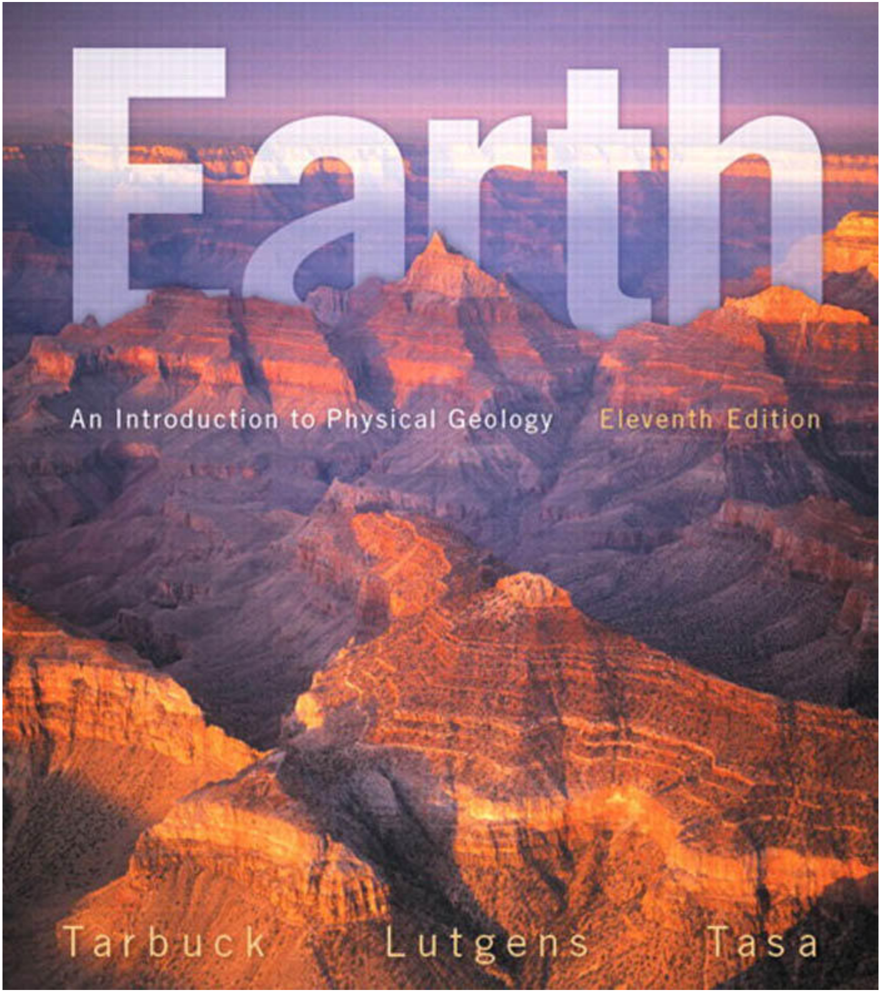

Earth

An Introduction to Physical Geology

Eleventh Edition

Tarbuck Lutgens Tasa

Earth

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ELEVENTH EDITION

Earth

An Introduction to Physical Geology

EDWARD J. TARBUCK

FREDERICK K. LUTGENS

Illustrated by

DENNIS TASA

PEARSON

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To Our Grandchildren

Shannon, Amy, Andy, Ali, and Michael

Allison and Lauren

Each is a bright promise for the future.

Brief Contents

Table of Contents

17 Groundwater 555

18 Glaciers and Glaciation 591

19 Deserts and Winds 635

Preface

Earth is a very small part of a vast universe, but it is our home. It provides the resources that support our modern society and the ingredients necessary to maintain life. Knowledge of our physical environment is critical to our well-being and vital to our survival. A basic geology course can help a person gain such an understanding. It can also take advantage of the interest and curiosity many of us have about our planet—its landscapes and the processes that create and alter them.

This eleventh edition of *Earth: An Introduction to Physical Geology*, like its predecessors, is a college-level text that is intended to be a meaningful, nontechnical survey for students taking their first course in geology. In addition to being informative and up-to-date, a major goal of *Earth* is to meet the need of students for a readable and user-friendly text, a book that is a highly usable tool for learning the basic principles and concepts of geology.

New to the Eleventh Edition

New Active Learning Path

Earth, eleventh 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 a new section called *Give It Some Thought*. The questions and problems in this section challenge learners by involving them in activities that require higher-order thinking skills that include application, analysis, and synthesis of material in the chapter.

Concepts in Review

This all-new end-of-chapter feature is an important part of the book's 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 concise, readable, visual overview of key ideas that makes it a valuable tool for student review.

Eye on Earth

Within every chapter are two to five 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 serve to focus students on visual analysis and critical thinking.

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.

SmartFigures—Art That Teaches

Inside every chapter are 6 or 7 *SmartFigures*. *Earth*, eleventh edition, has about 150 of them altogether. Just use your SmartPhone to scan the QR code next to such a figure, and the art comes alive! Prepared and narrated by Professor Callan Bentley, each 3- to 4-minute feature is a mini-lesson that examines and explains the concepts illustrated by the figure. It is truly *art that teaches*. For those without SmartPhones, SmartFigures are also available via www.masteringgeology.com and the eText.

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" exploring topics that not only promote greater understanding but also add interest to the story each chapter is telling.

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™, Geoscience Animation activities, SmartFigure activities, GEODe 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 textbook is to provide clear, understandable presentations that are accurate, engaging, and up-to-date. Our number-one goal is to keep *Earth* current, relevant, and highly readable for beginning students. With this goal in mind, every part of the book was examined carefully. Many discussions, case studies, and examples have been revised. The eleventh edition represents perhaps the *most extensive and thorough revision* in the long history of this textbook.

Distinguishing Features

Readability

The language of this book 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 eleventh 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 eleventh edition of *Earth*, 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 the basic principles of geology. As much as possible, we have attempted to provide the reader with a sense of the observational techniques and reasoning processes that constitute the discipline of geology.

A Strong Visual Component

Geology 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 book. Michael Collier, an award-winning geologist-photographer aided greatly in this quest. As you page through this book, you will see dozens of his extraordinary aerial photographs. His contribution truly helps bring geology alive for the reader.

The Teaching and Learning Package

MasteringGeology™ with Pearson eText

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.

- MasteringGeology provides a rich and flexible set of course materials to get instructors started quickly, including pre-built assignments that instructors can use as is or customize to fit their needs.
- MasteringGeology provides quick and easy access to information on student performance against learning outcomes. Instructors can quickly add their own learning outcomes, or use publisher-provided ones, to track student performance.
- The MasteringGeology gradebook and diagnostic tools capture the step-by-step work of every student, providing unique insight into class performance.
- Assignable items in MasteringGeology include:
  - **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.
  - **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.
  - Encounter Earth Activities, which provide interactive explorations of geology concepts using Google Earth™. Students work through the activities in Google Earth and then test their knowledge by answering the assessment questions, which include hints and specific wrong-answer feedback.
  - Animation Activities, which illuminate the most difficult-to-understand topics in geology. The animation activities include audio narration, a text transcript, and assignable multiple-choice questions with specific wrong-answer feedback.
  - GeoTutor Activities, which consist of sophisticated, high impact visuals that ask students to demonstrate their knowledge by synthesizing and analyzing core concepts using higher-order thinking skills.
  - Concept Check questions, Give It Some Thought questions, Reading questions, and Test Bank questions.
- MasteringGeology includes a Study Area for students to access all of their study resources. The Study Area includes geoscience animations, GEODe activities, *In the News* RSS feeds, Self-Study Quizzes, Web Links, Glossary, Flashcards, and an optional Pearson eText.

See www.masteringgeology.com.

Instructor's Resource Center

The authors and publisher have been pleased to work with a number of talented people who produced an excellent supplements package.

Instructor Resource Center (IRC) on DVD The IRC puts all your lecture resources in one easy-to-reach place:

- *All* of the line art, tables, and photos from the text in .jpg files
- More than 100 animations of key geologic processes
- *Images of Earth* photo gallery
- PowerPoint™ presentations
- *Instructor Manual* in Microsoft Word™
- *Test Bank File* in Microsoft Word

- TestGen® test-generation and management software
- Electronic transparency acetates

Animations The Geoscience Animation Library, fifth edition, includes animations that illuminate many difficult-to-visualize topics of physical geology. Created through a unique collaboration among five of Pearson's leading geoscience authors, these animations represent a significant leap forward in lecture presentation aids. They are provided both as Flash files and, for your convenience, preloaded into PowerPoint slides.

PowerPoint Presentations The IRC provides three PowerPoint files for each chapter. They help you cut down on your preparation time, no matter what your lecture needs:

- *Exclusively Art*—All the photos, art, and tables from the text, in order, loaded into PowerPoint slides.
- *Lecture Outline*—This set averages 50 slides per chapter and includes customizable lecture outlines with supporting art.
- *Classroom Response System (CRS) Questions*—Authored for use in conjunction with classroom response systems, these PowerPoints allow you to electronically poll your class for responses to questions, pop quizzes, attendance, and more.

Transparency Acetates Provided electronically, every table and most of Dennis Tasa's illustrations in *Earth*, eleventh edition, are available to be printed out as full-color, projection-enhanced transparencies.

Instructor Manual

The Instructor Manual has been designed to help seasoned and new professors alike, offering in each chapter an introduction to the chapter, outline, learning objectives/focus on concepts, teaching strategies, teacher resources, and answers to *Concept Checks*, *Eye on Earth*, and *Give It Some Thought* questions from the textbook.

