

TARBUCK

LUTGENS

Illustrated by TASA

A photograph of a natural rock arch made of reddish-brown sandstone, partially covered in snow. The arch frames a view of a blue lake and distant mountains under a clear blue sky. The foreground is a snowy ledge.

Earth

An Introduction to Physical Geology

TWELFTH EDITION

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An Introduction to Physical Geology

EDWARD J. TARBUCK

FREDERICK K. LUTGENS

Illustrated by
DENNIS TASA

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To Our Grandchildren

Shannon, Amy, Andy, Ali, and Michael

Allison and Lauren

Each is a bright promise for the future.

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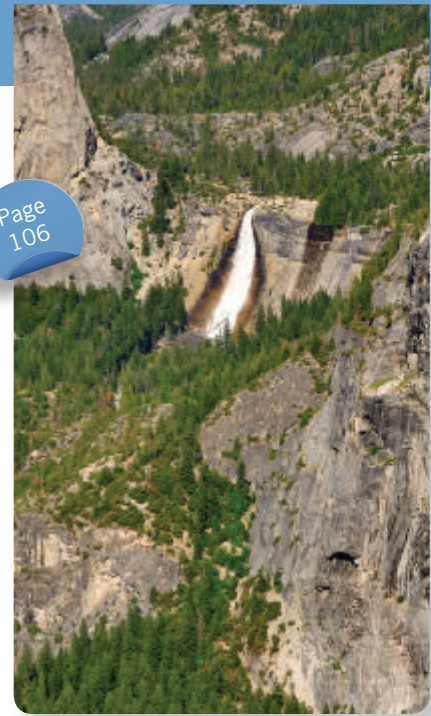
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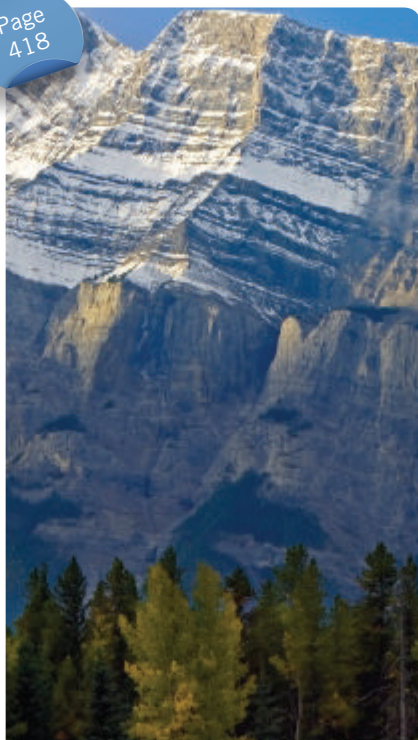
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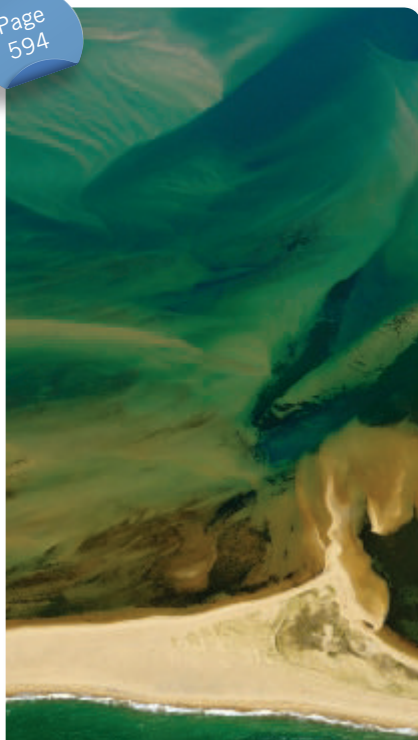
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Preface

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

This 12th edition of *Earth: An Introduction to Physical Geology*, like its predecessors, is a college-level text that is intended to be a meaningful, nontechnical survey for students taking their first course in geology. In addition to being informative and up-to-date, a major goal of *Earth* is to meet the need for a readable and user-friendly text, a book that is a highly usable tool for students learning the basic principles and concepts of geology.

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

New and Important Features

The 12th edition represents an extensive and thorough revision of *Earth* that integrates improved textbook resources with new online features to enhance the learning experience,

- **Significant updating and revision of content.** A basic function of a college science textbook is to present material in a clear, understandable way that is accurate, engaging, and up-to-date. In the long history of this textbook, our number-one goal has always been to keep *Earth* current, relevant, and highly readable for beginning students. To that end, every part of this text has been examined carefully. Many discussions, case studies, examples, and illustrations have been updated and revised.
- **SmartFigures that make *Earth* much more than a traditional textbook.** Through its many editions, an important strength of *Earth* has always been clear, logically organized, and well-illustrated explanations. Now, complementing and reinforcing this strength are a series of SmartFigures. Simply by scanning a SmartFigure with a mobile device and **Pearson's BouncePages Augmented Reality app** (FREE and available for iOS and Android),

students can link to hundreds of unique and innovative digital learning opportunities that will increase their insight and understanding of important ideas and concepts. We have also placed short URLs in the caption for every SmartFigure. This will ensure that students who may not have a smart phone, will have the ability to access these videos easily. SmartFigures are truly art that teaches! This 12th edition of *Earth* has more than 200 SmartFigures, of five different types:

