LUTGENS TARBUCK Illustrated by TASA

Essentials of GEOLOGY

13e

Pearson

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Frederick K. Lutgens

Edward J. Tarbuck

Illustrated by

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Pearson

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SMARTFIGURES

Use your mobile device to scan a SmartFigure identified by a Quick Response (QR) code, and a video or animation illustrating the SmartFigure's concept launches immediately. No slow websites or hard-to-remember logins required. These mobile media transform textbooks into convenient digital platforms, breathe life into your learning experience, and help you grasp difficult geology concepts.

CONDOR VIDEO
https://goo.gl/dPwXf4

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PREFACE

The thirteenth edition of *Essentials of 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 this book is to meet the need of students for a readable and user-friendly text that is a valuable tool for learning the basic principles and concepts of geology.

Although many topical issues are treated in the 13th edition of *Essentials*, it should be emphasized that the main focus of this new edition remains the same as the focus of each of its predecessors: to promote student understanding of 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 & Important Features

This 13th edition is an extensive and thorough revision of *Essentials of Geology* 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 provide clear, understandable presentations that are accurate, engaging, and up-to-date. In the long history of this textbook, our number-one goal has always been to keep *Essentials of Geology* current, relevant, and highly readable for beginning students. With this goal as a priority, every part of this text has been examined carefully. The following are a few examples. In Chapter 9, the text and figures for Section 9.3, "Locating the Source of an Earthquake," are substantially revised, and a discussion of the USGS Community Internet Intensity Map project is added. In Chapter 11, the treatment of stress, strain, and rock deformation are substantially revised, as is the final section on isostatic balance. In Chapter 12, the mechanism responsible for long-runout landslides is updated, with reference to the occurrence of such landslides on Mars, and the 2015 Nepal earthquake is used as a landslide-triggering event. In Chapter 13, a section on the loss of wetlands in coastal Louisiana is added, and the treatment of flood control is updated and tightened. Many discussions, case studies, examples, and illustrations have been updated and revised.
- **SmartFigures make this 13th edition much more than a traditional textbook.** Through its many editions, an important strength of *Essentials* has always been clear, logically organized, and well-illustrated explanations. Now complementing and reinforcing this strength are a series of SmartFigures. Simply by scanning the Quick Response (QR) code next to a SmartFigure with a mobile device, students can link to hundreds of unique and innovative digital learning opportunities that will increase their understanding of important ideas. Each SmartFigure also displays a short URL for students who may lack a smartphone. SmartFigures are truly media that teach! The more than 200 SmartFigures in the 13th edition of *Essentials of Geology* are of five 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. **SmartFigures Condor.** The 10 *Project Condor* videos take you to sites in the American Mountain West. By coupling videos acquired by a quadcopter aircraft with ground-level views, effective narrative, and helpful animations, these videos will engage you in real-life case studies.
  4. **SmartFigure Animations.** These animations bring the art to life, illustrating and explaining difficult-to-visualize topics more effectively than static art alone.
  5. **SmartFigure Videos.** Rather than providing 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.
- **Objective-driven active learning path.** Each chapter in this 13th edition begins with *Focus on Concepts:* a set of learning objectives that correspond to the chapter's major sections. By identifying key knowledge and skills, these objectives help students prioritize the material. Each major section concludes with *Concept Checks* so that students can check their learning. Two end-of-chapter features complete the learning path. *Concepts in Review* is coordinated with the *Focus on Concepts* at the beginning of the chapter and with the numbered sections within the chapter. It is a readable and concise overview of key ideas, with photos, diagrams, and questions. Finally, the questions and problems in *Give It Some Thought* challenge learners by requiring higher-order thinking skills to analyze, synthesize, and apply the 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, resulting in a visual program that is clear and easy to understand.

Digital & Print Resources

MasteringGeology™ with Pearson eText

Used by over 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 *Essentials of Geology*, 13th 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 smartphones, tablets, or laptops to respond to questions in class. With Learning Catalytics, you can assess students in real-time, using open-ended question formats to uncover student misconceptions and adjust lectures accordingly.
- **After class:** Assign an array of assignments such as Mobile Field Trips, Project Condor videos, GigaPan activities, Google Earth Encounter Activities, Geoscience Animations, 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 material including videos, geoscience animations, *In the News* articles, Self Study Quizzes, Web Links, Glossary, and Flashcards.

Pearson eText 2.0 gives students access to the text whenever and wherever they can access the Internet. Features of Pearson eText include:

- Now available on smartphones and tablets using the Pearson eText 2.0 app
- Seamlessly integrated videos and other rich media
- Fully accessible (screen-reader ready)
- Configurable reading settings, including resizable type and night reading mode
- Instructor and student note-taking, highlighting, bookmarking, and search

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

For Instructors

Instructor Resource Center (Download Only)

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

- The IRC provides all the line art, tables, and photos from the text in JPEG files.
- PowerPoint™ Presentations: Found in the IRC are 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 the photos, art, and tables from the text, in order, have been loaded into PowerPoint slides.
  - **Lecture outline.** This set averages 50 slides per chapter and includes customizable lecture outlines with supporting art.
  - **Classroom Response System (CRS) questions.** Authored for use in conjunction with classroom response systems, these PowerPoint files allow you to electronically poll your class for responses to questions, pop quizzes, attendance, and more.
- The IRC provides Word and PDF versions of the *Instructor Resource Manual.*

Instructor Resource Manual (Download Only)

The *Instructor Resource Manual* has been designed to help seasoned and new instructors alike, offering the following sections in each chapter: an introduction to the chapter, outline, learning objectives/focus on concepts; teaching strategies; teacher resources; and answers to *Concept Checks* and *Give It Some Thought* questions from the textbook. www.pearsonhighered.com/irc

TestGen Computerized Test Bank (Download Only)

TestGen is a computerized test generator that lets instructors view and edit Test Bank questions, transfer questions to tests, and print the test in a variety of customized formats. This Test Bank includes more than 2,000 multiple-choice, 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, www.pearsonhighered.com/irc

For Students

***Laboratory Manual in Physical Geology*, 11th Edition** by the American Geological Institute and the National Association of Geoscience Teachers, edited by Vincent Cronin, illustrated by Dennis G. Tasa (0134446607)

This user-friendly, best-selling lab manual examines the basic processes of geology and their applications to everyday life. Featuring contributions from more than 170 highly regarded geologists and geoscience educators, along with an exceptional illustration program by Dennis Tasa, *Laboratory Manual in Physical Geology*, 11th edition, offers an inquiry- and activities-based approach that builds skills and gives students a more complete learning experience in the lab. Pre-lab videos linked from the print labs introduce students to the content, materials, and techniques they will use each lab. These teaching videos help TAs prepare for lab setup and learn new teaching skills. The lab manual is available in MasteringGeology with Pearson eText, allowing teachers to use activity-based exercises to build students' lab skills.

***Dire Predictions: Understanding Global Climate Change*, 2nd Edition** by Michael Mann, Lee R. Kump (0133909778)

Periodic reports from the Intergovernmental Panel on Climate Change (IPCC) evaluate the risk of climate change brought on by humans. But the sheer volume of scientific data remains inscrutable to the general public, particularly to those who may still question the validity of climate change. In just over 200 pages, this practical text presents and expands upon the latest climate change data and scientific consensus of the IPCC's *Fifth Assessment Report* in a visually stunning and undeniably powerful way to the lay reader. Scientific findings that provide validity to the implications of climate change are presented in clear-cut graphic elements, striking images, and understandable analogies. The second edition integrates mobile media links to online media. The text is also available in various eText formats, including an eText upgrade option from MasteringGeology courses.

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, Christian Botting. We appreciate his enthusiasm, hard work, and quest for excellence. We also appreciate our conscientious project manager, Lizette Faraji, 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 13th edition of *Essentials of Geology* was certainly improved by the talents of our developmental editor, Margot Otway. Our sincere thanks to Margot for her fine work. It was the job of the production team, led by Patty Donovan at SPi Global, to turn our manuscript into a finished product. The team also included copyeditor Kitty Wilson, proofreader Erika Jordan, 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 four people who were very important contributors to this project:

- **Dennis Tasa.** 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 value not only his artistic talents, hard work, patience, and imagination but his friendship as well.
- **Michael Collier.** 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 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 *Essentials of Geology*, 13th edition. Thanks, Michael.
- **Callan Bentley.** Callan Bentley made many contributions to the new edition of *Essentials*. 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 assisted with the revision of Chapter 11, "Crustal Deformation & Mountain Building," and 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.
- **Scott Linneman.** We were fortunate to have Scott Linneman join the *Essentials of Geology* team as we prepared the 13th edition. Scott provided many thoughtful suggestions and ideas and was responsible for revising Chapter 12, "Mass Movement on Slopes: The Work of Gravity." Scott is an award-winning professor of geology and science education and director of the Honors Program at Western Washington University in Bellingham.

