exploring GEOLOGY

About the Cover

Parícutin Volcano, located in the Mexican state of Michoacán, stands where a Mexican family once tilled a quiet corn field. For three weeks they had heard what sounded like thunder though no clouds were nearby. Then, on February 20, 1943, an open fissure appeared in the field, and trees began to tremble. The ground hissed and swelled as sulfurous smoke and gray ash rose from the fissure. Volcanic fragments and blobs of magma were thrown skyward, from sand-sized grains carried upward by the winds to large volcanic bombs more than a meter in diameter that crashed around the volcanic vent. By the next day, a volcanic cone 50 m high stood in what had been the corn field the day before.

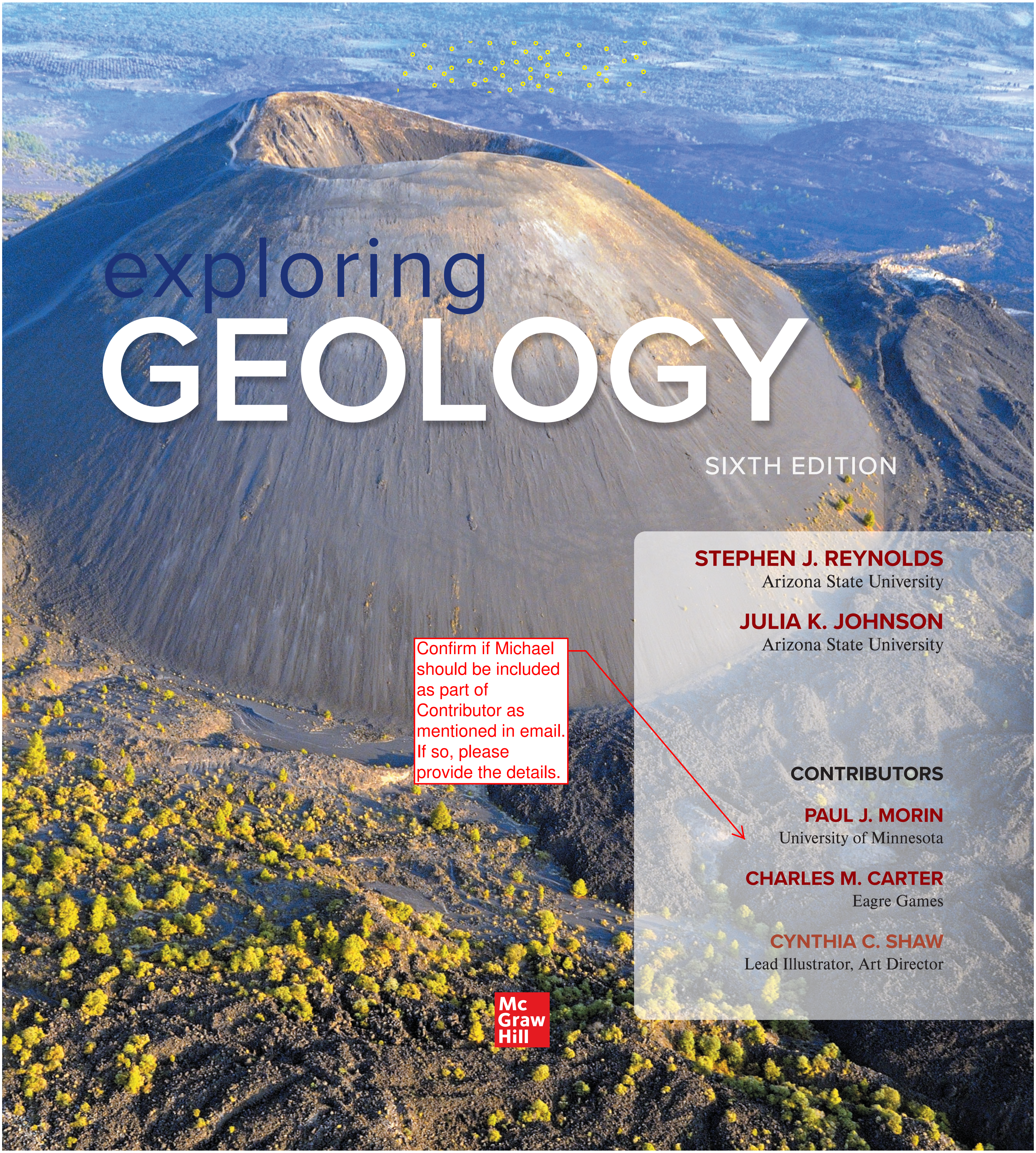
The cone erupted for nine years, giving scientists the unusual opportunity of witnessing the birth, life, and cessation of a volcano. What scientists witnessed was the steady growth of the cinder cone for the first year, with eruptions of lava increasing in frequency with time.

When the volcano became dormant in 1952, the cone had reached a height of 1,391 feet and almost a third of a cubic mile of lava had been erupted onto the surface. The town of San Juan Parangaricutiro was buried; only the steeples of its church remain above the dark, solidified lava flows. Ash had spread over many square miles of the surrounding countryside, blanketing vegetation and forcing local residents to settle elsewhere. The farmer who had first watched the birth of Parícutin planted a sign on his field before leaving: “This volcano is owned and operated by Dionisio Pulido.”

Parícutin lies within the broad Trans-Mexican Volcanic Belt, an almost east-west-trending swath of volcanoes that crosses the southern part of Mexico south of Mexico City. The volcanic belt is created as the Rivera and Cocos oceanic plates subduct beneath the southwestern edge of the North American plate.

Cover photograph by Michael Collier

Michael Collier received his BS in geology at Northern Arizona University, MS in structural geology at Stanford, and MD from the University of Arizona. He rowed boats commercially in Grand Canyon in the ’70s and ’80s, and then practiced family medicine in northern Arizona. Collier has published books about the geology of Grand Canyon, Death Valley, Denali, and Capitol Reef National Park. He has authored books on the Colorado River basin, glaciers of Alaska, and climate change in Alaska, as well as a three-book series on American mountains, rivers, and coastlines. As a special projects writer with the USGS, he produced books about the San Andreas fault, the downstream effects of dams, and climate change. Collier’s photography has been recognized with awards from the USGS, the National Park Service, the American Geosciences Institute, and the National Science Teachers Association.



exploring GEOLOGY

SIXTH EDITION

STEPHEN J. REYNOLDS
Arizona State University

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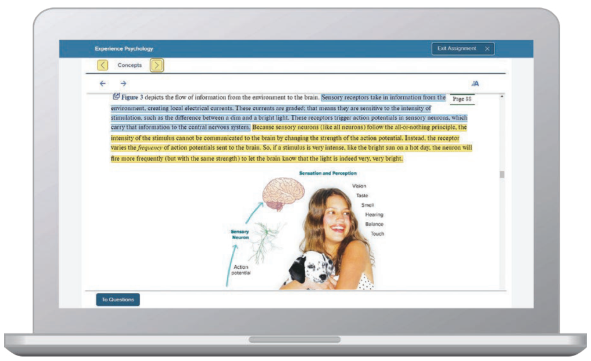

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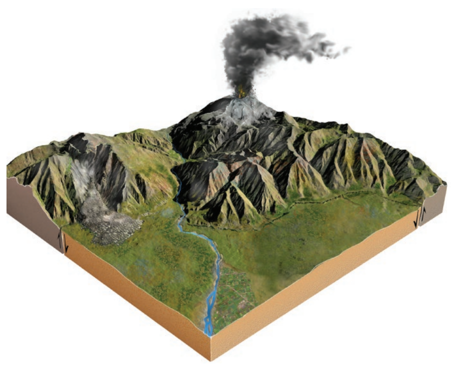