1. **SmartFigure Tutorials.** Each of these 2- to 4-minute tutorials, prepared and narrated by Professor Callan Bentley, is a mini-lesson that examines and explains the concepts illustrated by the figure.
2. **SmartFigure Mobile Field Trips.** Scattered throughout this new edition are 24 video field trips that explore classic geologic sites from Iceland to Hawaii. On each trip you will accompany geologist-pilot-photographer Michael Collier in the air and on the ground to see and learn about landscapes that relate to discussions in the chapter.
3. **SmartFigure Condor Videos.** The 10 *Condor* videos take you to sites in the American West. By coupling aerial footage acquired by a quadcopter aircraft with ground-level views, effective narratives, and helpful animations, these videos will engage you in real-life case studies.
4. **SmartFigure Animations.** Scanning the many figures with this designation brings art to life. These animations and accompanying narrations illustrate and explain many difficult-to-visualize topics and ideas more effectively than static art alone.
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- **Enhanced Modular, learning objective-driven, active learning path.** *Earth* is designed for learning. Every chapter begins with *Focus on Concepts*. Each numbered learning objective corresponds to a major section in the chapter. The statements identify the knowledge and skills students should master by the end of the chapter and help students prioritize key concepts. Within the chapter, each major section concludes with *Concept Checks* that allow students to check their understanding and comprehension of important ideas and terms before moving on to the next section. Two end-of-chapter features complete the learning path. *Concepts in Review* coordinates with the *Focus on Concepts* at the start of the chapter

and with the numbered sections within the chapter. It is a concise overview of key ideas, with photos, diagrams, and questions that help students focus on important ideas and test their understanding of key concepts. Chapters conclude with *Give It Some Thought* questions that challenge learners by involving them in activities that require higher-order thinking skills, such as application, analysis, and synthesis of chapter material.

- **An unparalleled visual program.** In addition to more than 100 new, high-quality photos and satellite images, dozens of figures are new or have been redrawn by the gifted and highly respected geoscience illustrator Dennis Tasa. Maps and diagrams are frequently paired with photographs for greater effectiveness. Further, many new and revised figures have additional labels that narrate the process being illustrated and guide students as they examine the figures. *Earth's* visual program is clear and easy to understand.
- **MasteringGeology.** MasteringGeology delivers engaging, dynamic learning opportunities—focused on course objectives and responsive to each student's progress—that are proven to help students learn course material and understand difficult concepts. Assignable activities in MasteringGeology include SmartFigure (Tutorial, Condor, Animation, Mobile Field Trip, Video) activities, GigaPan activities, Encounter Earth activities using Google Earth, GeoTutor activities, Geoscience Animation activities, GEODE tutorials, and more. MasteringGeology also includes all instructor resources and a robust Study Area with resources for students.

The Teaching and Learning Package

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- **Before class:** Assign adaptive Dynamic Study Modules and reading assignments from the eText with Reading Quizzes to ensure that students come prepared to class, having done the reading.
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MasteringGeology Student Study Area also provides students with self-study materials like geoscience animations, *GEODE: Earth* activities, *In the News* RSS feeds, Self Study Quizzes, Web Links, Glossary, and Flashcards.

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

Instructor's Resource Materials (IRM)

The IRM puts all your lecture resources in one easy-to-reach place:

- All of the line art, tables, and photos from the text in .jpg files
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 - The IRM provides three PowerPoint files for each chapter. Cut down on your preparation time, no matter what your lecture needs, by taking advantage of these components of the PowerPoint files:
- **Exclusive art.** All of the photos, art, and tables from the text, in order, loaded into PowerPoint slides.
- **Lecture outlines.** This set averages 50 slides per chapter and includes customizable lecture outlines with supporting art.
- **Classroom Response System (CRS) questions.** Authored for use in conjunction with classroom response systems, these PowerPoints allow you to electronically poll your class for responses to questions, pop quizzes, attendance, and more.

Instructor Manual (Download Only)

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

TestGen Computerized Test Bank (Download Only)

TestGen is a computerized test generator that lets instructors view and edit Test Bank questions, transfer questions to tests, and print tests in a variety of customized formats. The Test Bank includes more than 2,000 multiple-choice, matching, and essay questions. Questions are correlated to Bloom's Taxonomy, each chapter's learning objectives, the Earth Science Learning Objectives, and the Pearson Science Global Outcomes to help

instructors better map the assessments against both broad and specific teaching and learning objectives. The Test Bank is also available in Microsoft Word and can be imported into Blackboard.

Blackboard

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

Acknowledgments

Writing a college textbook requires the talents and cooperation of many people. It is truly a team effort, and the authors are fortunate to be part of an extraordinary team at Pearson Education. In addition to being great people to work with, all of them are committed to producing the best textbooks possible. Special thanks to our geology editor, Andy Dunaway, who invested a great deal of time, energy, and effort in this project. We appreciate his enthusiasm, hard work, and quest for excellence. We also appreciate our conscientious project managers, Crissy Dudonis and Nicole Antonio, whose job it was to keep track of all that was going on—and a lot was going on. As always, our marketing managers, Neena Bali and Mary Salzman, who talk with faculty daily, provide us with helpful advice and many good ideas. The 12th edition of *Earth* was certainly improved by the talents of our developmental editor, Veronica Jurgena. Many thanks. It was the job of the production team, led by Heidi Allgair at Cenveo® Publisher Services, to turn our manuscript into a finished product. The team also included copyeditor Kitty Wilson, compositor Annamarie Boley, proofreader Heather Mann, and photo researcher Kristin Piljay. We think these talented people did great work. All are true professionals, with whom we are very fortunate to be associated.

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

- Working with Dennis Tasa, who is responsible for all of the text's outstanding illustrations and several of its animations, is always special for us. He has been part of our team for more than 30 years. We not only value his artistic talents, hard work, patience, and imagination but his friendship as well.
- As you read this text, you will see dozens of extraordinary photographs by Michael Collier. Most are aerial shots taken from his nearly 60-year-old Cessna 180. Michael was also responsible for preparing the 24 remarkable Mobile Field Trips that are scattered through the text. Among his many awards is the American Geological Institute Award for Outstanding Contribution to the Public Understanding of Geosciences. We think that Michael's photographs and field

trips are the next best thing to being there. We were very fortunate to have had Michael's assistance on *Earth*, 12th edition. Thanks, Michael.

- Callan Bentley has been an important addition to the *Earth* team. Callan is an assistant professor of geology at Northern Virginia Community College in Annandale, where he has been honored many times as an outstanding teacher. He is a frequent contributor to *EARTH* magazine and is author of the popular geology blog *Mountain Beltway*. Callan was responsible for preparing the SmartFigure Tutorials that appear throughout the text. As you take advantage of these outstanding learning aids, you will hear his voice explaining the ideas. We appreciate Callan's contributions to this new edition of *Earth*.

