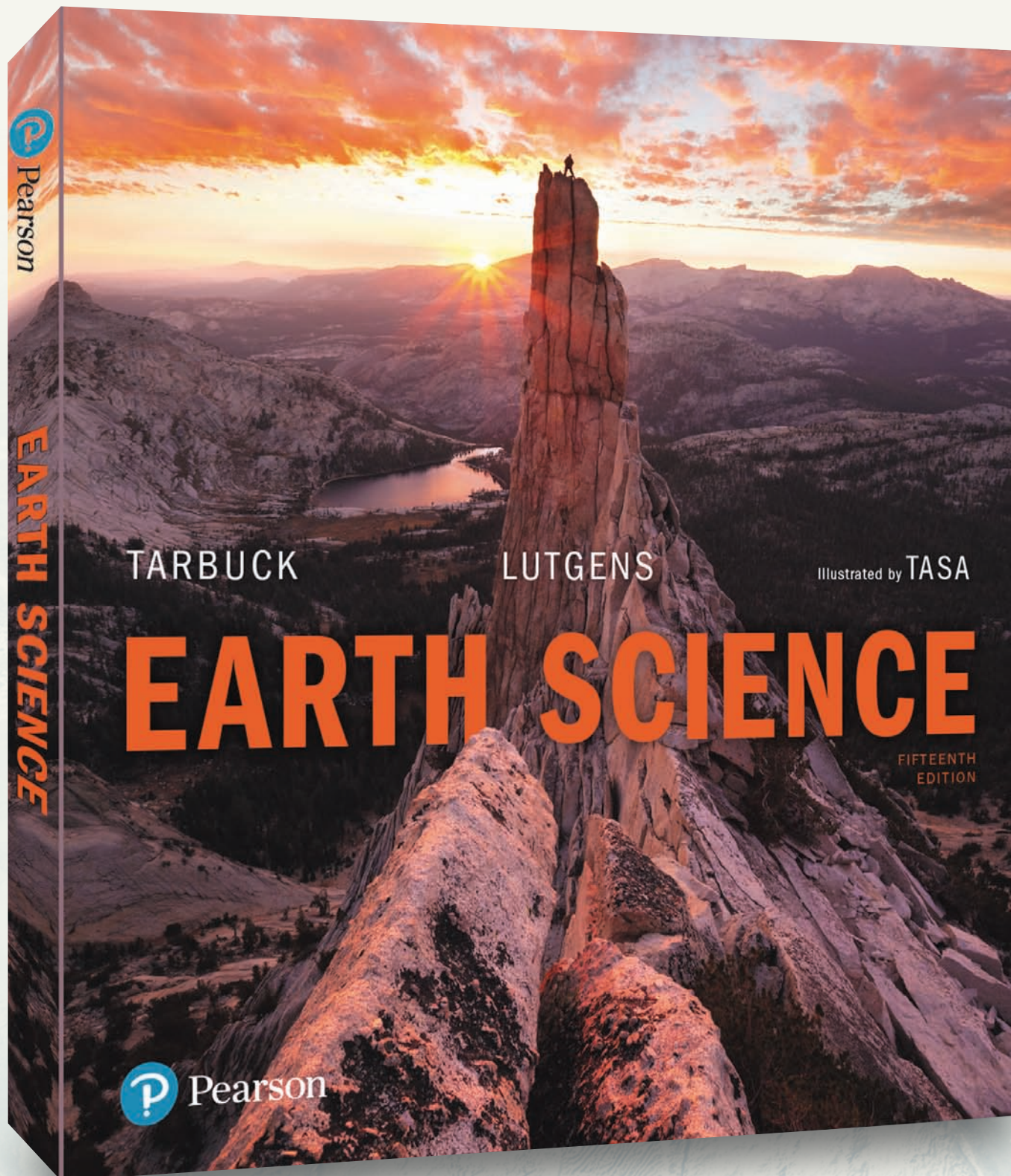
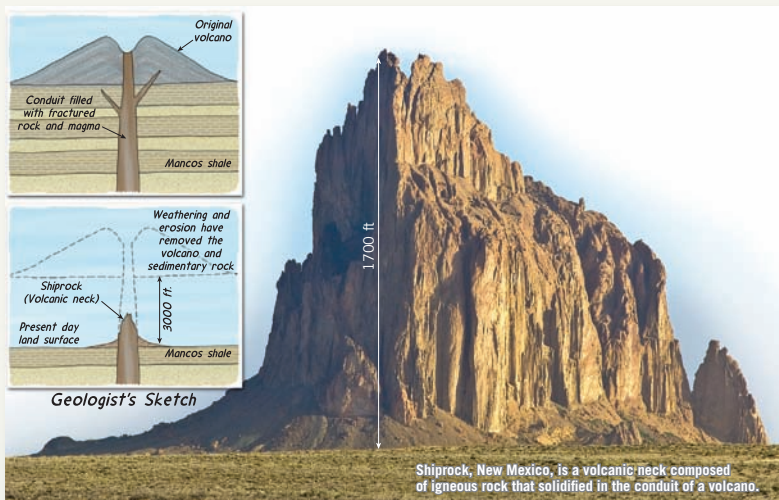


Use Dynamic Media to Bring Earth Science to Life



Bring Field Experience to Students' Fingertips...



▲ SmartFigure 6.26 Volcanic neck

Shiprock, New Mexico, is a volcanic neck that stands about 520 meters (1700 feet) high. It consists of igneous rock that crystallized in the vent of a volcano that has long since been eroded. (Photo by Dennis Tasa)

TUTORIAL

<https://goo.gl/TjW5uh>



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! QR Codes link to SmartFigures

Quick Response (QR) codes link to over 238 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 Earth Science to life.



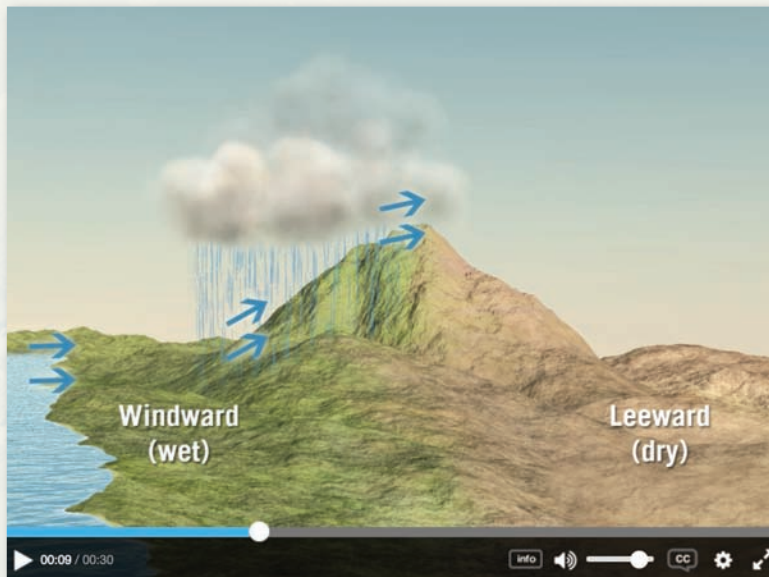
NEW! SmartFigures: Project Condor Quadcopter Videos

Bringing Earth Science to life for 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! SmartFigures: Mobile Field Trips

On each trip, students will accompany geologist-pilot-photographer Michael Collier in the air and on the ground to visit 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 15th edition include *Formation of a Water Gap*, *Ice Sculpts Yosemite*, *Fire and Ice Land*, *Dendrochronology*, and *Desert Geomorphology*.

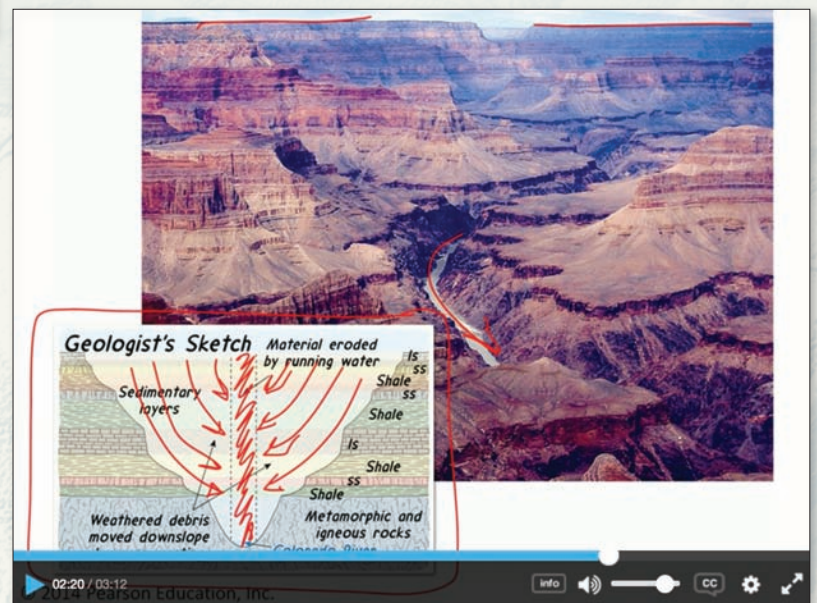


NEW! SmartFigures: Animations

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! SmartFigures: Tutorials


These brief tutorial videos present the student with a 3- to 4-minute feature (mini-lesson), most narrated and annotated by Professor Callan Bentley. Each lesson examines and explains the concepts illustrated by the figure. With over 150 SmartFigure Tutorials inside the text, students have a multitude of ways to enjoy art that teaches.



Clear Learning Path in Each Chapter

Each chapter in this 15th 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. Three end-of-chapter features continue the learning path. *Concepts in Review* are coordinated with the *Focus on Concepts* at the beginning of the chapter and with the numbered sections within the chapter, providing a readable and concise overview of key ideas, with photos, diagrams, and questions. The questions and problems in *Give It Some Thought* and *Examining the Earth System* challenge learners by requiring higher order thinking skills to analyze, synthesize, and apply the material.

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



6 Volcanoes and Other Igneous Activity

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. Compare and contrast the 1980 eruption of Mount St. Helens with the most recent eruption of Kilauea, which began in 1983.
2. Explain why some volcanic eruptions are explosive and others are quiescent.
3. List and describe the three categories of materials extruded during volcanic eruptions.
4. Draw and label a diagram that illustrates the basic features of a typical volcanic cone.
5. Summarize the characteristics of shield volcanoes and provide one example of this type of volcano.
6. Describe the formation, size, and composition of cinder cones.
7. List the characteristics of composite volcanoes and describe how they form.
8. Describe the major geologic hazards associated with volcanoes.
9. List volcanic landforms other than shield, cinder, and composite volcanoes and describe their formation.
10. Compare and contrast these intrusive igneous structures: dikes, sills, batholiths, stocks, and laccoliths.
11. Summarize the major processes that generate magma from solid rock.
12. Explain how the global distribution of volcanic activity is related to plate tectonics.

Eruption of ash from Mount Boino Volcano, 2011, in Java, Indonesia. (Photo provided by Richard Pacesa/Stockbook Images, Inc./Alamy Stock Photo)

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

CONCEPT CHECKS 6.8

1. Describe pyroclastic flows and explain why they are capable of traveling great distances.
2. What is a lahar?
3. List at least three volcanic hazards besides pyroclastic flows and lahars.

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

6 CONCEPTS IN REVIEW

Volcanoes and Other Igneous Activity

6.1 Mount St. Helens Versus Kilauea

Compare and contrast the 1980 eruption of Mount St. Helens with the most recent eruption of Kilauea, which began in 1983.

- Volcanic eruptions cover a broad spectrum from explosive eruptions, like that of Mount St. Helens in 1980, to the quiescent eruptions of Kilauea.

6.2 The Nature of Volcanic Eruptions

Explain why some volcanic eruptions are explosive and others are quiescent.

KEY TERMS: magma, lava, effusive eruption, viscosity, eruption column

- The two primary factors determining the nature of a volcanic eruption are the viscosity (resistance to flow) of the magma and its gas content. In general, magmas that contain more silica are more viscous, while those with lower silica content are more fluid. Temperature also influences viscosity. Hot lavas are more fluid, while cool lavas are more viscous.
- Basaltic magmas, which are fluid and have low gas content, tend to generate effusive (nonexplosive) eruptions. In contrast, silica-rich magmas (andesitic and rhyolitic), which are the most viscous and contain the greatest quantity of gases, are the most explosive.

? Although Kilauea mostly erupts in a gentle manner, what risks might you encounter if you chose to live nearby?



EXAMINING THE EARTH SYSTEM

1. Speculate about some of the possible consequences that a great and prolonged increase in explosive volcanic activity might have on each of Earth's four spheres.



John A. Heigold/Alamy

GIVE IT SOME THOUGHT

1. Examine the accompanying photo and complete the following:
 - a. What type of volcano is shown? What features helped you classify it as such?
 - b. What is the eruptive style of such volcanoes? Describe the likely composition and viscosity of its magma.
 - c. Which type of plate boundary is the likely setting for this volcano?
 - d. Name a city that is vulnerable to the effects of a volcano of this type.



USGS

4) *Give It Some Thought* and *Examining the Earth System* activities challenge learners by requiring higher-order thinking skills to analyze, synthesize, and apply chapter material.

Exposing Students to Source Data and the Tools of Science

NEW! Each chapter of the 15th edition now concludes with new *Data Analysis* activities. These brief capstone activities send students outside of the book to online science tools and data sets from organizations such as NASA, NOAA, and USGS, empowering students to apply and extend chapter concepts and develop their data analysis and critical thinking skills

DATA ANALYSIS

Recent Volcanic Activity

The Smithsonian Institution Global Volcanism Program and the USGS work together to compile a list of new and changing volcanic activity worldwide. NOAA also uses this information to issue Volcanic Ash Advisories to alert aircraft of volcanic ash in the air.

ACTIVITIES

Go to the Weekly Volcanic Activity Report page at <http://volcano.si.edu>.

- 1 What information is displayed on this page?
- 2 Click on Criteria and Disclaimers. Which volcanoes are not displayed on this map?
- 3 In what areas is most of the volcanic activity concentrated?
- 4 Click on Weekly Report. List the new volcanic activity locations. List three ongoing volcanic activity locations.

Click on the name of a volcano under New Activity/Unrest.

- 5 Where is this volcano located? Be sure to include the city, country, volcanic region name, latitude, and longitude.
- 6 What is the primary volcanic type?

- 7 Do some investigating online and in your textbook. What are the key characteristics for this type of volcano?
- 8 Briefly describe the most recent activity. How was this activity observed?
- 9 What are the dates for the most recent activity?
- 10 Click on Eruptive History. What is the earliest date listed for this volcano?
- 11 Find this volcano on the map on the previous page. Is this volcano near a plate boundary? If so, between which plates? (Use your textbook to determine the location of plate boundaries.)

Go to the Volcanic Ash Advisory Center (VAAC) page at www.ssd.noaa.gov/VAAC/washington.html.

- 12 List the VAAC locations.
- 13 Click on Current Volcanic Ash Advisories. When was the most recent Volcanic Ash Advisory issued? What is the location of this advisory?
- 14 Which of the new volcanic activity locations from question 4 currently have Volcanic Ash Advisories? For each, what is the date of the most recent advisory?

DATA ANALYSIS

The Aral Sea

The Aral Sea was once the fourth-largest lake in the world. This lake has now decreased in size by more than 80%, and the southern Aral Sea has disappeared altogether. This has had devastating effects on the communities around the lake.

ACTIVITIES

Go to NASA's Earth Observatory site at <http://earthobservatory.nasa.gov>, select World of Change under Special Collections and scroll to select Shrinking Aral Sea. As you step forward in time, you will see the aerial extent of the Aral Sea.

- 1 When did the Aral Sea begin to shrink? Why did the Aral Sea begin to shrink?
- 2 How has the shrinking lake affected the quality of the water and farmland in the area?
- 3 How has the lake's reduction affected summer and winter temperatures?

Step forward in time to see changes in the Aral Sea. The green region is the lake, and the white region around the lake is salt deposits. You may also click on Google Earth to step through time and use the measuring tool to answer some of these questions.

