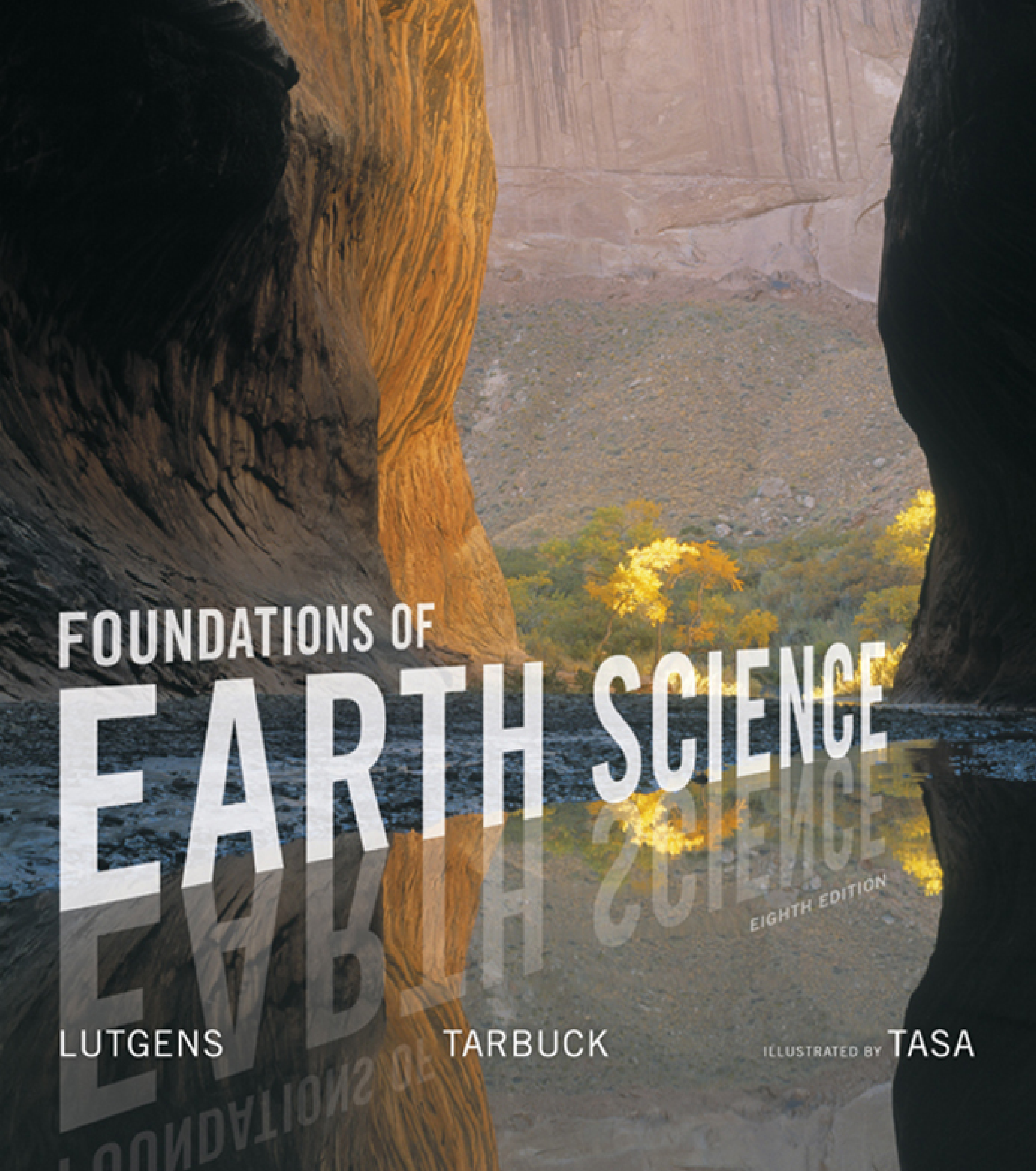
FOUNDATIONS OF
EARTH SCIENCE
EIGHTH EDITION
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EIGHTH EDITION

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FOUNDATIONS OF
EARTH SCIENCE

EIGHTH EDITION

FREDERICK K. LUTGENS
EDWARD J. TARBUCK

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To Our Grandchildren

Allison and Lauren

Shannon, Amy, Andy, Ali, and Michael

Each is a bright promise for the future.

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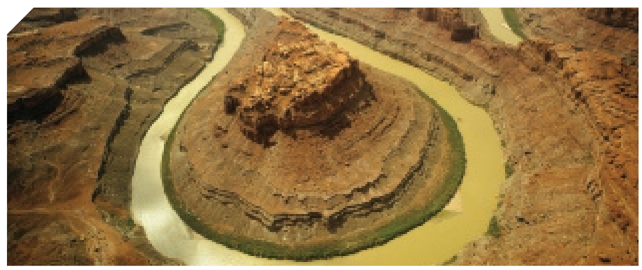

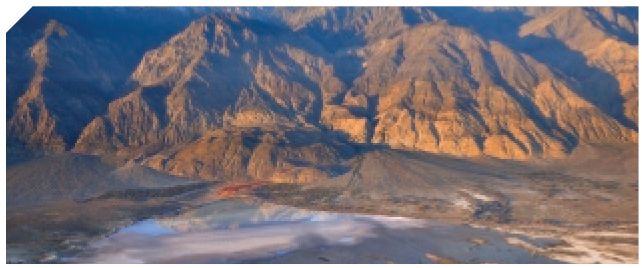

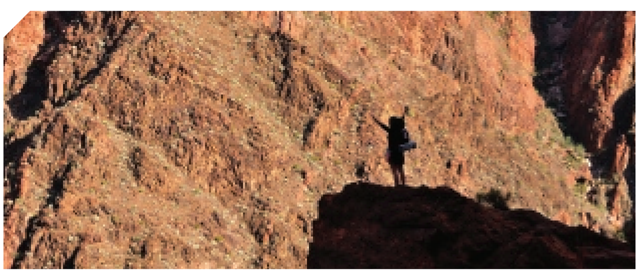

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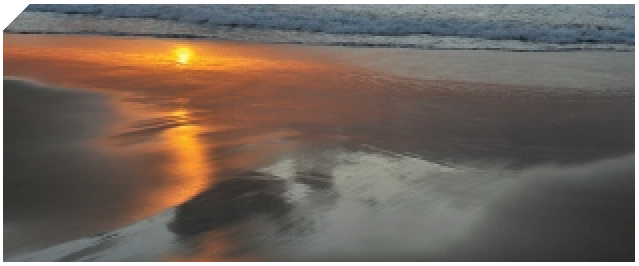

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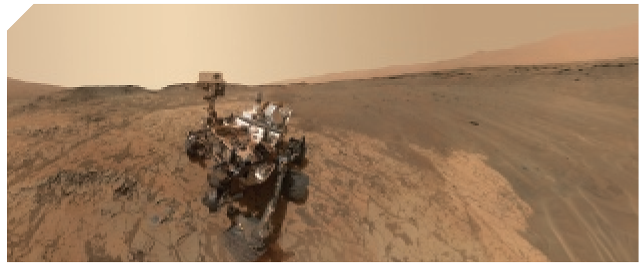

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Preface

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

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

New and Important Features

This eighth edition is an extensive and thorough revision of *Foundations of Earth Science* 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 *Foundations of Earth Science* 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 *Foundations* much more than a traditional textbook.** Through its many editions, an important strength of *Foundations of Earth Science* 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** (available for iOS and Android), students can follow hundreds of unique and innovative avenues that will increase their insight and understanding of important ideas and concepts. SmartFigures are truly art that teaches! This eighth edition of *Foundations* has more than 200 SmartFigures, of five different types:
  1. **SmartFigure Tutorials.** Each of these 2- to 4-minute features, 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 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 locations in the American West. By coupling aerial footage acquired by a drone 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.
  5. **SmartFigure Videos.** Rather than provide a single image to illustrate an idea, these figures include short video clips that help illustrate such diverse subjects as mineral properties and the structure of ice sheets.
- **Revised active learning path.** *Foundations of Earth Science* 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 readable and concise overview of key ideas, with photos, diagrams, and questions that also help students focus on important ideas and test their understanding of key concepts. Chapters conclude with *Give It Some Thought*. The questions and problems in this section 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. Overall, the visual program of this text 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 have been proven to help students learn course material and understand difficult concepts. Assignable activities in MasteringGeology include SmartFigure (Tutorial, Condor, Animation, Mobile Field Trip, and 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

MasteringGeology™ with Pearson eText

Used by more than 1 million science students, the Mastering platform is the most effective and widely used online tutorial, homework, and assessment system for the sciences. Now available with *Foundations of Earth Science,* eighth edition, **MasteringGeology**™ offers tools for use before, during, and after class:

- **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.
- **During class:** Learning Catalytics, a "bring your own device" student engagement, assessment, and classroom intelligence system, allows students to use a smartphone, tablet, or laptop to respond to questions in class. With Learning Catalytics, you can assess students in real-time, using open-ended question formats to determine student misconceptions, and adjust lectures accordingly.
- **After class:** Assign an array of assessment resources such as Mobile Field Trips, Project Condor videos, Interactive Simulations, GeoDrone activities, Google Earth Encounter Activities, and much more. Students receive wrong-answer feedback personalized to their answers, which will help them get back on track.