TestGen® Computerized Test Bank (Download Only)

TestGen is a computerized test generator that lets instructors view and edit *Test Bank* questions, transfer questions to tests, and print the test in a variety of customized formats. This *Test Bank* includes more than 2,000 multiple-choice, true/false, short-answer, matching, visually based, and essay questions. Questions are correlated to Bloom's Taxonomy, each chapter's learning objectives, the Earth Science Learning Objectives, and the Pearson Science Global Outcomes to help instructors better map the assessments against both broad and specific teaching and learning objectives. The *Test Bank* is also available in Microsoft Word and is importable into Blackboard.

See www.pearsonhighered.com/irc.

Blackboard Already have your own website set up? We will provide the Test Bank in Blackboard or formats for importation. Additional course resources are available on the IRC and are available for use, with permission.

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. We spent many hours having conversations with Derek Bacchus and Gary Hespenheid, two talented men who are largely responsible for *Earth*'s new design. We think it is a job well done. As always, our marketing manager, Maureen McLaughlin, provided helpful advice and many good ideas. *Earth* eleventh edition, was truly improved with the help of two developmental editors, Jay McElroy and Jonathan Cheney. Many thanks. The production team was led by Ed Thomas at Pearson Education and by Heidi Allgair at Element LLC. It was their job to make this book into a finished product. We think they did a great job. All are true professionals, with whom we are very fortunate to be associated.

The authors owe a special thanks to three people who were very important parts 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 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. Among his many awards is the American Geological Institute Award for Outstanding Contribution to the Public Understanding of the Geosciences. John S. Shelton, a pioneering geologist-pilot-photographer, wrote of Michael, "Collier's combination of skill and talents—writer, photographer, geologist, and pilot . . . is truly impressive. He is indeed master of both the medium and the message." We agree. Michael's photographs are the next best thing to being there. We were fortunate to have had Michael's assistance on *Earth*, eleventh edition. Thanks, Michael.
- Callan Bentley has been an important addition to the *Earth* 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 nearly 150 *Smart Figures* that appear throughout *Earth*'s 24 chapters. As you take advantage of these outstanding learning aids, you will hear his voice explaining the ideas. Callan also prepared all of the Concepts in Review found at the end of each chapter. We think these readable summaries are an important part of *Earth's* active learning approach. We appreciate Callan's contribution to the eleventh edition of *Earth*.

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:

John Bigolski, Kingsborough Community College
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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*, eleventh edition, would have been far more difficult without their patience and understanding.

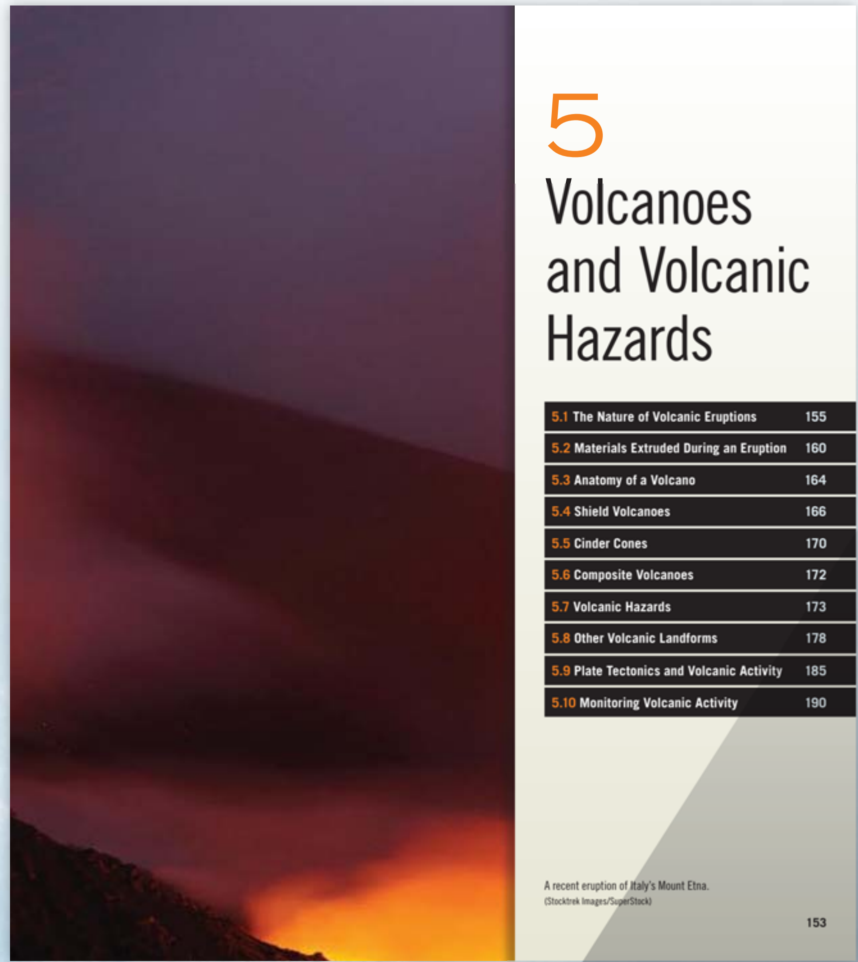
Ed Tarbuck

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.



5

Volcanoes and Volcanic Hazards

A recent eruption of Italy's Mount Etna. (Stocktrek Images/SuperStock)

153

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:

5.1 Explain why some volcanic eruptions are explosive and others are quiescent.
5.2 List and describe the three categories of materials extruded during volcanic eruptions.
5.3 Label a diagram that illustrates the basic features of a typical volcanic cone.
5.4 Summarize the characteristics of shield volcanoes and provide one example.
5.5 Describe the formation, size, and composition of cinder cones.
5.6 Discuss the formation, distribution, and characteristics of composite volcanoes.
5.7 Discuss the major geologic hazards associated with volcanoes.
5.8 List and describe volcanic landforms other than shield, cinder, and composite volcanoes.
5.9 Relate the types and distribution of volcanic activity to plate tectonics.
5.10 List and describe the techniques used to monitor potentially dangerous volcanoes.

On Sunday, May 18, 1980, the most destructive volcanic eruption to occur in North America in recorded history transformed Mount St. Helens, once a picturesque volcano, into a decapitated remnant. The blast blew out the entire north flank of the volcano. Almost instantaneously, a 400-square-kilometer area was devastated, and ash was propelled 18,000 meters into the stratosphere.

Not all volcanic eruptions are as violent as the 1980 Mount St. Helens event. Some volcanoes, such as Hawaii's Kilauea volcano, typically generate relatively quiet outpourings of fluid lavas. These quiescent eruptions are not without some fiery displays; occasionally fountains of incandescent lava spray hundreds of meters into the air. During Kilauea's most recent active phase, which began in 1983, more than 180 homes and a national park visitor center have been destroyed.

Why do some volcanoes, like Mount St. Helens, erupt explosively, whereas others, like Kilauea, are relatively quiescent? Why do volcanoes occur in chains like those that compose the Aleutian Islands and the Cascade Range in the Pacific Northwest? Why do some volcanoes form in the deep ocean basins, while others occur along margins of the continents? This chapter will deal with these and other questions, as we explore the nature and movement of magma and lava.

Eruption of Mount Etna, Sicily. (Photo by Martin Rietze/AGE Fotostock)

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.

5.4 CONCEPT CHECKS

1. Describe the composition and viscosity of the lava associated with shield volcanoes.
2. Are pyroclastic materials a significant component of shield volcanoes?
3. Where do most shield volcanoes form—on the ocean floor or on the continents?
4. Relate lava tubes to the extent of lava flows associated with shield volcanoes.
5. Where are the best-known shield volcanoes in the United States? Name some examples in other parts of the world.

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:

5.1 Explain why some volcanic eruptions are explosive and others are quiescent.
5.2 List and describe the three categories of materials extruded during volcanic eruptions.
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5.7 Discuss the major geologic hazards associated with volcanoes.
5.8 List and describe volcanic landforms other than shield, cinder, and composite volcanoes.
5.9 Relate the types and distribution of volcanic activity to plate tectonics.
5.10 List and describe the techniques used to monitor potentially dangerous volcanoes.

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 Words | Section Title | Learning Objective | Synthesis, Analysis, and Application

CONCEPTS IN REVIEW: VOLCANOES AND VOLCANIC HAZARDS

5.1 The Nature of Volcanic Eruptions

Explain why some volcanic eruptions are explosive and others are quiescent.

KEY WORDS viscosity, volatiles, eruption columns

- Volcanoes are places where liquid rock (lava) emerges at Earth's surface.
- Lava has some degree of viscosity (resistance to flow). In general, the more silica in the lava, the more viscous it is. The lower the silica content, the runnier the lava. Another factor that influences viscosity is temperature. Hot lavas are more runny, while cool lavas are more viscous.
- Viscous lavas clog the plumbing of a volcano, allowing great pressures to build up. High-silica, low-temperature lavas are most viscous and allow the greatest amount of pressure to build up before they "let go" in an eruption. In contrast, lavas that are low in silica and hot are most runny. Because basaltic lava is less viscous, much less pressure can build up, and it produces relatively gentle eruptions. Thus, volcanoes that erupt felsic lava (rhyolite) and intermediate lava (andesite) are more dangerous than those that erupt only mafic lava (basalt).