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

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

Ed Tarbuck
Fred Lutgens

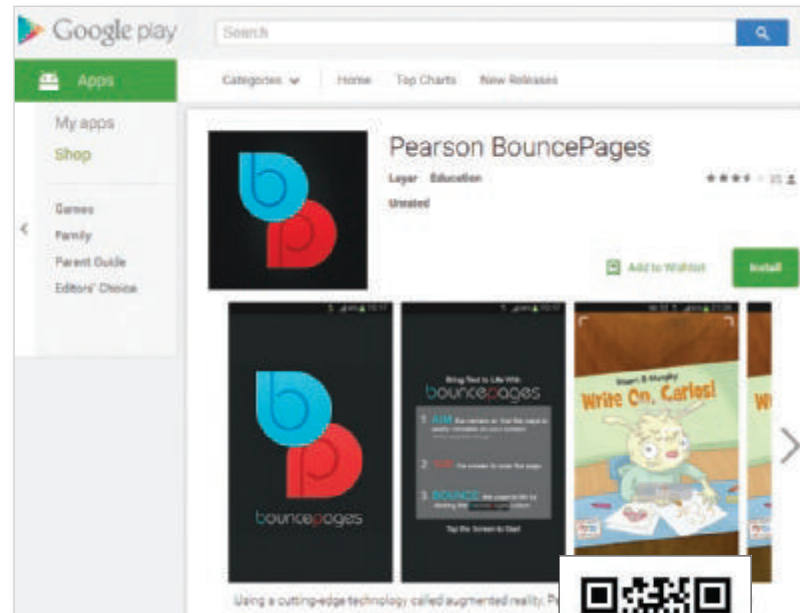
Augmented Reality Enhances the Reading Experience, Bringing the Textbook to Life



Using a cutting-edge technology called augmented reality, Pearson's BouncePages app launches engaging, interactive videos and animations that bring textbook pages to life. Use your mobile device to scan a SmartFigure identified by the BouncePages icon, and an animation or video illustrating the SmartFigure's concept launches immediately. No slow websites or hard-to-remember logins required.

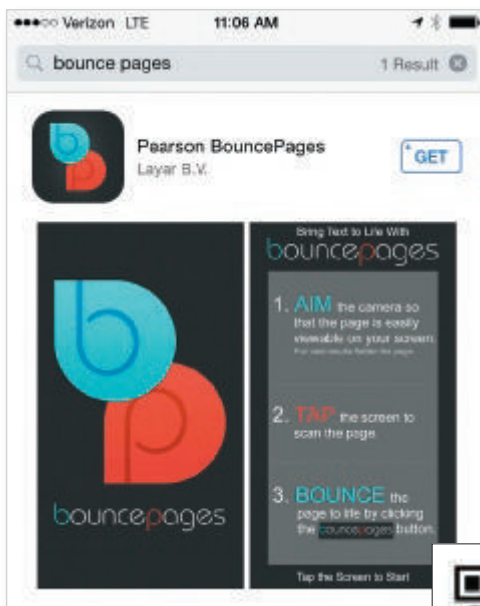
BouncePages' augmented reality technology transforms textbooks into convenient digital platforms, breathes life into your learning experience, and helps you grasp difficult academic concepts. Learning geology from a textbook will never be the same.

Download the FREE BP App for Android



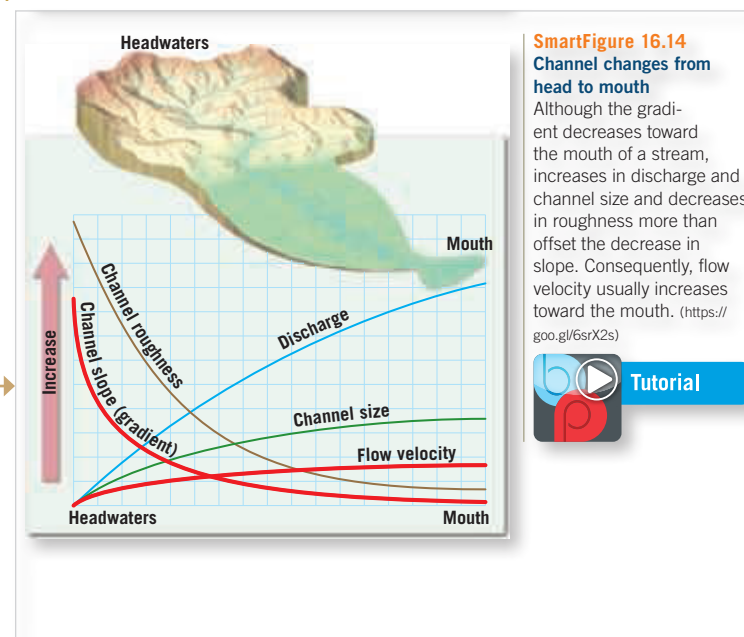
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By scanning figures associated with the BouncePages icon, students will be immediately connected to the digital world and will deepen their learning experience with the printed text.



