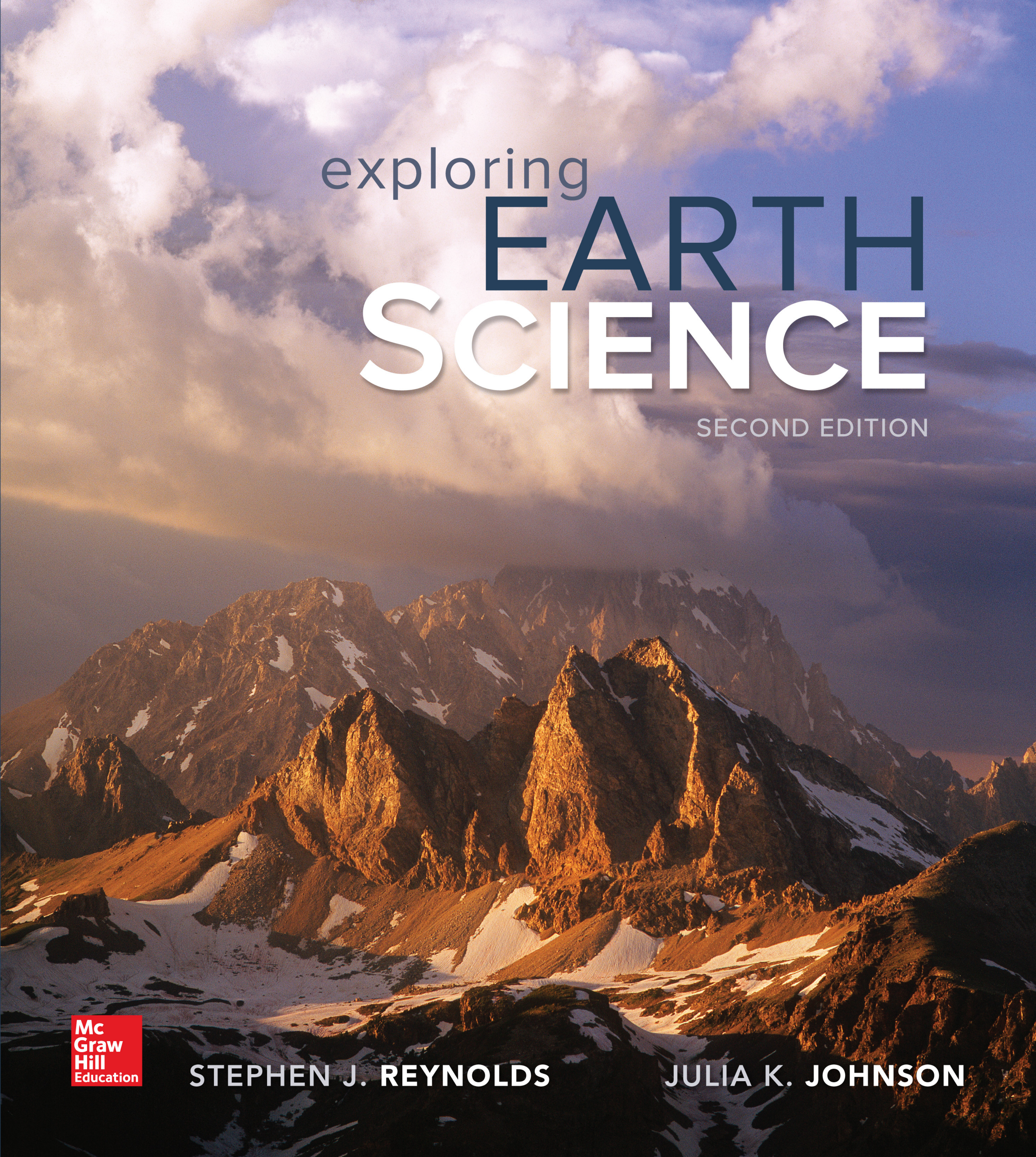

exploring EARTH SCIENCE

SECOND EDITION

STEPHEN J. REYNOLDS

JULIA K. JOHNSON

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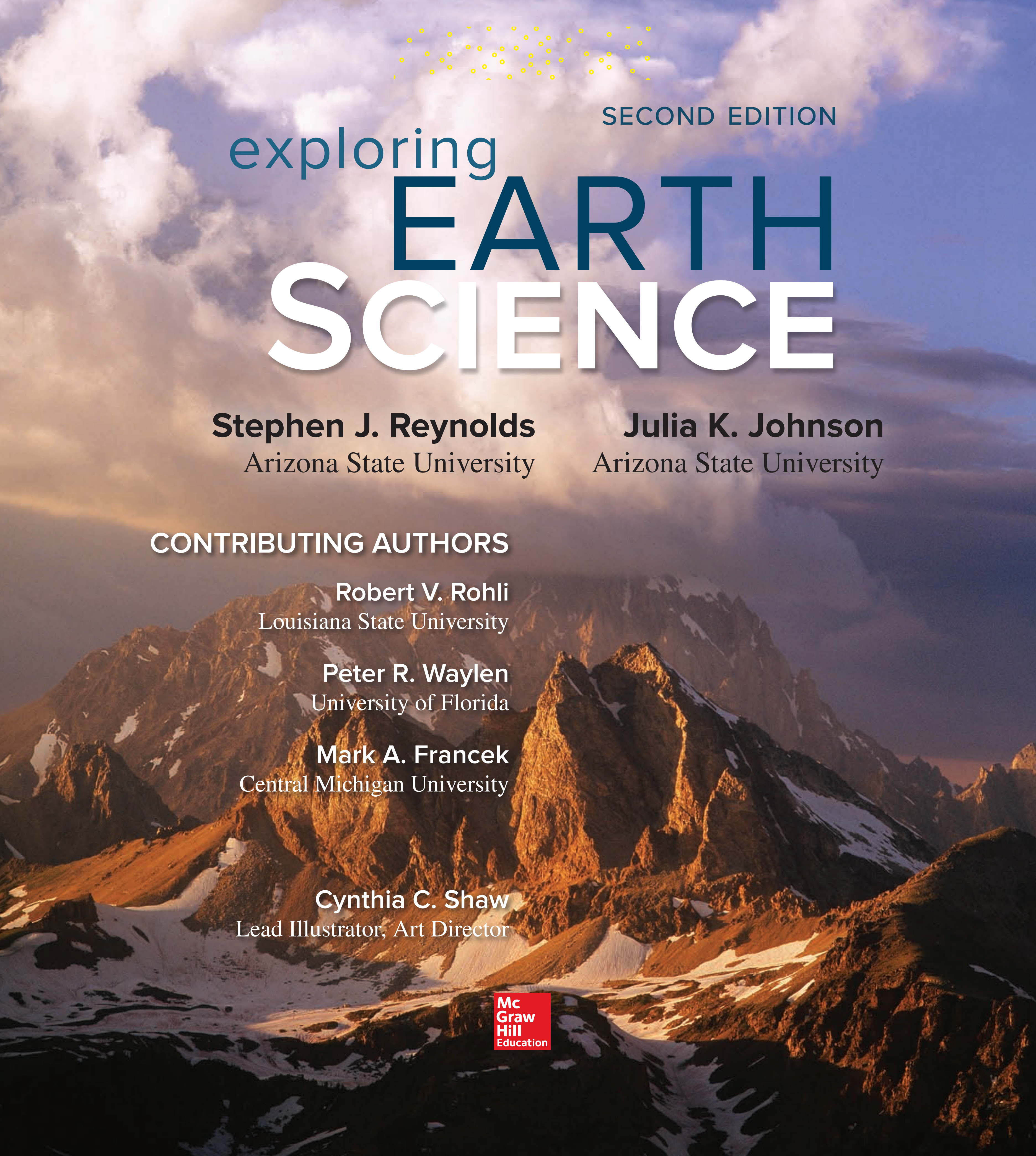
exploring

EARTH SCIENCE

About the Cover

The cover photograph by well-known photographer Michael Collier features the Grand Teton, its top shrouded in clouds. The peaks stand 13,775 feet above sea level, and are within one of the youngest mountain ranges of the extensive Rocky Mountain system. Although the mountain range is very young in geologic terms, it is cored with ancient metamorphic and igneous rocks, some of which formed as much as 2.6 billion years ago, at a time when the North American continent was first forming. The entire Teton Range, looming more than a mile above Jackson Hole, Wyoming, is along the rising edge of a fault-bounded crustal block that has been tilted – up on the east side and down on the west. This tilting and uplift started only five million years ago, and continues today. The Tetons have been thrust up into a windy world of intense weather, where clouds often gather and storms sometimes rage. During the Ice Ages, glaciers left gouges and imparted onto the peaks their overall shapes, and now precipitation pummels the peaks, helping carve the rock into spires and cliffs.

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 the Grand Canyon in the 1970s and '80s, then practiced family medicine in northern Arizona. Collier published books about the geology of Grand Canyon, Death Valley, Denali, and Capitol Reef national parks. He has done books on the Colorado River basin, glaciers of Alaska, climate change in Alaska, and 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, National Park Service, American Geosciences Institute, and National Science Teachers Association.



SECOND EDITION

exploring EARTH SCIENCE

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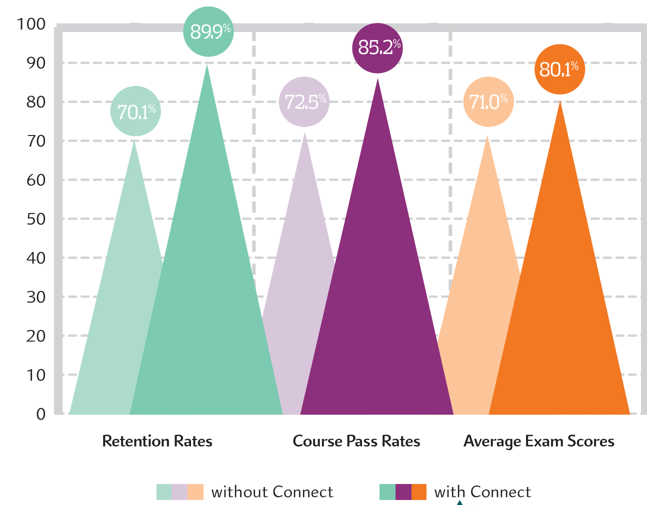

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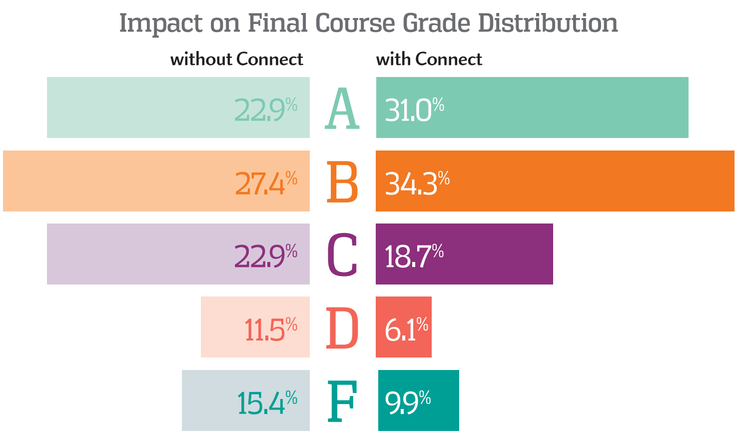

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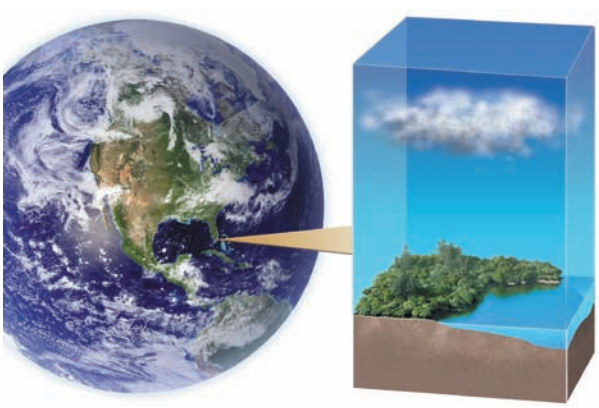

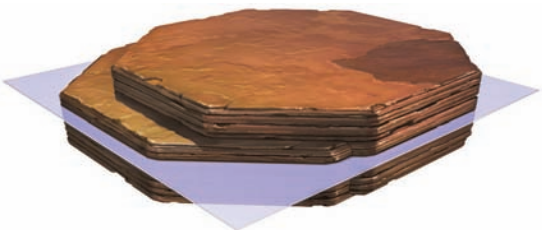

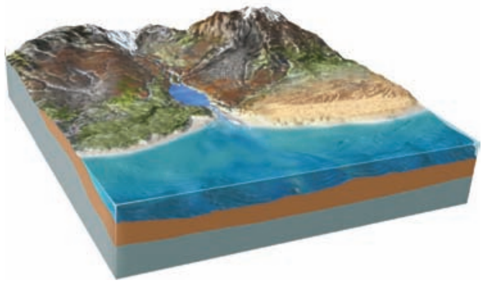

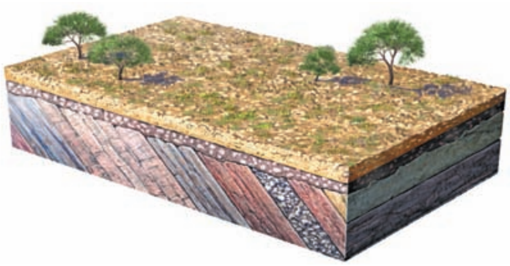

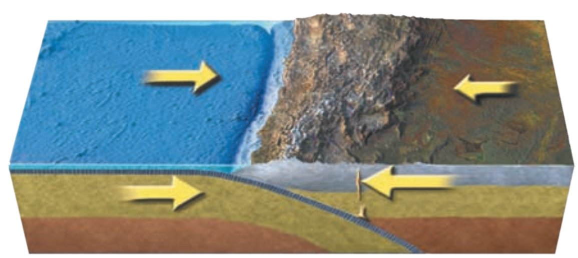

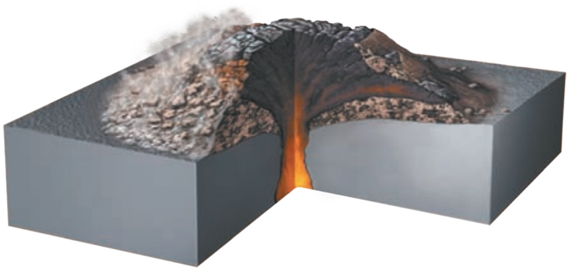

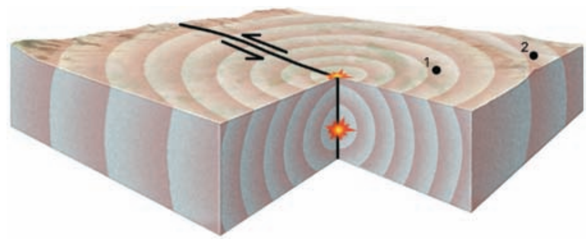
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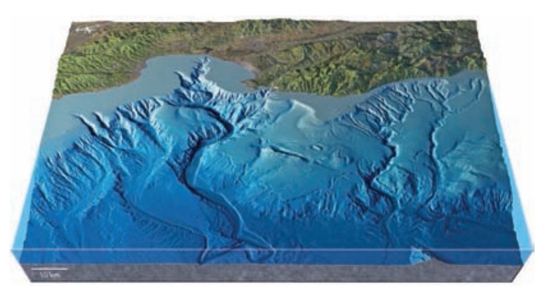

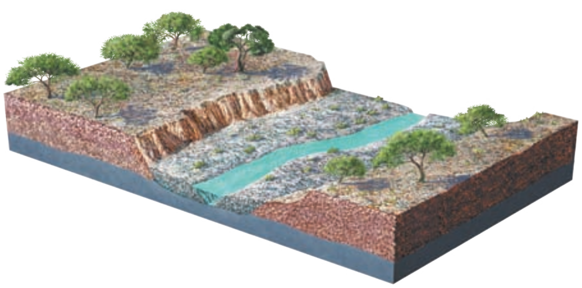

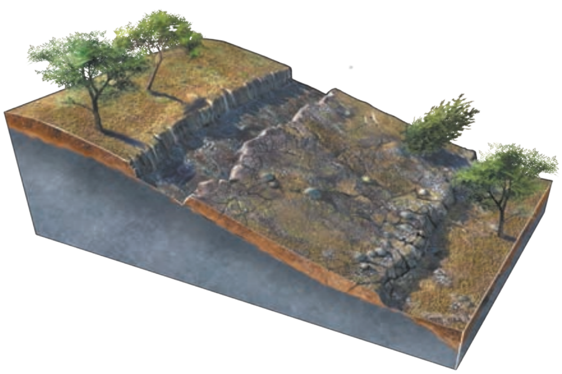

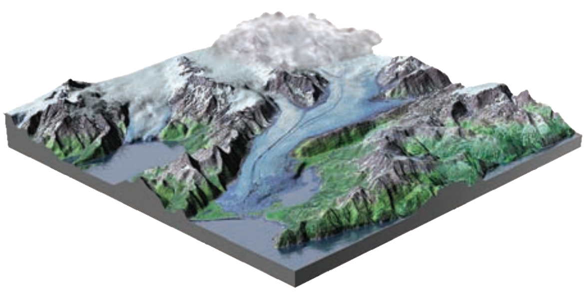

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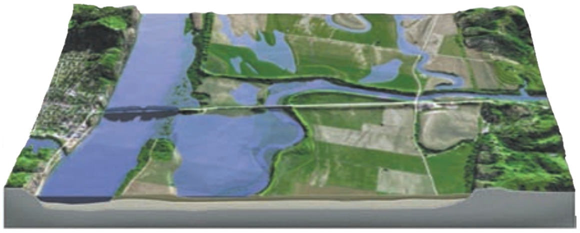