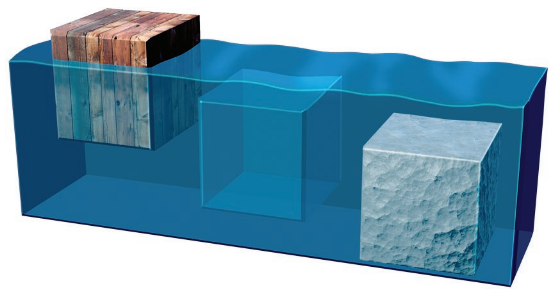

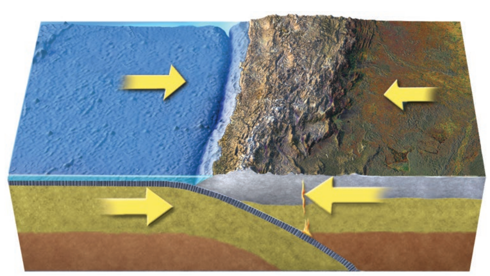

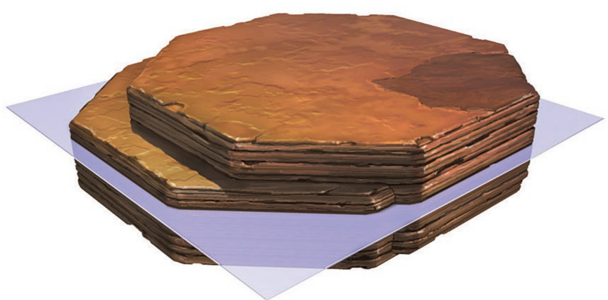

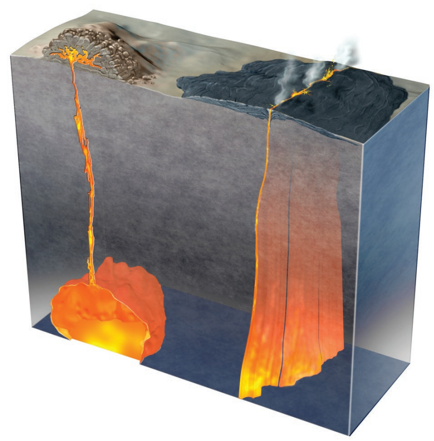

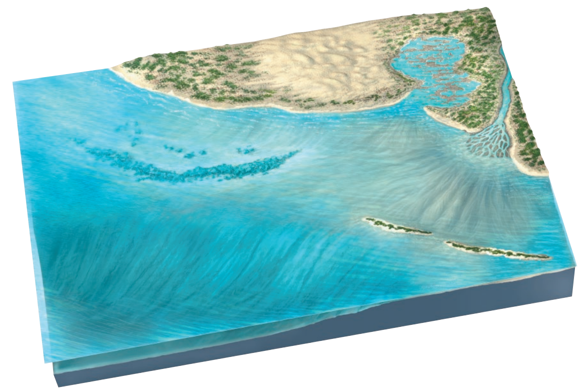

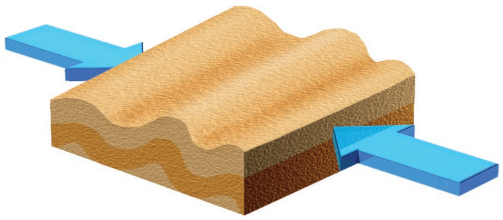

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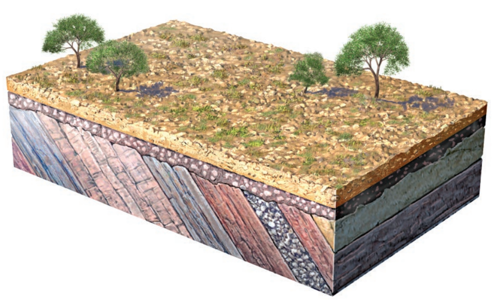

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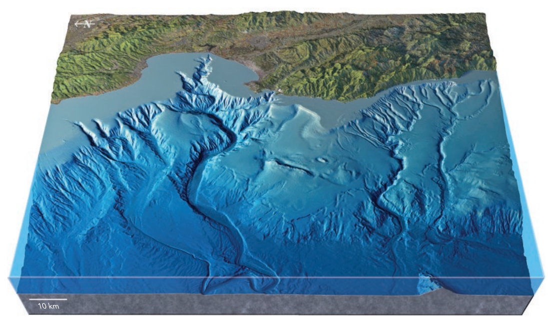

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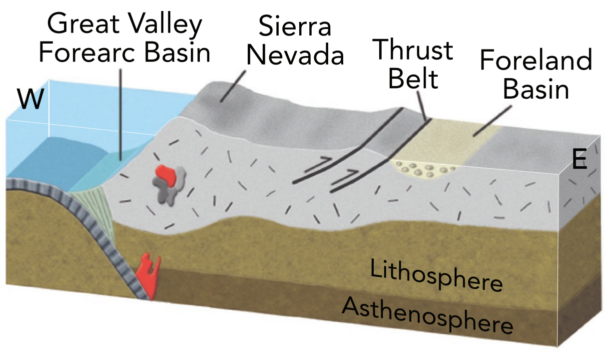

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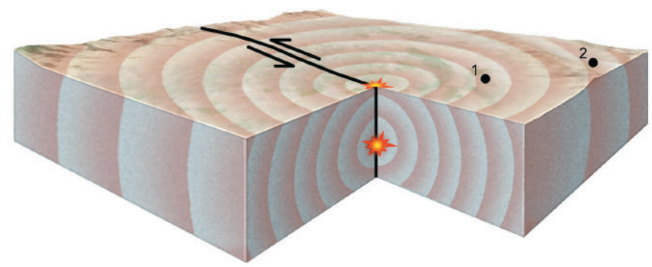

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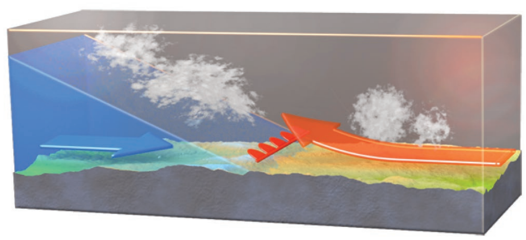

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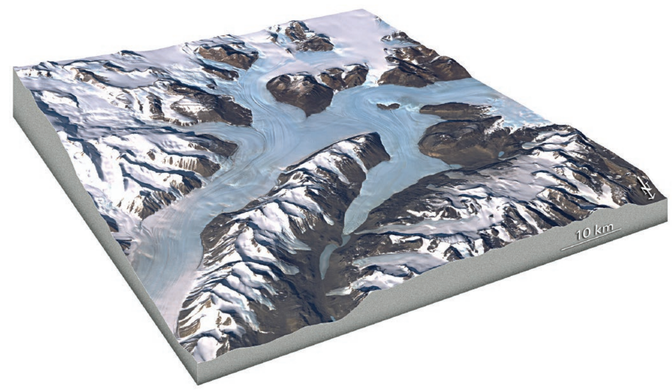

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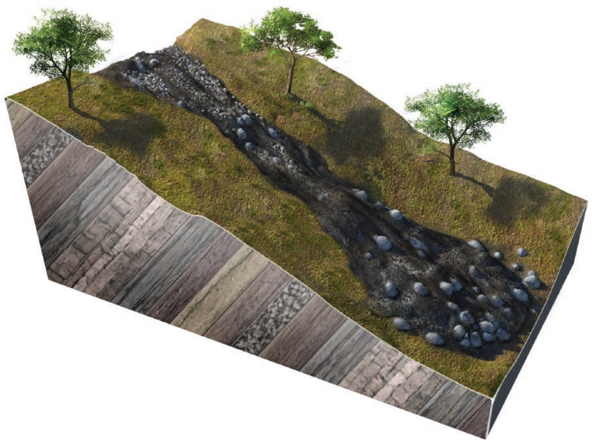