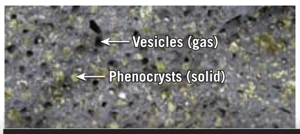
PONDER THE POSSIBILITIES Although Kilauea mostly erupts in a gentle manner, what would be the risks if you chose to live nearby?

5.2 Materials Extruded During A Volcanic Eruption

List and describe the three categories of materials extruded during volcanic eruptions.

KEY WORDS aa, pahoehoe, lava tube, block lava, pillow lava, pyroclastic materials, tephra

- Volcanoes bring gases and solid chunks to the surface, as well as liquid lava.
- Because of their low viscosity, basaltic lava flows can extend great distances from a volcano. Sometimes they travel over the surface as pahoehoe or aa flows. Sometimes the surface congeals but lava continues to flow below, in tunnels called lava tubes. When lava erupts in water, the outer surface is chilled instantly to obsidian, while the inside continues to flow, producing tube-shaped structures called pillow lavas.
- The gases most commonly emitted by volcanoes are water vapor and carbon dioxide. When these gases reach the surface, their rapid expansion results in explosive power that helps a volcano to "clear its throat" and produces a mass of lava fragments called pyroclastic materials. These hot gases have low densities, so they rise, picking up ash and lapilli to produce spectacular eruption columns.
- If bubbles of gas in the lava don't pop before solidification, they are preserved as voids called vesicles. Especially frothy rhyolitic lava can cool to make pumice, which often floats in water. Mafic lava, with lots of bubbles, cools to make scoria.
- Pyroclastic materials come in several sizes. From smallest to largest, they are ash, lapilli, and blocks or bombs, depending on whether the material left the volcano as solid fragments or as liquid blobs.



Volcanoes erupt solids, liquids, and gases. Mineral crystals that formed during slower cooling underground are carried upward as solid particles, the liquid lava itself crystallizes rapidly into a fine-grained groundmass, and vesicles represent the release of gases that were dissolved in the lava before eruption.

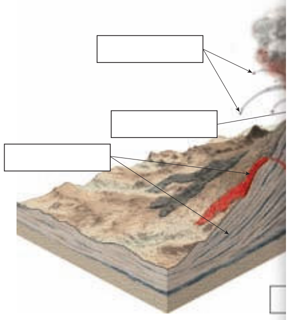
5.3 Anatomy of A Volcano

Label a diagram that illustrates the basic features of a typical volcanic cone.

KEY WORDS fissure, conduit, vent, volcanic cone, crater, parasitic cone, fumarole

- Volcanoes are varied in form but share a few common features. Most are roughly conical piles of extruded material that collect around a central vent. The vent is usually within a summit crater or caldera. On the flanks of the volcano, there may be smaller vents marked by small parasitic cones, or there may be fumaroles, spots where gas is expelled.

TAG IT Label the diagram: conduit, vent, crater, parasitic cone, fumarole



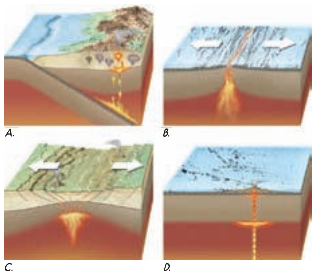
Consistent with the Focus on Concepts and Concept Checks, the **Concepts in Review** is structured around the section title, and the corresponding learning objective for each section.

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 geology. GIST questions relate back to the chapter's learning objectives, and can easily be assigned using MasteringGeology™.

GIVE IT SOME THOUGHT

1. Match each of the following volcanic landforms with the principle zone of volcanism (convergent plate boundaries, divergent plate boundaries, or intraplate volcanism) with which it is associated:
   a. Crater Lake
   b. Hawaii's Kilauea
   c. Mount St. Helens
   d. East African Rift
   e. Yellowstone
   f. Mount Pelée
   g. Deccan Plateau
   h. Fujiyama
2. Examine the accompanying photo and complete the following:
   a. What type of volcano is it? What features helped you classify it as such?
   b. What is the eruptive style of such volcanoes? Describe the likely composition and viscosity of its magma.
   c. Which of the three zones of volcanism is the likely setting for this volcano?
   d. Name a city that is vulnerable to the effects of a volcano of this type.

3. Divergent boundaries, such as the Mid-Atlantic Ridge, are characterized by outpourings of basaltic lava. Answer the following questions about divergent boundaries and their associated lavas:
   a. What is the source of these lavas?
   b. What causes the source rocks to melt?
   c. Describe a divergent boundary that would generate lavas with a large range of compositions.
4. For each of the accompanying four sketches, identify the geologic setting (zone of volcanism). Which of these settings will most likely generate explosive eruptions? Which will produce outpourings of fluid basaltic lavas?

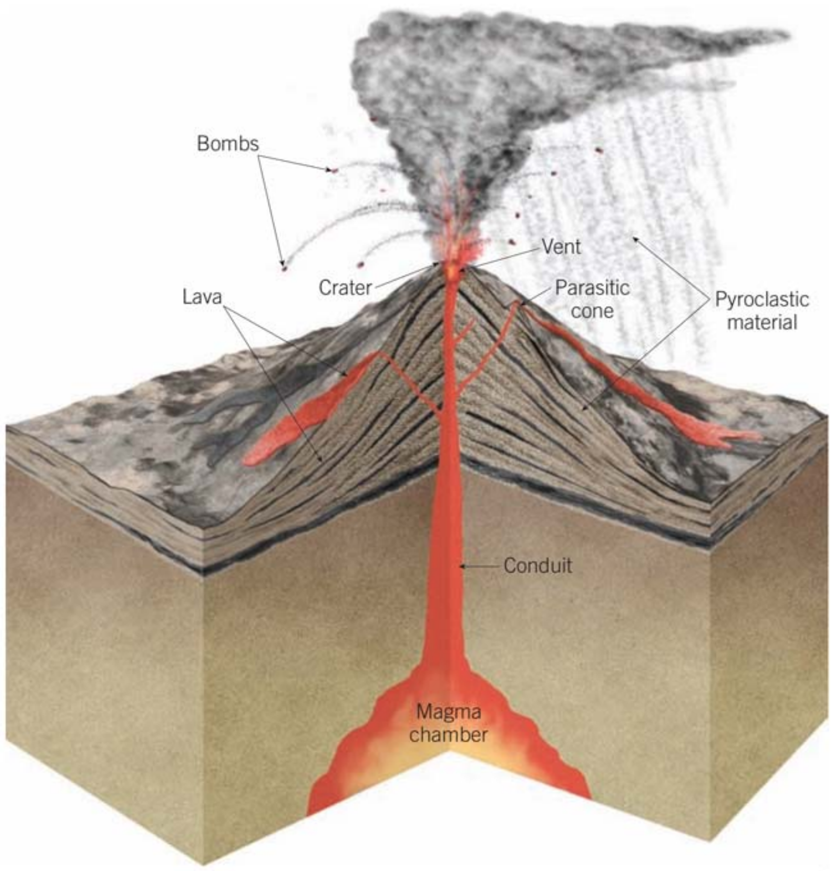


5. Assume that you want to monitor a volcano that has erupted several times in the recent past but appears to be quiet now. How might you determine if magma were actually moving through the crust beneath the volcano? Suggest at least two phenomena you would observe or measure.
6. Examine the accompanying photo and identify the volcanic landform shown.

7. Imagine that you are a geologist charged with the task of choosing three sites (anywhere in the world) where state-of-the-art volcano-monitoring systems will be deployed. What criteria would you use to select these sites? List some potential choices and your reasons for considering them.
8. Explain why an eruption of Mount Rainier, similar to the one that occurred at Mount St. Helens in 1980, would be considerably more destructive.
9. The accompanying image shows a geologist at the end of a large flow consisting of dense lava blocks that traveled down the flank of Mount Augustine.
   a. What is this type of flow called?
   b. What do volcanologists call the structure composed of broken lava blocks (emitting steam) visible near the summit of this volcano?

Dynamic visual program integrates text and technology

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

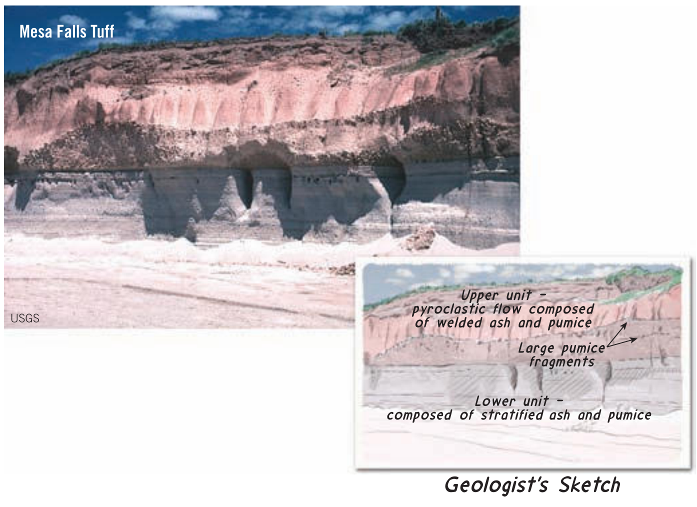


SMARTFIGURE 5.9
Anatomy of a volcano
Compare the structure of a "typical" composite cone to that of a shield volcano (Figure 5.10) and a cinder cone (Figure 5.11).

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.

