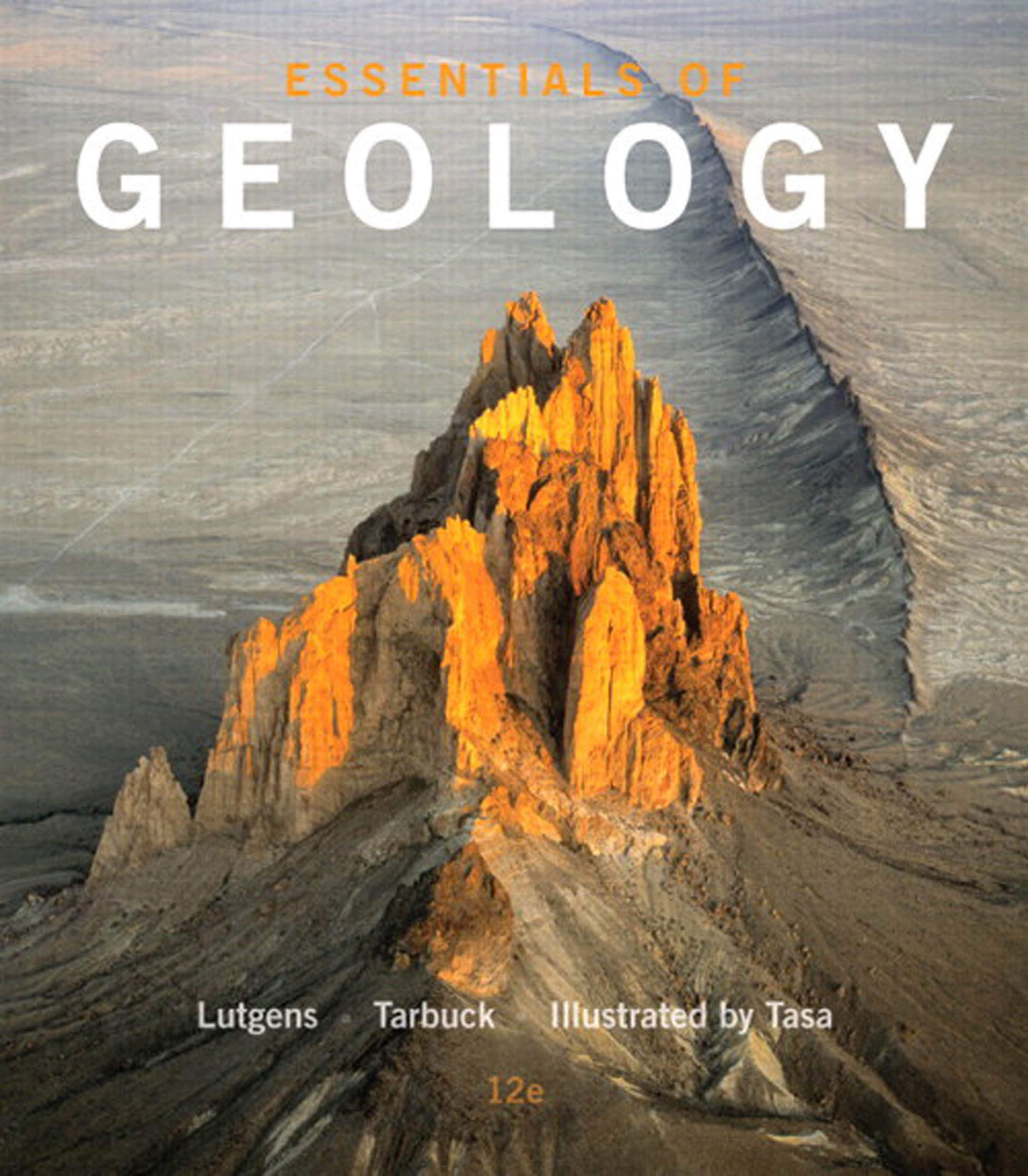
ESSENTIALS OF GEOLOGY



Lutgens · Tarbuck · Illustrated by Tasa

12e

ESSENTIALS OF GEOLOGY

12e

Frederick K. Lutgens
Edward J. Tarbuck

ILLUSTRATED BY

Dennis Tasa

PEARSON

Boston Columbus Indianapolis New York San Francisco Upper Saddle River
Amsterdam Cape Town Dubai London Madrid Milan Munich Paris Montréal Toronto
Delhi Mexico City São Paulo Sydney Hong Kong Seoul Singapore Taipei Tokyo

Acquisitions Editor: Andrew Dunaway
Senior Marketing Manager: Maureen McLaughlin
Project Manager: Crissy Dudonis
Project Management Team Lead: Gina M. Cheselka
Executive Development Editor: Jonathan Cheney
Director of Development: Jennifer Hart
Content Producer: Timothy Hainley
Project Manager, Instructor Media: Eddie Lee
Editorial Assistant: Sarah Shefveland
Senior Marketing Assistant: Nicola Houston
Full Service/Composition: Cenveo® Publisher Services
Project Manager, Full Service: Heidi Allgair
Photo Manager: Maya Melenchuk
Photo Researcher: Kristin Piljay
Text Permissions Manager: Alison Bruckner
Design Manager: Derek Bacchus
Interior Design: Elise Lansdon Design
Cover Design: Derek Bacchus
Photo and Illustration Support: International Mapping
Operations Specialist: Christy Hall
Cover Image Credit: Michael Collier

Credits and acknowledgments borrowed from other sources and reproduced, with permission, in this textbook appear on the appropriate page within text or are listed below.

Page 6: Quote from Aristotle, translated by Adams, F.D., in The Birth and Development of the Geological Sciences, Dover Publications, 1954; **Page 7:** Quote from James Hutton, Theory of the Earth, 1785; **Page 7:** Quote from William L. Stokes, Essentials of Earth History, Prentice Hall, Inc. 1973, p. 20; **Page 8:** Quote from James Hutton, Transactions of the Royal Society of Edinburgh, 1788; **Page 10:** Quote from Jacob Bronowski, The Common Sense of Science, p. 148, Harvard University Press, 1953; **Page 11:** Quote from F. James Rutherford and Andrew Ahlgren, Science for All Americans (New York: Oxford University Press, 1990), p. 7; **Page 11:** Quote from Speech delivered at Douai on December 7, 1854 on the occasion of his formal inauguration to the Faculty of Letters of Douai and the Faculty of Sciences of Lille), reprinted in: Pasteur Vallery-Radot, ed., Oeuvres de Pasteur (Paris, France: Masson and Co., 1939), vol. 7, page 131; **Page 37:** Quote from Alfred Wegener, The Origin of Continents and Oceans, translated from the 4th revised German ed. of 1929 by J. Birman (London: Methuen, 1966); **Page 38:** R. T. Chamberlain, quoted from Hallam, A. (1973) A Revolution in the Earth Sciences. Clarendon Press, Oxford; **Page 106:** Quote from Lee Green, MD, an associate professor at the University of Michigan Medical School; **Page 170:** Quote from Jack Eddy, "A Fragile Seam of Dark Blue Light," in Proceedings of the Global Change Research Forum. U.S. Geological Survey Circular 1086, 1993, p. 15; **Page 259:** Quote from Walter Mooney, a USGS seismologist; **Page 353:** Quote from Exploration of the Colorado River of the West (Washington, DC: Smithsonian Institution, 1875), p. 203; **Page 417:** Quote from J. D. Hays, John Imbrie, and N. J. Shackelton, "Variations in the Earth's Orbit: Pacemaker of the Ice Ages," Science 194 (1976): 1121–32. p. 1131; **Page 435:** Quote from R. A. Bagnold, The Physics of Blown Sand and Desert Dunes, 2005; **Page 476:** Quote from James Hutton, Transactions of the Royal Society of Edinburgh, 1805; **Page 486:** Quote from B. Bryson, A Short History of Nearly Everything (Broadway Books, 2003); **Page 545:** Quote from IPCC, "Summary for Policy Makers." In Climate Change 2013: The Physical Science Basis; **Page 551:** Quote from J. T. Overpeck, et al., "Arctic System on Trajectory to New, Seasonally Ice-Free States," EOS, Transactions, American Geophysical Union, 86 (34): 309, August 23, 2005; **Page 553:** National Assessment Synthesis Team, Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change (Washington, DC: U.S. Global Research Program, 2000), p. 19.