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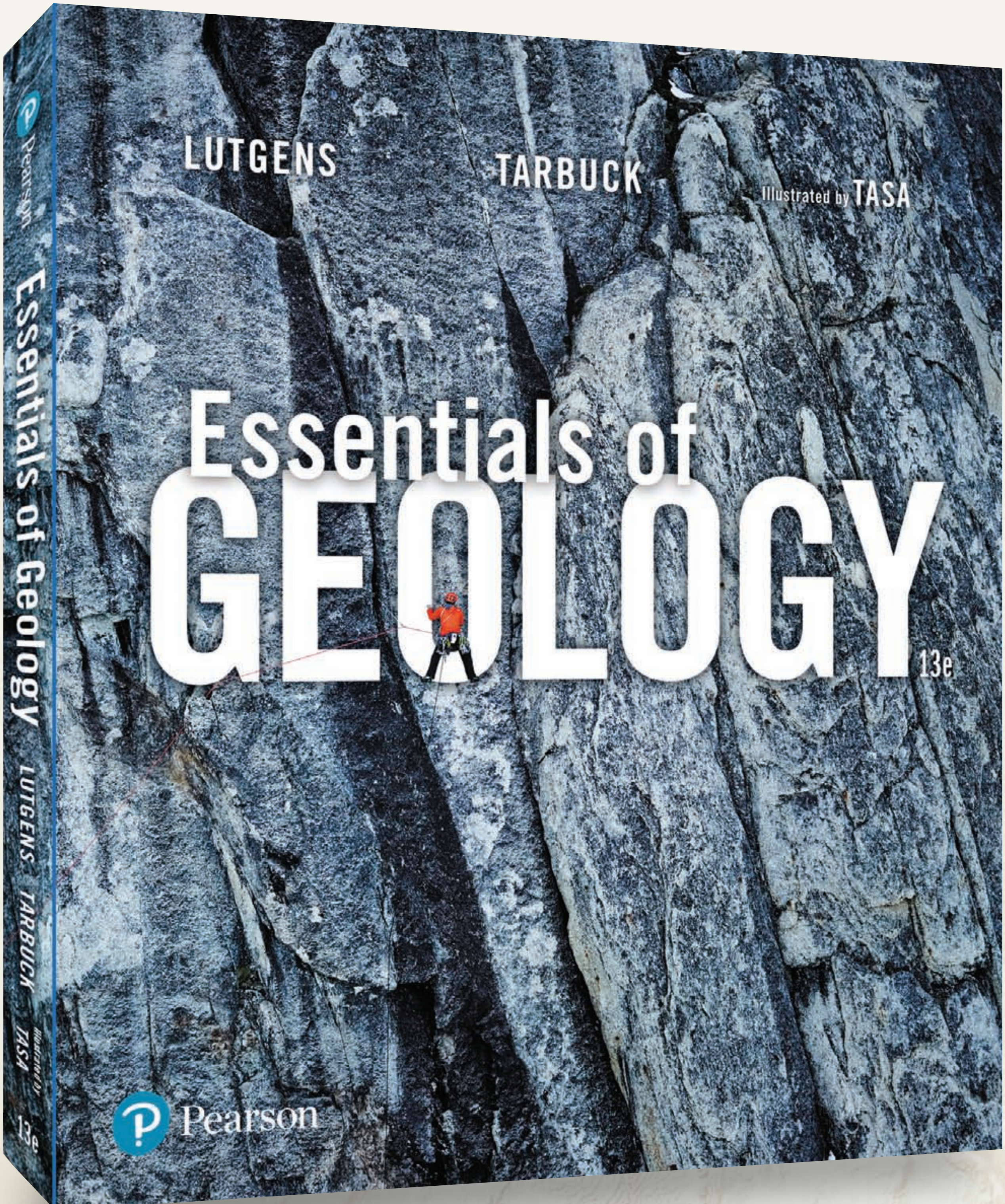
Last but certainly not least, we gratefully acknowledge the support and encouragement of our wives, Nancy Lutgens and Joanne Bannon. Preparation of this edition of *Essentials* would have been far more difficult without their patience and understanding.

Fred Lutgens
Ed Tarbuck

Use Dynamic Media to Bring Geology to Life



Bring Field Experience to Students' Fingertips...

NEW! QR Codes link out to SmartFigures

Quick Response (QR) codes link out to over 200 videos and animations, giving readers immediate access to five types of dynamic media: Project Condor Quadcopter Videos, Mobile Field Trips, Tutorials, Animations, and Videos to help visualize physical processes and concepts. SmartFigures extend the print book to bring geology to life.

How to download a QR Code Reader

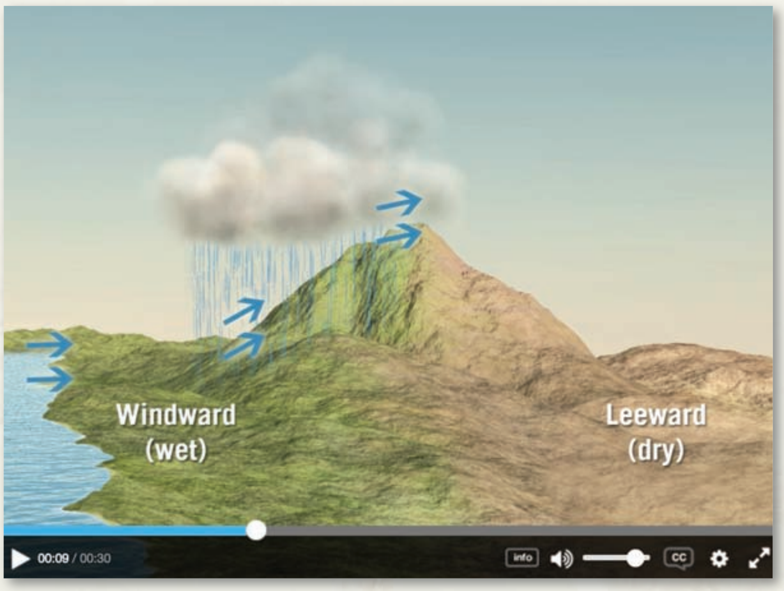
Using a smartphone, students are encouraged to download a QR Code reader app from Google Play or the Apple App Store. Many are available for free. Once downloaded, students open the app and point the camera to a QR Code. Once scanned, they're prompted to open the url to immediately be connected to the digital world and deepen their learning experience with the printed text.

NEW! SmartFigure: Project Condor Quadcopter Videos

Bringing Physical Geology to life for geology students, three geologists, using a quadcopter-mounted GoPro camera, have ventured into the field to film 10 key geologic locations and processes. These process-oriented videos, accessed through QR codes, are designed to bring the field to the classroom and improve the learning experience within the text.

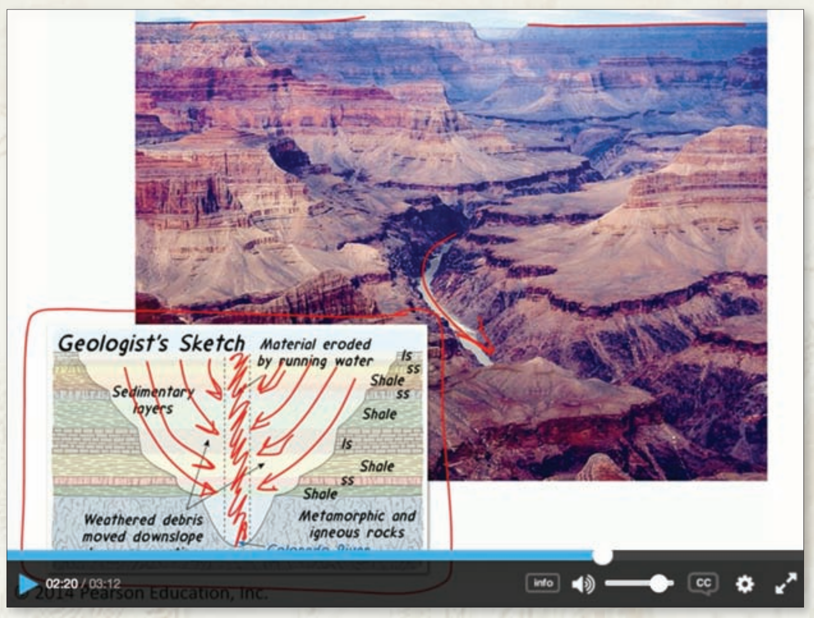
...with SmartFigures

NEW! SmartFigure: Mobile Field Trips
On each trip, students 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 QR codes throughout the text. New Mobile Field Trips for the 13th edition include *Formation of a Water Gap, Ice Sculpts Yosemite, Fire and Ice Land, Dendrochronology*, and *Desert Geomorphology*.



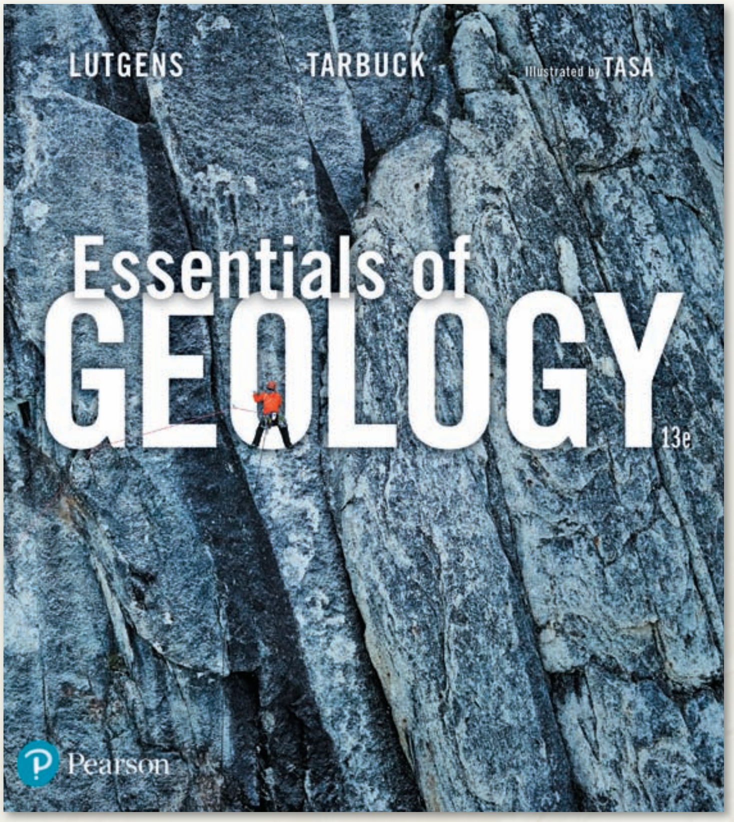
NEW! SmartFigure: Animations
Brief animations created by text illustrator Dennis Tasa animate a process or concept depicted in the textbook's figures. With QR codes, students are given a view of moving figures rather than static art to depict how geologic processes move throughout time.