- 4 What is the east–west distance between the easternmost edge of the Aral Sea in 1960 and the edge of the southern Aral Sea in 2000? 1960 and 2005? 1960 and 2010? 1960 and 2015?
- 5 What is the distance change between 2000 and 2005? 2005 and 2010? 2005 and 2015?
- 6 What is the average rate of distance change since 2000? (Remember that rate of change is the distance change divided by the number of years.)
- 7 Why was there a significant decline in the overall size of the southern Aral Sea after 2005?

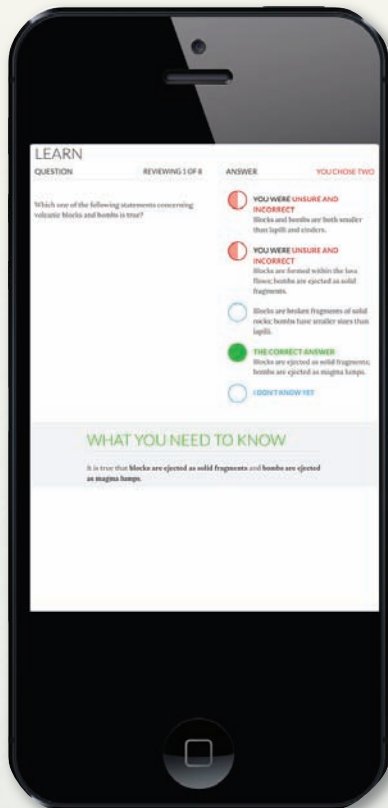
Go to “Shrinking Aral Sea” on NASA's Earth Observatory site (https://earthobservatory.nasa.gov/Features/WorldOfChange/aral_sea.php).

- 8 Compare this image to the Aral Sea images from Earth Observatory. Approximately when was the dust storm image taken? (Giving a range of years is fine.)
- 9 From which direction is the wind blowing?
- 10 How long is the dust storm at its longest distance? How wide is the dust storm at its widest distance?
- 11 Which towns are in the path of this dust storm?

Continuous Learning Before, During, and After Class

BEFORE CLASS

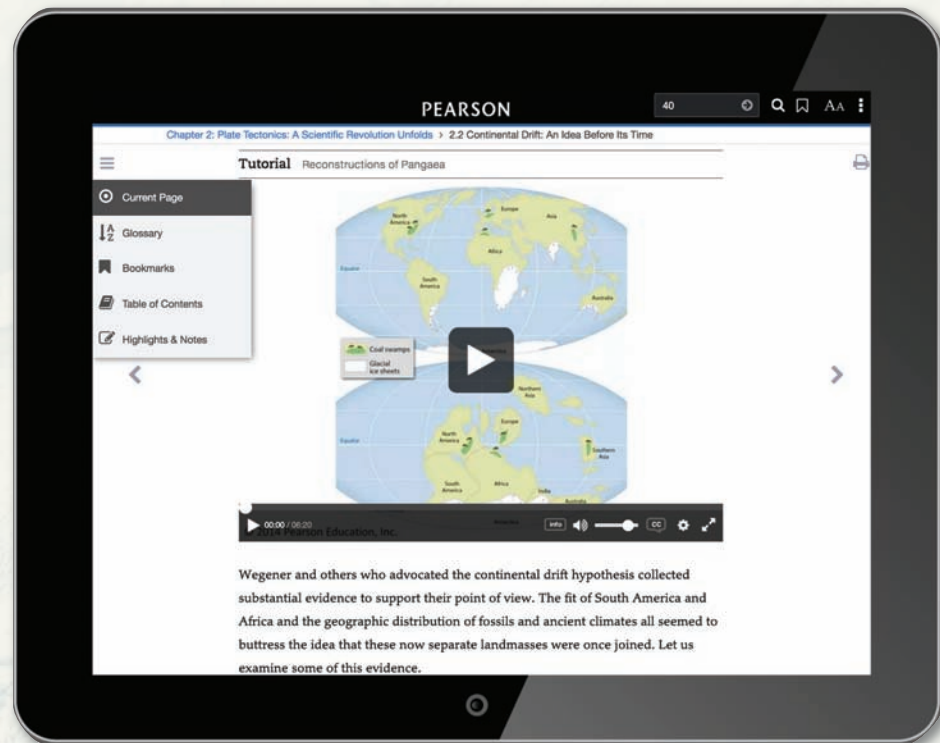
Mobile Media and Reading Assignments Ensure Students Come to Class Prepared



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 Quiz 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

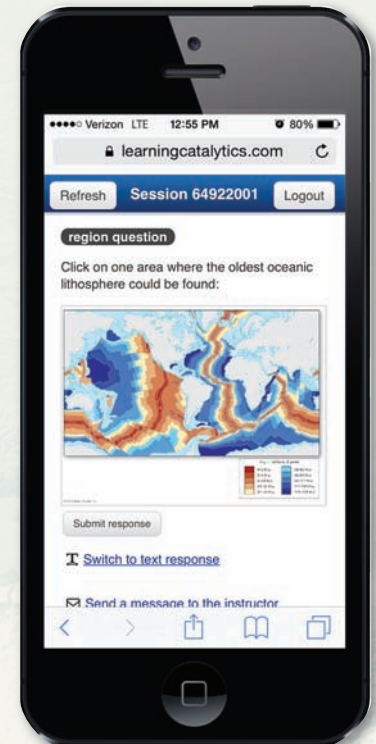
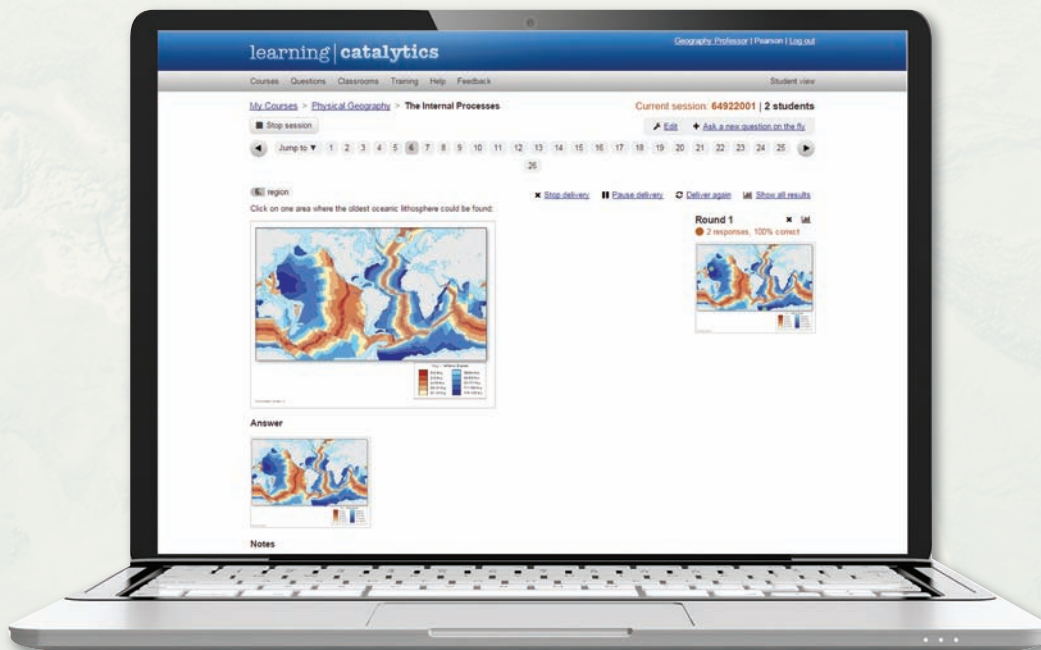
Engage students with Learning Catalytics

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

Part B - A Direction of Crustal Extension in Continental Rifts

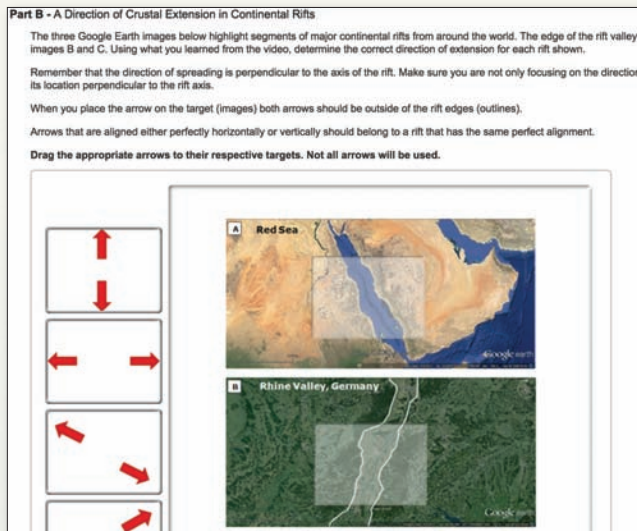
The three Google Earth images below highlight segments of major continental rifts from around the world. The edge of the rift valley is shown in images B and C. Using what you learned from the video, determine the correct direction of extension for each rift shown.

Remember that the direction of spreading is perpendicular to the axis of the rift. Make sure you are not only focusing on the direction of its location perpendicular to the rift axis.

When you place the arrow on the target (images) both arrows should be outside of the rift edges (outlines).

Arrows that are aligned either perfectly horizontally or vertically should belong to a rift that has the same perfect alignment.

Drag the appropriate arrows to their respective targets. Not all arrows will be used.




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 locations with Michael Collier in the air and on the ground to learn about places that relate to concepts in the chapter. In Mastering, these videos are accompanied by auto-gradable assessments that will track what students have learned.

Mobile Field Trip Video Quiz: Fire and Ice Land

Launch the Mobile Field Trip Video



When you have finished, answer the questions.

Part A

Which of the following scenarios best describes the activity present along the Mid-Atlantic Ridge?

- Magma wells up at the center of the ridge, which pushes the old seafloor apart as new seafloor is created.
- Magma is created by partial melting of crustal material as it sinks.
- A plume of hot mantle material is pushing up against the crust, adding material to the crust to thicken it.
- Segments of seafloor slide past each other without creating or destroying crustal material.
- Old seafloor is consumed as it is forced beneath another segment of seafloor.

Submit Hints My Answers Give Up Review Part

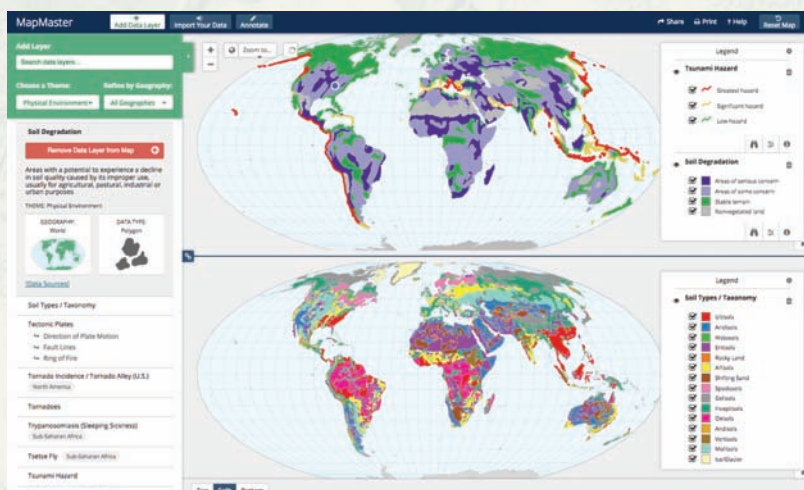
Part B

The Mid-Atlantic Ridge crosses through Iceland. Physical features such as tensional fractures and cinder cone volcanoes are all aligned NE-SW. What does this indicate about the directions the tectonic plates are moving?

- The tectonic plates are separating to the NW and SE.
- The tectonic plates are separating to the N and S.
- The tectonic plates are separating to the S and E.
- The tectonic plates are separating to the NE and SW.
- The tectonic plates are separating to the N and E.

Submit Hints My Answers Give Up Review Part

MapMaster



MapMaster interface showing a world map with various thematic layers overlaid, including Tectonic Plates, Soil Degradation, and Tsunami Hazard. The interface includes a search bar, a legend, and a list of layers on the right side.

NEW! MapMaster 2.0 Activities


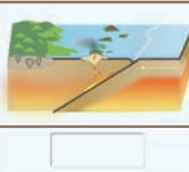
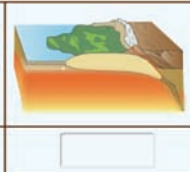
are inspired by GIS, allowing students to layer various thematic maps to analyze spatial patterns and data at regional and global scales. Now fully mobile, with enhanced analysis tools, such as split screen, the ability for students to geolocate themselves in the data, and the ability for students to upload their own data for advanced map making. This tool includes zoom, and annotation functionality, with hundreds of map layers leveraging recent data from sources such as NOAA, NASA, USGS, United Nations, CIA, World Bank, UN, PRB, and more.

Part A - Types of convergent plate boundaries
 Identify each type of convergent plate boundary.
 Drag the appropriate convergence labels to their respective targets.

Continental-continental convergence

Oceanic-oceanic convergence

Oceanic-continental convergence

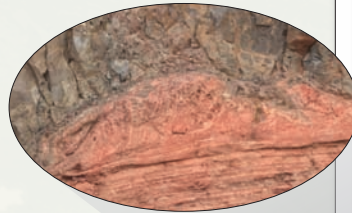




Submit [Hints](#) [My Answers](#) [Give Up](#) [Review Part](#)

GeoTutors

These coaching activities help students master the most challenging 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.



Part D - Making Observations
 After exploring the Giganpan field site, arrange the following observations/inferences by their respective rock unit. These observations/inferences describe the material, appearance and weathering pattern of the respective rock units.
 Drag the appropriate items into their respective bins. Each item may be used only once.

Rock Unit 1

Red and white in color

Appears to be made up of many thin layers

Weathers in small irregular shapes

Weathers in large blocks

Appears to be massive (no layers)

Sediments too small to see

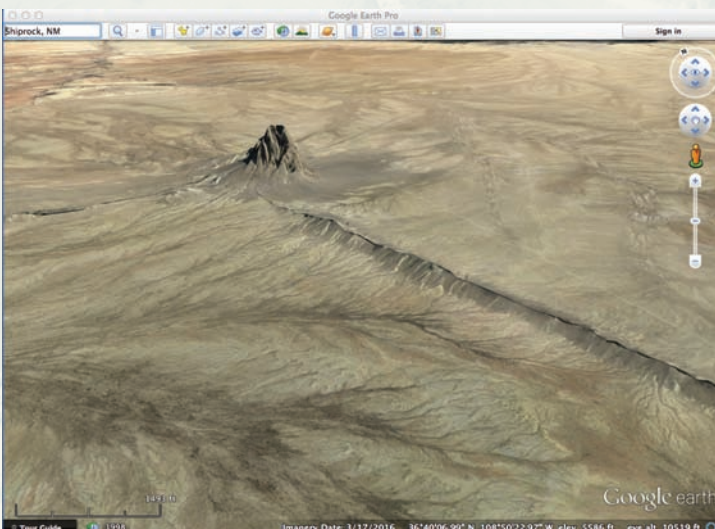
Rock Unit 2

Black and dark gray in color

Crystals too small to see

Submit [Hints](#) [My Answers](#) [Give Up](#) [Review Part](#)

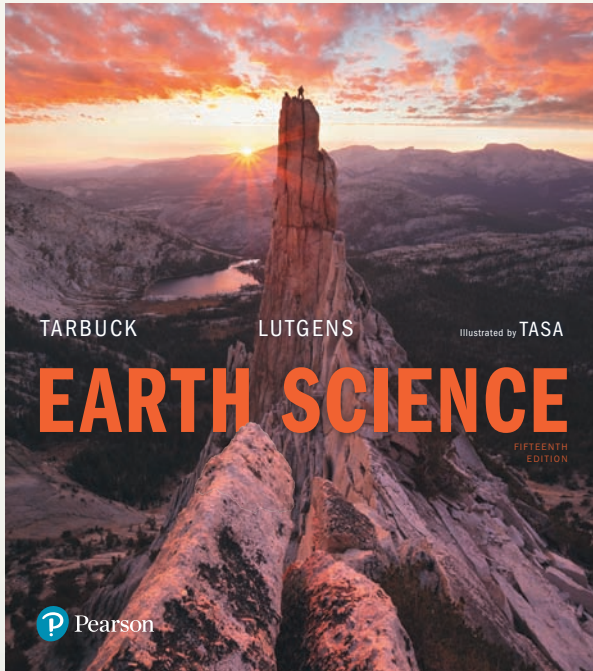
#1. Which rock unit produces



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 geoscience 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 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 format
- 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
- Full access to eText 2.0
- 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, the Earth Science Literacy Initiatives “Big Ideas”, 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.