MasteringGeology Student Study Area also provides students with self-study materials including all of the SmartFigures, geoscience animations, *GEODe: Earth Science* tutorials, *In the News* RSS feeds, Self Study Quizzes, Web Links, Glossary, and Flashcards.

For more information or access to MasteringGeology, please visit www.masteringgeology.com.

Instructor's Resource Materials (Download Only)

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:

- The IRM provides all of the line art, tables, and photos from the text in .jpg files.
- 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 70 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, and it offers 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*, *Concepts in Review,* 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 approximately 1,200 multiple-choice, matching, and essay questions. Questions are correlated to Bloom's Taxonomy, each chapter's learning objectives, the Earth Science Literacy Initiative Big Ideas, 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. www.pearsonhighered.com/irc

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 are committed to producing the best textbooks possible. Special thanks to our geoscience editor, Andy Dunaway, who invested a great deal

of time, energy, and effort in this project. We appreciate his enthusiasm, hard work, and quest for excellence. We also appreciate our conscientious project manager, 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 input. The eighth edition of *Foundations of Earth Science* was certainly improved by the talents of our developmental editor, Margot Otway. 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 some excellent animations, is always special for us. He has been part of our team for more than 30 years. We value not only 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 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 *Foundations of Earth Science,* eighth edition. Thanks, Michael.
- Callan Bentley has been an important addition to the *Foundations of Earth Science* team. Callan is a 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 *Foundations*.

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

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

Fred Lutgens
Ed Tarbuck

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ALWAYS LEARNING

AUGMENTED REALITY:

Bringing the Textbook to Life

SmartFigure 4.26 Dry climates Arid and semiarid climates cover about 30 percent of Earth's land surface. The dry region of the American West is commonly divided into four deserts, two of which extend into Mexico.

Tutorial

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.

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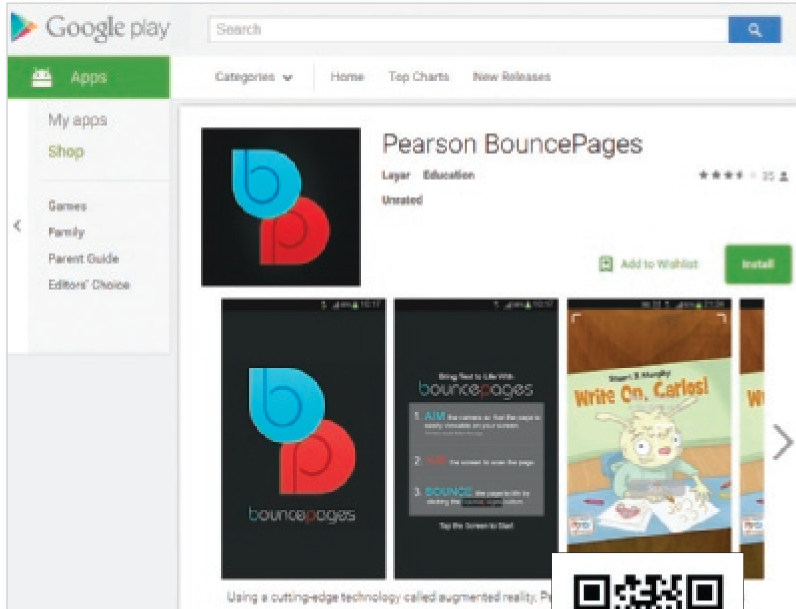

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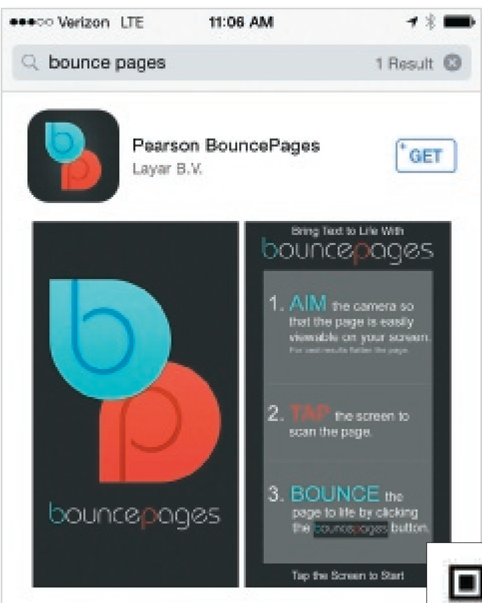
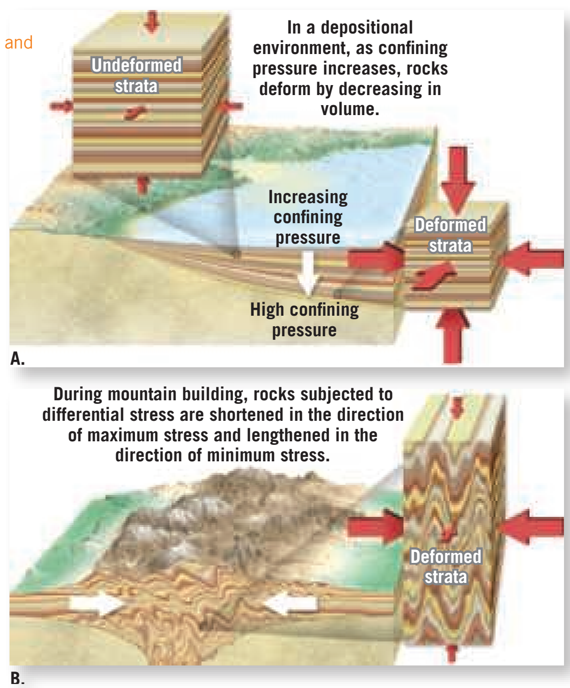


https://itunes.apple.com/us/app/pearson-bouncepages/id659370955?mt=8

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.

SmartFigure 2.31 Confining pressure and differential stress

Tutorial



Bring the Field to YOUR Teaching and Learning Experience

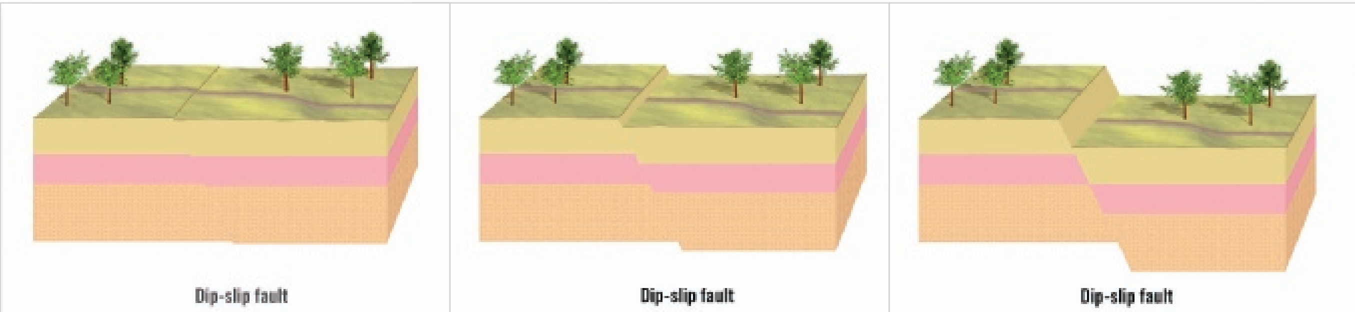
NEW! SmartFigure: Condor Videos. Bringing Physical Geology to life for GenEd students, three geologists, using a GoPro camera mounted to a quadcopter, have ventured out into the field to film **10 key geologic locations**. These process-oriented videos, accessed through BouncePages technology, are designed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

Condor Video

NEW! SmartFigure: Mobile Field Trips. Scattered throughout this new edition of *Foundations of Earth Science* 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.