HALLMARK! SmartFigure: Tutorials
These brief tutorial videos present the student with a 3- to 4-minute feature (mini-lesson) narrated and annotated by Professor Callan Bentley. Each lesson examines and explains the concepts illustrated by the figure. With over 100 SmartFigure Tutorials inside the text, students have a multitude of ways to enjoy art that teaches.



Award-Winning Contributing Authors

The language of this text is straightforward and written to be understood. Clear, readable discussions with a minimum of technical language is the rule. In the 13th edition, we have continued to improve readability with the addition of two new contributing authors, Scott Linnenman and Callan Bentley.



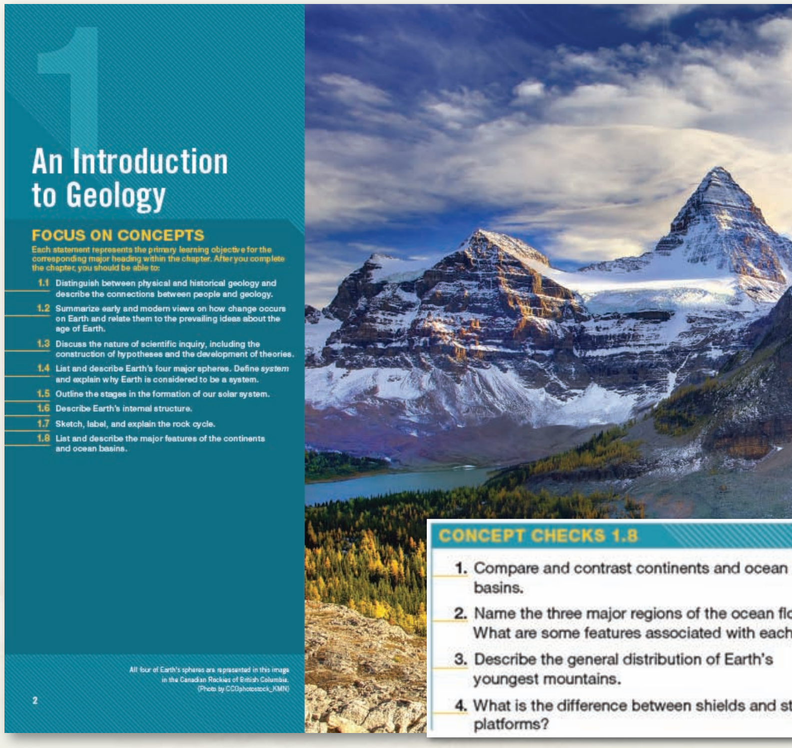
Scott Linneman provided many thoughtful suggestions and idea throughout the text and was responsible **for revising Chapter 12: Mass Movement on Slopes: The Work of Gravity.** Linneman is an award-winning Professor of Geology and Science Education and director of the Honors Program at Western Washington University in Bellingham.

Callan Bentley is 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. Bentley assisted with the **revision of Chapter 11: Crustal Deformation and Mountain Building** and created the SmartFigure Tutorials that appear throughout the text. As students take advantage of these outstanding learning aids, they will hear his voice explaining the ideas.

Objective-Driven Active Learning

Most chapters have been designed to be self-contained so that materials may be taught in a different sequence, according to the preference of the instructor or the needs of the laboratory. Thus, an instructor who wishes to discuss erosional processes prior to earthquakes, plate tectonics, and mountain building may do so without difficulty.

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.



1

An Introduction to Geology

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 Describe Earth's internal structure.

1.7 Sketch, label, and explain the rock cycle.

1.8 List and describe the major features of the continents and ocean basins.

All four of Earth's spheres are represented in this image in the Canadian Rockies of British Columbia. (Photo by CCOphotostock_KMN)

2

CONCEPT CHECKS 1.8

1. Compare and contrast continents and ocean basins.
2. Name the three major regions of the ocean floor. What are some features associated with each?
3. Describe the general distribution of Earth's youngest mountains.
4. What is the difference between shields and stable platforms?

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

Give It Some Thought activities challenge learners by requiring higher-order thinking skills to analyze, synthesize, and apply the material.

GIVE IT SOME THOUGHT

1 The length of recorded history for humankind is about 5000 years. Clearly, most people view this span as being very long. How does it compare to the length of geologic time? Calculate the percentage or fraction of geologic time that is represented by recorded history. To make calculations easier, round the age of Earth to the nearest billion.

2 After entering a dark room, you turn on a wall switch, but the light does not come on. Suggest at least three hypotheses that might explain this observation. Once you have formulated your hypotheses, what is the next logical step?

b. If you are flying in a commercial jet at an altitude of 12 kilometers (about 39,000 feet), about what percentage of the atmosphere's mass is below you?

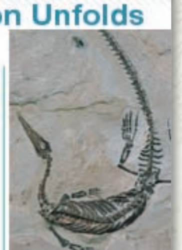
CONCEPTS IN REVIEW

Plate Tectonics: A Scientific Revolution Unfolds

2.1 From Continental Drift to Plate Tectonics

Summarize the view that most geologists held prior to the 1960s regarding the geographic positions of the ocean basins and continents.

- Fifty years ago, most geologists thought that ocean basins were very old and that continents were fixed in place. Those ideas were discarded with a scientific revolution that revitalized geology: the theory of plate tectonics. Supported by multiple kinds of evidence, plate tectonics is the foundation of modern Earth science.

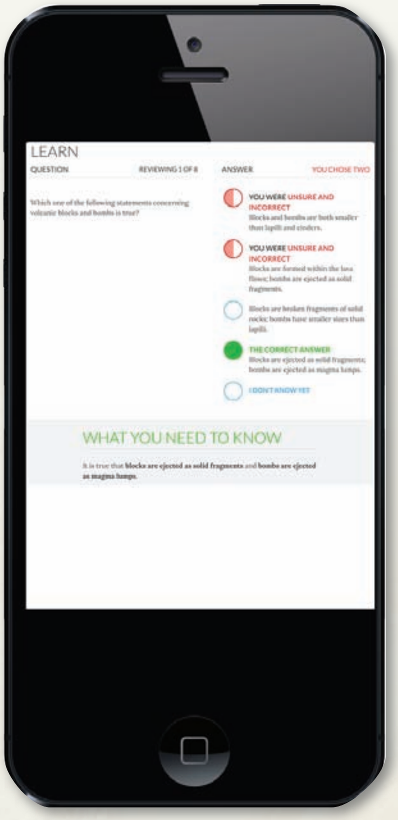


Concepts in Review provides students with a structured review of the chapter. Consistent with the Focus on Concepts and Concept Checks, the **Concepts in Review** is structured around the learning objective for each section.

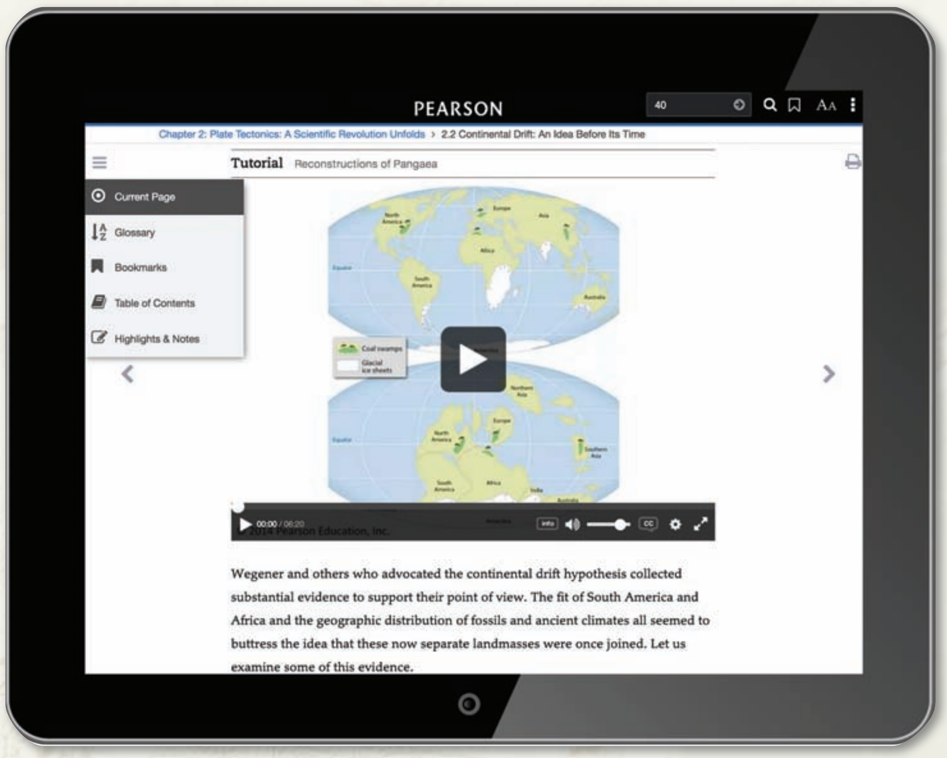
Continuous Learning
Before, During, and After Class

BEFORE CLASS

Mobile Media and Reading Assignments Ensure Students Come to Class Prepared



Updated! Dynamic Study Modules help students study effectively by continuously assessing student performance and providing practice in areas where students struggle the most. Each Dynamic Study Module, accessed by computer, smartphone, or tablet, promotes fast learning and long-term retention.



NEW! Interactive eText 2.0 gives students access to the text whenever they can access the internet. eText features include:

- 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.