EARTH SCIENCE

FIFTEENTH
EDITION



TARBUCK

LUTGENS

Illustrated by TASA

EARTH SCIENCE

FIFTEENTH
EDITION



330 Hudson Street, NY NY 10013

Executive Editor, Geosciences Courseware: Christian Botting
Director, Courseware Portfolio Management: Beth Wilbur
Content Producer: William Wenzler, Karen Sanatar
Managing Producer: Mike Early
Courseware Director, Content Development: Ginnie Simone Jutson
Courseware Sr. Analyst: Margot Otway
Editorial Assistant, Geosciences Courseware: Emily Bornhop
Rich Media Content Producer: Mia Sullivan, Libby Reiser
Full Service Vendor: SPi Global
Full Service Project Manager: Patty Donovan

Copyeditor: Kitty Wilson
Design Manager: Mark Ong
Cover and Interior Designer: Jeff Puda
Photo and Illustration Support: Kevin Lear, International Mapping
Rights and Permissions Project Manager: Matthew Perry
Rights and Permissions Management: Ben Ferrini
Manufacturing Buyer: Maura Zaldivar-Garcia
Senior Marketing Manager, Field: Mary Salzman
Marketing Assistant: Ami Sampat
Cover Image Credit: © Grant Ordelleide

Credits and acknowledgments borrowed from other sources and reproduced, with permission, in this textbook appear on the appropriate page within text or are listed below.

Page 9: From J. Bronowski, *The Common Sense of Science*, p. 148. © 1953 Harvard University Press. **Page 12:** From L. Pasteur, *Lecture*, University of Lille (7 December 1854). **Page 215:** From R.T. Chamberlain, "Some of the Objections to Wegener's Theory," In: *THEORY OF CONTINENTAL DRIFT: A SYMPOSIUM*, University of Chicago Press, pp. 83-87, 1928. **Page 264:** W. Mooney, *USGS Seismologist*. **Page 349:** From J. Hutton, *Theory of Earth*, 1700; From J. Hutton, *Transactions of the Royal Society of Edinburgh*, 1788. **Page 488:** From A.J. Herbertson, "Outlines of Physiography," 1901. **Page 566:** Sir Francis Bacon. **Page 644:** Copernicus, *De Revolutionibus, Orbium Coelestium (On the Revolution of the Heavenly Spheres)*. **Page 648:** Joseph Louis Lagrange, *Oeuvres de Lagrange*, 1867.

Copyright © 2018, 2015, 2012, 2009, 2006, 2003 Pearson Education, Inc. All Rights Reserved. Printed in the United States of America. This publication is protected by copyright, and permission should be obtained from the publisher prior to any prohibited reproduction, storage in a retrieval system, or transmission in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise. For information regarding permissions, request forms and the appropriate contacts within the Pearson Education Global Rights & Permissions department, please visit www.pearsoned.com/permissions/.

Many of the designations by manufacturers and sellers to distinguish their products are claimed as trademarks. Where those designations appear in this book, and the publisher was aware of a trademark claim, the designations have been printed in initial caps or all caps.

Library of Congress Cataloging-in-Publication Data

Names: Tarbuck, Edward J., author. | Lutgens, Frederick K., author.
Title: Earth science / Edward J. Tarbuck, Fred K. Lutgens;
illustrated by
Dennis Tasa.

Description: Fifteenth edition. | Hoboken, NJ: Pearson Education, [2017] | Includes index.

Identifiers: LCCN 2017013211 | ISBN 9780134543536 | ISBN 013454353X

Subjects: LCSH: Earth sciences—Textbooks.

Classification: LCC QE26.3.T38 2017 | DDC 550—dc23 LC record
available at <https://lcn.loc.gov/2017013211>

ISBN-10: 0-134-54353-X

ISBN-13: 978-0-134-54353-6

About Our Sustainability Initiatives

Pearson recognizes the environmental challenges facing this planet, as well as acknowledges our responsibility in making a difference. This book is carefully crafted to minimize environmental impact. The binding, cover, and paper come from facilities that minimize waste, energy consumption, and the use of harmful chemicals. Pearson closes the loop by recycling every out-of-date text returned to our warehouse.

Along with developing and exploring digital solutions to our market's needs, Pearson has a strong commitment to achieving carbon neutrality. As of 2009, Pearson became the first carbon- and climate-neutral publishing company, having reduced our absolute carbon footprint by 22% since then. Pearson has protected over 1,000 hectares of land in Columbia, Costa Rica, the United States, the UK and Canada. In 2015, Pearson formally adopted The Global Goals for Sustainable Development, sponsoring an event at the United Nations General Assembly and other ongoing initiatives. Pearson sources 100% of the electricity we use from green power and invests in renewable energy resources in multiple cities where we have operations, helping make them more sustainable and limiting our environmental impact for local communities.

The future holds great promise for reducing our impact on Earth's environment, and Pearson is proud to be leading the way. We strive to publish the best books with the most up-to-date and accurate content, and to do so in ways that minimize our impact on Earth. To learn more about our initiatives, please visit <https://www.pearson.com/sustainability.html>.



BRIEF CONTENTS

1 Introduction to Earth Science 3

UNIT 1 Earth Materials 30

2 Matter and Minerals 31

3 Rocks: Materials of the Solid Earth 57

UNIT 2 Forces Within 92

4 Plate Tectonics: A Scientific Revolution Unfolds 93

5 Earthquakes and Earth's Interior 127

6 Volcanoes and Other Igneous Activity 161

7 Crustal Deformation and Mountain Building 201

UNIT 3 Sculpting Earth's Surface 232

8 Weathering, Soil, and Mass Movement 233

9 Running Water and Groundwater 267

10 Glaciers, Deserts, and Wind 307

UNIT 4 Deciphering Earth's History 346

11 Geologic Time 347

12 Earth's Evolution Through Geologic Time 373

UNIT 5 The Global Ocean 406

13 The Ocean Floor 407

14 Ocean Water and Ocean Life 431

15 The Dynamic Ocean 451

UNIT 6 Earth's Dynamic Atmosphere 484

16 The Atmosphere: Composition, Structure, and Temperature 485

17 Moisture, Clouds, and Precipitation 517

18 Air Pressure and Wind 551

19 Weather Patterns and Severe Storms 577

20 World Climates and Global Climate Change 607

UNIT 7 Earth's Place in the Universe 636

21 Origins of Modern Astronomy 637

22 Touring Our Solar System 661

23 Light, Telescopes, and the Sun 693

24 Beyond Our Solar System 717

APPENDIX A Metric and English Units Compared 740

APPENDIX B Relative Humidity and Dew-Point Tables 741

Glossary 742

Index 754

CONTENTS

SmartFigures Media xiv
Digital & Print Resources xvii
Earth Science 15E: Major Changes in this Edition xxi

1 Introduction to Earth Science 3

FOCUS ON CONCEPTS 3

- 1.1 **What Is Earth Science?** 4
 - Geology 4
 - Oceanography 5
 - Meteorology 5
 - Astronomy 6
 - Earth Science Is Environmental Science 6
 - Scales of Space and Time in Earth Science 7
- 1.2 **The Nature of Scientific Inquiry** 8
 - Hypothesis 10
 - Theory 10
 - Scientific Methods 10
- EYE ON EARTH 1.1** 11
- 1.3 **Early Evolution of Earth** 11
 - The Universe Begins 11
 - The Solar System Forms 11

GEOGRAPHICS Solar System: Size and Scale 12

- The Inner Planets Form 14
- The Outer Planets Develop 14
- 1.4 **Earth as a System** 14
 - Earth's Spheres 14
 - Hydrosphere 15
 - Atmosphere 16
- EYE ON EARTH 1.2** 17
 - Biosphere 17
 - Geosphere 17
 - Earth System Science 19
 - The Earth System 19
- 1.5 **The Face of Earth** 21
 - Major Features of the Ocean Floor 21
- EYE ON EARTH 1.3** 24
 - Major Features of the Continents 24

Concepts in Review 26 | **Give It Some Thought** 28 |
Examining the Earth System 29 | **Data Analysis** 29

UNIT 1 Earth Materials 30

2 Matter and Minerals 31

FOCUS ON CONCEPTS 31

- 2.1 **Minerals: Building Blocks of Rocks** 32
 - Defining a Mineral 32
 - What Is a Rock? 33
- 2.2 **Atoms: Building Blocks of Minerals** 34
 - Properties of Protons, Neutrons, and Electrons 34
 - Elements: Defined by Their Number of Protons 34

GEOGRAPHICS Gold 36

- 2.3 **Why Atoms Bond** 36
 - The Octet Rule and Chemical Bonds 36

Ionic Bonds: Electrons Transferred 38
Covalent Bonds: Electron Sharing 38
Metallic Bonds: Electrons Free to Move 39

EYE ON EARTH 2.1 39

- 2.4 **Properties of Minerals** 40
 - Optical Properties 40
 - Crystal Shape, or Habit 41
 - Mineral Strength 41
 - Density and Specific Gravity 43
 - Other Properties of Minerals 43

EYE ON EARTH 2.2 44

- 2.5 **Mineral Groups** 44
 - Silicate Minerals 44
 - Common Light Silicate Minerals 45
 - Common Dark Silicate Minerals 47
 - Important Nonsilicate Minerals 48
- 2.6 **Minerals: A Nonrenewable Resource** 50
 - Renewable Versus Nonrenewable Resources 50
 - Mineral Resources and Ore Deposits 50

GEOGRAPHICS Gemstones 52

Concepts in Review 53 | **Give It Some Thought** 54 |
Examining the Earth System 55 | **Data Analysis** 55

3 Rocks: Materials of the Solid Earth 57

FOCUS ON CONCEPTS 57

- 3.1 **Earth as a System: The Rock Cycle** 58
 - The Basic Cycle 58
 - Alternative Paths 58
- 3.2 **Igneous Rocks: “Formed by Fire”** 60
 - From Magma to Crystalline Rock 60
 - Igneous Compositions 61
 - What Can Igneous Textures Tell Us? 62
 - Common Igneous Rocks 64
 - How Igneous Rocks Form 67
- EYE ON EARTH 3.1** 67
- 3.3 **Sedimentary Rocks: Compacted and Cemented Sediment** 69
 - Types of Sedimentary Rocks 70
 - Lithification of Sediment 74
 - Features of Sedimentary Rocks 74
- 3.4 **Metamorphic Rocks: New Rock from Old** 75
 - What Drives Metamorphism? 76
 - Metamorphic Textures 77
- EYE ON EARTH 3.2** 78
 - Common Metamorphic Rocks 79

GEOGRAPHICS Marble 80

- Other Metamorphic Rocks 82
- 3.5 **Resources from Rocks and Minerals** 82
 - Metallic Mineral Resources 82
 - Nonmetallic Mineral Resources 84
 - Energy Resources 85

EYE ON EARTH 3.3 87

Concepts in Review 88 | **Give It Some Thought** 90 |
Examining the Earth System 91 | **Data Analysis** 91

UNIT 2 Forces Within 92**4 Plate Tectonics: A Scientific Revolution Unfolds** 93**FOCUS ON CONCEPTS** 93

- 4.1 **From Continental Drift to Plate Tectonics** 94
- 4.2 **Continental Drift: An Idea Before Its Time** 95
 - Evidence: The Continental Jigsaw Puzzle 95
 - Evidence: Fossils Matching Across the Seas 96
 - Evidence: Rock Types and Geologic Features 97
 - Evidence: Ancient Climates 97
 - The Great Debate 98
- 4.3 **The Theory of Plate Tectonics** 99
 - Rigid Lithosphere Overlies Weak Asthenosphere 99
 - Earth's Major Plates 100
 - Plate Movement 100
- 4.4 **Divergent Plate Boundaries and Seafloor Spreading** 101
 - Oceanic Ridges and Seafloor Spreading 101
 - Continental Rifting 102
- 4.5 **Convergent Plate Boundaries and Subduction** 104
 - Oceanic–Continental Convergence 104
 - Oceanic–Oceanic Convergence 105
 - Continental–Continental Convergence 106
- 4.6 **Transform Plate Boundaries** 107
- EYE ON EARTH 4.1** 109
- 4.7 **How Do Plates and Plate Boundaries Change?** 109
 - The Breakup of Pangaea 109
 - Plate Tectonics in the Future 110
- 4.8 **Testing the Plate Tectonics Model** 111
 - Evidence: Ocean Drilling 111
 - Evidence: Mantle Plumes and Hot Spots 112
 - Evidence: Paleomagnetism 113
- 4.9 **How Is Plate Motion Measured?** 116
 - Geologic Measurement of Plate Motion 116
- EYE ON EARTH 4.2** 117
- 4.10 **What Drives Plate Motions?** 118
 - Forces That Drive Plate Motion 118
 - Models of Plate–Mantle Convection 119

Concepts in Review 120 | **Give It Some Thought** 123 | **Examining the Earth System** 124 | **Data Analysis** 125

5 Earthquakes and Earth's Interior 127**FOCUS ON CONCEPTS** 127

- 5.1 **What Is an Earthquake?** 128
 - Discovering the Causes of Earthquakes 128
 - Aftershocks and Foreshocks 130
 - Faults and Large Earthquakes 130
 - Fault Rupture and Propagation 131
- EYE ON EARTH 5.1** 132
- 5.2 **Seismology: The Study of Earthquake Waves** 132
 - Instruments That Record Earthquakes 132
 - Seismic Waves 133
- 5.3 **Locating the Source of an Earthquake** 134
- 5.4 **Determining the Size of an Earthquake** 136
 - Intensity Scales 136
 - Magnitude Scales 136
- 5.5 **Earthquake Destruction** 139
 - Destruction from Seismic Vibrations 139
 - Landslides and Ground Subsidence 140

EYE ON EARTH 5.2 141

- Fire 141
- Tsunamis 141
- 5.6 **Where Do Most Earthquakes Occur?** 144
 - Earthquakes Associated with Plate Boundaries 144
 - Damaging Earthquakes East of the Rockies 145
- 5.7 **Earthquakes: Predictions, Forecasts, and Mitigation** 146
 - Short-Range Predictions 146
 - Long-Range Forecasts 147

GEOGRAPHICS Seismic Risks on the San Andreas Fault System 148

- Minimizing Earthquake Hazards 150
- 5.8 **Earth's Interior** 152
 - Formation of Earth's Layered Structure 152
 - Probing Earth's Interior: "Seeing" Seismic Waves 152
 - Earth's Layered Structure 153

Concepts in Review 155 | **Give It Some Thought** 157 | **Examining the Earth System** 159 | **Data Analysis** 159

6 Volcanoes and Other Igneous Activity 161**FOCUS ON CONCEPTS** 161

- 6.1 **Mount St. Helens Versus Kilauea** 162
- 6.2 **The Nature of Volcanic Eruptions** 163
 - Magma: Source Material for Volcanic Eruptions 163
 - Effusive Versus Explosive Eruptions 164
 - Effusive Eruptions 164
 - How Explosive Eruptions Are Triggered 165
- 6.3 **Materials Extruded During an Eruption** 166
 - Lava Flows 166
 - Gases 168
 - Pyroclastic Materials 168
- 6.4 **Anatomy of a Volcano** 169
- 6.5 **Shield Volcanoes** 170
 - Mauna Loa: Earth's Largest Shield Volcano 170
 - Kilauea: Hawaii's Most Active Volcano 171
- 6.6 **Cinder Cones** 172
 - Parícutin: Life of a Garden-Variety Cinder Cone 173
- 6.7 **Composite Volcanoes** 173

