of Agriculture
United States Department of Energy
United States Environmental Protection Agency
United States Fish and Wildlife Service, Department of the Interior
United States Geological Survey, Department of the Interior

I would also like to thank Trent McDowell, who wrote and reviewed learning goal oriented content for LearnSmart.

Finally, I would like to thank all those who reviewed various parts of the manuscript during the course of this project. Their insightful comments, suggestions, and criticisms were of immense value.

Lewis Abrams *University of North Carolina–Wilmington*
Christine N. Aide *Southeast Missouri State University*
Michael T. Aide *Southeast Missouri State University*
Erin P. Argyilan *Indiana University Northwest*
Richard W. Aurisano *Wharton County Junior College*
Dirk Baron *California State University—Bakersfield*
Jessica Barone *Monroe Community College*
Mark Baskaran *Wayne State University*
Robert E. Behling *West Virginia University*
Prajukti Bhattacharyya *University of Wisconsin–Whitewater*
Thomas Boving *University of Rhode Island*
David A. Braaten *University of Kansas*
Eric C. Brevik *Dickinson State University*
Charles Brown *George Washington University*
Patrick Burkhart *Slippery Rock University of Pennsylvania*
Ernest H. Carlson *Kent State University*
James R. Carr *University of Nevada–Reno*
Patricia H. Cashman *University of Nevada–Reno*
Elizabeth Catlos *Oklahoma State University*
Robert Cicerone *Bridgewater State College*
Gary Cwick *Southeast Missouri State University*
Katherine Folk Clancy *University of Maryland*
Jim Constantopoulos *Eastern New Mexico University*
Geoffrey W. Cook *University of Rhode Island*
Heather M. Cook *University of Rhode Island*
Raymond Coveney *University of Missouri–Kansas City*
Ellen A. Cowan *Appalachian State University*
Anna M. Cruse *Oklahoma State University*
Gary J. Cwick *Southeast Missouri State University*
George E. Davis *California State University–Northridge*
Hailang Dong *Miami University of Ohio*
Yoram Eckstein *Kent State University*
Dori J. Farthing *SUNY–Geneseo*
Larry A. Fegel *Grand Valley State University*
James R. Fleming *Colby College*
Christine A. M. France *University of Maryland–College Park*
Tony Foyle *Penn State Erie, The Behrend College*
Alan Fryar *University of Kentucky*
Heather L. Gallacher *Cleveland State University*
Alexander E. Gates *Rutgers University–Newark*
David H. Griffing *Hartwick College*
John R. Griffin *University of Nebraska–Lincoln*
Syed E. Hasan *University of Missouri–Kansas City*
Chad Heinzel *Minot State University*
Donald L. Hoff *Valley City State University*
Brad Johnson *Davidson College*
Neil E. Johnson *Appalachian State University*
Steven Kadel *Glendale Community College*
Chris R. Kelson *University of Georgia*
John Keyantash *California State University–Dominguez Hills*

Karin Kirk *Carleton College*
Christopher Kofp *Mansfield University*
Gerald H. Krockover *Purdue University*
Glenn C. Kroeger *Trinity University*
Michael A. Krol *Bridgewater State College*
Jennifer Latimer *Indiana State University*
Liliana Lefticariu *Southern Illinois University*
Adrianne A. Leinbach *Wake Technical Community College*
Gene W. Lené *St. Mary's University of San Antonio*
Nathaniel Lorentz *California State University–Northridge*
James B. Maynard *University of Cincinnati*
Richard V. McGehee *Austin Community College*
Gretchen L. Miller *Wake Technical Community College*
Barry E. Muller *ERG Consult, LLC*
Klaus Neumann *Ball State University*
Barry E. Muller *ERG Consult, LLC*
Suzanne O'Brien *Stonehill College*
Duke Ophori *Montclair State University*
David L. Ozsvath *University of Wisconsin–Stevens Point*
Evangelos K. Paleologos *University of South Carolina–Columbia*
Alyson Ponomarenko *San Diego City College*
Libby Prueher *University of Northern Colorado*
Fredrick J. Rich *Georgia Southern University*
Paul Robbins *University of Arizona*
Michael Roden *University of Georgia*
Lee D. Slater *Rutgers University–Newark*
Edgar W. Spencer *Washington and Lee University*
Michelle Stoklosa *Boise State University*
Eric C. Straffin *Edinboro University of Pennsylvania*
Christiane Stidham *Stony Brook University*
Benjamin Surpless *Trinity University*
Sam Swanson *University of Georgia*
Gina Seegers Szablewski *University of Wisconsin–Milwaukee*
James V. Taranik *University of Nevada–Reno*
J. Robert Thompson *Glendale Community College*
Jody Tinsley *Clemson University*
Daniel L. Vaughn *Southern Illinois University*
Adil M. Wadia *University of Akron, Wayne College*
Miriam Weber *California State University–Monterey Bay*
David B. Wenner *University of Georgia*
John C. White *Eastern Kentucky University*
David Wilkins *Boise State University*
Ken Windom *Iowa State University*