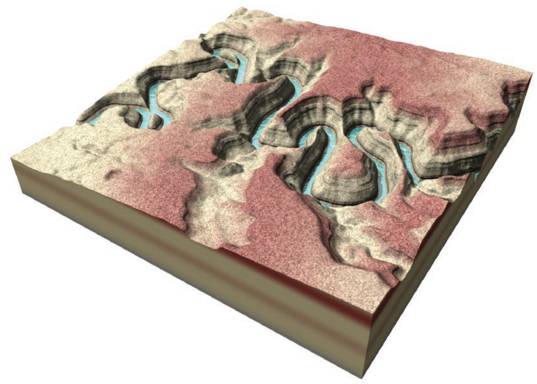

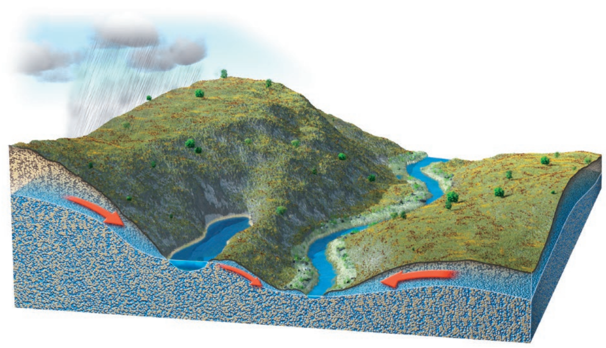

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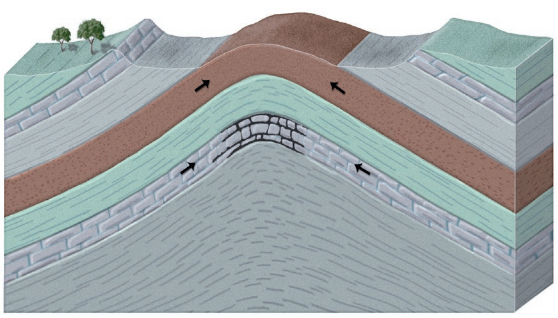

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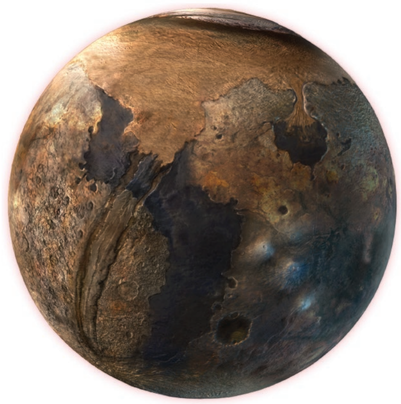


PREFACE

TELLING THE STORY . . .

WE WROTE *EXPLORING GEOLOGY* SO THAT STUDENTS could learn from the book on their own, freeing up instructors to teach the class in any way they want. I (Steve Reynolds) first identified the need for this book while I was a National Association of Geoscience Teachers' (NAGT) distinguished speaker. As part of my NAGT activities, I traveled around the country conducting workshops on how to infuse active learning and scientific inquiry into introductory college geology courses, including those with upwards of 200 students. In the first part of the workshop, I asked the faculty participants to list the main goals of an introductory geology college course, especially for nonmajors. At every school I visited, the main goals were similar and are consistent with the conclusions of the National Research Council (see box below):

Like most geologists, author Steve Reynolds prefers teaching students out in the field, where they can directly observe the geology and reconstruct the sequence of geologic events.

We have fixed standard bullet size. Please confirm.

- to engage students in the process of scientific inquiry so that they learn what science is and how it is conducted,
- to teach students how to observe and interpret landscapes and other aspects of their surroundings,
- to enable students to learn and apply important geologic concepts,
- to help students understand the relevance of geology to their lives, and
- to enable students to use their new knowledge, skills, and ways of thinking to become more informed citizens.

I then asked faculty members to rank these goals and estimate how much time they spent on each goal in class. At this point, many instructors recognized that their activities in class were not consistent with their own goals. Most instructors were spending nearly all of class time teaching content. Although this was one of their main goals, it commonly was not their top goal.

Next, I asked instructors to think about why their activities were not consistent with their goals. Inevitably, the answer was that most instructors spend nearly all of class time covering content because (1) textbooks include so much material that students have difficulty distinguishing what is important from what is not; (2) instructors needed to lecture so that students would know what is important; and (3) many students have difficulty learning independently from the textbook.

In most cases, textbooks drive the curriculum, so the author team decided that we should write a textbook that (1) contains only important material, (2) indicates clearly to the student what is important and what they need to know, and (3) is designed and written in such a way that students can learn from the book on their own. This type of book would give instructors freedom to teach in a way that is more consistent with their goals, including using local examples to illustrate geologic concepts and their relevance. Instructors would also be able to spend more class time teaching students to observe and interpret geology, and to participate in the process of scientific inquiry, which represents the top goal for many instructors.

NRC The National Research Council

NATIONAL COMMITTEE ON SCIENCE EDUCATION STANDARDS AND ASSESSMENT, NATIONAL RESEARCH COUNCIL

LEARNING SCIENCE IS AN ACTIVE PROCESS.

Learning science is something students do, not something that is done to them. In learning science, students describe objects and events, ask questions, acquire knowledge, construct explanations of natural phenomena, test those explanations in many different ways, and communicate their ideas to others. Science teaching must involve students in inquiry-oriented investigations in which they interact with their teachers and peers.

COGNITIVE AND SCIENCE-EDUCATION RESEARCH

To design a book that supports instructor goals, we immersed ourselves into cognitive and science-education research, especially research on how our brains process different types of information, what obstacles limit student learning from textbooks, and how students use visuals versus text while studying. We also conducted our own research on how students interact with textbooks, what students see when they observe photographs showing geologic features, and how they interpret geologic illustrations, including geologic maps and cross sections. *Exploring Geology* is the result of our literature search and of our own research. As you examine *Exploring Geology*, you will notice that it is stylistically different from most other textbooks, which will likely elicit a few questions.

HOW DOES THIS BOOK SUPPORT STUDENT CURIOSITY AND INQUIRY?

Exploring Geology promotes inquiry and science as an active process. It encourages student curiosity and aims to activate existing student knowledge by posing the title of every two-page spread and every subsection as a question. In addition, questions are dispersed throughout the book. Integrated into the book are opportunities for students to observe patterns, features, and examples before the underlying concepts are explained. That is, we employ a learning-cycle approach where student exploration precedes the introduction of geologic terms and the application of knowledge to a new situation. For example, chapter 15 on slope stability begins with a three-dimensional image of northern Venezuela, and readers are asked to observe where people are living in this area and what geologic processes might have formed these sites.

Inquire

"*Exploring Geology* is a seminal textbook for the new century, created by a unique team of authors who have synergistically merged their expertise in geology and geoscience teaching, cognitive science, and the graphic arts. The design of the book has been richly informed by current research on how students best learn geoscience, and what topics are essential and relevant. Each chapter is designed as a sequence of two-page inquiry modules; each module focuses on a specific topic, opens with an engaging question, and integrates clear, jargon-free explanations with generous, precisely detailed illustrations. In conventional textbooks, figures are often subordinate to columns and columns of type; in *Exploring Geology*, text and illustrations are mutually embedded in a topical mosaic. At the close of each chapter, a real-world application of the subject matter and an investigative exercise complete the learning cycle. This book is an innovative, accessible resource that fosters understanding through authentic geological inquiry and visualization, rather than dense exposition."

Steven Semken
School of Earth and Space Exploration, Arizona State University
Past President, National Association of Geoscience Teachers

WHY ARE THE PAGES DOMINATED BY ILLUSTRATIONS?

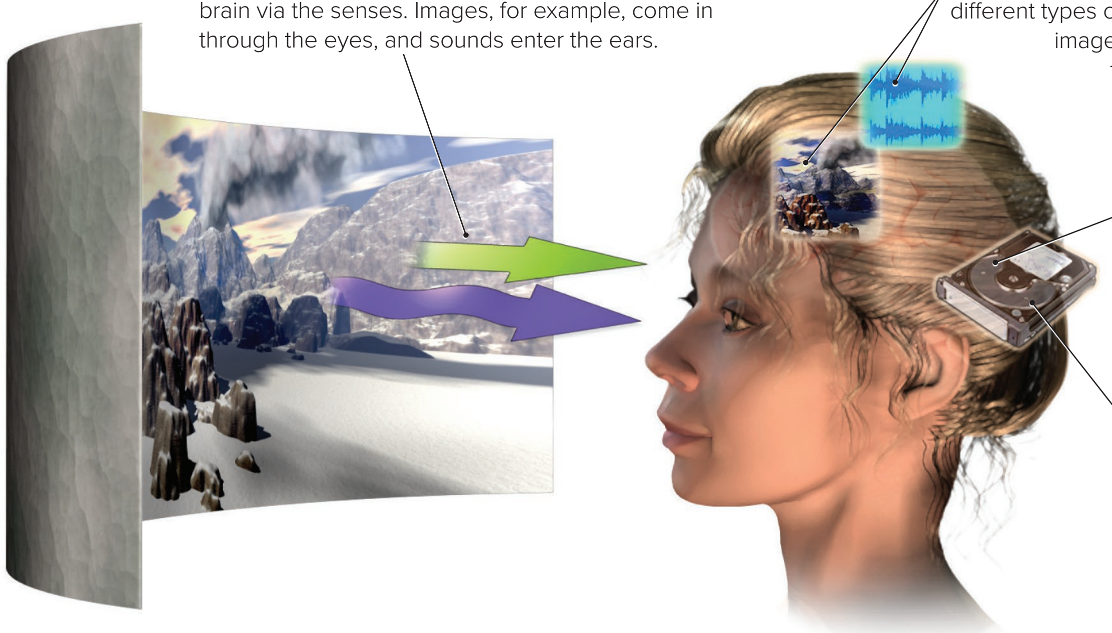
Geology is an extremely visual science. Typically, geology textbooks contain a variety of photographs, maps, cross sections, block diagrams, and other types of illustrations. These diagrams help portray the distribution and geometry of geologic units on the surface and in the subsurface in a way words could never do. In geology, a picture really is worth a thousand words or more.