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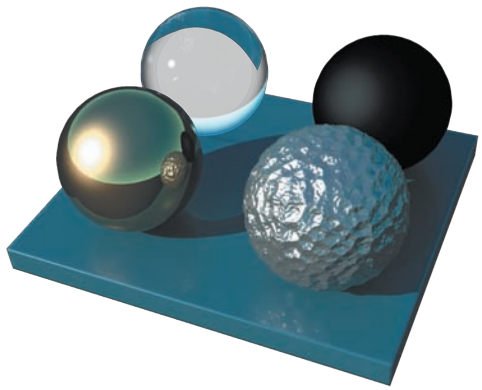

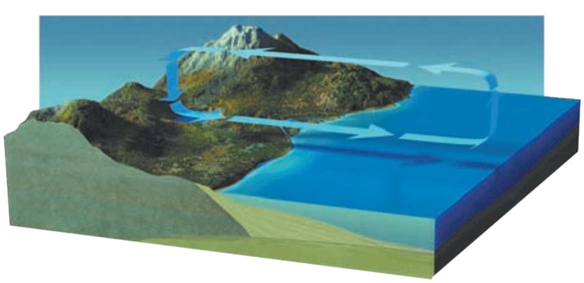

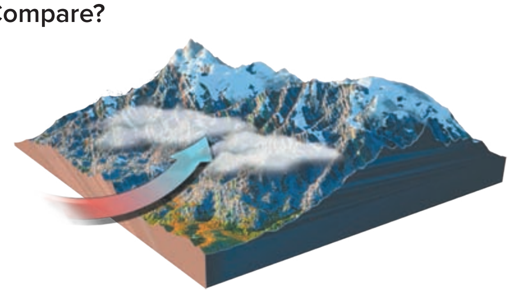

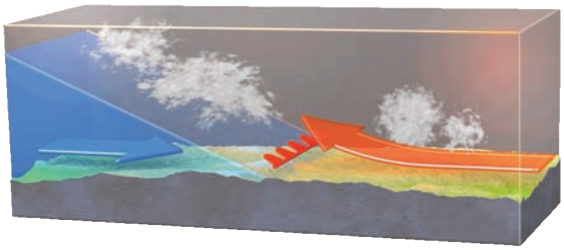

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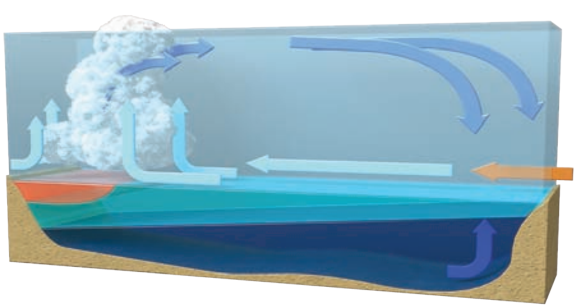

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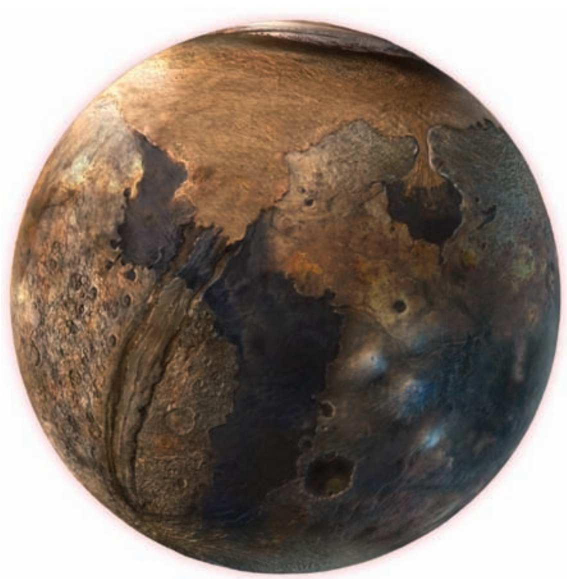

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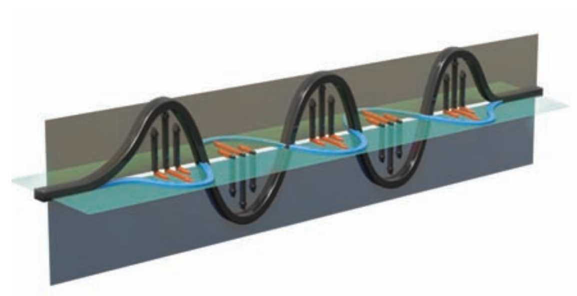


PREFACE

TELLING THE STORY . . .

WE WROTE *EXPLORING EARTH SCIENCE* 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 type of 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 science 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 science course, especially for nonmajors. At every school I visited, the main goals were similar to those listed below:

- 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 physical environment,
- to enable students to learn and apply important concepts of science,
- to help students understand the relevance of science 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 my coauthor (Julia Johnson) and I 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 concepts and their relevance. Instructors would also be able to spend more class time teaching students to observe and interpret landscapes, tectonics, and atmospheric or astronomic phenomena, and to participate in the process of scientific inquiry, which represents the top goal for many instructors.

COGNITIVE AND SCIENCE-EDUCATION RESEARCH

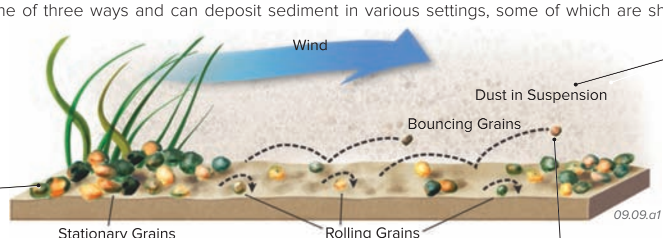
To design a book that supports instructor goals, we delved into cognitive and science-education research, especially research on how our brains process different types of information, what obstacles limit student learning from textbooks, and how students use visuals versus text while studying. We also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

A How Does Wind Transport Sediment?

Wind is generated by differences in air pressure and at times is strong enough to transport material, but only relatively small and lightweight fragments, like sand and clay. Transport of these materials by the wind is most efficient in dry climates, where there is limited vegetation to bind materials together and hold them on the ground.

1. Wind is capable of transporting sand and finer sediment, as well as lightweight plant fragments and other materials lying on the surface. It generally moves material in one of three ways and can deposit sediment in various settings, some of which are shown in the photographs below.

2. Most materials on Earth's surface are not moved by the wind because they are too firmly attached to the land (such as rock outcrops), are too large or heavy to be moved, or are both.

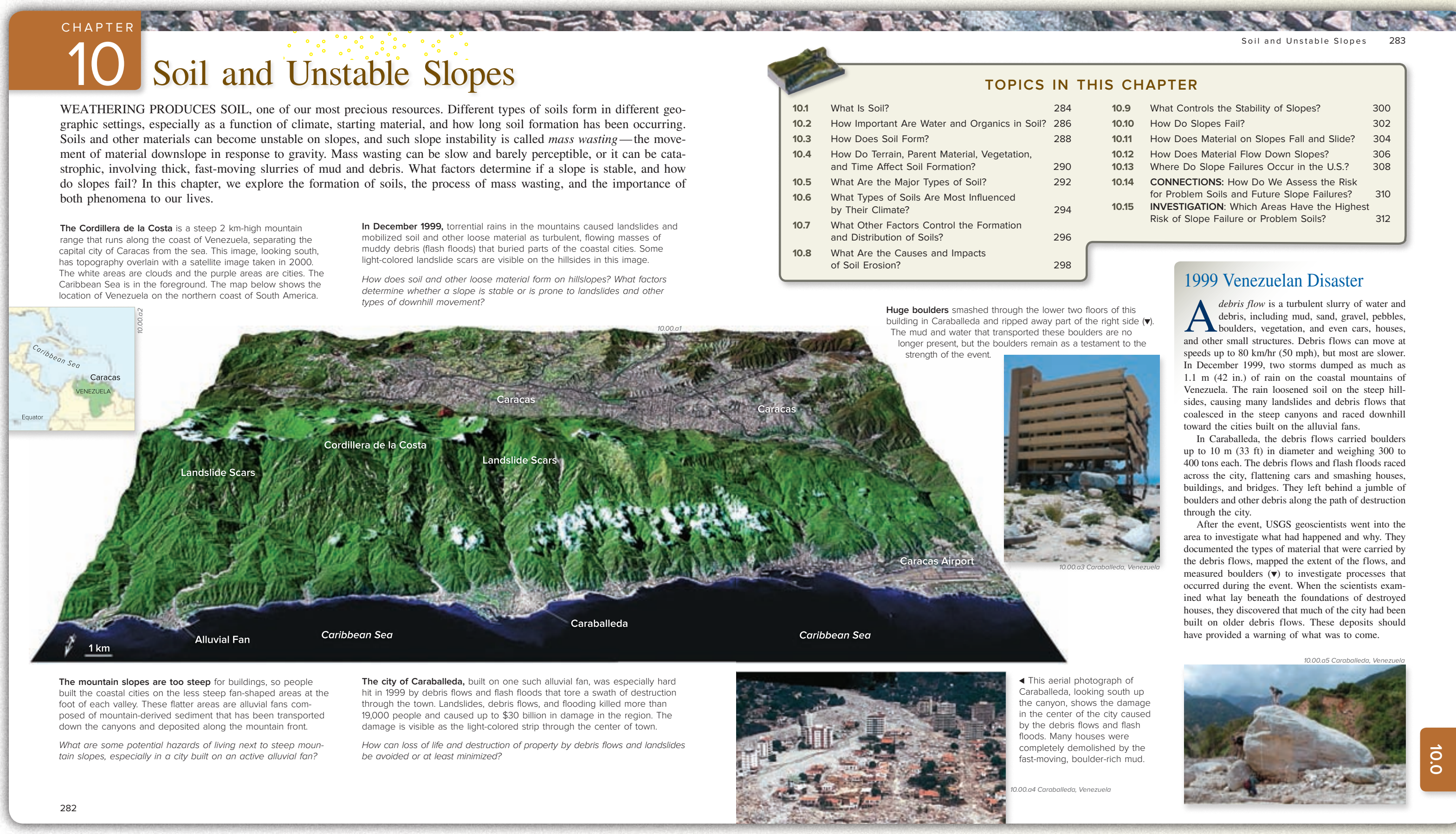


5. Wind can pick up and carry finer material, such as dust, silt, and salt. This mode of transport is called *suspension,* and wind can keep some particles in the air for weeks, transporting them long distances.

3. If wind velocity is great enough, it can roll or slide grains of sand and silt and other loose materials across the ground.

4. Very strong winds can lift sand grains, carry them short distances, and drop them. This process is akin to bouncing a grain along the surface and is called *saltation.*

HOW DOES THIS BOOK SUPPORT STUDENT CURIOSITY AND INQUIRY?



CHAPTER 10

Soil and Unstable Slopes

WEATHERING PRODUCES SOIL, one of our most precious resources. Different types of soils form in different geographic settings, especially as a function of climate, starting material, and how long soil formation has been occurring. Soils and other materials can become unstable on slopes, and such slope instability is called *mass wasting*—the movement of material downslope in response to gravity. Mass wasting can be slow and barely perceptible, or it can be catastrophic, involving thick, fast-moving slurries of mud and debris. What factors determine if a slope is stable, and how do slopes fail? In this chapter, we explore the formation of soils, the process of mass wasting, and the importance of both phenomena to our lives.

The Cordillera de la Costa is a steep 2 km-high mountain range that runs along the coast of Venezuela, separating the capital city of Caracas from the sea. This image, looking south, has topography overlain with a satellite image taken in 2000. The white areas are clouds and the purple areas are cities. The Caribbean Sea is in the foreground. The map below shows the location of Venezuela on the northern coast of South America.

In December 1999, torrential rains in the mountains caused landslides and mobilized soil and other loose material as turbulent, flowing masses of muddy debris (flash floods) that buried parts of the coastal cities. Some light-colored landslide scars are visible on the hillsides in this image.

How does soil and other loose material form on hillslopes? What factors determine whether a slope is stable or is prone to landslides and other types of downhill movement?

The mountain slopes are too steep for buildings, so people built the coastal cities on the less steep fan-shaped areas at the foot of each valley. These flatter areas are alluvial fans composed of mountain-derived sediment that has been transported down the canyons and deposited along the mountain front.

What are some potential hazards of living next to steep mountain slopes, especially in a city built on an active alluvial fan?

The city of Caraballeda, built on one such alluvial fan, was especially hard hit in 1999 by debris flows and flash floods that tore a swath of destruction through the town. Landslides, debris flows, and flooding killed more than 19,000 people and caused up to $30 billion in damage in the region. The damage is visible as the light-colored strip through the center of town.

How can loss of life and destruction of property by debris flows and landslides be avoided or at least minimized?

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Soil and Unstable Slopes 283

TOPICS IN THIS CHAPTER

Huge boulders smashed through the lower two floors of this building in Caraballeda and ripped away part of the right side (▼). The mud and water that transported these boulders are no longer present, but the boulders remain as a testament to the strength of the event.

10.00.a3 Caraballeda, Venezuela

1999 Venezuelan Disaster

A *debris flow* is a turbulent slurry of water and debris, including mud, sand, gravel, pebbles, boulders, vegetation, and even cars, houses, and other small structures. Debris flows can move at speeds up to 80 km/hr (50 mph), but most are slower. In December 1999, two storms dumped as much as 1.1 m (42 in.) of rain on the coastal mountains of Venezuela. The rain loosened soil on the steep hillsides, causing many landslides and debris flows that coalesced in the steep canyons and raced downhill toward the cities built on the alluvial fans.

In Caraballeda, the debris flows carried boulders up to 10 m (33 ft) in diameter and weighing 300 to 400 tons each. The debris flows and flash floods raced across the city, flattening cars and smashing houses, buildings, and bridges. They left behind a jumble of boulders and other debris along the path of destruction through the city.

After the event, USGS geoscientists went into the area to investigate what had happened and why. They documented the types of material that were carried by the debris flows, mapped the extent of the flows, and measured boulders (▼) to investigate processes that occurred during the event. When the scientists examined what lay beneath the foundations of destroyed houses, they discovered that much of the city had been built on older debris flows. These deposits should have provided a warning of what was to come.

◀ This aerial photograph of Caraballeda, looking south up the canyon, shows the damage in the center of the city caused by the debris flows and flash floods. Many houses were completely demolished by the fast-moving, boulder-rich mud.

10.00.a4 Caraballeda, Venezuela

10.00.a5 Caraballeda, Venezuela

10.0

Exploring Earth Science 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 new terms and the application of knowledge to a new situation. For example, chapter 10 on slope stability begins with a three-dimensional image of northern Venezuela, pictured above, and asks readers to observe where people are living in this area and what natural processes might have formed these sites.

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 (Lawson, 2003). For example, this book presents students with maps showing the spatial distribution of earthquakes, volcanoes, and mountain ranges and asks them to observe the patterns and think about what might be causing the patterns. Only then does the textbook introduce the concept of tectonic plates.

Also, the figure-based approach in this book allows terms to be introduced in their context rather than as a definition that is detached from a visual representation of the term. 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 italics, however, let a student know when they have encountered an important term during their reading. 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 pages where the term is defined in the context of a figure.