Bring the Field to YOUR Teaching and Learning Experience



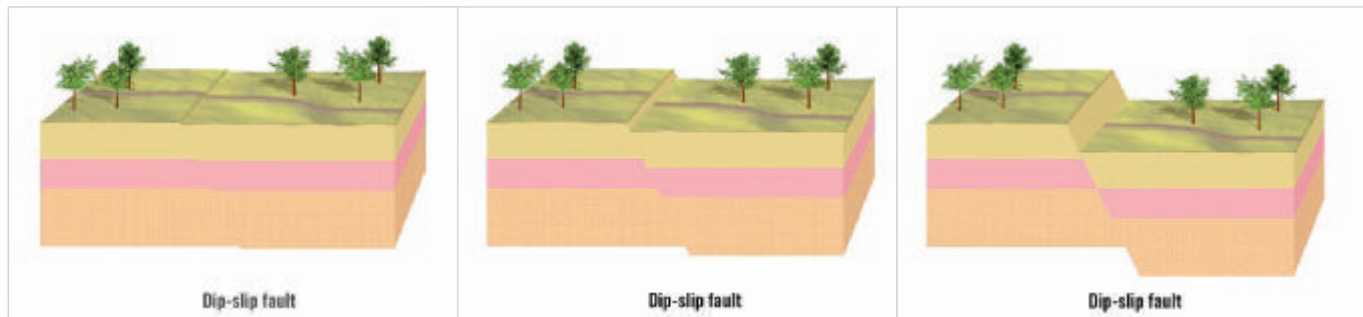
NEW! SmartFigure: Condor Videos. Bringing Physical Geology to life for GenEd students, three geologists, using a quadcopter with a GoPro camera mounted to it, have ventured out into the field to film 10 key geologic locations. These process-oriented videos, accessed through BouncePages technology, are designed to bring the field to the classroom or dorm room and enhance the learning experience in our texts.



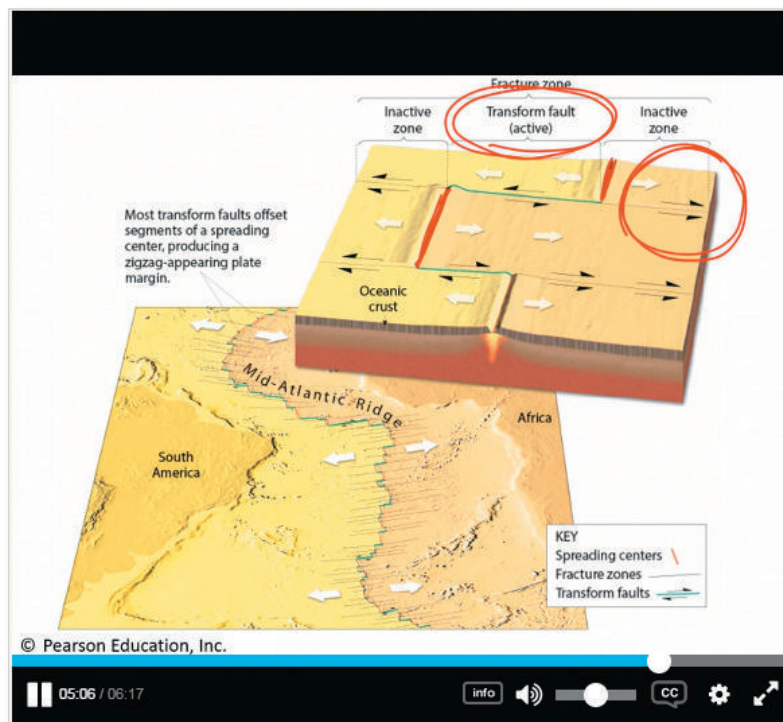
NEW! SmartFigure: Mobile Field Trips. Scattered throughout this new edition of Earth are **24 video field trips**. On each trip, you will accompany geologist-pilot-photographer Michael Collier in the air and on the ground to see and learn about iconic landscapes that relate to discussions in the chapter. These extraordinary field trips are accessed by using the BouncePages app to scan the figure in the chapter—usually one of Michael's outstanding photos.



Visualize Processes and Tough Topics



NEW! SmartFigure: Animations are brief videos, many created by text illustrator Dennis Tasa, that animate a process or concept depicted in the textbook's figures. This technology allows students to view moving figures rather than static art to depict how a geologic process actually changes through time. The videos can be accessed using Pearson's BouncePages app for use on mobile devices, and will also be available via MasteringGeology.



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



SmartFigure: Tutorials bring key chapter illustrations to life! Found throughout the book, these Tutorials are sophisticated, annotated illustrations that are also narrated videos. They are accessible on mobile devices via scannable BouncePages printed in the text and through the Study Area in MasteringGeology.



Improved Geospatial and Data Visualizations

GEO GRAPHICS 15.2 **Landslide Risks: United States and Worldwide**

According to the U. S. Geological Survey, each year in the United States, landslides cost nearly \$4 billion (2010 dollars) in damage repair and cause between 25 and 50 deaths. All states experience rapid mass-wasting processes, but not all areas have the same landslide potential. What's the risk where you live?

U.S. LANDSLIDE POTENTIAL

KEY

- VERY HIGH POTENTIAL
- HIGH POTENTIAL
- MODERATE POTENTIAL
- LOW POTENTIAL

- In parts of the Seattle area, volcanic mudflows called lahars are a potential threat.
- In the mountainous parts of the Pacific Northwest, heavy rains and melting snow often trigger rapid forms of mass wasting.
- Coastal California's steep slopes have a high landslide potential often triggered by winter storms or ground shaking associated with earthquakes.
- Strong wave activity undercuts and oversteepens coastal cliffs.
- In the center of the country, the plains states are relatively flat, so landslide potential is mostly low-to-moderate.
- High potential occurs along steep bluffs that flank river valleys.
- Florida and the adjacent Atlantic and Gulf coastal plains have some of the lowest potential because steep slopes are largely absent.
- In the East, landslides are most common in the Appalachian Mountains.

GLOBAL LANDSLIDE RISKS

Question: What do areas with the highest landslide potential have in common?

NASA scientists compiled this risk map based on topographic data, land cover classifications and soil types.

Purple and dark red indicate areas at highest risk.

Black dots identify locations of major landslides over a four-year span (2003-2006).

LANDSLIDE RISK

SLIGHT → MODERATE → SEVERE

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

GEO GRAPHICS 1.1 **World Population Passes 7 Billion**

This composite satellite image of Earth's city lights helps us appreciate the intensity of human occupation in many parts of the world. In the year 1900, only about 3 percent of the world's people were urban. Today about 61 percent are classified as urban.

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

WORLD'S 10 LARGEST METRO AREAS IN 2010
MILLIONS OF CITIZENS

- NEW YORK, USA: 18,490,000
- MEXICO CITY, MEXICO: 19,400,000
- SÃO PAULO, BRAZIL: 20,200,000

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

EYE ON EARTH 2.1

In December 2011 a new volcanic island formed near the southern end of the Red Sea. Less than 2 years later, in late October 2013, another volcanic island emerged in the same area. These volcanic islands are part of several small islands in the Zubair Group located off the west coast of Yemen, along the Red Sea Rift.