Innovate

In June 2008, The McGraw-Hill Companies announced that *Exploring Geology*, just released in its First Edition, had received the distinguished Corporate Achievement Award for Innovation. Each year, McGraw-Hill Higher Education publishes 200 to 300 titles in science, economics, marketing, humanities, and career education. *Exploring Geology* was recognized for its pioneering design and innovative pedagogical approach that is based on cognitive and science-education research. This unique text features over 2,600 extraordinary line-art drawings and photographs that support clearly articulated learning outcomes, authentic inquiry, and models of how geoscientists approach geologic problems. It represents a dramatically different approach, a new type of textbook, designed for today's students.

Exploring Geology contains a wealth of figures to take advantage of the visual nature of geology and the efficiency of figures in conveying geologic information. This book contains few large blocks of text, and most text is in smaller blocks that are specifically linked with illustrations. An example of our integrated figure-text approach is shown on the previous page and on the next page. In this approach, each short block of text is one or more complete sentences that succinctly describe a geologic feature, geologic process, or both of these. Most of these text blocks are connected to their illustrations with leader lines so that readers know exactly which feature or part of the diagram is being referenced by the text block. A reader does not have to search for the part of the figure that corresponds to a text passage, as occurs when a student reads a traditional textbook with large blocks of text referencing a figure that may appear on a different page.

The approach in *Exploring Geology* is consistent with the findings of cognitive scientists, who conclude that our minds have two different processing systems, one for processing pictorial information (images) and one for processing verbal information (speech and written words), as illustrated below. Images enter our consciousness through our eyes, and text can enter either through our eyes, such as when we read, or through our ears, as occurs during a lecture. Research into learning and cognition shows that having text enter via our ears, while our eyes examine an image, is among the best ways to learn.



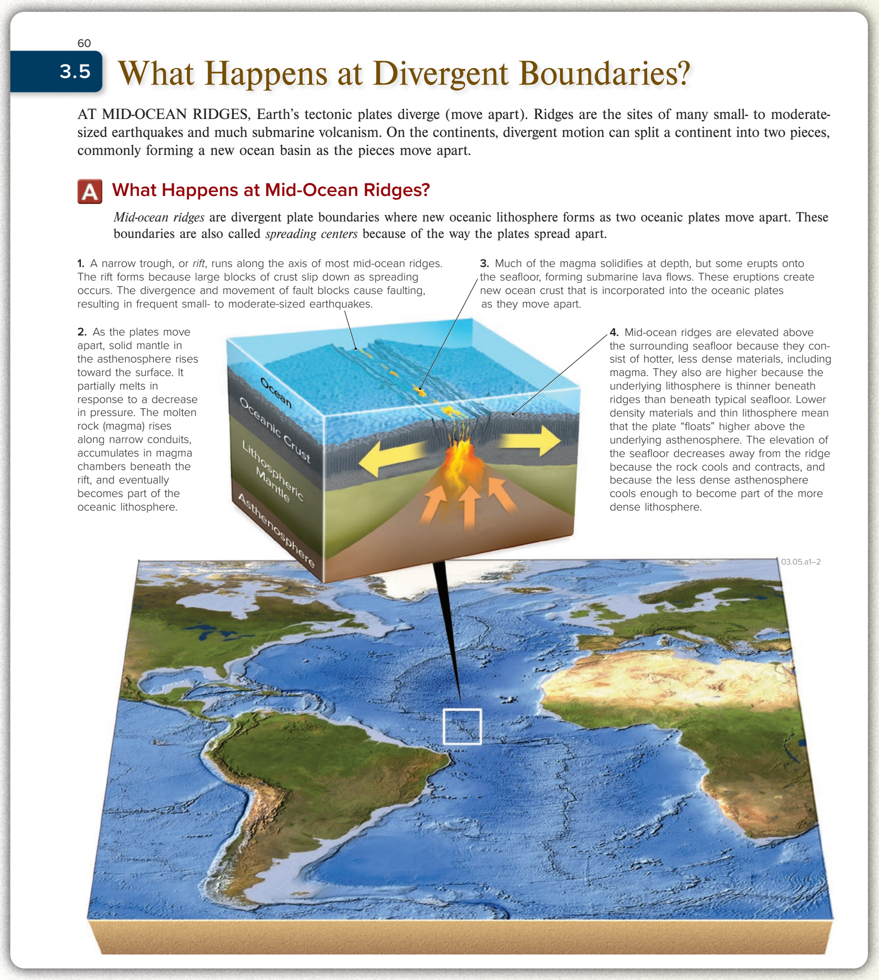
New experiences from the environment enter the brain via the senses. Images, for example, come in through the eyes, and sounds enter the ears.

Input from the senses is filtered and transferred into two different types of working memory, a *visual* area for images and a *phonetic* area for words. Each type of working memory has a very limited capacity to hold new information.

Information from working memory is processed further and transferred into long-term memory. Ideally, new information is linked to existing knowledge in long-term memory to build a more complete understanding.

When information from long-term memory is needed, it is retrieved into working memory, where it can be processed to make decisions.

Cognitive scientists also speak about two types of memory: *working memory* holds information and actively processes it, whereas *long-term memory* stores information until we need it. Both the verbal and pictorial processing systems have a limited amount of working memory, and our minds have to use much of our mental processing space to reconcile the two types of information in working memory. For information that has both pictorial and verbal components, as most geoscience information does, the amount of knowledge we retain depends on reconciling these two types of information, on transferring information from working memory to long-term memory, and on linking the new information with our existing mental framework. For this reason, this book integrates text and figures, as in the example shown here. For more information on cognitive load, see Jaeger, A.J., Shipley, T.F., and Reynolds, S.J., 2017, The roles of working memory and cognitive load in geoscience learning: *Journal of Geoscience Education*, v. 65, no. 4, p. 506-518.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3.5 What Happens at Divergent Boundaries?

AT MID-OCEAN RIDGES, Earth's tectonic plates diverge (move apart). Ridges are the sites of many small- to moderate-sized earthquakes and much submarine volcanism. On the continents, divergent motion can split a continent into two pieces, commonly forming a new ocean basin as the pieces move apart.

A What Happens at Mid-Ocean Ridges?

Mid-ocean ridges are divergent plate boundaries where new oceanic lithosphere forms as two oceanic plates move apart. These boundaries are also called *spreading centers* because of the way the plates spread apart.

1. A narrow trough, or *rift*, runs along the axis of most mid-ocean ridges. The rift forms because large blocks of crust slip down as spreading occurs. The divergence and movement of fault blocks cause faulting, resulting in frequent small- to moderate-sized earthquakes.

2. As the plates move apart, solid mantle in the asthenosphere rises toward the surface. It partially melts in response to a decrease in pressure. The molten rock (magma) rises along narrow conduits, accumulates in magma chambers beneath the rift, and eventually becomes part of the oceanic lithosphere.

3. Much of the magma solidifies at depth, but some erupts onto the seafloor, forming submarine lava flows. These eruptions create new ocean crust that is incorporated into the oceanic plates as they move apart.

4. Mid-ocean ridges are elevated above the surrounding seafloor because they consist of hotter, less dense materials, including magma. They also are higher because the underlying lithosphere is thinner beneath ridges than beneath typical seafloor. Lower density materials and thin lithosphere mean that the plate "floats" higher above the underlying asthenosphere. The elevation of the seafloor decreases away from the ridge because the rock cools and contracts, and because the less dense asthenosphere cools enough to become part of the more dense lithosphere.