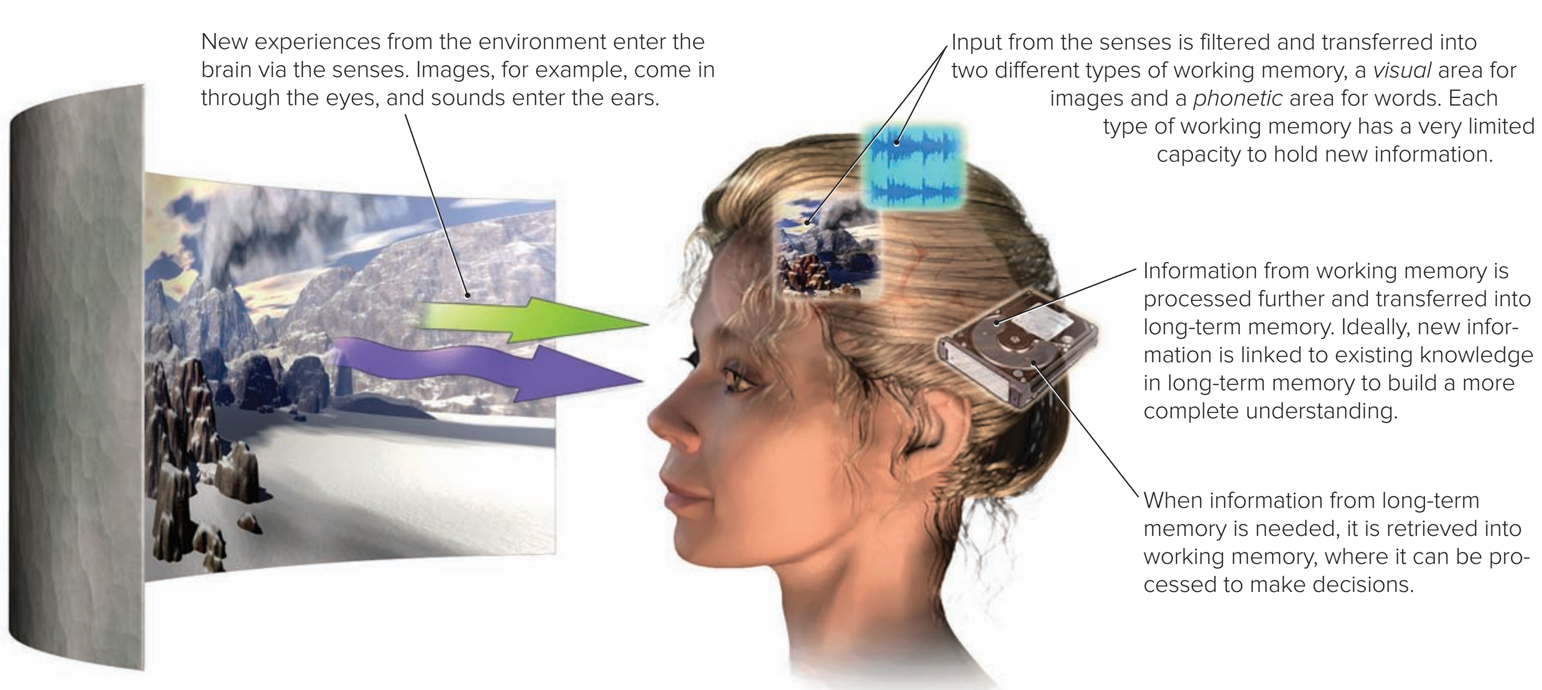
WHY ARE THE PAGES DOMINATED BY ILLUSTRATIONS?

Earth science is a visual science. Earth science textbooks contain a variety of photographs, maps, cross sections, block diagrams, and other types of illustrations. These diagrams help portray the spatial distribution and geometry of features in the landscape, atmosphere, oceans, and universe in ways words cannot. In earth sciences, a picture really is worth a thousand words.

Exploring Earth Science contains a wealth of figures to take advantage of the visual nature of earth science and the efficiency of figures in conveying earth science concepts. This book contains few large blocks of text—most text is in smaller blocks that are specifically linked to illustrations. Examples of our integrated figure-text approach are shown throughout the book. In this approach, each short block of text is one or more complete sentences that succinctly describe a feature, 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 in 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. Most short blocks are numbered to guide students to read the blocks in a specific order.

This approach is especially well suited to covering earth science topics because it allows the text to have a precise linkage to the features and geographic location of the aspect being described. A text block discussing the Intertropical Convergence Zone can have a leader that specifically points to the location of this feature. A cross section of atmospheric circulation, such as those related to El Niño conditions, can be accompanied by short text blocks that describe each part of the system and that are linked by leaders directly to specific locations on the figure. This allows the reader to concentrate on the concepts being presented, not deciding what part of the figure is being discussed.

The approach in *Exploring Earth Science* 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. 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 (Baddeley, 2007). 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 pictorial and verbal types of information in working memory. For information that has both pictorial and verbal components, as most earth-science 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.

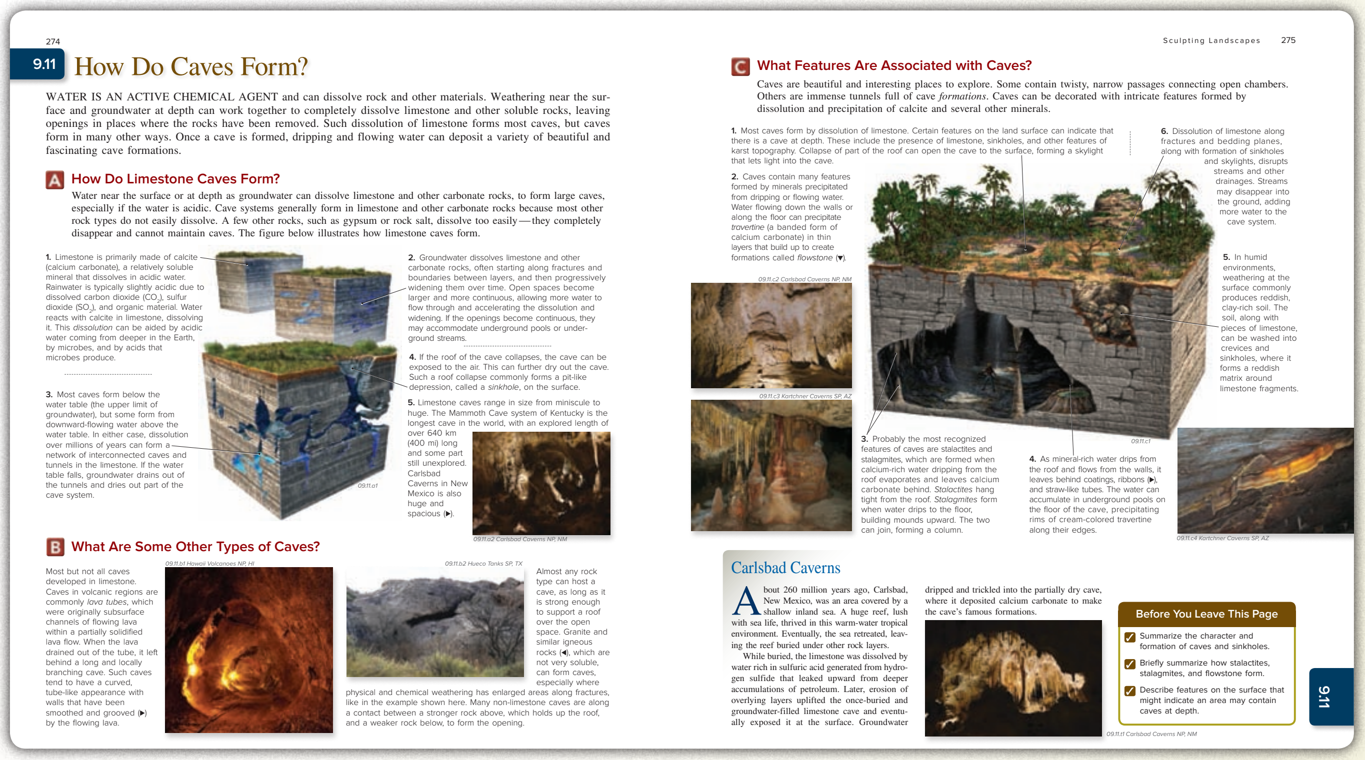


WHY ARE THERE SO MANY FIGURES?

This textbook contains more than 2,500 figures, which is two to three times the number in most earth science textbooks. One reason for this is that the book is designed to provide a concrete example of each process, environment, or feature being illustrated. Research shows that many college students require concrete examples before they can begin to build abstract concepts (Lawson, 1980). 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 numerous photographs, from geographically diverse places, help bring the sense of place into the student's reading. 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 below, conceptualized figures are integrated with photographs and text so that students can build a more coherent view of the environment or process.

Exploring Earth Science focuses on the most important earth science 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 (Mayer, 2001). 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 Earth Science* 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 scientific illustrators and artists who have worked on award-winning textbooks, on Hollywood movies, on television shows, for *National Geographic,* and in the computer-graphics and gaming industry. In most cases, the figures incorporate real data, such as satellite images, aerial photographs, weather and climatological data, and locations of earthquakes and volcanoes. Our own research shows that many students do not understand 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 that incorporates topography. Research findings by us and other researchers (Roth and Bowen, 1999) indicate that including people and human-related items in photographs and figures attracts undue attention, thereby distracting students from the 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 we are trying to (1) illustrate how geoscientists study earth science processes and features (2) reinforce 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.


274

9.11 How Do Caves Form?

WATER IS AN ACTIVE CHEMICAL AGENT and can dissolve rock and other materials. Weathering near the surface and groundwater at depth can work together to completely dissolve limestone and other soluble rocks, leaving openings in places where the rocks have been removed. Such dissolution of limestone forms most caves, but caves form in many other ways. Once a cave is formed, dripping and flowing water can deposit a variety of beautiful and fascinating cave formations.

A How Do Limestone Caves Form?

Water near the surface or at depth as groundwater can dissolve limestone and other carbonate rocks, to form large caves, especially if the water is acidic. Cave systems generally form in limestone and other carbonate rocks because most other rock types do not easily dissolve. A few other rocks, such as gypsum or rock salt, dissolve too easily—they completely disappear and cannot maintain caves. The figure below illustrates how limestone caves form.

1. Limestone is primarily made of calcite (calcium carbonate), a relatively soluble mineral that dissolves in acidic water. Rainwater is typically slightly acidic due to dissolved carbon dioxide (CO_2), sulfur dioxide (SO_2), and organic material. Water reacts with calcite in limestone, dissolving it. This *dissolution* can be aided by acidic water coming from deeper in the Earth, by microbes, and by acids that microbes produce.

2. Groundwater dissolves limestone and other carbonate rocks, often starting along fractures and boundaries between layers, and then progressively widening them over time. Open spaces become larger and more continuous, allowing more water to flow through and accelerating the dissolution and widening. If the openings become continuous, they may accommodate underground pools or underground streams.

3. Most caves form below the water table (the upper limit of groundwater), but some form from downward-flowing water above the water table. In either case, dissolution over millions of years can form a network of interconnected caves and tunnels in the limestone. If the water table falls, groundwater drains out of the tunnels and dries out part of the cave system.

4. If the roof of the cave collapses, the cave can be exposed to the air. This can further dry out the cave. Such a roof collapse commonly forms a pit-like depression, called a *sinkhole*, on the surface.

5. Limestone caves range in size from miniscule to huge. The Mammoth Cave system of Kentucky is the longest cave in the world, with an explored length of over 640 km (400 mi) long and some part still unexplored. Carlsbad Caverns in New Mexico is also huge and spacious (▶).

09.11.a1

09.11.a2 Carlsbad Caverns NP, NM

B What Are Some Other Types of Caves?

09.11.b1 Hawaii Volcanoes NP, HI

09.11.b2 Hueco Tanks SP, TX

Most but not all caves developed in limestone. Caves in volcanic regions are commonly *lava tubes*, which were originally subsurface channels of flowing lava within a partially solidified lava flow. When the lava drained out of the tube, it left behind a long and locally branching cave. Such caves tend to have a curved, tube-like appearance with walls that have been smoothed and grooved (▶) by the flowing lava.

Almost any rock type can host a cave, as long as it is strong enough to support a roof over the open space. Granite and similar igneous rocks (◀), which are not very soluble, can form caves, especially where physical and chemical weathering has enlarged areas along fractures, like in the example shown here. Many non-limestone caves are along a contact between a stronger rock above, which holds up the roof, and a weaker rock below, to form the opening.

Sculpting Landscapes 275

C What Features Are Associated with Caves?

Caves are beautiful and interesting places to explore. Some contain twisty, narrow passages connecting open chambers. Others are immense tunnels full of cave *formations*. Caves can be decorated with intricate features formed by dissolution and precipitation of calcite and several other minerals.

1. Most caves form by dissolution of limestone. Certain features on the land surface can indicate that there is a cave at depth. These include the presence of limestone, sinkholes, and other features of karst topography. Collapse of part of the roof can open the cave to the surface, forming a skylight that lets light into the cave.

2. Caves contain many features formed by minerals precipitated from dripping or flowing water. Water flowing down the walls or along the floor can precipitate *travertine* (a banded form of calcium carbonate) in thin layers that build up to create formations called *flowstone* (▼).

09.11.c2 Carlsbad Caverns NP, NM

09.11.c3 Kartchner Caverns SP, AZ

3. Probably the most recognized features of caves are stalactites and stalagmites, which are formed when calcium-rich water dripping from the roof evaporates and leaves calcium carbonate behind. *Stalactites* hang tight from the roof. *Stalagmites* form when water drips to the floor, building mounds upward. The two can join, forming a column.

4. As mineral-rich water drips from the roof and flows from the walls, it leaves behind coatings, ribbons (▶), and straw-like tubes. The water can accumulate in underground pools on the floor of the cave, precipitating rims of cream-colored travertine along their edges.

5. In humid environments, weathering at the surface commonly produces reddish, clay-rich soil. The soil, along with pieces of limestone, can be washed into crevices and sinkholes, where it forms a reddish matrix around limestone fragments.

6. Dissolution of limestone along fractures and bedding planes, along with formation of sinkholes and skylights, disrupts streams and other drainages. Streams may disappear into the ground, adding more water to the cave system.

09.11.c1

09.11.c4 Kartchner Caverns SP, AZ

Carlsbad Caverns

About 260 million years ago, Carlsbad, New Mexico, was an area covered by a shallow inland sea. A huge reef, lush with sea life, thrived in this warm-water tropical environment. Eventually, the sea retreated, leaving the reef buried under other rock layers.

While buried, the limestone was dissolved by water rich in sulfuric acid generated from hydrogen sulfide that leaked upward from deeper accumulations of petroleum. Later, erosion of overlying layers uplifted the once-buried and groundwater-filled limestone cave and eventually exposed it at the surface. Groundwater dripped and trickled into the partially dry cave, where it deposited calcium carbonate to make the cave's famous formations.

09.11.t1 Carlsbad Caverns NP, NM

Before You Leave This Page

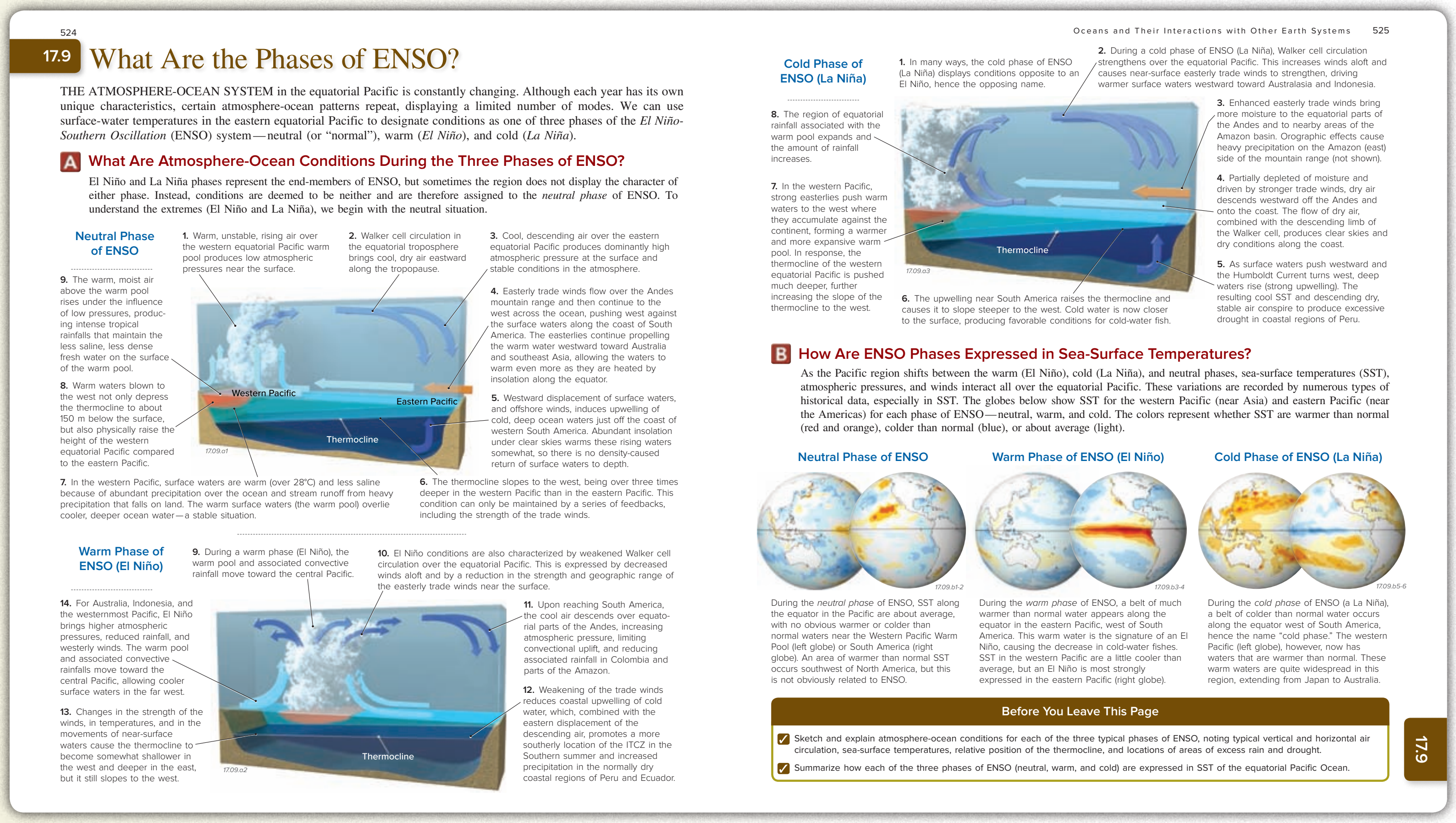
- ✓ Summarize the character and formation of caves and sinkholes.
- ✓ Briefly summarize how stalactites, stalagmites, and flowstone form.
- ✓ Describe features on the surface that might indicate an area may contain caves at depth.