Geologist's Sketches encourage students to see the world through the eyes of a professional geologist. This unique feature consists of a particular photograph shown alongside a sketched version of the same image.



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, eleventh edition.

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

GEOGRAPHICS

Eruption of Mount Vesuvius, AD 79

One well-documented volcanic eruption of historic proportions was the AD 79 eruption of the Italian volcano we now call Mount Vesuvius. For centuries prior to this eruption, Vesuvius had been relatively quiescent and its slopes were adorned with vineyards. However, the tranquility abruptly ended, and in less than 24 hours the entire city of Pompeii and a few thousand of its residents were entombed beneath a layer of volcanic ash and pumice that fell like rain.

Mount Vesuvius has had more than two dozen explosive eruptions since AD 79, the most recent occurring in 1944. Today, roughly 3 million people inhabit the area around Mount Vesuvius, making it potentially one of the most dangerous volcanoes in the world.

Olivier Goujon/Robert Harding

Ruins of Pompeii Nearly 17 centuries after the eruption, excavation of Pompeii gave archeolo-

Leonard von Matt/Photo Researchers, Inc.

Victims of the AD 79 eruption of Mount Vesuvius The remains of human victims were quickly ... fall caused the ash ... mains decomposed ... nineteenth-century ... by pouring plaster

Jose Fuste Raga/Corbis/Glow Images

Mount Vesuvius today This image of Naples, Italy, with Vesuvius in the background, should prompt us to consider how volcanic crises might be managed in the future.

177

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 is a close-up view of a massive granite feature in the Sierra Nevada of California. (Photo by Marli Miller)

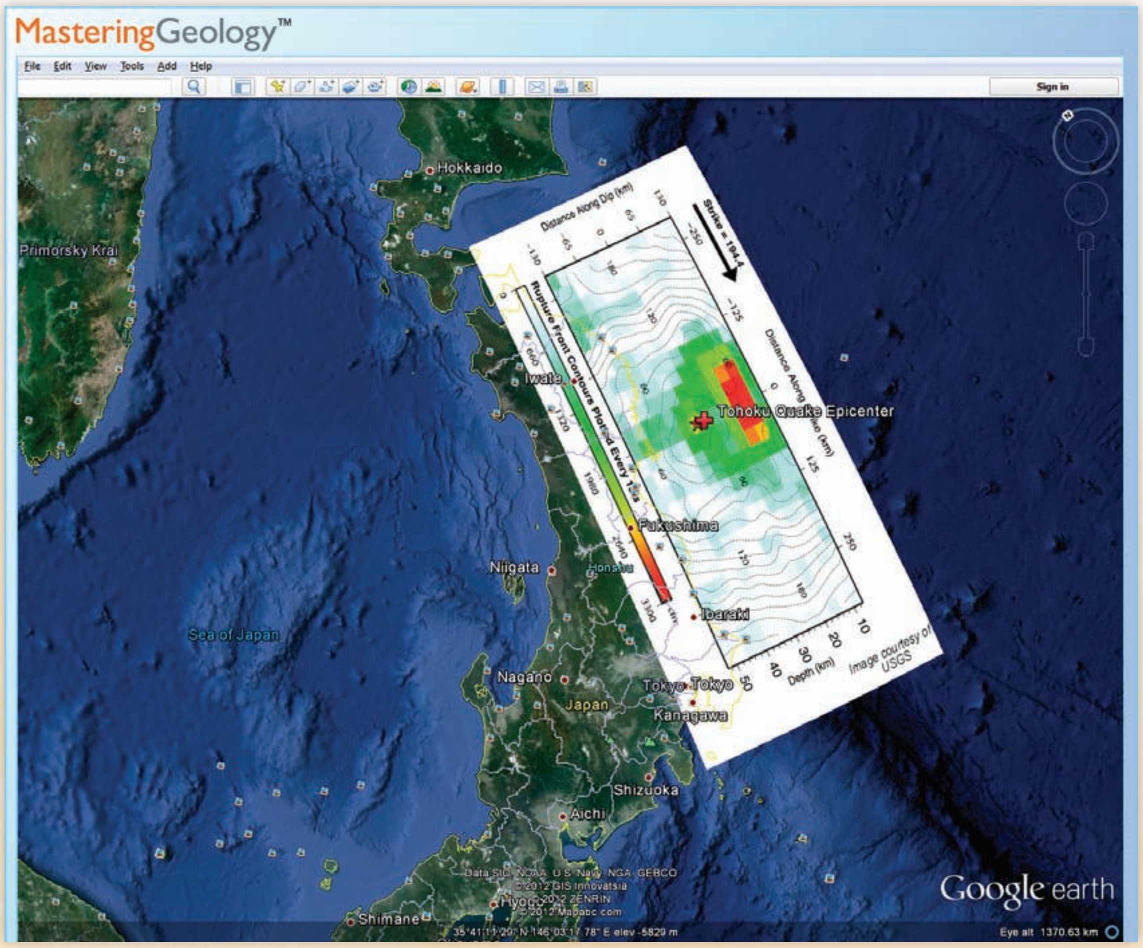
Question 1 Relatively thin slabs of granite are separating from this rock mass. Describe the process that caused this to occur.

Question 2 What term is applied to this process? What term describes the dome-like feature that results?

MasteringGeology™

www.masteringgeology.com

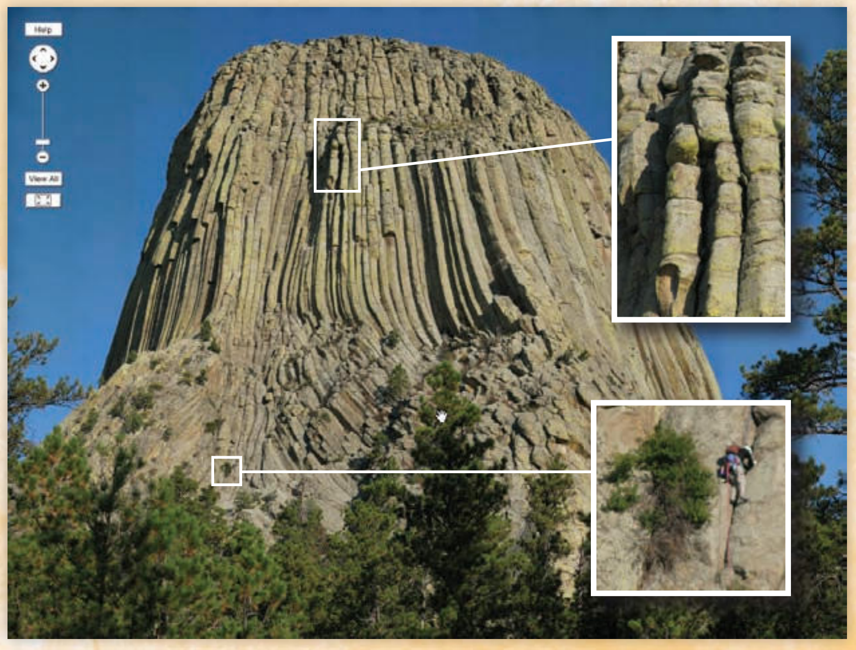
MasteringGeology delivers engaging, dynamic learning opportunities—focused on course objectives and responsive to each student's progress—that are proven to help students absorb course material and understand difficult geologic concepts.

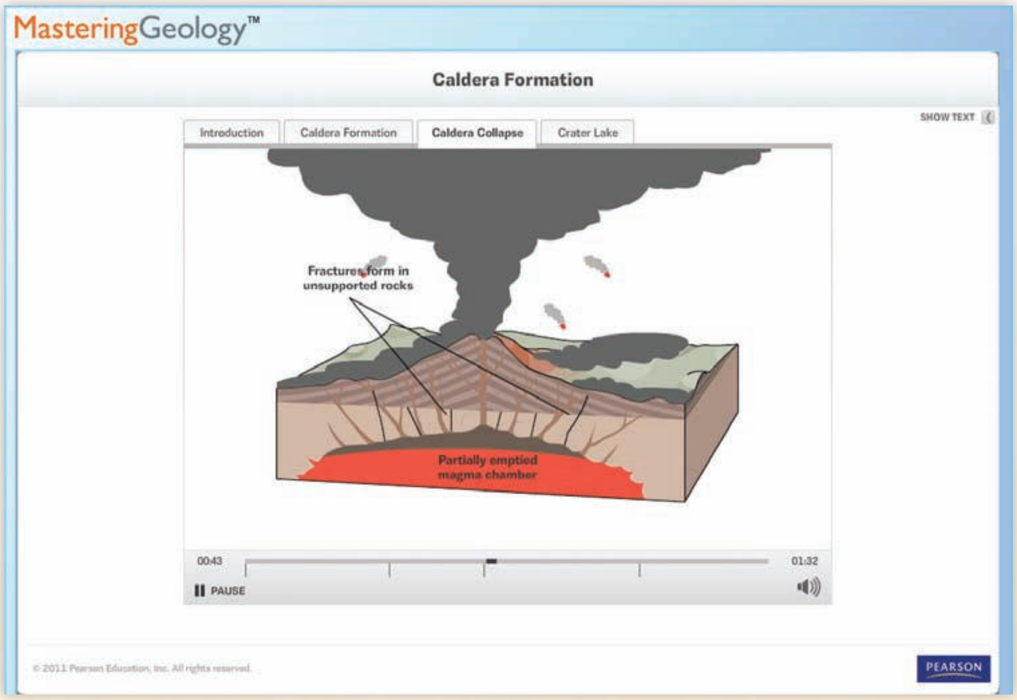


Encounter Activities provide rich, interactive explorations of geology concepts using the dynamic features of Google Earth™ to visualize and explore Earth's physical landscape. Dynamic assessment includes questions related to core geology concepts. All explorations include corresponding Google Earth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

