Earth Science

Tarbuck · Lutgens · Illustrated by Tasa

FOURTEENTH EDITION

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Earth Science

Edward J. Tarbuck
Frederick K. Lutgens

Illustrated by
Dennis Tasa

PEARSON

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BRIEF CONTENTS

FIND SMART FIGURES 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.*

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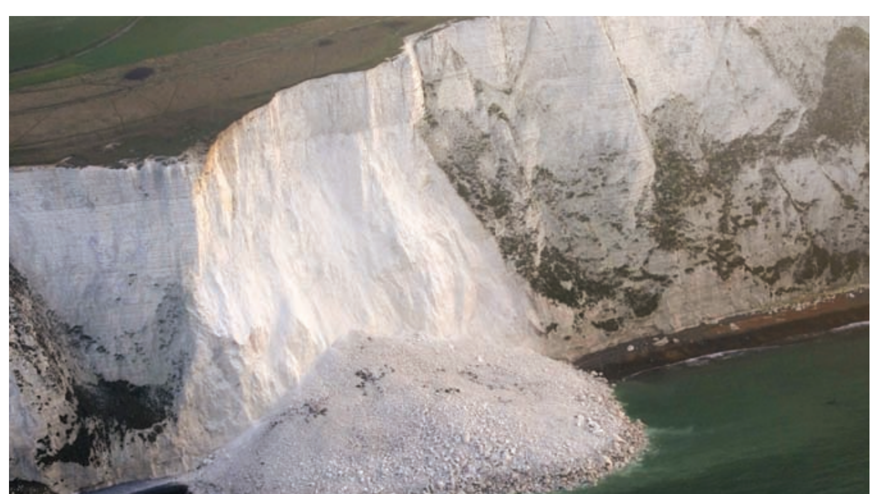

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CHIKYU

PREFACE

Earth Science, 14th edition, is a college-level text designed for an introductory course in Earth science. It consists of seven units that emphasize broad and up-to-date coverage of basic topics and principles in geology, oceanography, meteorology, and astronomy. The textbook is intended to be a meaningful, nontechnical survey for undergraduate students who have little background in science. Usually these students are taking an Earth science class to meet a portion of their college's or university's general requirements.

In addition to being informative and up-to-date, *Earth Science,* 14th edition, strives to meet the need of beginning students for a readable and user-friendly text and a highly usable tool for learning basic Earth science principles and concepts.

NEW TO THIS EDITION

- **SmartFigures—art that teaches.** Inside every chapter are several *SmartFigures*. *Earth Science,* 14th edition, has more than 100 of these figures. Just use your mobile device to scan the Quick Response (QR) code next to a SmartFigure, and the art comes alive. Each 3- to 5-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 Earth Science are thirteen Mobile 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 will scan a QR code that accompanies a figure in the chapter—usually one of Michael's outstanding photos.
- **New and expanded active learning path.** *Earth Science,* 14th 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. 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. Chapters conclude with sections called *Give It Some Thought* and *Examining the Earth System*. The questions and problems in these sections challenge learners by involving them in activities that require higher-order thinking skills such as application, analysis, and synthesis of material in the chapter. The questions and problems in Examining the Earth System are intended to develop an awareness of and appreciation for some of the Earth system's many interrelationships.
- **Concepts in Review.** This all-new end-of-chapter feature is an important part of the text'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, which makes it a valuable review tool for students. Photos, diagrams, and questions also help students focus on important ideas and test their understanding.
- **Eye on Earth.** Within every chapter are two or three images, often aerial or satellite views, that challenge students to apply their understanding of basic facts and principles. A brief explanation of each image is followed by questions that help focus students on visual analysis and critical thinking.
- **GEOgraphics.** As you turn the pages of each chapter, you will encounter striking visual features that we call GEOgraphics. They are engaging magazine-style "geo-essays" that explore topics that promote greater understanding and add interest to the story each chapter is telling.
- **An unparalleled visual program.** In addition to more than 200 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. The result 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, Mobile Field Trips, GeoTutor activities, GigaPan® activities, Geoscience Animation activities, GEODe tutorial activities, 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 text book is to provide clear, understandable presentations that are accurate, engaging, and up-to-date. Our number-one goal is to keep *Earth Science* 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. This 14th edition represents perhaps the *most extensive and thorough revision* in the long history of this textbook.
- **Learning Catalytics™.** Learning Catalytics is a "bring your own device" student engagement, assessment, and classroom intelligence system. 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.

DISTINGUISHING FEATURES

Readability

The language of this textbook 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 this 14th 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 have been substantially rewritten in an effort to make the material easier to understand.

Focus on Basic Principles

Although many topical issues are treated in this 14th edition of *Earth Science*, 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 Earth science 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 Earth sciences.

A Strong Visual Component

Earth science is highly visual, and art and photographs play a critical role in an introductory textbook. As in all 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–photographer aided greatly in this quest. As you read through this text, you will see dozens of his extraordinary aerial photographs. His contribution truly helps bring geology alive for the reader.

FOR THE INSTRUCTOR

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

MasteringGeology from Pearson is an online homework, tutorial, and assessment system 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 Earth™, SmartFigure activities, GeoTutor activities, GigaPan® activities, Geoscience Animation activities, GEODe tutorial activities, and more
- Additional Give It Some Thought questions, Test Bank questions, and Reading Quizzes
- A student Study Area with Geoscience Animations, GEODe: Earth Science activities, SmartFigures, Video Field Trips *In the News* RSS feeds, Self Study Quizzes, Web Links, Glossary, and Flashcards
- Pearson eText for *Earth Science*, 14th 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 Instructor's Resource DVD puts all your lecture resources in one easy-to-reach place:

- Three PowerPoint® presentations for each chapter
- The Geoscience Animation Library
- All the line art, tables, and photos from the text, in .jpg files
- "Images of Earth" photo gallery
- Instructor's Manual in Microsoft Word
- Test Bank in Microsoft Word
- TestGen test-generation and management software

PowerPoints®

The Instructor's Resource DVD provides three PowerPoint files for each chapter to cut down on your preparation time, no matter what your lecture needs:

- **Art.** All the line art, tables, and photos from the text have been preloaded into PowerPoint slides for easy integration into your presentations.
- **Lecture outline.** This set averages 35 slides per chapter and includes customizable lecture outlines with supporting art.
- **Classroom Response System (CRS) questions.** These questions have been authored for use in conjunction with any classroom response system. You can electronically poll your class for responses to questions, pop quizzes, attendance, and more.

Animations and "Images of Earth"

The Pearson Prentice Hall Geoscience Animation Library includes more than 100 animations illustrating many difficult-to-visualize topics in Earth science. Created through a unique collaboration among five of Pearson Prentice Hall'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" allows you to supplement your personal and text-specific 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 with Test Bank

The *Instructor's Manual* contains 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

Use this electronic version of the Test Bank to customize and manage your tests. Create multiple versions, add or edit questions, add illustrations, and so on. This powerful software easily addresses your customization needs.

Course Management

Pearson Prentice Hall offers instructor and student media for the 14th edition of *Earth Science* 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 *Earth Science*, 14th edition, have been further refined, with the goal of focusing the students' efforts and improving their understanding of Earth science concepts.

MasteringGeology from Pearson is an online homework, tutorial, and assessment system 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 Earth science concepts.
- **GEODe: Earth Science.** An interactive visual walkthrough of each chapter's content.
- *In the News* **RSS Feeds.** Current Earth science events and news articles are pulled into the site, with assessment.
- **SmartFigures and Mobile Field Trips**
- **Pearson eText**
- **Optional Self Study Quizzes**
- **Web Links**
- **Glossary**
- **Flashcards**

FOR THE LABORATORY

Applications and Investigations in Earth Science, 8th edition, was written by Ed Tarbuck, Fred Lutgens, and Ken Pinzke. This full-color laboratory manual contains 23 exercises that provide students with hands-on experience in geology, oceanography, meteorology, astronomy, and Earth science skills. The lab manual is available at a discount when purchased with the text; please contact your local Pearson representative for more details.

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. *Earth Science,* 14th edition, was truly improved with the help of our developmental editor, Jonathan Cheney. Many thanks. The production team was led by Gina Cheselka at Pearson Education and by Heidi Allgair at Cenveo® Publisher Services. It was their job to make this text into a finished product. The talents of copy editor Kitty Wilson, compositor Annamarie Boley, and photo researcher Kristin Piljay were an important part of the production process. We think they all did a great job. They are true professionals, with whom we are very fortunate to be associated.

The authors owe a special thanks to three people who were a very important part of 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 a 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, an award-winning geologist, author, and photographer. 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 the 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 *Earth Science*, 14th edition. Thanks, Michael.
- Callan Bentley has been an important addition to the *Earth Science* 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 *Earth Science*'s 24 chapters. As you take advantage of these outstanding learning aids, you will hear his voice explaining the ideas. Callan also helped with the preparation of the Concepts in Review feature found at the end of each chapter. We appreciate Callan's contributions to this new edition of *Earth Science*.