WHY ARE THERE SO MANY FIGURES?

This textbook contains more than 2,600 figures, which is two to three times the number in most introductory geology textbooks. One reason for this is that the book is designed to provide a concrete example of each rock type, environment, or geologic feature being illustrated. Research shows that many college students require concrete examples before they can begin to build abstract concepts. Also, many students have limited travel experience, so photographs and other figures allow them to observe places, environments, and processes they have not been able to observe firsthand. The inclusion of an illustration for each text block reinforces the notion that the point being discussed is important. In many cases, as in the example in this Preface, conceptualized figures are

Visualize

"This is it! This is a book that my students can use to *learn*, not just 'do the reading.' The focus on questions on every page draws students in, and the immediacy of the illustration and text focused on each question makes it almost impossible for students not to want to plunge in to find out how each question is answered. And the centrality of high-quality illustrations, rather than exhaustive text, is a key component for helping students learn once they are engaged. Geoscience is a visual science, and this approach helps students visualize geologic processes in the real world, truly learning rather than simply preparing to parrot back definitions. Do I worry that this book isn't packed with text? Not in the slightest! With examples, real-world data, and research results easily accessible on the Internet, I don't want or need an introductory textbook that tries to be encyclopedic. I want a book that engages students, captures their imaginations, and helps them learn. This is the book!"

Barbara J. Tewksbury
Hamilton College
Past President, American Geological Institute
Past President, National Association of Geoscience Teachers

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7.2 What Sedimentary Environments Are Near Shorelines and in Oceans?

OCEANS AND THEIR SHORELINES are dynamic environments with wind, waves, and ocean currents transporting sediment eroded from the coastline or brought in from elsewhere. The characteristics of each environment, especially the types of sediment, depend mostly on the proximity to shore, the availability of sediment, and the depth, temperature, and clarity of the water. Examine the large figure below and try to envision what you would expect in each setting, including the type of sediment that would occur there.

07.02.a2 Carmel, CA

1. *Beaches* are stretches of coastline along which sediment has accumulated (◀). Most beaches consist of sand, pieces of shells, and rounded gravel, cobbles, or boulders. The setting determines which of these components is most abundant. Some shorelines have bedrock all the way to the ocean and so they have little or no beach. Wide, sandy beaches are more inviting as places to relax and play.

07.02.a3 Akumal, Mexico

2. The water near the shoreline may be sheltered by offshore reefs or islands. The sheltered water, called a *lagoon* (◀), is commonly shallow, calm, and perhaps warm. The nearshore parts of lagoons contain sand, mud, and stones derived from land, whereas the outer parts may have sand and pieces of coral eroded from a reef.

07.02.a4 Raja Ampat, Indonesia

3. Where ocean water is shallow, warm, and clear, coral and other marine creatures construct *reefs* (◀), which can parallel the coast, encircle islands, or form irregular mounds and platforms. Reefs typically protect the shoreline from the energetic, big waves of the deeper ocean.

4. Away from the shoreline, many landmasses are flanked by continental shelves and slopes consisting of layers of mud, sand, and carbonate minerals. Material from these sites can move down the slope in landslides or in turbulent, flowing masses of sand, mud, and water called *turbidity currents*. The slopes of some continents are incised by branching *submarine canyons* (not shown here) that funnel sediment toward deeper waters.

07.02.a1

5. The deep part of the seafloor is a dark, cold environment that is commonly several kilometers beneath the surface. It generally receives less sediment than areas closer to land, and its sediment is dominated by fine, windblown dust and by remains of mostly single-celled marine organisms.

Sedimentary Environments and Rocks 179

07.02.a5 Namibia

6. Sandy dunes that are inland from beaches are called *coastal dunes* (◀). These dunes commonly form where sand and finer sediment from the beach are blown or washed inland and then reshaped by the wind. When strong winds blow onto land, sand can move from the beach to the dunes, and sand can move back toward the beach when winds blow toward the sea or lake.

07.02.a6 Olympic Peninsula, WA

7. Some shorelines include low areas, called *tidal flats* (▶), that are flooded by the seas during high tide but exposed to the air during low tide. Most tidal flats are covered by mud and sand or are rocky. Some low parts of the land adjacent to tidal flats can accumulate salt and other *evaporite minerals* as seawater and terrestrial (on-land) waters evaporate under hot, arid (dry) conditions.

07.02.a7 Mississippi Delta, LA

8. In addition to the parts of deltas overlapping the shore, *submarine deltas* extend in some places for tens of kilometers offshore (▲). The muddy or sandy front of the delta may be unstable, and material can slide or tumble down the slope, sending sediment into deeper water.

9. Other accumulations of sand rise above the shallow coastal waters as long, narrow islands, called *barrier islands*. Most barrier islands, such as the one below (▼), are only hundreds of meters wide. The areas between barrier islands and the shoreline are commonly shallow lagoons or saltwater marshes.

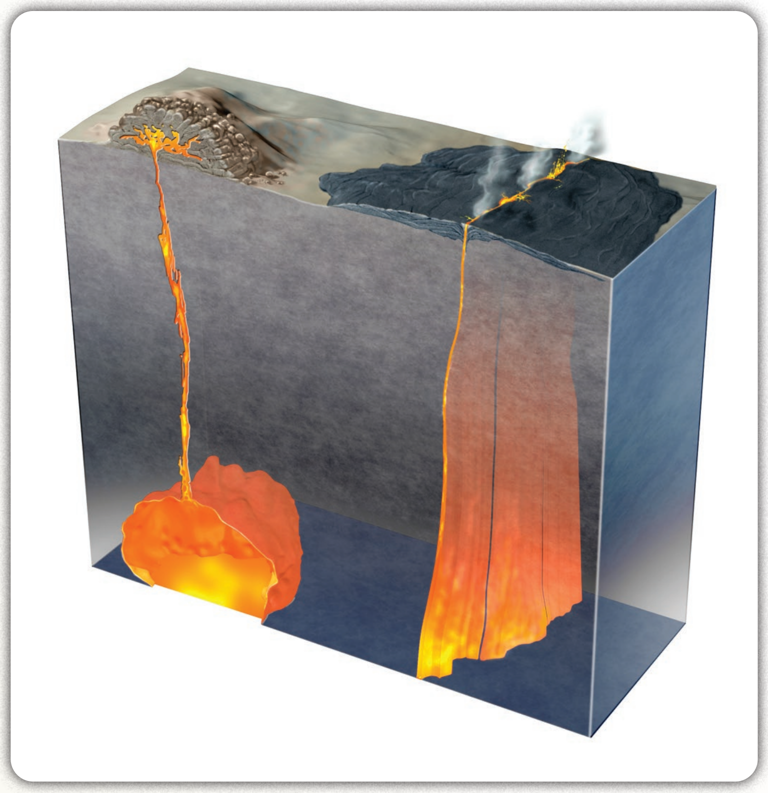
07.02.a8 Santa Rosa Island, FL

Before You Leave This Page

☑ Sketch and describe the main sedimentary environments in oceanic and nearshore environments.