Library of Congress Cataloging-in-Publication Data

Lutgens, Frederick K.
Essentials of geology/Frederick K. Lutgens, Edward J. Tarbuck; illustrated by Dennis Tasa.–Twelfth edition.
pages cm
Includes index.
ISBN-13: 978-0-321-94773-4
ISBN-10: 0-321-94773-8
1. Geology–Textbooks. I. Tarbuck, Edward J. II. Title.
QE26.3.L87 2015
550–dc23

2014043897

1 2 3 4 5 6 7 8 9 10—CKV—18 17 16 15 14

PEARSON

www.pearsonhighered.com

ISBN-10: 0-321-94773-8
ISBN-13: 978-0-321-94773-4

Find SmartFigures and Mobile Field Trip Figures

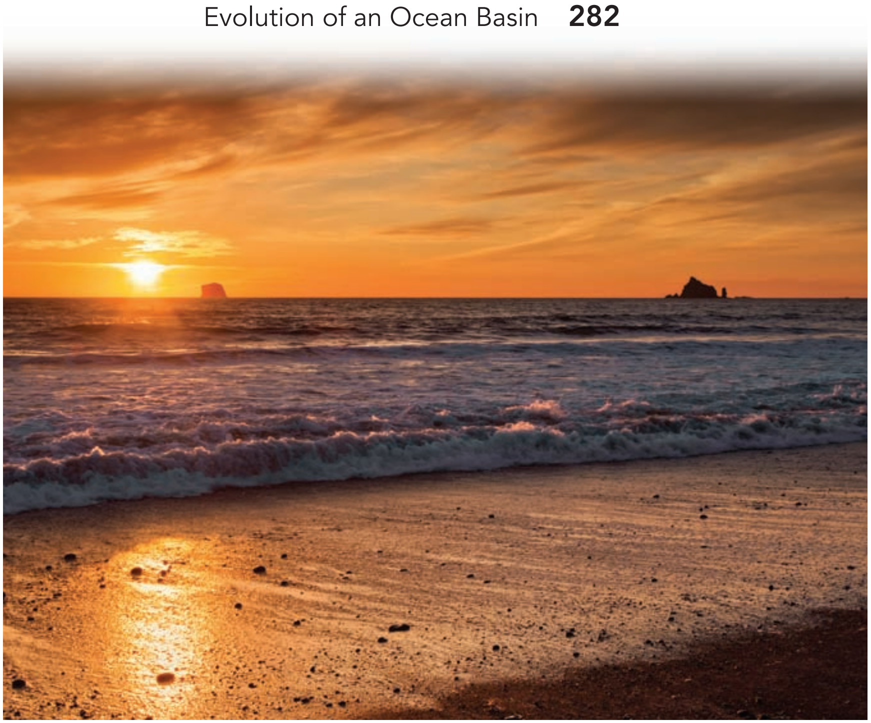
In addition to the many informative and colorful illustrations and photos throughout this text, you will find two kinds of special figures that offer additional learning opportunities. These figures contain QR codes which the student can scan with a smart phone to explore exciting expanded online learning materials.

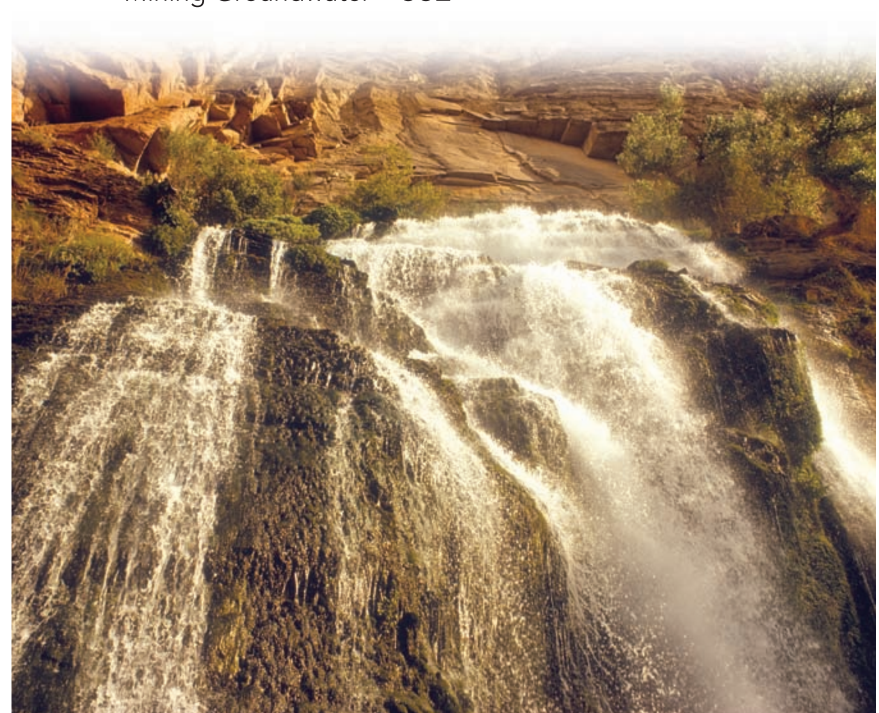
Find **SmartFigures** where you see this icon.

Find **Mobile Field Trip** Figures where you see this icon.

Brief Contents

Contents





Preface

The 12th edition of *Essentials of Geology,* like its predecessors, is a college-level text for students taking their first and perhaps only course in geology. The text is intended to be a meaningful, nontechnical survey for people with little background in science. Usually students are taking this class to meet a portion of their college's or university's general requirements.

In addition to being informative and up-to-date, a major goal of *Essentials of Geology* is to meet the need of beginning students for a readable and user-friendly text; a text that is a highly usable tool for learning the basic principles and concepts of geology.

New to the This Edition

- **New and expanded active learning path.** *Essentials of Geology*, 12th edition, is designed for learning. Every chapter begins with *Focus on Concepts*. Each numbered learning objective corresponds to a major section in the chapter. The statements identify the knowledge and skills students should master by the end of the chapter, helping students prioritize key concepts.


9

Earthquakes and Earth's Interior

Focus on Concepts

Each statement represents the primary learning objective for the corresponding major heading within the chapter. After you complete the chapter, you should be able to:

9.1 Sketch and describe the mechanism that generates most earthquakes.

9.2 Compare and contrast the types of seismic waves and describe the principle of the seismograph.

9.3 Explain how seismographs are used to locate the epicenter of an earthquake.

9.4 Distinguish between intensity scales and magnitude scales.

9.5 List and describe the major destructive forces that earthquake vibrations can trigger.

9.6 Locate Earth's major earthquake belts on a world map and label the regions associated with the largest earthquakes.

9.7 Compare and contrast the goals of short-range earthquake predictions and long-range forecasts.

9.8 Explain how Earth acquired its layered structure and briefly describe how seismic waves are used to probe Earth's interior.

9.9 List and describe each of Earth's major layers.

Tsunami striking the coast of Japan on March 11, 2011. *(Photo by Sadatsugu Tomizawa/AFP/Getty Images)*

9.1 What Is an Earthquake?

Sketch and describe the mechanism that generates most earthquakes.

Did You Know?

Literally thousands of earthquakes occur daily! Fortunately, the majority of them are too small to be felt by people, and the majority of larger ones occur in remote regions. Their existence is known only because of sensitive seismographs.

