Seventeenth Edition

PHYSICAL Geology

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Mc Graw Hill

PHYSICAL GEOLOGY, SEVENTEENTH EDITION

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BRIEF CONTENTS

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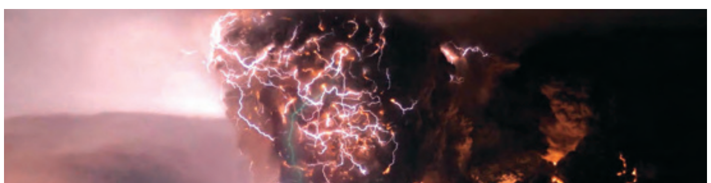

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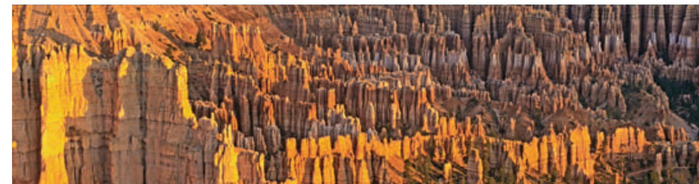

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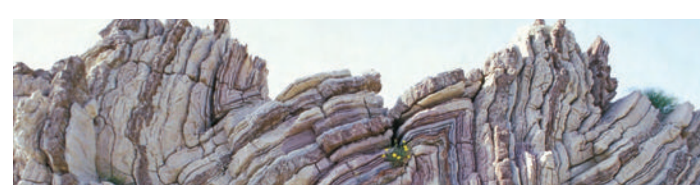

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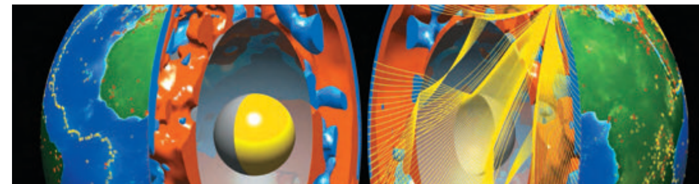

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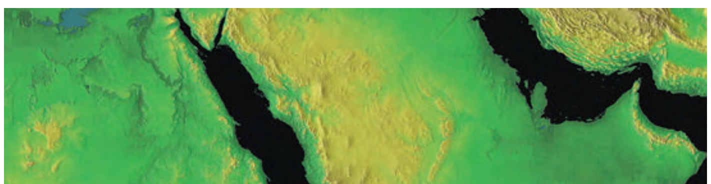

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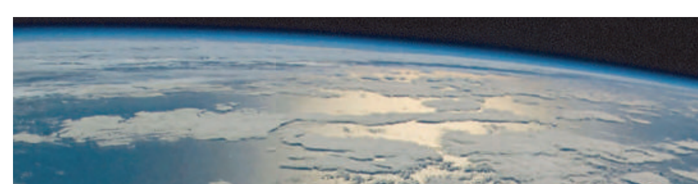

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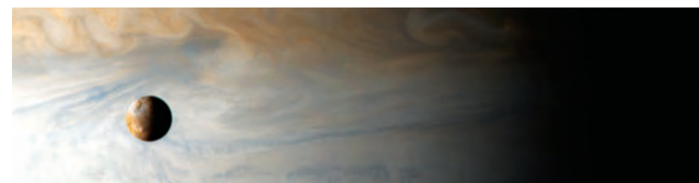


NASA/JPL/University of Arizona

PREFACE

WHY USE THIS BOOK?

One excellent reason is that it's tried and true. Since the book was first published in 1979, over 1,000,000 students have read this text as an introduction to physical geology. Proportionately, geology instructors have relied on this text for over 5,000 courses to explain, illustrate, and exemplify basic geologic concepts to both majors and non-majors. Today, the seventeenth edition continues to provide contemporary perspectives that reflect current research, recent natural disasters, unmatched illustrations, and unparalleled learning aids. We have worked closely with contributors, reviewers, and our editors to publish the most accurate and current text possible.

APPROACH

Our purpose is to clearly present the various aspects of physical geology so that students can understand the logic of what scientists have discovered, as well as the elegant way the parts are interrelated to explain how Earth, as a whole, works.

This approach is epitomized by our treatment of plate tectonics. Plate tectonics is central to understanding how the Earth works. Rather than providing a full-fledged presentation of plate tectonics at the beginning of the textbook and overwhelming students, *Physical Geology* presents the essentials of plate tectonics in the first chapter. Subsequent chapters then detail interrelationships between plate tectonics and major geologic topics. For example, chapter 3, on igneous activity, includes a thorough explanation of how plate tectonics accounts for the generation of magma and resulting igneous rocks. Chapter 19, typically covered late in the course, presents a full synthesis of plate tectonics. By this time, students have learned the many aspects of physical geology and can appreciate the elegance of plate tectonics as a unifying paradigm.