9.11

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 (Sweller, 1994) has profound implications for student learning during lectures and while reading textbooks. Two-page spreads and sections help prevent cognitive overload by providing natural breaks that allow students to stop and consolidate the new information before moving on.

Each spread has a unique number, such as 17.9 for the ninth topical two-page spread in chapter 17. 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* provided to the instructor, who then deletes or adds entries to suit the instructor's learning goals and distributes the list to students before the students begin reading the book. In this way, the *What-to-Know List* guides the students' studying.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17.9 What Are the Phases of ENSO?

THE ATMOSPHERE-OCEAN SYSTEM in the equatorial Pacific is constantly changing. Although each year has its own unique characteristics, certain atmosphere-ocean patterns repeat, displaying a limited number of modes. We can use surface-water temperatures in the eastern equatorial Pacific to designate conditions as one of three phases of the *El Niño-Southern Oscillation* (ENSO) system—neutral (or "normal"), warm (*El Niño*), and cold (*La Niña*).

A What Are Atmosphere-Ocean Conditions During the Three Phases of ENSO?

El Niño and La Niña phases represent the end-members of ENSO, but sometimes the region does not display the character of either phase. Instead, conditions are deemed to be neither and are therefore assigned to the *neutral phase* of ENSO. To understand the extremes (El Niño and La Niña), we begin with the neutral situation.

Neutral Phase of ENSO

1. Warm, unstable, rising air over the western equatorial Pacific warm pool produces low atmospheric pressures near the surface.

2. Walker cell circulation in the equatorial troposphere brings cool, dry air eastward along the tropopause.

3. Cool, descending air over the eastern equatorial Pacific produces dominantly high atmospheric pressure at the surface and stable conditions in the atmosphere.

4. Easterly trade winds flow over the Andes mountain range and then continue to the west across the ocean, pushing west against the surface waters along the coast of South America. The easterlies continue propelling the warm water westward toward Australia and southeast Asia, allowing the waters to warm even more as they are heated by insolation along the equator.

5. Westward displacement of surface waters, and offshore winds, induces upwelling of cold, deep ocean waters just off the coast of western South America. Abundant insolation under clear skies warms these rising waters somewhat, so there is no density-caused return of surface waters to depth.

6. The thermocline slopes to the west, being over three times deeper in the western Pacific than in the eastern Pacific. This condition can only be maintained by a series of feedbacks, including the strength of the trade winds.

7. In the western Pacific, surface waters are warm (over 28°C) and less saline because of abundant precipitation over the ocean and stream runoff from heavy precipitation that falls on land. The warm surface waters (the warm pool) overlie cooler, deeper ocean water—a stable situation.

8. Warm waters blown to the west not only depress the thermocline to about 150 m below the surface, but also physically raise the height of the western equatorial Pacific compared to the eastern Pacific.

9. The warm, moist air above the warm pool rises under the influence of low pressures, producing intense tropical rainfalls that maintain the less saline, less dense fresh water on the surface of the warm pool.

Western Pacific
Eastern Pacific
Thermocline
17.09.a1

Warm Phase of ENSO (El Niño)

9. During a warm phase (El Niño), the warm pool and associated convective rainfall move toward the central Pacific.

10. El Niño conditions are also characterized by weakened Walker cell circulation over the equatorial Pacific. This is expressed by decreased winds aloft and by a reduction in the strength and geographic range of the easterly trade winds near the surface.

11. Upon reaching South America, the cool air descends over equatorial parts of the Andes, increasing atmospheric pressure, limiting convectional uplift, and reducing associated rainfall in Colombia and parts of the Amazon.

12. Weakening of the trade winds reduces coastal upwelling of cold water, which, combined with the eastern displacement of the descending air, promotes a more southerly location of the ITCZ in the Southern summer and increased precipitation in the normally dry coastal regions of Peru and Ecuador.

13. Changes in the strength of the winds, in temperatures, and in the movements of near-surface waters cause the thermocline to become somewhat shallower in the west and deeper in the east, but it still slopes to the west.

14. For Australia, Indonesia, and the westernmost Pacific, El Niño brings higher atmospheric pressures, reduced rainfall, and westerly winds. The warm pool and associated convective rainfalls move toward the central Pacific, allowing cooler surface waters in the far west.

Thermocline
17.09.a2

Oceans and Their Interactions with Other Earth Systems 525

Cold Phase of ENSO (La Niña)

1. In many ways, the cold phase of ENSO (La Niña) displays conditions opposite to an El Niño, hence the opposing name.

2. During a cold phase of ENSO (La Niña), Walker cell circulation strengthens over the equatorial Pacific. This increases winds aloft and causes near-surface easterly trade winds to strengthen, driving warmer surface waters westward toward Australasia and Indonesia.

3. Enhanced easterly trade winds bring more moisture to the equatorial parts of the Andes and to nearby areas of the Amazon basin. Orographic effects cause heavy precipitation on the Amazon (east) side of the mountain range (not shown).

4. Partially depleted of moisture and driven by stronger trade winds, dry air descends westward off the Andes and onto the coast. The flow of dry air, combined with the descending limb of the Walker cell, produces clear skies and dry conditions along the coast.

5. As surface waters push westward and the Humboldt Current turns west, deep waters rise (strong upwelling). The resulting cool SST and descending dry, stable air conspire to produce excessive drought in coastal regions of Peru.

6. The upwelling near South America raises the thermocline and causes it to slope steeper to the west. Cold water is now closer to the surface, producing favorable conditions for cold-water fish.

7. In the western Pacific, strong easterlies push warm waters to the west where they accumulate against the continent, forming a warmer and more expansive warm pool. In response, the thermocline of the western equatorial Pacific is pushed much deeper, further increasing the slope of the thermocline to the west.

8. The region of equatorial rainfall associated with the warm pool expands and the amount of rainfall increases.

Thermocline
17.09.a3

B How Are ENSO Phases Expressed in Sea-Surface Temperatures?

As the Pacific region shifts between the warm (El Niño), cold (La Niña), and neutral phases, sea-surface temperatures (SST), atmospheric pressures, and winds interact all over the equatorial Pacific. These variations are recorded by numerous types of historical data, especially in SST. The globes below show SST for the western Pacific (near Asia) and eastern Pacific (near the Americas) for each phase of ENSO—neutral, warm, and cold. The colors represent whether SST are warmer than normal (red and orange), colder than normal (blue), or about average (light).

Neutral Phase of ENSO

17.09.b1-2

During the *neutral phase* of ENSO, SST along the equator in the Pacific are about average, with no obvious warmer or colder than normal waters near the Western Pacific Warm Pool (left globe) or South America (right globe). An area of warmer than normal SST occurs southwest of North America, but this is not obviously related to ENSO.

Warm Phase of ENSO (El Niño)

17.09.b3-4

During the *warm phase* of ENSO, a belt of much warmer than normal water appears along the equator in the eastern Pacific, west of South America. This warm water is the signature of an El Niño, causing the decrease in cold-water fishes. SST in the western Pacific are a little cooler than average, but an El Niño is most strongly expressed in the eastern Pacific (right globe).

Cold Phase of ENSO (La Niña)

17.09.b5-6

During the *cold phase* of ENSO (a La Niña), a belt of colder than normal water occurs along the equator west of South America, hence the name "cold phase." The western Pacific (left globe), however, now has waters that are warmer than normal. These warm waters are quite widespread in this region, extending from Japan to Australia.

Before You Leave This Page

✓ Sketch and explain atmosphere-ocean conditions for each of the three typical phases of ENSO, noting typical vertical and horizontal air circulation, sea-surface temperatures, relative position of the thermocline, and locations of areas of excess rain and drought.

✓ Summarize how each of the three phases of ENSO (neutral, warm, and cold) are expressed in SST of the equatorial Pacific Ocean.

17.9

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

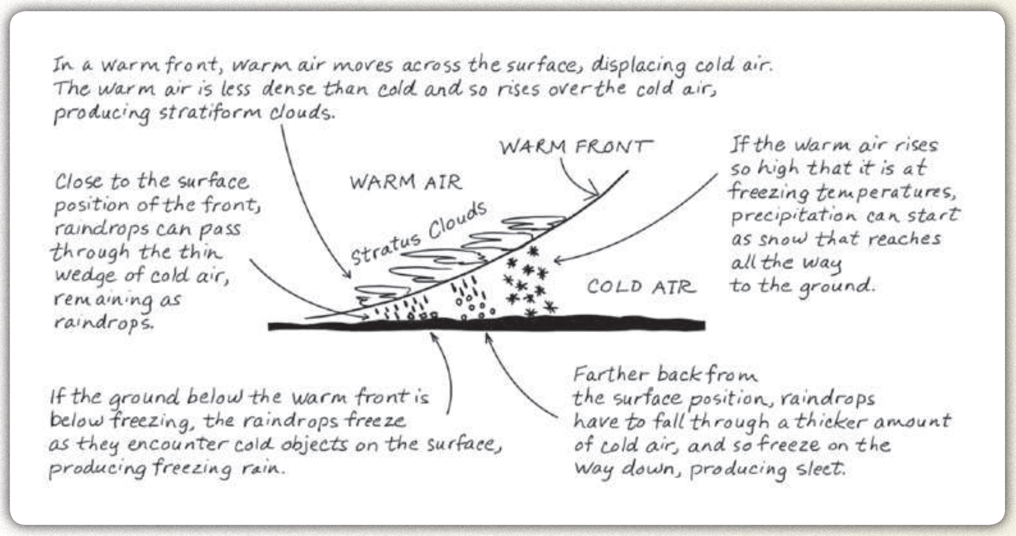
- Information is presented in relatively small and coherent chunks that allow a student to focus on one important aspect or earth system at a time.
- Students know when they are done with this particular topic and can self-assess their understanding with the *Before You Leave This Page* list.
- Two-page spreads allow busy students to read or study a complete topic in a short interval of study time, such as the 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 most of 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. Two-page spreads provide the instructor with unparalleled flexibility in deciding what to assign and what not to cover. It allows this book to be easily used for one-semester and two-semester courses.

This textbook, which is purposely designed to allow students to learn on their own, in combination with the components of McGraw-Hill's online learning system (*Connect, SmartBook*, *LearnSmart*), allows an instructor to offload much student learning to out-of-class times. An instructor can rely on the book to teach students content that the instructor does not wish to cover in class, opening up class time for teaching the most important aspects or those with local relevance, for modelling scientific reasoning, or for having students solve earth-science problems. The book and online materials easily provide the necessary components to allow an instructor to use a flipped-class approach, to teach a hybrid class, or for a fully online course. We do all of these.

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 features, describe how the features form, characterize the main processes, and summarize histories (Johnson and Reynolds, 2005). An example of a concept sketch is shown to the right.



Concept sketches are an excellent way to actively engage students in class and to assess their understanding of earth science features, processes, and history. Concept sketches are well suited to the visual nature of earth science, especially cross sections, maps, and block diagrams. Earth scientists 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 tectonic processes, the subsurface geometry of rock units, the evolution of landscapes, circulation in the atmosphere and oceans, and motions of astronomical objects. Our research data show that a student who can draw, label, and explain a concept sketch generally has a good understanding of that concept. In our classes, exams are two concept sketches out of a list of 10 to 12 possible questions provided to students ahead of time.

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HOW IS THIS BOOK ORGANIZED?

Two-page spreads are organized into 20 chapters that are arranged into five major parts: (1) introduction to earth systems, earth materials, and geologic time; (2) tectonic processes and features; (3) landscapes; (4) the atmosphere and oceans; and (5) the solar system and universe. The first chapter provides an overview of earth science, how we represent location and geologic features, the scientific approach, and an introduction to *earth systems*—a unifying theme interwoven throughout the rest of the book. Chapter 2 introduces minerals and mineral resources, providing an example of our approach in this book of presenting information about mineral, energy, and water resources in the chapter that is most pertinent to each topic. Chapter 3 follows with an introduction to earth materials and to the processes that form the main families of rocks. Part one of the book ends with Chapter 4, which presents the important concepts about determining sequences of events, ages of rocks, and other aspects of geologic time.

The second part of the book covers various aspects of tectonics. Chapter 5 begins with having students observe large-scale features on land and the seafloor, as well as patterns of earthquakes and volcanoes, as a lead-in to tectonic plates. Integrated into the chapter are two-page spreads on continental drift, paleomagnetism, continental and oceanic hot spots, and evolution of the modern oceans and continents. This is followed by Chapter 6, which explores volcanism, volcanoes, and other igneous processes and features. Chapter 7 begins with general principles of deformation and geologic structures, emphasizing how these are expressed in landscapes. The second half of Chapter 7 takes these principles of deformation and applies them to earthquakes, including their causes, settings, and resulting damage. Chapter 8, the final chapter in the second part of the book, explores explanations for mountains and other regions of high elevations, the formation of continents, and features along continental margins. It also explores the origin of local mountains and basins, a topic unique to this textbook, and provides an introduction to oil and natural gas, including shale gas and oil.

The third part of the book focuses on the broad field of geomorphology—the form and evolution of landscapes. It begins with Chapter 9, a visually oriented introduction to processes that sculpt landscapes and redistribute earth materials. This chapter presents a brief introduction to weathering, erosion, and transport. Wind erosion, transport, deposition, and resulting landforms are integrated into Chapter 9, rather than being a separate, sparse-content chapter that forcibly brings in non-wind topics, as is done in other textbooks. This chapter also illustrates the formation of arches, natural bridges, karst topography, and caves, all of which are topics of interest to many students.

The remaining chapters in the third part of the book cover different aspects of geomorphology. Chapter 10 treats the formation, description, and classification of soils, followed by a figure-based presentation of mass wasting and slope stability. Chapter 11 integrates information about glaciers, coasts, and changing sea level, to highlight the interactions among different earth systems. It introduces glacial movement, landforms, and deposits, along with the causes of glaciation. This chapter then moves to coastal processes, landforms, and hazards, and it ends with the consequences of changing sea level on landforms and humans, emphasizing the role of glaciers in raising and lowering sea level. Chapter 12, the final chapter in this third part, is about various topics involving water, including the hydrologic cycle, water use, streams, stream processes, different types of streams, and flooding. The second half of the chapter explores the relationship between surface water and groundwater, including the important topics of contamination and overpumping of groundwater.

The fourth part of the book is about the atmosphere and oceans. It begins with Chapter 13, an introduction to energy, matter, and the atmosphere, providing a solid background for later chapters. Chapter 14 follows this up with coverage about the processes and manifestations of atmospheric motion. It features separate two-page spreads on circulation in the tropics, high latitudes, and mid-latitudes, allowing students to concentrate on one part of the system at a time, leading to a synthesis of lower-level and upper-level winds. Chapter 14 also covers air pressure, the Coriolis effect, and seasonal and regional winds. These topics lead naturally into Chapter 15, which is an introduction to atmospheric moisture, including clouds and various forms of precipitation. Within the chapter are globes and other maps presenting global, regional, and seasonal patterns of humidity and precipitation. Chapter 16 follows this with a visual, map-oriented discussion of weather and storms, including cyclones, tornadoes, and other severe weather. The next chapter (Chapter 17) is devoted to the oceans and their interactions with the atmosphere and cryosphere. It features sections on ocean currents, sea-surface temperatures, ocean salinity, and a thorough treatment of ENSO. The chapters in this part build into Chapter 18, which presents various aspects of climate, including the controls on climate and climate classification. Chapter 18 features a two-page spread on each of the main climate groups, illustrated with a rich blend of globes, process-oriented figures, climographs, and photographs. These spreads are built around the globes, each of which portray a few related climate types, enabling students to concentrate on the distribution and controls of each climate type. The climate chapter also has a data-oriented presentation on the important topic of climate change, especially the data for climate change, the controlling factors, and predicted consequences. It ends with a two-page spread on alternative (non–fossil fuel) energy sources.

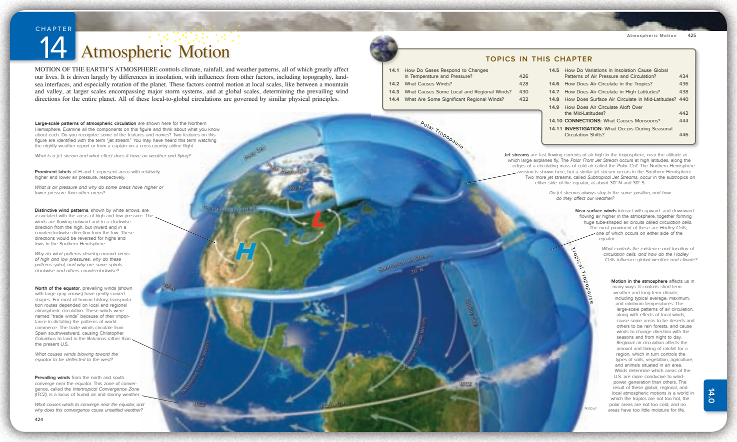
The fifth and final group of chapters focuses on the solar system and the rest of the universe. Chapter 19 presents a highly visual introduction to various objects in the solar system and how we study and investigate them. It is followed by Chapter 20, the final chapter in the book, which explores the rest of the universe. It begins with a treatment of how we observe the universe and our framework for referencing these observations. It introduces forces, motions, and light, presenting the laws of motion of Newton and Kepler. The chapter successively explores stars, stellar evolution, stellar remnants, and galaxies, ending with a discussion of cosmology and the early history of the universe.