An **earthquake** is ground shaking caused by the sudden and rapid movement of one block of rock slipping past another along fractures in Earth's crust called **faults.** Most faults are locked, except for brief, abrupt movements when sudden slippage produces an earthquake. Faults are locked because the confining pressure exerted by the overlying crust is enormous, causing these fractures in the crust to be "squeezed shut."

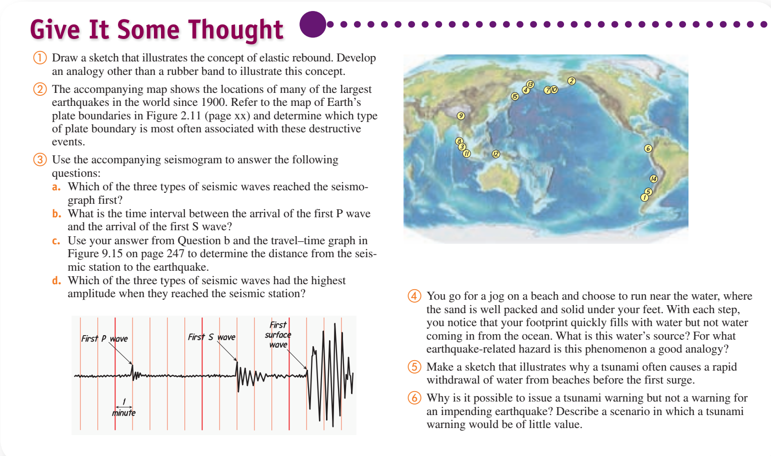
Earthquakes tend to occur along preexisting faults where internal stresses have caused the crustal rocks to rupture or break into two or more units. The location where slippage begins is called the **hypocenter,** or **focus.**

Figure 9.1 Presidential palace damaged during the 2010 Haiti earthquake *(Photo by Luis Acosta/AFP/Getty Images)*

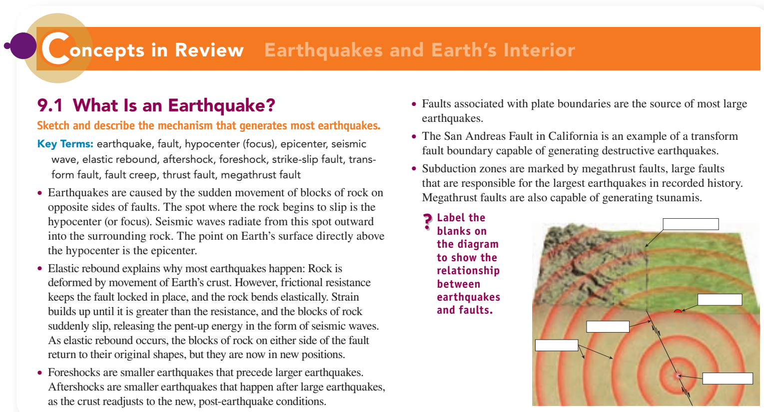
Within the chapter, each major section concludes with *Concept Checks* that allow students to check their understanding and comprehension of important ideas and terms before moving on to the next section.

Concept Checks 9.1

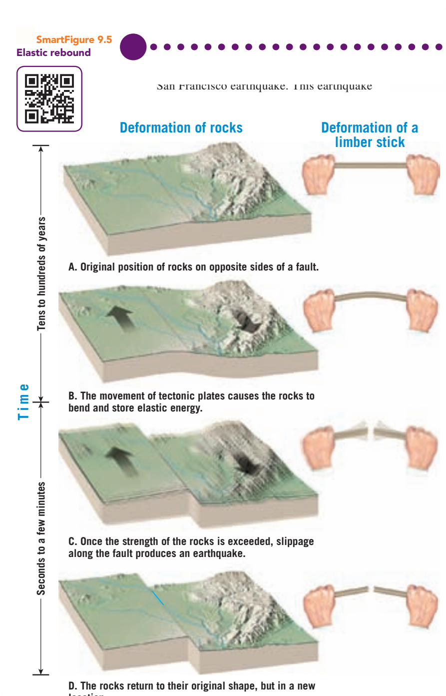
1. What is an earthquake? Under what circumstances do most large earthquakes occur?
2. How are faults, hypocenters, and epicenters related?
3. Who was the first person to explain the mechanism by which most earthquakes are generated?
4. Explain what is meant by *elastic rebound*.
5. What is the approximate duration of an earthquake that occurs along a 300-kilometer- (200-mile-) long fault?
6. Defend or rebut this statement: Faults that do not experience fault creep may be considered safe.
7. What type of faults tend to produce the most destructive earthquakes?



Each chapter concludes with *Give It Some Thought*. The questions and problems in this section challenge learners by involving them in activities that require higher-order thinking skills, such as application, analysis, and synthesis of material in the chapter. Some of the GIST problems are intended to develop an awareness of and appreciation for some of the Earth system's many interrelationships.



- **Concepts in Review.** This new end-of-chapter feature is an important part of the book's revised active learning path. Each review is coordinated with the *Focus on Concepts* at the beginning of the chapter and with the numbered sections within the chapter. It is a readable and concise overview of key ideas, with photos, diagrams, and questions that also help students focus on important ideas and test their understanding of key concepts.



- **SmartFigures—art that teaches.** *SmartFigures. Essentials of Geology*, 12th edition, has more than 100 of these figures distributed through each chapter. Just use your mobile device to scan the Quick Response (QR) code next to a SmartFigure, and the art comes alive. Each 2- to 3-minute feature, prepared and narrated by Professor Callan Bentley, is a mini-lesson that examines and explains the concepts illustrated by the figure. It is truly *art that teaches.*

- **Mobile Field Trips.** Scattered through this new edition of *Essentials of Geology* are thirteen video field trips. On each trip, you will accompany geologist–pilot–photographer Michael Collier in the air and on the ground to see and learn about landscapes that relate to discussions in the chapter. These extraordinary field trips are accessed in the same way as SmartFigures: You simply scan a QR code that accompanies a figure in the chapter—usually one of Michael's outstanding photos.

- **Revised organization.** Earlier editions of this text had a more traditional chapter organization, in which the theory of plate tectonics was fully developed relatively late in the text. A major change to *Essentials of Geology*, 12th edition, is a reorganization in which this basic theory is presented in Chapter 2 to reflect the unifying role that plate tectonics plays in our understanding of planet Earth. With the basic framework of plate tectonics firmly established, we turn to discussions of Earth materials and the related processes of volcanism and metamorphism. This is followed by chapters that examine earthquakes, the origin and evolution of the ocean floor, and crustal deformation and mountain building. Along the way, students will clearly see the relationships among these phenomena and the theory of plate tectonics.
- **An unparalleled visual program.** In addition to more than 150 new, high-quality photos and satellite images, dozens of figures are new or have been redrawn by renowned geoscience illustrator Dennis Tasa. Maps and diagrams are frequently paired with photographs for greater effectiveness. Further, many new and revised figures have additional labels that narrate the process being illustrated and guide students as they examine the figures resulting in is a visual program that is clear and easy to understand.
- **MasteringGeology™.** MasteringGeology delivers engaging, dynamic learning opportunities—focused on course objectives and responsive to each student's progress—that are proven to help students absorb course material and understand difficult concepts. Assignable activities in MasteringGeology include Encounter Earth activities using Google Earth™, SmartFigure activities, GeoTutor activities, GigaPan® activities, Geoscience Animation activities, GEODe tutorials, and more. MasteringGeology also includes all instructor resources and a robust Study Area with resources for students.
- **Significant updating and revision of content.** A basic function of a college science textbook is to provide clear, understandable presentations that are accurate, engaging, and up-to-date. Our number-one goal is to keep *Essentials of Geology* current, relevant, and highly readable for beginning students. Every part of this text has been examined carefully with this goal in mind. Many discussions, case studies, and examples have been revised. The 12th edition represents perhaps the *most extensive and thorough revision* in the long history of this textbook.