CHANGES TO THE SEVENTEENTH EDITION

New to the Seventeenth Edition

Each chapter has been revised and updated, and an overview of notable changes made to each chapter is given below:

Chapter 1 has been updated to reflect current resource usage and to improve readability. The information on careers in geology contained in box 1.3 has been updated.

Chapter 2 has been updated to improve readability. Figure 2.2 has been edited to improve clarity. The web box has been removed.

Chapter 3 includes an updated rock cycle figure that incorporates hand sample images of rocks rather than sketches. Changes have been made to section 3.3 to improve comprehension. Figure 3.25 has been replaced with a more modern image. The section on igneous activity and plate tectonics has been reorganized to improve flow.

Chapter 4 has been updated to reflect the change in eruption status at Kilauea, and a new box (4.2) has been added that describes the dramatic end of the Kilauea eruption.

Chapter 5 includes a revised rock cycle diagram that includes photos of rocks rather than sketches. The section on solution weathering and table 5.1 have been modified to more clearly show the solution of calcite. The effect of increased surface area on weathering processes has been revised to emphasize its importance.

Chapter 6 contains minor changes to increase clarity. A revised rock cycle figure has also been added to this chapter.

Chapter 7 has been updated to improve readability.

Chapter 8 has been updated to improve readability and clarify the Precambrian as a supereon. Box 8.2 has been updated to reflect the change in name of the K-T boundary to the K-Pg boundary.

Chapter 9 has minor rewrites to improve readability, and landslide fatality statistics have been updated.

Chapter 10 has undergone significant revision. Numerous sections have been updated and revised to improve readability and clarity. Figure 10.5 now includes aerial photos of rivers paired with sketches to illustrate the different types of drainage patterns. Box 10.1 on the controlled floods in the Grand Canyon has been replaced with a new box on the environmental consequences of the Three Gorges Dam in China. We have also added a new alluvial fan photo and replaced figure 10.37 with a new graph that more clearly shows how urbanization affects discharge rate. The summary and questions at the end of the chapter have also been revised.

Chapter 11 includes an extensively revised "fracking" box and new figure that more clearly explains the process of hydraulically fracturing a confined aquifer during horizontal drilling, and an updated discussion of possible environmental problems. Figure 11.16 has also been revised to more accurately illustrate a gasoline plume.

Chapter 12 has been edited to improve readability and contains new images of a U-shaped valley and a hanging valley. Box 12.2 has been updated to reflect more recent research on glacial surges and evidence for life in subglacial lakes in the Antarctic.

Chapter 13 includes an expanded discussion of deserts around the world and a revision of figure 13.3.

Chapter 14 has been extensively edited to improve readability. Box 14.1 has been revised and now includes a sea-level curve showing fluctuation from past glaciations and also a sea-level curve illustrating more recent variation and projected future sea-level rise based on IPCC emission scenarios. Box 14.2 has been updated to include category 5 Hurricanes Michael and Dorian. The summary has been revised to reflect the relationship between coastal landforms and processes and sea-level changes.

Chapter 15 contains edits of text and figures throughout the chapter to help clarify material for the student and improve readability.

Chapter 16 has been updated to include the largest, most deadly liquefaction event ever recorded after the 2018 Sulawesi, Indonesia, earthquake and associated tsunami that was intensified by submarine

Flow Images

landslides and offshore morphology. Figure 16.4 has been replaced with a new diagram that more realistically shows the motion of body and surface waves. Minor edits were made throughout the chapter to improve clarity.

Chapter 17 has been extensively revised. Many sections have been rewritten to improve clarity and make the subject more approachable. We have added photos of geologists using geophysical equipment in the field. The gravity section now includes a geoid image from NASA's GRACE mission. We replaced figure 17.2 with a new seismic reflection profile from the SHIRE research project at the Hikurangi plate margin that shows intensely folded and faulted sediments. Box 17.1 has been updated to reflect the successful results of the EarthScope program, and we also included a new seismic tomography image from the mantle plume under Yellowstone. We added a new planetary geology box (17.2) that discusses the interiors of other planets. We also replaced the "Earth's Spinning Core" box with a new box (17.3) describing "Geophysical Methods of Exploration: How a Geologist Sees Underground." The summary has been expanded and completely rewritten in a more narrative style.

Chapter 18 has undergone minor edits of text and photo captions. We have adopted *Wadati-Benioff zone* to more accurately name this important tectonic feature.

Chapter 19 begins with a rewritten introduction that more clearly states how the plate tectonic theory has unified the study of geology. The "Early Case for Continental Drift" section has also been rewritten, and the entire chapter has been extensively revised to improve readability and clarity.

Chapter 20 has undergone minor editing for improved readability.

Chapter 21 has been updated to reflect the rapid changes in the study of climate change. Figures 21.11, 21.12, 21.14, and 21.18 have been updated to include the most recent data available. Figures 21.22 and 21.20 have been updated to reflect current understanding of the impacts of climate change.