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

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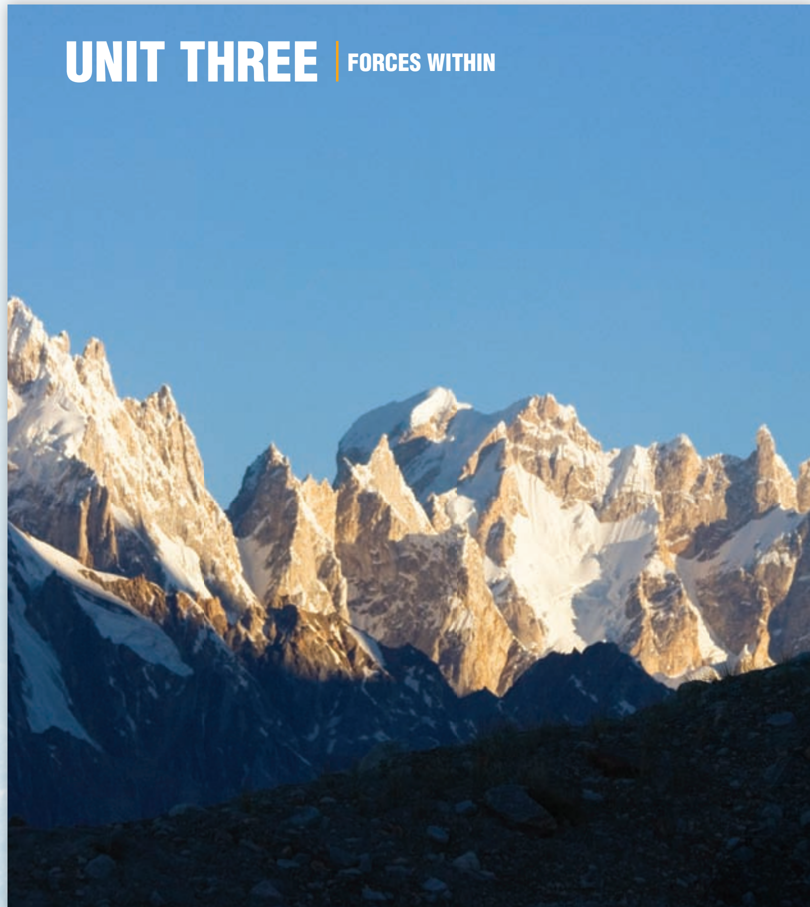
Last, but certainly not least, we gratefully acknowledge the support and encouragement of our wives, Joanne Bannon and Nancy Lutgens. Preparation of *Earth Science*, 14th edition, would have been far more difficult without their patience and understanding.

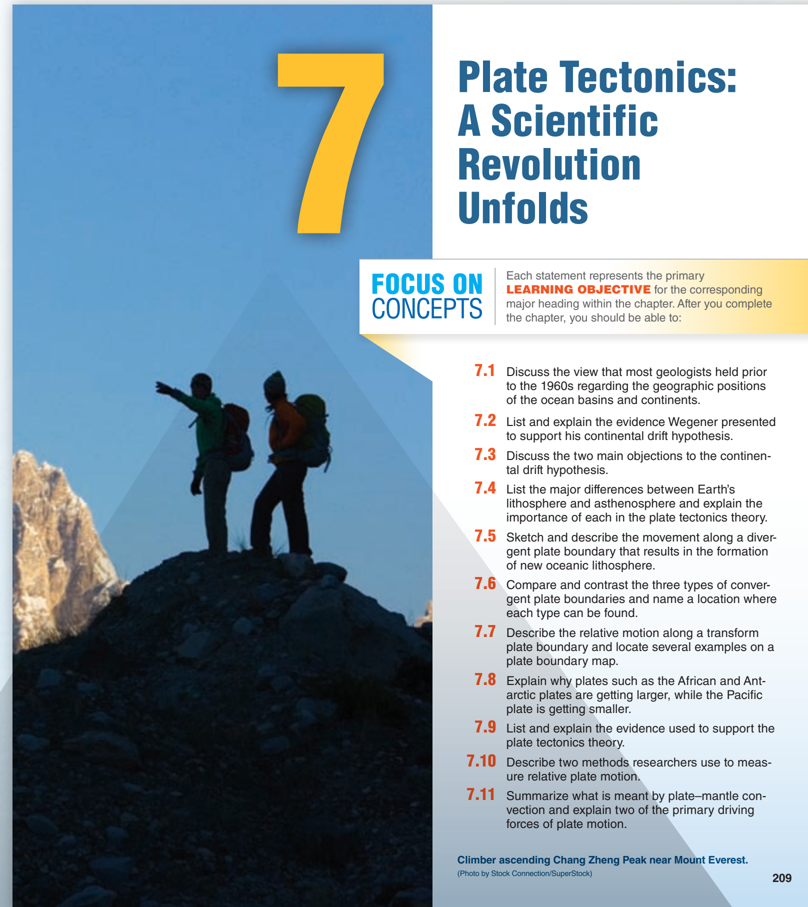
Ed Tarbuck
Fred Lutgens

New learning path helps students master the concepts

The new edition is designed to support a new **four-part learning path**, an innovative structure which facilitates active learning and easily allows students to focus on important ideas as they pause to assess their progress at frequent intervals.

The chapter-opening **Focus on Concepts** lists the learning objectives for each chapter. Each section of the chapter is tied to a specific learning objective, providing students with a clear learning path to the chapter content.





7

Plate Tectonics: A Scientific Revolution Unfolds

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:

- **7.1** Discuss the view that most geologists held prior to the 1960s regarding the geographic positions of the ocean basins and continents.
- **7.2** List and explain the evidence Wegener presented to support his continental drift hypothesis.
- **7.3** Discuss the two main objections to the continental drift hypothesis.
- **7.4** List the major differences between Earth's lithosphere and asthenosphere and explain the importance of each in the plate tectonics theory.
- **7.5** Sketch and describe the movement along a divergent plate boundary that results in the formation of new oceanic lithosphere.
- **7.6** Compare and contrast the three types of convergent plate boundaries and name a location where each type can be found.
- **7.7** Describe the relative motion along a transform plate boundary and locate several examples on a plate boundary map.
- **7.8** Explain why plates such as the African and Antarctic plates are getting larger, while the Pacific plate is getting smaller.
- **7.9** List and explain the evidence used to support the plate tectonics theory.
- **7.10** Describe two methods researchers use to measure relative plate motion.
- **7.11** Summarize what is meant by plate–mantle convection and explain two of the primary driving forces of plate motion.

Climber ascending Chang Zheng Peak near Mount Everest. (Photo by Stock Connection/SuperStock)

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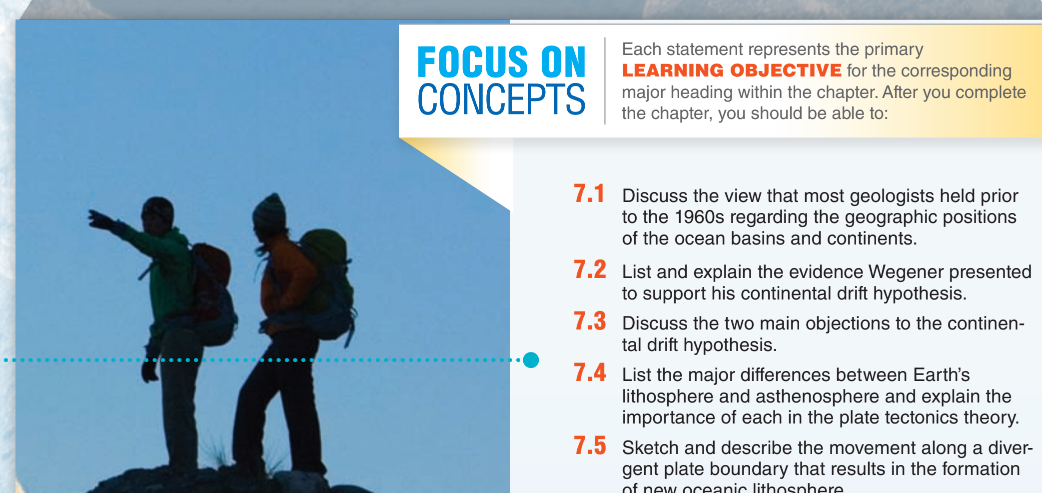
Each chapter section concludes with **Concept Checks**, a feature that lists questions tied to the section's learning objective, allowing students to monitor their grasp of significant facts and ideas.

7.4 CONCEPT CHECKS

1. What major ocean floor feature did oceanographers discover after World War II?
2. Compare and contrast the lithosphere and the asthenosphere.
3. List the seven largest lithospheric plates.
4. List the three types of plate boundaries and describe the relative motion at each of them.



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- **7.5** Sketch and describe the movement along a divergent plate boundary that results in the formation of new oceanic lithosphere.

Concepts in Review, a fresh approach to the typical end-of-chapter material, provides students with a structured and highly visual review of the chapter.

Key Terms | Section Title | Learning Objective | Review Statements

Consistent with the Focus on Concepts and Concept Checks, the **Concepts in Review** is structured around the section title and the corresponding learning objective for each section.

7 CONCEPTS IN REVIEW — Plate Tectonics: A Scientific Revolution Unfolds

7.1 FROM CONTINENTAL DRIFT TO PLATE TECTONICS

Discuss the view that most geologists held prior to the 1960s regarding the geographic positions of the ocean basins and continents.

- Fifty years ago, most geologists thought that ocean basins were very old and that continents were fixed in place. Those ideas were discarded with a scientific revolution that revitalized geology: the theory of plate tectonics. Supported by multiple kinds of evidence, plate tectonics is the foundation of modern Earth science.

7.2 CONTINENTAL DRIFT: AN IDEA BEFORE ITS TIME

List and explain the evidence Wegener presented to support his continental drift hypothesis.