Meet the Author

James Reichard James Reichard is a Professor in the Department of Geology and Geography at Georgia Southern University. He obtained his Ph.D. in Geology (1995) from Purdue University, specializing in hydrogeology, and his M.S. (1984) and B.S. (1981) degrees from the University of Toledo, where he focused on structural and petroleum geology. Prior to earning his Ph.D., he worked as an environmental consultant in Cleveland, Ohio, and as a photogeologist in Denver, Colorado.

James (Jim) grew up in the flat glacial terrain of northwestern Ohio. Each summer, he went on an extended road trip with his family and traveled the American West. It was during this time that Jim was exposed to a variety of scenic landscapes. Although he had no idea how the landscapes formed, he was fascinated nonetheless. It was not until college, when Jim had to satisfy a science requirement, that he finally came across the field of geology. Here, he discovered a science that could explain how different landscapes actually form. From that moment on, he was hooked on geology. This eventually led Jim to a graduate degree in geology, after which he was able to fulfill his dream of living and working in Colorado. Then, due to one of life's many unexpected opportunities, he accepted a position with an environmental firm back in Ohio. This ultimately led to a Ph.D. from Purdue and a faculty position at Georgia Southern University, where he currently enjoys teaching and doing research in environmental geology and hydrogeology. His personal interests include hiking, camping, and sightseeing.

It is through this textbook that Professor Reichard hopes to excite students about how geology shapes the environment in which we live, similar to the way he became excited about geology in his youth. To help meet this goal, he has tried to write this book with the student's perspective in mind in order keep it more interesting and relevant. Hopefully, students who read the text will begin to share some of Professor Reichard's fascination with how geology plays an integral role in our everyday lives.