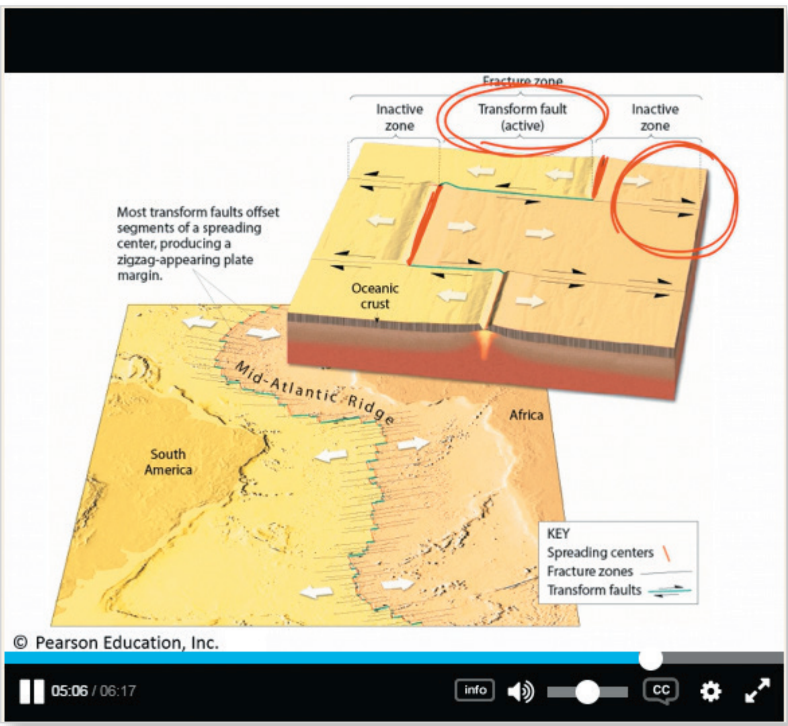
Mobile Field Trip

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.

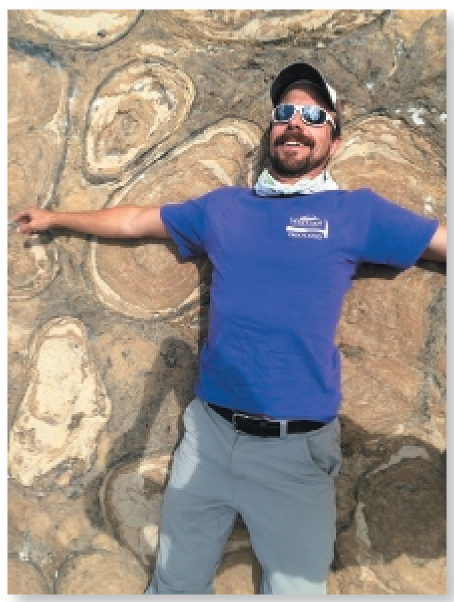
Animation



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.

Tutorial

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.



Modular Approach Driven by Learning Objectives

The new edition is designed to support a four-part learning path, an innovative structure that 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.

UNIT IV

DECIPHERING EARTH'S HISTORY

8

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:

8.1 Explain the principle of uniformitarianism and discuss how it differs from catastrophism.

8.2 Distinguish between numerical and relative dating and apply relative dating principles to determine a time sequence of geologic events.

8.3 Define *fossil* and discuss the conditions that favor the preservation of organisms as fossils. List and describe various fossil types.

8.4 Explain how rocks of similar age that are in different places can be matched up.

8.5 Discuss three types of radioactive decay and explain how radioactive isotopes are used to determine numerical dates.

8.6 Distinguish among the four basic time units that make up the geologic time scale and explain why the time scale is considered to be a dynamic tool.

8.7 Explain how reliable numerical dates are determined for layers of sedimentary rock.

This hiker is on the Kaibab Trail in Arizona's Grand Canyon National Park. Millions of years of Earth history are exposed in the canyon's rock walls. (Photo by Michael Collier)

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

8.2 CONCEPT CHECKS

1. Distinguish between numerical dates and relative dates.
2. Sketch and label five simple diagrams that illustrate each of the following: superposition, original horizontality, lateral continuity, cross-cutting relationships, and inclusions.
3. What is the significance of an unconformity?
4. Distinguish among angular unconformity, disconformity, and nonconformity.

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.

CONCEPTS IN REVIEW

Geologic Time

8.1 A Brief History of Geology

Explain the principle of uniformitarianism and discuss how it differs from catastrophism.

KEY TERMS: catastrophism, uniformitarianism

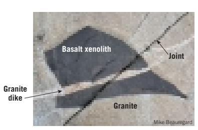
- Early ideas about the nature of Earth were based on religious traditions and notions of great catastrophes.
- In the late 1700s, James Hutton emphasized that the same slow processes have acted over great spans of time and are responsible for Earth's rocks, mountains, and landforms. This similarity of processes over vast spans of time led to this principle being called uniformitarianism.

8.2 Creating a Time Scale—Relative Dating Principles

Distinguish between numerical and relative dating and apply relative dating principles to determine a time sequence of geologic events.

KEY TERMS: numerical date, relative date, principle of superposition, principle of original horizontality, principle of lateral continuity, principle of cross-cutting relationships, inclusion, conformable, unconformity, angular unconformity, disconformity, nonconformity

- The two types of dates that geologists use to interpret Earth history are (1) relative dates, which put events in their proper sequence of formation, and (2) numerical dates, which pinpoint the time in years when an event took place.
- Relative dates can be established using the principles of superposition, original horizontality, lateral continuity, cross-cutting relationships, and inclusions. Unconformities, gaps in the geologic record, may be identified during the relative dating process.



? The accompanying photo shows four features. Place the features in the proper sequence, from oldest to youngest. Explain your reasoning.

8.3 Fossils: Evidence of Past Life

Define *fossil* and discuss the conditions that favor the preservation of organisms as fossils. List and describe various fossil types.

KEY TERMS: fossil, paleontology

- Fossils are remains or traces of ancient life. Paleontology is the branch of science that studies fossils.
- Fossils can form through many processes. For an organism to be preserved as a fossil, it usually needs to be buried rapidly. Also, an organism's hard parts are most likely to be preserved because soft tissue decomposes rapidly in most circumstances.

? What term is used to describe the type of fossil that is shown here? Briefly describe how it formed.

8.4 Correlation of Rock Layers

Explain how rocks of similar age that are in different places can be matched up.

KEY TERMS: correlation, principle of fossil succession, index fossil, fossil assemblage

- Matching up exposures of rock that are the same age but are in different places is called correlation. By correlating rocks from around the world, geologists developed the geologic time scale and obtained a fuller perspective on Earth history.
- Fossils can be used to correlate sedimentary rocks in widely separated places by using the rocks' distinctive fossil content and applying the principle of fossil succession. The principle states that fossil organisms succeed one another in a definite and determinable order, and, therefore, a time period can be recognized by examining its fossil content.
- Index fossils are particularly useful in correlation because they are widespread and associated with a relatively narrow time span. The overlapping ranges of fossils in an assemblage may be used to establish an age for a rock layer that contains multiple fossils.
- Fossils may be used to establish ancient environmental conditions that existed when sediment was deposited.

8.5 Determining Numerical Dates with Radioactivity

Discuss three types of radioactive decay and explain how radioactive isotopes are used to determine numerical dates.