KEY TERMS continental drift, supercontinent, Pangaea

- German meteorologist Alfred Wegener formulated the idea of continental drift in 1917. He suggested that Earth's continents are not fixed in place but have moved slowly over geologic time.
- Wegener reconstructed a super-continent called Pangaea that existed about 200 million years ago, during the late Paleozoic and early Mesozoic.
- Wegener's evidence that Pangaea existed but later broke into pieces that drifted apart included (1) the shape of the continents, (2) continental fossil organisms that matched across oceans, (3) matching rock types and modern mountain belts, and (4) sedimentary rocks that recorded ancient climates, including glaciers on the southern portion of Pangaea.

Q Why did Wegener choose organisms such as *Glossopteris* and *Mesosaurus* as evidence for continental drift, as opposed to other fossil organisms such as sharks or jellyfish?

John Cancalosi/AGE Fotostock

7.3 THE GREAT DEBATE

Discuss the two main objections to the continental drift hypothesis.

- Wegener's hypothesis suffered from two flaws: It proposed tidal forces as the mechanism for the motion of continents, and it implied that the continents would have plowed their way through weaker oceanic crust, like a boat cutting through a thin layer of sea ice. Geologists rejected the idea of continental drift when Wegener

7.4 THE THEORY OF PLATE TECTONICS

List the major differences between Earth's lithosphere and asthenosphere and explain the tectonics theory.

KEY TERMS ocean ridge system, theory of plate tectonics, lithosphere, asthenosphere, lithospheric plate (plate)

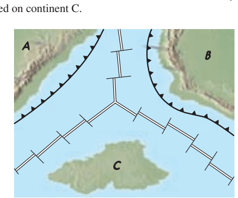
- Research conducted during World War II led to new insights that helped revive Wegener's hypothesis of co revealed previously unknown features, including an extremely long mid-ocean ridge system. Sampling of th young relative to the continents.
- The lithosphere is Earth's outermost rocky layer that is broken into plates. It is relatively stiff and deforms b is the asthenosphere, a relatively weak layer that deforms by flowing. The lithosphere consists both of crust upper mantle.
- There are seven large plates, another seven intermediate-size plates, and numerous relatively small m that may either be divergent (moving apart from each other), convergent (moving toward each other), each other).

Give It Some Thought (GIST) is found at the end of each chapter and consists of questions and problems asking students to analyze, synthesize, and think critically about Earth science. GIST questions relate back to the chapter's learning objectives, and can easily be assigned using MasteringGeology™.

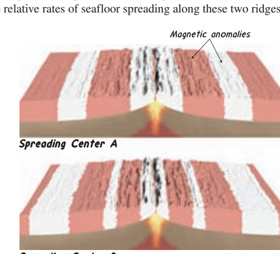
GIVE IT SOME THOUGHT

1. After referring to the section in the Introduction titled "The Nature of Scientific Inquiry," answer the following:
   - **a.** What observation led Alfred Wegener to develop his continental drift hypothesis?
   - **b.** Why did the majority of the scientific community reject the continental drift hypothesis?
   - **c.** Do you think Wegener followed the basic principles of scientific inquiry? Support your answer.
2. Referring to the accompanying diagrams that illustrate the three types of convergent plate boundaries, complete the following:
   - **a.** Identify each type of convergent boundary.
   - **b.** On what type of crust do volcanic island arcs develop?
   - **c.** Why are volcanoes largely absent where two continental blocks collide?
   - **d.** Describe two ways that oceanic–oceanic convergent boundaries are different from oceanic–continental boundaries. How are they similar?

3. Some predict that California will sink into the ocean. Is this idea consistent with the theory of plate tectonics? Explain.
4. Refer to the accompanying hypothetical plate map to answer the following questions:
   - **a.** How many portions of plates are shown?
   - **b.** Are continents A, B, and C moving toward or away from each other? How did you determine your answer?
   - **c.** Explain why active volcanoes are more likely to be found on continents A and B than on continent C.
   - **d.** Provide at least one scenario in which volcanic activity might be triggered on continent C.



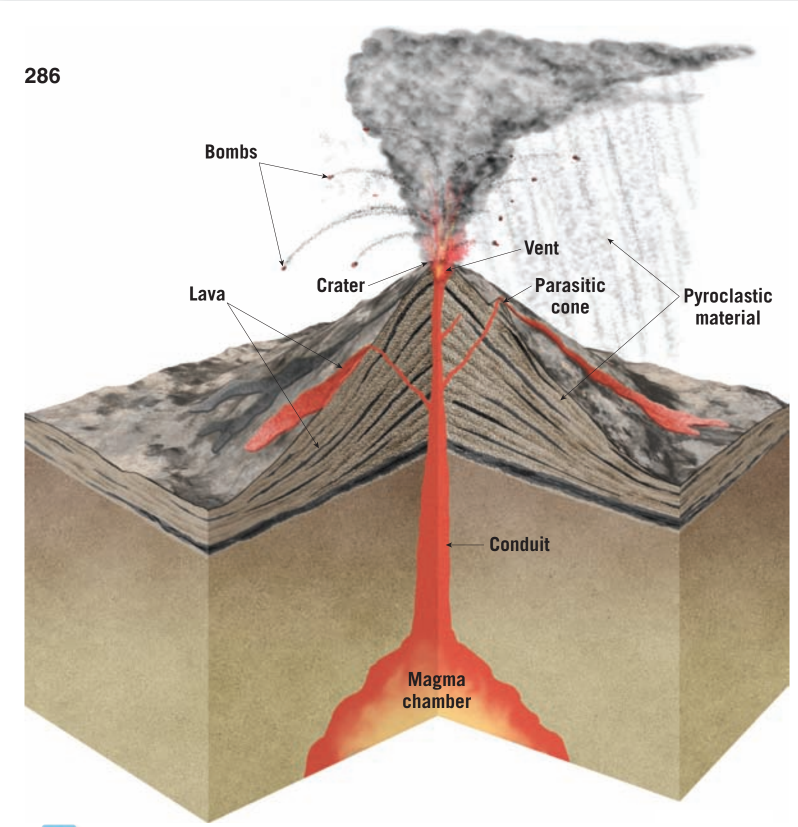
5. Volcanoes, such as the Hawaiian chain, that form over mantle plumes are some of the largest shield volcanoes on Earth. However, several shield volcanoes on Mars are gigantic compared to those on Earth. What does this difference tell us about the role of plate motion in shaping the Martian surface?
6. Imagine that you are studying seafloor spreading along two different oceanic ridges. Using data from a magnetometer, you produced the two accompanying maps. From these maps, what can you determine about the relative rates of seafloor spreading along these two ridges? Explain.



7. Australian marsupials (kangaroos, koala bears, etc.) have direct fossil links to marsupial opossums found in the Americas. Yet the modern marsupials in Australia are markedly different from their American relatives. How does the breakup of Pangaea help to explain these differences (see Figure 7.24)?
8. Density is a key component in the behavior of Earth materials and is especially important in understanding key aspects of plate tectonics. Describe three different ways that density and/or density differences play a role in plate tectonics.

Dynamic visual program integrates text and technology

Carefully selected art and photos aid understanding, add realism, and heighten student interest.



SmartFigure 9.10 Anatomy of a Volcano Compare the structure of a “typical” composite cone to that of a shield volcano (Figure 9.11) and a cinder cone (Figure 9.12).

NEW! SmartFigures bring key chapter illustrations to life! Found throughout the book, SmartFigures are sophisticated, annotated illustrations that are also narrated videos. The SmartFigure videos are accessible on mobile devices via scannable Quick Response (QR) codes printed in the text and through the Study Area in MasteringGeology. See the Preface for more detailed information on SmartFigures.

Callan Bentley, SmartFigure author, is an assistant professor of geology at Northern Virginia Community College (NOVA) in Annandale, Virginia. Trained as a structural geologist, Callan teaches introductory level geology at NOVA, including field-based and hybrid courses. Callan writes a popular geology blog called *Mountain Beltway*, contributes cartoons, travel articles, and book reviews to *EARTH Magazine*, and is a leader in the two-year college geoscience community.