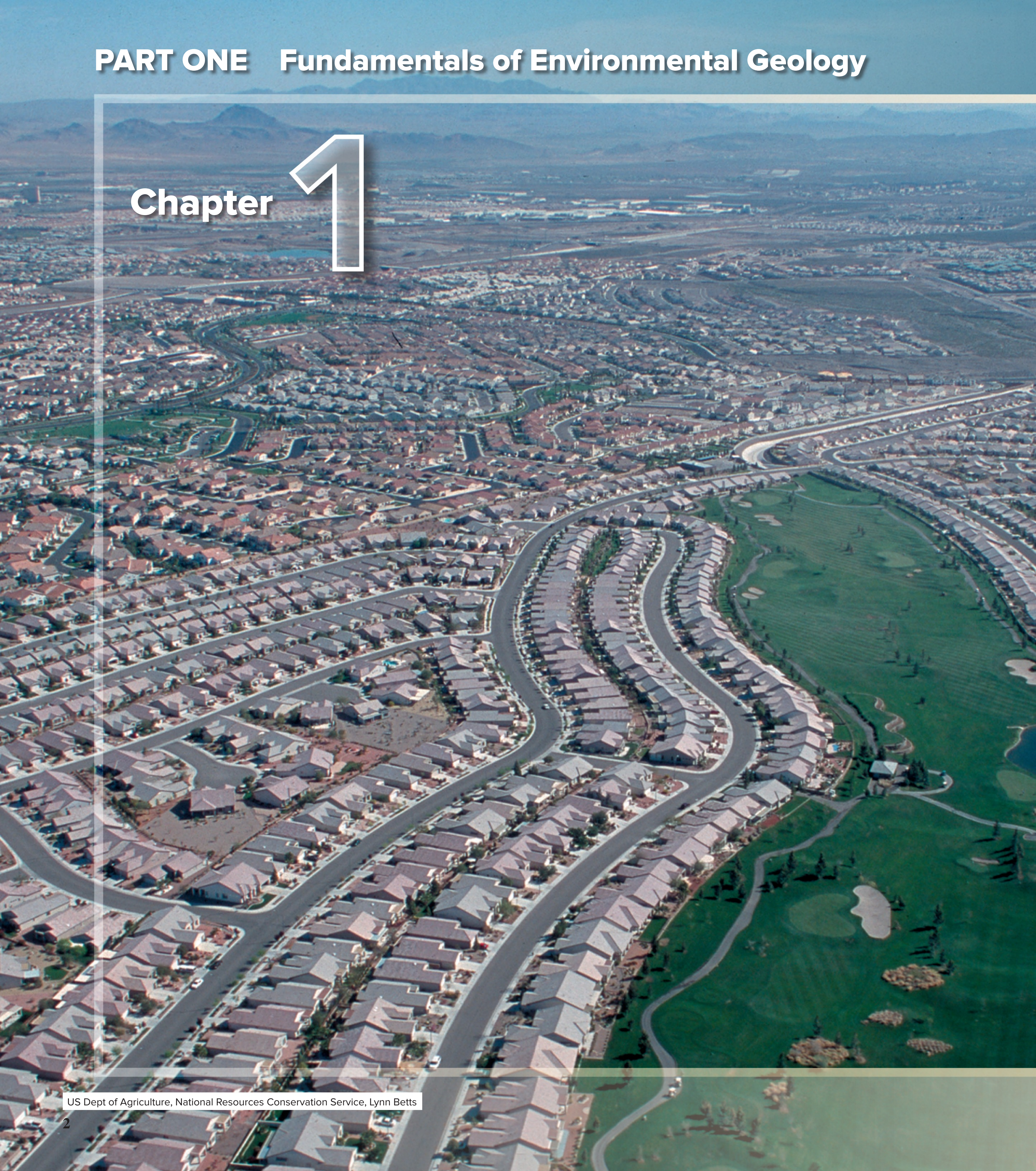
Crater Lake National Park, Oregon.

© Jim Reichard

Environmental
GEOLOGY

PART ONE Fundamentals of Environmental Geology

Chapter 1



US Dept of Agriculture, National Resources Conservation Service, Lynn Betts

Humans and the Geologic Environment

Aerial photo showing extensive urban sprawl in the desert environment of Las Vegas, Nevada. Modern humans have been able to thrive in such harsh environments because of our ability to generate electrical power to run air conditioners and to bring in water from reservoirs and underground aquifers. However, population growth is threatening to outstrip Earth's ability to provide the resources needed to sustain our population. Humans therefore must find a way to stabilize population growth and limit our consumption of resources.

CHAPTER OUTLINE

- **Introduction**
- **What Is Geology?**
- **Scientific Inquiry**
  - How Science Operates
  - Science and Society
- **Environmental Geology**
- **Environmental Problems and Time Scales**
  - Geologic Time
  - Environmental Risk and Human Reaction
- **Earth as a System**
- **The Earth and Human Population**
  - Population Growth
  - Limits to Growth
  - Sustainability
  - Ecological Footprint
- **Environmentalism**

LEARNING OUTCOMES

After reading this chapter, you should be able to:

- Describe the major focus of the discipline called environmental geology.
- Characterize how scientists develop hypotheses and theories as a means of understanding the natural world.
- Describe the concept of geologic time and how the geologic time scale was constructed.
- Explain how geologic time and the rate at which natural processes operate affect how humans respond to environmental issues.
- Describe how Earth operates as a system and why humans are an integral part of the system.
- Explain the concept of exponential population growth and how it relates to geologic hazards and resource depletion.
- Define the concept of sustainability in terms of the living standard of developed nations and also in terms of the human impact on the biosphere.