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

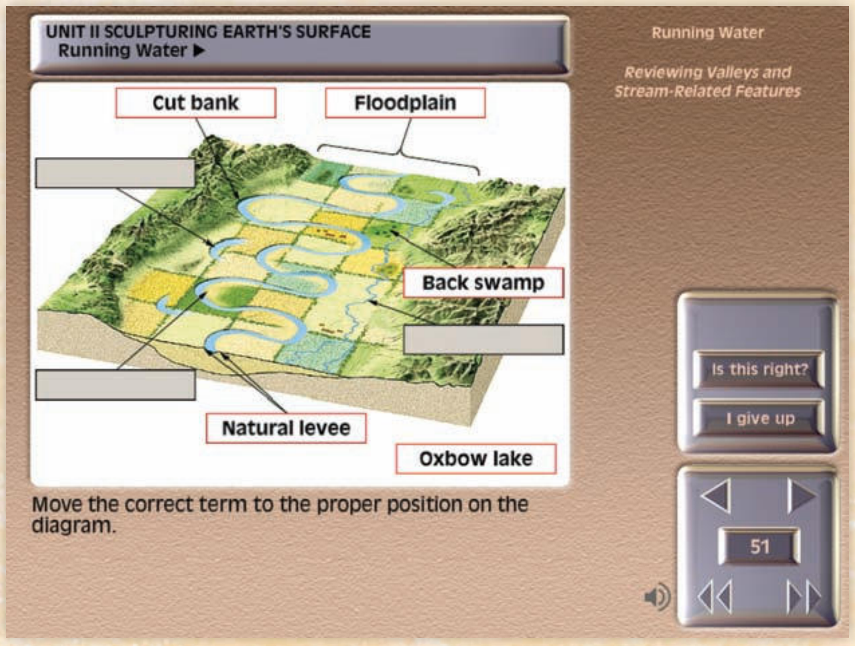
NEW! GigaPan® Activities take advantage of the GigaPan high-resolution panoramic picture technology developed by Carnegie Mellon University in conjunction with NASA. Photos and accompanying questions correlate with concepts in the student book.



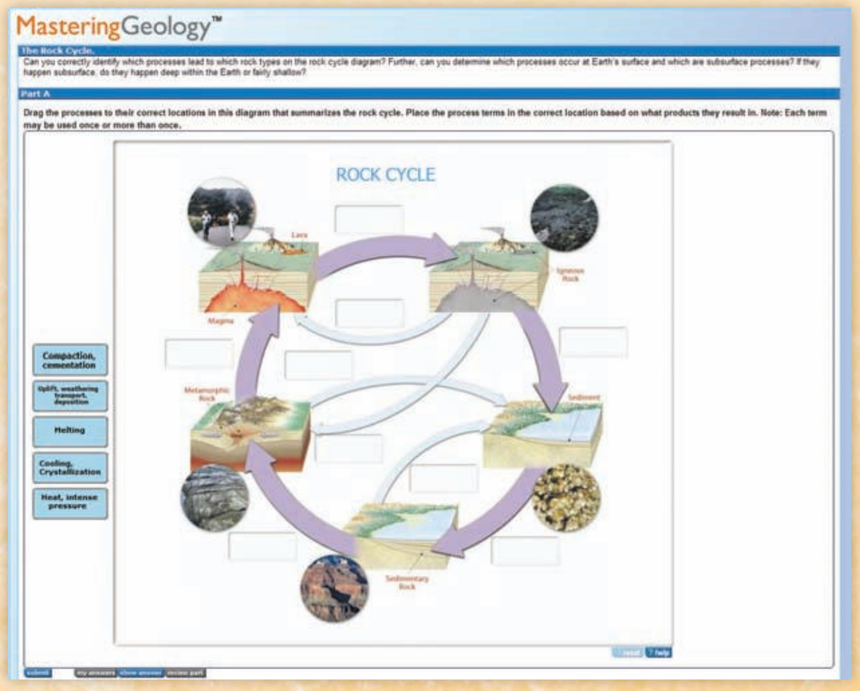


Geoscience Animations and Activities illuminate the most difficult-to-visualize topics from across the physical geosciences. MasteringGeology allows instructors to easily assign the animations and corresponding assessment questions, all of which include hints and specific wrong-answer feedback.

GEODe Activities provide an interactive visual walkthrough of each chapter's 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, challenge learners by involving them in activities that require higher-order thinking skills such as synthesis, analysis, and application.



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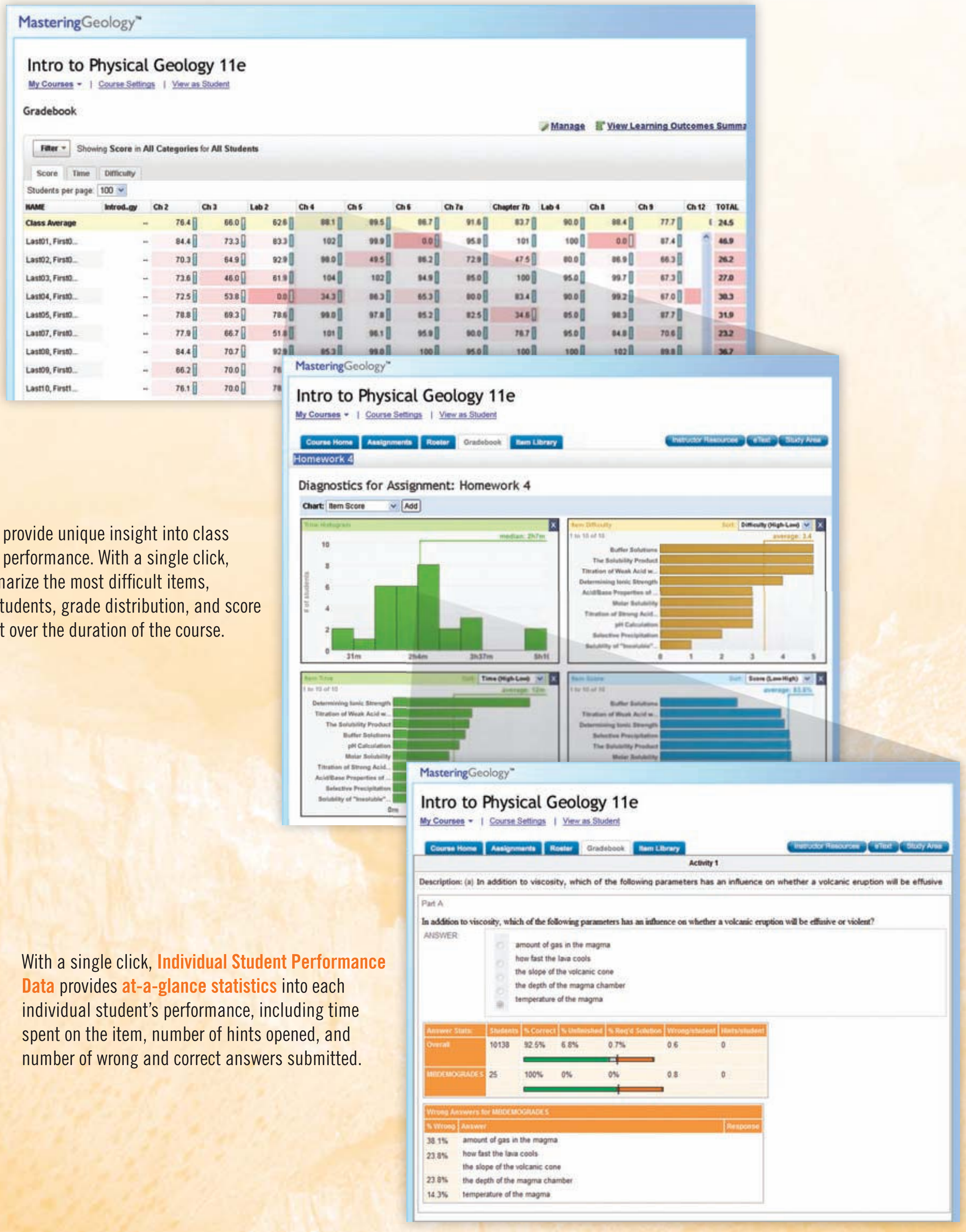
With the Mastering gradebook and diagnostics, instructors will be better informed about students' progress than ever before. Mastering captures the step-by-step work of every student—including wrong answers submitted, hints requested, and time taken at every step of every problem—all providing unique insight into the most common misconceptions of the class.

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



Diagnostics provide unique insight into class and student performance. With a single click, charts summarize the most difficult items, vulnerable students, grade distribution, and score improvement over the duration of the course.

With a single click, **Individual Student Performance Data** provides **at-a-glance statistics** into each individual student's performance, including time spent on the item, number of hints opened, and number of wrong and correct answers submitted.

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Learning Outcomes

MasteringGeology provides quick and easy access to information on student performance against learning outcomes and makes it easy for instructors to share those results.