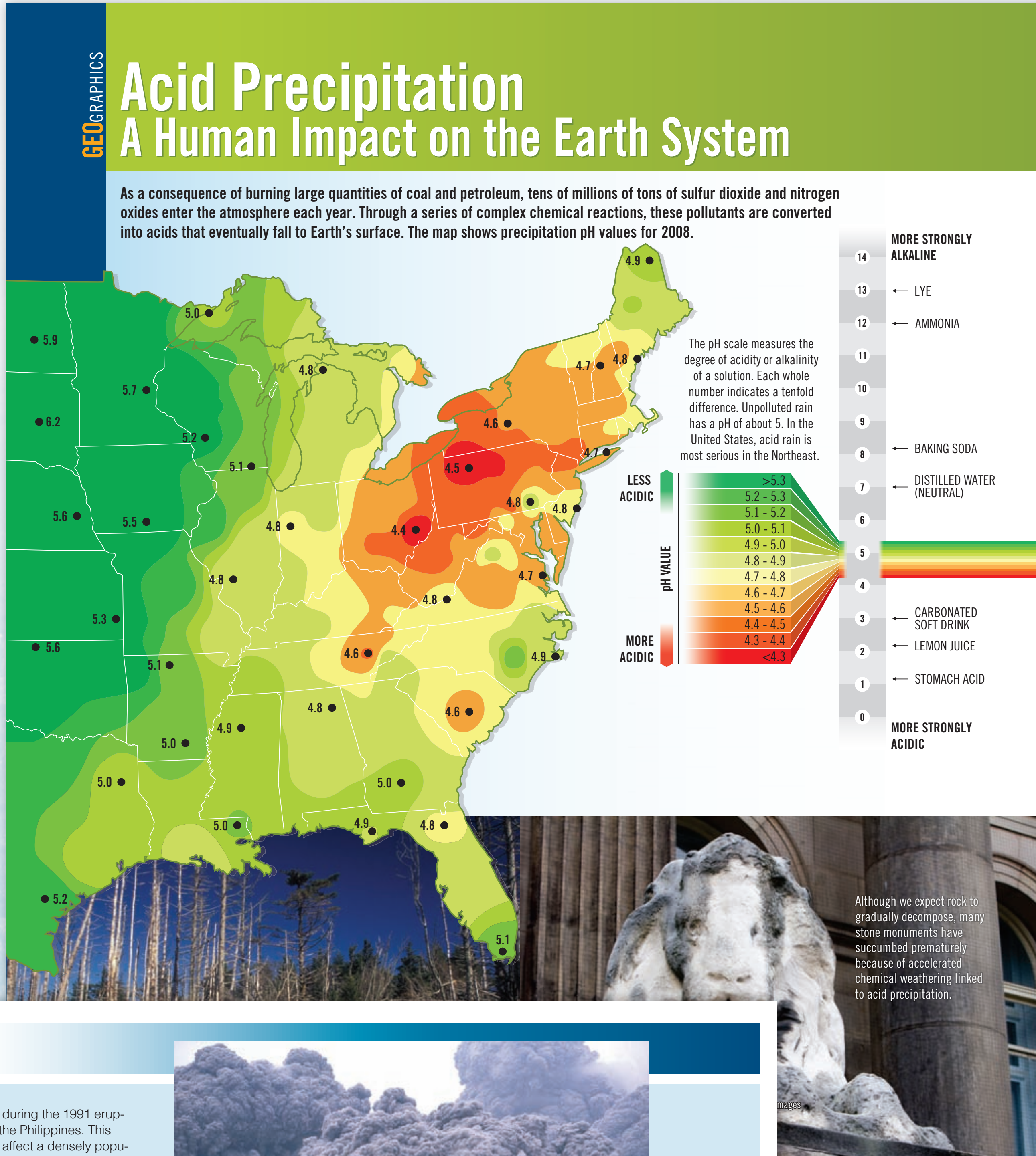
Mobile Field Trips

Scattered through this new edition of Earth Science 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 will scan a QR code that accompanies a figure in the chapter—usually one of Michael's outstanding photos.

Mobile Field Trip 9.25 Sill Exposed in Utah's Sinbad Country The dark, essentially horizontal bands are sills of basaltic composition that intruded horizontal layers of sedimentary rock. (Photo by Michael Collier)

As you turn the pages of this book, you will see dozens of extraordinary photographs by Michael Collier. Most are aerial shots taken from his nearly 60-year-old Cessna 180. Michael is an award-winning geologist, author, and photographer. Michael's photographs are the next best thing to being there. We were fortunate to have had Michael's assistance on Earth Science, Fourteenth edition.

NEW! GEOgraphics use contemporary, compelling visual representations to illustrate complex concepts, enhancing students' ability to synthesize and recall information.



NEW! Eye on Earth features engage students in active learning, asking them to perform critical thinking and visual analysis tasks to evaluate data and make predictions.

EYE ON EARTH

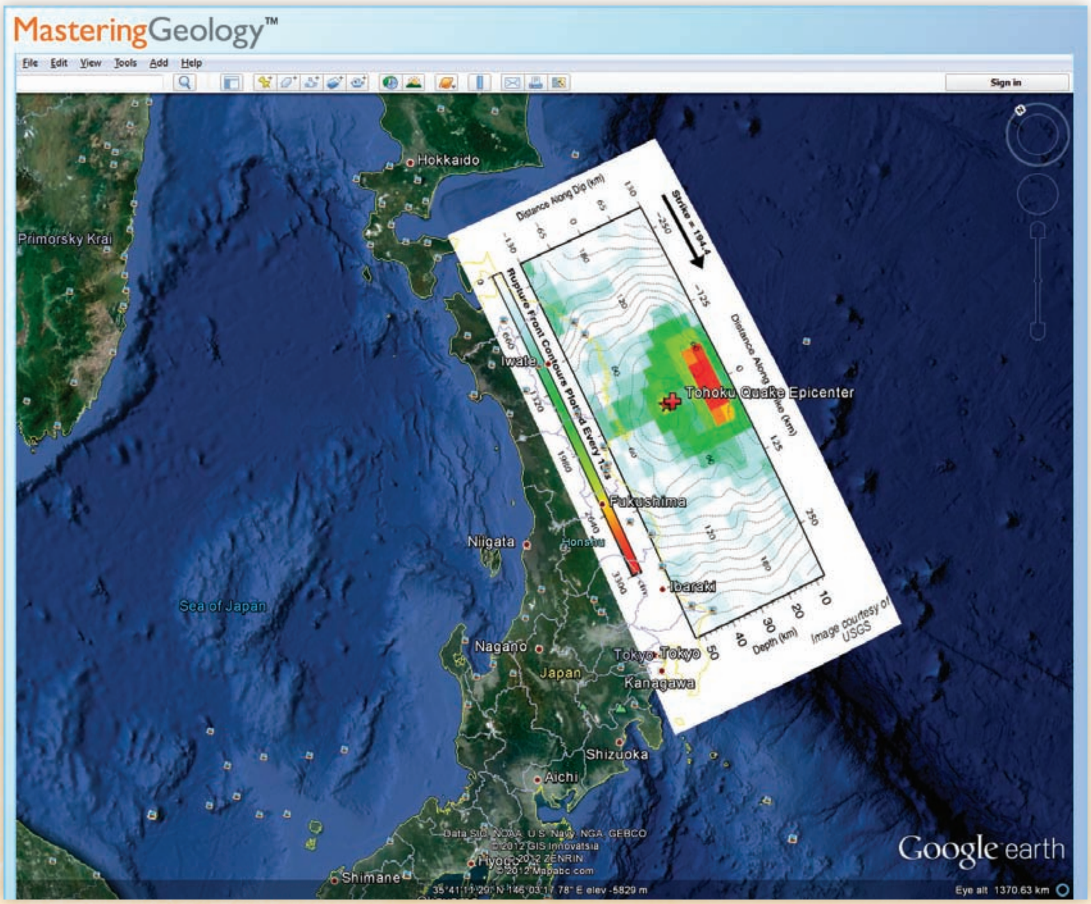
This image was obtained during the 1991 eruption of Mount Pinatubo in the Philippines. This was the largest eruption to affect a densely populated area in recent times. Timely forecasts of the event by scientists were credited with saving at least 5000 lives. (Alberto Garcia/CORBIS)

QUESTION 1 *What name is given to the ash- and pumice-laden cloud that is racing toward the photographer?*

QUESTION 2 *At what speeds can these fiery clouds move down steep mountain slopes?*

MasteringGeology™ www.masteringgeology.com

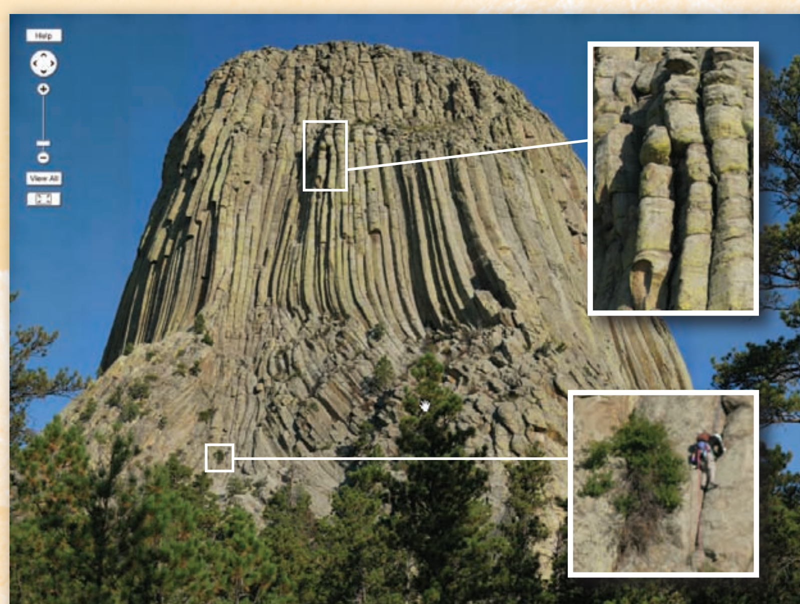
Available for the Earth science course, MasteringGeology delivers engaging, dynamic learning opportunities—focused on course objectives and responsive to each student's progress—that are proven to help students absorb course material and understand difficult Earth science concepts.