Introduction

© StockTrek/Getty Images

Earth is unique among the other planets in the solar system in that it has an environment where life has been able to thrive, evolving over billions of years from single-cell bacteria to complex plants and animals. There have been three critical factors that have led to the diversity of life we see today. One is that Earth's surface temperatures are in the range where water can exist in both the liquid and vapor states. The second is that our planet was able to retain its atmosphere, which in turn allows the water to move between the liquid and vapor states in a cyclic manner. Last, Earth has a natural mechanism for removing carbon dioxide from the atmosphere, namely, the formation of carbonate rocks (e.g., limestone). This has prevented a buildup of carbon dioxide and a runaway greenhouse effect, similar to what happened on Venus, where surface temperatures today exceed 800°F (425°C). With respect to humans *(Homo sapiens),* our most direct ancestors have been part of Earth's biosphere for only the past 200,000 years, whereas other hominid species go back as far as 6 to 7 million years. Compared to Earth's 4.6-billion-year history, humans have existed for a very brief period of time. However, rapid population growth combined with the Industrial Revolution has resulted in profound changes in Earth's surface environment. The focus of this textbook will be on the interaction between humans and Earth's geologic environment. We will pay particular attention to how people use resources such as soils, minerals, and fossil fuels and how we interact with natural processes, including floods, earthquakes, landslides, and so forth.

One of the key reasons humans have been able to thrive is our ability to understand and modify the environment in which we live. For example, consider that for most of history people lived directly off the land. To survive they had to be keenly aware of the environment in order to find food, water, and shelter. This forced some people to travel with migrating herds of wild animals, who in turn were following seasonal changes in their own food and water supplies. Eventually we learned to clear the land and grow crops in organized settlements. As they practiced agriculture, humans became skilled at recognizing those parts of the landscape with the most productive soils. The best soils, however, were commonly found in low-lying areas along rivers and periodically inundated by floodwaters. To reduce the risk of floods, people learned to seek out farmland on higher ground and place their homes even higher, thereby avoiding all but the most extreme floods. In addition to reducing the risk of floods and other natural hazards, we learned how to take advantage of Earth's mineral and energy resources. This led directly to the Industrial Revolution and the modern consumer societies of today.

Although humans have benefited greatly by modifying the environment and using Earth's resources, this activity has also resulted in unintended and undesirable consequences. For example, in order to grow crops and build cities it was necessary to remove forests and grasslands that once covered the natural landscape. This reduced the land's ability to absorb water, thereby increasing the frequency and severity of floods. Also, the use of mineral and energy resources by modern societies creates waste by-products that can poison our streams and foul the air we breathe. The prolific use of fossil fuels is even altering the planet's climate system and contributing to the problem of global warming. It has become abundantly clear that the human race is an integral part of the Earth system and that our actions affect the very environment upon which we depend.

While the link between environmental degradation and human activity may be clear to scientists, it is not always so obvious to large segments of the population. A well-established concept with respect to environmental degradation is known as the **tragedy of the commons**, which is where the self-interest of individuals results in the destruction of a common or shared resource. A common resource includes such things as a river used for water supply, wood in a forest, grassland for grazing animals, and fish in the sea. Consider a coastal village whose primary source of food is the local fishing grounds offshore. This resource is renewable as long as the fish are not harvested at a faster rate than they can reproduce; hence, everyone in the village benefits. However, if the village grows too large, the increased demand can make the fishing unsustainable. As the fish become scarcer, the competition for the remaining fish gets more intense as the individual fisherman try to feed their families. The fisherman's self-interest creates a downward spiral where all members of society ultimately suffer as the fishery becomes so depleted that it collapses and is unable to recover.

Another phenomenon that can contribute to environmental degradation is when citizens in consumer societies become disconnected from the natural environment. An example is the United States, where many people now live and work in climate-controlled buildings and get their food from grocery stores as opposed to growing their own (Figure 1.1). People then tend to lose their sense of being connected with the natural world, despite the fact they remain dependent upon the environment as were our ancient ancestors. As with the tragedy of the commons, a lack of environmental awareness can lead to serious problems and hardships for society.

FIGURE 1.1 In modern consumer societies few people live directly off the land, but instead buy most of their food in stores. This trend has led to a greater disconnection between people and the natural environment upon which they still depend.