TWO-PAGE SPREADS

Most of the book consists of *two-page spreads*, each of which is about one or more closely related topics. Each chapter has four main types of two-page spreads: opening, topical, connections, and investigation.

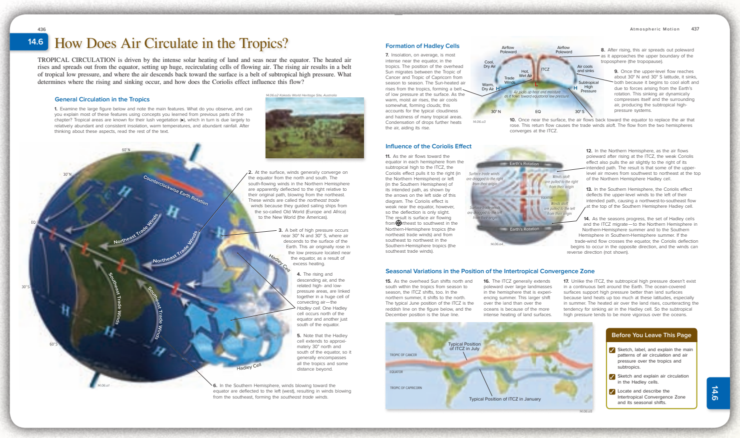
Opening Two-Page Spread

Opening spreads introduce the chapter, engaging the student by highlighting some interesting and relevant aspects and posing questions to activate prior knowledge and curiosity.



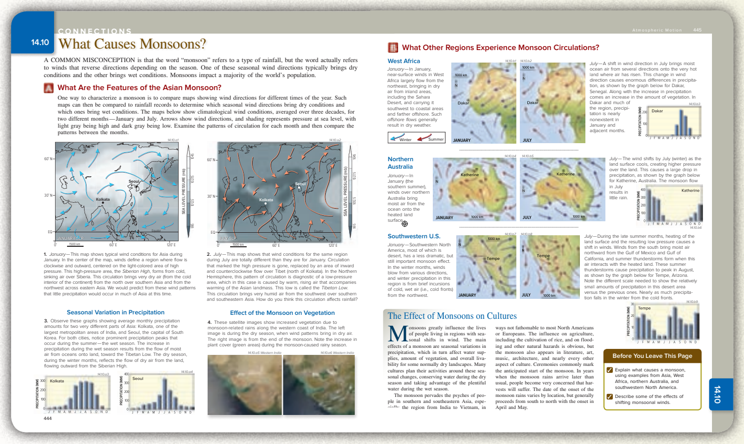
Topical Two-Page Spread

Topical spreads comprise most of the book. They convey the content, help organize knowledge, describe and illustrate processes, and provide a spatial context. The first topical spread in a chapter usually includes some aspects that are familiar to most students, as a bridge or scaffold into the rest of the chapter. Most chapters have at least one two-page spread illustrating how earth science processes impact society and commonly another two-page spread that specifically describes how earth scientists study typical problems.



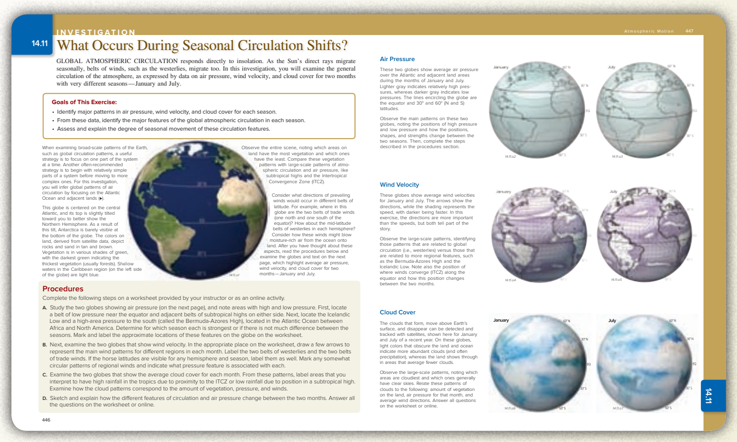
Connections Two-Page Spread

The next-to-last two-page spread in each chapter is a *Connections spread* 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 concepts and features covered in the chapter, often explicitly illustrating how we investigate an earth science problem and how these problems have relevance to society.



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 relevant questions. Some involve actual global data. Investigations are modeled after the types of problems geoscientists 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 part of a laboratory exercise, as worksheet-based homework, or as online activities.



NEW IN THE SECOND EDITION

The second edition of *Exploring Geology* represents a significant revision, with every chapter receiving additions and improvements, including 188 new photographs. Some changes will be obvious, while others are more subtle but nevertheless substantial. The style, approach, and sequence of chapters is unchanged, but every chapter received new photographs, many 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 one chapter gained two two-page spreads and another had two spreads completely revised. Many sections of two-page spreads were revised in content and layout, such as by the addition of a photograph not in the previous edition. Nearly all changes were made in response to comments by reviewers and students. The most important revisions are listed below:

- This edition features completely different fonts from the previous edition. The new fonts were chosen partly to improve the readability on portable electronic devices, while retaining fidelity to a quality printed book. This font replacement resulted in countless small changes in the layout of individual text blocks on every two-page spread. In addition to replacing all of the fonts within the text, all figure labels were replaced with the new font, a process that required opening, editing, and commonly resizing every illustration that had text, as in the axes of graphs. In addition, all labels were incorporated into the actual artwork, rather than overlaying them on the artwork using the page-layout program, as was done for many figures in the previous edition. This involved adding labels to hundreds of illustrations, but it has the benefit of having every label as an integral part of its associated art file, a useful feature for constructing PowerPoint files.
- This edition contains 188 new photographs, with a deliberate intention to represent a wider geographic diversity and to provide more detail and clarity about various processes and features, whether on land, in the atmosphere, and in the water. Most of these new photographs represent upgrades of existing photographs from the previous edition, but a number are new photographs in the layout. Also, for this edition, we individually reprocessed nearly all photographs that were derived from scanned slides, using technology and techniques that were not available when the original scanned versions were generated and processed. This reprocessing involved opening up the original high-resolution scans or digital photograph and using modern image-processing software to correct brightness, contrast, and color balance, and to remove visual noise. The resulting improvements will be noticeable for many images in the printed book, but they are more conspicuous in the digital e-book and especially in the high-resolution images we provide instructors for use in classrooms.
- This edition contains many new and replaced figures and even more that were lightly revised, such as replacing fonts. Figures from the first edition were replaced with new versions to update information so that it is more recent, to improve student understanding of certain complex topics, and for improved appearance. All fonts were replaced in every figure that has text.
- This edition contains two new two-page spreads on sedimentary environments and a new section on impact craters. We also thoroughly revised the coverage of climate change, more prominently featuring recent climate change at the start of the discussion. This is followed by a new section that discusses the types of climate proxies, using a more geologic, photograph-based approach in place of the previous collection of small graphs of proxies. In the next spread, which covers factors that could cause climate change, the role of CO_2 was moved up front to again start the discussion focussed on factors involved in recent climate change, followed by those that affect climate on geologic time scales.
- Many 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 data. For example, we updated information on Pluto, comets, satellite temperatures, sea-level rise, and many other relatively minor data points.
- Throughout the book, we added numbers to most text boxes to guide students to read the text boxes in a specific order. We also renumbered many figure numbers so that they are in the same order as the newly numbered text boxes. For all chapter-ending Investigations, we replaced numbers with letters in the Procedures lists to avoid confusion with newly numbered text boxes.
- Every box with the learning objectives was changed from "Before You Leave This Page Be Able To" to simply "Before You Leave This Page." This is more concise, and opened up room on nearly every two-page spread.

CHAPTER 1 received a moderate revision, mostly involving nine new photographs (five replacing existing ones) and the reprocessing of most other photographs. The investigation received four additional photographs to depict important features students need to consider in their deliberations. The chapter also has one revised illustration that now incorporates an actual photograph of Pluto.

CHAPTER 2 received a light revision, with eight new photographs, mostly of rocks and mineral resources. Some other photographs were processed from the original scans. Fonts were replaced throughout, resulting in many small changes in wording and layout, as occurred in every chapter.

CHAPTER 3 was heavily revised, featuring 36 new photographs and two new two-page spreads that present an early, visual overview of sedimentary environments on land, near shorelines, and in the ocean. Two new page-spanning illustrations and 14 additional photos accompany this new material. Two of the new photographs are from the Franciscan of California, and are accompanied by a new, brief introduction to melange. Other new photographs are mostly from Florida, Texas, and New Mexico.

CHAPTER 4 contains nine new photographs of rocks, fossils, and environments. It has a new section on impact craters accompanied by three new illustrations. It also now incorporates a new photograph and modified discussion of concretions. Several sections received significant edits.

CHAPTER 5 on plate tectonics is mostly unchanged, but every illustration with text was edited to replace the fonts. Several maps were revised, including the one showing North American transform faults.

CHAPTER 6 has 14 new or replaced photographs representing more diverse locations, including Joshua Tree National Park. It has a new photograph of the Valles Caldera and a number of reprocessed ones. Two photographs of Augustine pyroclastic eruptions were reprocessed and recropped to better convey the vertical extent of the eruptions. In addition to font changes, the chapter has two rebuilt illustrations.

CHAPTER 7 includes eight new photographs of structures and landscape features, including ones in a heavily revised section showing features related to erosion of tilted layers. There is also a new short section on erosion of fault scarps, accompanied by a new photograph. Several illustrations were moderately revised, mostly ones showing seismic waves.

CHAPTER 8 contains eight new photographs illustrating the landscape appearance of different types of rocks. Several sections were reordered and heavily edited around the new photographs. A map of sedimentary basins was revised to better display the geographic features in the area covered by each basin.

CHAPTER 9 on sculpting landscapes was heavily revised, with 24 new photographs of weathered limestone, caves, karst topography, and problem soils. The new photographs are mostly from Florida, Texas, and Carlsbad Caverns National Park. The new photographs of Carlsbad illustrate the size of the cavern better than most textbook images we have seen. The section on trading location for time was vastly improved through changes in layout and a new photograph from Monument Valley that perfectly illustrates the concept.

CHAPTER 10 contains 10 new photographs of soils and slopes, including new photographs specifically retaken of the Slumgullion Landslide and a new computer-generated 3D-perspective showing the 2017 Big Sur landslide.

CHAPTER 11 has 25 new photographs, mostly of coastal regions of Florida and glacial features of the western U.S. and Alaska. The chapter was renamed using coasts instead of shorelines, and text and headings were changed throughout to reflect this change.

CHAPTER 12 on streams, flooding, and groundwater now features 15 new photographs of streams and stream-related features. There are newly inserted photographs of cutbanks, point bars, and entrenched meanders, accompanied by changes in layout and text editing to accomodate the new images. One photograph of a spring was deleted. All the graphs and maps were revised for new fonts and other improvements, such as arrow colors depicting groundwater flow.

CHAPTER 13 is the first of the atmosphere chapters, and received only minor revisions. It contains five new photographs. Each illustration, including each of the many graphs, was edited for the change in fonts and incorporation of labels in the art files.

CHAPTER 14 was for the most part lightly revised, except for font changes in all the illustrations. There are three new versions of figures showing upper-level polar circulation and two new versions of global wind patterns and the Coriolis effect. There is one new photograph, and the investigation has a new layout.

CHAPTER 15 has a number of new versions of illustrations and one new photograph. Globes showing humidity were rebuilt and rerendered, with a clearer legend. There are new versions of figures showing Rossby waves, clouds, freezing rain, and sleet. Global amounts of precipitation are now shown with three globes rather than one flat map. As for all the globes in the book, the authors provide a media file for every globe shown.

CHAPTER 16 had minor revisions on most two-page spreads, but major revisions on some. Major revisions included sections about lightning and upper-level lightning phenomena, where in both cases text was separated from the figures to improve readability and for use in presentation software. The Investigation was heavily revised to include data and discussion of upper-level airflow patterns. The chapter has three new photographs.

CHAPTER 17 features, in additon to all the font changes, several newly redone illustrations, such as on global wind directions and the Southern Oscillation. We revised the labels, layout, and order of globes showing ocean currents. There are two new photographs.

CHAPTER 18 displays major revisions to figures and some two-page spreads. All the climate globes, of which there are many, were rebuilt using new 3D files and rerendered. Likewise, all figures with part of a globe were redrawn using the new renders. We updated a number of figures to show the most current data, such as on sea-level rise, extent of Arctic sea ice, global temperatures, and CO_2. We redid the first two spreads on climate change, aiming to consolidate the discussion of recent climate change at the start of the discussion, followed by climate change over geologic timescales. Graphs of proxies were replaced with photographs to provide a more geologic approach and to better convey the diversity of types of climate proxy data. The role of CO_2 was moved up in the discussion of the possible causes of climate change, with the intent of again leading with recent climate change and then moving to long-term climate changes. A graph of sunspot data was replaced with a photograph.

CHAPTER 19 had moderate revisions, with the addition of four new images depicting more recent images of Pluto, nebulae, and a comet. We added or refined the discussions of Pluto, Ceres, comets, the age of the solar system, and the number of moons of Jupiter, each reflecting current information.

CHAPTER 20 on the Universe had very minor revisions, but fonts on the many text-rich illustrations were replaced, which often involved repositioning and changing layout of the text. Some figures received minor additional revisions.

FRONT AND BACK MATTER, including the *Preface*, *Glossary*, and *Index,* were revised and updated to reflect the revised table of contents and changes in page numbers due to reorganizations.

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Writing a totally new type of introductory earth science textbook would not be possible without the suggestions and encouragement we received from instructors who reviewed various incarnations of text and artwork in this book. We are especially grateful to people who contributed entire days either reviewing our books or attending symposia to openly discuss the vision, challenges, and refinements of this kind of new approach. We also appreciate the support of hundreds of instructors who have reported great success with using our books in their classrooms, validating our unusual approach and encouraging us to extend our original vision into various fields of earth science.

This book is a decidedly collaborative effort, incorporating material from our two other textbooks. Our colleagues Chuck Carter, Mike Kelly, and Paul Morin contributed materials to our *Exploring Geology* textbook, and some of this content is included here. Likewise, we have greatly benefitted from our collaboration with geographers Bob Rohli, Peter Waylen, and Mark Francek on our *Exploring Physical Geography* textbook, which provided the starting materials for chapters on the atmosphere and oceans. We gratefully acknowledge the words, figures, organization suggestions, and friendship provided by these colleagues.

This book contains over 2,500 figures, several times more than a typical introductory earth science textbook. This massive art program required great effort and artistic abilities from the illustrators and artists who turned our vision and sketches into what truly are pieces of art. We are especially appreciative of Cindy Shaw, who was lead illustrator, art director, and a steady hand that helped guide the project. For many figures, she extracted data from NOAA and NASA websites and then converted the data into exquisite maps and other illustrations. Cindy also fine-tuned or extensively reworked the authors' layouts, standardized various aspects of the illustrations, and prepared the final figures for printing. This second edition was especially onerous for Cindy, because the two main fonts were replaced throughout the book and in every figure label. Cindy also moved labels from the page-layout program into the art files, partly so that the labels are present in PowerPoint images. Chuck Carter produced many spectacular pieces of art, including virtual places featured in the chapter-ending Investigations. Susie Gillatt contributed many of her wonderful photographs from around the world, photographs that helped us tell the story in a visual way. She also color corrected and retouched most of the photographs in the book, including every image in this edition that was derived from a scanned color slide, and there were many. We also used visually unique artwork by Daniel Miller, David Fierstein, and Susie Gillatt. Suzanne Rohli performed magic with GIS files and helped in many other ways. We were ably assisted in data compilation and other tasks by students and former students Cheryl Replogle, Jenna Donatelli, Emma Harrison, Abeer Hamden, Peng Jia, Javier Vázquez, and Courtney Merjil. Terra Chroma, Inc., of Tucson, Arizona, supported many aspects in the development of this book, including funding parts of the extensive art program and maintaining the *ExploringEarthScience.com* website.

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Finally, a project like this is truly life consuming, especially when the authors do the writing, illustrating, photography, near-final page layout, media development, and development of assessments, teaching ancillaries, and the instructor's website. We are extremely appreciative of the support, patience, and friendship we received from family members, friends, colleagues, and students who shared our sacrifices and successes during the creation of this new vision of a textbook. Steve Reynolds thanks the ever-cheerful, supportive, and talented Susie Gillatt; John and Kay Reynolds; and our mostly helpful book-writing companions, Widget, Jasper, and Ziggy. Julia Johnson thanks Annabelle Louise and Hazel Johnson, and the rest of her family for enthusiastic support and encouragement. Steve and Julia appreciate the support of their wonderful colleagues at ASU and elsewhere.