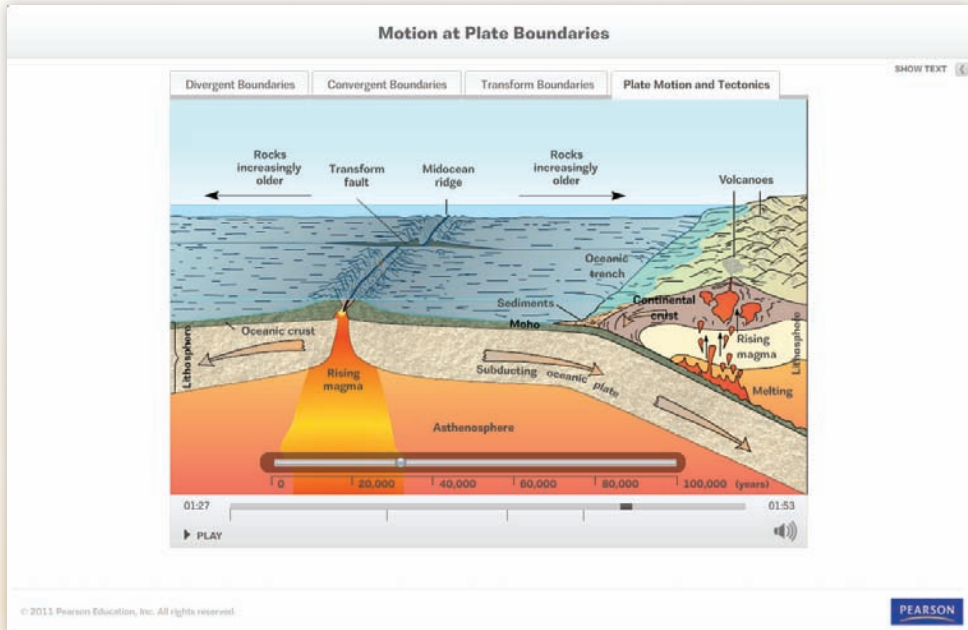
Encounter Activities provide rich, interactive explorations of Earth science concepts using the dynamic features of Google Earth™ to visualize and explore Earth's varied physical landscapes. Dynamic assessment includes questions related to core Earth science concepts. All explorations include corresponding Google Earth KMZ media files, and questions include hints and specific wrong-answer feedback to help coach students toward mastery of the concepts.

NEW! Inquiry-based interactive simulations, developed to allow students to manipulate Earth processes, assist students in mastering the most difficult Earth science processes as identified by today's instructors.

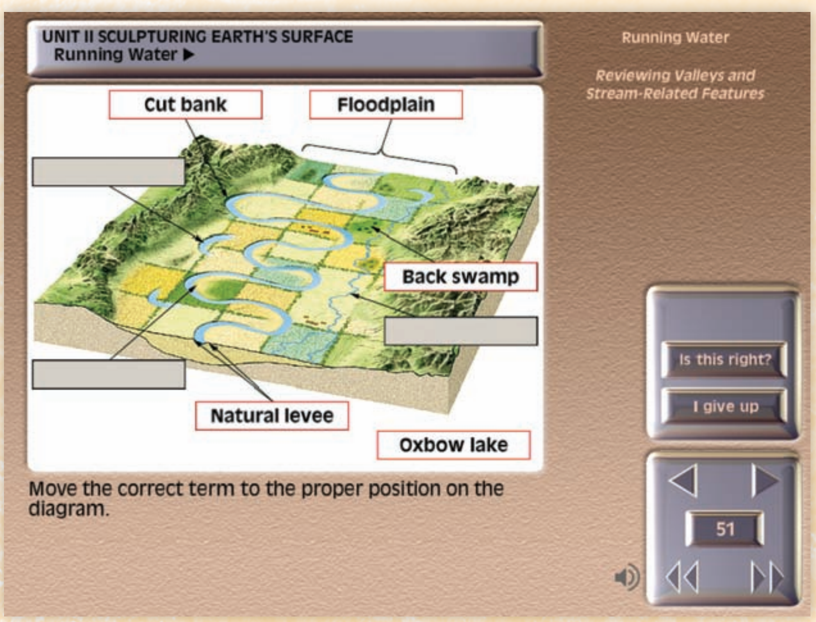
NEW! GigaPan® Activities take advantage of the GigaPan high-resolution panoramic picture technology developed by Carnegie Mellon University in conjunction with NASA. Photos and accompanying questions correlate with concepts in the student book.



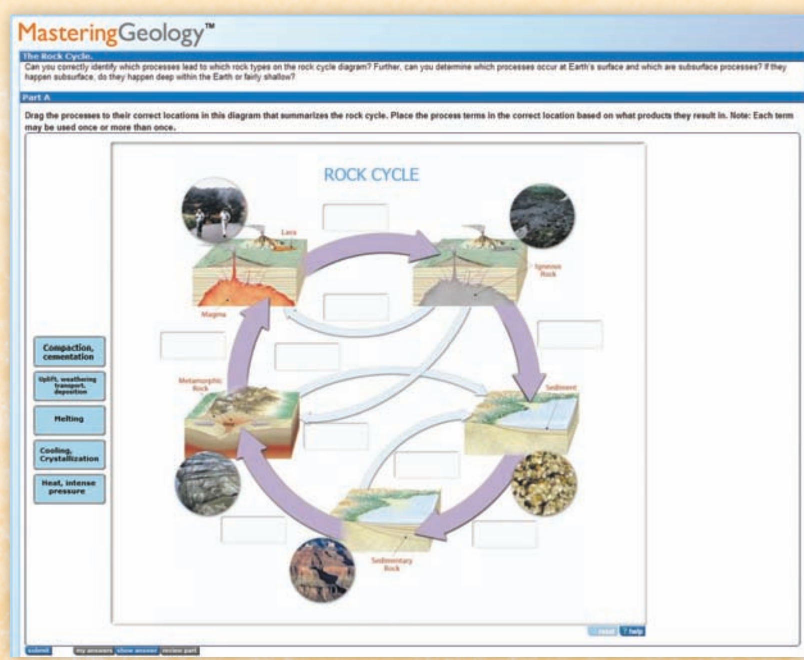
Geoscience Animations and Activities illuminate difficult-to-visualize topics from across the physical geosciences. MasteringGeology allows instructors to easily assign the animations and corresponding assessment questions, all of which include hints and specific wrong-answer feedback.



GEODe Tutorials provide an interactive visual walkthrough of core content through animations, videos, illustrations, photographs, and narration. Activities include assessment questions to test those concepts with hints and specific wrong-answer feedback.



Give It Some Thought questions and problems relate back to each chapter's learning objectives and challenge learners by involving them in activities that require higher-order thinking skills such as synthesis, analysis, and application.



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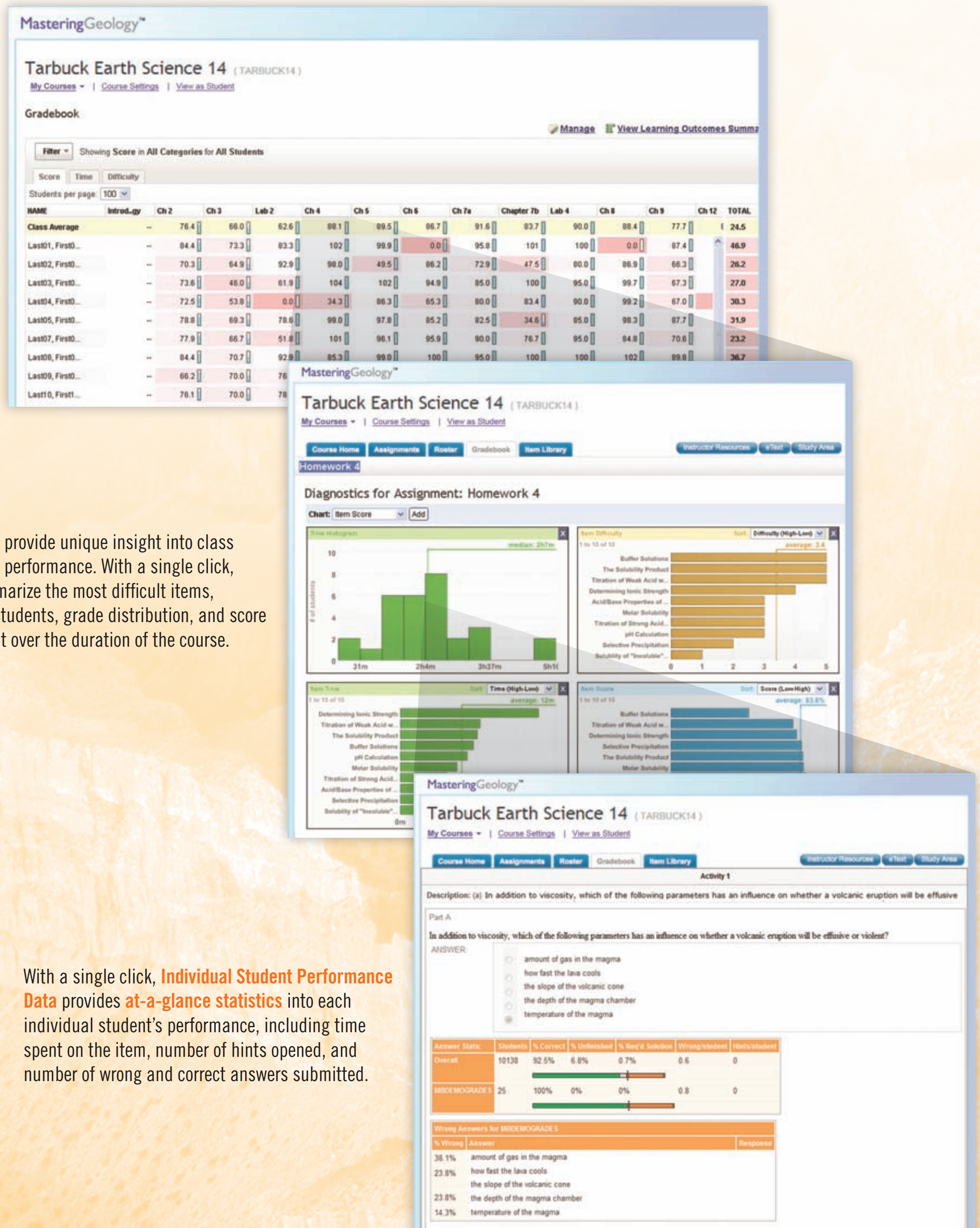

The **Gradebook** records all scores for automatically graded assignments. Shades of red highlight struggling students and challenging assignments.