(Left) © Glowimages/Punchstock; (Right) © The McGraw-Hill Companies, Inc./Andrew Resek, photographer

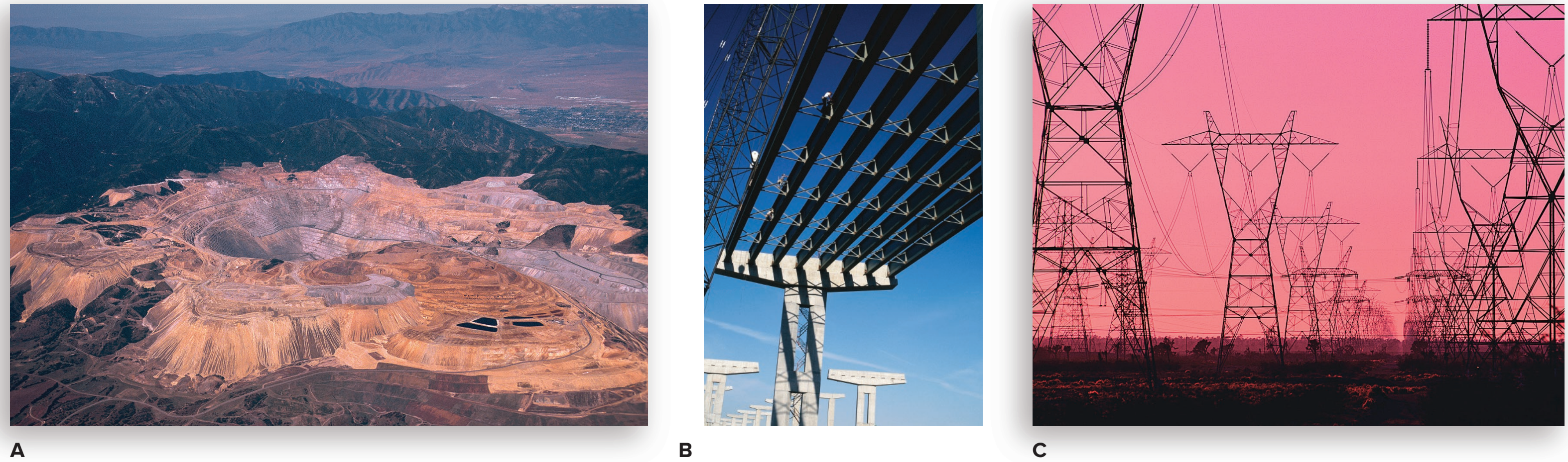


FIGURE 1.2 Rock and mineral deposits (A) provide the raw materials used for building (B) and operating our modern societies. The geologic resources known as fossil fuels provide the bulk of the energy used for powering (C) the industrial, transportation, and residential sectors of society.
(a) © Dr. Parvinder Sethi; (b) © Skip Nall/Getty Images; (c) © PhotoLink/Getty Images

FIGURE 1.3 In addition to locating resources, geologists study hazardous earth processes and use this knowledge to help society avoid or minimize the loss of life and property damage. Photo (A) shows a building that was destroyed during the 1995 earthquake in Kobe, Japan, and (B) shows the results of an earthquake-induced landslide in Las Colinas, El Salvador, in 2001.
(a) Roger Hutchinson/NOAA; (b) USGS

What Is Geology?

The science of **geology** is the study of the solid earth, which includes the materials that make up the planet and the various processes that shape it. Many students who are unfamiliar with geology tend to think it is just a study of rocks, and therefore must not be very interesting. However, this perception commonly changes once students realize how intertwined their own lives are with the geologic environment. For example, the success of our high-tech society is directly tied to certain minerals whose physical properties are used to perform vital tasks. Perhaps the most important are minerals containing the element copper, a metal whose ability to conduct electricity is absolutely essential to our modern way of life. Imagine doing without electric lights, refrigerators, televisions, cell phones, and the like. Because geologists study how minerals form, mining companies hire geologists to look for places where valuable minerals have become concentrated (Figure 1.2). Equally important is the ability of geologists to locate deposits of oil, gas, and coal, as these serve as society's primary source of energy. Geologists also provide valuable information as to how society can minimize the risk from hazardous Earth processes such as floods, landslides, earthquakes, and volcanic eruptions (Figure 1.3).