QUESTION 1 What type of plate boundary produced these new volcanic islands?

QUESTION 2 What two plates border the Red Sea Rift?

QUESTION 3 Are these two plates moving *toward* or *away* from each other?

Red Sea

Haycock

New volcanic island, 2013

Rugged

Arabian plate

New island

African plate

Eritrea

Yemen

Ethiopia

Djibouti

Somalia

NASA

Modular Approach Driven by Learning Objectives

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

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

10 Crustal Deformation



Wyoming's Grand Teton are the result of crustal deformation created by tectonic forces that operate in Earth's interior.

FOCUS ON CONCEPTS

Each statement represents the primary **LEARNING OBJECTIVE** for the corresponding major heading within the chapter. After you complete the chapter you should be able to:

- 10.1 Describe the three types of differential stress and name the type of plate boundary most commonly associated with each.
- 10.2 Compare and contrast brittle and ductile deformation.
- 10.3 List and describe five common folded structures.
- 10.4 Sketch and briefly describe the relative motion of rock bodies located on opposite sides of normal, reverse, and thrust faults as well as both types of strike-slip faults.
- 10.5 Explain how strike and dip are measured and how these measurements tell geologists about the orientations of rock structures located mainly below Earth's surface.

Concepts in Review, a fresh approach to the typical end-of-chapter material, provides students with a structured and highly visual review of each chapter. Consistent with the Focus on Concepts and Concept Checks, the **Concepts in Review** is structured around the section title and the corresponding learning objective for each section.

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

10.5 Concept Checks

1. Distinguish between the two measurements used to establish the orientation of deformed strata.
2. Briefly describe the method geologists use to infer the orientation of rock structures that lie mainly below Earth's surface.

10 Concepts in Review Crustal Deformation

10.1 What Causes Rock to Deform?
Describe the three types of differential stress and name the type of plate boundary most commonly associated with each.

KEY TERMS: deformation, rock structure (geologic structure), stress, confining pressure, differential stress, compressional stress, tensional stress, shear stress, strain

Rock structures are generated when rocks are deformed by bending or breaking due to differential stress. Crustal deformation produces geologic structures that include folds, faults, joints, foliation, and rock cleavage.

Stress is the force that drives rock deformation. When stress has the same magnitude in every direction, it is called confining pressure. Alternatively, when the amount of stress coming from one direction is greater in magnitude than the stress coming from another direction, we call it differential stress. There are three main types of differential stress: compressional, tensional, and shear stress.

Strain is the change in the shape of a rock body caused by stress. Classify the following everyday situations as illustrating confining pressure, compressional stress, tensional stress, or shear stress: (a) a watermelon being run over by a steamroller, (b) a person diving to the bottom of the deep end of a swimming pool, (c) playing a game of top-of-war, (d) kneading bread dough, and (e) slipping on a banana peel.

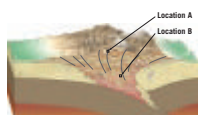
10.2 How Do Rocks Deform?
Compare and contrast brittle and ductile deformation.

KEY TERMS: elastic deformation, brittle deformation, ductile deformation, outcrop

There are several types of deformation. Elastic deformation is a temporary stretching of the chemical bonds in a rock. When the stress is released, the bonds snap back to their original lengths. When stress is greater than the strength of the bonds, the rock deforms in either a brittle or ductile fashion. Brittle deformation occurs when rocks break into smaller pieces, whereas ductile deformation is a solid-state flow that allows a rock to bend without fracturing.

The rate at which differential stress is applied also affects how rocks deform. Silly Putty provides a good analogy. If pulled apart quickly, silly Putty tends to break, whereas if pulled apart slowly, it tends to stretch (ductile flow) without breaking.

Examine the accompanying illustration of a collision between two tectonic plates. At which location (A or B) would brittle deformation be more prevalent than ductile deformation?



10.3 Folds: Rock Structures Formed by Ductile Deformation
List and describe five common folded structures.

KEY TERMS: fold, anticline, syncline, dome, basin, monocline

Folds are wavelike undulations in layered rocks that develop through ductile deformation in rocks undergoing compressional stress.

The shape of a fold does not necessarily correlate to the shape of the landscape above it. Rather, surface topography usually reflects patterns of differential weathering.

A fold is said to plunge when its axis penetrates the ground at an angle. This results in a V-shaped outcrop pattern of the folded layers.

Domes and basins are large folds that produce nearly circular-shaped outcrop patterns. The overall shape of a dome or basin is like a saucer or a bowl, either right-side-up (basin) or inverted (dome).

Monoclines are large step-like folds in otherwise horizontal strata that result from subsurface faulting. Imagine a carpet draped over a short staircase to envision how the strata can go from horizontal to tilted and back to horizontal again.

10.4 Faults and Joints: Structures Formed by Brittle Deformation
Sketch and briefly describe the relative motion of rock bodies located on opposite sides of normal, reverse, and thrust faults as well as both types of strike-slip faults.

KEY TERMS: fault, slip-slip fault, hanging wall block, footwall block, normal fault, fault-block mountain, horst, graben, half-graben, detachment

Faults are fractures along which one rock body slides past another.

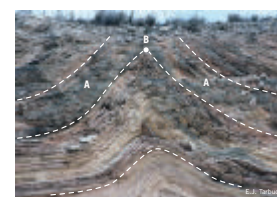
The direction of offset on a fault may be determined by comparing the blocks of rock on either side of the fault surface. Faults in which movement is primarily parallel to the dip of the fault surface are called dip-slip faults. Dip-slip faults are classified as normal faults if the hanging wall moves down relative to the footwall and as reverse faults if the hanging wall moves up relative to the footwall. Large

Give It Some Thought

1. Is granite or mica schist more likely to fold or flow rather than fracture when subjected to differential stress? Explain.
2. What type of deformation is illustrated by a coin that was run over by a passing train?