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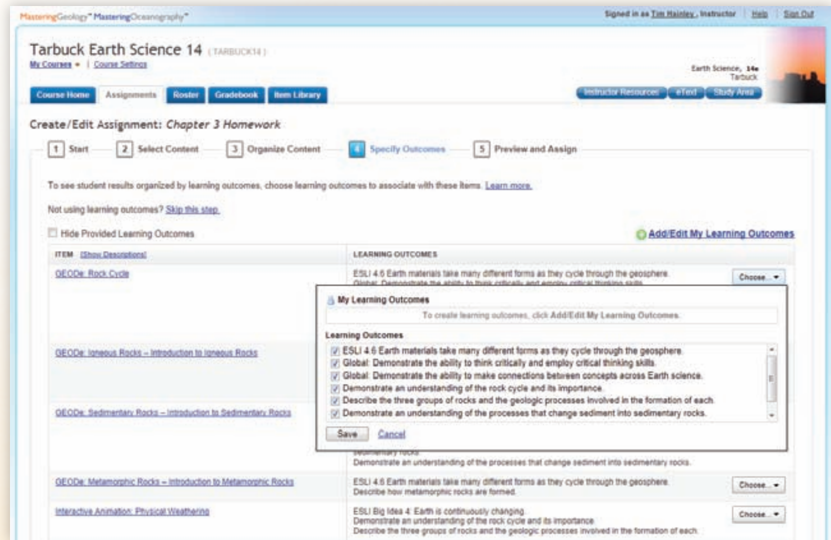

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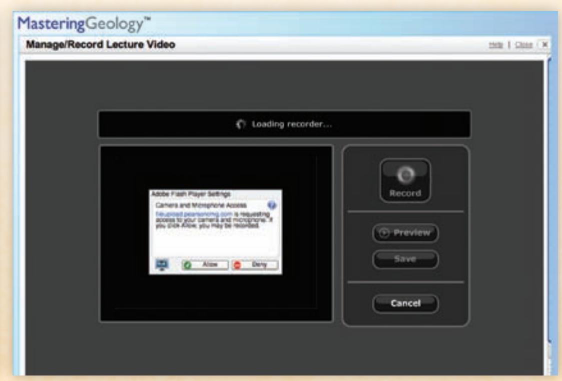

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1 Introduction to Earth Science

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 List and describe the sciences that collectively make up Earth science. Discuss the scales of space and time in Earth science.

1.2 Discuss the nature of scientific inquiry and distinguish between a hypothesis and a theory.

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

1.4 List and describe Earth's four major spheres.

1.5 Label a diagram that shows Earth's internal structure. Briefly explain why the geosphere can be described as being mobile.

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

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

An afternoon rainstorm near Muddy Creek in southern Utah.
(Photo by Michael Collier)

The spectacular eruption of a volcano, the magnificent scenery of a rocky coast, and the destruction created by a hurricane are all subjects for an Earth scientist. The study of Earth science deals with many fascinating and practical questions about our environment. What forces produce mountains? Why is our daily weather variable? Is climate really changing? How old is Earth, and how is our planet related to the other planets in the solar system? What causes ocean tides? What was the Ice Age like? Will there be another? Can a successful well be located at a particular site?

The subject of this text is *Earth science*. To understand Earth is not an easy task because our planet is not a static and unchanging mass. Rather, it is a dynamic body with many interacting parts and a long and complex history.

1.1 WHAT IS EARTH SCIENCE? List and describe the sciences that collectively make up Earth science. Discuss the scales of space and time in Earth science.

Earth science is the name for all the sciences that collectively seek to understand Earth and its neighbors in space. It includes geology, oceanography, meteorology, and astronomy. Understanding Earth science 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 severe storms, landslides, and volcanic eruptions occur. Conversely, many changes take place so gradually that they go unnoticed during a lifetime. Scales of size and space also vary greatly among the phenomena studied in Earth science.

Mobile Field Trip 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)

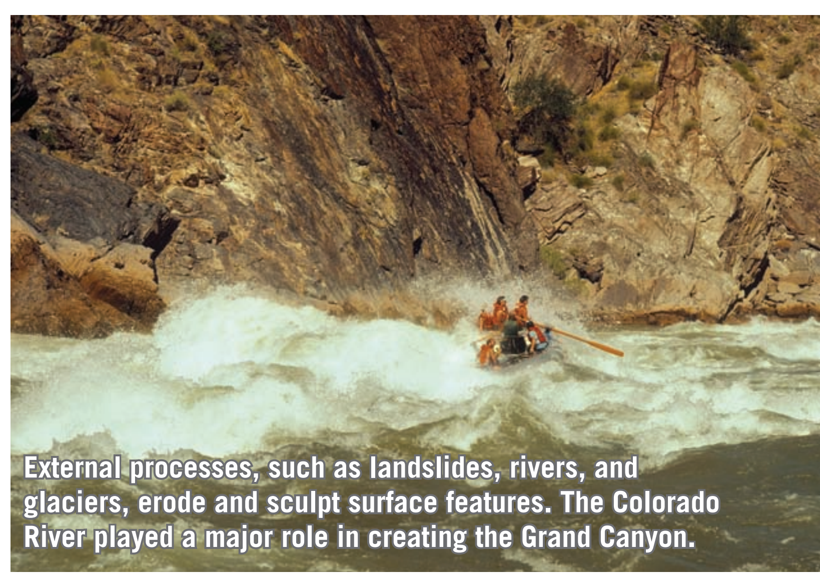
Earth science is often perceived as science that is performed in the out of doors, and rightly so. A great deal of an Earth scientist's study is based on observations and experiments conducted in the field. But Earth science is also conducted in the laboratory, where, for example, the study of various Earth materials provides insights into many basic processes, and the creation of complex computer models allows for the simulation of our planet's complicated climate system. Frequently, Earth scientists require an understanding and application of knowledge and principles from physics, chemistry, and biology. Geology, oceanography, meteorology, and astronomy are sciences that seek to expand our knowledge of the natural world and our place in it.

Geology

In this book, Units 1–4 focus on the science of **geology**, a word that literally means "study of Earth." Geology is traditionally divided into two broad areas: physical and historical.

Physical geology examines the materials composing Earth and seeks to understand the many processes that operate beneath and upon its surface (**FIGURE 1.1**). Earth is a dynamic, ever-changing planet. Internal forces create earthquakes, build mountains, and produce volcanic structures. At the surface, external processes break rock apart and sculpt a broad array of landforms. The erosional

Internal processes are those that occur beneath Earth's surface. Sometimes they lead to the formation of major features at the surface.



External processes, such as landslides, rivers, and glaciers, erode and sculpt surface features. The Colorado River played a major role in creating the Grand Canyon.

effects of water, wind, and ice result in a great diversity of landscapes. Because rocks and minerals form in response to Earth's internal and external processes, their interpretation is basic to an understanding of our planet.

In contrast to physical geology, the aim of *historical geology* is to understand the origin of Earth and the development of the planet through its 4.6-billion-year history. 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.

Oceanography

Earth is often called the "water planet" or the "blue planet." Such terms relate to the fact that more than 70 percent of Earth's surface is covered by the global ocean. If we are to understand Earth, we must learn about its oceans. Unit 5, *The Global Ocean*, is devoted to **oceanography**. Oceanography is actually not a separate and distinct science. Rather, it involves the application of all sciences in a comprehensive and interrelated study of the oceans in all their aspects and relationships. Oceanography integrates chemistry, physics, geology, and biology. It includes the study of the composition and movements of seawater, as well as coastal processes, seafloor topography, and marine life.

Meteorology

The continents and oceans are surrounded by an atmosphere. Unit 6, *Earth's Dynamic Atmosphere*, examines the mixture of gases that is held to the planet by gravity and thins rapidly with altitude. Acted on by the combined effects of Earth's motions and energy from the Sun, and influenced by Earth's land and sea surface, the formless and invisible atmosphere reacts by producing an infinite variety of weather, which in turn creates the basic pattern of global climates. **Meteorology** is the study of the atmosphere and the processes that produce weather and climate. Like oceanography, meteorology involves the application of other sciences in an integrated study of the thin layer of air that surrounds Earth.

Astronomy

Unit 7, *Earth's Place in the Universe*, demonstrates that an understanding of Earth requires that we relate our planet to the larger universe. Because Earth is related to all the other objects in space, the science of **astronomy**—the study of the universe—is very useful in probing the origins of our own environment. Because we are so closely acquainted with the planet on which we live, it is easy to forget that Earth is just a tiny object in a vast universe. Indeed, Earth is subject to the same physical laws that govern the many other objects populating the great expanses of space. Thus, to understand explanations of our planet's origin, it is useful to learn something about the other members of our solar system. Moreover, it is helpful to view the solar system as a part of the great assemblage of stars that comprise our galaxy, which is but one of many galaxies.