Chapter 22 has been updated to reflect changes in the demand for, and price of, various resources, as well as changes in global production and estimates of total reserves remaining.

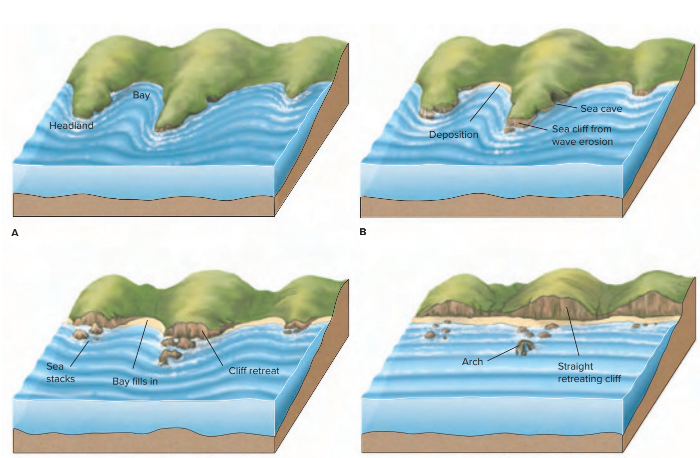
Chapter 23 has been edited to significantly improve readability. Multiple images of planets and moons have been replaced with newer images that have become available in recent years. The section on Mars has been updated to reflect new results from the *InSight* mission, and the section on Pluto has been completely rewritten to reflect new knowledge gained from the *New Horizons mission*.

KEY FEATURES

Superior Photo and Art Programs

Geology is a visually oriented science, and one of the best ways to learn it is by studying illustrations and photographs. The outstanding photo and art programs in this text feature accuracy in scale, realism, and aesthetic appeal that provides students with the best visual learning tools available in the market. We strive to have the best photographs possible so that they are the next best thing to seeing geology on a field trip. We are again pleased to feature aerial photography from award-winning photographer/geologist Michael Collier, who gives students a birds-eye view of spectacular geology from western North America.

©Michael Collier



Learning Objectives

Each chapter begins with a bulleted list of learning objectives to help students focus on what they should know and understand after reading the chapter.

> **LEARNING OBJECTIVES**
>
> - Differentiate between effusive and explosive eruptions, and describe the eruptive products associated with them.
> - Explain the relationship between magma composition, temperature, dissolved gas, and viscosity and relate them to eruptive violence.
> - Describe the five major types of volcanoes in terms of shape and eruptive style.

Environmental Geology Boxes

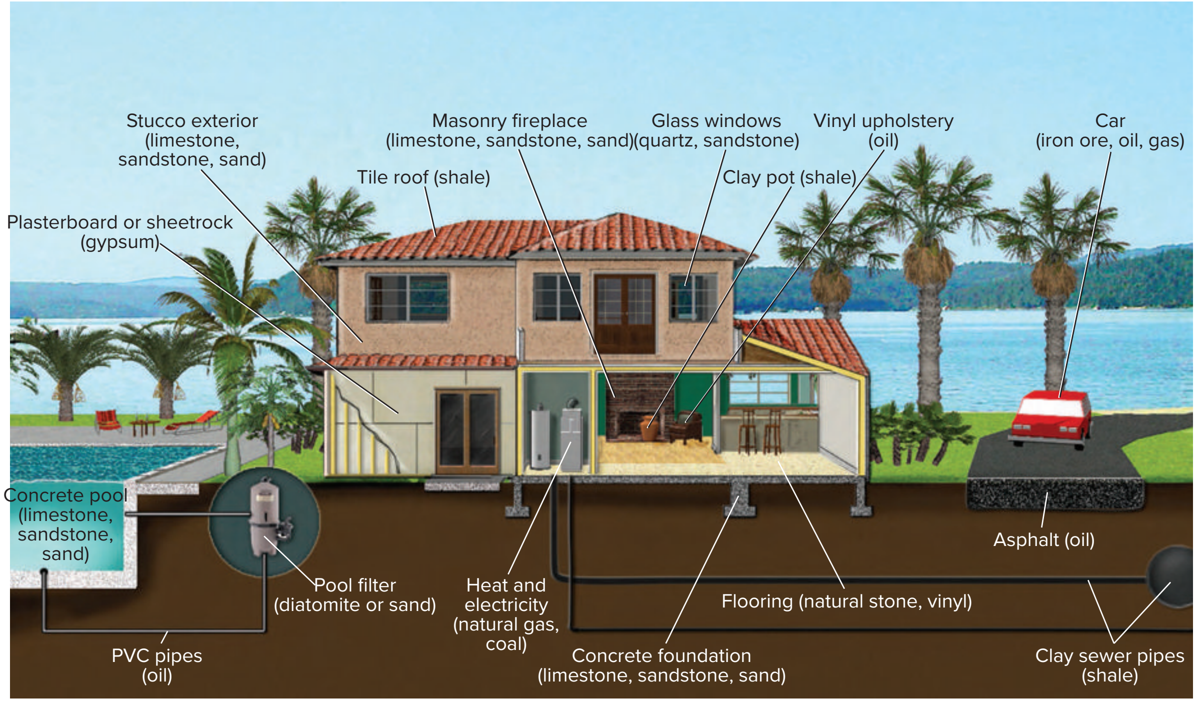
Discuss topics that relate the chapter material to environmental issues, including impact on humans (For example: "Radon—A Radioactive Health Hazard" and "Coasts in Peril--The Effects of Rising Sea Level," "Sinkholes as a Geologic Hazard," "The Gulf of Mexico Spill--The Cost of Oil Exploration in Ever More Difficult-to-Reach Areas," and "The Nuclear Crisis in Japan--The Future of Nuclear Power Put to the Test").