Geology has traditionally been divided into two main subdisciplines: physical geology and historical geology. **Physical geology** involves the study of the solid earth and the processes that shape and modify the planet, whereas **historical geology** interprets Earth's past by unraveling the information held in rocks. The most important geologic tool in both disciplines is Earth's 4-billion-year-old collection of rocks known as the *geologic rock record.* This vast record contains a wealth of information on topics ranging from the evolution of life-forms to the rise and fall of mountain ranges to changes in climate and sea level. Over the past 30 years or so a new subdiscipline has emerged called **environmental geology**, whereby geologic information is used to address problems arising from the interaction between humans and the geologic environment. Environmental geology is becoming increasingly important as population continues to expand, which in turn is leading to widespread pollution and shortages of certain resources, particularly water and energy. Population growth has also resulted in greater numbers of people living in areas where floods, earthquakes, volcanic eruptions, and landslides pose a serious risk to life and property.

The first step in solving our environmental problems is to understand the way in which various Earth processes operate and how humans interact with these processes. Once this interaction is understood, appropriate action can be taken to reduce or minimize the problems. The most effective way of accomplishing this is through *science,* which is the methodical approach developed by humans for learning about the natural world. Because science is critical to addressing our environmental problems, we will begin by taking a brief look at how science operates.

Scientific Inquiry

By our very nature, humans are curious about our surroundings. This natural curiosity has ultimately led to the development of a systematic and logical process that tries to explain how the physical world operates. We call this process *science,* which comes from the Latin word *scientia,* meaning "knowledge." Over the past several thousand years the human race has accumulated a staggering amount of scientific knowledge. Although we now understand certain aspects of the natural world in great detail, there is still a lot we do not understand. Throughout this period of discovery the public has generally remained fascinated with what scientists have learned about the physical world. Evidence for this fascination is the continued popularity of science programs currently available on television. It seems rather odd then that one of the common complaints in science courses is that nonscience majors find the subject boring. This raises the question of what is it about science courses that tends to cause students to lose their natural interest in science?

One reason, perhaps, for the loss of interest is that students are often required to memorize trivial facts and terminology. The problem is compounded when it is not made clear how this information is relevant to our own lives. Focusing on just the facts is unfortunate because it is the *explanation* of the facts that makes science interesting, not necessarily the facts themselves. Take, for example, the fact that coal is found on the continent of Antarctica, which sits directly over the South Pole (Figure 1.4). Because coal forms only in swamps where vegetation and liquid water are abundant, we can logically conclude that Antarctica at one time must have been relatively ice-free. This means that either the climate was much warmer in the past, or Antarctica was once located much closer to the equator. This leads us to ask the obvious: What could have caused the global climate to change so dramatically? Conversely, how could this giant landmass actually move to its present position? To answer these questions scientists must gather additional data (i.e., facts). This data will likely result in even more questions that need to be answered.

Science therefore can be thought of as a method by which people use data to discover how the natural world operates. Unlocking the secrets of nature is truly exciting, which is why most scientists love what they do. Anyone who has found a fossil or an old coin, for example, can relate to the thrill of discovery. A key point here is that nearly everyone practices science each and every day. When we observe dark clouds moving toward us we process this information (i.e., data) along with past observations, and logically conclude that a storm is approaching and that it is wise to seek shelter. A fisherman who keeps changing lures until he or she finds one that attracts a certain type of fish is also practicing science. Because science is fundamental to the topics discussed in this textbook, we will explore the actual process in more detail in the next section.

FIGURE 1.4 The basic goal of science is to use facts or data to explain different aspects of our natural world. For example, the coal beds shown here in Antarctica are a scientific fact. It's also a fact that coal forms only in lush swamps, which means Antarctica must have been ice-free at some point in the geologic past. The best explanation for this is that Earth's climate was much warmer in the past, or that Antarctica was once much closer to the equator.
Dr. Barrie McKelvey and N.C.N. Stephenson, Dept of Geophysics, University of New England

How Science Operates

Modern scientific studies of the physical world are based on the premise that the entire universe, not just planet Earth, behaves in a consistent and often predictable manner. When an event or phenomenon is observed repeatedly and consistently, it can be described as having a pattern. Discovering patterns in nature is important because it allows us to predict future events. For example, people long ago observed that the ocean rises and falls along coastlines on a regular basis. This pattern, known as the tides, is so regular that we can accurately predict when the sea will reach its maximum and minimum heights each day. In contrast, events such as floods and volcanic eruptions occur repeatedly, but on a more irregular or random basis. The random nature of certain types of events means that scientists can only predict their future occurrences in terms of statistical probabilities. Although recognizing natural patterns is a key component of science, the goal is to explain *how* and *why* things happen in the first place.