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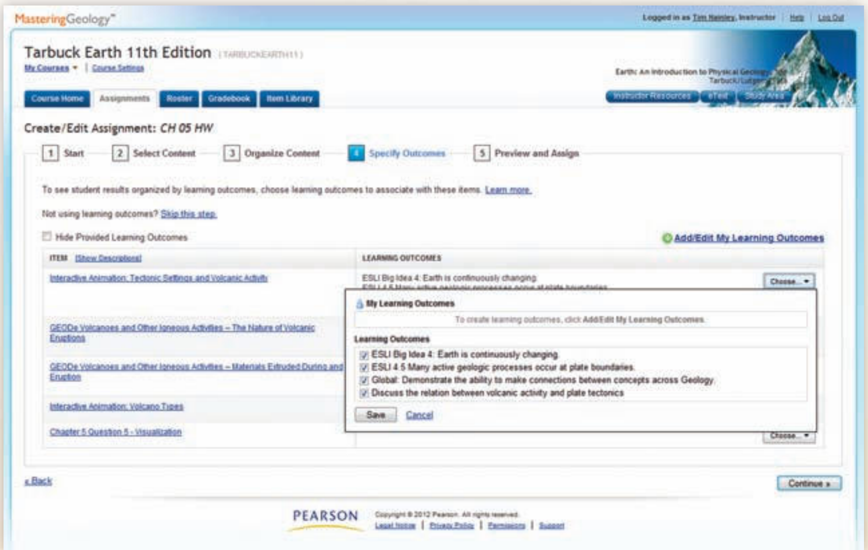
- Effortlessly export results to a spreadsheet and further customize and/or share with chairs, deans, administrators, and/or accreditation boards.



Easy to Customize

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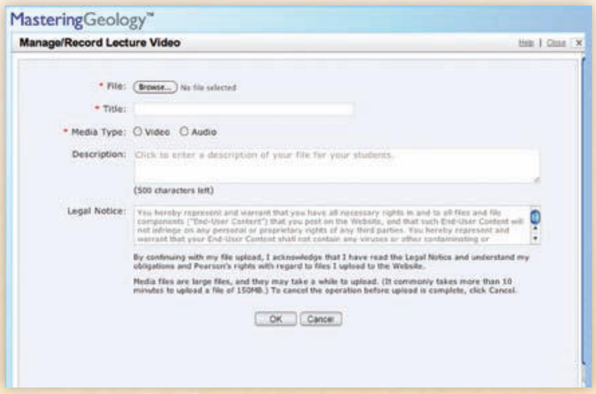
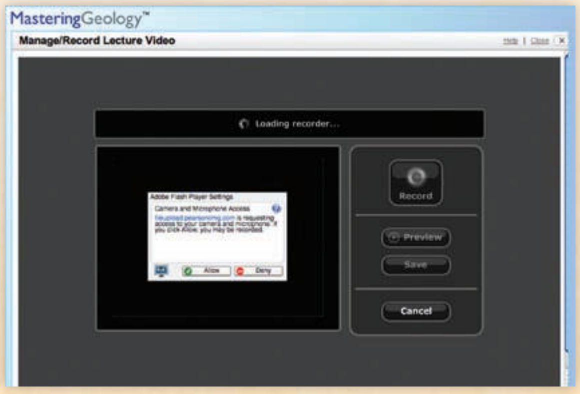
Instructors can upload their own video and audio files from their hard drives to share with students, as well as record video from their computer's webcam directly into MasteringGeology—no plug-ins required. Students can download video and audio files to their local computer or launch them in Mastering to view the content.





Pearson eText gives students access to *Earth: An Introduction to Physical Geology, Eleventh Edition* whenever and wherever they can access the Internet. The eText pages look exactly like the printed text, and include powerful interactive and customization functions. Users can create notes, highlight text in different colors, create bookmarks, zoom, click hyperlinked words and phrases to view definitions, and view as a single page or as two pages. Pearson eText links students to associated media files, enabling them to view an animation as they read the text, and offers a full-text search and the ability to save and export notes. The Pearson eText also includes embedded URLs in the chapter text with active links to the Internet.

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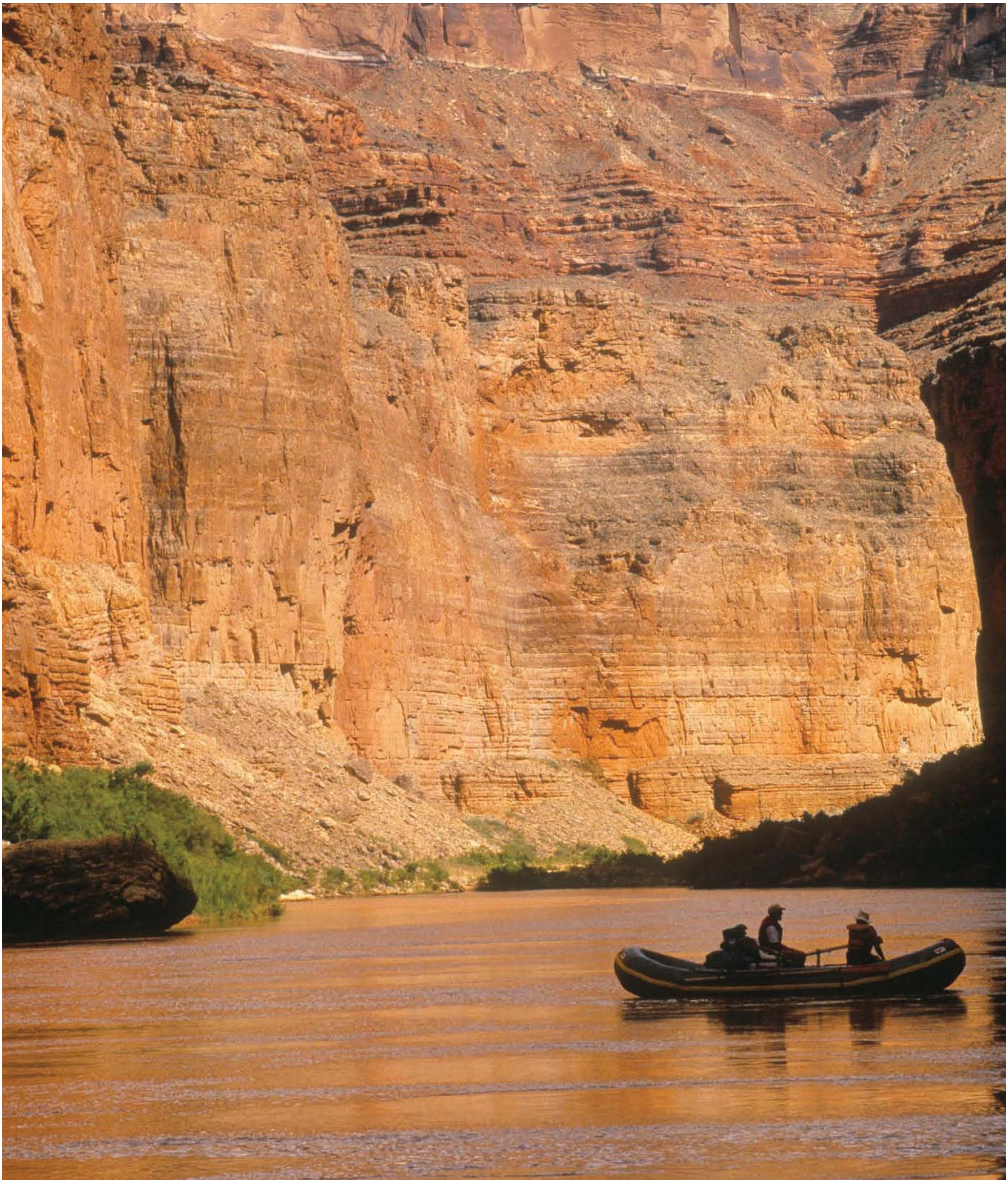
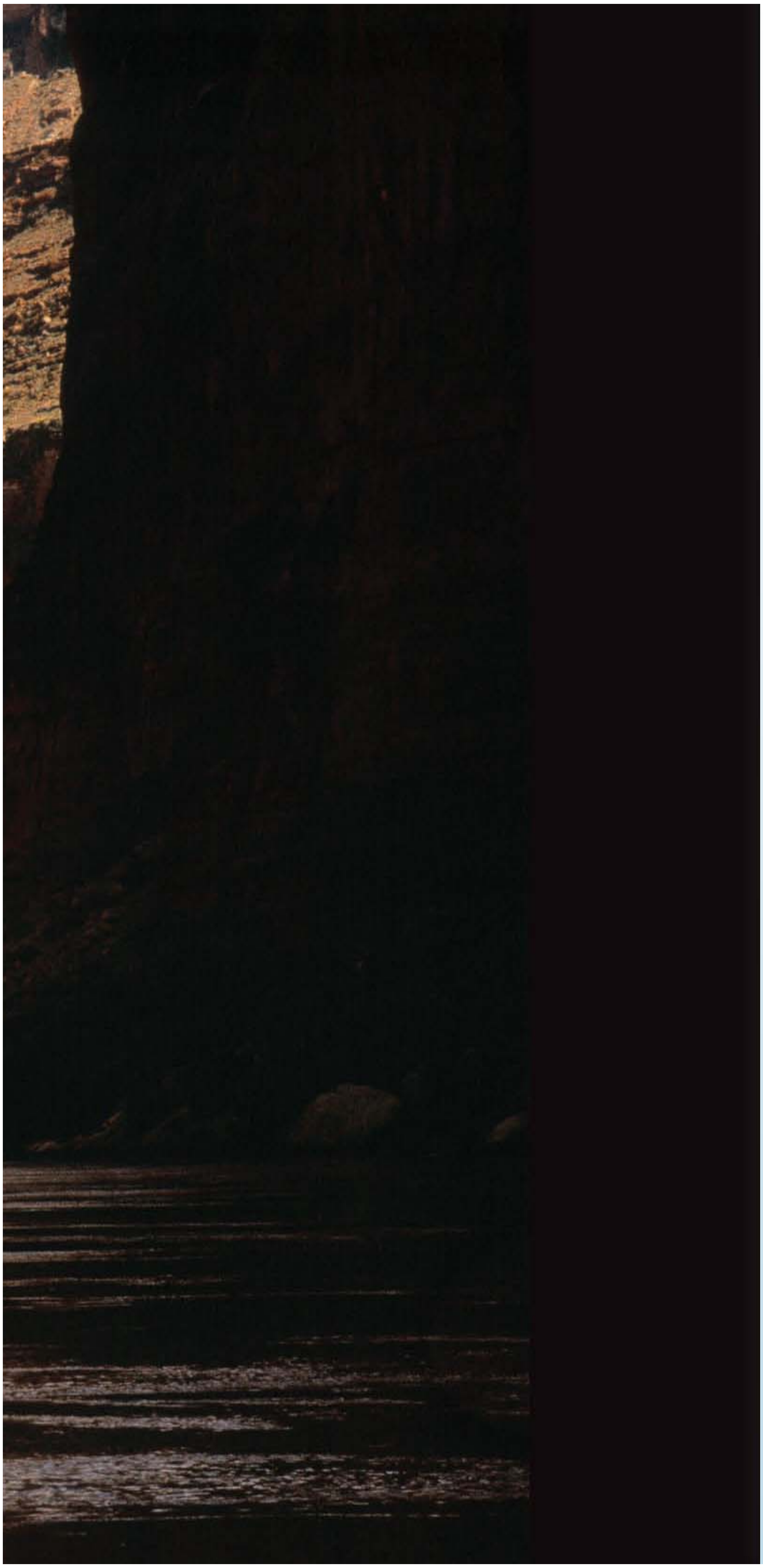