KEY TERMS: radioactivity, radioactive decay, radiometric dating, half-life, radiocarbon dating

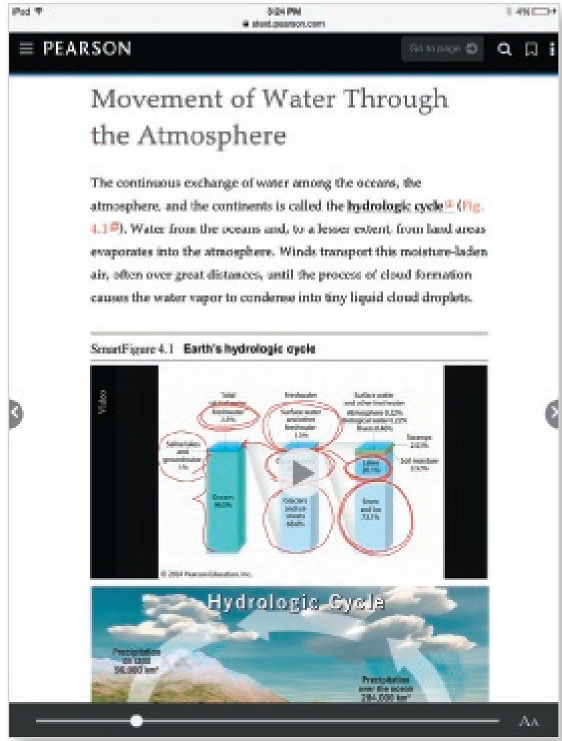
GIVE IT SOME THOUGHT

1. The accompanying image shows the metamorphic rock gneiss, a basaltic dike, and a fault. Place these three features in their proper sequence (which came first, second, and third) and explain your logic.
2. A mass of granite is in contact with a layer of sandstone. Using a principle described in this chapter, explain how you might determine whether the sandstone was deposited on top of the granite or whether the magma that formed the granite was intruded after the sandstone was deposited.
3. This scenic image is from Monument Valley in the northeastern corner of Arizona. The bedrock in this region consists of layers of sedimentary rocks. Although the prominent rock exposures ("monuments") in this photo are widely separated, we can infer that they represent a once-continuous layer. Discuss the principle that allows us to make this inference.
4. The accompanying photo shows two layers of sedimentary rock. The lower layer is shale from the late Mesozoic era. Note the old river channel that was carved into the shale after it was deposited. Above is a younger layer of boulder-rich breccia. Are these layers conformable? Explain why or why not. What term from relative dating applies to the line separating the two layers?
5. Refer to Figure 8.9, which shows the historic angular unconformity at Scotland's Siccar Point that James Hutton studied in the late 1700s. Refer to this photo for the following exercises.
   - **a.** Describe in general what occurred to produce this feature.
   - **b.** Suggest ways in which at least three of Earth's four spheres could have been involved.
   - **c.** The Earth system is powered by energy from two sources. How are both sources represented in the Siccar Point unconformity?
6. These polished stones are called *gastroliths*. Explain how such objects can be considered fossils. What category of fossil are they? Name another example of a fossil in this category.
7. If a radioactive isotope of thorium (atomic number 90, mass number 232) emits 6 alpha particles and 4 beta particles during the course of radioactive decay, what are the atomic number and mass number of the stable daughter product?
8. A hypothetical radioactive isotope has a half-life of 10,000 years. If the ratio of radioactive parent to stable daughter product is 1:3, how old is the rock that contains the radioactive material?
9. Solve the problems below that relate to the magnitude of Earth history. To make calculations easier, round Earth's age to 5 billion years.
   - **a.** What percentage of geologic time is represented by recorded history? (Assume 5000 years for the length of recorded history.)
   - **b.** Humans and their close relatives (hominins) have been around for roughly 5 million years. What percentage of geologic time is represented by the history of this group?
   - **c.** The first abundant fossil evidence does not appear until the beginning of the Cambrian period, about 540 million years ago. What percentage of geologic time is represented by abundant fossil evidence?
10. A portion of a popular college text in historical geology includes 10 chapters (281 pages) in a unit titled "The Story of Earth." Two chapters (49 pages) are devoted to Precambrian time. By contrast, the last two chapters (67 pages) focus on the most recent 23 million years, with 25 of those pages devoted to the Holocene Epoch, which began 10,000 years ago.
    - **a.** Compare the percentage of pages devoted to the Precambrian to the actual percentage of geologic time that this span represents.
    - **b.** How does the number of pages about the Holocene compare to its actual percentage of geologic time?
    - **c.** Suggest some reasons why the text seems to have such an unequal treatment of Earth history.
11. The accompanying diagram is a cross section of a hypothetical area. Place the lettered features in the proper sequence, from oldest to youngest. Where in the sequence can you identify an unconformity?

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™

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.



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

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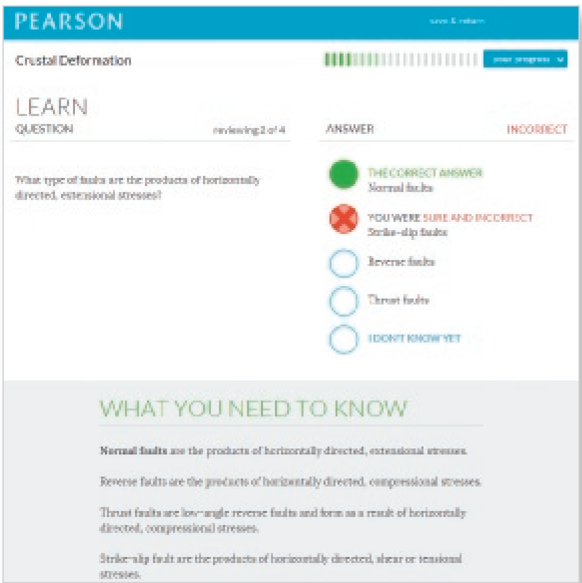
Before Class

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



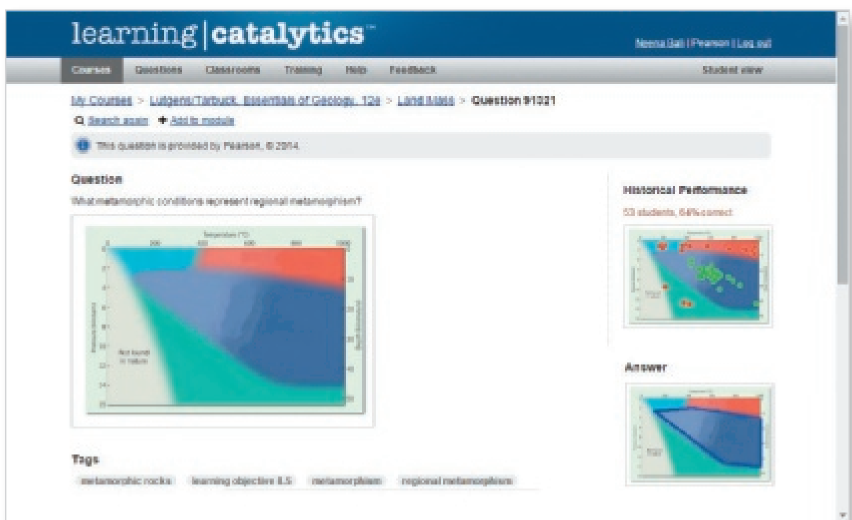
Dynamic Study Modules enable students to study effectively on their own in an adaptive format. Students receive an initial set of questions with a unique answer format asking them to indicate their confidence.