The process by which the physical world is examined in a logical manner is commonly referred to as the **scientific method**. The basic approach is to first gather factual data about the world through observations or by conducting experiments. Examples of data include such things as temperature readings, frequency of floods, and fossils preserved within rocks. Note that all scientific data can be observed and/or physically measured. Also, data are considered to be facts provided that scientists working independently of each other are able to repeat the work and obtain similar results. Once data are collected, scientists then seek to develop an explanation for the data itself and any patterns it may contain. For example, suppose a researcher collects marine fossils from rock layers that are 10,000 feet above sea level. The next step would be to develop a scientific explanation for the fossils that is consistent with other known data. In this case, any explanation would have to be consistent with the fact that the planet does not contain enough water for sea level to ever have been 10,000 feet higher than it is today. Logic dictates then that any plausible explanation must include a mechanism for uplifting the fossil-bearing rocks from sea level to their present position.

The term **hypothesis** refers to a scientific explanation of data that can be tested in such a way that it can be shown to be false or incorrect; something scientists refer to as being *falsifiable*. Supernatural explanations are not considered scientific simply because they are not testable and cannot be shown to be false. This concept of a hypothesis being falsifiable may seem odd since people generally think about trying to prove ideas to be true rather than false. Nevertheless, this is an important concept in science because a hypothesis is considered valid so long as additional testing does not show it to be false. Take, for example, how fossil evidence shows that dinosaurs went extinct 65 million years ago, whereas the first fossils of primitive humans (hominids) do not show up in the rock record until around 7 million years ago. Scientists have logically concluded, or hypothesized, that humans never coexisted with dinosaurs. This hypothesis would be proven to be false if hominid fossils are ever found in rocks of the same age as those that contain dinosaur fossils. Because extensive searches have never yielded such hominid fossils, the hypothesis that people and dinosaurs did not coexist remains valid.

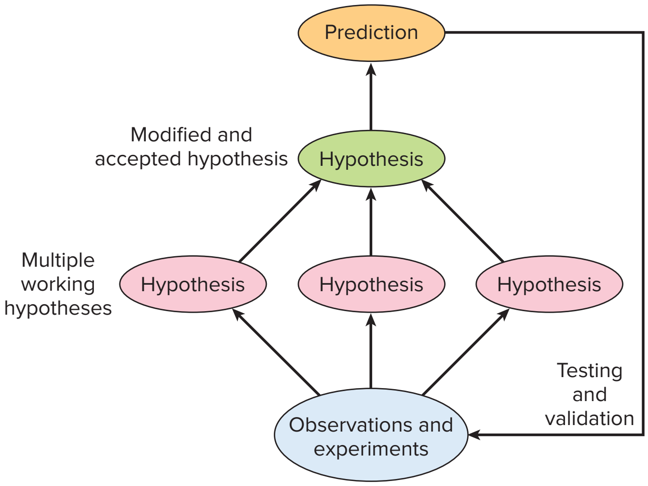


FIGURE 1.5 A scientific hypothesis is an explanation of known observations and experimental data. Multiple hypotheses are commonly developed, with most being discarded or modified as new data are gathered during testing and validation. Over time, a refined hypothesis normally emerges from the process and becomes generally accepted by the scientific community. Validation involves the ability of a hypothesis to predict future events.

Another key aspect of the methodology we call science is that during the early stages of an investigation researchers commonly come up with more than one plausible hypothesis for a given set of data. As shown in Figure 1.5, scientists refer to these different explanations as **multiple working hypotheses**, which are all considered valid so long as they are consistent with existing data. Because the goal of science is to seek out the best possible explanation, researchers continue to collect new data as they try to disprove one or more of the hypotheses. If an individual hypothesis is shown to be false, then it must either be modified or removed from consideration. Over time, this process of eliminating and refining hypotheses by gathering new data gives scientists greater and greater confidence in the validity of the remaining hypotheses. Note in Figure 1.5 that hypotheses are validated by their ability to predict future observations or experimental data. It should be emphasized that geology is more of an observational science than an experimental one, such as chemistry. This means that geologic hypotheses are typically tested or validated by making predictions that are confirmed through additional observations as opposed to controlled lab experiments. A good example is the hypothesis that humans and dinosaurs did not coexist, something that cannot be tested in a lab, but rather by observing more of the fossil record.