Earth Science Is Environmental Science

Earth science is an environmental science that explores many important relationships between people and the natural environment. Many of the problems and issues addressed by Earth science are of practical value to people.

Natural Hazards Natural hazards are a part of living on Earth. Every day they adversely affect literally millions of people worldwide and are responsible for staggering damages. Among the hazardous Earth processes studied by Earth scientists are volcanoes, floods, tsunami, earthquakes, landslides, and hurricanes. Of course, these hazards are *natural* processes. They become hazards only when people try to live where these processes occur.

For most of history, most people lived in rural areas. According to the United Nations, that changed in 2008, and today more people live 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 (**FIGURE 1.2**). Coastal sites are becoming more vulnerable because development often destroys

FIGURE 1.2 Hurricane Sandy A portion of the New Jersey shoreline shortly after this huge storm struck in late October 2012. The storm was especially destructive because it struck a region with a high population density and extensive development. Shifting shoreline sands and the desire of people to occupy these areas are often in conflict. (Photo by AP Photo/ Mike Groll)

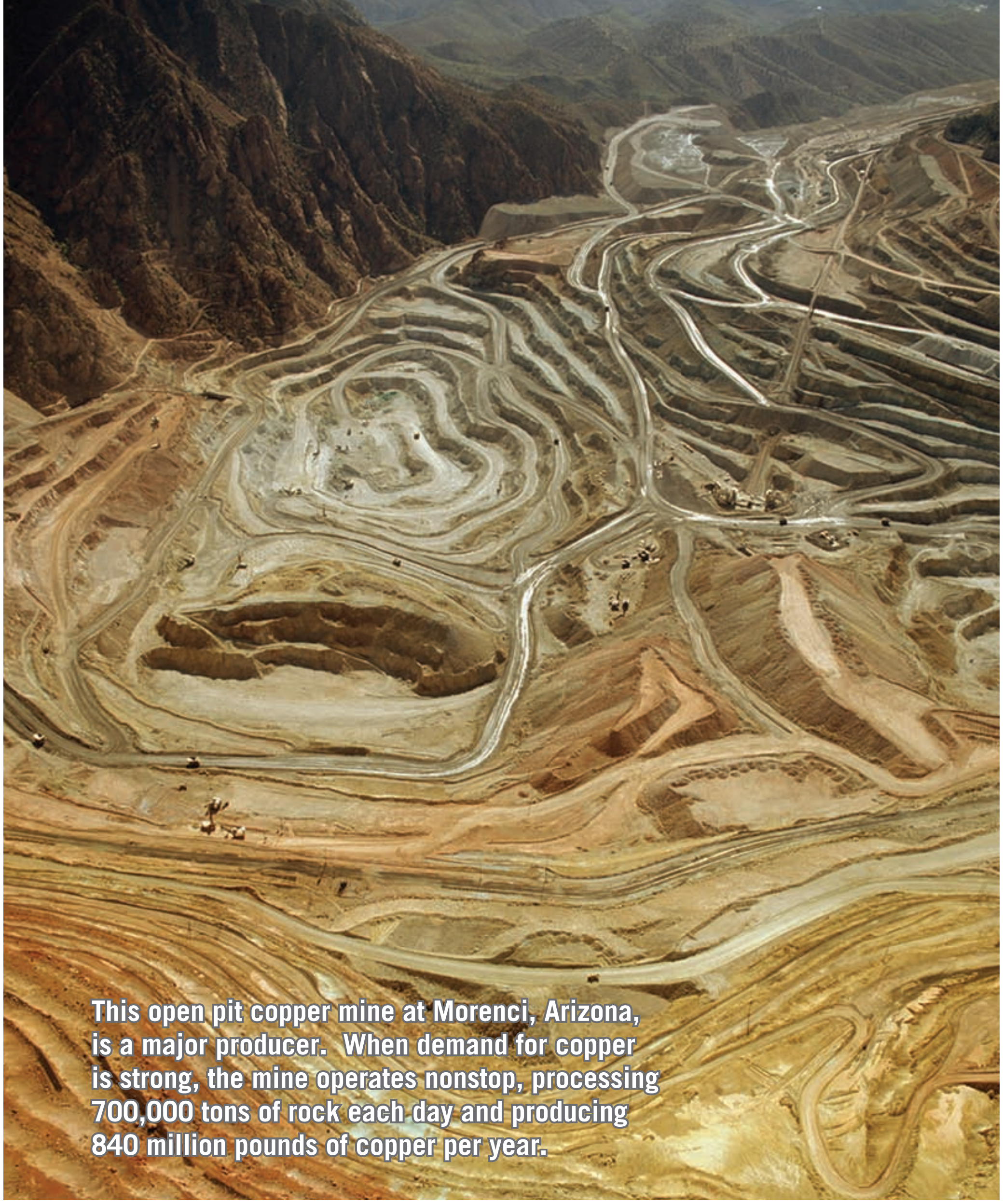


FIGURE 1.3 Copper Mine Resources represent an important link between people and Earth science. (Photo by Michael Collier)

natural defenses such as wetlands and sand dunes. In addition, there is a growing threat associated with human influences on the Earth system such as sea level rise that is linked to global climate change.[1] Other 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 Resources represent another important focus that is of great practical value to people. They include water and soil, a great variety of metallic and nonmetallic minerals, and energy (**FIGURE 1.3**). Together they form the very foundation of modern civilization. Earth science deals with the formation and occurrence of these vital resources and also with maintaining supplies and with the environmental impact of their extraction and use.

People Influence Earth Processes Not only do Earth processes have an impact on people, but we humans can dramatically influence Earth processes as well. Human activities alter the composition of the atmosphere that trigger air pollution episodes and cause global climate change (**FIGURE 1.4**). River flooding is natural, but the magnitude and frequency of flooding can be changed 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 often has the opposite effect.

At various 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

[1]The idea of the Earth system is explored later in the chapter. Global climate change and its effects are a focus of Chapter 20.

FIGURE 1.4 Urban Air Pollution A severe air pollution episode at Beijing, China, on March 18, 2008. Fuel combustion by factories, power plants, and motor vehicles provided a high proportion of the pollutants. Meteorological factors determine whether pollutants remain trapped in the city or are dispersed. (Photo by AP Photo/Ng Han)

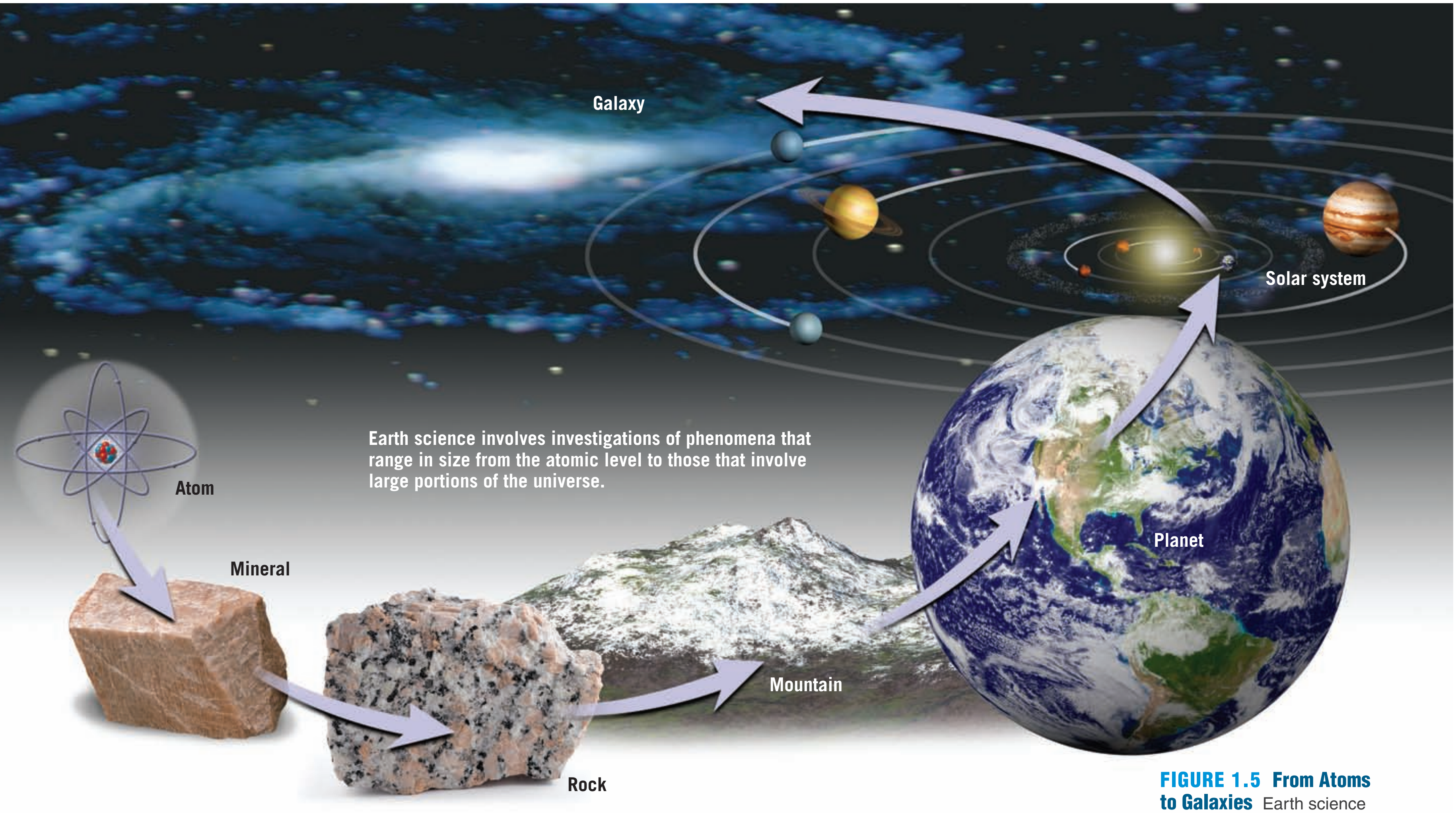


FIGURE 1.5 From Atoms to Galaxies Earth science studies phenomena on many different scales.

a chapter that does not address some aspect of natural hazards, environmental issues, or resources. Significant parts of some chapters provide the basic knowledge and principles needed to understand environmental problems.