1 An Introduction to Geology

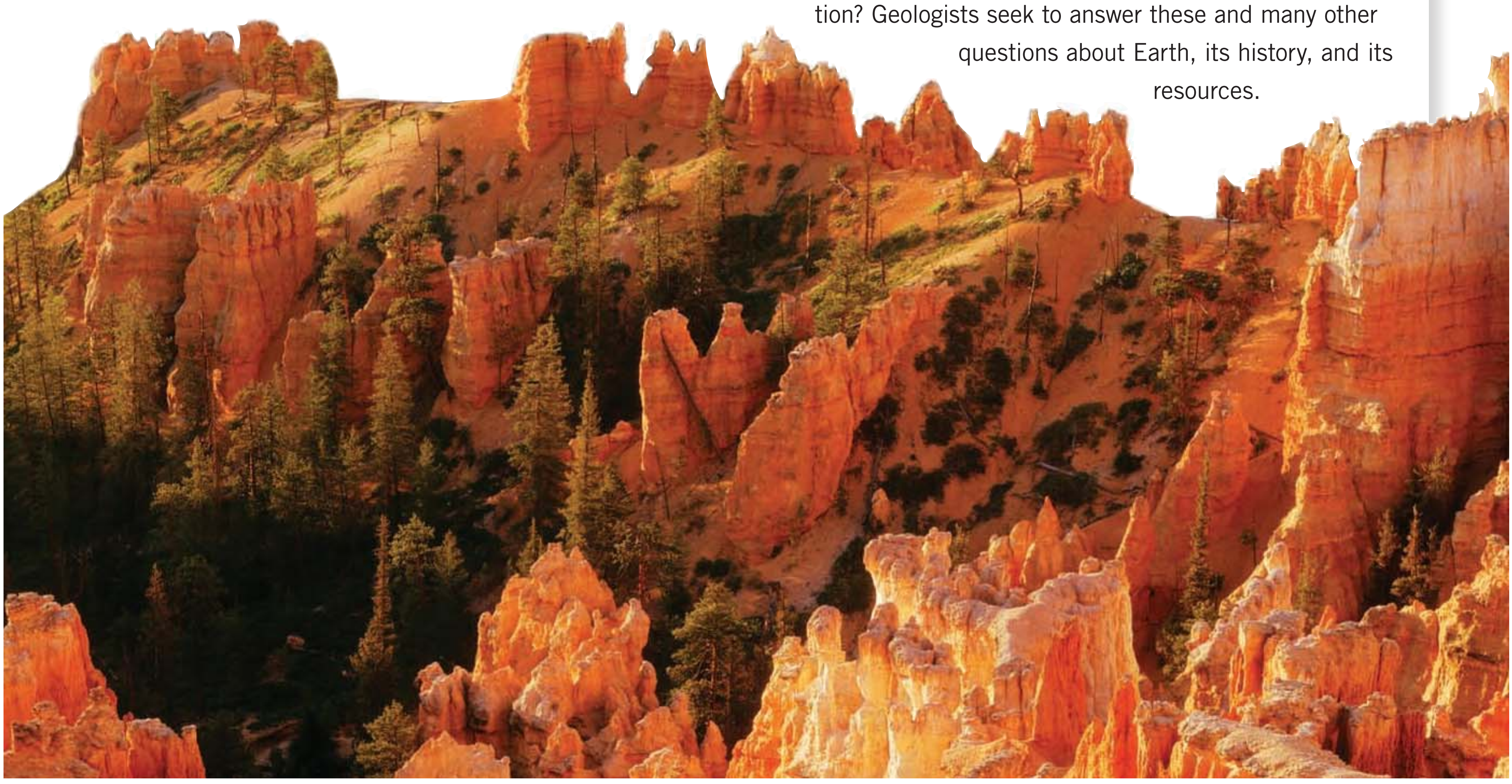
Rafting the Colorado River in Arizona's Marble Canyon.
(Photo by Michael Collier)

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 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 the 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 look 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.



Bryce Canyon in southern Utah. Rocks contain information about the processes that produce them. (Photo by Michael Collier)

1.1 Geology: The Science of Earth

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 submicroscopic, 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.

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

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)

GEOGRAPHICS

World Population Passes 7 BILLION

Complicating all environmental issues is rapid world population growth and everyone's aspiration to a better standard of living. There is a ballooning demand for resources and a growing pressure for people to live in environments having significant geologic hazards.