3. Refer to the accompanying photo to answer the following questions:
 - a. Name the type of fold shown.
 - b. Would you describe this fold as symmetrical or asymmetrical?



- a. What name is given to the part of the fold labeled A?
 - b. Is the white dot labeled B located along the fold line, hinge line, or dip line of this particular fold?
4. Refer to the accompanying diagrams to answer the following:
 - a. What type of dip-slip fault is shown in Diagram 1? Were the dominant forces during faulting tensional, compressional, or shear?

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

Continuous Learning Before, During, and After Class with **MasteringGeology**TM

MasteringGeology delivers engaging, dynamic learning opportunities—focusing on course objectives responsive to each student’s progress—that are proven to help students learn geology course material and understand challenging concepts.

Before Class

Dynamic Study Modules and eText 2.0 provide students with a preview of what’s to come.

The screenshot shows a 'PEARSON' interface for 'Crustal Deformation'. A question asks: 'What type of faults are the products of horizontally directed, extensional stresses?'. The user selected 'Normal faults', which is marked as 'THE CORRECT ANSWER'. Other options include 'Strike-slip faults', 'Reverse faults', 'Thrust faults', and 'UNKNOWN KNOW SET'. Below the question, a section titled 'WHAT YOU NEED TO KNOW' provides definitions for Normal, Reverse, Thrust, and Strike-slip faults.

Dynamic Study Modules enable students to study effectively on their own in an adaptive format. Students receive an initial set of questions with a unique answer format asking them to indicate their confidence.

Once completed, Dynamic Study Modules include explanations using material taken directly from the text.

The screenshot shows a 'PEARSON' eText 2.0 interface for the chapter 'Movement of Water Through the Atmosphere'. It includes a text paragraph about the hydrologic cycle and a 'SmartFigure 4.1 Earth's hydrologic cycle' which is a circular diagram showing the flow of water between the atmosphere, land, and oceans. Below the diagram is a video player titled 'Hydrologic Cycle'.

NEW! Interactive eText 2.0 complete with embedded media. eText 2.0 is mobile friendly and ADA accessible.

- Now available on smartphones and tablets.
- Seamlessly integrated videos and other rich media.
- Accessible (screen-reader ready).
- Configurable reading settings, including resizable type and night reading mode.
- Instructor and student note-taking, highlighting, bookmarking, and search.

During Class

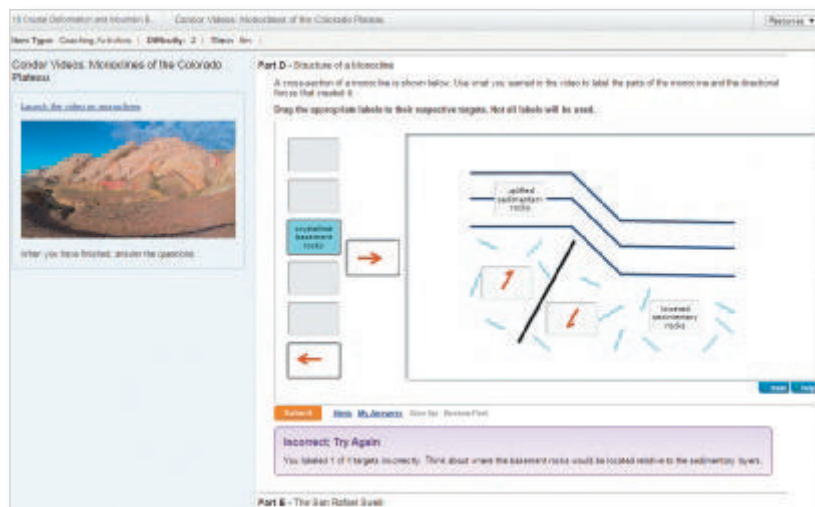
Engage Students with Learning Catalytics

Learning Catalytics, a “bring your own device” student engagement, assessment, and classroom intelligence system, allows students to use their smartphone, tablet, or laptop to respond to questions in class.

The screenshot shows the 'learning catalytics' interface. A question asks: 'What metamorphic conditions represent regional metamorphism?'. The question is accompanied by a P-T diagram showing different metamorphic zones. The interface also displays 'Historical Performance' (33 students, 64% correct) and an 'Answer' section with a smaller version of the P-T diagram. Tags include 'metamorphic rocks', 'learning objective 3.3', 'metamorphism', and 'regional metamorphism'.

After Class

Easy-to-Assign, Customizable, and Automatically Graded Assignments

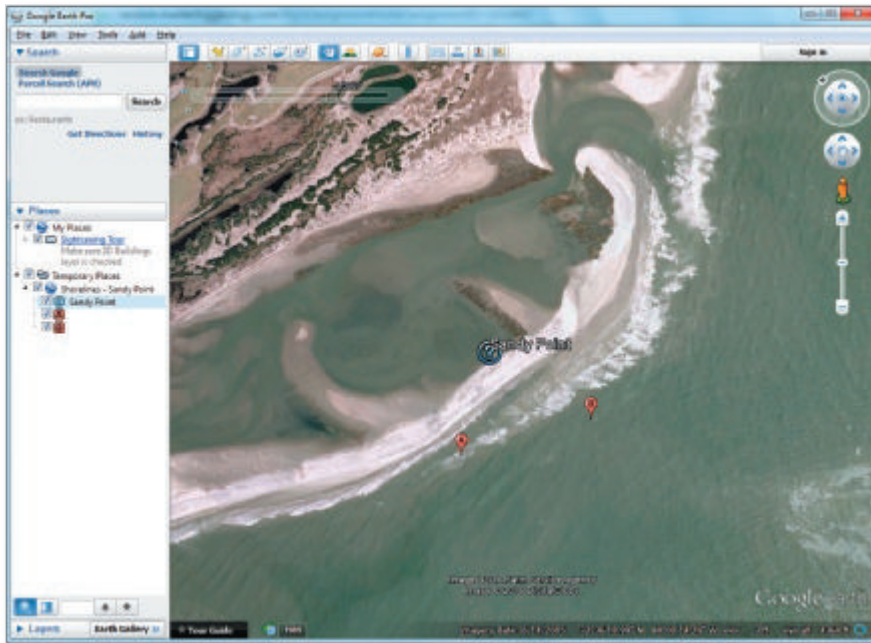


NEW! Project Condor Videos capture stunning footage of the Mountain West region with a quadcopter and a GoPro camera. A series of videos have been created with annotations, sketching, and narration to improve the way students learn about faults and folds, streams, volcanoes, and so much more. In Mastering, these videos are accompanied by questions designed to assess students on the main takeaways from each video.