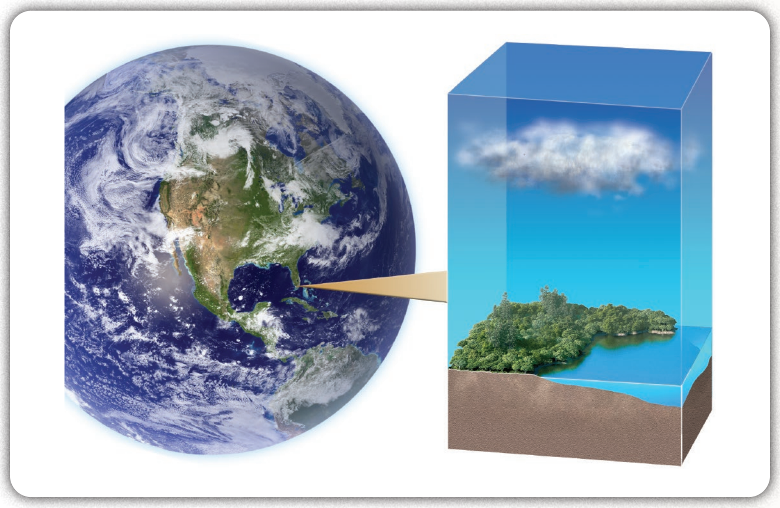
7.2

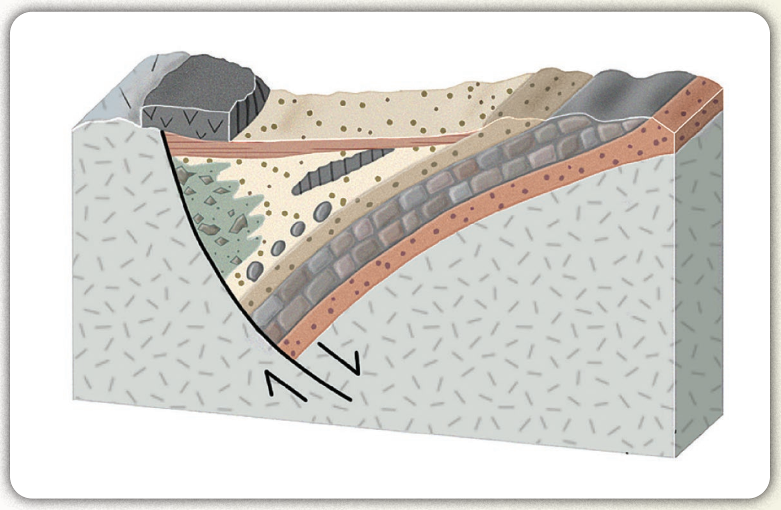
integrated with photographs and text so that students can build a more coherent view of the environment or process.

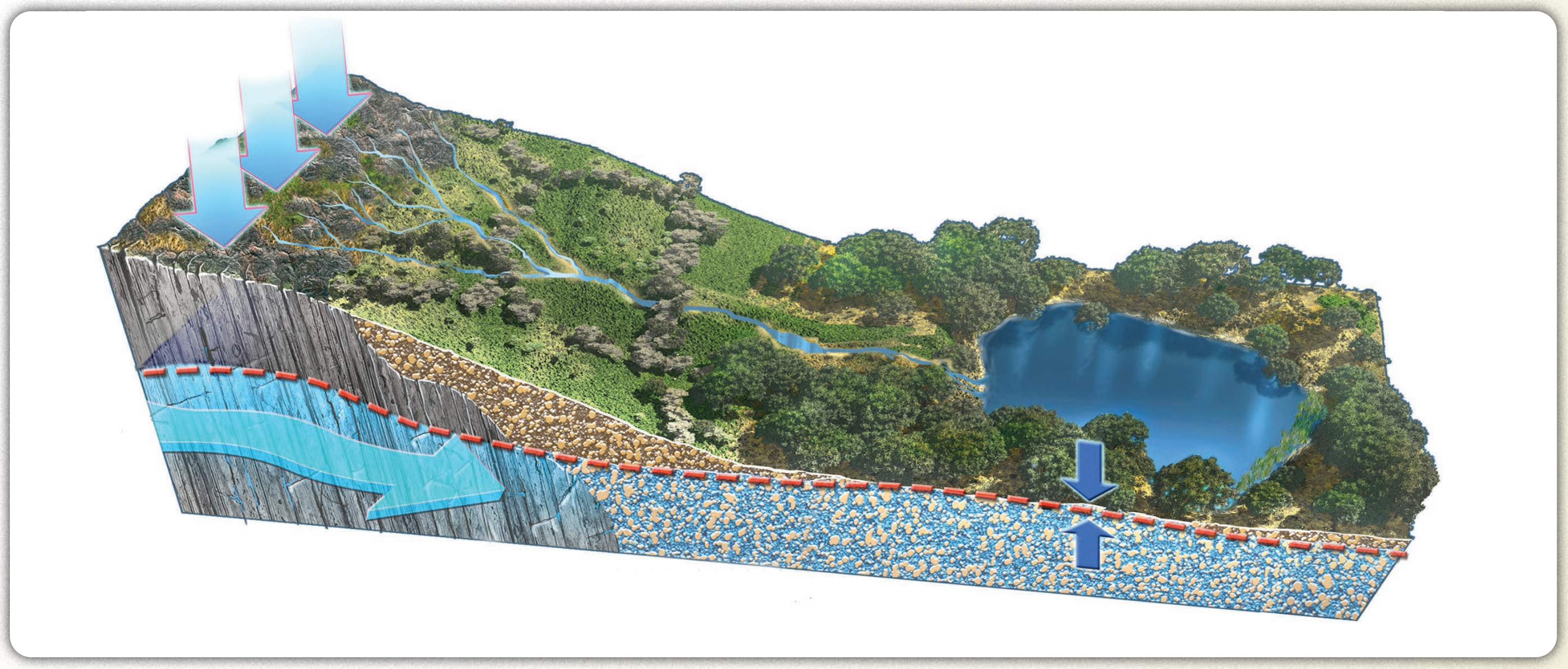


Exploring Geology focuses on the most important geologic concepts and makes a deliberate attempt to eliminate text that is not essential for student learning of these concepts. Inclusion of information that is not essential tends to distract and confuse students rather than illuminate the concept; thus you will see fewer words. Cognitive and science-education research has identified a redundancy effect, where information that restates and expands upon a more succinct description actually results in a decrease in student learning. Specifically, students learn less if a long figure caption restates information contained elsewhere on the page, such as in a long block of text that is detached from the figure. We avoid the redundancy effect by including only text that is integrated with the figure.

The style of illustrations in *Exploring Geology* was designed to be more inviting to today's visually oriented students who are used to photo-realistic, computer-rendered images in movies, videos, and computer games. For this reason, many of the figures were created by world-class artists who have worked on Hollywood movies, on television shows, for *National Geographic,* and in the computer-graphics industry. In most cases, the figures incorporate real data, such as satellite images and aerial photographs. Our own research shows that many students do not understand geologic cross sections and other subsurface diagrams, so nearly every cross section in this book has a three-dimensional aspect, and many maps are presented in a perspective view with topography. Research findings by us and others indicate that including people and human-related items on photographs and figures attracts undue attention, thereby distracting students from the geologic features being illustrated. As a result, our photographs have nondistracting indicators of scale, like dull coins and plain marking pens. Figures and photographs do not include people or human-related items unless (1) we are trying to illustrate how geoscientists study geologic processes and features, (2) illustrate the relevance of the processes on humans, or (3) help students appreciate that geoscience can be done by diverse types of people, potentially including them, as depicted in our photographs.







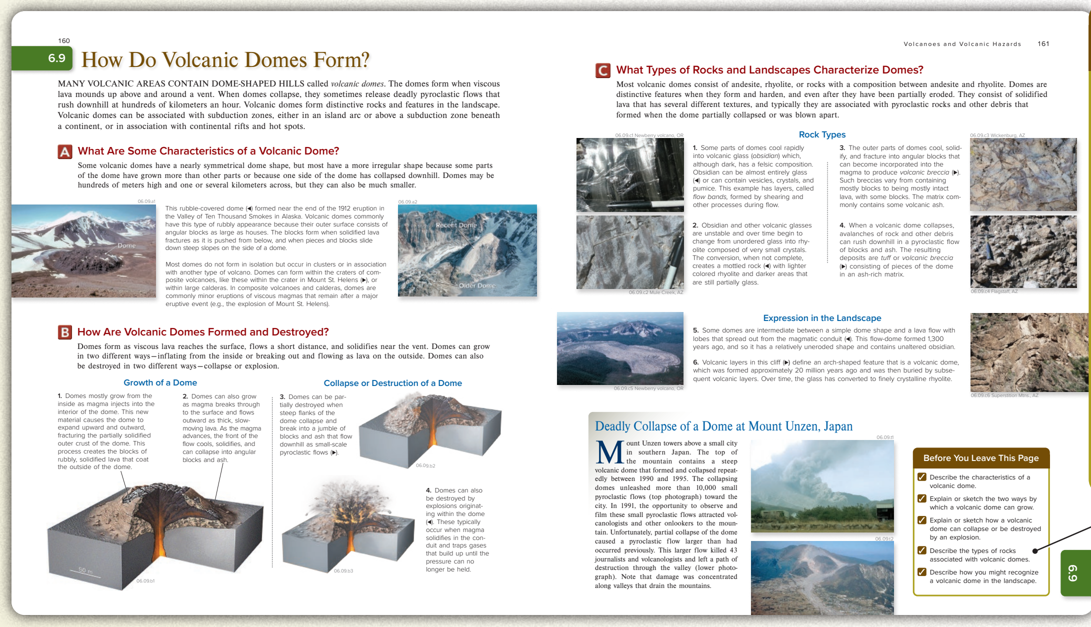
HOW ARE GEOLOGIC TERMS INTRODUCED IN THIS BOOK?