GEOGRAPHICS Kilauea's East Rift Zone Eruption 174

- 6.8 **Volcanic Hazards** 177
 - Pyroclastic Flow: A Deadly Force of Nature 177
 - Lahars: Mudflows on Active and Inactive Cones 178
 - Other Volcanic Hazards 179

EYE ON EARTH 6.1 180

- 6.9 **Other Volcanic Landforms** 180
 - Calderas 180
 - Fissure Eruptions and Basalt Plateaus 182
 - Volcanic Necks 183
- 6.10 **Intrusive Igneous Activity** 184
 - Nature of Intrusive Bodies 184
 - Tabular Intrusive Bodies: Dikes and Sills 184
 - Massive Intrusive Bodies: Batholiths, Stocks, and Laccoliths 186
- EYE ON EARTH 6.2** 188
- 6.11 **Partial Melting and the Origin of Magma** 188
 - Partial Melting 188
 - Generating Magma from Solid Rock 188
- 6.12 **Plate Tectonics and Volcanism** 190
 - Volcanism at Divergent Plate Boundaries 190
 - Volcanism at Convergent Plate Boundaries 191
 - Intraplate Volcanism 191

Concepts in Review 195 | **Give It Some Thought** 197 | **Examining the Earth System** 199 | **Data Analysis** 199

7 Crustal Deformation and Mountain Building 201

FOCUS ON CONCEPTS 201

- 7.1 **Crustal Deformation 202**
 - What Causes Rocks to Deform? 202
 - Types of Deformation 203
 - Factors That Affect How Rocks Deform 204
- 7.2 **Folds: Rock Structures Formed by Ductile Deformation 205**
 - Anticlines and Synclines 205
 - Domes and Basins 206
 - Monoclines 208
- EYE ON EARTH 7.1 209**
- 7.3 **Faults and Joints: Rock Structures Formed by Brittle Deformation 209**
 - Dip-Slip Faults 209
 - Strike-Slip Faults 212
 - Joints 212
- 7.4 **Mountain Building 214**
- 7.5 **Subduction and Mountain Building 215**
 - Island Arc-Type Mountain Building 215
 - Andean-Type Mountain Building 215
 - Sierra Nevada, Coast Ranges, and Great Valley 216
- 7.6 **Collisional Mountain Belts 217**
 - Cordilleran-Type Mountain Building 217
 - Alpine-Type Mountain Building: Continental Collisions 219
 - The Himalayas 219
 - The Appalachians 221
- EYE ON EARTH 7.2 221**
- 7.7 **Vertical Motions of the Crust 223**
 - The Principle of Isostasy 223

GEOGRAPHICS The Laramide Rockies 224

How High Is Too High? 227

Concepts in Review 227 | Give It Some Thought 229 | Examining the Earth System 231 | Data Analysis 231

UNIT 3 Sculpting Earth's Surface 232

8 Weathering, Soil, and Mass Movement 233

FOCUS ON CONCEPTS 233

- 8.1 **Earth's External Processes 234**
- 8.2 **Weathering 235**
 - Mechanical Weathering 235

GEOGRAPHICS Some Everyday Examples of Weathering 236

GEOGRAPHICS The Old Man of the Mountain 238

Chemical Weathering 239

EYE ON EARTH 8.1 240

Differential Weathering 241

- 8.3 **Soil: An Indispensable Resource 243**

An Interface in the Earth System 243

What Is Soil? 243

Soil Texture and Structure 244

- 8.4 **Controls of Soil Formation 244**

Parent Material 244

Climate 245

Time 245

Plants and Animals 245

Topography 246

- 8.5 **Describing and Classifying Soils 247**

The Soil Profile 247

Classifying Soils 248

EYE ON EARTH 8.2 249

- 8.6 **Soil Erosion: Losing a Vital Resource 250**

Erosion by Water and Wind 250

Rates of Erosion 250

Controlling Soil Erosion 251

- 8.7 **Mass Movement on Slopes: The Work of Gravity 252**

Landslides as Geologic Hazards 252

The Role of Mass Movement in Landscape Development 252

Slopes Change Through Time 252

Controls and Triggers of Mass Movement 252

GEOGRAPHICS Landslides as Natural Disasters 253

- 8.8 **Types of Mass Movement 256**

Classifying Mass Movements 256

EYE ON EARTH 8.3 257

Rapid Forms of Mass Movement 257

Slow Forms of Mass Movement 259

Concepts in Review 260 | Give It Some Thought 263 |

Examining the Earth System 264 | Data Analysis 265

9 Running Water and Groundwater 267

FOCUS ON CONCEPTS 267

- 9.1 **Earth as a System: The Hydrologic Cycle 268**

Earth's Water 268

Water's Paths 268

Storage in Glaciers 268

Water Balance 269

- 9.2 **Running Water 269**

Drainage Basins 269

River Systems 270

Drainage Patterns 271

- 9.3 **Streamflow Characteristics 272**

Factors Affecting Flow Velocity 272

Changes from Upstream to Downstream 273

- 9.4 **The Work of Running Water 274**

Stream Erosion 274

Transportation of Sediment 275

EYE ON EARTH 9.1 276

Deposition of Sediment 277

- 9.5 **Stream Channels 277**

Bedrock Channels 277

Alluvial Channels 277

- 9.6 **Shaping Stream Valleys 280**

Base Level and Stream Erosion 280

Valley Deepening 280

Valley Widening 281

Changing Base Level and Incised Meanders 281

- 9.7 **Depositional Landforms 282**

Deltas 282

Natural Levees 284

EYE ON EARTH 9.2 284

Alluvial Fans 285

- 9.8 **Floods and Flood Control 285**

Causes of Floods 285

Flood Control 285

GEOGRAPHICS Flash Floods 286

- 9.9 **Groundwater: Water Beneath the Surface 288**

The Importance of Groundwater 288

Geologic Importance of Groundwater 288

Distribution of Groundwater 288

- Storage and Movement of Groundwater 289
 - Groundwater Movement 290
 - 9.10 **Wells, Artesian Systems, and Springs** 291
 - Wells and Artesian Systems 291
 - Springs 292
 - EYE ON EARTH 9.3** 293
 - 9.11 **Environmental Problems Related to Groundwater** 294
 - Treating Groundwater as a Nonrenewable Resource 294
 - Land Subsidence Caused by Groundwater Withdrawal 295
 - Groundwater Contamination 296
 - 9.12 **The Geologic Work of Groundwater** 297
 - Caverns 297
 - Karst Topography 298
- Concepts in Review** 300 | **Give It Some Thought** 303 |
Examining the Earth System 304 | **Data Analysis** 305

10 Glaciers, Deserts, and Wind 307

FOCUS ON CONCEPTS 307

- 10.1 **Glaciers and the Earth System** 308
 - Glaciers: A Part of Two Basic Cycles 308
 - Valley (Alpine) Glaciers 308
 - Ice Sheets 309
- GEOGRAPHICS** **Antartica Fact File** 310
 - Other Types of Glaciers 312
- 10.2 **How Glaciers Move** 313
 - Observing and Measuring Movement 313
 - Budget of a Glacier: Accumulation Versus Wastage 314
- EYE ON EARTH 10.1** 315
- 10.3 **Glacial Erosion** 316
 - How Glaciers Erode 317
 - Landforms Created by Glacial Erosion 317
- 10.4 **Glacial Deposits** 320
 - Types of Glacial Drift 320
 - Moraines, Outwash Plains, and Kettles 321
 - Drumlins, Eskers, and Kames 323
- 10.5 **Other Effects of Ice Age Glaciers** 324
 - Crustal Subsidence and Rebound 324
 - Sea-Level Changes 324
 - Changing Rivers 325
 - Ice Dams Create Proglacial Lakes 325
 - Pluvial Lakes 325
- 10.6 **The Ice Age** 326
 - Extent of Ice Age Glaciation 326
 - Causes of Ice Ages 327
 - Plate Tectonics 327
 - Variations in Earth's Orbit 328
 - Other Factors 329
- 10.7 **Deserts** 330
 - Distribution and Causes of Dry Lands 330
 - Geologic Processes in Arid Climates 331
- 10.8 **Basin and Range: The Evolution of a Mountainous Desert Landscape** 332
 - EYE ON EARTH 10.2** 334
- 10.9 **Wind Erosion** 335
 - Deflation, Blowouts, and Desert Pavement 335
 - Wind Abrasion 336
- 10.10 **Wind Deposits** 337
 - Loess 337
 - Sand Dunes 337
- EYE ON EARTH 10.3** 337
 - Types of Sand Dunes 339

Concepts in Review 340 | **Give It Some Thought** 343 |
Examining the Earth System 344 | **Data Analysis** 345

UNIT 4 Deciphering Earth's History 346

11 Geologic Time 347

FOCUS ON CONCEPTS 347

- 11.1 **A Brief History of Geology** 348
 - Catastrophism 348
 - The Birth of Modern Geology 348
 - Geology Today 349
- 11.2 **Creating a Time Scale: Relative Dating Principles** 349
 - The Importance of a Time Scale 349
 - Numerical and Relative Dates 350
 - Principle of Superposition 350
 - Principle of Original Horizontality 350
 - Principle of Lateral Continuity 351
 - Principle of Cross-Cutting Relationships 351
 - Principle of Inclusions 351
- EYE ON EARTH 11.1** 352
 - Unconformities 352
 - Applying Relative Dating Principles 354
- EYE ON EARTH 11.2** 355
- 11.3 **Fossils: Evidence of Past Life** 356
 - Types of Fossils 356

GEOGRAPHICS How is paleontology different from archaeology? 357

- Conditions Favoring Preservation 358
- 11.4 **Correlation of Rock Layers** 358
 - Correlation Within Limited Areas 358
 - Fossils and Correlation 360
- 11.5 **Numerical Dating with Nuclear Decay** 361
 - Reviewing Basic Atomic Structure 361
 - Changes to Atomic Nuclei 361
 - Radiometric Dating 362
 - Half-Life 362
 - Using Unstable Isotopes 363
 - Dating with Carbon-14 363
- 11.6 **Determining Numerical Dates for Sedimentary Strata** 364
 - EYE ON EARTH 11.3** 365
- 11.7 **The Geologic Time Scale** 365
 - Structure of the Time Scale 366
 - Precambrian Time 367
 - Terminology and the Geologic Time Scale 367

Concepts in Review 368 | **Give It Some Thought** 369 |
Examining the Earth System 370 | **Data Analysis** 371

12 Earth's Evolution Through Geologic Time 373

FOCUS ON CONCEPTS 373

- 12.1 **What Makes Earth Habitable?** 374
 - The Right Planet 374
 - The Right Location 375
 - The Right Time 375
 - Viewing Earth's History 375
- 12.2 **Birth of a Planet** 377
 - From the Big Bang to Heavy Elements 377
 - From Planetesimals to Protoplanets 377
 - Earth's Early Evolution 377
- 12.3 **Origin and Evolution of the Atmosphere and Oceans** 379
 - Earth's Primitive Atmosphere 379
 - Oxygen in the Atmosphere 380
 - Evolution of Earth's Oceans 380

- 12.4 **Precambrian History: The Formation of Earth's Continents** 381
 - Earth's First Continents 382
 - The Making of North America 384
 - Supercontinents of the Precambrian 384
- EYE ON EARTH 12.1** 385
- 12.5 **Geologic History of the Phanerozoic: The Formation of Earth's Modern Continents** 386
 - Paleozoic History 386
 - Mesozoic History 387
 - Cenozoic History 388
- 12.6 **Earth's First Life** 389
 - Origin of Life 389
 - Earth's First Life: Prokaryotes 391
 - Evolution of Eukaryotes 391
- 12.7 **Paleozoic Era: Life Explodes** 392
 - Early Paleozoic Life—Forms 392
 - Mid-Paleozoic Life 392
 - Vertebrates Move to Land 393
 - Reptiles: The First True Terrestrial Vertebrates 394
 - The Great Permian Extinction 394
- EYE ON EARTH 12.2** 394
- 12.8 **Mesozoic Era: Dinosaurs Dominate the Land** 396
 - Gymnosperms: The Dominant Mesozoic Trees 396
 - Reptiles Take Over the Land, Sea, and Sky 396
 - Demise of the Dinosaurs 397
- 12.9 **Cenozoic Era: Mammals Diversify** 399
 - From Dinosaurs to Mammals 399
 - Mammal Groups 400
 - Humans: Mammals with Large Brains and Bipedal Locomotion 400
 - Large Mammals and Extinction 401

Concepts in Review 402 | **Give It Some Thought** 404 | **Examining the Earth System** 405 | **Data Analysis** 405

UNIT 5 The Global Ocean 406

13 The Ocean Floor 407

FOCUS ON CONCEPTS 407

- 13.1 **The Vast World Ocean** 408
 - Geography of the Oceans 408
 - Comparing the Oceans to the Continents 409
- 13.2 **An Emerging Picture of the Ocean Floor** 409
 - Mapping the Seafloor 409
 - Provinces of the Ocean Floor 412
- 13.3 **Continental Margins** 414
 - Passive Continental Margins 414
- EYE ON EARTH 13.1** 415
 - Active Continental Margins 416
- 13.4 **Features of Deep-Ocean Basins** 417
 - Deep-Ocean Trenches 417
 - Abyssal Plains 418
 - Volcanic Structures on the Ocean Floor 418
- 13.5 **The Oceanic Ridge System** 419
 - Anatomy of the Oceanic Ridge System 419

GEOGRAPHICS Explaining Coral Atolls: Darwins Hypothesis 420

- Why Is the Oceanic Ridge Elevated? 422
- 13.6 **Seafloor Sediments** 422
 - Types of Seafloor Sediments 423
 - Seafloor Sediment—A Storehouse of Climate Data 424
- 13.7 **Resources from the Seafloor** 424
 - Energy Resources 424
 - Other Resources 425

Concepts in Review 426 | **Give It Some Thought** 428 | **Examining the Earth System** 429 | **Data Analysis** 429

14 Ocean Water and Ocean Life 431

FOCUS ON CONCEPTS 431

- 14.1 **Composition of Seawater** 432
 - Salinity 432
 - Sources of Sea Salts 432
 - Processes Affecting Seawater Salinity 433
 - Recent Increase in Ocean Acidity 434
- 14.2 **Variations in Temperature and Density with Depth** 435
 - Temperature Variations 435
 - Density Variations 435
 - Ocean Layering 436
- EYE ON EARTH 14.1** 436
- 14.3 **The Diversity of Ocean Life** 437
 - Classification of Marine Organisms 437
 - Marine Life Zones 439
- EYE ON EARTH 14.2** 440
- 14.4 **Ocean Productivity** 441
 - Productivity in Polar Oceans 441

GEOGRAPHICS Deep-Sea Hydrthermal Vents 442

- Productivity in Tropical Oceans 444
- Productivity in Midlatitude Oceans 444
- 14.5 **Oceanic Feeding Relationships** 445
 - Trophic Levels 445
 - Transfer Efficiency 445
 - Food Chains and Food Webs 445

Concepts in Review 447 | **Give It Some Thought** 448 | **Examining the Earth System** 449 | **Data Analysis** 449

15 The Dynamic Ocean 451

FOCUS ON CONCEPTS 452

- 15.1 **The Ocean's Surface Circulation** 452
 - The Pattern of Surface-Ocean Currents 452
- 15.2 **Upwelling and Deep-Ocean Circulation** 455
 - Coastal Upwelling 455
 - Deep-Ocean Circulation 455
- 15.3 **The Shoreline: A Dynamic Interface** 457
 - The Coastal Zone 457
 - Coastal Features and Terminology 457
 - Beaches 458
- 15.4 **Ocean Waves** 459
 - Wave Characteristics 459
- EYE ON EARTH 15.1** 460
 - Circular Orbital Motion 460
 - Waves in the Surf Zone 460
- 15.5 **The Work of Waves** 461
 - Wave Erosion 461
 - Sand Movement on the Beach 462
- 15.6 **Shoreline Features** 464
 - Erosional Features 464
 - Depositional Features 465
 - The Evolving Shore 466
- 15.7 **Contrasting America's Coasts** 467
 - Coastal Classification 467