DigitalGlobe/Contributor/Getty Images

Gregory Bull/AP Images

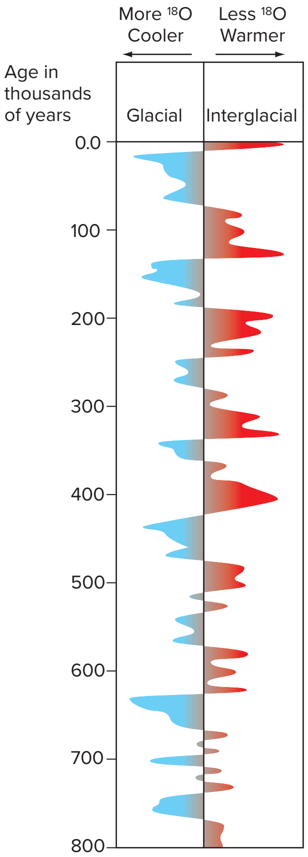
In Greater Depth Boxes

Discuss phenomena that are not necessarily covered in a geology course (For example: "Precious Gems," "Is There Oil Beneath My Property? First Check the Geologic Structure," and "Valuable Sedimentary Rocks") or present material in greater depth (e.g., "Calculating the Age of a Rock").



Earth Systems Boxes

Highlight the interrelationships between the geosphere, the atmosphere, and other Earth systems (For example: "Global Warming and Glaciers" and "Oxygen Isotopes and Climate Change").



Planetary Geology Boxes

Compare features elsewhere in the solar system to their Earthly counterparts (For example: "Sedimentary Rocks: The Key to Mars' Past").

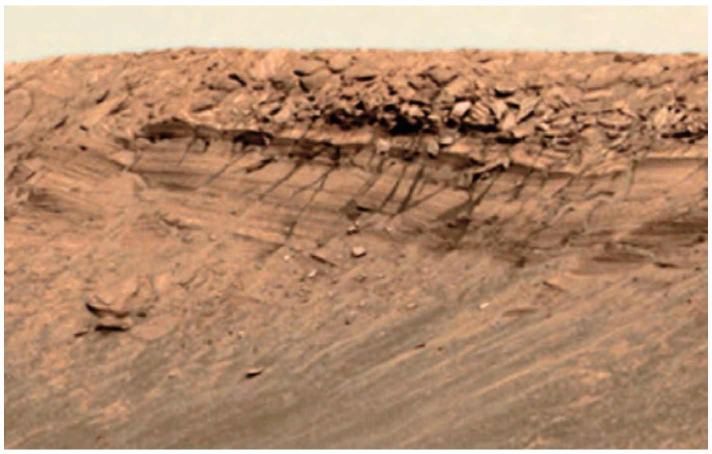
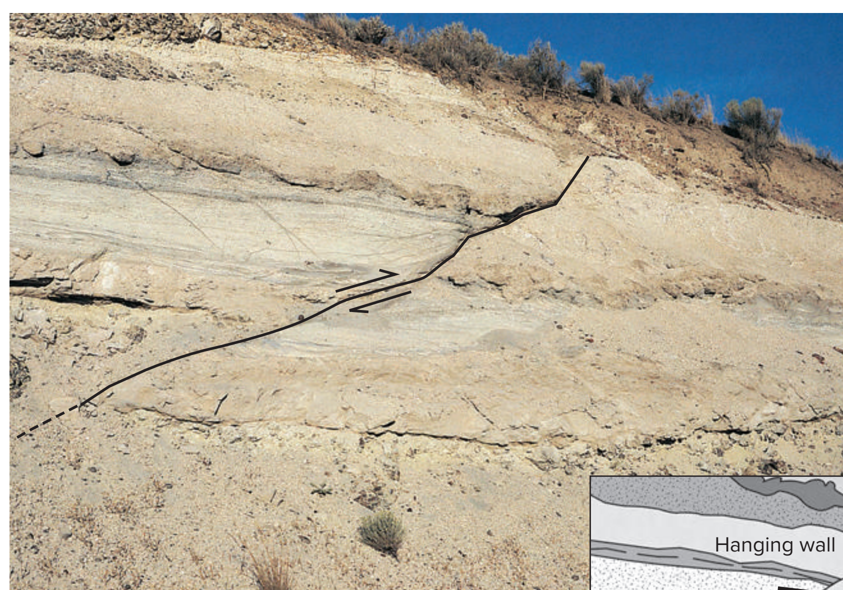