Distinguishing Features

Readability

The language of this text is straightforward and *written to be understood*. Clear, readable discussions with a minimum of technical language are the rule. The frequent headings and subheadings help students follow discussions and identify the important ideas presented in each chapter. In the 12th edition, we have continued to improve readability by examining chapter organization and flow and by writing in a more personal style. Significant portions of several chapters were substantially rewritten in an effort to make the material easier to understand.

Focus on Basic Principles and Instructor Flexibility

Although many topical issues are treated in the 12th edition of *Essentials of Geology*, it should be emphasized that the main focus of this new edition remains the same as the focus of each of its predecessors: to promote student understanding of basic principles. As much as possible, we have attempted to provide the reader with a sense of the observational techniques and reasoning processes that constitute the science of geology.

As in previous editions, we have designed most chapters to be self-contained so that material may be taught in a different sequence, according to the preference of the instructor or the dictates of the laboratory. Thus, an instructor who wishes to discuss erosional processes prior to earthquakes, plate tectonics, and mountain building may do so without difficulty.

A Strong Visual Component

Geology is highly visual, and art and photographs play a critical role in an introductory textbook. As in previous editions, Dennis Tasa, a gifted artist and respected geoscience illustrator, has worked closely with the authors to plan and produce the diagrams, maps, graphs, and sketches that are so basic to student understanding. The result is art that is clearer and easier to understand than ever before.

Our aim is to get *maximum effectiveness* from the visual component of the text. Michael Collier, an award-winning geologist–pilot–photographer, aided greatly in this quest. As you read through this text, you will see dozens of his extraordinary aerial photographs. His contributions truly help bring geology alive for the reader.

The Teaching and Learning Package

For the Instructor

Pearson continues to improve the instructor resources for this text, with the goal of providing dynamic teaching aids and saving you time in preparing for your classes.

MasteringGeology™

MasteringGeology is an online homework, tutorial, and assessment product designed to improve results by helping students quickly master concepts. Students using MasteringGeology benefit from self-paced tutorials that feature specific wrong-answer feedback and hints to keep them engaged and on track. MasteringGeology™ offers:

- Assignable activities, including Encounter Earth activities using Google EarthTM, SmartFigure activities, Mobile Field Trip activities GeoTutor activities, GigaPan® activities, Geoscience Animation activities, GEODe tutorials, and more
- Additional Concept Check and Give It Some Thought questions, Test Bank questions, and Reading Quizzes
- A student Study Area with Geoscience Animations, GEODe: Essentials of Geology activities, *In the News* RSS feeds, Self Study Quizzes, Web Links, Glossary, and Flashcards
- Pearson eText for *Essentials of Geology*, 12th edition, which gives students access to the text whenever and wherever they can access the Internet and includes powerful interactive and customization functions

  See www.masteringgeology.com

Learning Catalytics

Learning Catalytics™ is a "bring your own device" student engagement, assessment, and classroom intelligence system. With Learning Catalytics you can:

- Assess students in real time, using open-ended tasks to probe student understanding.
- Understand immediately where students are and adjust your lecture accordingly.
- Improve your students' critical-thinking skills.
- Access rich analytics to understand student performance.
- Add your own questions to make Learning Catalytics fit your course exactly.
- Manage student interactions with intelligent grouping and timing.

Learning Catalytics is a technology that has grown out of twenty years of cutting edge research, innovation, and implementation of interactive teaching and peer instruction. Available integrated with MasteringGeology. www.learningcatalytics.com

Instructor's Resource DVD

The IRDVD provides an integrated collection of resources designed to help instructors make efficient and effective use of their time. It features:

- **Three pre-built PowerPoint™ presentations:** The first presentation contains all the images/figures/tables from the text embedded within the PowerPoint slides, while the second includes a complete and customizable lecture outline with supporting art, and the third includes Classroom Response System (CRS) Questions.
- **The Geoscience Animation Library** including more than 100 animations that illustrate many difficult-to-visualize topics of geology. Created through a unique collaboration among five of Pearson's leading geoscience authors, these animations represent a significant step forward in lecture presentation aids. They are provided both as Flash files and, for your convenience, preloaded into PowerPoint slides.
- **Images of Earth** photo gallery allowing you to supplement your personal slides with an amazing collection of more than 300 geologic photos contributed by Marli Miller (University of Oregon) and other professionals in the field. The photos are available on the Instructor's Resource DVD.
- **Instructor's Manual** containing learning objectives, chapter outlines, answers to end-of-chapter questions, and suggested short demonstrations to spice up your lecture. The Test Bank incorporates art and averages 75 multiple-choice, true/false, short-answer, and critical thinking questions per chapter.
- **TestGen:** An electronic version of the Testbank that allows you to customize and manage your tests. Testbank is also available in Microsoft Word.
- All the art, tables and photos in the text in .jpg files

Course Management

Pearson offers instructor and student media for this 12th edition of *Essentials of Geology* in formats compatible with Blackboard and other course management platforms. Contact your local Pearson representative for more information.

For the Student

The student resources to accompany *Essentials of Geology*, 12th edition, have been further refined, with the goal of focusing the students' efforts and improving their understanding of the concepts of geology.

MasteringGeology™

MasteringGeology from Pearson is an online homework, tutorial, and assessment product designed to improve results by helping students quickly master concepts. Students using MasteringGeology benefit from self-paced tutorials that feature specific wrong-answer feedback and hints to keep them engaged and on track. MasteringGeology™ also offers students the Study Area, which contains:

- **Geoscience Animation Library.** More than 100 animations illustrating many difficult to understand geology concepts.
- **GEODe: Essentials of Geology.** An interactive visual walkthrough of basic ideas and concepts
- ***In the News* RSS Feeds.** Current geological events and news articles are pulled into the site, with assessment.
- **SmartFigures**

- **Mobile Field Trips**
- **Pearson eText**
- **Optional Self Study Quizzes**
- **Web Links**
- **Glossary**

Acknowledgments

Writing a college textbook requires the talents and cooperation of many people. It is truly a team effort, and the authors are fortunate to be part of an extraordinary team at Pearson Education. In addition to being great people to work with, all are committed to producing the best textbooks possible. Special thanks to our geology editor, Andy Dunaway, who invested a great deal of time, energy, and effort in this project. We appreciate his enthusiasm, hard work, and quest for excellence. We also appreciate our conscientious project manager, Crissy Dudonis, whose job it was to keep track of all that was going on—and a lot was going on. The text's new design and striking cover resulted from the creative talents of Derek Bacchus and his team. We think it is a job well done. As always, our marketing manager, Maureen McLaughlin, provided helpful advice and many good ideas. *Essentials of Geology*, 12th edition, was truly improved with the help of our developmental editor Jonathan Cheney. Many thanks. It was the job of the production team, led by Heidi Allgair at Cenveo® Publisher Services, to turn our manuscript into a finished product. The team also included copyeditor Kitty Wilson, compositor Annamarie Boley, proofreader Heather Mann, and photo researcher Kristin Piljay. We think these talented people did great work. All are true professionals, with whom we are very fortunate to be associated.