Pre-Lecture Reading Quizzes are easy to customize and assign

Reading Questions ensure that students complete the assigned reading before class and stay on track with reading assignments. Reading Questions are 100% mobile ready and can be completed by students on mobile devices.

with MasteringGeology™

DURING CLASS

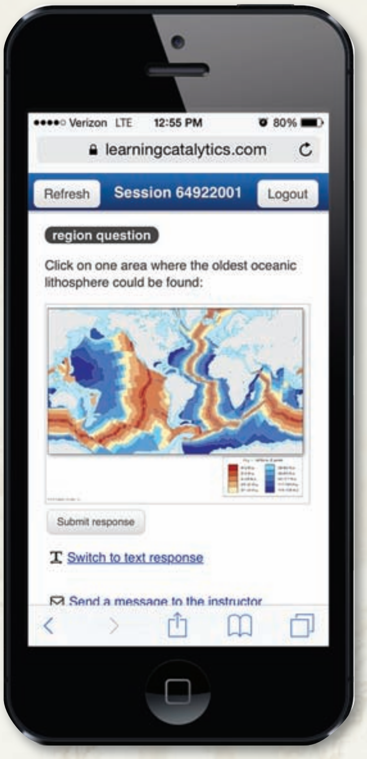
Engage students with Learning Catalytics

What has teachers and students excited? 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. With Learning Catalytics, you can:

- Assess students in real time using open-ended question formats to uncover student misconceptions and adjust lecture accordingly.
- Automatically create groups for peer instruction based on student response patterns, to optimize discussion productivity.

"My students are so busy and engaged answering Learning Catalytics questions during lecture that they don't have time for Facebook."

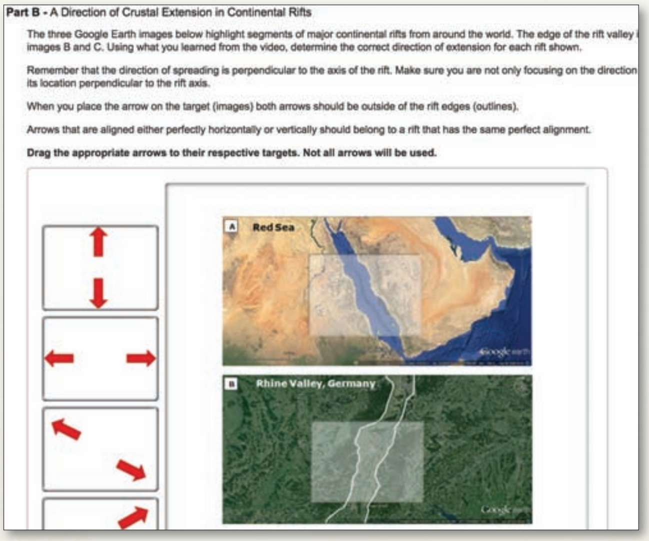
Declan De Paor, Old Dominion University



MasteringGeology™

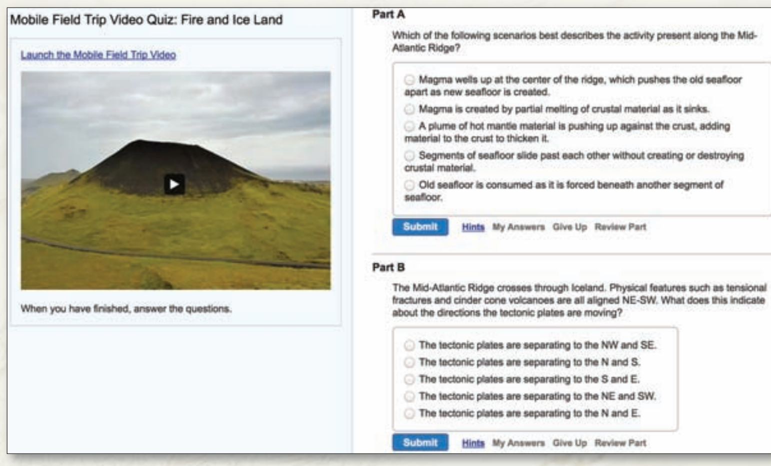
AFTER CLASS

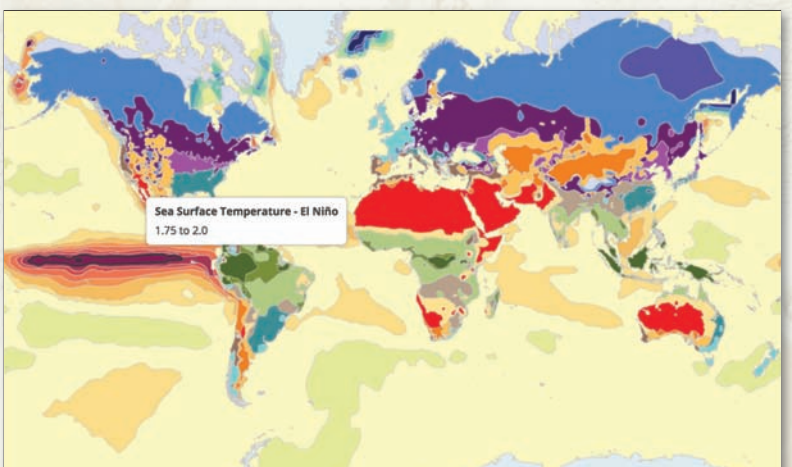
Easy to Assign, Customizable, Media-Rich, and Automatically Graded Assignments



NEW! Project Condor Quadcopter Videos
A series of quadcopter videos with annotations, sketching, and narration help improve the way students learn about monoclines, streams and terraces, and so much more. In MasteringGeology™, these videos are accompanied by assessments to test student understanding.

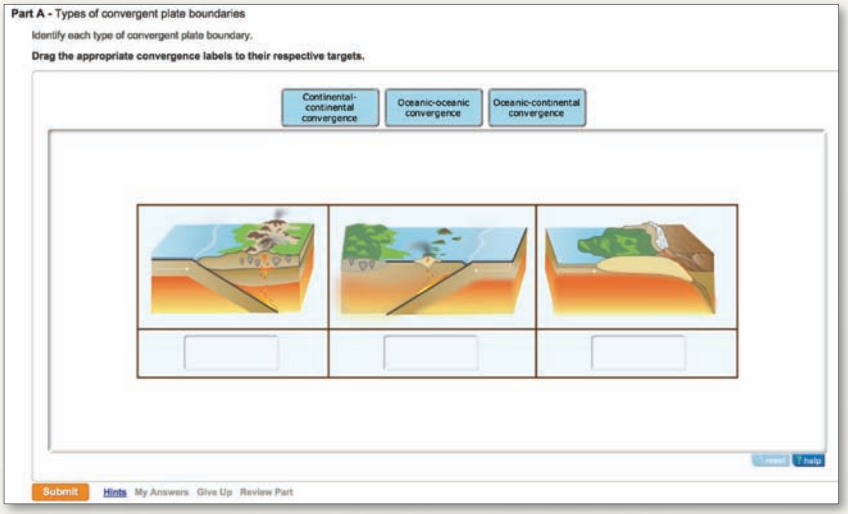
NEW! 24 Mobile Field Trips take students to iconic geological locations with Michael Collier in the air and on the ground to see and learn about geologic locations that relate to concepts in the chapter. In Mastering, these videos are accompanied by auto-gradable assessments that will track what students have learned.





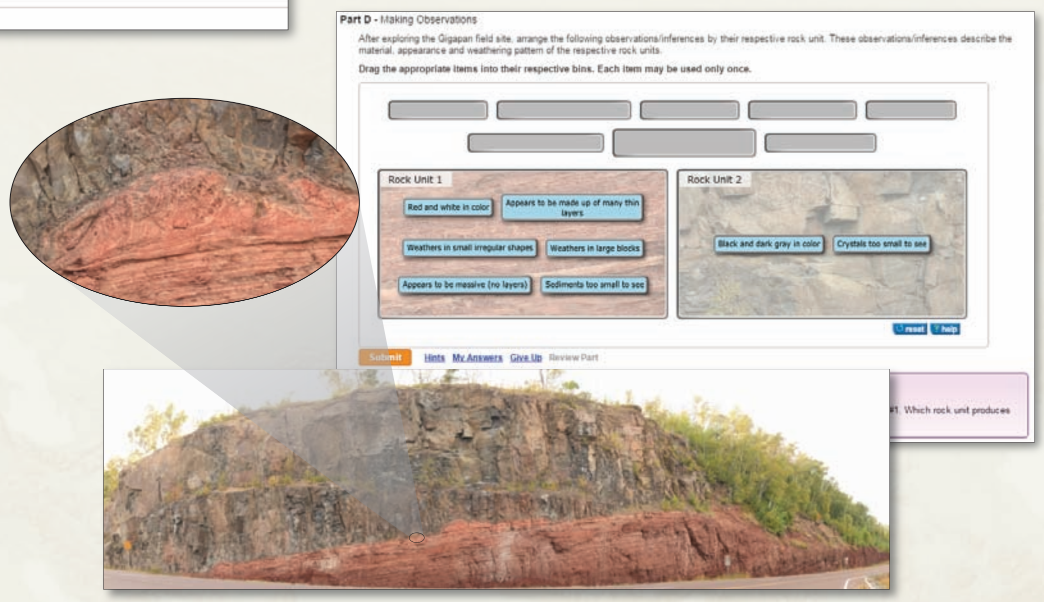
NEW! MapMaster 2.0
GIS-inspired interactive map activities help to enhance students' data analysis and spatial reasoning skills, and overall geologic literacy.

www.masteringgeology.com



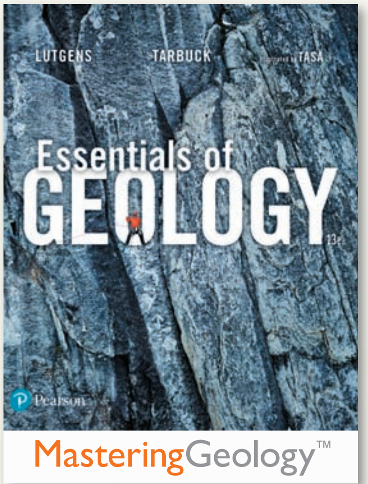
GeoTutors
These coaching activities help students master important physical geoscience concepts with highly visual, kinesthetic activities focused on critical thinking and application of core geoscience concepts.