Photo by NASA/JPL/Cornell

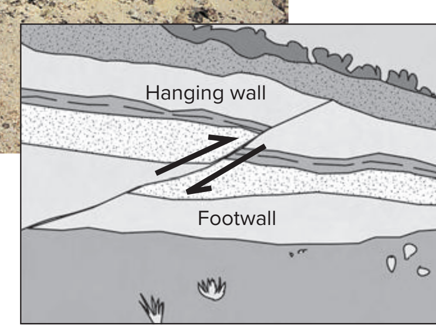
NASA/JPL-Caltech/MSSS

A Geologist's View

Photos accompanied by an illustration depicting how a geologist would view the scene are featured in the text. Students gain experience understanding how the trained eye of a geologist views a landscape in order to comprehend the geologic events that have occurred.



Diane Carlson



Study Aids are found at the end of each chapter and include:

- *Summaries* bring together and summarize the major concepts of the chapter.
- *Terms to Remember* include all the boldfaced terms covered in the chapter so that students can verify their understanding of the concepts behind each term.
- *Testing Your Knowledge Quizzes* allow students to gauge their understanding of the chapter and are aligned with the learning objectives presented at the beginning of each chapter. (The answers to the multiple choice portions are posted on Connect.)
- *Expanding Your Knowledge Questions* stimulate a student's critical thinking by asking questions with answers that are not found in the textbook.

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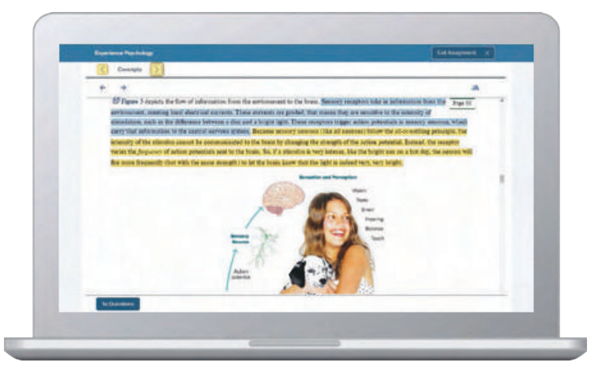

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"I really liked this app—it made it easy to study when you don't have your text-book in front of you."

- Jordan Cunningham, Eastern Washington University

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Instructor Resources

The following resources can be found on Connect:

- ***Presentation Tools*** Everything you need for outstanding presentations.
  - Animations—Numerous full-color animations illustrating important processes are provided. Harness the visual impact of concepts in motion by importing these files into classroom presentations or online course materials.
  - Lecture PowerPoints—with animations fully embedded.
  - JPEG images—Full-color digital files of all illustrations that can be readily incorporated into presentations, exams, or custom-made classroom materials.
  - Tables—Tables from the text are available in electronic format.
- ***Google Earth and Virtual Vista Exercises***—Descriptions and questions to help students visualize and analyze geologic features.
- ***Instructor's Manual***—The instructor's manual contains chapter outlines, lecture enrichment ideas, and critical thinking questions.
- ***Computerized Test Bank***—A comprehensive bank of test questions is provided within a computerized test bank. Instructors can select questions from multiple McGraw-Hill test banks or author their own, and then either print the test for paper distribution or give it online.

ACKNOWLEDGMENTS

We have tried to write a book that will be useful to both students and instructors. We would be grateful for any comments by users, especially regarding mistakes within the text or sources of good geological photographs.

Although he is no longer listed as an author, this edition bears a lot of the writing style and geologic philosophy of the late David McGeary. He was coauthor of the original edition, published in 1979. His authorship continued through the seventh edition, after which he retired and turned over revision of his half of the book to Diane Carlson. We greatly appreciate his role in making this book successful way beyond what he or his original coauthor ever dreamed of.

Tom Arny wrote the planetary geology chapter for the tenth edition. This chapter was revised and updated by Steve Kadel for the eleventh and twelfth editions and by Mark Boryta for the fifteenth edition. Chris Cappa and Delphine Farmer wrote the chapter on climate change for the fourteenth edition, and Professor Cappa has continued to revise chapter 21 in subsequent editions. We greatly appreciate the publisher's "book team" whose names appear on the copyright page. Their guidance, support, and interest in the book were vital for the completion of this edition.

Thank you also to Cindy Shaw for her contribution to the superior art program of the eleventh and twelfth editions.

Diane Carlson would like to thank her husband Reid Buell for his tireless support, and for his technical assistance with engineering geology and hydrogeology material, in several chapters. Charles Plummer thanks his wife Beth Strasser for assistance with photography in the field, and for her perspective as a paleontologist and anthropologist. Lisa Hammersley would like to thank her husband Chris Cappa for his support, and for agreeing to find time to write the climate change chapter for this book.