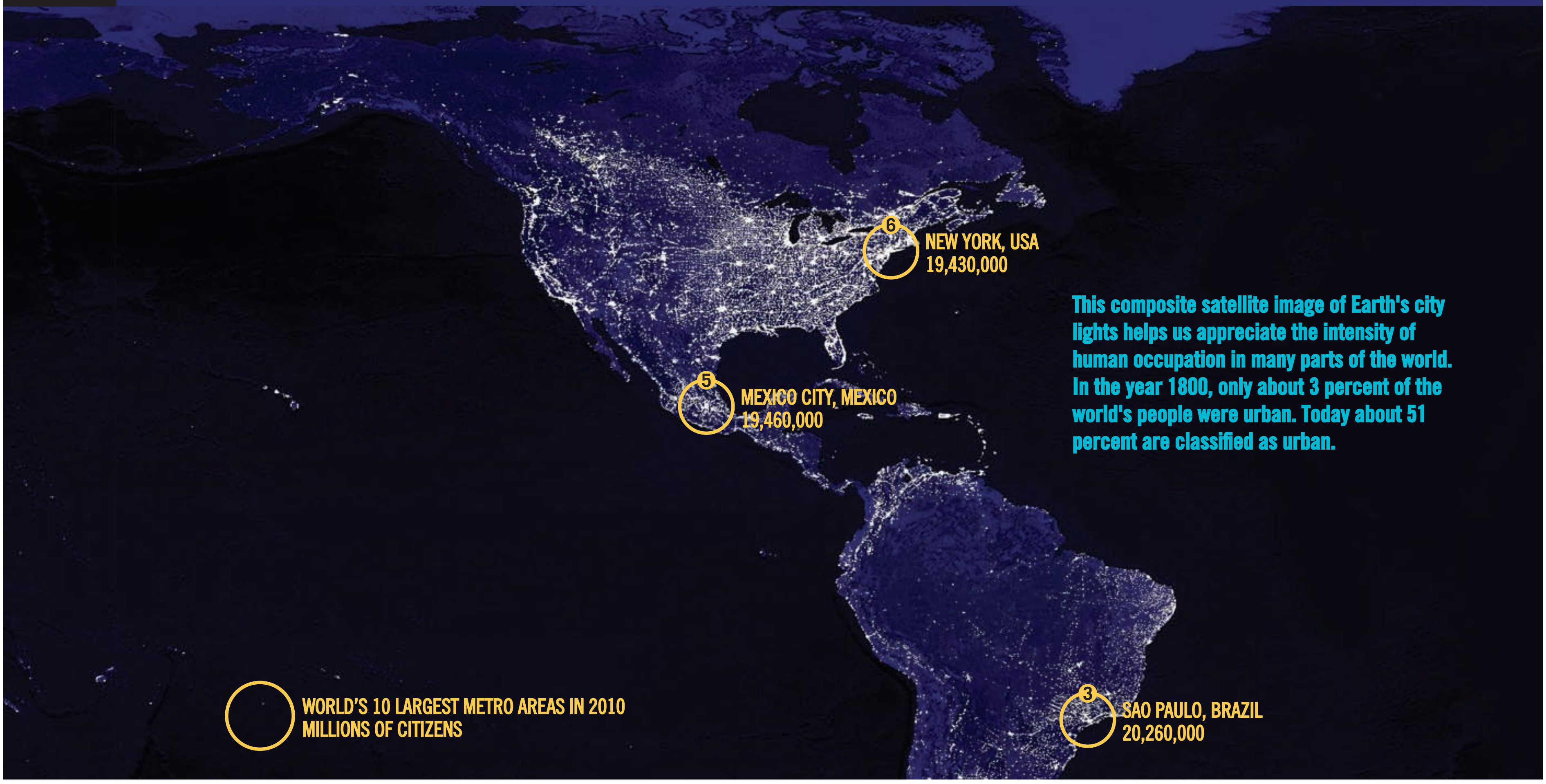


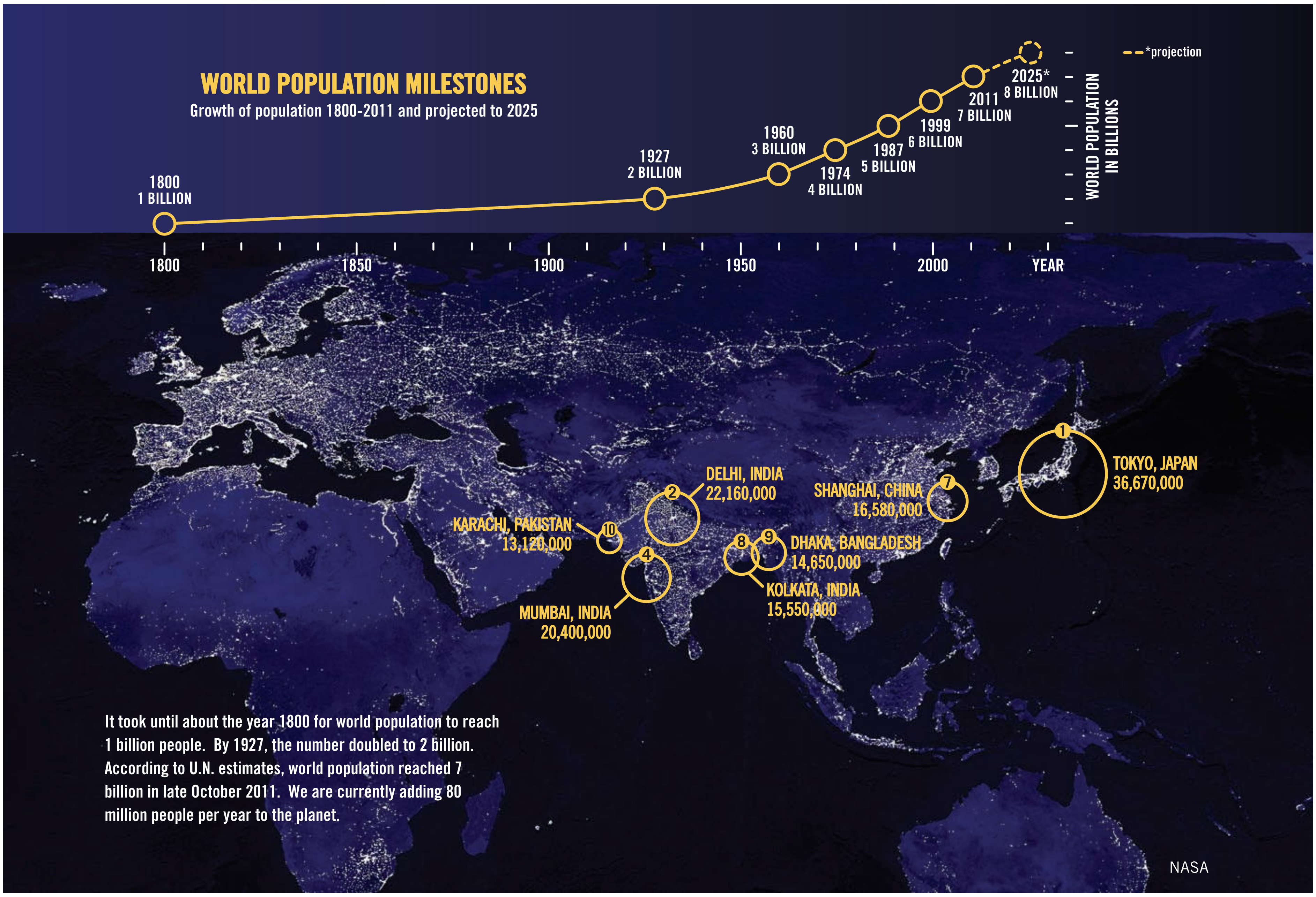
FIGURE 1.2 In the field and in the lab
Geology not only involves outdoor fieldwork but work in the laboratory as well.
(Photo by British Antarctic Survey/Photo Researchers, Inc.)


This paleontologist is collecting fossils in Antarctica. Later, a detailed analysis will occur in the lab.

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

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

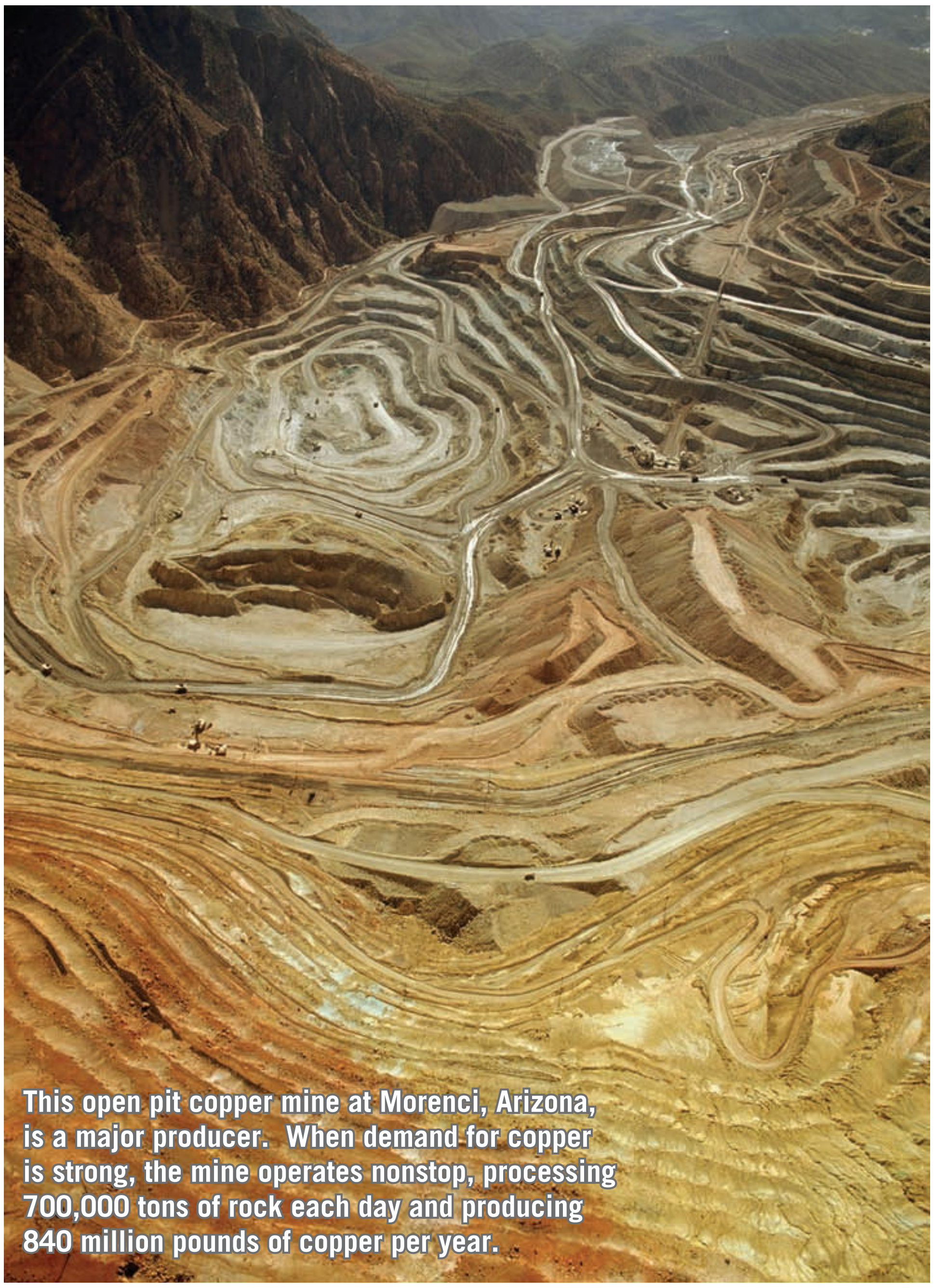


FIGURE 1.4 Copper mine
Resources represent an important link between people and geology. (Photo by Michael Collier)

practices, coupled with rapid population growth, are increasing vulnerability.

Resources represent 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 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 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 appropriate places throughout this book, you will have an opportunity 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.

1.1 CONCEPT CHECKS

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

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, Hutton 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."

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 always had the same relative importance or that they 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