GigaPan Activities allow students to take advantage of a virtual field experience with high-resolution imaging technology developed by Carnegie Mellon University in conjunction with NASA.



Encounter Activities
Using Google Earth™ to visualize and explore Earth's physical landscape, Encounter activities provide rich, interactive explorations of geology and earth science concepts. Dynamic assessments include questions related to core geology concepts. All explorations include corresponding Google Earth KMZ media files, and questions include hints and specific wrong-answer feedback to help coach students toward mastery of the concepts.

Resources for YOU, the Instructor



MasteringGeology™ provides you with everything you need to prep for your course and deliver a dynamic lecture, all in one convenient place. Resources include:

LECTURE PRESENTATION ASSETS FOR EACH CHAPTER

- PowerPoint Lecture Outlines
- PowerPoint clicker questions and Jeopardy-style quiz show questions
- All book images and tables in JPEG and PowerPoint formats

TEST BANK

- The Test Bank in Microsoft Word formats
- Computerized Test Bank, which includes all the questions from the printed test bank in a format that allows you to easily and intuitively build exams and quizzes.

TEACHING RESOURCES

- Instructor Resource Manual in Microsoft Word and PDF formats
- Pearson Community Website (https://communities.pearson.com/northamerica/s/)

Measuring Student Learning Outcomes?

All MasteringGeology assignable content is tagged to learning outcomes from the book and Bloom's Taxonomy. You also have the ability to add your own learning outcomes, helping you track student performance against your learning outcomes. You can view class performance against the specified learning outcomes and share those results quickly and easily by exporting to a spreadsheet.

SELECT MAJOR CHANGES IN *ESSENTIALS OF GEOLOGY* 13E

Global

- QR codes for additional SmartFigures added, including Mobile Field Trips; SmartFigure types indicated in figure captions

Chapter 1

- Subsection "Origin of Planet Earth" substantially revised
- New *Did You Know* feature added (Section 1.5)
- Two *Give It Some Thought* questions modified
- Substantively revised figures: 1.13, 1.17, 1.18, 1.20, 1.23, 1.24
- Eleven new photographs

Chapter 2

- *Concept Check* questions for Section 2.6 revised
- Treatment of whole-mantle convection and plumes substantially rewritten for clarity and currency (Section 2.10)
- One *Give It Some Thought* question added and one modified
- Substantively revised figures: 2.9, 2.11, 2.17–2.19, 2.29, 2.30, 2.31, 2.35
- Two new photographs

Chapter 3

- Introduction to mineral properties revised (Section 3.4)
- One new *Give It Some Thought* question added; one modified
- Figure 3.33 now combines illustration and tabular data
- New figures: 3.26, 3.28, 3.33. Figures that have been revised substantively: 3.5 (atomic weight changed to atomic mass), 3.8, 3.9. 3.11, 3.12
- Three new photographs

Chapter 4

- Treatment of magmatic volatiles revised for clarity (Section 4.1)
- Subsection "Compositional Categories" rewritten for clarity; replaces former subsection "Granitic (Felsic) versus Basaltic (Mafic) Compositions" (Section 4.2)
- Terminology "felsic/intermediate/mafic" given priority over "granitic/andesitic/basaltic" (Section 4.4)
- Subsection "Temperature Increase: Melting Crustal Rocks" substantially rewritten for clarity (Section 4.5)
- Improved description of how mineral grains interact with a melt of changing composition
- Footnote added noting complex formation history of Palisades Sill (under "Magmatic Differentiation and Crystal Settling" in Section 4.6)
- Stocks now treated in the section on batholiths (paragraph 4 under "Batholiths" in Section 4.8)
- One *Give It Some Thought* question modified
- Substantively revised figures: 4.5, 4.12, 4.16, 4.17, 4.33
- Eight new photographs

Chapter 5

- Section 5.2, "The Nature of Volcanic Eruptions," largely rewritten
- Paragraph added to cover silica-rich pyroclastic intraplate volcanism
- In Section 5.10, volcanism at divergent boundaries now treated before volcanism at divergent boundaries
- Two new *Give It Some Thought* questions added; one modified
- New figures: 5.3 (replaces 12e Table 5.1), 5.8 (replaces 12e Figure 5.7). Figures that have been revised substantively: 5.5, 5.12, 5.16, 519, 5.21, 5.32
- Twelve new photographs

Chapter 6

- New discussion of oxidation as an agent of weathering ("Oxidation" in Section 6.3)
- In the subsection "Controls of Soil Formation," order of topics changed to put "Time" later (Section 6.5)
- Two new *Give It Some Thought* questions added
- Substantively revised figures: 6.11, 6.24
- Five new photographs

Chapter 7

- Updated treatment of energy resources, including expanded discussion of emissions from coal combustion and changes in oil and gas production due to fracking (Section 7.8)
- Revised treatment of the slowest limb of the carbon cycle (Section 7.9, including Figure 7.34)
- One new *Give It Some Thought* question added
- New figure, 7.33. Figure 7.30 substantively expanded
- Five new photographs

Chapter 8

- New contextual paragraph added at start of Section 8.1
- Improved introduction of temperature and pressure as agents of metamorphism at the end of Section 8.1
- Description and figure of a stretched pebble conglomerate added to help students understand the concept of differential stress (subection "Differential Stress" in Section 8.2)
- In subsection"Other Metamorphic Textures," improved treatment of nonfoliated metamorphic rocks, including coverage of hornfels (Section 8.3)
- One new *Give It Some Thought* question
- Four figures added: 8.5, 8.23, 8.27, 8.29. Figures that have been modified substantively: 8.4, 8.6, 8.10, 8.11, 8.24, 8.26
- Eight new photographs

Chapter 9

- Subsection "Faults & Large Earthquakes" substantially rewritten for clarity and conciseness (Section 9.1)
- Section 9.3, "Locating the Source of an Earthquake," substantially revised, including three figures
- Discussion added for the U.S.G.S. Community Internet Intensity Map project, including a figure (within "Intensity Scales" in Section 9.4)
- Section 9.8 reorganized to put the subsection "Probing Earth's Interior: "Seeing" Seismic Waves" first; treatment of Earth's layered structure substantially revised
- Two new *Give It Some Thought* questions added;
- Two figures added: 9.16, 9.23. Figures that have been modified substantively: 9.10, 9.13–9.15, 9.27 (completely redrawn)
- Two new photographs

Chapter 10

- One *Give It Some Thought* question replaced with a new one
- One new figure added: 10.4 (two-page global sea-floor map). Figures that have been modified substantively: 10.12, 10.16, 10.21
- Two new photographs

Chapter 11

- Treatment of deformation, stress, and strain in Section 11.1 significantly clarified
- Discussion of the factors that affect how rocks deform significantly clarified (Section 11.1)
- Distinction between faults and joints now covered at the start of Section 11.3
- Description of thrust faulting in the formation of the Himalayas improved (paragraph 4 under "The Himalayas" in Section 11.6)
- Description of isostatic balance and its effects rewritten (Section 11.7)
- One new *Give It Some Thought* question added

- Three figures added: 11.4, 11.5, 11.21. Figures that have been modified substantively: 11.3, 11.6–11.8, 11.10, 11.12, 11.14–11.16, 11.18, 11.19, 11.23, 11.27, 11.29, 11.30
- Six new photographs

Chapter 12

- "Mass movement" introduced in place of older term "mass wasting."
- Landslides introduced more thoroughly at the start of Section 12.1
- Treatment of mass movements that lack an obvious trigger clarified and moved to the start of section 12.2
- Treatment of mechanism for long-runout landslides updated (subsection "Rate of Movement" in Section 12.3)
- Definition and description of normal faults made clearer (first paragraph of section "Normal Faults" in Section 11.3)
- 2015 Nepal earthquake added as example of a landslide-triggering event (subsection "Examples from Plate Boundaries: California and Nepal" in Section 12.2)
- New *Did You Know* about 2013 Bingham Canyon Copper Mine landslide added (Section 12.2)
- One new *Give It Some Thought* question added
- Figure 12.11 modified substantively
- Six new photographs

Chapter 13

- Section 13.1 largely rewritten
- Selected paragraphs of Section 13.2 tightened; headward erosion added as final paragraph in section "Drainage Basins; formation of a water gap added at the end of "Drainage Patterns."
- Section on the loss of wetlands from the Mississipi delta and coastal Louisiana added (subsection "Vanishing Wetlands" in Section 13.7)
- Treatment of flood control updated and tightened (Section 13.8)
- One new *Give It Some Thought* question added
- Figure 13.29 added; "Floods & Flood Control" now supported by four new figures 13.31–13.33; Figure 13.24 substantively changed
- Three new photographs

Chapter 14

- Section added on Geothermal Energy (p. 385 in Section 14.5)
- Section added on the impact of prolonged drought on groundwater resources (p. 387 of Section 14.5)
- Three figures added: 14.21, 14.23, 14.29. Figures that have been modified substantively: 14.1, 14,3, 14,22
- Three new photographs

Chapter 15

- Information on Larsen B ice shelf updated (p. 402 in Section 15.1)
- New *Give It Some Thought* question
- Figures that have been replaced or modified substantively: 15.3, 15.4, 15.6, 15.9, 15.11, 15.22
- Five new photographs

Chapter 16

- New *Give It Some Thought* question
- Figures that have been modified substantively: 16.2, 16,3, 16.9
- Three new photographs