We are appreciative of the following contributing authors for their work on the seventeenth edition:

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Amelia Vankeuren, *California State University, Sacramento*

The following individuals helped write and review learning goal–oriented content for LearnSmart for Geology:

Sylvester Allred, *Northern Arizona University*
Lisa Hammersley, *California State University, Sacramento*
Arthur C. Lee, *Roane State Community College*

Through each edition of *Physical Geology*, we have had outstanding feedback from reviewers who have provided careful evaluations and useful suggestions for improvement.

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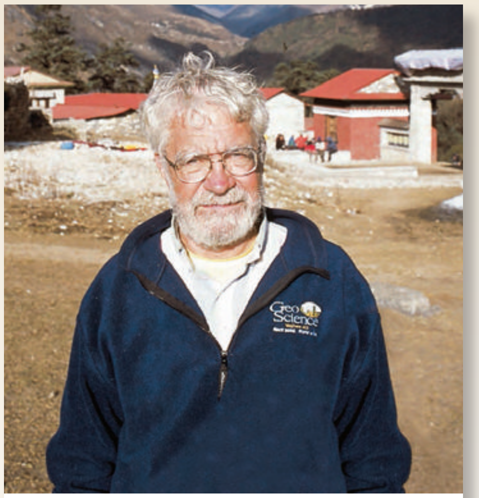
Pete van Hengstum, *Texas A&M University at Galveston*
Stacey Verardo, *George Mason University*
Amy J. Wagner, *California State University, Sacramento*

MEET THE AUTHORS



Charles Plummer

Charles Plummer at Tengboche, in the Himalayan Mountains of Nepal.

Reid Buell

Diane Carlson at Convict Lake in the Sierra Nevada Mountains of California.

Christopher Cappa

Lisa Hammersley on the coast of Northern California

CHARLES PLUMMER Professor Charles "Carlos" Plummer grew up in the shadows of volcanoes in Mexico City. There, he developed a love for mountains and mountaineering that eventually led him into geology. He received his B.A. degree from Dartmouth College. After graduation, he served in the U.S. Army as an artillery officer. He resumed his geological education at the University of Washington, where he received his M.S. and Ph.D. degrees. His geologic work has been in mountainous and polar regions, notably Antarctica (where a glacier is named in his honor). He taught at Olympic Community College in Washington and worked for the U.S. Geological Survey before joining the faculty at California State University, Sacramento.

At CSUS, he taught optical mineralogy, metamorphic petrology, and field courses as well as introductory courses. He retired from teaching in 2003. He skis, has a private pilot license, and is certified for open-water SCUBA diving. (plummercc@csus.edu)

DIANE CARLSON Professor Diane Carlson grew up on the glaciated Precambrian shield of northern Wisconsin and received an A.A. degree at Nicolet College in Rhinelander and a B.S. in geology at the University of Wisconsin at Eau Claire. She continued her studies at the University of Minnesota–Duluth, where she focused on the structural complexities of high-grade metamorphic rocks along the margin of the Idaho batholith for her master's thesis. The lure of the West and an opportunity to work with the U.S. Geological Survey to map the Colville batholith in northeastern Washington led her to Washington State University for her Ph.D. Dr. Carlson accepted a position at California State University, Sacramento, after receiving her doctorate and taught physical geology, structural geology, environmental geology, field techniques, and field geology. Professor Carlson is a recipient of the Outstanding Teacher Award from the CSUS School of Arts and Sciences. She is also engaged in researching the structural and tectonic evolution of part of the Foothill Fault System in the northern Sierra Nevada of California. (carlsondh@csus.edu)

LISA HAMMERSLEY Dr. Lisa Hammersley hails originally from England and received a B.Sc. in geology from the University of Birmingham. After graduating, she traveled the world for a couple of years before returning to her studies and received a Ph.D. in geology from the University of California at Berkeley. She joined the faculty at California State University, Sacramento in 2003, where she taught natural disasters, physical geology, geology of Mexico, mineralogy, and metallic ore deposits, receiving the Outstanding Teacher Award from the College of Natural Sciences and Mathematics in 2011. Dr. Hammersley specializes in igneous petrology with an emphasis on geochemistry. Her interests involve understanding magma chamber processes and how they affect the evolution of volcanic systems. She has worked on volcanic systems in Ecuador, Mexico, and the United States. Dr. Hammersley has also worked in the field of geoarcheology, using geologic techniques to identify the sources of rocks used to produce stone grinding tools found near the pyramids of Teotihuacan in Mexico. She is currently serving as the Associate Dean of the College of Natural Sciences and Mathematics. (hammersley@csus.edu)

CHAPTER 1

Introducing Geology, the Essentials of Plate Tectonics, and Other Important Concepts

Mount Robson, 3,954 meters (12,972 feet) above sea level, is the highest peak in the Canadian Rocky Mountains.
J. A. Kraulis/Masterfile

LEARNING OBJECTIVES

- Know what physical geology is, and describe some of the things it is used for.
- Define a system, and describe the four Earth systems (spheres).
- Distinguish between the Earth's internal and external heat engines and list the processes driven by them.
- List the three major internal zones of the Earth.
- Describe the lithosphere and the asthenosphere.
- Sketch and label the different types of plate boundaries.
- Summarize the scientific method, and define the meaning of the word *theory.*
- Know the age of the Earth.