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

During Class

Engage Students with Learning Catalytics

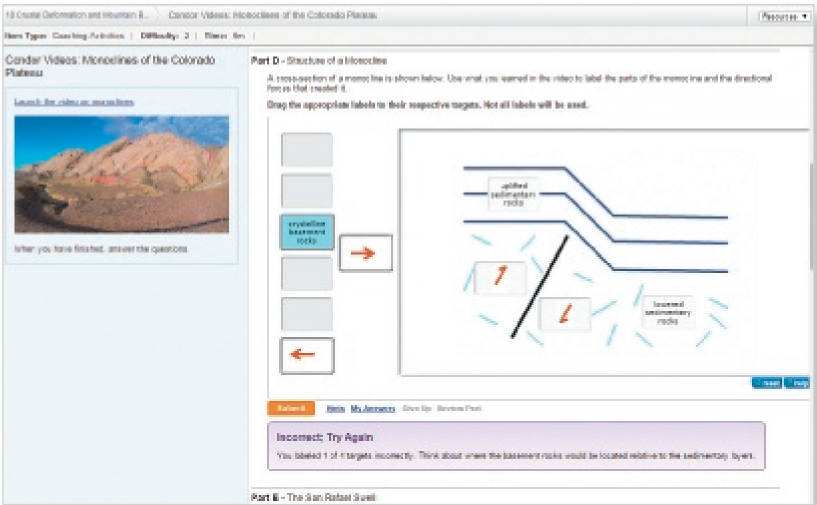
Learning Catalytics, a "bring your own device" student engagement, assessment, and classroom intelligence system, allows students to use their smartphone, tablet, or laptop to respond to questions in class.



MasteringGeology™

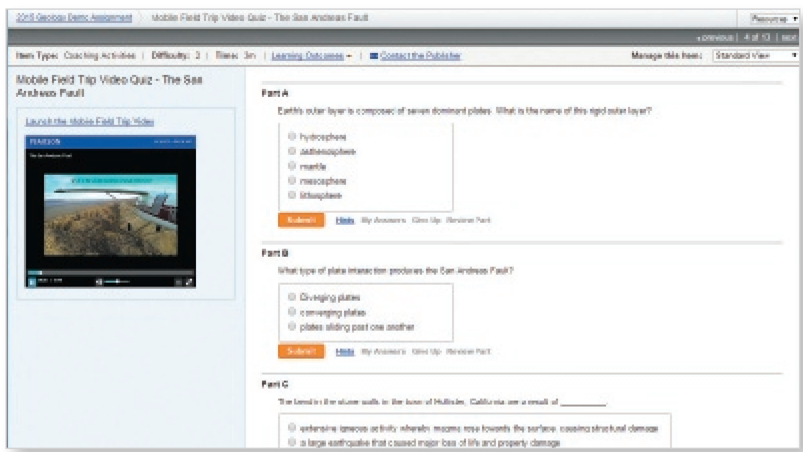
After Class

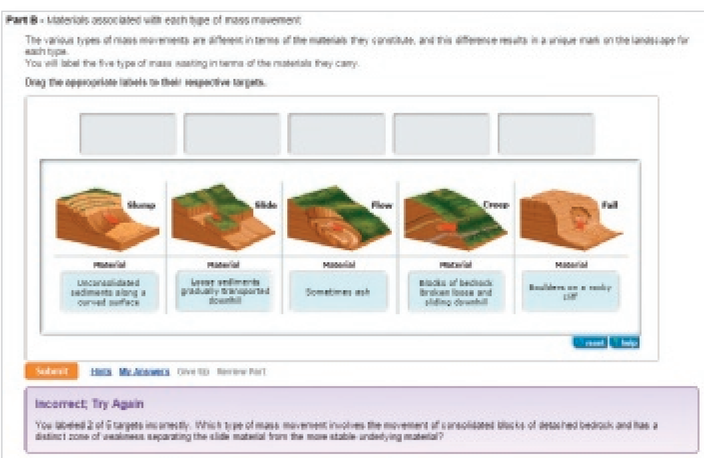
Easy-to-Assign, Customizeable, and Automatically Graded Assignments



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.

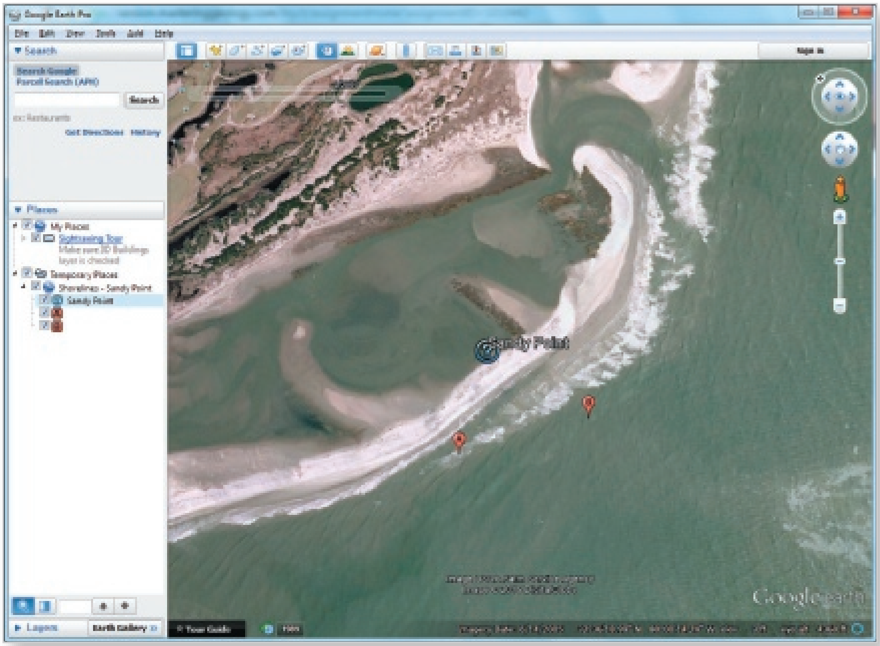
NEW! Mobile Field Trips take students to classic geologic locations as they accompany geologist–pilot–photographer–author Michael Collier in the air and on the ground to see and learn about landscapes that relate to concepts in the chapter. In Mastering, these videos will be accompanied by auto-gradable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



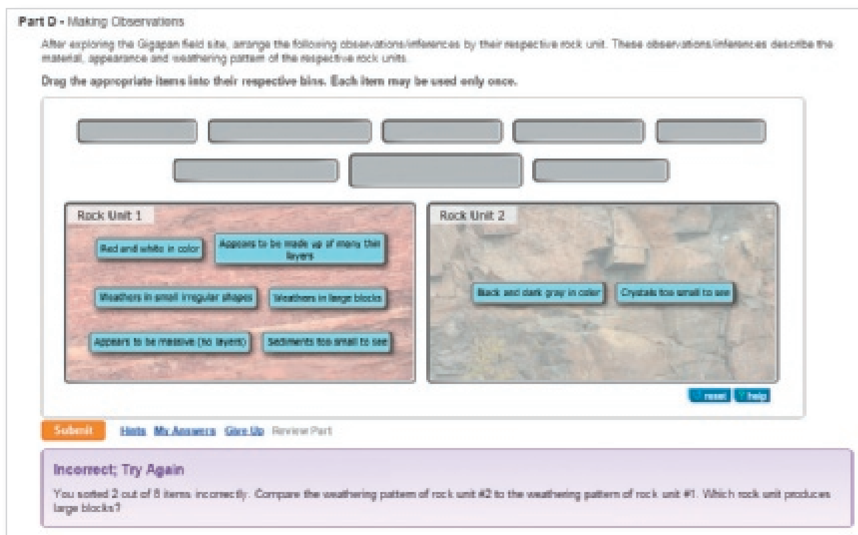


GeoTutor coaching activities help students master important geologic concepts with highly visual, kinesthetic activities focused on critical thinking and application of core geoscience concepts.

MasteringGeology™



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 concepts. All explorations include corresponding Google Earth KMZ media files, and questions include hints and specific wrong-answer feedback to help coach students toward mastery of the concepts 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.

Additional MasteringGeology assignments available:

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

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:

I.1 List and describe the sciences that collectively make up Earth science. Discuss the scales of space and time in Earth science.

I.2 Describe the four "spheres" that comprise Earth's natural environment.