The authors owe special thanks to three people who were very important contributors to this project:

- Working with Dennis Tasa, who is responsible for all of the text's outstanding illustrations, is always special for us. He has been part of our team for more than 30 years. We not only value his artistic talents, hard work, patience, and imagination but his friendship as well.
- As you read this text, you will see dozens of extraordinary photographs by Michael Collier. Most are aerial shots taken from his nearly 60-year-old Cessna 180. Michael was also responsible for preparing the remarkable Mobile Field Trips that are scattered through the text. Among his many awards is the American Geological Institute Award for Outstanding contribution to the Public Understanding of Geosciences. We think that Michael's photographs and field trips are the next best thing to being there. We were very fortunate to have had Michael's assistance on *Essentials of Geology*, 12th edition. Thanks, Michael.
- Callan Bentley has been an important addition to the *Essentials of Geology* team. Callan is an assistant professor of geology at Northern Virginia Community College in Annandale, where he has been honored many times as an outstanding teacher. He is a frequent contributor to *Earth* magazine and is author of the popular geology blog *Mountain Beltway*. Callan was responsible for preparing the SmartFigures that appear throughout the text. As you take advantage of these outstanding learning aids, you will hear his voice explaining the ideas. Callan also contributed to the Concepts in Review feature found at the end of each chapter. We appreciate Callan's contributions to this new edition of *Essentials of Geology*.

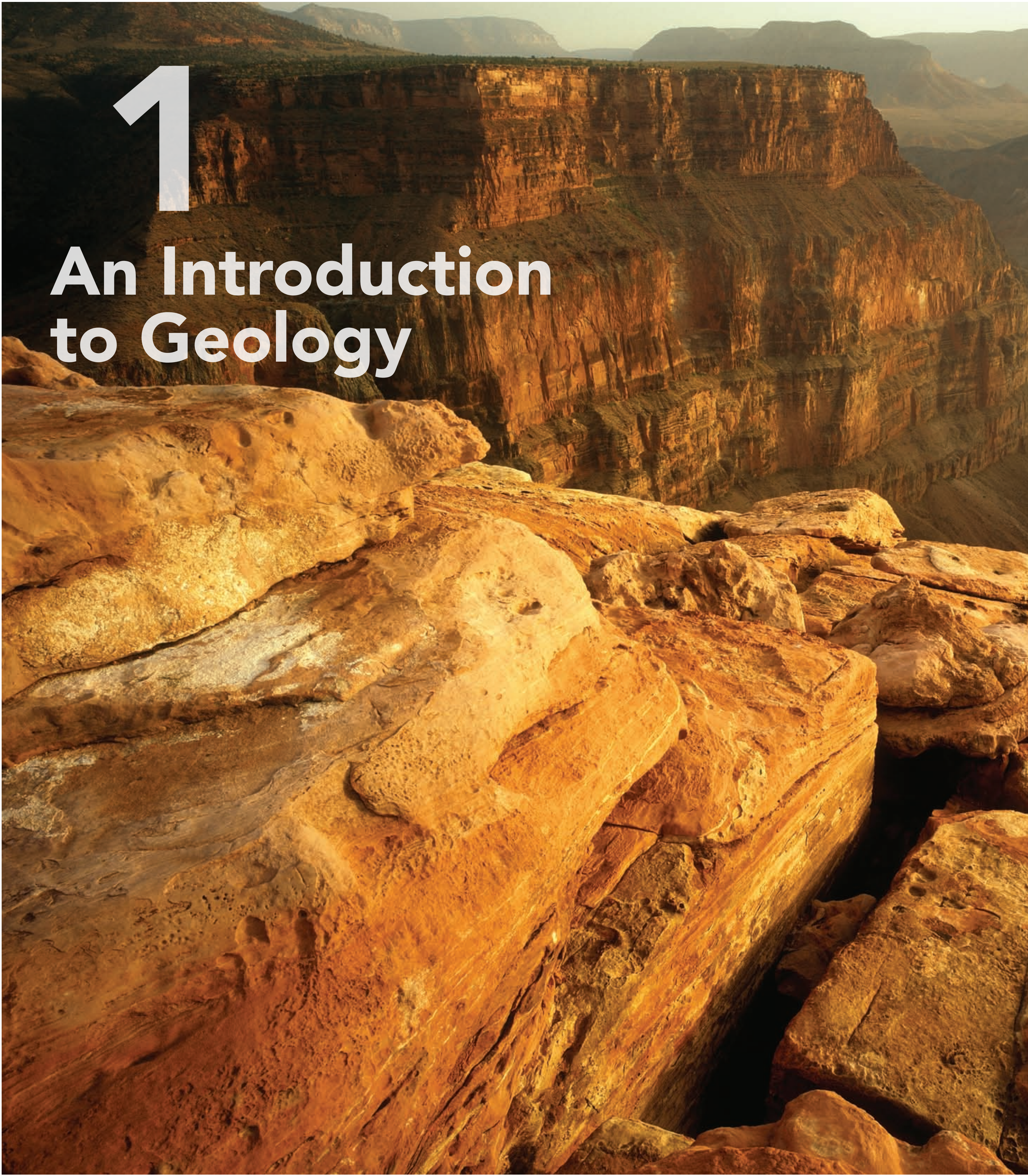
Great thanks also go to those colleagues who prepared in-depth reviews. Their critical comments and thoughtful input helped guide our work and clearly strengthened the text. Special thanks to:

Tania Anders, Texas A&M University–Corpus Christi
Jamie Barnes, University of Texas–Austin
David Bradley, Georgia Southern University
Alan Coulson, Clemson University
Sarah de la Rue, Purdue–Calumet
Noah Fay, Pima Community College
Thomas Gerber, Indiana University of PA
Wayne Henderson, California State University–Fullerton
Edgar Kessler, Northampton Community College
Katherine Knierim, University of Arkansas
Sam Matson, Boise State University
Charles Merguerian, Hofstra University
Stephen Moysey, Clemson University
Jodi Ryder, Central Michigan University
Robert Shuster, University of Nebraska–Omaha
Gordana Vlahovic, North Carolina Central College
Merry Wilson, Scottsdale Community College
Chris Woltemade, Shippensburg University
Adam Woods, California State University–Fullerton
Sally Zellers, University of Central Missouri
James Zollweg, Boise State University

Last, but certainly not least, we gratefully acknowledge the support and encouragement of our wives, Nancy Lutgens and Joanne Bannon. Preparation of *Essentials of Geology*, 12th edition, would have been far more difficult without their patience and understanding.

Fred Lutgens
Ed Tarbuck

1 An Introduction to Geology



Focus on Concepts

Each statement represents the primary learning objective for the corresponding major heading within the chapter. After you complete the chapter, you should be able to:

1.1 Distinguish between physical and historical geology and describe the connections between people and geology.

1.2 Summarize early and modern views on how change occurs on Earth and relate them to the prevailing ideas about the age of Earth.

1.3 Discuss the nature of scientific inquiry, including the construction of hypotheses and the development of theories.

1.4 List and describe Earth's four major spheres.

1.5 Define *system* and explain why Earth is considered to be a system.

1.6 Outline the stages in the formation of our solar system.

1.7 Describe Earth's internal structure.

1.8 Sketch, label, and explain the rock cycle.

1.9 List and describe the major features of the continents and ocean basins.

The view from Toroweap Overlook along the North Rim of Arizona's Grand Canyon National Park. *(Photo by Michael Collier)*

The spectacular eruption of a volcano, the terror brought by an earthquake, the magnificent scenery of a mountain range, and the destruction created by a landslide or flood are all subjects for a geologist. The study of geology deals with many fascinating and practical questions about our physical environment. What forces produce mountains? Will there soon be a major earthquake in California? What was the Ice Age like, and will there be another? How were ore deposits formed? Where should we search for water? Will plentiful oil be found if a well is drilled in a particular location? Geologists seek to answer these and many other questions about Earth, its history, and its resources.

1.1 Geology: The Science of Earth

Distinguish between physical and historical geology and describe the connections between people and geology.