Wherever possible, we introduce terms after students have an opportunity to observe the feature or concept that is being named. This approach is consistent with several educational philosophies, including a learning cycle and just-in-time teaching. Research on learning cycles shows that students are more likely to retain a term if they already have a mental image of the thing being named. For example, this book presents students with the collection of igneous rocks shown to the right and asks them to think about how they would classify the rocks. Only then does the textbook present a classification of igneous rocks.

Also, the figure-based approach allows terms to be introduced in their context rather than as a definition that is detached from a visual representation of the term. In this book, we introduce new terms in italics rather than in boldface because boldfaced terms on a textbook page cause students to immediately focus mostly on the terms rather than build an understanding of the concepts. The book includes a glossary for those students who wish to look up the definition of a term to refresh their memory. To expand comprehension of the definition, each entry in the glossary references the page where the term is defined in the context of a figure.

WHY DOES THE BOOK CONSIST OF TWO-PAGE SPREADS?

This book consists of two-page spreads, most of which are further subdivided into sections. Research has shown that because of our limited amount of working memory, much new information is lost if it is not incorporated into long-term memory. Many students keep reading and highlighting their way through a textbook without stopping to integrate the new information into their mental framework. New information simply displaces existing information in working memory before it is learned and retained. This concept of cognitive load has profound implications for student learning during lectures and while reading textbooks. Two-page spreads and subsections help prevent cognitive overload by providing natural breaks that allow students to stop and consolidate the new information before moving on.



6.9 How Do Volcanic Domes Form?

A What Are Some Characteristics of a Volcanic Dome?

B How Are Volcanic Domes Formed and Destroyed?

C What Types of Rocks and Landscapes Characterize Domes?

Deadly Collapse of a Dome at Mount Unzen, Japan

Before You Leave This Page

- ✓ Describe the characteristics of a volcanic dome.
- ✓ Explain or sketch the two ways by which a volcanic dome can grow.
- ✓ Explain or sketch how a volcanic dome can collapse or be destroyed by an explosion.
- ✓ Describe the types of rocks associated with volcanic domes.
- ✓ Describe how you might recognize a volcanic dome in the landscape.

Each spread has a unique number, such as 6.9 for the 9th topical two-page spread in chapter 6 (see previous page). These numbers help instructors and students keep track of where they are and what is being covered. Each two-page spread, except for those that begin and end a chapter, contains a *Before You Leave This Page* checklist that indicates what is important and what is expected of students before they move on. This list contains learning objectives for the spread and provides a clear way for the instructor to indicate to the student what is important. The items on these lists are compiled into a master *What-to-Know* list.

SIGNIFICANT ADVANTAGES OFFERED BY *EXPLORING GEOLOGY*

Two-page spreads and integrated *Before You Leave This Page* lists offer the following advantages to the student:

- Information is presented in relatively small and coherent chunks that allow a student to focus on one important aspect or geologic system at a time.
- Students know when they are done with this particular topic and can self-assess their understanding with the *Before You Leave This Page* list.
- Two-page spreads allow busy students to read or study a complete topic in a short interval of study time, like during breaks between classes.
- All test questions and assessment materials are tightly articulated with the *Before You Leave This Page* lists so that exams and quizzes cover precisely the same material that was assigned to students via the *What-to-Know* list.

The two-page spread approach also has huge advantages for the instructor. Before writing this book, the authors wrote the items for the *Before You Leave This Page* lists. We then used this list to decide what figures were needed, what topics would be discussed, and in what order. In other words, *the textbook was written from the learning objectives*. The *Before You Leave This Page* lists provide a straightforward way for an instructor to tell students what information is important. Because we provide the instructor with a master *What-to-Know* list, an instructor can selectively assign or eliminate content by providing students with an edited *What-to-Know* list. Alternatively, an instructor can give students a list of assigned two-page spreads or sections within two-page spreads. In this way, the instructor can identify content for which students are responsible, even if the material is not covered in class.

HOW IS THIS BOOK ORGANIZED?

Two-page spreads are organized into 19 chapters that are arranged into five major groups: (1) introduction to Earth and the science of geology, (2) earth materials and the processes that form them, (3) geologic time and tectonic systems, (4) climate and surface processes, and (5) capstone chapters on resources and planetary geology. The first three chapters provide an overview of geology, the scientific approach to geology, and plate tectonics—a unifying theme interwoven throughout the rest of the book. The next five chapters cover earth materials, including minerals (chapter 4), different families of rocks and structures (chapters 5–8), and the processes that form or modify rocks. Unlike many geology books, *Exploring Geology* begins the discussion of earth materials with an examination of landscapes—something students can relate to—as a lead-in to rocks, then to minerals, and finally to atoms, the most abstract topic in geology books. The sedimentary environments chapter includes a brief introduction to weathering, setting the stage for the discussion of clastic sediments but saving a more detailed discussion of weathering and soils for the part of the book that deals with surficial processes. Also, this book integrates the closely related topics of metamorphism and deformation into a single chapter.

After earth materials, we cover the principles of geologic time, emphasizing how geologists reconstruct Earth's history (chapter 9). We then move on to ocean basins, mountains and basins, and earthquakes (chapters 10–12), all of which integrate and apply information about rocks, structures, geologic time, and plate tectonics. These chapters provide important details about aspects of plate tectonics after students have gained an understanding of rocks, structures, and geologic time from earlier chapters. We have also incorporated a small component of historical geology, including evolution of the continents and ocean basins.

Next, we briefly discuss weather and climate (chapter 13) to provide a backdrop for subsequent chapters on surface processes and to introduce timely topics, such as hurricanes and climate change. This chapter also discusses deserts, drought, and rain forests. Glaciers, coasts, and sea-level changes are integrated into a single chapter (chapter 14) to present a system approach to earth processes and to emphasize the interplay between glaciations, sea level, and the character of the shoreline. Chapter 15 focuses on weathering, soils, and slope stability; chapter 16 presents streams and flooding; and chapter 17 covers surface-water and groundwater resources and groundwater-related problems.

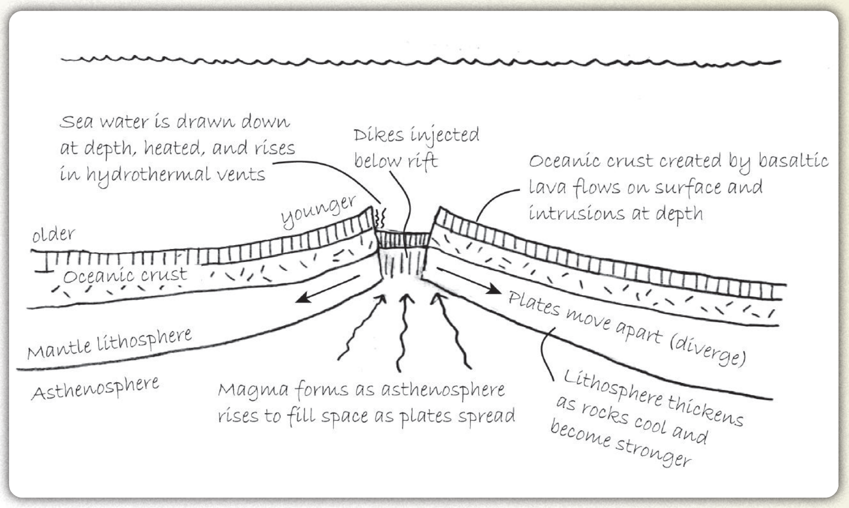
We consider the last two chapters to be capstones, integrating and applying previous topics to enable students to understand energy and mineral resources (chapter 18) and planetary geology (chapter 19). These two chapters give students and instructors an opportunity to see how an understanding of rock types, rock-forming processes, geologic structures, geologic time, and the flow of water and other fluids can help us understand important resources and the surfaces of other planetary bodies. The late placement of both chapters allows a more comprehensive treatment of these topics than would be possible if they were incorporated into earlier chapters.