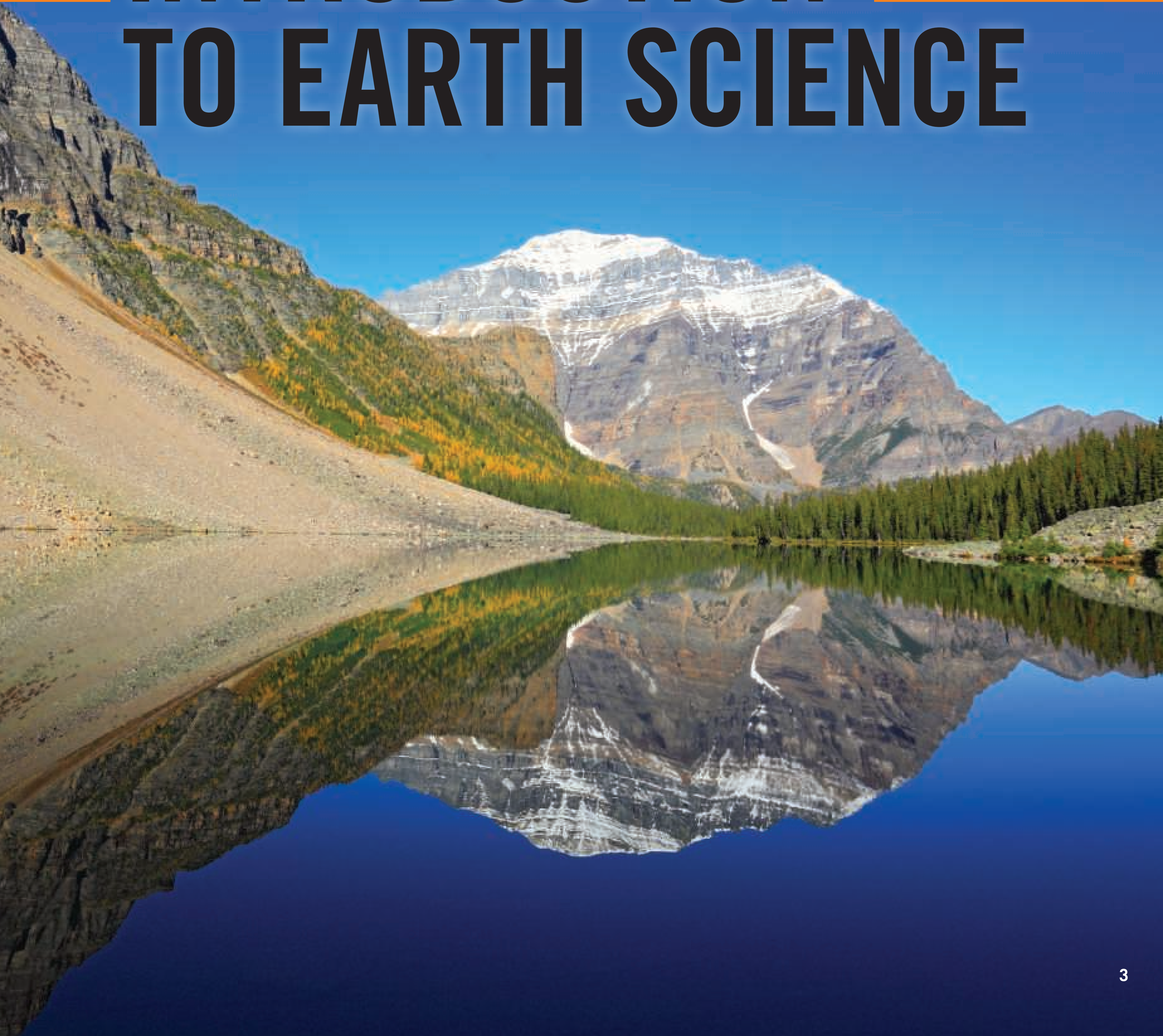
I.3 Define *system* and explain why Earth is considered to be a system.

I.4 Summarize some important connections between people and the physical environment.

I.5 Discuss the nature of scientific inquiry and distinguish between a hypothesis and a theory.

Earth's four spheres—the geosphere (solid Earth), atmosphere (air), hydrosphere (water), and biosphere (life)—are represented in this scene in the Canadian Rockies. (Photo by John E. Marriott/Glow Images)

INTRODUCTION TO EARTH SCIENCE



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

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

I.1 What Is Earth Science?

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

Earth science is the name for all the sciences that collectively seek to understand Earth and its neighbors in space. It includes geology, oceanography, meteorology, and astronomy. Throughout its long existence, Earth has been changing. In fact, it is changing as you read this page and will continue to do so into the foreseeable future. Sometimes the changes are rapid and violent, as when severe storms, landslides, and volcanic eruptions occur. Conversely, many changes take place so gradually that they go unnoticed during a lifetime. Scales of size and space also vary greatly among the phenomena studied in Earth science.

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

Geology

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

Physical geology examines the materials composing Earth and seeks to understand the many processes that operate beneath and upon its surface. Earth is a dynamic, ever-changing planet. *Internal processes* create earthquakes, build mountains, and produce volcanic structures (**Figure I.1**). At the surface, *external processes* break rock apart and sculpt a broad array of landforms. The erosional effects of water, wind, and ice result in a great diversity of landscapes. Because rocks and minerals form in response to Earth's internal and external processes, their interpretation is basic to an understanding of our planet.

In contrast to physical geology, the aim of *historical geology* is to understand the origin of Earth and the development of the planet through its 4.6-billion-year history (**Figure I.2**). It strives to establish an orderly chronological arrangement of the multitude of physical and biological changes that have occurred in the geologic past. The study of physical geology logically precedes the study of Earth history because we must first understand how Earth works before we attempt to unravel its past.

Oceanography

Earth is often called the "water planet" or the "blue planet." Such terms relate to the fact that more than 70 percent of Earth's surface is covered by the global ocean. If we are to understand Earth, we must learn about its oceans. Unit 5, *The Global Ocean*, is devoted to **oceanography**.

Oceanography is actually not a separate and distinct science. Rather, it involves the application of all sciences in a comprehensive and interrelated study of the oceans in all their aspects and relationships. Oceanography integrates chemistry, physics, geology, and biology. It includes the study of the composition and movements of seawater, as well as coastal processes, seafloor topography, and marine life.

Meteorology

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

Astronomy

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

Figure I.1 Volcanic eruption Molten lava from Hawaii's Kilauea volcano is spilling into the Pacific Ocean. Internal processes are those that occur beneath Earth's surface. Sometimes they lead to the formation of major features at the surface. (Photo by Stuart Westmoreland/ Cultura/ Getty Images)

SmartFigure I.2 Arizona's Grand Canyon The erosional work of the Colorado River along with other external processes created this natural wonder. For someone studying historical geology, hiking down the South Kaibab Trail in Grand Canyon National Park is a trip through time. These rock layers hold clues to millions of years of Earth history. (Photo by Michael Collier) (http://goo.gl/7KwQLk)