GEOGRAPHICS A Brief Tour of America's Coasts 468

- Atlantic and Gulf Coasts 470
- Pacific Coast 470

EYE ON EARTH 15.2 472

- 15.8 **Stabilizing the Shore** 472
 Hard Stabilization 472
 Alternatives to Hard Stabilization 474
EYE ON EARTH 15.3 475
- 15.9 **Tides** 476
 Causes of Tides 476
 Monthly Tidal Cycle 477
 Tidal Patterns 477
 Tidal Currents 478
- Concepts in Review** 479 | **Give It Some Thought** 481 |
Examining the Earth System 482 | **Data Analysis** 483

UNIT 6 Earth's Dynamic Atmosphere 484

16 The Atmosphere: Composition, Structure, and Temperature 485

FOCUS ON CONCEPTS 485

- 16.1 **Focus on the Atmosphere** 486
 Weather in the United States 486
 Weather and Climate 486
EYE ON EARTH 16.1 487
- 16.2 **Composition of the Atmosphere** 488
 Major Components 488
 Carbon Dioxide 488
 Variable Components 489
 Ozone Depletion: A Global Issue 490
- 16.3 **Vertical Structure of the Atmosphere** 491
 Pressure Changes 491
 Temperature Changes 491
- 16.4 **Earth–Sun Relationships** 493
 Earth's Motions 493
 What Causes the Seasons? 493
 Earth's Orientation 494
 Solstices and Equinoxes 495
EYE ON EARTH 16.2 497
- 16.5 **Energy, Heat, and Temperature** 497
 Mechanism of Heat Transfer: Conduction 498
 Mechanism of Heat Transfer: Convection 498
EYE ON EARTH 16.3 498
 Mechanism of Heat Transfer: Radiation 499
- 16.6 **Heating the Atmosphere** 500
 What Happens to Incoming Solar Radiation? 500
 Reflection and Scattering 501
 Absorption 501
 Heating the Atmosphere: The Greenhouse Effect 502
- 16.7 **For the Record: Air Temperature Data** 503
- 16.8 **Why Temperatures Vary: The Controls of Temperature** 504
 Land and Water 504
 Altitude 506
 Geographic Position 506
 Cloud Cover and Albedo 506
EYE ON EARTH 16.4 508
- 16.9 **World Distribution of Temperature** 508
- Concepts in Review** 510 | **Give It Some Thought** 513 |
Examining the Earth System 514 | **Data Analysis** 515

17 Moisture, Clouds, and Precipitation 517

FOCUS ON CONCEPTS 517

- 17.1 **Water's Changes of State** 518
 Ice, Liquid Water, and Water Vapor 518
 Latent Heat 518
- 17.2 **Humidity: Water Vapor in the Air** 520
 Saturation 520
 Mixing Ratio 520
 Relative Humidity 521
 Dew-Point Temperature 522
 How Is Humidity Measured? 523
- 17.3 **Adiabatic Temperature Changes and Cloud Formation** 524
 Adiabatic Temperature Changes 524
 Adiabatic Cooling and Condensation 524
- 17.4 **Processes That Lift Air** 525
 Orographic Lifting 525
 Frontal Lifting 526
 Convergence 526
 Localized Convective Lifting 527
- 17.5 **The Critical Weathermaker: Atmospheric Stability** 527
 Types of Stability 528
EYE ON EARTH 17.1 530
 Stability and Daily Weather 531
- 17.6 **Condensation and Cloud Formation** 531
 Condensation Nuclei and Cloud Formation 531
 Cloud Classification 531
- 17.7 **Types of Fog** 535
 Fogs Caused by Cooling 535
 Evaporation Fogs 536
- 17.8 **How Precipitation Forms** 537
EYE ON EARTH 17.2 537
 Precipitation from Cold Clouds: The Bergeron Process 538
 Precipitation from Warm Clouds: The Collision–Coalescence Process 539
- 17.9 **Forms of Precipitation** 539
 Rain, Drizzle, and Mist 539
 Snow 540
 Sleet and Freezing Rain (Glaze) 540
 Hail 540
 Rime 542
- 17.10 **Measuring Precipitation** 543
 Measuring Snowfall 543
 Precipitation Measurement by Weather Radar 543

GEOGRAPHICS Our Water Supply 544

- Concepts in Review** 545 | **Give It Some Thought** 548 |
Examining the Earth System 549 | **Data Analysis** 549

18 Air Pressure and Wind 551

FOCUS ON CONCEPTS 551

- 18.1 **Understanding Air Pressure** 552
 Visualizing Air Pressure 552
 Measuring Air Pressure 553
- 18.2 **Factors Affecting Wind** 554
 Pressure Gradient Force 554
 Coriolis Effect 556
 Friction with Earth's Surface 556
- 18.3 **Highs and Lows** 558
 Cyclonic and Anticyclonic Winds 558
 Weather Generalizations About Highs and Lows 558

- 18.4 General Circulation of the Atmosphere 560**
 Circulation on a Nonrotating Earth 560
 Idealized Global Circulation 561
EYE ON EARTH 18.1 561
 Influence of Continents 562
 The Westerlies 563
- 18.5 Local Winds 563**
 Land and Sea Breezes 563
 Mountain and Valley Breezes 564
 Chinook and Santa Ana Winds 564
- 18.6 Measuring Wind 565**
EYE ON EARTH 18.2 566
- 18.7 El Niño, La Niña, and the Southern Oscillation 567**
 Global Impact of El Niño 567
 Global Impact of La Niña 567
 Southern Oscillation 569
- 18.8 Global Distribution of Precipitation 569**
 The Influence of Pressure and Wind Belts 569
 Other Factors 569
EYE ON EARTH 18.3 570

Concepts in Review 571 | **Give It Some Thought** 573 |
Examining the Earth System 574 | **Data Analysis** 575

19 Weather Patterns and Severe Storms 577

FOCUS ON CONCEPTS 577

- 19.1 Air Masses 578**
 What Is an Air Mass? 578
 Source Regions 579
 Weather Associated with Air Masses 579
EYE ON EARTH 19.1 581
- 19.2 Fronts 581**
 Warm Fronts 582
 Cold Fronts 582
 Stationary Fronts and Occluded Fronts 583
- 19.3 Midlatitude Cyclones 584**
 Idealized Weather of a Midlatitude Cyclone 585
 The Role of Airflow Aloft 587
EYE ON EARTH 19.2 587
- 19.4 Thunderstorms 588**
 What's in a Name? 588
 Thunderstorm Occurrence 588
 Stages of Thunderstorm Development 589
- 19.5 Tornadoes 590**
 Tornado Development and Occurrence 591
 Tornado Climatology 592
 Tornado Destruction and Loss of Life 593
EYE ON EARTH 19.3 594
 Tornado Forecasting 594
- 19.6 Hurricanes 595**
 Profile of a Hurricane 596
 Hurricane Formation and Decay 598
 Hurricane Destruction 598
 Monitoring Hurricanes 600

Concepts in Review 601 | **Give It Some Thought** 603 |
Examining the Earth System 604 | **Data Analysis** 605

20 World Climates and Global Climate Change 607

FOCUS ON CONCEPTS 607

- 20.1 The Climate System 608**
- 20.2 World Climates 609**
EYE ON EARTH 20.1 609
 Climate Classification 609
 The Köppen Classification 610
- 20.3 Humid Tropical (A) Climates 612**
 The Wet Tropics 612
 Tropical Wet and Dry 614
- 20.4 Dry (B) Climates 615**
 Low-Latitude Deserts and Steppes 615
 Middle-Latitude Deserts and Steppes 615
- 20.5 Humid Middle-Latitude Climates (C and D Climates) 616**
 Humid Middle-Latitude Climates with Mild Winters (C Climates) 616
 Humid Middle-Latitude Climates with Severe Winters (D Climates) 618
- 20.6 Polar (E) Climates 619**
- 20.7 Highland Climates 620**
- 20.8 Human Impact on Global Climate 621**
 Rising CO₂ Levels 622
EYE ON EARTH 20.2 622
 The Atmosphere's Response 623
 The Role of Trace Gases 624
 How Aerosols Influence Climate 624
- 20.9 Climate-Feedback Mechanisms 626**
 Types of Feedback Mechanisms 626
 Computer Models of Climate: Important yet Imperfect Tools 626
- 20.10 Some Possible Consequences of Global Warming 627**
 Sea-Level Rise 627
 The Changing Arctic 629
 The Potential for "Surprises" 630

Concepts in Review 631 | **Give It Some Thought** 633 |
Examining the Earth System 634 | **Data Analysis** 635

UNIT 7 Earth's Place in the Universe 636

21 Origins of Modern Astronomy 637

FOCUS ON CONCEPTS 637

- 21.1 Ancient Astronomy 638**
 The Golden Age of Astronomy 638
 Ptolemy's Model of the Universe 640
- 21.2 The Birth of Modern Astronomy 641**
 Nicolaus Copernicus 642
 Tycho Brahe 642
 Johannes Kepler 643
 Galileo Galilei 644
 Sir Isaac Newton 646
- 21.3 Patterns in the Night Sky 647**
 Constellations 647
 The Celestial Sphere 647

GEOGRAPHICS Orion the Hunter 648

Measurements Using the Celestial Sphere 650

- 21.4 The Motions of Earth 651**
 Earth's Rotation: Spinning on Its Axis 651
 Earth's Orbit Around the Sun 652
 Other Motions of Earth 653
- 21.5 Motions of the Earth–Moon System 653**
 Lunar Motions 653
 Phases of the Moon 653
- 21.6 Eclipses of the Sun and Moon 655**
- Concepts in Review 656 | Give It Some Thought 658 |
 Examining the Earth System 659 | Data Analysis 659**

22 Touring Our Solar System 661

FOCUS ON CONCEPTS 661

- 22.1 Our Solar System: An Overview 662**
 Nebular Theory: Formation of the Solar System 663
 The Planets: Internal Structures and Atmospheres 664
 Planetary Impacts 666
- 22.2 Earth's Moon: A Chip Off the Old Block 667**
 How Did the Moon Form? 668
 The Lunar Surface 668
- EYE ON THE UNIVERSE 22.1 668**
- 22.3 Terrestrial Planets 670**
 Mercury: The Innermost Planet 670
 Venus: The Veiled Planet 671
 Mars: The Red Planet 672

GEOGRAPHICS Mars Exploration 674

- 22.4 Jovian Planets 677**
 Jupiter: Lord of the Heavens 677
 Saturn: The Elegant Planet 679
 Uranus and Neptune: Twins 681
- EYE ON THE UNIVERSE 22.2 681**
- 22.5 Small Solar System Bodies 683**
 Asteroids: Leftover Planetesimals 683
 Comets: Dirty Snowballs 684
 Meteors, Meteoroids, and Meteorites 685
 Dwarf Planets 687

**Concepts in Review 688 | Give It Some Thought 690 |
 Examining the Earth System 691 | Data Analysis 691**

23 Light, Telescopes, and the Sun 693

FOCUS ON CONCEPTS 693

- 23.1 Light: Messenger from Space 694**
 Nature of Light 694
 Why Study Light? 694
- 23.2 What Can We Learn from Light? 695**
 Three Types of Spectra 695
 What Does Light Tell Us About Composition? 696
 What Does Light Tell Us About Temperature? 696
 What Does Light Tell Us About the Motion of Distant Objects? 697
- 23.3 Collecting Light Using Optical Telescopes 698**
 Refracting Telescopes 698
 Reflecting Telescopes 698
 Why Build Large Optical Telescopes? 699
 Advances in Light Collection 700

EYE ON THE UNIVERSE 23.1 701

- 23.4 Radio- and Space-Based Astronomy 702**
 Radio Telescopes: Observing the Invisible 702
 Orbiting Observatories: Detecting All Forms of Light 703

GEOGRAPHICS Hubble Space Telescope 704

- The Hubble Space Telescope and Beyond 706
- 23.5 Our Star: The Sun 707**
 The Sun's Surface 707
 The Sun's Atmosphere 707
 The Sun's Interior 708
 The Source of Solar Energy 708
- 23.6 The Active Sun 709**
 Sunspots 709
 Prominences 710
 Solar Flares and Coronal Mass Ejections 711

**Concepts in Review 712 | Give It Some Thought 714 |
 Examining the Earth System 714 | Data Analysis 715**

24 Beyond Our Solar System 717

FOCUS ON CONCEPTS 717

- 24.1 Classifying Stars 718**
 Stellar Luminosity 718
 Stellar Color and Temperature 719
 Hertzsprung–Russell Diagrams (H-R Diagrams) 719
- 24.2 Stellar Evolution 721**
 Stellar Birth 721
 Protostar Stage 722
 Main-Sequence Stage 722
 Red Giant Stage 722
 Burnout and Death 723
- 24.3 Stellar Remnants 725**
 White Dwarfs 725
 Neutron Stars 725
 Black Holes 726

EYE ON THE UNIVERSE 24.1 727

- 24.4 Galaxies and Galaxy Clusters 727**

GEOGRAPHICS The Milky Way 728

- Types of Galaxies 730
 Galaxy Clusters 731
 Galactic Collisions 732
- 24.5 The Universe 732**
 How Large Is It? 732
 A Brief History of the Universe 733
 Evidence for an Expanding Universe 734
 Predictions of the Big Bang Theory 735
 What Is the Fate of the Universe? 735

**Concepts in Review 737 | Give It Some Thought 738 |
 Examining the Earth System 739 | Data Analysis 739**

APPENDIX A Metric and English Units Compared 740

APPENDIX B Relative Humidity and Dew-Point Tables 741

Glossary 742

Index 754

SmartFigure Media

Use your mobile device and a free Quick Response (QR) code reader app to scan a SmartFigure identified by a 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 challenging Earth Science concepts.