NEW! 24 Mobile Field Trips take students to classic geologic locations as they accompany geologist-pilot-photographer-author Michael Collier in the air and on the ground to see and learn about landscapes that relate to concepts in the chapter. In Mastering, these videos will be accompanied by auto-gradable assessments that will track what students have learned.

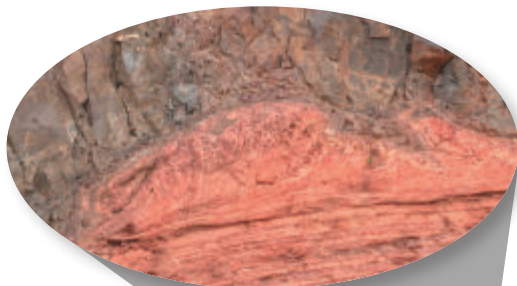


GeoTutor coaching activities help students master important geologic concepts with highly visual, kinesthetic activities focused on critical thinking and application of core geoscience concepts.



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

NEW! GigaPan Activities allow students to take advantage of a virtual field experience with high-resolution picture technology that has been developed by Carnegie Mellon University in conjunction with NASA.



Part D - Making Observations

After exploring the GigaPan field site, arrange the following observations/inferences by their respective rock unit. These observations/inferences describe the material, appearance and weathering pattern of the respective rock units.

Drag the appropriate items into their respective bins. Each item may be used only once.

Rock Unit 1

Red and white in color

Appears to be made up of many thin layers

Weather in small irregular shapes

Weather in large blocks

Appears to be massive (NO layers)

Sediments too small to see

Rock Unit 2

Dark and dark gray in color

Crystals too small to see

[Submit](#) [Hints](#) [My Answers](#) [Clear All](#) [Review Part](#)

Incorrect; Try Again

You sorted 2 out of 8 items incorrectly. Compare the weathering pattern of rock unit #2 to the weathering pattern of rock unit #1. Which rock unit produces large blocks?



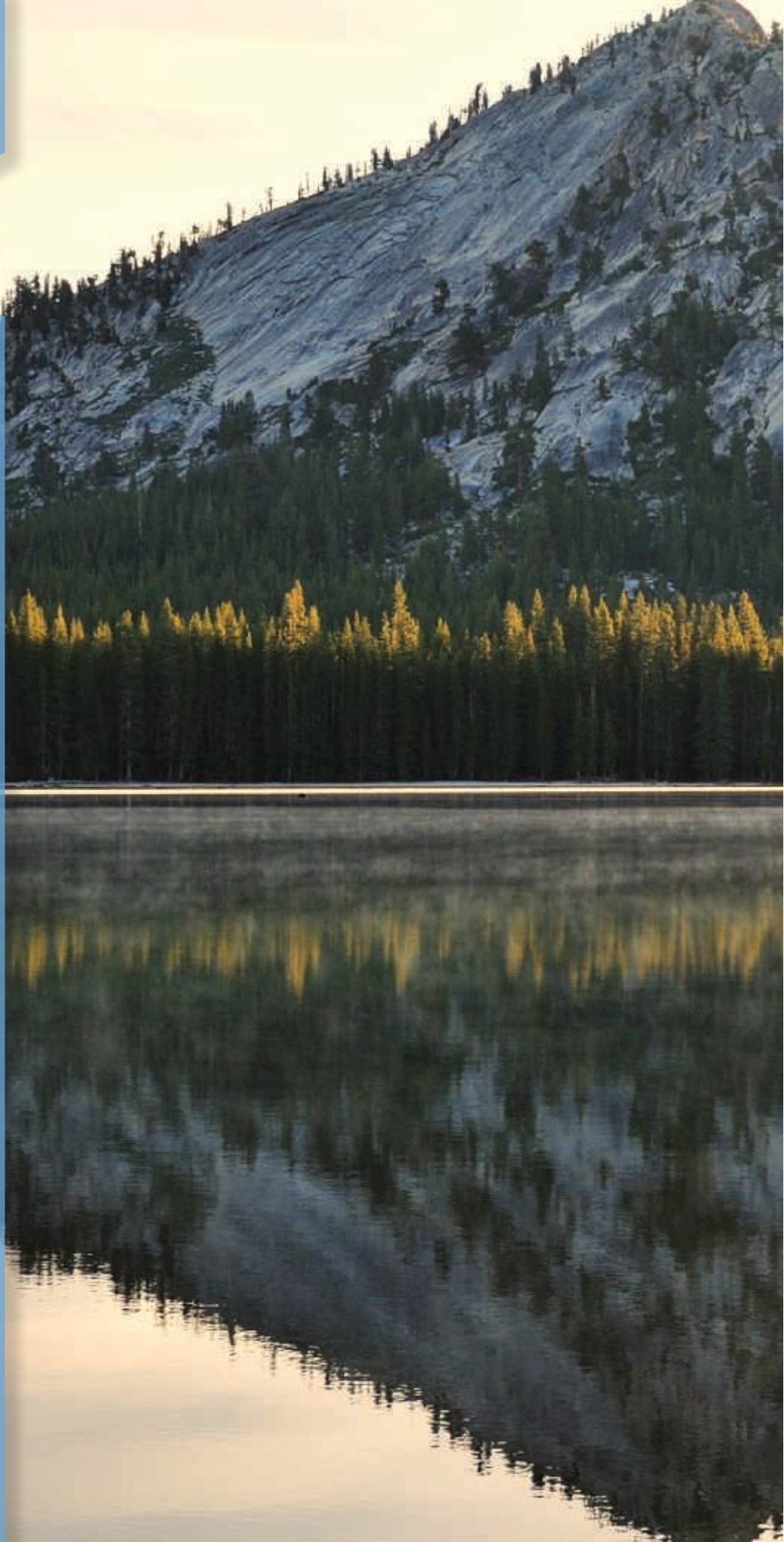
Additional MasteringGeology assignments available:

- SmartFigures
- Interactive Animations
- Give It Some Thought Activities
- Reading Quizzes
- MapMaster Interactive Maps

1

An Introduction to Geology

Earth's four spheres, atmosphere, hydrosphere, geosphere, and biosphere, are represented in this image from California's Yosemite National Park.
(Photo by Michael Collier)





**FOCUS ON
CONCEPTS**

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

- 1.1 Distinguish between physical and historical geology and describe the connections between people and geology.**
- 1.2 Summarize early and modern views on how change occurs on Earth and relate them to the prevailing ideas about the age of Earth.**
- 1.3 Discuss the nature of scientific inquiry, including the construction of hypotheses and the development of theories.**
- 1.4 List and describe Earth's four major spheres. Define *system* and explain why Earth is considered to be a system.**
- 1.5 Outline the stages in the formation of our solar system.**
- 1.6 Sketch Earth's internal structure and label and describe the main subdivisions.**
- 1.7 Sketch, label, and explain the rock cycle.**
- 1.8 List and describe the major features of the continents and ocean basins.**

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

1.1 Geology: The Science of Earth

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

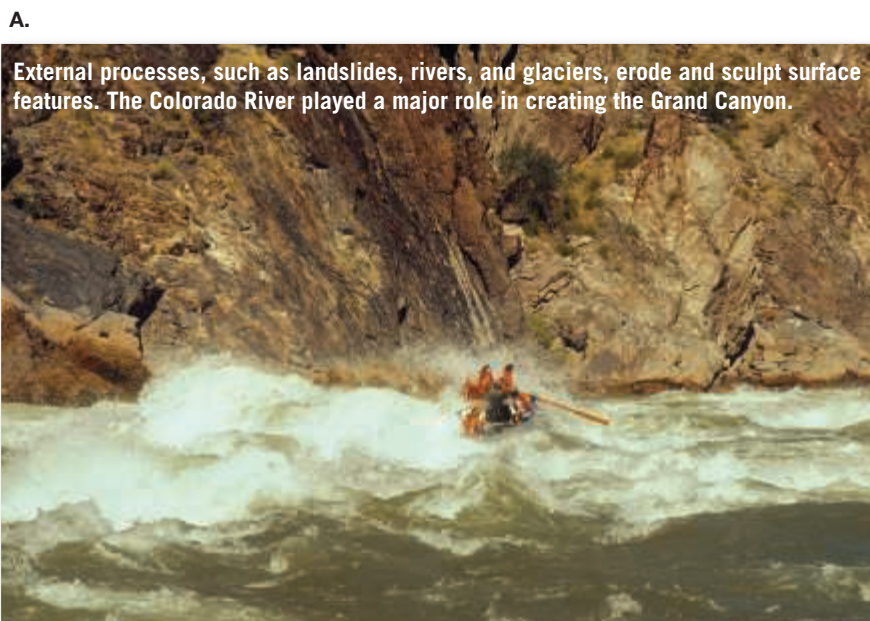
The subject of this text is **geology**, from the Greek *geo* (Earth) and *logos* (discourse). Geology is the science that pursues an understanding of planet Earth. Understanding Earth is challenging because our planet is a dynamic body with many interacting parts and a complex history. Throughout its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

Figure 1.1
Internal and external processes The processes that operate beneath and upon Earth's surface are an important focus of physical geology. (River photo by Michael Collier; volcano photo by AM Design/Alamy Live News/Alamy Images)

Physical and Historical Geology

Geology is traditionally divided into two broad areas—physical and historical. **Physical geology**, which is the primary focus of this book, examines the materials composing Earth and seeks to understand the many processes that operate beneath and upon its surface (Figure 1.1). The aim of **historical geology**, on the other

hand, is to understand Earth's origins and its development through time. Thus, it strives to establish an orderly chronological arrangement of the multitude of physical and biological changes that have occurred in the geologic past. The study of physical geology logically precedes the study of Earth history because we must first understand how Earth works before we attempt to unravel its past. It should also be pointed out that physical and historical



geology are divided into many areas of specialization. Every chapter of this book represents one or more areas of specialization in geology.

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

Geology, People, and the Environment

The primary focus of this book is to develop your understanding of basic geologic principles, but along



A.



B.

Figure 1.2

In the field and in the lab

Geology involves not only outdoor fieldwork but work in the laboratory as well. **A.** This research team is gathering data at Mount Nyiragongo, an active volcano in the Democratic Republic of the Congo. (Carsten Peter/National Geographic Image Collection/Alamy) **B.** This researcher is using a petrographic microscope to study the mineral composition of rock samples. (Photo by Jon Wilson/Science Source)

the way, we explore numerous important relationships between people and the natural environment. Many of the problems and issues that geologists address are of practical value.

Natural hazards are a part of living on Earth. Every day they adversely affect millions of people worldwide and are responsible for staggering damages. Among the hazardous Earth processes that geologists study are volcanoes, floods, tsunamis, earthquakes, and

landslides. Of course, geologic hazards are *natural* processes. They become hazards only when people try to live where these processes occur (Figure 1.3).



Figure 1.3

Tsunami destruction

Undersea earthquakes sometimes create large, fast-moving ocean waves that can cause significant death and destruction in coastal areas. This tsunami struck densely populated Fukushima, Japan, in 2011, causing major damage to a nuclear power plant. Geologic hazards are natural processes. They become hazards only when people try to live where these processes occur. (Photo by Mainichi Newspaper/Aflo/Newscom)