Figure 1.1 Internal and external processes The processes that operate beneath and upon Earth's surface are an important focus of physical geology. *(Volcano photo by Lucas Jackson/Reuters; glacier photo by Michael Collier)*

The subject of this text is **geology**, from the Greek *geo* (Earth) and *logos* (discourse). Geology is the science that pursues an understanding of planet Earth. Understanding Earth is challenging because our planet is a dynamic body with many interacting parts and a complex history. Throughout its long existence, Earth has been changing. In fact, it is changing as you read this page and will continue to do so into the foreseeable future. Sometimes the changes are rapid and violent, as when landslides or volcanic eruptions occur. Just as often, change takes place so slowly that it goes unnoticed during a lifetime. Scales of size and space also vary greatly among the phenomena that geologists study. Sometimes geologists must focus on phenomena that are microscopic, and at other times they must deal with features that are continental or global in scale.

Physical and Historical Geology

Geology is traditionally divided into two broad areas—physical and historical. **Physical geology**, which is the primary focus of this book, examines the materials composing Earth and seeks to understand the many processes that operate beneath and upon its surface (**Figure 1.1**). The aim of **historical geology**, on the other hand, is to understand the origin of Earth and its development through time. Thus, it strives to establish an orderly chronological arrangement of the multitude of physical and biological changes that have occurred in the geologic past. The study of physical geology logically precedes the study of Earth history because we must first understand how Earth works before we attempt to unravel its past. It should also be pointed out that physical and historical geology are divided into many areas of specialization. Every chapter of this book represents one or more areas of specialization in geology.

Figure 1.2 In the field and in the lab Geology not only involves outdoor fieldwork but work in the laboratory as well. *(Photo by British Antarctic Survey/Science Source)*

Geology is perceived as a science that is done outdoors—and rightly so. A great deal of geology is based on observations, measurements, and experiments conducted in the field. But geology is also done in the laboratory, where, for example, the analysis of minerals and rocks provides insights into many basic processes and the microscopic study of fossils unlocks clues to past environments (**Figure 1.2**). Frequently, geology requires an understanding and application of knowledge and principles from physics, chemistry, and biology. Geology is a science that seeks to expand our knowledge of the natural world and our place in it.

Geology, People, and the Environment

The primary focus of this book is to develop an understanding of basic geologic principles, but along the way we will explore numerous important relationships between people and the natural environment. Many of the problems and issues addressed by geology are of practical value to people.

Natural hazards are a part of living on Earth. Every day they adversely affect millions of people worldwide and are responsible for staggering damages (**Figure 1.3**). Among the hazardous Earth processes that geologists study are volcanoes, floods, tsunamis, earthquakes, and landslides. Of course, geologic hazards are *natural* processes. They become hazards only when people try to live where these processes occur.

According to the United Nations, in 2008, for the first time, more people lived in cities than in rural areas. This global trend toward urbanization concentrates millions of people into megacities, many of which are vulnerable to natural hazards. Coastal sites are becoming more vulnerable because development often destroys natural defenses such as wetlands and sand dunes. In addition, there is a growing threat associated with human influences on the Earth system; one example is sea-level rise that is linked to global climate change. Some megacities are exposed to seismic (earthquake) and volcanic hazards where inappropriate land use and poor construction practices, coupled with rapid population growth, are increasing vulnerability.

Resources are another important focus of geology that is of great practical value to people. They include water and soil, a great variety of metallic and nonmetallic

Figure 1.3 Earthquake destruction Geologic hazards are natural processes. They become hazards only when people try to live where these processes occur. *(Photo by Yasuyoshi Chiba/AFP/Getty Images/Newscom)*

Did You Know?

Each year an average American requires huge quantities of Earth materials. Imagine receiving your annual share in a single delivery. A large truck would pull up to your home and unload 12,965 lb of stone, 8945 lb of sand and gravel, 895 lb of cement, 395 lb of salt, 361 lb of phosphate, and 974 lb of other nonmetals. In addition, there would be 709 lb of metals, including iron, aluminum, and copper.

Did You Know?

It took until about the year 1800 for the world population to reach 1 billion. By 1927, the number had doubled to 2 billion. According to United Nations estimates, world population reached 7 billion in late October 2011. We are currently adding about 80 million people per year to the planet.

Figure 1.4 Drilling for oil Energy and mineral resources represent an important link between people and geology. Petroleum provides more than 36 percent of U.S. energy consumption. *(Photo by Peter Bowater/Science Source)*

minerals, and energy (**Figure 1.4**). Together they form the very foundation of modern civilization. Geology deals not only with the formation and occurrence of these vital resources but also with maintaining supplies and with the environmental impact of their extraction and use.

Geologic processes clearly have an impact on people. In addition, we humans can dramatically influence geologic processes. For example, river flooding is natural, but the magnitude and frequency of flooding can be affected significantly by human activities such as clearing forests, building cities, and constructing dams. Unfortunately, natural systems do not always adjust to artificial changes in ways that we can anticipate. Thus, an alteration to the environment that was intended to benefit society sometimes has the opposite effect.

At appropriate places throughout this book, you will have opportunities to examine different aspects of our relationship with the physical environment. It will be rare to find a chapter that does not address some aspect of natural hazards, environmental issues, or resources. Significant parts of some chapters provide the basic geologic knowledge and principles needed to understand environmental problems.

Concept Checks 1.1

1. Name and distinguish between the two broad subdivisions of geology.
2. List at least three different geologic hazards.
3. Aside from geologic hazards, describe another important connection between people and geology.

1.2 The Development of Geology

Summarize early and modern views on how change occurs on Earth and relate them to the prevailing ideas about the age of Earth.

The nature of our Earth—its materials and processes—has been a focus of study for centuries. Writings about such topics as fossils, gems, earthquakes, and volcanoes date back to the early Greeks, more than 2300 years ago.

Certainly the most influential Greek philosopher was Aristotle. Unfortunately, Aristotle's explanations about the natural world were not based on keen observations and experiments. Instead, they were arbitrary pronouncements. He believed that rocks were created under the "influence" of the stars and that earthquakes occurred when air crowded into the ground, was heated by central fires, and escaped explosively. When confronted with a fossil fish, he explained that "a great many fishes live in the earth motionless and are found when excavations are made." Although Aristotle's explanations may have been adequate for his day, they unfortunately continued to be viewed as authoritative for many centuries, thus inhibiting the acceptance of more up-to-date ideas. After the Renaissance of the 1500s, however, more people became interested in finding answers to questions about Earth.

Catastrophism

In the mid-1600s, James Ussher, Anglican Archbishop of Armagh, Primate of all Ireland, published a major work that had immediate and profound influences. A respected scholar of the Bible, Ussher constructed a chronology of human and Earth history in which he calculated that Earth was only a few thousand years old, having been created in 4004 B.C. Ussher's treatise earned widespread acceptance among Europe's scientific and religious leaders, and his chronology was soon printed in the margins of the Bible itself.

During the seventeenth and eighteenth centuries, Western thought about Earth's features and processes was strongly influenced by Ussher's calculation. The result was a guiding doctrine called **catastrophism**. Catastrophists believed that Earth's landscapes were shaped primarily by great catastrophes. Features such as mountains and canyons, which today we know take great spans of time to form, were explained as having been produced by sudden and often worldwide disasters produced by unknowable causes that no longer operate. This philosophy was an attempt to fit the rates of Earth processes to the then-current ideas on the age of Earth.

The Birth of Modern Geology

Against the backdrop of Aristotle's views and an Earth created in 4004 B.C., a Scottish physician and gentleman farmer named James Hutton published *Theory of the Earth* in 1795. In this work, Hutton put forth a fundamental principle that is a pillar of geology today: **uniformitarianism**. It states that the *physical, chemical, and biological laws that operate today have also operated in the geologic past.* This means that the forces and processes that we observe presently shaping our planet have been at work for a very long time. Thus, to understand ancient rocks, we must first understand present-day processes and their results. This idea is commonly stated as *the present is the key to the past.*

Prior to Hutton's *Theory of the Earth*, no one had effectively demonstrated that geologic processes occur over extremely long periods of time. However, Hutton persuasively argued that forces that appear small can, over long spans of time, produce effects that are just as great as those resulting from sudden catastrophic events. Unlike his predecessors, Hutton carefully cited verifiable observations to support his ideas.