CONDOR VIDEO

Continental Rifting
<https://goo.gl/RXv8qH>



Chapter 1

- 1.2 **MOBILE FIELD TRIP:** A Geologist's Grand Canyon (p. 5)
- 1.6 **TUTORIAL:** Geologic Time (p. 8)
- 1.9 **TUTORIAL:** The Nebular Theory (p. 13)
- 1.11 **VIDEO:** Planets and Moons: Earthrise the 45th Anniversary (p. 15)
- 1.16 **TUTORIAL:** Earth's Layers (p. 18)
- 1.21 **TUTORIAL:** Shields, Platforms, and Mountain Belts (p. 25)

Chapter 2

- 2.3 **TUTORIAL:** Minerals vs. Rocks (p. 33)
- 2.12 **TUTORIAL:** Mineral Color (p. 40)
- 2.13 **VIDEO:** Mineral Streak (p. 40)
- 2.15 **TUTORIAL:** Mineral Habit (p. 41)
- 2.16 **TUTORIAL:** Mineral Hardness (p. 42)
- 2.17 **ANIMATION:** Types of Cleavage (p. 42)
- 2.18 **TUTORIAL:** Mineral Cleavage (p. 43)
- 2.21 **VIDEO:** Calcite Reacting with a Weak Acid (p. 44)
- 2.24 **TUTORIAL:** Silicate Minerals (p. 46)

Chapter 3

- 3.1 **TUTORIAL:** The Rock Cycle (p. 59)
- 3.4 **TUTORIAL:** Igneous Composition (p. 62)
- 3.5 **TUTORIAL:** Igneous Textures (p. 63)
- 3.8 **TUTORIAL:** Classification of Igneous Rocks (p. 65)
- 3.9 **MOBILE FIELD TRIP:** Yosemite: Granite and Glaciers (p. 66)
- 3.15 **MOBILE FIELD TRIP:** The Sedimentary Rocks of Capitol Reef National Park (p. 69)
- 3.21 **TUTORIAL:** Bonneville Salt Flats (p. 73)
- 3.22 **TUTORIAL:** Coal (p. 73)
- 3.26 **ANIMATION:** Foliation of Metamorphic Rock (p. 75)
- 3.28 **TUTORIAL:** Confining Pressure & Differential Stress (p. 77)
- 3.29 **ANIMATION:** Foliation (p. 78)
- 3.32 **MOBILE FIELD TRIP:** Metamorphic Rocks in the Adirondacks, New York (p. 82)
- 3.37 **TUTORIAL:** Oil Traps (p. 86)

Chapter 4

- 4.2 **TUTORIAL:** Pangaea (p. 95)
- 4.9 **TUTORIAL:** Crust vs. Lithosphere (p. 99)
- 4.12 **MOBILE FIELD TRIP:** Fire and Ice Land (p. 102)
- 4.13 **TUTORIAL:** Divergent Boundaries (p. 103)
- 4.14 **CONDOR VIDEO:** Continental Rifting (p. 103)
- 4.15 **TUTORIAL:** Convergent Boundaries (p. 105)
- 4.18 **ANIMATION:** Continental-Continental Convergence (p. 106)
- 4.19 **TUTORIAL:** Transform Boundaries (p. 107)
- 4.21 **MOBILE FIELD TRIP:** The San Andreas Fault (p. 108)
- 4.29 **TUTORIAL:** Magnetic Reversals (p. 115)
- 4.31 **ANIMATION:** Magnetic Reversals (p. 116)

Chapter 5

- 5.4 **TUTORIAL:** Faults Cause Earthquakes (p. 130)
- 5.8 **ANIMATION:** Seismographs (p. 132)
- 5.9 **TUTORIAL:** P and S Waves (p. 133)
- 5.11 **ANIMATION:** Seismic Wave Motion (p. 134)
- 5.16 **TUTORIAL:** Intensity vs. Magnitude (p. 137)
- 5.25 **TUTORIAL:** Liquefaction (p. 141)
- 5.26 **TUTORIAL:** Tsunamis (p. 142)
- 5.27 **ANIMATION:** Tsunami (p. 142)

Chapter 6

- 6.5 **VIDEO:** Eruption Columns (p. 165)
- 6.11 **TUTORIAL:** Anatomy of a Volcano (p. 170)
- 6.12 **MOBILE FIELD TRIP:** Kilauea Volcano (p. 171)
- 6.13 **ANIMATION:** Volcano Types (p. 171)
- 6.14 **MOBILE FIELD TRIP:** S.P. Crater (p. 172)
- 6.15 **CONDOR VIDEO:** Cinder Cones and Basaltic Lava Flows (p. 173)
- 6.22 **ANIMATION:** Formation of a Caldera (p. 181)
- 6.23 **TUTORIAL:** Yellowstone Caldera (p. 182)
- 6.26 **TUTORIAL:** Shiprock (p. 184)
- 6.27 **ANIMATION:** Intrusive Igneous Activity (p. 185)
- 6.28 **MOBILE FIELD TRIP:** Dikes and Sills in the Sinbad Country (p. 185)
- 6.29 **CONDOR VIDEO:** Intrusive Igneous Bodies (p. 186)
- 6.37 **TUTORIAL:** The Cascade Range (p. 192)
- 6.38 **TUTORIAL:** Plate Tectonics & Volcanoes (p. 194)
- 6.39 **TUTORIAL:** Hot Spots & Flood Basalts (p. 194)

Chapter 7

- 7.1 **TUTORIAL:** Brittle vs. Ductile (p. 202)
- 7.6 **CONDOR VIDEO:** Anticlines and Synclines (p. 206)
- 7.7 **TUTORIAL:** Folds (p. 206)
- 7.8 **MOBILE FIELD TRIP:** Sheep Mountain Anticline (p. 207)
- 7.9 **TUTORIAL:** Domes & Basins (p. 207)
- 7.12 **CONDOR VIDEO:** Monoclines of the Colorado Plateau (p. 208)
- 7.13 **CONDOR VIDEO:** Faults Versus Joints (p. 209)
- 7.14 **ANIMATION:** Faults (p. 210)
- 7.16 **TUTORIAL:** Faults (p. 210)
- 7.17 **MOBILE FIELD TRIP:** Death Valley (p. 211)
- 7.18 **ANIMATION:** Reverse Faults (p. 211)
- 7.19 **ANIMATION:** Thrust Faults (p. 212)
- 7.27 **TUTORIAL:** Terrane Accretion (p. 218)
- 7.28 **ANIMATION:** Terrane Formation (p. 219)
- 7.29 **ANIMATION:** Himalayas (p. 220)
- 7.30 **TUTORIAL:** Himalayas (p. 220)
- 7.31 **TUTORIAL:** Appalachians (p. 222)
- 7.32 **MOBILE FIELD TRIP:** The Folded Rocks of Massanutten Mountain (p. 223)

7.33 ANIMATION: Isostatic Adjustment (p. 226)

7.34 TUTORIAL: Isostasy (p. 226)

Chapter 8

8.1 TUTORIAL: Mass Wasting in the Grand Canyon (p. 234)

8.2 ANIMATION: Arches National Park (p. 235)

8.3 TUTORIAL: Physical & Chemical Weathering (p. 237)

8.5 TUTORIAL: Sheeting (p. 237)

8.6 TUTORIAL: Ice Wedgings (p. 239)

8.8 TUTORIAL: Spheroidal Weathering (p. 241)

8.9 MOBILE FIELD TRIP: Bisti Badlands (p. 242)

8.10 TUTORIAL: Weathering Rates (p. 242)

8.15 TUTORIAL: Soil Horizons (p. 247)

8.23 MOBILE FIELD TRIP: Landslide! (p. 254)

8.28 ANIMATION: Mass Movements: Five Main Types (p. 256)

8.30 TUTORIAL: Gros Ventre (p. 258)

8.32 TUTORIAL: Creep (p. 259)

Chapter 9

9.1 TUTORIAL: The Water Cycle (p. 268)

9.3 TUTORIAL: Drainage Basins (p. 270)

9.4 TUTORIAL: Headward Erosion (p. 270)

9.8 MOBILE FIELD TRIP: The Mississippi River (p. 273)

9.10 TUTORIAL: Head to Mouth (p. 274)

9.12 ANIMATION: Sediment Transport by Streams (p. 275)

9.15 TUTORIAL: Meandering (p. 278)

9.16 ANIMATION: Formation of an Oxbow Lake (p. 279)

9.20 CONDOR VIDEO: Meandering Rivers (p. 281)

9.21 TUTORIAL: Incised Meanders (p. 282)

9.22 CONDOR VIDEO: River Terraces and Base Level (p. 282)

9.24 MOBILE FIELD TRIP: Mississippi River Delta (p. 283)

9.25 ANIMATION: Natural Levee Development with Flooding (p. 284)

9.32 ANIMATION: Cones of Depression (p. 291)

9.33 TUTORIAL: Artesian Systems (p. 292)

9.40 MOBILE FIELD TRIP: A Mammoth Cave (p. 297)

Chapter 10

10.1 MOBILE FIELD TRIP: The Glaciers of Alaska (p. 309)

10.2 VIDEO: Greenland Ice Sheet Stratigraphy (p. 309)

10.3 MOBILE FIELD TRIP: Ice Land (p. 312)

10.7 TUTORIAL: The Glacial Budget (p. 314)

10.12 MOBILE FIELD TRIP: The Glaciers of Alaska (p. 318)

10.13 ANIMATION: Formation of a Glacial Trough (p. 319)

10.16 MOBILE FIELD TRIP: A Trip to Cape Cod (p. 321)

10.20 TUTORIAL: Depositional Glacial Landforms (p. 323)

10.21 ANIMATION: Changing Sea Level (p. 324)

10.27 TUTORIAL: Orbital Forcing of Ice Ages (p. 329)

10.30 TUTORIAL: Deserts (p. 331)

10.32 MOBILE FIELD TRIP: Basin and Range Landscape Evolution (p. 333)

10.33 CONDOR VIDEO: Death Valley (p. 334)

10.34 VIDEO: Satellite Tracks Saharan Dust to Amazon in 3-D (p. 335)

10.35 ANIMATION: Sediment Transport by Winds (p. 335)

10.37 TUTORIAL: Desert Pavement (p. 336)

10.39 MOBILE FIELD TRIP: The Dunes of White Sands National Monument (p. 338)

10.40 TUTORIAL: Dune Movement (p. 338)

10.41 TUTORIAL: Dune Types (p. 339)

Chapter 11

11.5 VIDEO: Principles of Relative Dating (p. 351)

11.7 TUTORIAL: Relative Dating (p. 352)

11.8 TUTORIAL: Unconformities (p. 353)

11.13 TUTORIAL: Geologic Histories (p. 355)

11.18 TUTORIAL: Fossil Ranges (p. 360)

11.21 TUTORIAL: Half Life (p. 362)

Chapter 12

12.4 TUTORIAL: Formation of Earth (p. 378)

12.10 TUTORIAL: Early Crustal Growth (p. 383)

12.12 TUTORIAL: Growth of North America (p. 384)

12.15 TUTORIAL: Glaciation of Antarctica (p. 386)

12.17 TUTORIAL: Appalachians (p. 388)

12.26 TUTORIAL: Evolution of the Tetrapods (p. 395)

Chapter 13

13.2 TUTORIAL: Oceans vs. Land (p. 409)

13.6 TUTORIAL: Ocean Exploration (p. 411)

13.10 TUTORIAL: Active and Passive Margins (p. 415)

13.12 TUTORIAL: Active and Passive Margins (p. 416)

13.17 TUTORIAL: Seafloor Spreading (p. 422)

13.19 TUTORIAL: Hydrogenous Sediment (p. 423)

Chapter 14

14.2 TUTORIAL: Salinity (p. 433)

14.3 TUTORIAL: Tracking Sea Ice Changes (p. 433)

14.5 TUTORIAL: The pH Scale, Including pH Values of Common Substances (p. 434)

14.8 TUTORIAL: The Thermocline (p. 436)

14.12 TUTORIAL: Benthos (p. 439)

14.16 TUTORIAL: Productivity (p. 444)

14.19 TUTORIAL: Energy Flow & Efficiency (p. 446)

Chapter 15

15.1 ANIMATION: The Gulf Stream (p. 452)

15.2 TUTORIAL: Gyres (p. 453)

15.5 TUTORIAL: Coastal Upwelling (p. 455)

15.7 ANIMATION: Deep Ocean Conveyor Belt Circulation (p. 456)

15.11 ANIMATION: Wave Motion and Period (p. 459)

15.12 TUTORIAL: Wave Motion (p. 460)

15.13 ANIMATION: Wave Motion and Wave Refraction (p. 461)

15.16 TUTORIAL: Wave Refraction (p. 463)

15.17 TUTORIAL: Longshore Currents (p. 463)

15.21 MOBILE FIELD TRIP: A Trip to Cape Cod (p. 466)

15.24 TUTORIAL: East Coast Estuaries (p. 470)

15.34 ANIMATION: Tidal Cycle (p. 477)

15.35 TUTORIAL: Tidal Patterns (p. 478)

Chapter 16

16.6 TUTORIAL: The Mauna Loa CO₂ Record (p. 489)

16.7 VIDEO: The Road to Glory (p. 489)

16.8 TUTORIAL: The Ozone Hole (p. 490)

16.12 VIDEO: Sun Angle Changes (p. 493)

16.13 VIDEO: Sun Angle Influences Solar Intensity (p. 494)

16.15 ANIMATION: Earth-Sun Relations (p. 495)

- 16.16 **TUTORIAL:** Solstices & Equinoxes (p. 495)
- 16.19 **TUTORIAL:** 3 Mechanisms of Heat Transfer (p. 498)
- 16.22 **TUTORIAL:** Solar Radiation Paths (p. 500)
- 16.25 **TUTORIAL:** 3 Planets, 3 Climates (p. 502)
- 16.27 **TUTORIAL:** Isotherm Maps (p. 504)
- 16.30 **TUTORIAL:** Maritime Temperatures (p. 506)
- 16.34 **TUTORIAL:** Cloudy vs. Clear Days (p. 507)
- 16.36 **TUTORIAL:** January vs. July (p. 509)

Chapter 17

- 17.1 **TUTORIAL:** Changes of State in Water (p. 518)
- 17.2 **ANIMATION:** Changes of State in Water (p. 519)
- 17.8 **TUTORIAL:** Dewpoint (p. 523)
- 17.13 **TUTORIAL:** Frontal Wedging & Convergence (p. 526)
- 17.16 **ANIMATION:** Atmospheric Stability (p. 528)
- 17.17 **TUTORIAL:** Atmospheric Stability (p. 529)
- 17.20 **TUTORIAL:** Types of Clouds (p. 532)
- 17.22 **VIDEO:** Satellite View of Fog (p. 535)
- 17.25 **TUTORIAL:** Fog (p. 537)

Chapter 18

- 18.2 **TUTORIAL:** Air Pressure (p. 553)
- 18.7 **TUTORIAL:** Isobars on Weather Maps (p. 555)
- 18.8 **VIDEO:** The Coriolis Effect (p. 556)
- 18.11 **ANIMATION:** Winds Aloft vs. Surface Winds (p. 558)
- 18.14 **ANIMATION:** Cyclones and Anticyclones (p. 559)
- 18.17 **TUTORIAL:** Global Circulation (p. 561)
- 18.19 **TUTORIAL:** Local Winds (p. 564)

Chapter 19

- 19.4 **TUTORIAL:** Lake-Effect Snow (p. 580)
- 19.7 **ANIMATION:** Warm Fronts (p. 582)
- 19.8 **TUTORIAL:** Cold Fronts (p. 583)
- 19.11 **TUTORIAL:** Mid-Latitude Cyclones (p. 585)
- 19.12 **TUTORIAL:** Mid-Latitude Cyclones (p. 586)
- 19.18 **TUTORIAL:** Thunderstorms (p. 590)
- 19.20 **VIDEO:** National Severe Storms Laboratory (NSSL) in the Field (p. 591)
- 19.21 **ANIMATION:** Tornado Wind Patterns (p. 591)
- 19.22 **TUTORIAL:** Mesocyclones and Tornadoes (p. 592)
- 19.25 **VIDEO:** The Benefits of Doppler Radar (p. 595)
- 19.27 **VIDEO:** Hurricanes and Air Masses (p. 596)
- 19.29 **VIDEO:** Ocean Today: The Making of a Super Storm (p. 597)
- 19.33 **VIDEO:** Hot Towers and Hurricane Intensification (p. 600)
- 19.34 **VIDEO:** Hot Towers and Hurricane Intensification (p. 601)

Chapter 20

- 20.6 **TUTORIAL:** Tropical Climates (p. 613)
- 20.15 **TUTORIAL:** Polar Climates (p. 620)
- 20.16 **TUTORIAL:** Highland Climates (p. 621)
- 20.26 **VIDEO:** Sea Level Changes Related to Formation and Melting of Glaciers (p. 628)
- 20.27 **TUTORIAL:** Shoreline Shift (p. 629)
- 20.28 **VIDEO:** Climate Change in the Arctic (p. 629)

Chapter 21

- 21.3 **TUTORIAL:** Eratosthenes and Earth's Circumference (p. 639)
- 21.5 **TUTORIAL:** Epicycles & Retrograde Motion (p. 640)
- 21.6 **TUTORIAL:** Epicycles & Retrograde Motion (p. 641)
- 21.15 **TUTORIAL:** Using a Telescope, Galileo Discovered that Venus has Phases Just Like the Moon (p. 645)
- 21.17 **TUTORIAL:** Planetary Positions (p. 647)
- 21.20 **TUTORIAL:** The North Star (p. 650)
- 21.26 **TUTORIAL:** Phases of the Moon (p. 654)
- 21.27 **TUTORIAL:** Solar Eclipse (p. 655)
- 21.28 **TUTORIAL:** Eclipses (p. 656)

Chapter 22

- 22.1 **TUTORIAL:** Orbits of the Planets (p. 662)
- 22.3 **TUTORIAL:** Planets with Atmospheres (p. 665)
- 22.7 **TUTORIAL:** Lunar Impact Basins (p. 669)
- 22.13 **TUTORIAL:** Olympus Mons (p. 673)
- 22.34 **TUTORIAL:** Meteor Crater (p. 686)
- 22.35 **TUTORIAL:** Meteor Crater (p. 687)

Chapter 23

- 23.3 **TUTORIAL:** Three Types of Spectra (p. 695)
- 23.8 **TUTORIAL:** The Doppler Effect (p. 697)
- 23.12 **TUTORIAL:** Optical Telescopes (p. 699)
- 23.22 **TUTORIAL:** Structure of the Sun (p. 707)

Chapter 24

- 24.2 **TUTORIAL:** Hertzsprung-Russell Diagram (p. 720)
- 24.5 **TUTORIAL:** Life Cycle of the Sun (p. 723)
- 24.11 **TUTORIAL:** Spiral Galaxies (p. 727)
- 24.19 **TUTORIAL:** Red Shift (p. 735)

PREFACE

Earth Science, 15th 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, *Earth Science*, 15th 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 15th edition is an extensive and thorough revision 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 *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.
- **Revised organization** In the geology portion of the text, the unit on *Forces Within* now precedes the unit on *Sculpting Earth's Surface*. This was done in response to many users and reviewers of previous editions who wanted the theory of plate tectonics presented earlier in the text because of the unifying role it plays in our understanding of planet Earth. Of course, each unit is basically independent of the others and can be taught in any order desired by the instructor.
- **SmartFigures that make *Earth Science* much more than a traditional textbook.** Through its many editions, an important strength 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 the Quick Response (QR) code next to a SmartFigure with a mobile device, 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 fifteenth edition of *Earth Science* has more than 220 SmartFigures, of five different types, including many new videos and animations:

1. SmartFigure Tutorials. Each of these 3- to 4-minute features, most 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 *Project Condor* videos take you to locations in the American West. By coupling aerial footage acquired by a drone quadcopter aircraft with ground-level views, effective narratives, annotations, and helpful animations, these videos transport you into the field and engage you in real-life case studies.