Chapter 17

- Section 17.1 ("The Shoreline & Ocean Waves") has been revised to cover both the basic features of shorelines and the behavior of ocean waves. Beaches are now covered along with shoreline processes in Section 17.2 ("Beaches & Shoreline Processes"). Both sections have been tightened to focus more on processes and less on terminology
- Explanation of wave refraction reworded for greater clarity
- Section 17.6 ("Stabilizing the Shore") moved to later in the chapter than in the preceding edition; it now follows Sections 17.4 ("Contrasting America's Coasts") and 17.5 ("Hurricanes: The Ultimate Hazard")
- Section 17.4 ("Contrasting America's Coasts") reorganized to start with the the basic classification of coasts as emergent or submergent. This section also now uses cliff retreat at Pacifica, CA as a topical example of erosion on an emergent coast
- Section 17.5 ("Hurricanes: The Ultimate Hazard") now uses Superstorm Sandy as an example and covers the effect of sea-level rise on vulnerability
- The response of Staten Island to Superstorm Sandy added as an example of a decision to change how coastal land is used ("Changing Land Use" in Section 17.6)
- Four new photographs

Chapter 18

- Section "Correlation within Limited Areas" tightened (in Section 18.3)
- Text and figures for Section 18.4, "Numerical Dating with Nuclear Decay," substantially revised for better clarity and effectiveness
- Section 18.5, "Determining Numerical Dates for Sedimentary Strata," moved so that it now immediately follows Section 18.4
- Two *Give It Some Thought* questions added
- Figures that have been modified substantively: 18.19–18.22, 18.24
- Two new photographs

Chapter 19

- In the section "Oxygen in the Atmosphere," updated treatment of the effects on land organisms of the apparent high levels of oxygen in the Pennsylvanian (in Section 19.3)
- Acasta Gneiss added to discussion of Earth's oldest dated rocks (in Section 19.4)
- Section "Supercontinents and Climate" substantially revised (in Section 19.4)
- Figure 19.17 added, illustrating the major provinces of the Appalachian Mountains (in Section 19.5)
- Paragraphs on the origin of prokaryotes, eukaryotes, and photosynthesis substantively revised ("Earth's First Life: Prokaryotes" in Section 19.6)
- Updated discussion of the origin of tetrapods ("Vertebrates Move to Land" in Section 19.7)
- Updated treatment of the extinction of nonavian dinosaurs ("Demise of the Dinosaurs" in Section 19.7)
- Updated treatment of hominin evolution ("Humans: Mammals with Large Brains & Bipedal Locomotion" in Section 19.9)
- New *Give It Some Thought* question
- Five new photographs

Chapter 20

- Within Section 20.2 ("Detecting Climate Change,") section "Climates Change" added, including Figures 20.2 and 20.3
- In Section 20.5, context-setting second paragraph added
- Section "Rising CO_2 Levels" updated to include current data, including updated discussion of tropical deforestation
- Section "The Atmosphere's Response" updated to reflect the 2013–2014 IPCC 5th Assessment Report
- Section "The Role of Trace Gases" updated to reflect current science, and section "How Aerosols Influence Climate" moved into this section
- Section 20.7, "Climate Feedback Mechanisms," updated to reflect current science
- Table 20.1, "IPCC Projections for the Late Twenty-First Century," added to Section 20.8, and section updated to reflect current science
- Section "The Changing Arctic" largely revised
- Section "The Potential for Surprises" updated
- Three new *Give it Some Thought* questions added
- New figures added: 20.2, 20.3, 20.8, 20.34. Figures modified or updated substantively: 20.21, 20.23, 20.25, 20.26, 20.31, 20.25. Several new photographs.

Essentials of GEOLOGY

13e

1 An Introduction to Geology

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 Describe Earth's internal structure.

1.7 Sketch, label, and explain the rock cycle.

1.8 List and describe the major features of the continents and ocean basins.

All four of Earth's spheres are represented in this image in the Canadian Rockies of British Columbia. (Photo by CCOphotostock_KMN)

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 are ice ages like, and will there be another? How were ore deposits formed? Where should we search for water? Will plentiful oil be found if a well is drilled in a particular location? Geologists seek to answer these and many other questions about Earth, its history, and its resources.

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 features that are continental or global in scale, such as the formation of major mountain ranges.

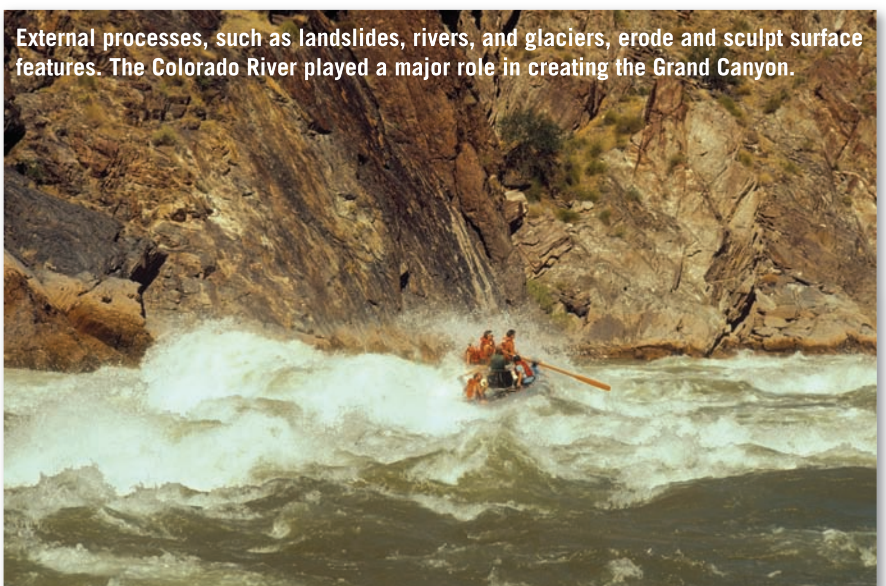
Physical and Historical Geology

Geology is traditionally divided into two broad areas—physical and historical. **Physical geology**, which is the primary focus of this book, examines the materials composing Earth and seeks to understand the many processes that operate beneath and upon its surface (**Figure 1.1**). The aim of **historical geology**, on the other hand, is to understand the origin of Earth and its development through time. Thus, it strives to establish an orderly chronological arrangement of the multitude of physical and biological changes that have occurred in the geologic past. The study of physical geology logically precedes the study of Earth history because we must first understand how Earth works before we attempt to unravel its past. It should also be pointed out that physical and historical geology are divided into many areas of specialization. Every chapter of this book represents one or more areas of specialization in geology.

Geology is perceived as a science that is done outdoors—and rightly so. A great deal of geology is based on observations, measurements, and experiments conducted in the field. But geology is also done in the laboratory, where, for example, 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,

▼ **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)

A.



External processes, such as landslides, rivers, and glaciers, erode and sculpt surface features. The Colorado River played a major role in creating the Grand Canyon.

B.

Internal processes are those that occur beneath Earth's surface. Sometimes they lead to the formation of major features at the surface, such as Italy's Mt. Etna.

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. (Photo by Carsten Peter/National Geographic Image Collection/Alamy) **B.** This researcher is using a petrographic microscope to study the mineral compositions of rock samples. (Photo by Jon Wilson/Science Source)

Did You Know?
Each year an average American requires huge quantities of Earth materials. Imagine receiving your annual share in a single delivery. A large truck would pull up to your home and unload 12,965 lb of stone, 8945 lb of sand and gravel, 895 lb of cement, 395 lb of salt, 361 lb of phosphate, and 974 lb of other nonmetals. In addition, there would be 709 lb of metals, including iron, aluminum, and copper.

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 the way we will explore numerous important relationships between people and the natural environment. Many of the problems and issues addressed by geology are of practical value to people.

Natural hazards are a part of living on Earth. Every day they adversely affect millions of people worldwide and are responsible for staggering damages. 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**).

According to the United Nations, more people now live in cities than in rural areas. This global trend toward urbanization concentrates millions of people into megacities, many of which are vulnerable to natural hazards. Coastal sites are becoming more vulnerable because development often destroys natural defenses such as wetlands and sand dunes. In addition, there is a growing threat associated with human influences on the Earth system; one example is sea-level rise that is linked to global climate change. Some megacities are exposed to seismic (earthquake) and volcanic hazards, the threat of which may be compounded by inappropriate land use, poor construction practices, and rapid population growth.

Resources are another important focus of geology that is of great practical value to people. Resources include water and soil, a great variety of metallic and nonmetallic minerals, and energy (**Figure 1.4**). Together they form the very foundation of modern civilization. Geology deals not only with the formation and occurrence of these vital resources but also with maintaining

▼ **Figure 1.3 Earthquake destruction** During a three-week span in spring 2015, the small Himalayan country of Nepal experienced two major earthquakes. There were more than 8000 fatalities and nearly a half million homes destroyed. Geologic hazards are natural processes. They become hazards only when people try to live where these processes occur. The debris flow shown in Figure 1.15 and the volcanic eruption related to Figure 1.17 are also examples of geologic hazards that had deadly consequences. (Photo by Roberto Schmidt/AFP/Getty Images)

Did You Know?
It took until about the year 1800 for the world population to reach 1 billion. By 1927, the number had doubled to 2 billion. According to United Nations estimates, world population reached 7 billion in late October 2011. We are currently adding about 80 million people per year to the planet.

supplies and with the environmental impact of their extraction and use.

Geologic processes clearly have an impact on people. In addition, we humans can dramatically influence geologic processes. For example, landslides and river flooding occur naturally, but the magnitude and frequency of these processes can be affected significantly by human activities such as clearing forests, building cities, and constructing dams. Unfortunately, natural systems do not always adjust to artificial changes in ways that we can anticipate. Thus, an alteration to the environment that was intended to benefit society sometimes has the opposite effect.

At appropriate places throughout this textbook, you will have opportunities to examine different aspects of our relationship with the physical environment. Nearly every chapter addresses some aspect of natural hazards, resources, and the environmental issues associated with each. Significant parts of some chapters provide the basic geologic knowledge and principles needed to understand environmental problems.