SPECIAL TEXT FEATURES

Concept Sketches

Most items on the *Before You Leave This Page* list are by design suitable for student construction of concept sketches. Concept sketches are sketches that are annotated with complete sentences that identify geologic features, describe how the features form, characterize the main geologic processes, and summarize geologic histories (▶).

Concept sketches are an excellent way to actively engage students in class and to assess their understanding of geologic features, processes, and history. Concept sketches are well suited to the visual nature of geology, especially cross sections, maps, and block diagrams. Geologists are natural sketchers using field notebooks, blackboards, publications, and even napkins, because sketches are an important way to record observations and thoughts, organize knowledge, and try to visualize geometries of rock bodies and sequences of events. The step-by-step process of creating a concept sketch is explored further in Chapter 1. An instructor does not need to use concept sketches with this book (it works well with and is accompanied by more traditional types of assessment, such as test banks), but students can use concept sketches to build deeper understanding of key topics. We provide a list of concept-sketch questions to instructors, but it is easy for instructors to create their own, such as for topics not in the textbook.



For more information, see Johnson, J. K., and Reynolds, S. J., 2005. Concept sketches—Using student- and instructor-generated annotated sketches for learning, teaching, and assessment in geology courses. *Journal of Geoscience Education*, v. 53, pp. 85–95.

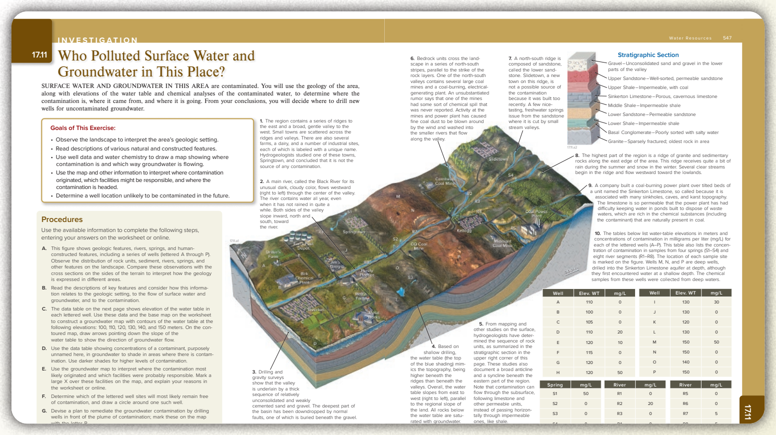
TWO-PAGE SPREADS

Most of the book consists of *two-page spreads*, each of which is about one or more closely related topics. Topical spreads convey the geologic content and help organize knowledge.

Each chapter has at least one two-page spread illustrating how geology impacts society and another two-page spread that specifically describes how geoscientists study typical problems.

The penultimate two-page spread in each chapter is a *Connections* spread, which is designed to help students connect and integrate the various concepts from the chapter and to show how these concepts can be applied to an actual location. *Connections* are about real places that illustrate the geologic concepts and features covered in the chapter and explicitly illustrate how a geologic problem is investigated and how geologic problems have relevance to society. The *Connections* spread also prepares the student for a following *Investigation* two-page spread.

Each chapter ends with an *Investigation* spread that is an exercise in which students apply the knowledge, skills, and approaches learned in the chapter. These exercises mostly involve virtual places that students explore and investigate to make observations and interpretations and to answer a series of geologic questions.



Investigations are modeled after the types of problems geologists investigate, and they use the same kinds of data and illustrations encountered in the chapter. The Investigation includes a list of goals for the exercises and step-by-step instructions, including calculations and methods for constructing maps, graphs, and other figures. These investigations can be completed by students in class, as worksheet-based homework, or as online activities.

NEW IN THE SIXTH EDITION

The sixth edition of *Exploring Geology* includes numerous significant revisions, with every chapter receiving additions and improvements. This edition also features a new Appendix. The style, approach, and sequence of chapters is unchanged, but every chapter received new photographs, new or revised figures, major to minor editing of text blocks and, in some cases, reorganization. We revised many text blocks to improve clarity and conciseness, or to present recent discoveries and events. Most chapters contain the same number and order of two-page spreads, but four chapters each gained a new two-page spread, and other chapters had sections that were completely revised. Many changes were made in response to comments by reviewers and students. The book contains many edits as a result of careful re-reading of the entire book. The most important revisions are listed below:

- The most obvious change is the addition of an Appendix, which focuses on helping students improve their quantitative and spatial skills, such as how to convert from one unit to another and how to contour data. The Appendix consists of one-page and two-page sections, each related to and referenced from a specific two-page spread in the body of the book. There is coverage of general scientific literacy topics, such as scientific notation, how to read and plot graphs, the fundamental gas laws, and units of matter, energy, and motion. There are also geoscience-specific topics, including calculating rates of seafloor spreading, how to read a weather map, how to construct a hydrograph, and estimating the frequency of flooding.
- This edition contains nearly 150 new photographs, with a deliberate intention to represent a wider geographic diversity, to provide clearer examples, to expand the discussion of specific topics, and to provide more information about a geologic process, material, or feature. In addition, we reprocessed a small number of existing photographs to improve their fidelity.
- This edition contains nearly 110 new or replaced illustrations. Many illustrations from the previous edition were replaced with new versions to update information so that it is more current, to improve student understanding of certain complex topics, and for improved appearance. Some of these revisions consisted only of adding labels and shading.
- This edition contains two-page spreads that are entirely new. In chapter 1, we added a two-page spread on how to learn using concept sketches, which are simple sketches annotated with labels and complete sentences to explain features, processes, and interrelationships. Concept sketches were, and still are, mentioned in the Preface, but the new two-page spread provides a step-by-step approach for constructing a concept sketch by way of an example. We created a new gemstones two-page spread for the chapter on minerals (chapter 4). Chapter 13 gained a two-page spread as a consequence of expansion of the discussion of wind-related processes and features, especially types of sand dunes. A new two-page spread in chapter 16 explores the characteristics and formation of natural bridges and arches.
- Another major change occurred in chapter 2, which explores strategies and examples for how to understand and study earth features and processes. We completely revised two two-page spreads about the scientific method. We explain inductive versus deductive versus abductive reasoning, and we further explore observations versus interpretations, as well as the distinction between science done by hypothesis testing and scientific discoveries that arose from exploration.
- A number of two-page spreads have been extensively revised with improved layout, illustrations, and text. In addition to the new or revised illustrations, we updated text to reflect new ideas or new data. For example, we updated figures for increases in global temperatures, sea-surface temperatures, and CO_2 content of the atmosphere.
- Throughout the book, most text boxes are now numbered sequentially within a section. This will help direct students to read the text boxes in a specific order and helps with the sequence of presentation on phones and other small devices. It also allows an instructor to reference text in a more specific way.
- This edition features a different serif font from the previous edition. This font is highly readable on portable electronic devices while retaining fidelity to a quality printed book. This font replacement resulted in small changes in layout of individual text blocks on almost every page.

CHAPTER 1 received a major revision, with an aim toward guiding students to begin observing and interpreting landscapes earlier than in previous editions. Accordingly, we moved an observing landscapes two-page spread from chapter 2 to early in chapter 1, and we followed it with the new two-page spread on concept sketches, a spread also focused on landscapes. Our thinking was that most instructors, including us, begin showing photographs of landscapes on the first day of class, so students should have an early introduction about how to observe different features in a landscape. The chapter includes eight new photographs and five new or revised illustrations. As in all chapters, we wrote new text or often significantly edited text and layouts when we replaced a photograph. The chapter has a reference to the first entry in the Quantitative and Spatial Skills Appendix, which summarizes the units we use to describe matter, energy and motion. All other entries in the Appendix are referenced in the appropriate chapter, although not all Appendix references are listed below.

CHAPTER 2 focuses on teaching students scientific problem solving and was heavily revised. The chapter lost the aforementioned observing landscape two-page spread (to chapter 1), and now the first topical two-page spread (after the opener) immediately helps students starting to think about how to use modern environments to interpret the origin of rocks and other past deposits. In addition, the four pages specifically on the process of science are almost all new material, including coverage of different types of reasoning. The chapter has 11 new photographs compared to the previous edition and two revised illustrations. In addition to the two-page spread that was moved to chapter 1, this chapter lost two figures, one photograph, and one table compared to the previous edition.