4. SmartFigure Animations. These animations and accompanying narratives bring art to life, illustrating and explaining difficult-to-visualize topics and ideas 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.

- **Revised active learning path.** *Earth Science* is designed for learning. Here is how it is accomplished. Each chapter has 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.

1. 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.

2. 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.

3. *Concepts in Review* is an end-of-chapter feature that 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.

4. The questions and problems in *Give It Some Thought* and *Examining the Earth System* challenge learners by involving them in activities that require higher-order thinking skills, such as application, analysis, and synthesis of chapter material. In addition, the activities in *Examining the Earth System* are intended to develop an awareness of and appreciation for some of the Earth system's many interrelationships.

5. The end-of-chapter review material now includes an all-new capstone activity called *Data Analysis* that sends students online to use a variety of interactive science resources and data sets from sources such as USGS, NASA, and NOAA to use various tools to perform data analysis and critical thinking tasks.

- **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 *Earth Science* visual program is clear and easy to understand.
- **MasteringGeology™.** MasteringGeology™ delivers engaging, dynamic learning opportunities—focused on course objectives and responsive to each student’s progress—that are proven to help students learn course material and understand difficult concepts. Assignable activities in MasteringGeology™ include SmartFigure (Tutorials, Condor Videos, Animation, Mobile Field Trips, Videos) activities, GigaPan® activities, “Encounter” Earth activities using Google Earth™ activities, GeoTutor activities on the most challenging topics in the geosciences, Geoscience Animation activities, and more. MasteringGeology™ also includes all instructor resources, a robust Study Area with resources for students, and an optional eText version of the textbook.

Digital & Print Resources

MasteringGeology™ with Pearson eText

Used each year by over 2 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 *Earth Science*, 15th 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 for 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 activities such as Mobile Field Trips, Project Condor Quadcopter 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.

The 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 the 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 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 Literacy Initiatives ‘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, and other LMS. www.pearsonhighered.com/irc

Instructor Resource Materials (Download Only)

All of your lecture resources are now in one easy-to-reach place:

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

For Students

Applications and Investigations in Earth Science, 9th Edition (0134746244)

This manual can be used for any Earth Science lab course, in conjunction with any text. This versatile and adaptable collection of introductory-level laboratory experiences goes beyond traditional offerings to examine the basic principles and concepts of the Earth sciences. With integration of mobile-ready Pre-Lab Videos, the **Ninth Edition** minimizes the need for faculty instruction in the lab, freeing instructors to interact directly with students. Widely praised for its concise coverage and dynamic illustrations by Dennis Tasa, the text contains twenty-three step-by-step exercises that reinforce major topics in geology, oceanography, meteorology, and astronomy.

This edition includes a new lab exercise on Volcanoes, and incorporates MasteringGeology™—the most complete, easy-to-use, and engaging tutorial and assessment tool available. MasteringGeology includes a variety of highly visual, applied, kinesthetic, and automatically-gradable activities to support each lab, as well as a robust Study Area with a variety of media and reference resources, and an eText version of the lab manual.

Laboratory Manual in Physical Geology, 11th Edition by the American Geosciences 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. Now with more than 10 new lab activities, the lab manual is also 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 optional 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 are committed to producing the best textbooks possible. Special thanks to our Earth Science editor, Christian Botting. We appreciate his enthusiasm, hard work, and quest for excellence. We also appreciate our conscientious Content Producer, Liam Wenzler, 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 15th edition of *Earth Science* 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 Heather Mann, and photo researcher Kristin Piljay. We think these talented people do 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 not only value his artistic talents, hard work, patience, and imagination, but his friendship as well.
- As you read this text, you will see dozens of extraordinary photographs by Michael Collier. Most are aerial shots taken from his 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 Geosciences Institute Award for Outstanding contribution to the Public Understanding of Geosciences. We think that Michael's photographs and field trips are the next best thing to being there. We were very fortunate to have had Michael's assistance on *Earth Science*, 15th edition. Thanks, Michael.
- Callan Bentley has been an important addition to the *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.

Great thanks also go to those colleagues who prepared in-depth reviews. In particular, we appreciate the valuable input provided by Professor Alan Trujillo at Palomar College, who assisted with the revision of the oceanography chapters, and Professor Redina Herman at Western Illinois University, who helped us strengthen the meteorology chapters. Redina is also responsible for preparing the new end-of-chapter *Data Analysis* feature.

The critical comments and thoughtful input from many other reviewers also helped guide our work and clearly strengthened the text. Special thanks to:

Anna Banda, *El Centro College*
Marianne Caldwell, *Hillsborough Community College - Dale Mabry Campus*
Jennifer Cole, *Western Kentucky University*
Jay Lennartson, *University of North Carolina - Greensboro*
William Meddaugh, *Midwestern State University*
Jeff Niemitz, *Dickinson College*
Mark Peebles, *St. Petersburg College*
Jeff Richardson, *Columbus State Community College*
Sue Riggins, *California State University, Chico*
Kristin Riker-Coleman, *University of Wisconsin - Superior*
Troy Schinkel, *Central Connecticut State University*
Karl Schulze, *Waubonsee Community College*
Christiane Stidham, *Stony Brook University*
John Stimac, *Eastern Illinois University*
Dave Voorhees, *Waubonsee Community College*
Natalie Whitcomb, *Polk State College*

Last but certainly not least, we gratefully acknowledge the support and encouragement of our wives, Joanne Bannon and Nancy Lutgens. Preparation of *Earth Science 15e* would have been far more difficult without their patience and understanding.

Ed Tarbuck
Fred Lutgens

EARTH SCIENCE 15E: MAJOR CHANGES IN THIS EDITION

Global:

- Units 2 and 3 of the book are transposed, so that tectonics and related phenomena are now covered before surface processes.
- Many new SmartFigures are added, including three new types of SmartFigures: *Project Condor* Videos, Animations (many by Dennis Tasa), and Videos.
- Much of the Tasa art is improved with bolder labels or better placement of labels and text.
- New *Data Analysis* activities now conclude each chapter.

Chapter 1:

- The text description of the standard scientific method is replaced with the pictorial version in Figure 1.8.
- In “The Solar System Forms,” the description of the collapse of the protosolar nebula is revised and updated.
- Section 1.4, “Earth as a System,” now includes the sections on Earth’s spheres (hydrosphere, geosphere, biosphere, atmosphere), formerly covered in their own section.
- The 14th edition section that introduced Earth’s structure and the basic features of plate tectonics (“A Closer Look at the Geosphere”) has been eliminated. In its place, the discussion of the geosphere in Section 1.4 is expanded to introduce Earth’s layered structure.
- Section 1.5, “The Face of Earth,” is reorganized to cover the ocean basins before the continents, rather than the reverse.
- The 14th edition *GeoGraphics* on world population is eliminated.
- Four new figures are added (Figures 1.1, 1.2, 1.8, 1.18), and three Tasa figures are substantively altered (Figs 1.9, 1.14, 1.16). Six 14th edition figures are deleted (Figures 1.1, 1.3, 1.16–1.19).
- One *Give It Some Thought* question is modified; two 14th edition questions are deleted. One *Examining the Earth System* question is deleted.

Chapter 2:

- In Section 2.4, “Properties of Minerals,” the distinction between diagnostic and ambiguous properties is added at the start.
- In Section 2.5, “Mineral Groups,” the treatment of the silicate groups is extensively revised. The opening paragraphs of the section “Important Nonsilicate Minerals” are also revised.
- The title of Section 2.6 is changed to “Minerals: A Nonrenewable Resource” from “Natural Resources.”
- Two new figures are added: Figure 2.25 and Figure 2.32 (which replaces 14th edition Table 2.1 and Figure 2.31). Six figures are substantively revised: 2.5, 2.8, 2.9, 2.11, 2.12, 2.24; *GeoGraphics* 2.1 is also revised.
- One *Give It Some Thought* question is added and one modified; two 14th edition questions are deleted.

Chapter 3:

- Section “Silica Content as an Indicator of Composition” is removed (in Section 3.2).
- Section “Detrital sedimentary rocks” in Section 3.3 is significantly revised.
- Section “Other Metamorphic Rocks” is added at the end of Section 3.4.
- Section “Nonmetallic Mineral Resources” in Section 3.5 is substantially revised.
- Section “Energy Resources” in Section 3.5 is updated and substantially revised, including the addition of Figure 3.38 to illustrate hydraulic fracturing.
- Three new figures are added: Figures 3.6, 3.22, and 3.38. Eight figures are altered substantively: 3.7, 3.16–3.18, 3.20, 3.21, 3.30, and 3.34.
- One *Give It Some Thought* question is added and one modified; two 14th edition questions are deleted.

Chapter 4:

- The section “Rigid Lithosphere Overlies Weak Asthenosphere” is revised to emphasize the importance of density differences (in Section 4.3).
- The treatment of mantle plumes is updated (“Evidence: Mantle Plumes and Hot Spots” in Section 4.8).
- “Forces that Drive Plate Motion” omits mantle drag (in Section 4.10).
- “Models of Plate–Mantle Convection” in Section 4.10 is updated.
- Two 14th edition figures are deleted (Figures 7.9, 7.11). Fourteen figures are altered substantively: 4.9–4.11, 4.14, 4.15, 4.18, 4.19, 4.21, 4.22, 4.29–4.31, 4.35, and 4.36.
- One *Give It Some Thought* question is added; two are augmented with new question parts.

Chapter 5:

- The chapter introduction describes the 2015 Nepal earthquake.
- The section “Faults and Large Earthquakes” is reorganized to discuss convergent boundaries before transform boundaries, and both discussions are substantially revised. (In Section 5.1.)
- A revised and expanded section “Fault Rupture and Propagation” replaces the 14th edition section “Fault Rupture” (in Section 5.1).
- Section 5.3, “Locating the Source of an Earthquake,” is new to the chapter; in the 14th edition, this topic was handled by the *GeoGraphics* “Finding the Epicenter of an Earthquake” (now omitted).
- The section “Intensity Scales” in Section 5.3 now covers the USGS “Did You Feel It?” Community Internet Intensity maps.

- Section 5.6 now covers intraplate as well as plate-boundary earthquakes. (In the 14th edition, intraplate earthquakes were handled in the *GeoGraphics* “Historic Earthquakes East of the Rockies,” now omitted.)
- In Section 5.7, the discussion of earthquake prediction and forecasting is extensively revised and updated. A new section “Minimizing Earthquake Hazards” is added, including discussion of earthquake-resistant structures and earthquake warning systems.
- In Section 5.8, the section “Probing Earth’s Interior: “Seeing” Seismic Waves” is significantly revised, as are portions of “Earth’s Layered Structure.”
- Seven new figures are added: 5.13 and 5.14 (which replace the 14th edition *GeoGraphics* “Finding the Epicenter of an Earthquake”); 5.31 and 5.32 (which replace the 14th edition *GeoGraphics* “Historic Earthquakes East of the Rockies”); 5.16, 5.36, and 5.37. Two 14th edition figures are deleted (8.1 and 8.14), in addition to the two *GeoGraphics* just mentioned.
- Six figures are altered substantively: 5.5, 5.18, 5.19, 5.26, 5.35, and 5.38, as well as *GeoGraphics* 5.1.
- Two *Give It Some Thought* questions are added and one is revised; six questions from the 14th edition are deleted.

Chapter 6:

- Considerable editing is done throughout to improve clarity.
- Section 6.2 is substantially rewritten, particularly the sections “Magma: Source Materials for Volcanic Eruptions” and “Effusive Versus Explosive Eruptions.”
- More emphasis is put on the fact that most volcanism is submarine (for instance, first paragraph under “Lava Flows” in Section 6.3; the expanded Figure 6.8 on pillow lavas; and the opening paragraph of Section 6.11.)
- Some descriptive text is deleted from the end of “Kilauea: Hawaii’s Most Active Volcano” in favor of the *GeoGraphics* on the East Rift Zone (end of Section 6.5)
- 2014 Mount Ontaki incident is added to section on pyroclastic flows, in place of 1991 Mt Unzen flow.
- The section on the destruction of Pompeii is added to Section 6.8; the *GeoGraphics* on this topic is removed.
- The *Eye on Earth* feature on the 1991 Mt Pinatubo eruption is replaced with one about the 2015 eruption of Mount Sinabung.
- The discussion of eruption mechanism for Yellowstone-type caldera eruptions is updated and tightened.
- The discussion of kimberlite and related pipes is deleted from the end of Section 6.9.
- Extensive editing for clarity and readability is done in the section “Decrease in Pressure: Decompression Melting” (in Section 6.11).
- In Section 6.12, volcanism at divergent boundaries is covered before that at convergent boundaries.
- A paragraph on intraplate volcanism associated with mantle plumes is added at the end of Section 6.12.

- Three new figures are added (6.19, 6.31, 6.39); six figures are substantively altered (6.3, 6.8, 6.12, 6.20, 6.21, 6.33, 6.34); two *GeoGraphics* are deleted.
- Three *Give It Some Thought* questions are replaced with new questions; two 14th edition questions are deleted. One *Examining the Earth System* question is deleted.

Chapter 7:

- Section 7.1 is substantially rewritten to improve clarity and effectiveness, including revised treatment of stress and strain, the types of rock deformation, and the factors that affect deformation style.
- The distinction between faults and joints is now covered at the start of Section 7.3.
- The treatment of joints is substantially revised (“Joints” in Section 7.3).
- The description of thrust faulting in the formation of the Himalayas is revised for clarity (paragraph 4 under “The Himalayas” in Section 7.6).
- The description of isostatic balance and its effects is substantially rewritten to improve clarity (Section 7.7).
- More than half of the 35 numbered figures are either substantively revised (19 figures) or new (3 figures). New: 7.4, 7.5, 7.22. Substantively revised: 7.3, 7.6–7.8, 7.12, 7.14, 7.16–7.19, 7.20, 7.21, 7.23–7.25, 7.27, 7.29, 7.30, 7.32. *Eye on Earth* 7.1 and *GeoGraphics* 7.1 are also revised. Three 14th edition figures are omitted: 10.4, 10.18, and 10.20.
- One new *Give It Some Thought* questions is added; three 14th edition questions are deleted.