For example, when Hutton argued that mountains are sculpted and ultimately destroyed by weathering and the work of running water and that their wastes are carried to the oceans by processes that can be observed, he said, "We have a chain of facts which clearly demonstrate . . . that the materials of the wasted mountains have traveled through the rivers"; and further, "There is not one step in all this progress . . . that is not to be actually perceived." He then went on to summarize this thought by asking a question and immediately providing the answer: "What more can we require? Nothing but time."

Mobile Field Trip

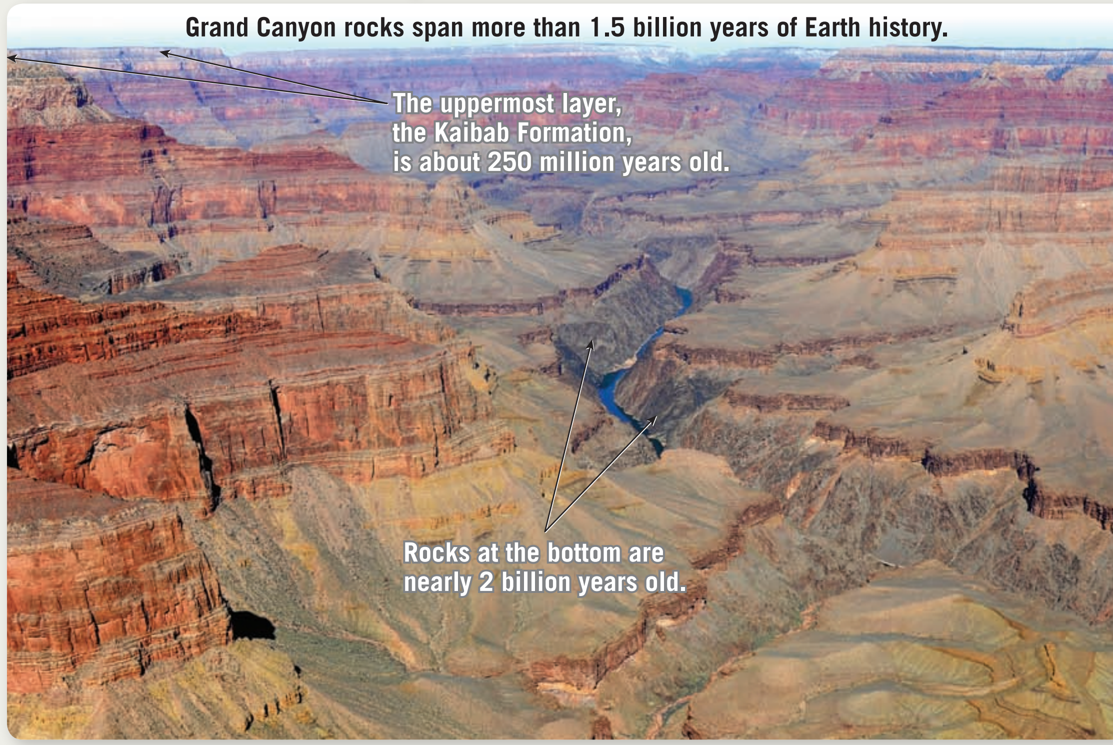


Figure 1.5 Earth history—Written in the rocks The Grand Canyon of the Colorado River in northern Arizona. *(Photo by Dennis Tasa)*

Geology Today

Today the basic tenets of uniformitarianism are just as viable as in Hutton's day. Indeed, today we realize more strongly than ever before that the present gives us insight into the past and that the physical, chemical, and biological laws that govern geologic processes remain unchanging through time. However, we also understand that the doctrine should not be taken too literally. To say that geologic processes in the past were the same as those occurring today is not to suggest that they have always had the same relative importance or that they have operated at precisely the same rate. Moreover, some important geologic processes are not currently observable, but evidence that they occur is well established. For example, we know that Earth has experienced impacts from large meteorites even though we have no human witness accounts of those impacts. Nevertheless, such events have altered Earth's crust, modified its climate, and strongly influenced life on the planet.

The acceptance of uniformitarianism meant the acceptance of a very long history for Earth. Although Earth processes vary in intensity, they still take a very long time to create or destroy major landscape features. The Grand Canyon provides a good example (**Figure 1.5**).

Did You Know?

Shortly after Archbishop Ussher determined an age for Earth, another biblical scholar, Dr. John Lightfoot of Cambridge, felt he could be even more specific. He wrote that Earth was created "on the 26th of October 4004 BC at 9 o'clock in the morning." (As quoted in William L. Stokes, *Essentials of Earth History*, Prentice Hall, Inc. 1973, p. 20.)

Did You Know?

Estimates indicate that erosional processes are lowering the North American continent at a rate of about 3 cm per 1000 years. At this rate, it would take 100 million years to level a 3000 m (10,000 ft) high peak.

The rock record contains evidence which shows that Earth has experienced many cycles of mountain building and erosion. Concerning the ever-changing nature of Earth through great expanses of geologic time, Hutton made a statement that was to become his most famous. In concluding his classic 1788 paper published in the *Transactions of the Royal Society of Edinburgh*, he stated, "The results, therefore, of our present enquiry is, that we find no vestige of a beginning—no prospect of an end."

In the chapters that follow, we will be examining the materials that compose our planet and the processes that modify it. It is important to remember that, although many features of our physical landscape may seem to be unchanging over the decades we observe them, they are nevertheless changing—but on time scales of hundreds, thousands, or even many millions of years.

The Magnitude of Geologic Time

Among geology's important contributions to human knowledge is the discovery that Earth has a very long and complex history. Although Hutton and others recognized that geologic time is exceedingly long, they had no methods to accurately determine the age of Earth. Early time scales simply placed the events of Earth history in the proper sequence or order, without knowledge of how long ago in years they occurred.

Today our understanding of radioactivity allows us to accurately determine numerical dates for rocks that represent important events in Earth's distant past (**Figure 1.6**). For example, we know that the dinosaurs died out about 65 million years ago. Today the age of Earth is put at about 4.6 billion years. Chapter 18 is devoted to a much more complete discussion of geologic time and the geologic time scale.

The concept of geologic time is new to many nongeologists. People are accustomed to dealing with increments of time that are measured in hours, days, weeks, and years. Our history books often examine events over spans of centuries, but even a century is difficult to appreciate fully. For most of us, someone or something that is 90 years old is *very old*, and a 1000-year-old artifact is *ancient.*

By contrast, those who study geology must routinely deal with vast time periods—millions or billions (thousands of millions) of years. When viewed in the context of Earth's 4.6-billion-year history, a geologic event that occurred 100 million years ago may be characterized as "recent" by a geologist, and a rock sample that has been dated at 10 million years may be called "young." An appreciation for the magnitude of geologic time is important in the study of geology because many processes are so gradual that vast spans of time are needed