▲ **Figure 1.4 Copper mining** Mineral and energy resources represent an important link between people and geology. This large open pit mine is in Arizona. (Photo by Ball Miwako/Alamy)

CONCEPT CHECKS 1.1

1. Name and distinguish between the two broad subdivisions of geology.
2. List at least three different geologic hazards.
3. Aside from geologic hazards, describe another important connection between people and geology.

1.2 The Development of Geology

Summarize early and modern views on how change occurs on Earth and relate them to the prevailing ideas about the age of Earth.

The nature of our Earth—its materials and processes—has been a focus of study for centuries. Writings about such topics as fossils, gems, earthquakes, and volcanoes date back to the early Greeks, more than 2300 years ago.

The Greek philosopher Aristotle strongly influenced later Western thinking. Unfortunately, Aristotle's explanations about the natural world were not based on keen observations and experiments. He arbitrarily stated that rocks were created under the "influence" of the stars and that earthquakes occurred when air crowded into the ground, was heated by central fires, and escaped explosively. When confronted with a fossil fish, he explained that "a great many fishes live in the earth motionless and are found when excavations are made." Although Aristotle's explanations may have been adequate for his day, they unfortunately continued to be viewed as authoritative for many centuries, thus inhibiting the acceptance of more up-to-date ideas. After the Renaissance of the 1500s, however, more people became interested in finding answers to questions about Earth.

Catastrophism

In the mid-1600s, James Ussher, Anglican Archbishop of Armagh, Primate of all Ireland, published a major work that had immediate and profound influences. A respected scholar of the Bible, Ussher constructed a chronology of human and Earth history in which he calculated that Earth was only a few thousand years old, having been created in 4004 B.C.E. Ussher's treatise earned widespread acceptance among Europe's scientific and religious leaders, and his chronology was soon printed in the margins of the Bible itself.

During the seventeenth and eighteenth centuries, Western thought about Earth's features and processes was strongly influenced by Ussher's calculation. The result was a guiding doctrine called **catastrophism**. Catastrophists believed that Earth's landscapes were shaped primarily by great catastrophes. Features such as mountains and canyons, which today we know take great spans of time to form, were explained as resulting from sudden and often worldwide disasters produced by unknowable causes that no longer operate. This philosophy was an attempt to fit the rates of Earth processes to the then-current ideas about the age of Earth.

The Birth of Modern Geology

Against the backdrop of Aristotle's views and the idea of an Earth created in 4004 B.C.E. a Scottish physician and gentleman farmer named James Hutton published *Theory of the Earth* in 1795. In this work, Hutton put forth a fundamental principle that is a pillar of geology today: **uniformitarianism**. It states that the *physical, chemical, and biological laws that operate today have also operated in the geologic past.* This means that the forces and processes that we observe presently shaping our planet have been at work for a very long time. Thus, to understand ancient rocks, we must first understand present-day processes and their results. This idea is commonly stated as *the present is the key to the past.*

Prior to Hutton's *Theory of the Earth*, no one had effectively demonstrated that geologic processes occur over extremely long periods of time. However, Hutton persuasively argued that forces that appear small can, over long spans of time, produce effects that are just as great as those resulting from sudden catastrophic events. Unlike his predecessors, Hutton carefully cited verifiable observations to support his ideas. For example, when Hutton argued that mountains are sculpted and ultimately destroyed by weathering and the work of running water and that the products are carried to the oceans by observable processes, he said, "We have a chain of facts which clearly demonstrate . . . that the materials of the wasted mountains have traveled through the rivers"; and further, "There is not one step in all this progress . . . that is not to be actually perceived." He then went on to summarize this thought by asking a question and immediately providing the answer: "What more can we require? Nothing but time."

Geology Today

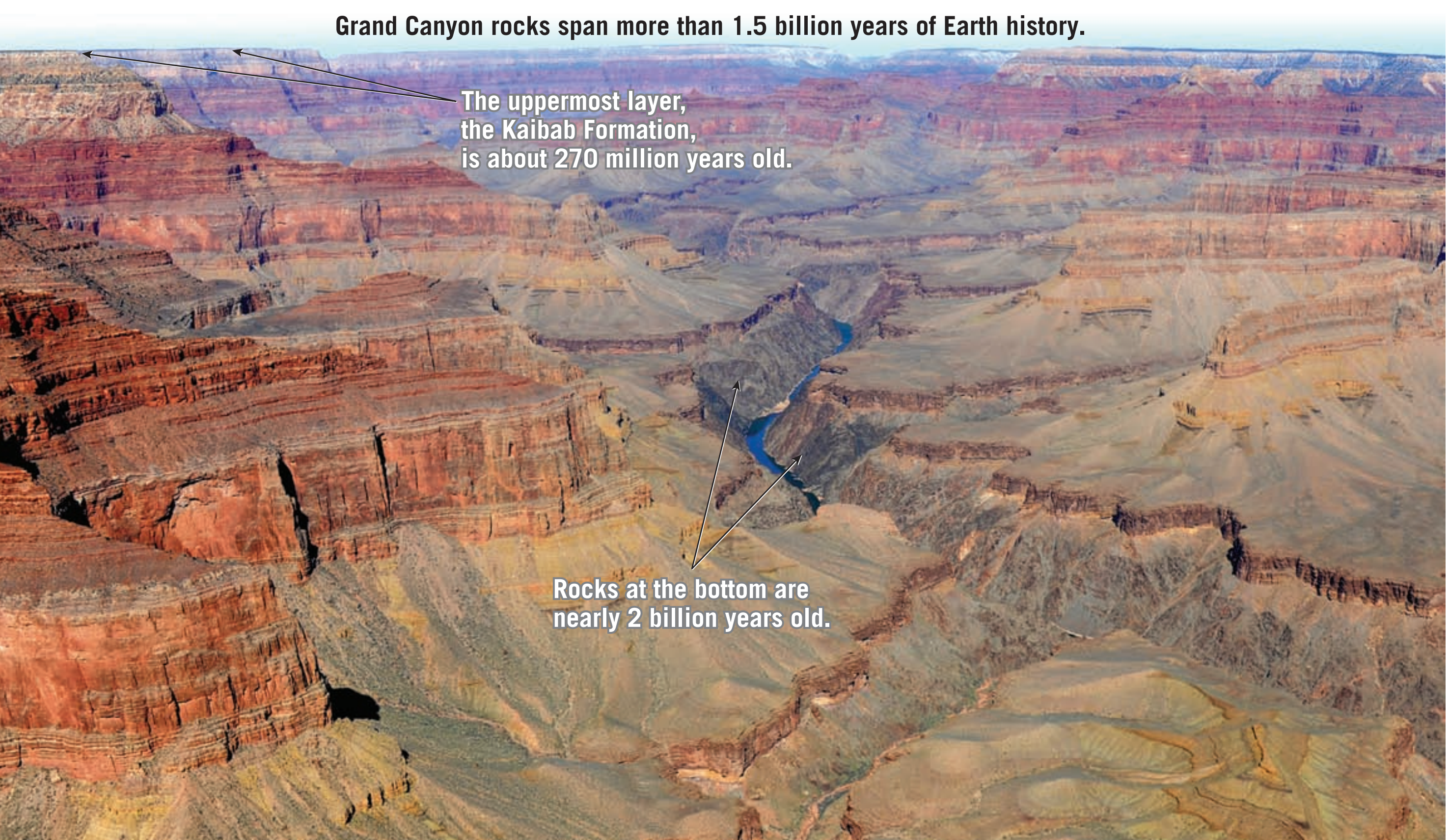
Today the basic tenets of uniformitarianism are just as viable as in Hutton's day. Indeed, today we realize more strongly than ever before that the present gives us insight into the past and that the physical, chemical, and biological laws that govern geologic processes remain unchanging through time. However, we also understand that the doctrine should not be taken too literally. To say that geologic processes in the past were the same as those occurring today is not to suggest that they have always had the same relative importance or that they have operated at precisely the same rate. Moreover, some important geologic processes are not currently observable, but evidence that they occur is well established. For example, we know that impacts from large meteorites have altered Earth's climate and influenced the history of life, even though we have no historical accounts of such impacts.

The acceptance of uniformitarianism meant the acceptance of a very long history for Earth. Although Earth processes vary in intensity, they almost always take a very long time to create or destroy major landscape features. The Grand Canyon provides a good example (**Figure 1.5**).

The rock record contains evidence which shows that Earth has experienced many cycles of mountain building and erosion. Concerning the ever-changing nature of Earth through great expanses of geologic time, Hutton famously stated in 1788: "The results, therefore, of our present enquiry is, that we find no vestige of a beginning—no prospect of an end."