The terms *theory* and *hypothesis* are sometimes used interchangeably, but actually have different meanings. As indicated in Figure 1.6, a **theory** describes the relationship between several different and well-accepted hypotheses, providing a more comprehensive or unified explanation of how the world operates. In other words, a theory ties together seemingly unrelated hypotheses and allows us to see the "big picture." For example, the theories of atomic matter, relativity, and evolution unify various hypotheses within their respective disciplines of chemistry, physics, and biology. In geology the central unifying theory is known as the theory of plate tectonics (Chapter 4). This important theory explains how Earth's rigid crust is broken up into separate plates, which are in constant motion due to forces associated with the planet's internal heat. The movement of tectonic plates influences the location of continents and circulation of ocean currents, and consequently has a strong effect on the global climate system and biosphere on which we humans depend. As with all scientific theories, the theory of plate tectonics provides scientists with a larger context for understanding an array of different hypotheses. It should be emphasized that when scientists use the term *theory,* it has an entirely different meaning compared to its use by the general public. In common everyday language, the word "theory" is used to describe some educated guess or speculation. In science, however, a theory is a widely accepted and logical explanation of natural phenomena that has survived rigorous testing. Later we will examine how these different meanings of *theory* can impact public debate and policy considerations of environmental issues.

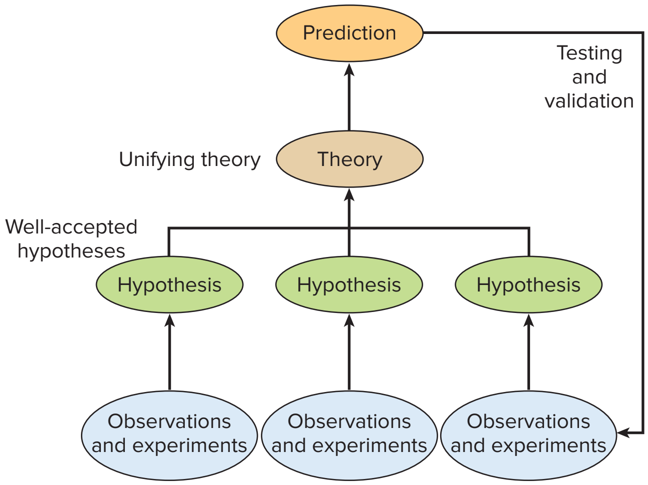


FIGURE 1.6 Scientific theories describe the relationship among different hypotheses and provide a more comprehensive or unified explanation of how the natural world operates. As with all scientific explanations, theories undergo repeated testing and validation.

There are some phenomena in nature where the relationship between different data occurs so regularly and with so little deviation that scientists refer to the relationship as a **law**. In some cases a law can be expressed mathematically, as in Newton's three laws of motion and gravitational law. An example of a law in geology is the *law of superposition,* which states that in a sequence of layered rocks derived from weathering and erosion (i.e., sedimentary rocks, Chapter 3), the layer on top is the youngest and the one on the bottom is the oldest. This simple and intuitive idea that sedimentary layers become progressively older with depth has been invaluable in using the geologic rock record to unravel Earth's history. Scientific laws, therefore, are quite useful despite the fact they do not necessarily unify different hypotheses and provide grand explanations as do theories.

A good example of how knowledge is advanced through the use of science is the discovery of the planet Neptune. Early astronomers noted strange wobbles in the elliptical orbits of the planets around the Sun, but could not explain the wobbling with the existing knowledge. It was not until after Isaac Newton published his theory of gravitation in 1687 that astronomers could explain that the wobbling was caused by the gravitational effects of planets in adjoining orbits. In the 1800s, scientists remained puzzled by the wobble in the orbit of Uranus since it was the outermost known planet at the time. This led some astronomers to predict that an unknown planet existed beyond Uranus's orbit and was causing the wobble. The planet Neptune was then discovered in 1846 when astronomers pointed a telescope at the exact position in