The authors are grateful for the many students who have worked with us on projects, infused our classrooms with energy and enthusiasm, and provided excellent constructive feedback about what works and what doesn't work. We wrote this book to help instructors, including us, make students' time in our classes even more interesting, exciting, and informative. Thank you all!

REVIEWERS

Special thanks and appreciation go out to all reviewers of *Exploring Earth Science*, *Exploring Geology*, and *Exploring Physical Geography*. This book was improved by many beneficial suggestions, new ideas, and invaluable advice provided by the reviewers of these three books. We appreciate all the time they devoted to reviewing manuscript chapters, attending focus groups, surveying students, and promoting this text to their colleagues.

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Stephen J. Reynolds received an undergraduate geology degree from the University of Texas at El Paso, and M.S. and Ph.D. degrees in structure/tectonics and regional geology from the University of Arizona. He then spent ten years directing the geologic framework and mapping program of the Arizona Geological Survey, where he completed the 1988 *Geologic Map of Arizona*. Steve is a professor in the School of Earth and Space Exploration at Arizona State University, where he teaches Physical Geology, Structural Geology, Advanced Field Geology, Orogenic Systems, Cordilleran Regional Geology, Teaching Methods in the Geosciences, and others. He helped establish the ASU Center for Research on Education in Science, Mathematics, Engineering, and Technology (CRESMET), and was President of the Arizona Geological Society.

Steve has authored or edited over 200 geologic maps, articles, and reports, including the 866-page *Geologic Evolution of Arizona*. He also coauthored *Structural Geology of Rocks and Regions*, a structural geology textbook, and *Observing and Interpreting Geology*, a laboratory manual for physical geology. Working with a team of geographers, he authored *Exploring Physical Geography*, which follows the style and approach of his award-winning *Exploring Geology* textbook.

His current geologic research focuses on structure, tectonics, stratigraphic correlations, landscape evolution, and mineral deposits of the Southwest. For several decades, he has conducted science-education research on student learning in college geoscience courses, especially the role of visualization. He was the first geologist with his own eye-tracking laboratory, where he and his students demonstrated that students learn more when using the unique design, layout, and approach of this textbook, compared to how much (or little) they learn from a traditional textbook.

Steve is known for innovative, award-winning teaching methods, and has a widely used website. He was a National Association of Geoscience Teachers (NAGT) distinguished speaker, and he often travels across the country presenting talks and workshops on visualization and on how to infuse active learning and inquiry into large introductory geoscience classes. He is commonly an invited speaker to national workshops and symposia on active learning, visualization, and teaching methods in college geoscience courses. He has been a long-time industry consultant in mineral, energy, and water resources, and has received outstanding alumni awards from UTEP and the University of Arizona.

JULIA K. JOHNSON

Julia K. Johnson is a full-time faculty member in the School of Earth and Space Exploration at Arizona State University. She received an undergraduate degree from Ricks College in eastern Idaho and undergraduate and graduate degrees from Arizona State University. Her graduate research involved structural geology and geoscience education research.

She teaches introductory geoscience to more than 2,000 students per year, both online and in person. She also supervises the associated in-person and online labs, and is the lead author of both the online and in-person versions of *Observing and Interpreting Geology, a Laboratory Manual for Physical Geology*, an innovative laboratory manual in which all learning is built around a virtual world (Painted Canyon). She helps coordinate the introductory geoscience teaching efforts of the School of Earth and Space Exploration (SESE), guiding other instructors as they incorporate active learning, inquiry, and online materials into large lecture classes. She is responsible for the design and deployment of online resources for SESE's introductory physical geology courses, including the lecture and lab components.

Julia coordinated an innovative project focused on redesigning introductory geology classes so that they incorporated more online content and asynchronous learning. This project was very successful in improving student performance, mostly due to the widespread implementation of concept sketches and partly due to Julia's approach of decoupling multiple-choice questions and concept-sketch questions during exams and other assessments. As a result of these successful and innovative efforts, Julia was asked to be a Redesign Scholar for the National Center for Academic Transformation.

Julia is recognized as one of the best science teachers at ASU, and has received student-nominated teaching awards and very high teaching evaluations in spite of her challenging classes. Her efforts have helped dramatically increase enrollments in introductory geoscience courses and the number of majors. She coauthored the widely used *Exploring Geology* and *Exploring Physical Geography* textbooks. Julia has authored publications on geology and science-education research, including a widely cited article in the *Journal of Geoscience Education* on concept sketches. She also developed a number of websites used by students around the world, including the *Visualizing Topography* and *Biosphere 3D* websites. She leads many geologic field trips for schools and professional groups in the Phoenix region.

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Robert Rohli, coauthor of *Exploring Physical Geography* and *Louisiana Weather and Climate*, received a B.A. in geography from the University of New Orleans, an M.S. degree in atmospheric sciences from The Ohio State University, and a Ph.D. in geography from Louisiana State University (LSU). He is a professor of geography at LSU and also faculty director of the LSU Residential Colleges Program. His teaching and research interests are in synoptic and applied meteorology/climatology, atmospheric circulation variability, and hydroclimatology. Major themes in his teaching include the systems approach to earth systems, collaboration among students from different disciplines, and development of applied problem-solving skills. He has been an active supporter of undergraduate education initiatives, including the Louisiana Geographic Education Alliance. He has authored more than 60 research articles, encyclopedia articles, and proceedings papers, mostly on topics related to synoptic or applied climatology.

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Peter Waylen, coauthor of *Exploring Physical Geography*, is professor of geography at the University of Florida, where he served as chair for seven years. He holds a B.Sc. in geography from the London School of Economics, England, and a Ph.D. from McMaster University, Canada. He was also assistant professor at the University of Saskatchewan. Peter's teaching and research interests are in the fields of hydrology and climatology, particularly the temporal and spatial variability of risks of such hazards as floods, droughts, freezes, and heat waves, and the way in which these vary in the long run, driven by global-scale phenomena like ENSO. He teaches Introductory Physical Geography, Principles of Geographic Hydrology, and Models in Hydrology, and was selected University of Florida Teacher of the Year in 2002. His research is principally interdisciplinary and collaborative with colleagues and students. His research results appear in over 100 refereed articles and book chapters on geography, hydrology, and climatology.

MARK A. FRANCEK

Mark Francek, coauthor of *Exploring Physical Geography*, is a geography professor at Central Michigan University (CMU). He earned his doctorate in geography from the University of Wisconsin-Milwaukee, his master's from the University of South Carolina, and his bachelor's degree from the State University College at Geneseo, New York. He has teaching and research interests in earth science education, physical geography, and soil science. He has authored and coauthored more than 30 scholarly papers, and has presented his research at numerous conferences. At CMU, Mark served as director of the Environmental Studies Program and director of the Science and Technology Residential College. He has received numerous teaching awards, including the Carnegie Foundation for the Advancement of Teaching Michigan Professor of the Year and the Presidents Council of State Universities of Michigan Distinguished Professor of the Year. His "Earth Science Sites of the Week" Listserv highlights the best earth science websites.

CYNTHIA SHAW

Cindy Shaw, lead illustrator and art director for this book, holds a B.A. in zoology from the University of Hawaii–Manoa as well as a master's in education from Washington State University, where she researched the use of guided illustration as a teaching and learning tool in the science classroom. Now focusing on earth science, mapping, and coral reef ecology, she writes and illustrates for textbooks and museums, and develops ancillary educational materials through her business, Aurelia Press. Her kids' novel, *Grouper Moon*, is used in many U.S. and Caribbean science classrooms, and is making an impact on shaping childrens' attitudes toward fisheries conservation. Currently landlocked in Richland, Washington, Cindy escapes whenever possible to travel, hike, and dive the reefs to field-sketch and do reference photography for her projects. She is also lead illustrator and art director for recent editions of *Exploring Geology* and *Exploring Physical Geography*. In this role, Cindy generates new illustrations, often researching the necessary data for those illustrations, standardizes illustrations contributed by other artists, finalizes page layout, and prepares files for electronic delivery of all materials to the compositors.

PAUL J. MORIN

Paul Morin, coauthor of *Exploring Geology*, is director of the Polar Geospatial Center at the University of Minnesota, which supports National Science Foundation scientific and research operations through remote sensing and other geospatial data. Paul co-founded the GeoWall Consortium, which promoted the use of visualization and stereo projection in the classroom. Over the past five years, Paul has been instrumental in bringing earth science visualization to science museums around the world.

SUSANNE GILLATT

Susie Gillatt received a bachelor of arts degree from the University of Arizona and is president of Terra Chroma, Inc., a multimedia studio. She focuses on scientific illustration and photo preparation for academic books and journals. Many photographs in this book were contributed by Susie from her travels to experience different landscapes, ecosystems, and cultures around the world. Her award-winning art, which combines photographs of nature with digital painting, has been displayed in galleries in Arizona, Colorado, and Texas.

CHUCK CARTER

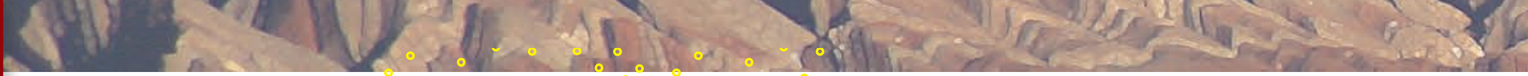
Chuck Carter has worked in the science and entertainment industries for three decades. He developed the innovative video game, *Myst*, and more than two dozen other video games in a variety of art, animation, and management roles, including computer graphics supervisor and art director. His illustrations and animations have appeared in *National Geographic*, *Scientific American*, *Wired*, the BBC, NASA, and Disney's *Mission to Mars*. Chuck is president of Eagre Games, designing fully immersive adventures, including *ZED*.

DANIEL MILLER

Daniel Miller is a self-taught artist, beginning his career as a silversmith, then goldsmith, painter and sculptor, designer, and art director. Attaining his goal of working in the film industry, he created notable sculptural elements for many major films, including *Stargate* and *Chronicles of Riddick*. He was a concept artist and matte painter for films and video games. He completed large-scale sculptural installments, including *Fountains of the Gods* at Caesars Palace in Las Vegas, where he lives and pursues his passion for oil painting.

exploring

Earth  Science

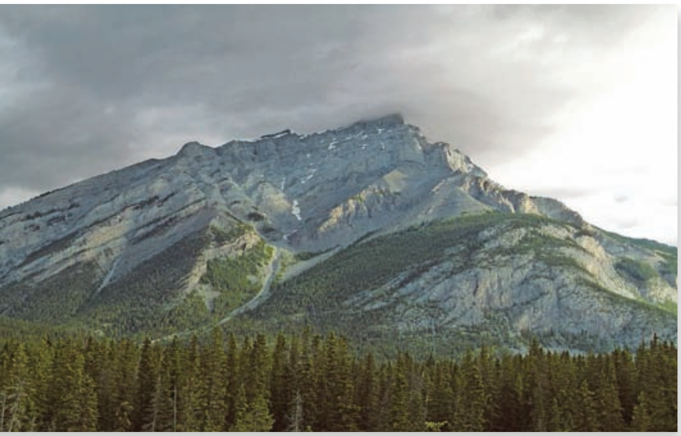


CHAPTER 1

The Nature of Earth Science

EARTH SCIENCE FOCUSES ON THE FOUR COMPONENTS of the earth system—land, water, air, and life—and their interactions. Processes within the solid earth cause volcanoes and earthquakes, form mountains, and rearrange continents. Most of Earth's surface is covered by oceans, but water also forms ecologically important lakes, rivers, and wetlands. Above the surface, the atmosphere contains gases essential to life, as well as clouds, precipitation, wind, and storms. Living things depend upon and interact with the land, water, atmosphere, and energy from space. Together, the various components of our planet control the climate and overall suitability for life, the distribution of natural resources, and the susceptibility for floods, landslides, and other natural disasters. Earth science is the study of the solid earth, oceans, atmosphere, life, and our setting in space.

North America and Central America have a wealth of interesting features. The large image below (▼) is computer-generated and combines different types of data to show features on the land, in the oceans, and in the atmosphere. The shading and colors on land are from space-based satellite images, and whitish colors in the atmosphere are clouds of various types and heights. Can you find the region where you live or visit? What types of landscape features, water bodies, and clouds are there?

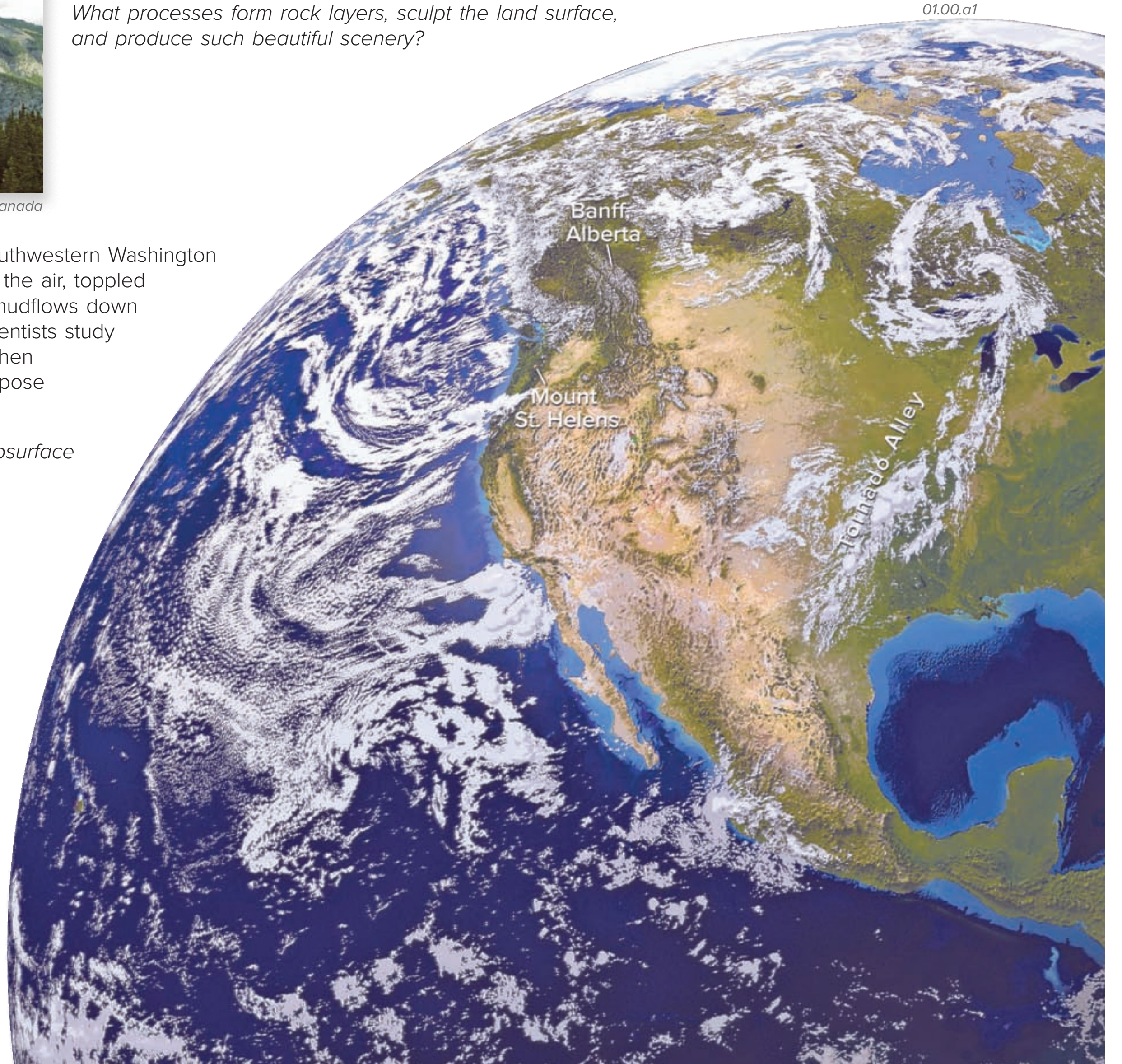


01.00.a2 Banff, Alberta, Canada

◄ **The dramatic scenery of Banff, Alberta**, in the Canadian Rockies, features spectacularly tilted and folded rock layers expressed in various shades of gray. Exposed to sunlight, moisture, plants, animals, and the downward pull of gravity, the rock layers begin to disintegrate, some forming precipitous cliffs and others wearing away into slopes covered by loose pieces. The mountains interact with the atmosphere, causing clouds, rain, and snow to be concentrated over the mountains, influencing the growth of trees and other plants, and affecting the lives of the various creatures, including mammals and birds.

What processes form rock layers, sculpt the land surface, and produce such beautiful scenery?

01.00.a1



The 1980 eruption of Mount St. Helens in southwestern Washington (▼) ejected huge amounts of volcanic ash into the air, toppled millions of trees, unleashed large floods and mudflows down nearby valleys, and killed 57 people. Earth scientists study volcanic phenomena to determine how and when volcanoes erupt and what hazards volcanoes pose to humans and other creatures.

How do studies of the Earth's surface and subsurface help us determine where it is safe to live?