Chapter 8:

- “Mass movement” is used throughout the chapter in place of “mass wasting.”
- The section “Differential Weathering” in Section 4.2 now includes the content of the 14th edition Section 4.3, “Rates of Weathering”; the concept of differential weathering now introduces the section.
- In Section 8.4, “Controls of Soil Formation,” the section on climate is revised and is placed second rather than third.
- Section 8.5, “Describing and Classifying Soils,” includes the topics of the 14th edition Sections 4.6 (“The Soil Profile”) and 4.7 (“Classifying Soils”).
- In Section 8.6, erosion by water and by wind are now covered in one section.
- The section “Controls and Triggers of Mass Movement” in Section 8.7 is significantly revised. The Oso, Washington slide is added as an example of water as a trigger.
- Section 8.8, “Types of Mass Movement,” includes the topics of the 14th edition Sections 4.11 (“Classifying Mass Wasting Processes”), 4.12 (“Rapid Forms of Mass Wasting”), and 4.13 (“Slow Forms of Mass Wasting”).
- Within Section 8.8, the treatment of the mechanism for long-runout landslides is updated (section “Rate of Movement” in Section 8.8);

the section “Debris Flow” provides a more unified treatment of dry versus wet debris flows and omits the Nevado del Ruiz lahars; and the final paragraph on liquefaction is omitted (because it is treated in Chapter 5, which now precedes this chapter).

- One figure is replaced with a new version (Fig. 8.23); four figures are revised substantively (Figs 8.10, 8.19, 8.28, 8.29, and also *Eye on Earth* 8.3); two 14th edition figures are deleted (Figs 4.20, 4.28).
- Two 14th edition *Give It Some Thought* questions are deleted.

Chapter 9:

- “Stream Erosion,” now covers corrosion as a means of forming bedrock channels in soluble rocks. Also, in “Suspended Load,” Figure 9.14 added to help explain the significance of settling velocity. (Both in Section 9.4.)
- Coverage of stream terraces (including Figure 9.22) is added at the end of Section 9.6.
- Section 9.7 now covers intermittent growth of alluvial fans in dry area
- A discussion of the April 2011 Mississippi flooding is added at the start of “Causes of Floods” in Section 9.8; the description of the 1889 dam burst on the Little Conemaugh River is removed.
- The section “Artificial Levees” in Section 9.8 is revised to describe the use of floodways to protect levees.
- Section 9.10 is reorganized to cover wells and artesian systems before springs.
- Seven new figures are added (9.4, 9.8, 9.14, 9.22, 9.26, 9.27, 9.40); three figures are substantively revised (9.2, 9.21, 9.35); five 14th edition figures are deleted (5.1, 5.16, 5.24, 5.25, 5.38). One *GeoGraphics* and one *Eye on Earth* are also deleted.
- One new *Give It Some Thought* question is added; two 14th edition questions are deleted. One *Examining the Earth System* question is added, and four are deleted.

Chapter 10:

- The section on observing and measuring the movement of glacial ice is revised and tightened (in Section 10.2).
- The introduction to “Landforms Created by Glacial Erosion” is rewritten to emphasize the distinction between the effects of valley glaciers and ice sheets (in Section 10.3).
- Section 10.4 is revised to include separate sections on glacial till and stratified drift.
- Section 10.5, “Other Effects of Ice Age Glaciers,” is reorganized, and section on sea-level changes are updated.
- Section 10.6 is revised to include Section 10.7 from the previous edition (“Causes of Ice Ages”); it also includes some updating, clarification, and shortening.
- Ten figures are added or substantively altered: 10.4 (photo replaces sketch), 10.8 (new figure part added), 10.9 (new example of retreating glacier), 10.10 (new photo), 10.12 (altered), 10.13 (new figure), 10.17 (new figure), 10.18 (altered), 10.34 (altered), 10.35 (altered).

- One *Give It Some Thought* question is added and one deleted. One *Examining the Earth System* question is deleted.

Chapter 11:

- Section 11.5 is retitled “Numerical Dating with Nuclear Decay” (from “Dating with Radioactivity”), and the text is changed to refer to unstable nuclei and nuclear decay in preference to radioactive nuclei and radioactivity.
- The section “Changes to Atomic Nuclei” (formerly “Radioactivity”) is significantly revised for clarity, including revision of Figure 11.19.
- Within the section “Radiometric dating,” the description of how daughter nuclei accumulate in a crystal is expanded for clarity.
- Vignettes are added to Figure 11.21 to help convey the concept of half-life.
- The discussion of loss of isotopes as a source of dating error is revised for clarity and no longer refers to closed and open systems (in the section “Using Unstable Isotopes”).
- Section 11.7, “The Geologic Time Scale,” is moved to the end of the chapter; it no longer comes between the sections “Numerical Dating with Nuclear Decay” and “Determining Numerical Dates for Sedimentary Strata.”
- The section “Precambrian Time” within Section 11.7 provides more detail on why the time scale is less detailed for the Precambrian than the Phanerozoic.
- Eight figures are substantively revised (Figures 11.15, 11.16, 11.19–11.22, 11.24, 11.25). One 14th edition *GeoGraphics* is deleted.

Chapter 12:

- The opening paragraphs of Section 12.1 are revised to discuss exoplanet discoveries and the concept of a habitable zone.
- In Section 12.3 (“Origin and Evolution of the Atmosphere and Oceans”), the section “Earth’s Primitive Atmosphere” is somewhat expanded, and the section “Oxygen in the Atmosphere” is significantly revised, including an expanded treatment of the Great Oxygenation Event.
- The section “Making Continental Crust” is partially revised and includes mention of the Isua rocks.
- In “Supercontinents and Climate,” the discussion of Antarctic glaciation is updated.
- Sections 12.6 through 12.9, on the origin and evolution of life, are significantly updated and revised throughout, and a new section on the end-Cretaceous extinction (“Demise of the Dinosaurs”) is added, replacing the former *GeoGraphics* on this topic.
- Nine new figures are added: 12.1, 12.2, 12.17, 12.24, 12.28, 12.29 (replacing the 14th edition 12.29), and 12.33–12.35. Six figures are substantively altered (12.3, 12.10, 12.12, 12.16, 12.18, 12.32). Six 14th edition figures are deleted (12.1, 12.2, 12.13, 12.18, 12.20, 12.22).
- Three *Give It Some Thought* questions are modified; three 14th edition questions are deleted.

Chapter 13:

- Four figures are substantively altered (13.5, 13.6, 13.13, 13.17); Figure 13.22 now incorporates the photo from a former *Eye on Earth*, which is deleted.

Chapter 14:

- Four figures are substantively altered: Figures 14.2, 14.3, 14.13 (now incorporates the former Table 14.2), and 14.14.
- Three 14th edition *Give It Some Thought* questions are deleted.

Chapter 15:

- The order of Sections 15.7 and 15.8 is reversed: Section 15.7 (“Contrasting America’s Coasts”) now precedes Section 15.8 (Stabilizing the Shore).
- Section 15.7 is reorganized so that it starts by classifying coasts as emergent and submergent.
- In Section 15.8, the conversion of vulnerable shoreline to parks in Staten Island after Hurricane Sandy is added as an example of coastal land-use change.
- Two figures are substantively altered (15.7, 15.25). Three figures are added: 15.8 (replaces 14th edition 15.8), 15.26, 15.29 (replaces 14th edition 15.26). Two 14th edition figures are deleted (15.30, 15.36).
- One *Examining the Earth System* question is deleted.

Chapter 16:

- In Section 16.2, a paragraph about tropospheric ozone as a pollutant is added.
- Figure 16.18 on the solstices and equinoxes is added, and the corresponding text coverage is made briefer (end of Section 16.4).
- Coverage of thermals is added to the section “Mechanism of Heat Transfer: Convection” (in Section 16.5).
- The description of the greenhouse effect is revised for clarity (end of Section 16.6).
- Two figures are substantively altered (16.6, 16.16). Three figures are added: 16.4, 16.14 (replaces 14th edition 16.14), 16.18, 16.20, 16.23 (replaces 14th edition 16.22). One 14th edition figure is deleted (16.9), as well as figure parts from Figures 16.7 and 16.8. The 14th edition *GeoGraphics* is also deleted.
- One *Examining the Earth System* question is deleted.

Chapter 17:

- In Section 7.2, the sections “Dew Point Temperature” and “How Is Humidity Measured?” are significantly revised for clarity.
- Sections 17.3 (“Adiabatic Temperature Changes and Cloud Formation”) and 17.4 (“Processes that Lift Air”) are substantially revised to improve clarity.

- Section 17.7, “Types of Fog,” is thoroughly rewritten to improve clarity.
- The description of how hail forms is revised for clarity (Section “Hail” in Section 17.9).
- Eleven figures are substantively altered (17.4–17.6, 17.12, 17.14, 17.17–27.19, 17.20, 17.27, 17.34); *GeoGraphics* 17.1 also modified. Two figures are added (17.29, 17.31), and also *Eye on Earth* 17.1. One *Eye on Earth* from the 14th edition is deleted.
- One new *Give It Some Thought* question is added; four questions from the 14th edition are deleted. Two *Examining the Earth System* questions are deleted.

Chapter 18:

- Section 18.7 (“El Nino, La Nina, and the Southern Oscillation”) is substantially revised.
- Six figures are substantively altered (18.3, 18.14, 18.17, 18.18, 18.24, 18.25). Two figures are added: 18.6 (replaces 14th edition 18.6), 18.8 (replaces 14th edition 18.8). Two 14th edition figures are deleted (18.26, 18.27), as well as the 14th edition *GeoGraphics*.
- One *Examining the Earth System* question is deleted.

Chapter 19:

- The introduction to fronts is revised (beginning of Section 9.2).
- The sections “Tornado Development and Occurrence” and “Tornado Climatology” are significantly revised (in Section 19.5).
- A subsection “The Role of Satellites” is added to the section “Monitoring Hurricanes” in Section 19.6.
- Eight figures are substantively altered (19.2, 19.3, 19.5, 19.14, 19.16, 19.22, 19.28, 19.34). Two figures are added: 19.25 (replaces 14th edition 19.26) and 19.33. One 14th edition figure is deleted (19.15), as well as the 14th edition *GeoGraphics*.
- One new *Give It Some Thought* question is added; one question from the 14th edition is deleted.

Chapter 20:

- Section 20.8, “Human Impact on Global Climate,” is revised and brought up to date. This section also now covers aerosols (formerly covered in its own later section).
- Section 20.10, “Some Possible Consequences of Global Warming,” revised and brought up to date.
- Two new figures are added: 20.26 (replaces 14th edition Fig 20.27) and 20.28. Three figures are substantively altered (20.19, 20.20, 20.25). Two 14th edition figures are deleted (20.15, 20.29). The *GeoGraphics* and one *Eye on Earth* from the 14th edition are deleted.
- One *Give It Some Thought* question is deleted.

Chapter 21:

- This chapter is edited extensively for conciseness and clarity.
- Section 21.1 is significantly revised for clarity, particularly the section “The Golden Age of Astronomy.”
- Section 21.2 is significantly revised for conciseness and, in places, for clarity. Also, Kepler’s third law is now expressed mathematically (section “Johannes Kepler”), and, for Newton’s law of gravitation, the exact proportionality between mass, distance, and gravitational force is given (section “Isaac Newton”).
- Within Section 21.3, “Patterns in the Night Sky” (formerly titled “Positions in the Sky”), star positions are now described in terms of direction and altitude rather than right ascension and declination. Also, the new section “Measurements Using the Celestial Sphere” now covers angular size and angular distance.
- Section 21.4, “The Motions of Earth,” no longer describes precession de novo; instead, it reviews the cycles of eccentricity, axial tilt, and precession that were described in Chapter 10.
- Section 21.5, “Motions of the Earth–Moon System,” now discusses tidal locking as the reason why one side of the Moon always faces Earth.
- Two new figures are added (21.21, 21.22). Six figures are substantively altered (21.6, 21.11, 21.15, 21.17, 21.18, 21.27). One 14th edition figure is deleted (21.27).
- Two new *Give It Some Thought* questions are modified; two 14th edition questions are deleted. One *Examining the Earth System* question is deleted.

Chapter 22:

- In addition to the sections updated for currency (noted below), the chapter is revised extensively for clarity and conciseness.
- The sections “Nebular Theory: Formation of the Solar System,” “Mars: The Red Planet,” “Comets: Dirty Snowballs,” and “Dwarf Planets” are updated to reflect current research, as is the treatment of cryovolcanism on moons of the outer planets.
- Four new figures are added (22.16, 22.18, 22.33, 22.36). Twelve figures are substantively altered (22.2, 22.4, 22.7, 22.12, 22.17, 22.20, 22.23, 22.28, 22.29, 22.30, 22.32, 22.25), as well as is *Geo-Graphics* 22.1. Five 14th edition figures are deleted (22.11, 22.22, 22.25, 22.35, 22.37).
- One 14th edition *Give It Some Thought* question is deleted; one *Examining the Earth System* question is deleted.

Chapter 23:

- In addition to the changes discussed below, the text and figures are revised extensively for clarity and conciseness. The chapter now puts more emphasis on current knowledge and less on history.
- Section 23.2, “What Can We Learn from Light?” is thoroughly revised. Line spectra are now referred to as emission and

absorption spectra, rather than bright-line and dark-line spectra. The treatment of what spectra tell us about composition and temperature is expanded and put in its own subsections. The explanation of the Doppler effect is revised for clarity. The section now covers the speed of light in vacuum.

- Section 23.3, “Collecting Light Using Optical Telescopes,” is almost completely rewritten, with a stronger focus on how observing is done today. The treatment of active optics, adaptive optics, telescope arrays, and astrophotography using film and CCDs is expanded and divided into new subsections.
- Section 23.4, “Radio- and Space-Based Astronomy,” is largely rewritten or new, with sections on spaced-based observatories in radio, infrared, x-ray, and gamma-ray wavelengths and on the James Webb Space Telescope.
- Section 23.5, “Our Star: The Sun” is revised, reorganized, and somewhat expanded, with separate sections on the Sun’s surface, atmosphere, and interior. It also now covers hydrogen fusion by the p–p process as the source of the Sun’s energy.
- Section 23.6, “The Active Sun,” is significantly revised, with more coverage of the structure and role of Sun’s magnetic field.
- More than half of the figures in the chapter (17 of 30) are revised, replaced, or new. Six figures are substantively altered: 23.1–23.3, 23.20, 23.21, 23.24. Eleven are new: 23.4, 23.6, 23.7, 23.8 (replaces 14th edition 23.6), 23.13, 23.16, 23.18, 23.20, 23.21 (replaces 14th edition 23.17), 23.27, 23.29. Ten 14th edition figures are deleted: 23.4, 23.6, 23.9, 23.13, 23.16, 23.17–23.19, 23.22, 23.25.
- Two 14th edition *Give It Some Thought* questions are deleted.

Chapter 24:

- Section 24.1, “Classifying Stars,” now covers stellar luminosity, color, and temperature as well as the H-R diagram and the classes of stars.
- The 14th edition Section 24.2 on the types of nebulae is deleted; retained material is placed elsewhere in this chapter and in Chapter 23.
- Section 24.2, “Stellar Evolution,” is extensively revised and updated.
- Sections 24.3 (“Stellar Remnants”) and 24.4 (“Galaxies and Galaxy Clusters”) are significantly revised for clarity and conciseness, and Section 24.4. includes new information on dwarf galaxies.
- The section on the Universe is moved to the end of the chapter, revised, and combined with the treatment of cosmology.
- Two new figures are added (24.4, 24.9); Figure 24.1 is replaced with a new photo of a different object. Six figures substantively altered (24.2, 24.3, 24.5, 24.8, 24.10, 24.20)). Five 14th edition figures are deleted (24.3–24.7).
- Three 14th edition *Give It Some Thought* questions are deleted; one *Examining the Earth System* question is deleted.