Scales of Space and Time in Earth Science

When we study Earth, we must contend with a broad array of space and time scales (**FIGURE 1.5**). Some phenomena are relatively easy for us to imagine, such as the size and duration of an afternoon thunderstorm or the dimensions of a sand dune. Other phenomena are so vast or so small that they are difficult to imagine. The number of stars and distances in our galaxy (and beyond!) or the internal arrangement of atoms in a mineral crystal are examples of such phenomena.

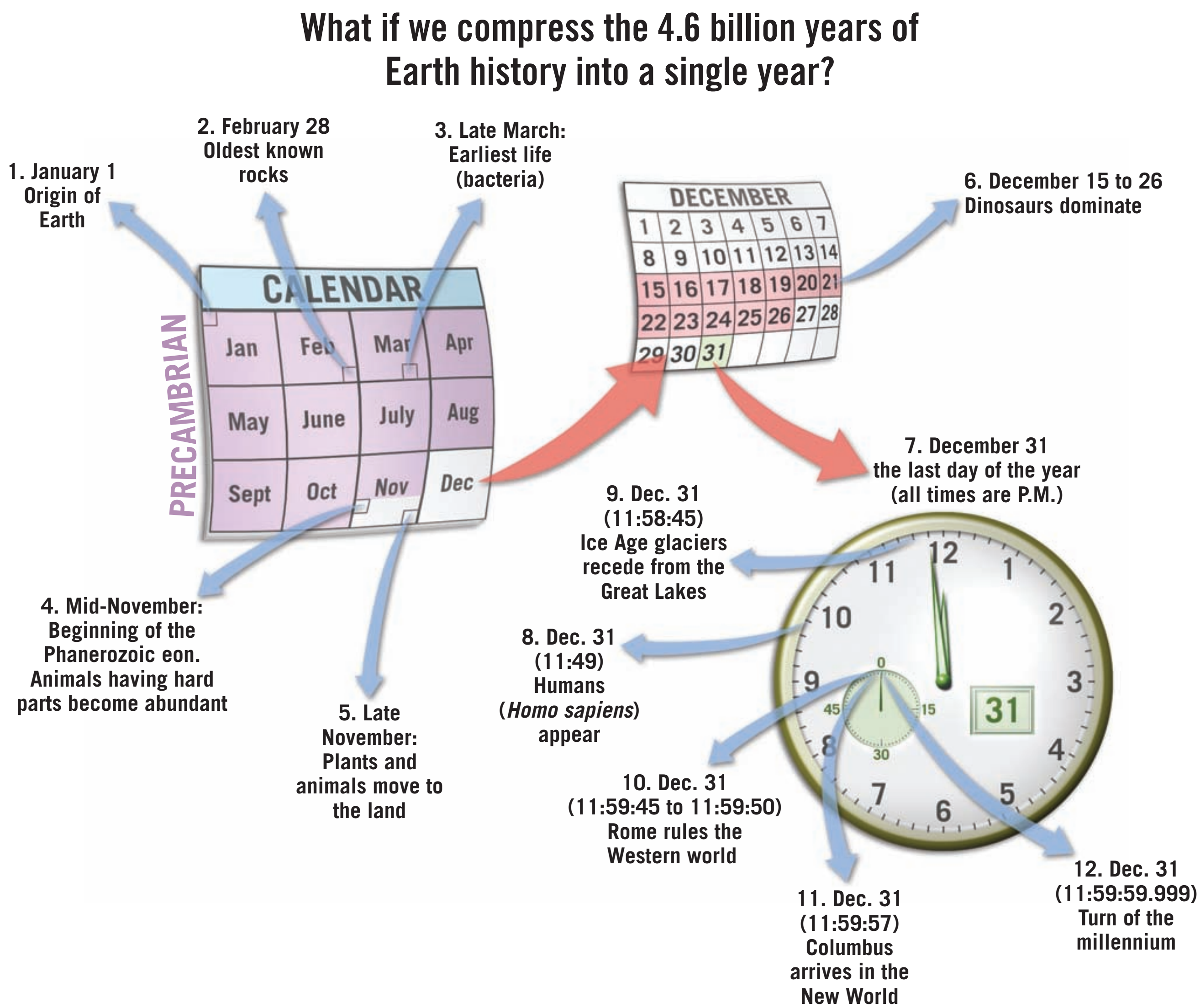
Some of the events we study occur in fractions of a second. Lightning is an example. Other processes extend over spans of tens or hundreds of millions of years. For example, the lofty Himalaya Mountains began forming nearly 50 million years ago, and they continue to develop today.

The concept of **geologic time**, the span of time since the formation of Earth, is new to many nonscientists. 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*.

Those who study Earth science 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, an 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 our planet because many processes are so gradual that vast spans of time are needed 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, seven

SmartFigure 1.6
Magnitude of Geologic Time



days a week and never stopped, it would take about two lifetimes (150 years) to reach 4.6 billion!

The preceding analogy is just one of many 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. **FIGURE 1.6** provides another interesting way of viewing the age of Earth.

Over the past 200 years or so, Earth scientists have developed the *geologic time scale* of Earth history. It divides the 4.6-billion-year history of Earth into many different units and provides a meaningful time frame within which the events of the geologic past are arranged (see Figure 11.24, page 364). The principles used to develop the geologic time scale are examined in some detail in Chapter 11.

1.1 CONCEPT CHECKS

1. List and briefly describe the sciences that collectively make up Earth science.
2. Name the two broad subdivisions of geology and distinguish between them.
3. List at least four different natural hazards.
4. Aside from natural hazards, describe another important connection between people and Earth science.
5. List two examples of size/space scales in Earth science that are at opposite ends of the spectrum.
6. How old is Earth?
7. If you compress geologic time into a single year, how much time has elapsed since Columbus arrived in the New World?

1.2 THE NATURE OF SCIENTIFIC INQUIRY

Discuss the nature of scientific inquiry and distinguish between a hypothesis and a theory.

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? Developing an understanding of how science is done and how scientists work is another important theme that appears throughout this book. You will explore the difficulties in gathering data and some of the ingenious methods that have been developed to overcome these difficulties. You will also see many examples of how hypotheses are formulated and tested, as well as learn about the evolution and development of some major scientific theories.

All science is based on the assumption that the natural world behaves in a consistent and predictable manner that is comprehensible through careful, systematic study. The overall goal of science is to discover the underlying patterns in nature and then to use this knowledge to make predictions about what should or should not be expected, given certain facts or circumstances. For example, by understanding the processes that produce certain cloud types, meteorologists are often able to predict the approximate time and place of their formation.

The development of new scientific knowledge involves some basic logical processes that are universally accepted. To determine what is occurring in the natural world, scientists collect scientific facts through observation and measurement (**FIGURE 1.7**). The types of facts or data that are collected generally seek to answer a well-defined question about the natural world. Because some error is inevitable, the accuracy of a particular measurement or observation is always open to question. Nevertheless, these data are essential to science and serve as the springboard for the development of scientific hypotheses and theories.

FIGURE 1.7 Observation and Measurement Gathering data and making careful observations are basic parts of scientific inquiry. (Instrument photo by Bobbé Christopherson; paleontologist photo by British Antarctic Survey/Science Source)

Hypothesis

Once facts have been gathered and principles have been formulated to describe a natural phenomenon, investigators try to explain how or why things happened in the manner observed. They often do this by constructing a tentative (or untested) explanation, which is called a scientific **hypothesis**. It is best if an investigator can formulate more than one hypothesis to explain a given set of observations. If an individual scientist is unable to devise multiple hypotheses, others in the scientific community will almost always develop alternative explanations. A spirited debate frequently ensues. As a result, extensive research is conducted by proponents of opposing hypotheses, and the results are made available to the wider scientific community in scientific journals.

Before a hypothesis can become an accepted part of scientific knowledge, it must pass objective testing and analysis. If a hypothesis cannot be tested, it is not scientifically useful, no matter how interesting it might seem. The verification process requires that *predictions* be made based on the hypothesis being considered and that the predictions be tested by comparing them against objective observations of nature. Put another way, hypotheses must fit observations other than those used to formulate them in the first place. Hypotheses that fail rigorous testing are ultimately discarded. The history of science is littered with discarded hypotheses. One of the best known is the Earth-centered model of the universe—a proposal that was supported by the apparent daily motion of the Sun, Moon, and stars around Earth. As the mathematician Jacob Bronowski so ably stated, "Science is a great many things, but in the end they all return to this: Science is the acceptance of what works and the rejection of what does not."