01.00.a3 Mount St. Helens, WA

TOPICS IN THIS CHAPTER

Earth's atmosphere is dynamic, with constantly moving air masses and clouds that produce precipitation (rain, snow, and hail) and locally cause severe storms, like the ominous line of clouds shown below (▼). Heating from the Sun provides the energy for winds, as well as atmospheric moisture for clouds and storms, so Earth's setting in space influences important aspects of our planet, including climate and seasons. Severe weather, including tornadoes, is especially common in the center of the U.S. along a north-south region often called "Tornado Alley."

How do clouds and storms form, and how does the Sun influence winds?

01.00.a4 Tornado Alley, Central U.S.

The oceans, like the atmosphere, are dynamic, with waves and ocean currents that move water and energy from one region to another, and various manifestations of life, such as coral reefs (▼). The major influences on the oceans are the Sun, the rotation of Earth around its axis, and the configuration of the seafloor and continents.

How do the oceans interact with and influence the land, seafloor, atmosphere, and life?

01.00.a5 Cayman Islands

A View of North America

North America is a diverse continent, ranging from the low, tropical rain forests of Central America to the high Rocky Mountains of western Canada. In the large image of North America on the left, the colors on land are from satellite images that show the distribution of rock, soil, plants, and lakes. Green colors represent dense vegetation, including forests shown in darker green, and fields and grassy plains shown in lighter green. Brown colors represent deserts and other regions that have less vegetation, including regions where rock and sand are present. Lakes are shown with a solid blue color. Clouds for a single day are overlain on Earth's surface, but should be viewed as one snapshot of a continuously playing movie—the clouds will have moved by the next day. The image is computer generated from several data sets and is not an actual photograph.

The colors of the ocean reflect the depth to the underlying seafloor, but the actual shape of the seafloor is not shown. Light blue colors represent shallow areas, such as those flanking the continent, whereas dark blue represents places where the seafloor is deep. Observe the larger features on land, at sea, and in the atmosphere. Ask yourself the following questions: What is this feature? Why is it located here? How did it form? In short, what is its story?

Notice that the two sides of North America are very different from each other and from the middle of the continent. The western part of North America has many rugged mountains and deep valleys. The mountains in the eastern United States are more subdued, and the East Coast is surrounded by a broad shelf (shown in a light blue-gray) that continues out beneath the Atlantic Ocean. The center of the continent has no mountains but has broad plains, hills, river valleys, and large lakes. These variations in landscapes greatly affect weather and regional climates.

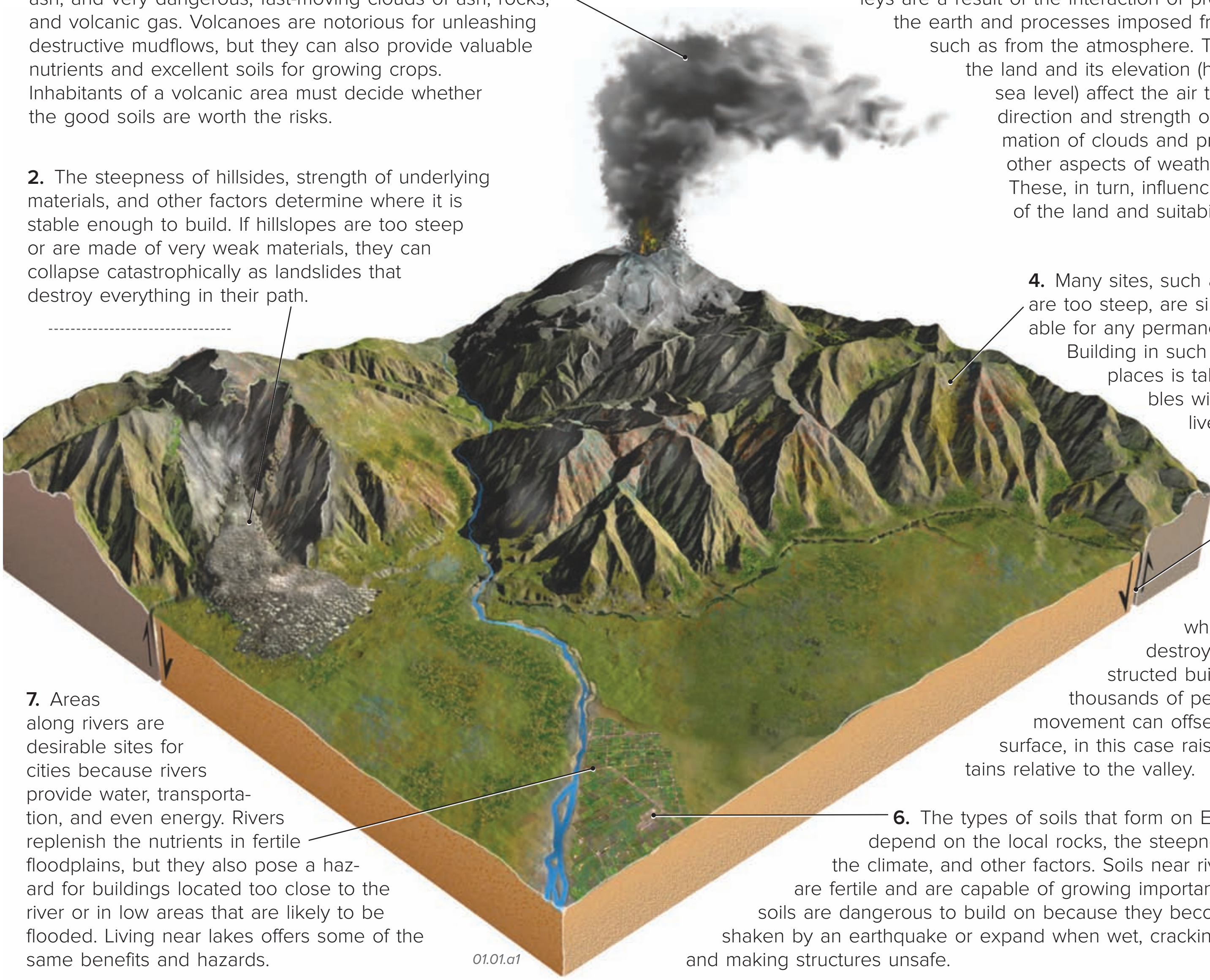
All of the features on this image of Earth are part of earth science. Earth science explains why the mountains on the two sides of the continent are so different and when and how the mountains formed. It explains processes that operate within the waters of the oceans. Earth science addresses climate, weather, water resources, and landscapes, and the impact of these aspects on life. The land, oceans, atmosphere, and life are greatly affected by the Sun, Moon, and certain other features in the universe, so earth science also involves many aspects of *astronomy*. Earth science especially deals with the interactions of these various components, focusing on the Earth as a series of systems, an approach often called *earth-system science*. As shown throughout this book, earth's systems affect many aspects of our society.

1.1 How Do Earth's Features and Processes Influence Where and How We Live?

EARTH PROCESSES INFLUENCE OUR LIVES IN MANY WAYS. A major influence is the shape and character of the land on which we live. This aspect of earth science is part of the discipline of *geology*, the study of the earth. Geologic features and processes constrain where people can live because they determine whether a site is safe from landslides, floods, or other natural hazards. Some areas are suitable building sites, but others are underlain by unstable earth materials that could cause damage to any structure built there. Geologic factors also control the distribution of energy and mineral resources and croplands. The land is imprinted by interactions with the Sun, weather, water, and life, and the entire system is investigated by many types of scientists, including geographers, climatologists, oceanographers, and ecologists. Collectively, we call such scientists *earth scientists* or *geoscientists*.

A Where Is It Safe to Live?

The landscape around us contains many clues about whether a place is relatively safe or whether it is a natural disaster waiting to happen. What important clues should guide our choice of a safe place to live?



1. Volcanoes erupt molten lava, columns of hot volcanic ash, and very dangerous, fast-moving clouds of ash, rocks, and volcanic gas. Volcanoes are notorious for unleashing destructive mudflows, but they can also provide valuable nutrients and excellent soils for growing crops. Inhabitants of a volcanic area must decide whether the good soils are worth the risks.

2. The steepness of hillsides, strength of underlying materials, and other factors determine where it is stable enough to build. If hillslopes are too steep or are made of very weak materials, they can collapse catastrophically as landslides that destroy everything in their path.

3. The location, height, and shape of mountains and valleys are a result of the interaction of processes within the earth and processes imposed from above, such as from the atmosphere. The shape of the land and its elevation (height above sea level) affect the air temperatures, direction and strength of winds, the formation of clouds and precipitation, and other aspects of weather and climate. These, in turn, influence the sculpting of the land and suitability for life.

4. Many sites, such as slopes that are too steep, are simply not suitable for any permanent buildings. Building in such extremely risky places is taking huge gambles with people's lives and property.

5. Slip along faults in Earth's crust causes earthquakes, which can destroy poorly constructed buildings and kill thousands of people. Such movement can offset the land surface, in this case raising the mountains relative to the valley.

6. The types of soils that form on Earth's surface depend on the local rocks, the steepness of slope, the climate, and other factors. Soils near rivers commonly are fertile and are capable of growing important crops. Other soils are dangerous to build on because they become weak when shaken by an earthquake or expand when wet, cracking foundations and making structures unsafe.

7. Areas along rivers are desirable sites for cities because rivers provide water, transportation, and even energy. Rivers replenish the nutrients in fertile floodplains, but they also pose a hazard for buildings located too close to the river or in low areas that are likely to be flooded. Living near lakes offers some of the same benefits and hazards.

01.01.a1

B How Do Earth Processes Influence Our Lives?

To explore how earth features and processes affect our lives, observe this photograph, which shows a number of different features, including clouds, snowy mountains, slopes, and a grassy field with horses and cows (the small, dark spots). For each feature you recognize, think about what is there and what processes might be occurring. Then, think about how these features and processes influence the life of the animals and how they would influence your life if this was your home. Think broadly, considering aspects of the land, atmosphere, and any expressions of water or life. Think about this before reading on.

In the distance are snow-covered mountains partially covered with clouds. Snow and clouds both indicate the presence of water, an essential ingredient for life. The mountains have a major influence on water in this scene. As the snow melts, water flows downhill toward the lowlands, to the horses and cows.

The horses and cows roam on a flat, grassy pasture, avoiding slopes that are steep or barren of vegetation. The steepness of slopes reflects the strength of the rocks and soils, and the flat pasture resulted from loose sand and other materials that were laid down during flooding along a desert stream. Where is the likely source of the water needed to grow grass in the pasture?

01.01.b1 Henry Mtns., UT

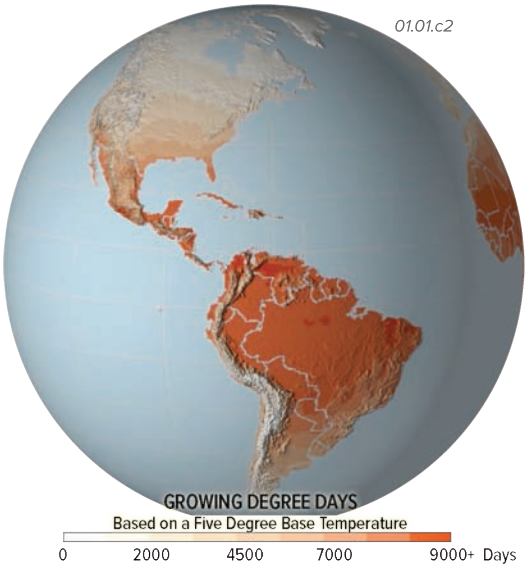
C What Factors Control Where We Can Grow Food?

The suitability of an area for growing crops and raising livestock depends on many factors, especially the overall climate, which incorporates the temperatures, amount and timing of precipitation, and various seasonal effects, such as number of days without freezing temperatures. The climate, steepness of slopes, type of earth materials, types of plants and animals, and other factors in turn control the type and thickness of soil.

The two globes below show important controls on agriculture and ranching. The left globe represents the average amount of precipitation, with darker purple indicating higher amounts of precipitation. The right globe depicts the length of the growing season and how warm it is, using a calculated number called the growing degree days, with darker orange representing conditions with longer, warmer days (generally more favorable for growing plants). What are the conditions where you live, and can you explain some of the patterns?

01.01.c1

01.01.c2



Before You Leave This Page

- ✓ Sketch or list some ways that earth processes control where it is safe to live and the landscape around us.
- ✓ Explain some factors that influence where we can grow food.

1.1

1.2 How Does Earth Science Explain Our World?

THE WORLD HAS INTERESTING FEATURES at all scales. Views from space show oceans, continents, mountain belts, and clouds. Traveling through the countryside, we notice smaller things — a beautiful rock formation or soft, green hills. Upon closer inspection, the rocks may include fossils that provide evidence of ancient life and past climates. Here, we give examples of how earth science explains big and small features of our world.

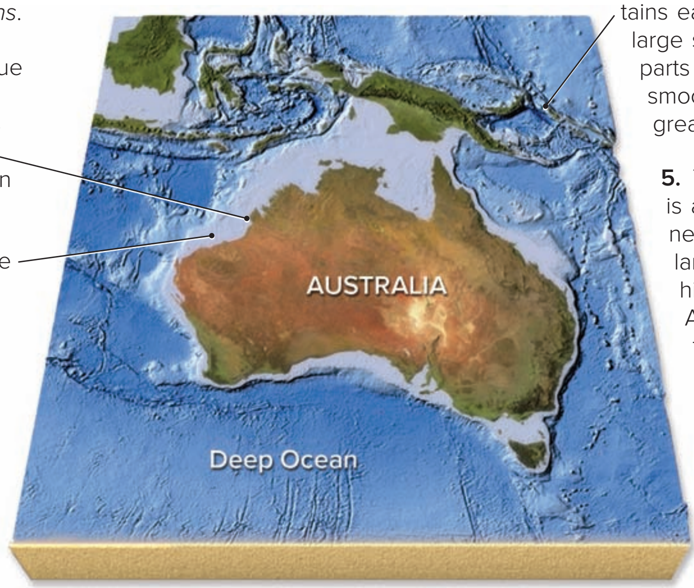
A How Do Continents Differ from Ocean Basins?

Examine the figure below, which is a computer-generated view of the continent of Australia and the surrounding ocean basins. Colors on land show vegetation, rocks, soil, and sand, whereas colors in the oceans indicate depth, with darker blue being the deepest seafloor. Note the main features, especially those on the seafloor.

1. This map illustrates one of the most important distinctions on Earth — our planet is divided into *continents* and *oceans*.

2. The boundary between the blue colors of the oceans and the greens and browns of the land is the coastline, which outlines the familiar shape of Australia as seen on world maps.

3. Surrounding the land is a fringe of seafloor that is not very deep, represented on this map by light blue colors. This fringe of shallow seafloor, called the *continental shelf*, is wider on the north side of the continent than on the other three sides. Earth scientists consider the continent to continue past the coastline and to the outer edge of the continental shelf.



01.02.a1

4. The seafloor beneath deep parts of the ocean is locally complex, containing chains of submarine mountains east of Australia and long features that look like large scratch marks south of the continent. The deep parts of the seafloor are much rougher than the smooth-appearing continental shelf. Seafloor depths greatly influence ocean temperatures and currents.

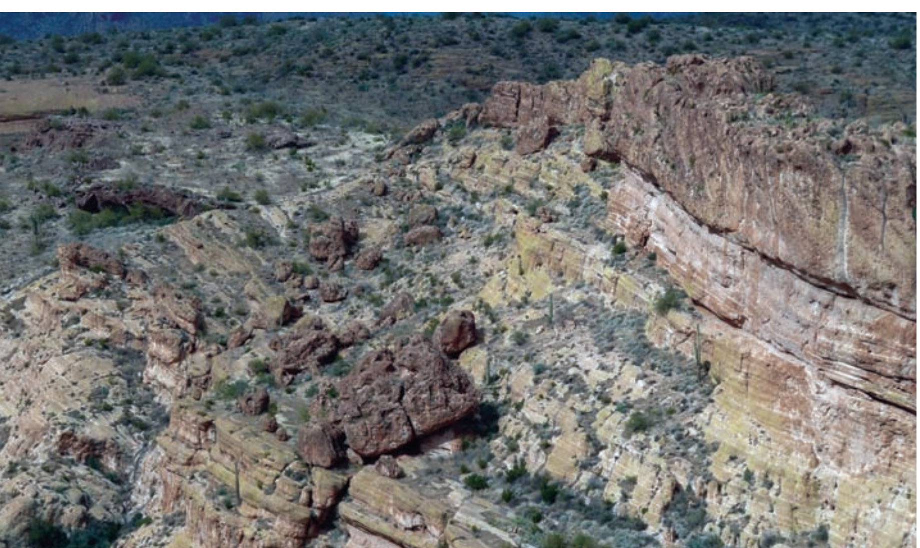
5. The distinction between continents and oceans is a reflection of differences in the types and thicknesses of the rocks and in how each formed. The land varies in elevation and character, such as higher, vegetation-covered mountains in eastern Australia than in the rest of the continent. Within the oceans are major variations in the depth and character of the seafloor from place to place. There is a large variation in the temperature of the ocean in this region, with very warm seawater temperatures to the north and very cold seawater to the south. The landscape, oceans, and other factors affect the weather, climate, abundance and movement of water, and the overall conditions for life.

B What Stories Do Landscapes Tell?