Have you ever looked out of the window of an airplane and wondered about the landforms that you see below you, or examined a pebble on a beach and wondered how it got there? Have you ever listened to a news report about a major natural disaster such as an earthquake, flood, or volcanic eruption, and asked yourself why it happened and what you would do if you found yourself in such a situation? What about the materials used to manufacture the electronics you use every day or the gasoline used to fuel your car—have you ever thought about where they come from, how they formed, and how we exploit them? These topics are all parts of **geology**—the scientific study of the Earth. Geologists use the scientific method to explain natural aspects of the Earth, such as what it is made of and the processes that affect it, and to interpret Earth's history. This chapter is an introduction to geology. We will first explore the uses of geology before introducing some of the important concepts such as the modern theory of plate tectonics and geologic time. These concepts form a framework for the rest of the book. Understanding the "big picture" presented here will aid you in comprehending the chapters that follow.

Strategy for Using This Textbook

- As authors, we try to be thorough in our coverage of topics so the textbook can serve you as a resource. Your instructor may choose, however, to concentrate only on certain topics for *your* course. Find out which topics and chapters you should focus on in your studying and concentrate your energies there.
- Your instructor may present additional material that is not in the textbook. Take good notes in class.
- Try not to get overwhelmed by terms. (Every discipline has its own language.) If you associate a term with a concept or mental picture, remembering the term comes naturally when you understand the concept. (You remember names of people you know because you associate personality and physical characteristics with a name.) You may find it helpful to learn the meanings of frequently used prefixes and suffixes for geological terms. These can be found in appendix G.
- **Boldfaced** terms are ones you are likely to need to understand because they are important to the entire course.
- *Italicized* terms are not as important but may be necessary to understand the material in a particular chapter.
- Pay particular attention to illustrations. Geology is a visually oriented science, and the photos and artwork are at least as important as the text. You should be able to sketch important concepts from memory.
- Find out to what extent your instructor expects you to learn the material in the boxes. They offer an interesting perspective on geology and how it is used, but much of the material might well be considered optional for an introductory course and not vital to your understanding of major topics. Many of the In Greater Depth boxes are meant to be challenging—do not be discouraged if you need your instructor's help in understanding them.
- Read through the appropriate chapter before going to class. Reread it after class, concentrating on the topics covered in the lecture or discussion. Especially concentrate on concepts that you do not fully understand. Return to previously covered chapters to refresh your memory on necessary background material.
- Use the end-of-chapter material for review. The Summary is just that, a summary. Don't expect to get through an exam by only reading the summary and not the rest of the chapter. Use the Terms to Remember to see if you can visually or verbally associate the appropriate concept with each term. Answer the Testing Your Knowledge questions in writing. Be honest with yourself. If you are fuzzy on an answer, return to that portion of the chapter and reread it. Remember that these are just a sampling of the kinds of questions that might be on an exam.
- Geology, like most science, builds on previously acquired knowledge. You must retain what you learn from chapter to chapter. If you forget or did not learn significant concepts covered early in your course, you will find it frustrating later in the course. (To verify this, turn to chapter 20 and you will probably find it intimidating; but if you build on your knowledge as you progress through your course, the chapter material will fall nicely into place.)
- Be curious. Geologists are motivated by a sense of discovery. We hope you will be, too.

1.1 WHO NEEDS GEOLOGY?

Geology benefits you and everyone else on this planet. The clothes you wear, the food you eat, your smart phone, and your car exist because of what geologists have discovered about the

Earth. The Earth can also be a killer. You might have survived an earthquake, flood, or other natural disaster thanks to action taken based on what scientists have learned about these hazards. Before getting into important scientific concepts, we will look at some of the ways geology has benefited you and will continue to do so.

Supplying Things We Need

We depend on the Earth for energy resources and the raw materials we need for survival, comfort, and pleasure. Every manufactured object relies on Earth's resources—even something as simple as a pencil (figure 1.1). Earth processes, at work for millions of years, have localized material into concentrations that humans can mine or extract. By learning how the Earth works and how different kinds of substances are distributed and why, we can intelligently search for metals, sources of energy, and gems. Even maintaining a supply of sand and gravel for construction purposes depends on an understanding of geology.