Mobile Field Trip

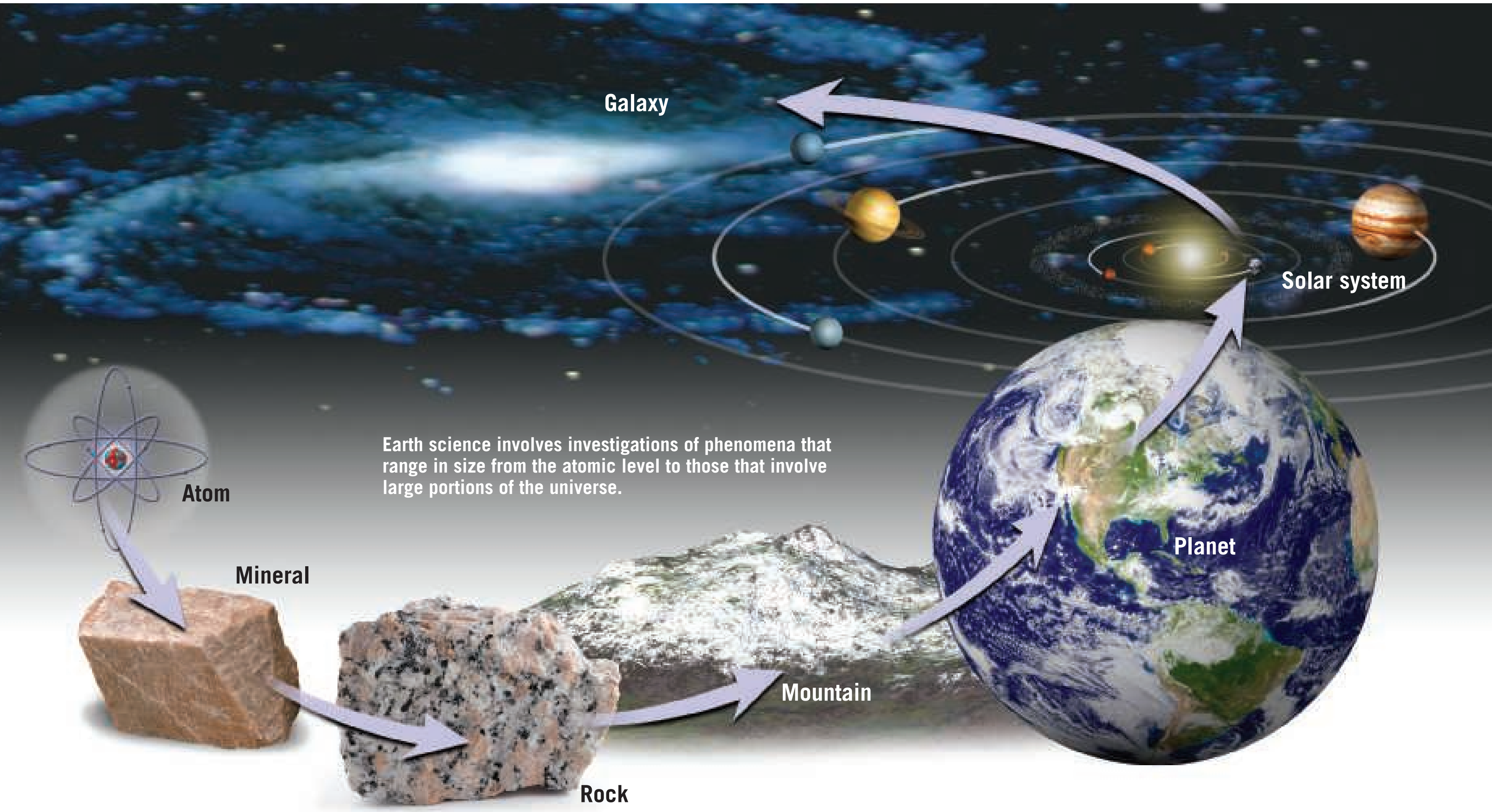


Figure I.3 From atoms to galaxies Earth science involves investigations of phenomena that range in size from atoms to galaxies and beyond.

about the other members of our solar system. Moreover, it is helpful to view the solar system as a part of the great assemblage of stars that comprise our galaxy, which is but one of many galaxies.

Scales of Space and Time in Earth Science

When we study Earth, we must contend with a broad array of space and time scales (**Figure I.3**). Some phenomena are relatively easy for us to imagine, such as the size and duration of an afternoon thunderstorm or the dimensions of a sand dune. Other phenomena are so vast or so small that they are difficult to imagine. The number of stars and distances in our galaxy (and beyond!) or the internal arrangement of atoms in a mineral crystal are examples of such phenomena.

Some of the events we study occur in fractions of a second. Lightning is an example. Other processes extend over spans of tens or hundreds of millions of years. The lofty Himalaya Mountains began forming about 45 million years ago, and they continue to develop today.

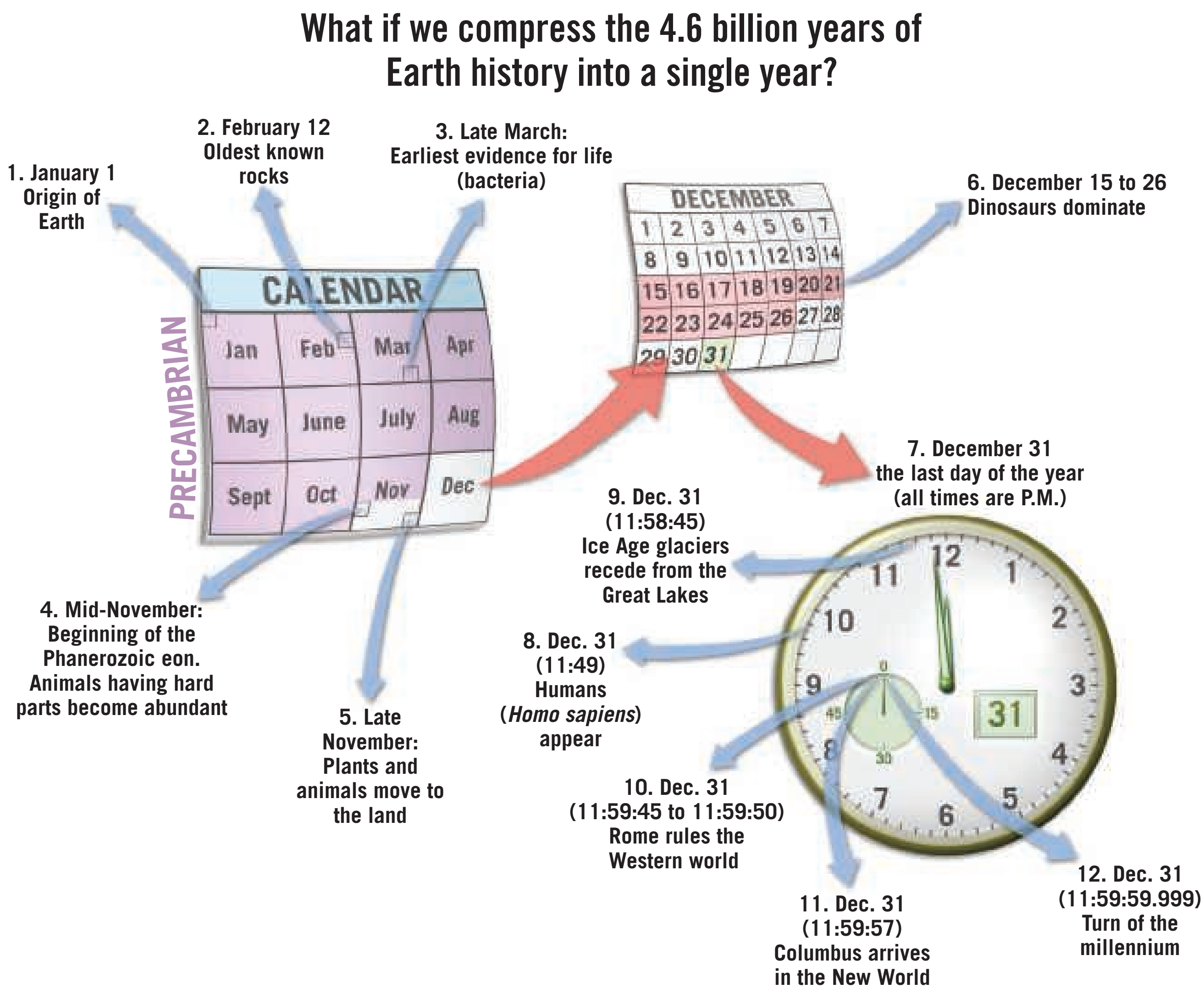
The concept of **geologic time**, the span of time since the formation of Earth, is new to many nonscientists. People are accustomed to dealing with increments of time that are measured in hours, days, weeks, and years. Our history books often examine events over spans of centuries, but even a century is difficult to appreciate fully. For most of us, someone or something that is 90 years old is *very old*, and a 1000-year-old artifact is *ancient*.

By contrast, those who study Earth science must routinely deal with vast time periods—millions or billions (thousands of millions) of years. When viewed in the context of Earth's nearly 4.6-billion-year history, an event that occurred 100 million years ago may be characterized as "recent" by a geologist, and a rock sample that has been dated at 10 million years may be called "young."

An appreciation for the *magnitude of geologic time* is important in the study of our planet because many processes are so gradual that vast spans of time are needed

Did You Know?

The circumference of Earth is slightly more than 40,000 km (nearly 25,000 mi). It would take a jet plane traveling at 1000 km/hr (620 mi/hr) 40 hours (1.7 days) to circle the planet.



SmartFigure I.4
Magnitude of geologic time
(https://goo.gl/odwyUE)
Tutorial

before significant changes occur. How long is 4.6 billion years? If you were to begin counting at the rate of one number per second and continued 24 hours a day, 7 days a week and never stopped, it would take about two lifetimes (150 years) to reach 4.6 billion!