Observe this photograph of a canyon wall. After you have done this, think of at least two questions about what you notice, before you read the text. Go ahead, try it!

1. The landscape has cliffs and slopes composed of rock units that are shades of tan, brown, and yellow. There are not many plants.

2. In the bottom half of the image, some large, angular blocks of brownish rock are perched near the edge of a lower cliff.



3. Several questions about the landscape come to mind. What types of rocks are exposed here? How did the large, brownish blocks get to their present position? How long will it take for the blocks to fall or slide off the lower cliff? Why are there few plants?

4. The answer to each question helps explain part of the scene. The first and last questions are about the *present*, the second is about the *past*, and the third is about the *future*. The easiest questions to answer are usually about the present, and the hardest ones are about the past or the future.

5. All of the rocks in this view are volcanic rocks, typical of those formed during a very explosive type of volcanic eruption. There are few plants because this region is relatively dry and hot (a desert).

6. The large blocks are composed of the same material as the upper brown cliff and were part of that cliff before falling or sliding downhill.

7. It is difficult to predict when the blocks will fall off the lower cliff. Some blocks near the edge could fall in the next rainstorm, but others will probably be there for hundreds of thousands of years.

01.02.b1 Superstition Mtns., AZ

C How Has the Global Climate Changed Since the Ice Age?

These computer-generated images show where glaciers and large ice sheets were during the last ice age and where they are today. Note how the extent of these features changed in this relatively short period of time. What caused this change, and what might happen in the future because of global warming or cooling?

28,000 Years Ago

Twenty-eight thousand years ago, Earth's climate was slightly cooler than it is today. Cool climates permitted continental ice sheets to extend across most of Canada and into the upper Midwest of the United States. Ice sheets also covered parts of northern Asia and Europe.

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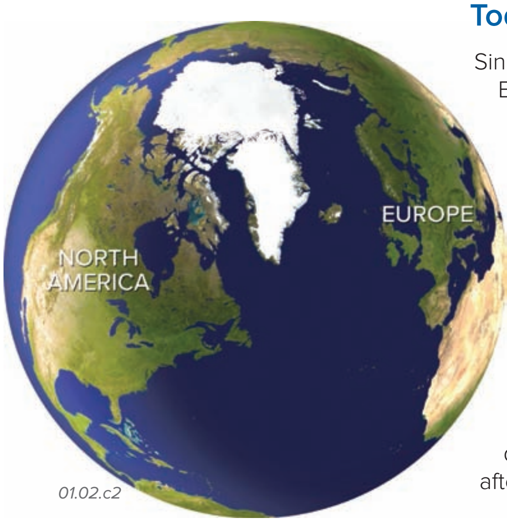


01.02.c2

Today

Since 20,000 years ago, Earth's climate warmed enough to melt back the ice sheets to where they are today. Our knowledge of the past extent of ice sheets comes from earth scientists who examine the landscape for appropriate clues, including glacial features and deposits that remained after the glaciers retreated.

D What Is the Evidence That Life in the Past Was Different from Life Today?

Museums and action movies contain scenes, like the one below, of dinosaurs lumbering or scampering across a land covered by exotic plants. Where does the evidence for these strange creatures come from?

▶ This mural, painted by artist Karen Carr, is two stories tall and shows what types of life are interpreted to have been on Earth during the Jurassic Period, approximately 160 million years ago. Dinosaurs roamed the landscape, while the ancestors of birds began to take flight. Flowering plants were not yet abundant and grasses had not yet appeared, so non-flowering trees, bushes, and ground cover dominated the landscape.

01.02.d1

01.02.d2 Dinosaur NP, UT

◀ Fossil bones of Jurassic dinosaurs are common in Dinosaur National Park, Utah. From such bones and other information, we can infer how long ago these creatures roamed the planet, what the creatures looked like, how big they were, how they lived, and why they died. Studying the rock layers that enclose the bones provides clues to the local and global environments at the time of the dinosaurs. Rocks and fossils are the record of past geologic events, environments, and prehistoric creatures.

Before You Leave This Page

- ✓ Explain the difference in appearance between continents and oceans.
- ✓ Describe some things we can learn about Earth's past by observing its landscapes, rocks, and fossils.

1.3 What Forces and Processes Affect Our Planet?

EARTH IS SUBJECT TO VARIOUS FORCES. Some forces arise within Earth, and others come from the Sun and Moon. Especially important is gravity, the mutual attraction that any two objects exert on one another. The interactions between these forces and Earth's land, water, air, and inhabitants control most natural processes and influence our lives in many ways.

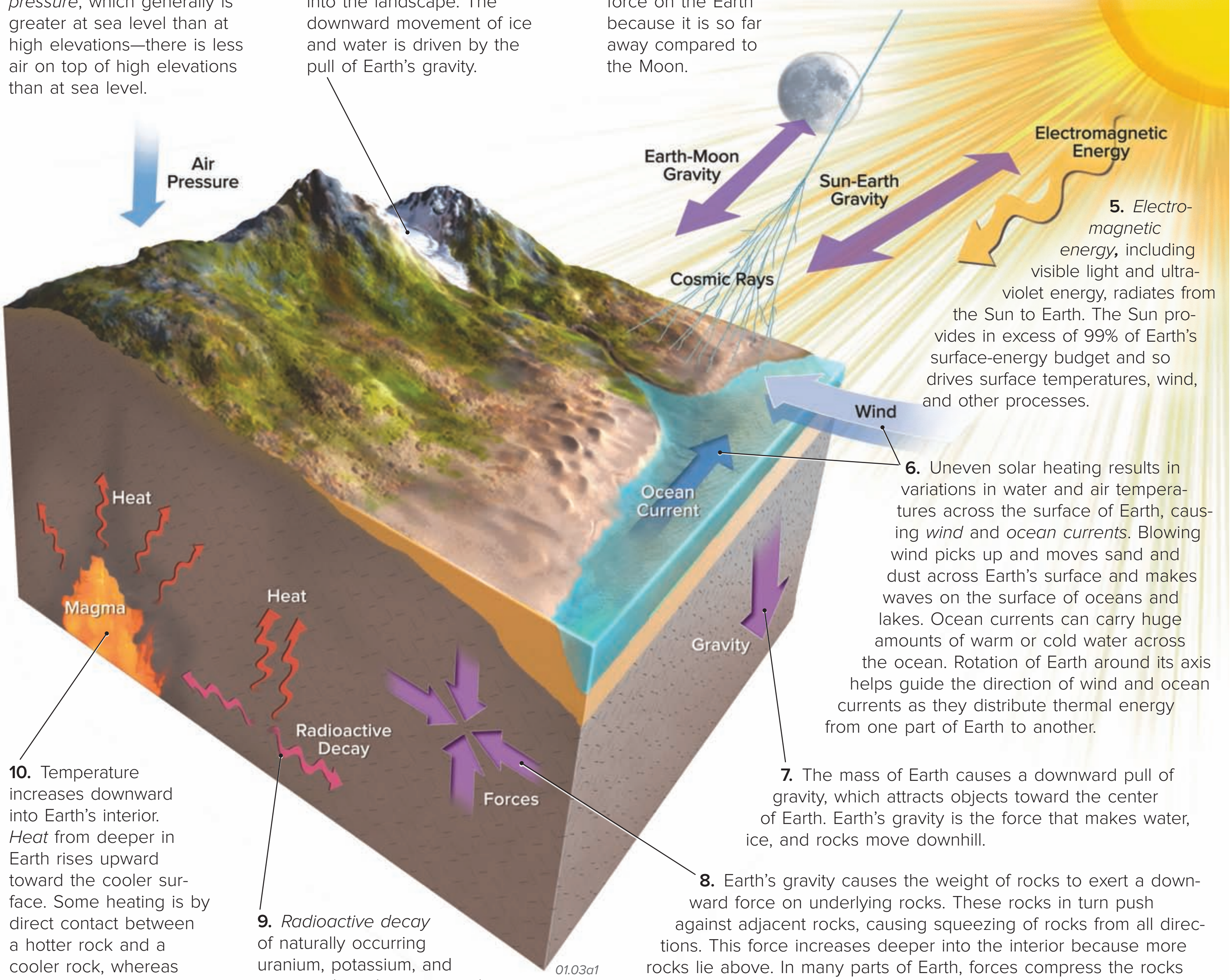
A How Do Forces and Processes Affect Earth?

1. Earth's *gravity* causes air in the atmosphere to press down on Earth's surface and on its inhabitants. The weight of this air causes *atmospheric pressure*, which generally is greater at sea level than at high elevations—there is less air on top of high elevations than at sea level.

2. *Water*, in either liquid or frozen forms, moves downhill in streams and glaciers, transporting rocks and other debris and carving downward into the landscape. The downward movement of ice and water is driven by the pull of Earth's gravity.

3. The Sun and Moon exert a *gravitational pull* on Earth. Although the Sun is much larger, it exerts less force on the Earth because it is so far away compared to the Moon.

4. *Cosmic rays*, high-energy radiation mostly originating deep into the universe, strike the Earth's atmosphere and surface. Cosmic rays pose danger to electronics and people outside the atmosphere and also influence some processes in the atmosphere.



5. *Electromagnetic energy,* including visible light and ultraviolet energy, radiates from the Sun to Earth. The Sun provides in excess of 99% of Earth's surface-energy budget and so drives surface temperatures, wind, and other processes.

6. Uneven solar heating results in variations in water and air temperatures across the surface of Earth, causing *wind* and *ocean currents*. Blowing wind picks up and moves sand and dust across Earth's surface and makes waves on the surface of oceans and lakes. Ocean currents can carry huge amounts of warm or cold water across the ocean. Rotation of Earth around its axis helps guide the direction of wind and ocean currents as they distribute thermal energy from one part of Earth to another.

7. The mass of Earth causes a downward pull of gravity, which attracts objects toward the center of Earth. Earth's gravity is the force that makes water, ice, and rocks move downhill.

8. Earth's gravity causes the weight of rocks to exert a downward force on underlying rocks. These rocks in turn push against adjacent rocks, causing squeezing of rocks from all directions. This force increases deeper into the interior because more rocks lie above. In many parts of Earth, forces compress the rocks equally from all directions, but additional forces arise by other processes deep within Earth, such as from the subsurface movement of rocks and magma. Forces generated in one area can be transferred to an adjacent area, causing sideways pushing, pulling, or shearing on the rocks.

9. *Radioactive decay* of naturally occurring uranium, potassium, and certain other elements produces heat, especially in the crust where these radioactive elements are concentrated.

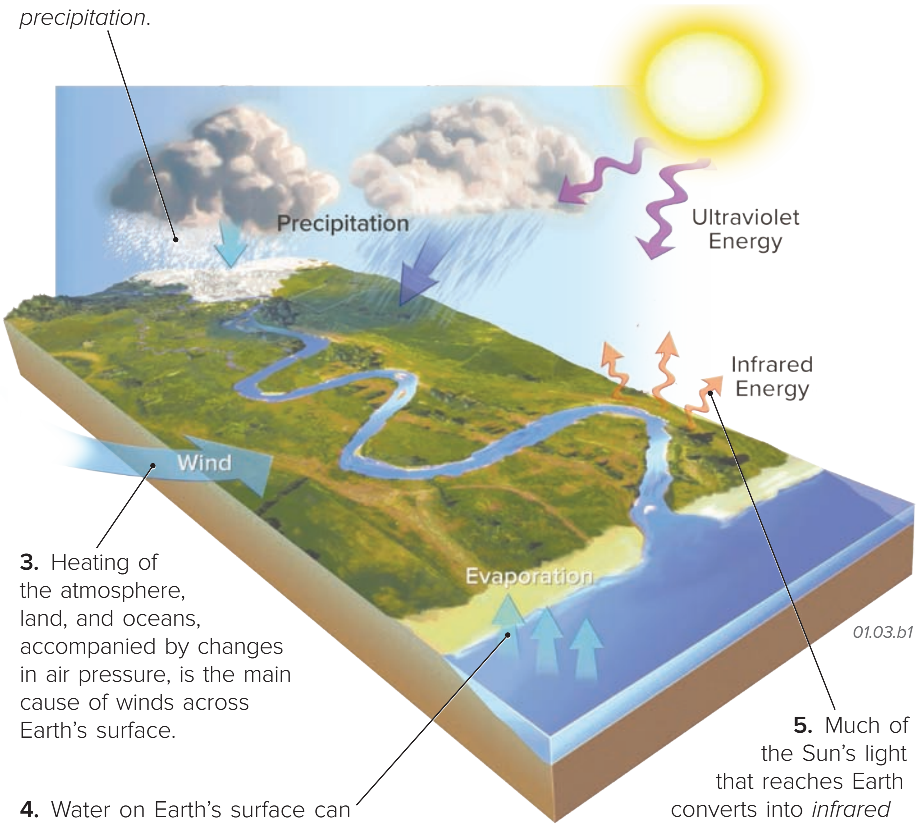
10. Temperature increases downward into Earth's interior. *Heat* from deeper in Earth rises upward toward the cooler surface. Some heating is by direct contact between a hotter rock and a cooler rock, whereas other transfer of heat occurs via a moving material, especially rising molten rock (magma).

B How Do Earth's Surface and Atmosphere Interact with Solar Energy?

Critical interactions occur between radiative energy from the Sun (insolation) and Earth's atmosphere, oceans, and land. These interactions express themselves in wind, clouds, rain, snow, and the climate of an area. Our atmosphere shields Earth from cosmic radiation, transfers water from one place to another, and permits life to exist. Like the oceans, the atmosphere is constantly moving, producing winds, clouds, and storms that impact Earth's surface.

1. The atmosphere is mostly gaseous nitrogen and oxygen, but it includes a low, but important, percentage of water vapor, most of which *evaporated* from Earth's oceans. Under certain conditions, the water vapor condenses to produce clouds, which are made of tiny water droplets or ice crystals. Rain, snow, and hail may fall from clouds back to the surface as *precipitation*.

2. The Sun produces vast amounts of energy, including *ultraviolet radiation* and visible light. In the upper levels of the atmosphere, oxygen absorbs most of the Sun's harmful ultraviolet radiation and prevents it from reaching Earth's surface, where it would have a detrimental effect on many forms of life. Most of the Sun's energy, including light and other forms of radiation, passes through the atmosphere, eventually reaching Earth, warming the planet and providing light for plants and animals.



3. Heating of the atmosphere, land, and oceans, accompanied by changes in air pressure, is the main cause of winds across Earth's surface.

4. Water on Earth's surface can *evaporate*, becoming water vapor in the atmosphere. Most *water vapor* comes from evaporation in the oceans, but some also comes from evaporation of lakes, rivers, irrigated fields, and other sites of surface water. Some comes from evaporation of water drops in clouds. Plants take moisture from soils, surface waters, or air, and release water vapor into the atmosphere through the process of *evapotranspiration*.

5. Much of the Sun's light that reaches Earth converts into *infrared energy*, a form of energy related to heat. Some of this energy radiates upward and is trapped by the atmosphere, which warms in a process called the *greenhouse effect*. This process regulates global temperatures, which are moderate enough to allow water to exist as liquid water, gaseous water vapor, and solid ice. Water is a key requirement for life.

Energy and Forces

Earth's energy supply originates from internal and external sources. *Internal energy* comes from within Earth and includes heat energy trapped when the planet formed and heat that is produced by radioactive decay. This heat drives many internally generated processes, including mountain building and the melting of rocks at depth to produce magma and volcanoes.

The most significant source of *external energy* is the Sun, which bathes Earth in light, thermal energy, and other electromagnetic energy. Thermal energy and light from the Sun are more intense in equatorial areas of Earth than in polar areas, causing temperature differences in the atmosphere, oceans, and on land. The resulting temperature differences help drive wind and ocean currents. Sunlight is also the primary energy source for plants, through the process of *photosynthesis*.

Early in Earth's history, meteoroids and other objects left over from the formation of the solar system bombarded the planet. During the impacts, *kinetic energy* (energy due to movement of an object) changed into thermal energy, adding a tremendous amount of heat, some of which remains stored in Earth's hot interior.

Internal forces also affect Earth. All objects that have mass exert a gravitational attraction on other masses. If a mass is large and close, the pull of gravity is relatively strong. Earth's gravity acts to pull objects toward the center of the planet. Gravity is probably the most important agent on Earth for moving material from one place to another. It causes loose rocks, flowing glaciers, and running water to move downhill from higher elevations to lower ones, and it drives ocean currents and wind. Moving water, ice, air, and rocks can etch down into Earth's surface, shaping landscapes.

Objects on Earth also feel an *external* pull of gravity from the Sun and Moon. Gravity between the Sun and Earth maintains our planet's orbit around the Sun. The Moon's pull of gravity on Earth is stronger than that of the Sun and causes more observable effects, especially the rise and fall of ocean tides. Many earth scientists and astronomers conclude that long-term changes in Earth's orbit around the Sun and in the tilt of Earth's rotation axis result in large climatic changes, helping start and stop episodes of glaciation.

Before You Leave This Page

- ✓ Describe the different kinds of energy that impact Earth from the outside, and what effects they have on our planet.
- ✓ List the different kinds of energy that arise within Earth's interior and explain their origins.
- ✓ Sketch and explain how Earth's surface and atmosphere interact with solar energy.