Modern society currently depends on abundant and cheap energy sources. Nearly all our vehicles and machinery are powered by petroleum, coal, or nuclear power and depend on energy sources concentrated unevenly in the Earth. The U.S. economy, in particular, is geared to petroleum and natural gas as cheap sources of energy. It is important to remember, however, that these resources took hundreds of millions of years to form, and they are being rapidly depleted. In recent years, the United States has been able to reduce its reliance on imported oil by developing technology to access oil that was previously too difficult or too expensive to extract. Finding more of this diminishing resource will require more money and increasingly sophisticated knowledge of geology. Although many people are not aware of it, we face similar problems with diminishing resources of other materials, notably metals such as iron, aluminum, copper, and tin, each of which has been concentrated in a particular environment by the action of the Earth's geologic processes.

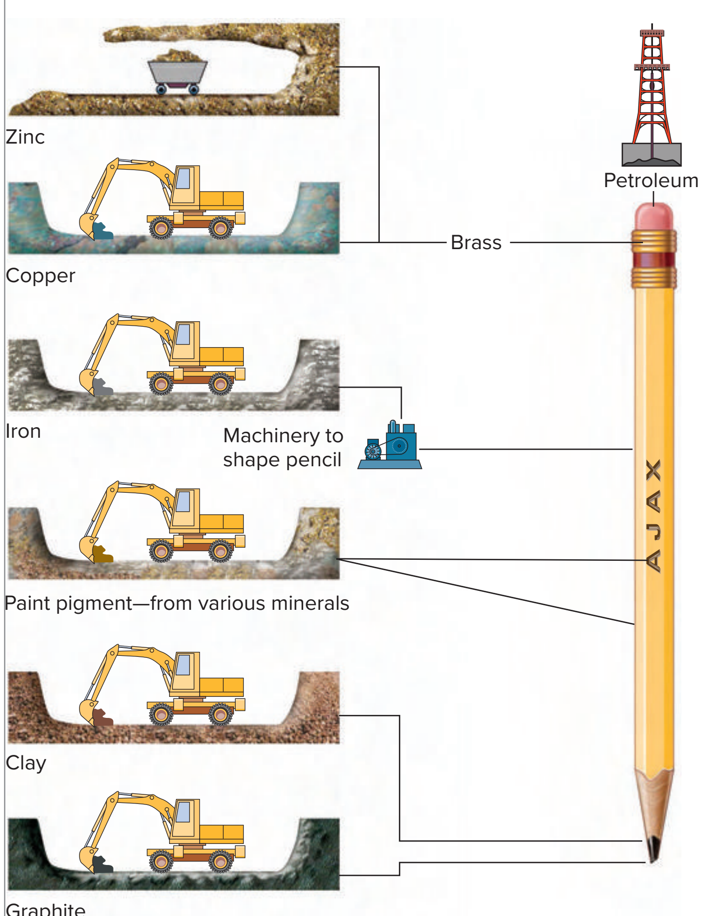


FIGURE 1.1

Earth's resources needed to make a wooden pencil.

Just how much of our resources do we use? According to the Minerals Education Coalition, approximately 18,430 kilograms (40,633 pounds; for metric conversions, go to appendix E) of resources, including energy resources, must be mined annually to provide for every person in the United States. The amount of each commodity mined per person per year is 4,501 kilograms stone, 3,332 kilograms sand and gravel, 306 kilograms limestone for cement, 70 kilograms clays, 174 kilograms salt, 283 kilograms other nonmetals, 116 kilograms iron ore, 12 kilograms aluminum ore, 3 kilograms copper, 8 kilograms lead and zinc, 3 kilograms manganese, and 5 kilograms other metals. Americans' yearly per capita consumption of energy resources includes 3,626 liters (958 gallons) of petroleum, 1,908 kilograms of coal, 2,775 cubic meters (97,988 cubic feet) of natural gas, and 0.06 kilograms of uranium.

Protecting the Environment

Our demands for more energy and metals have, in the past, led us to extract them with little regard for effects on the environment and therefore, on ourselves. Mining of coal, if done carelessly, for example, can release acids into water supplies. Understanding geology can help us lessen or prevent damage to the environment—just as it can be used to find the resources in the first place.

The environment is further threatened because these are nonrenewable resources. Petroleum and metal deposits do not grow back after being harvested. As demands for these commodities increase, so does the pressure to disregard the ecological damage caused by the extraction of the remaining deposits. As the supply of resources decreases, we are forced to exploit them from harder-to-reach locations. The Deepwater Horizon oil spill in the Gulf of Mexico in 2010 was due in part to the very deep water in which drilling was taking place (see box 22.2).

Geology has a central role in these issues. Oil companies employ geologists to discover new oil fields, while the public and government depend on other geologists to assess the potential environmental impact of petroleum's removal from the ground, the transportation of petroleum (see box 1.1), and disposal of any toxic wastes from petroleum products.

The consumption of resources, in particular energy resources, is also affecting the Earth's climate. Chapter 21 covers the evidence for global climate change and its connection to greenhouse gases released by burning fossil fuels.