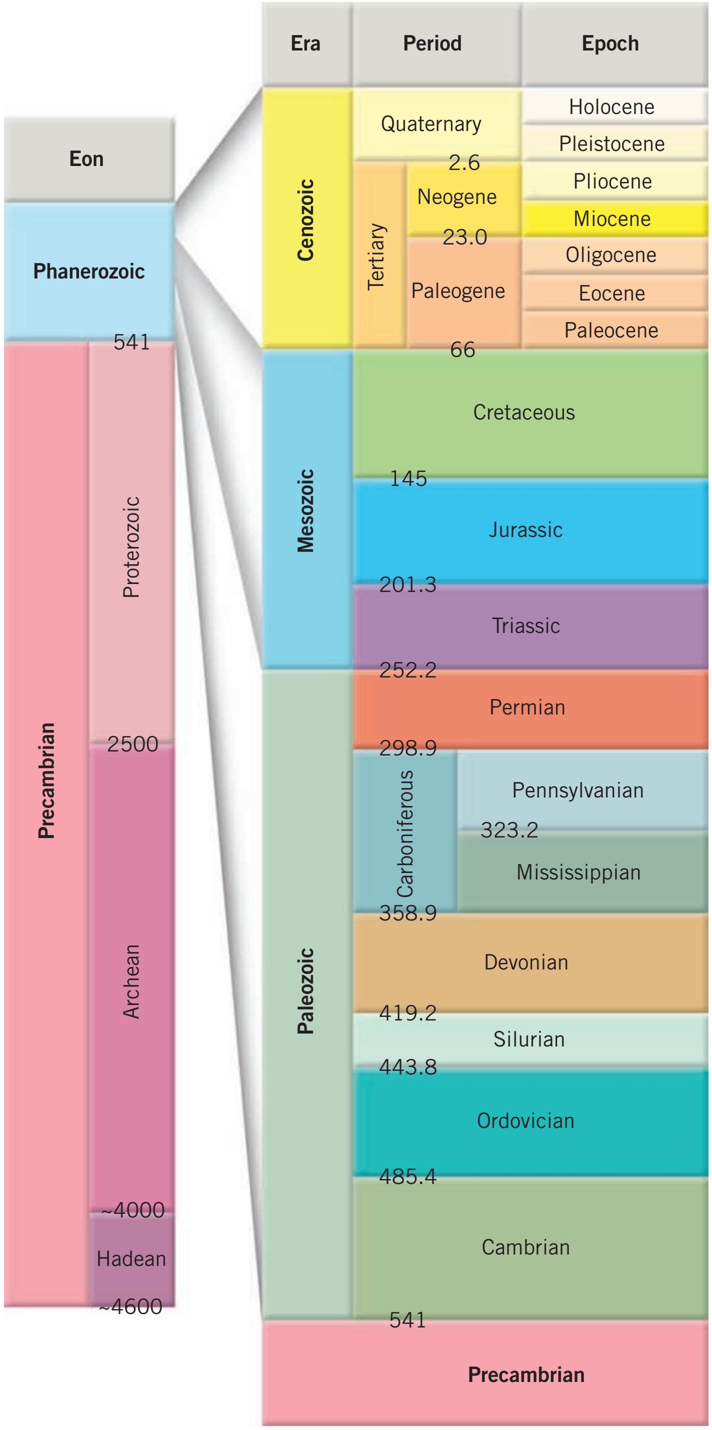
In the chapters that follow, we will be examining the materials that compose our planet and the processes that modify it. It is important to remember that, although many features of our physical landscape may seem to be unchanging over the decades we observe them, they are nevertheless changing—but on time scales of hundreds, thousands, or even many millions of years.

Did You Know?
Shortly after Archbishop Ussher determined an age for Earth, another biblical scholar, Dr. John Lightfoot of Cambridge, felt he could be even more specific. He wrote that Earth was created "on the 26th of October 4004 BC at 9 o'clock in the morning." (As quoted in William L. Stokes, *Essentials of Earth History*, Prentice Hall, Inc. 1973, p. 20.)



◀ **SmartFigure 1.5**
Earth history—Written in the rocks The Grand Canyon of the Colorado River in northern Arizona. (Photo by Dennis Tasa)

MOBILE FIELD TRIP
https://goo.gl/kECNV1



▲ **Figure 1.6 Geologic time scale: A basic reference** The time scale divides the vast 4.6-billion-year history of Earth into eons, eras, periods, and epochs. Numbers on the time scale represent time in millions of years before the present. The Precambrian accounts for more than 88 percent of geologic time. The geologic time scale is a dynamic tool that is periodically updated. Numerical ages appearing on this time scale are those that were currently accepted by the International Commission on Stratigraphy (ICS) in 2015. The color scheme used on this chart was selected because it is similar to that used by the ICS. The ICS is responsible for establishing global standards for the time scale.

The Magnitude of Geologic Time

Among geology's important contributions to human knowledge is the discovery that Earth has a very long and complex history. Although James Hutton and others recognized that geologic time is exceedingly long, they had no methods to accurately determine the age of Earth. Early time scales simply placed the events of Earth history in the proper sequence or order, without knowledge of how long ago in years they occurred.

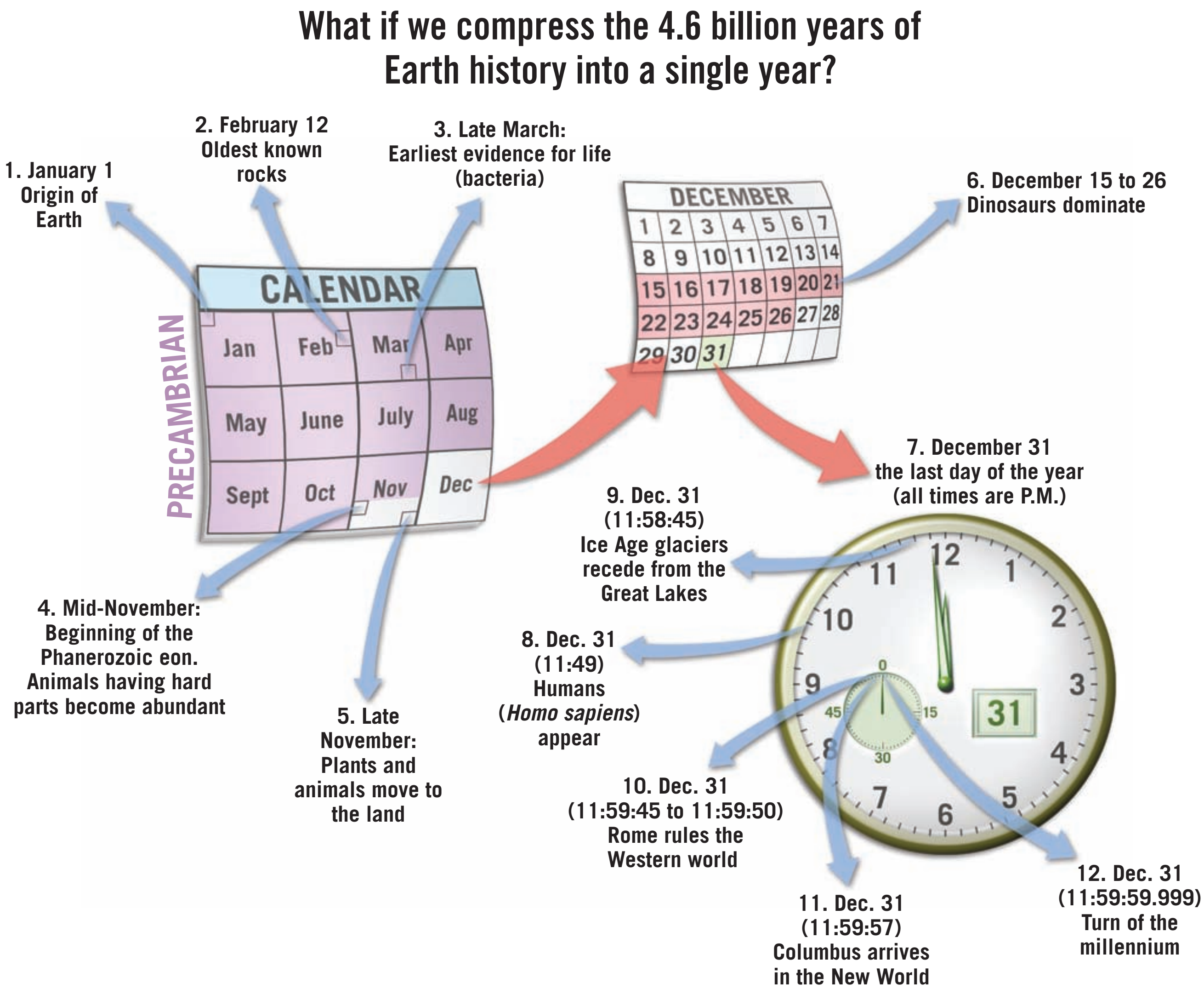
Today our understanding of radioactivity allows us to accurately determine numerical dates for rocks that represent important events in Earth's distant past (**Figure 1.6**). For example, we know that the dinosaurs died out about 66 million years ago. Today the age of Earth is put at about 4.6 billion years. Chapter 18 is devoted to a much more complete discussion of geologic time and the geologic time scale.

The concept of geologic time is new to many non-geologists. 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 geology must routinely deal with vast time periods—millions or billions (thousands of millions) of years. When viewed in the context of Earth's 4.6-billion-year history, a geologic 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 geology because many processes are so gradual that vast spans of time are needed 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! **Figure 1.7** provides another interesting way of viewing the expanse of geologic time. This 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.

CONCEPT CHECKS 1.2

1. Describe Aristotle's influence on geology.
2. Contrast catastrophism and uniformitarianism. How did each view the age of Earth?
3. How old is Earth?
4. Refer to Figure 1.6 and list the eon, era, period, and epoch in which we live.



◀ **SmartFigure 1.7**
Magnitude of geologic time

TUTORIAL
https://goo.gl/V1WFRd

1.3 The Nature of Scientific Inquiry

Discuss the nature of scientific inquiry, including the construction of hypotheses and the development of theories.

In our modern society, we are constantly reminded of the benefits derived from science. But what exactly is the nature of scientific inquiry? Science is a process of producing knowledge, based on making careful observations and on creating explanations that make sense of the observations. Developing an understanding of how science is done and how scientists work is an important theme that appears throughout this textbook. You will explore the difficulties in gathering data and some of the ingenious methods that have been developed to overcome these difficulties. You will also see many examples of how hypotheses are formulated and tested, and you will learn about the evolution and development of some major scientific theories.

All science is based on the assumption that the natural world behaves in a consistent and predictable manner that is comprehensible through careful, systematic study. The overall goal of science is to discover the underlying patterns in nature and then to use that knowledge to make predictions about what should or should not be expected, given certain facts or circumstances. For example, by knowing how oil deposits form, geologists are able to predict the most favorable sites for exploration and, perhaps as importantly, how to avoid regions that have little or no potential.

The development of new scientific knowledge involves some basic logical processes that are universally accepted. To determine what is occurring in the natural world,