The previous is just one of many analogies that have been conceived in an attempt to convey the magnitude of geologic time. Although helpful, all of them, no matter how clever, only begin to help us comprehend the vast expanse of Earth history. **Figure I.4** provides another interesting way of viewing the age of Earth.

Over the past 200 years or so, Earth scientists have developed a *geologic time scale* of Earth history. It subdivides the 4.6-billion-year history of Earth into many different units and provides a meaningful time frame within which the events of the geologic past are arranged (see Figure 8.23, page 266). The geologic time scale and the principles used to develop it are examined in Chapter 8.

I.1 CONCEPT CHECKS

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

Did You Know?

The Sun contains 99.86 percent of the mass of the solar system, and its circumference is 109 times that of Earth. A jet plane traveling at 1000 km/hr (620 mi/hr) would require nearly 182 days to circle the Sun.

I.2 Earth's Spheres

Describe the four "spheres" that comprise Earth's natural environment.

The images in **Figure I.5** are considered classics because they let humanity see Earth differently than ever before. These early views profoundly altered our conceptualizations of Earth and remain powerful images decades after they were first viewed. Such images remind us that our home is, after all, a planet—small, self-contained, and in some ways even fragile. Bill Anders, the *Apollo 8* astronaut who took the "Earthrise" photo, expressed it this way: "We came all this way to explore the Moon, and the most important thing is that we discovered the Earth."

Figure I.5 Two classic views of Earth from space (Johnson Space Center/NASA)

View called "Earthrise" that greeted *Apollo 8* astronauts as their spacecraft emerged from behind the Moon in December 1968. This classic image let people see Earth differently than ever before.

A.

This image taken from *Apollo 17* in December 1972 is perhaps the first to be called "The Blue Marble." The dark blue ocean and swirling cloud patterns remind us of the importance of the oceans and atmosphere.

B.

As we look closely at our planet from space, it becomes clear that Earth is much more than rock and soil. In fact, the most conspicuous features in Figure I.5A are not continents but swirling clouds suspended above the surface and the vast global ocean. These features emphasize the importance of air and water to our planet.

The closer view of Earth from space shown in Figure I.5B helps us appreciate why traditionally the physical environment is divided into three major parts: the water portion of our planet, called the hydrosphere; Earth's gaseous envelope, called the atmosphere; and, of course, the solid Earth, or geosphere.

It should be emphasized that our environment is highly integrated and not dominated by water, air, or rock alone. Rather, it is characterized by continuous interactions as air comes in contact with rock, rock with water, and water with air. Moreover, the biosphere, the totality of life-forms on our planet, extends into each of the three physical realms and is an equally integral part of the planet. Thus, Earth can be thought of as consisting of four major spheres: the hydrosphere, atmosphere, geosphere, and biosphere.

The interactions among Earth's four spheres are incalculably complex. **Figure I.6** provides an easy-to-visualize example. The shoreline is an obvious meeting place for rock, water, and air. In this scene, ocean waves that were created by the drag of air moving across the water are breaking against the rocky shore. The force of the water can be powerful, and the erosional work that is accomplished can be great.

Hydrosphere

Earth is sometimes called the *blue planet.* Water, more than anything else, makes Earth unique. The **hydrosphere** is a dynamic mass of water that is continually moving, evaporating from the oceans to the atmosphere, precipitating to the land, and flowing back to the ocean. The global ocean is certainly the most prominent feature of the hydrosphere, blanketing nearly 71 percent of Earth's surface to an average depth of about 3800 meters (12,500 feet). It accounts for more than 96 percent of Earth's water (**Figure I.7**). The hydrosphere also includes the freshwater found underground and in streams, lakes, and glaciers. Moreover, water is an important component of all living things.

Although freshwater accounts for just a tiny fraction of the total, its importance goes beyond supporting life

Did You Know?

The volume of ocean water is so large that if Earth's solid mass were perfectly smooth (level) and spherical, the oceans would cover Earth's entire surface to a uniform depth of more than 2000 m (1.2 mi)!

on land. Streams, glaciers, and groundwater are responsible for sculpturing and creating many of our planet's varied landforms. Water in the atmosphere, in the form of clouds and water vapor, plays a critical role in weather and climate processes.

Figure I.6 Interactions among Earth's spheres The shoreline is one obvious interface—a common boundary where different parts of a system interact. In this scene, ocean waves (hydrosphere) that were created by the force of moving air (atmosphere) break against a rocky shore (geosphere). The force of the water can be powerful, and the erosional work that is accomplished can be great. (Photo by Michael Collier)

Atmosphere

Earth is surrounded by a life-giving gaseous envelope called the **atmosphere** (**Figure I.8**). When we watch a high-flying jet plane cross the sky, it seems that the atmosphere extends upward for a great distance. However, when compared to the thickness (radius) of the solid Earth (about 6400 kilometers [4000 miles]), the atmosphere is a very shallow layer. Despite its modest dimensions, this thin blanket of air is nevertheless an integral part of the planet. It not only provides the air we breathe but also acts to protect us from the dangerous radiation emitted by the Sun. The energy exchanges that continually occur between the atmosphere and Earth's surface, as well as between the atmosphere and space, produce the effects we call *weather* and *climate*. Climate has a strong influence on

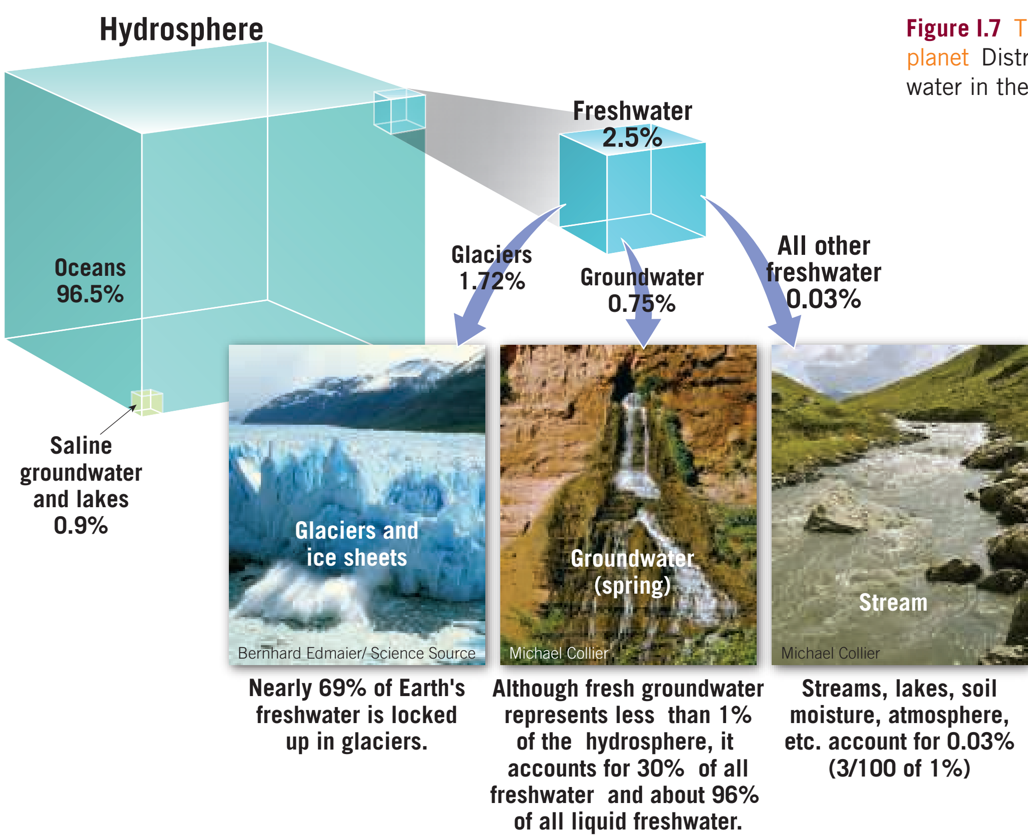


Figure I.7 The water planet Distribution of water in the hydrosphere.

Did You Know?
Since the mid-1970s, the global average surface temperature has increased by about 0.6°C (1°F). By the end of the twenty-first century, the global average surface temperature may increase by an additional 2° to 4.5°C (3.5° to 8.1°F).