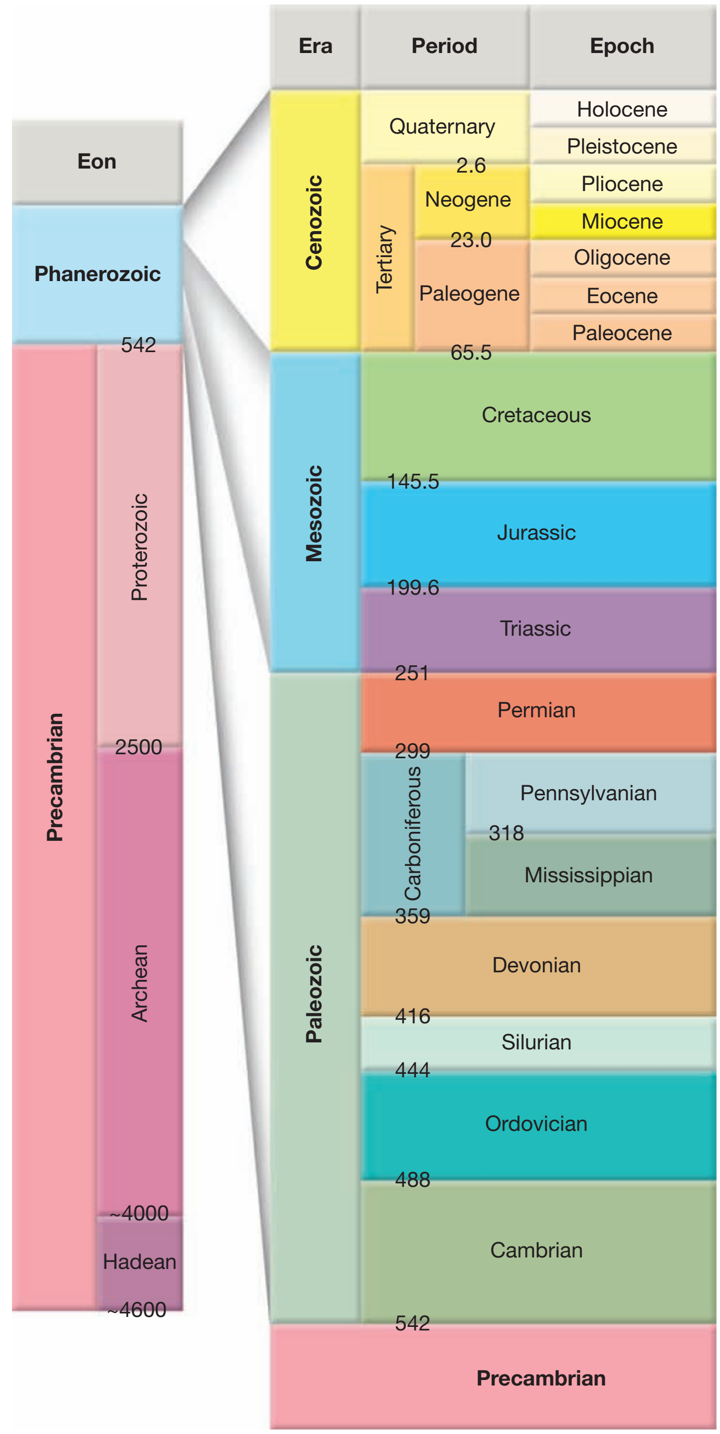
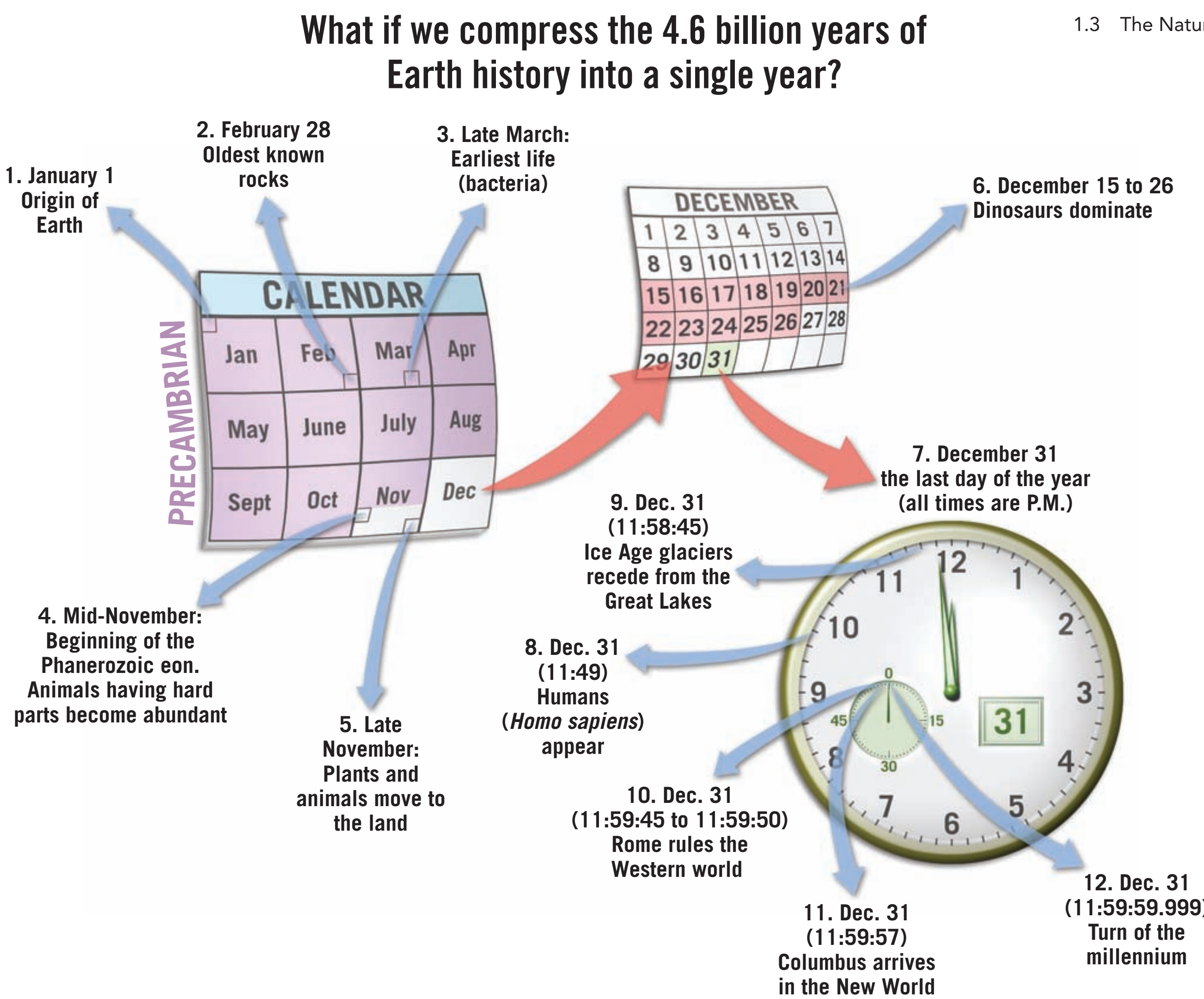


Figure 1.6 Geologic time scale: A basic reference The time scale divides the vast 4.6-billion-year history of Earth into eons, eras, periods, and epochs. Numbers on the time scale represent time in millions of years before the present. The Precambrian accounts for more than 88 percent of geologic time.



SmartFigure 1.7
Magnitude of geologic time

before significant changes occur. How long is 4.6 billion years? If you were to begin counting at the rate of one number per second and continued 24 hours a day, 7 days a week and never stopped, it would take about two lifetimes (150 years) to reach 4.6 billion! **Figure 1.7** provides another interesting way of viewing the expanse of geologic time.

The foregoing is just one of many analogies that have been conceived in an attempt to convey the magnitude of geologic time. Although helpful, all of them, no matter how clever, only begin to help us comprehend the vast expanse of Earth history.

Concept Checks 1.2

1. Describe Aristotle's influence on geology.
2. Contrast catastrophism and uniformitarianism. How did each view the age of Earth?
3. How old is Earth?
4. Refer to Figure 1.6 and list the eon, era, period, and epoch in which we live.
5. Why is an understanding of the magnitude of geologic time important for a geologist?

1.3 The Nature of Scientific Inquiry

Discuss the nature of scientific inquiry, including the construction of hypotheses and the development of theories.

As members of a modern society, we are constantly reminded of the benefits derived from science. But what exactly is the nature of scientific inquiry? Science is a process of producing knowledge. The process depends both on making careful observations and on creating explanations that make sense of the observations. Developing an