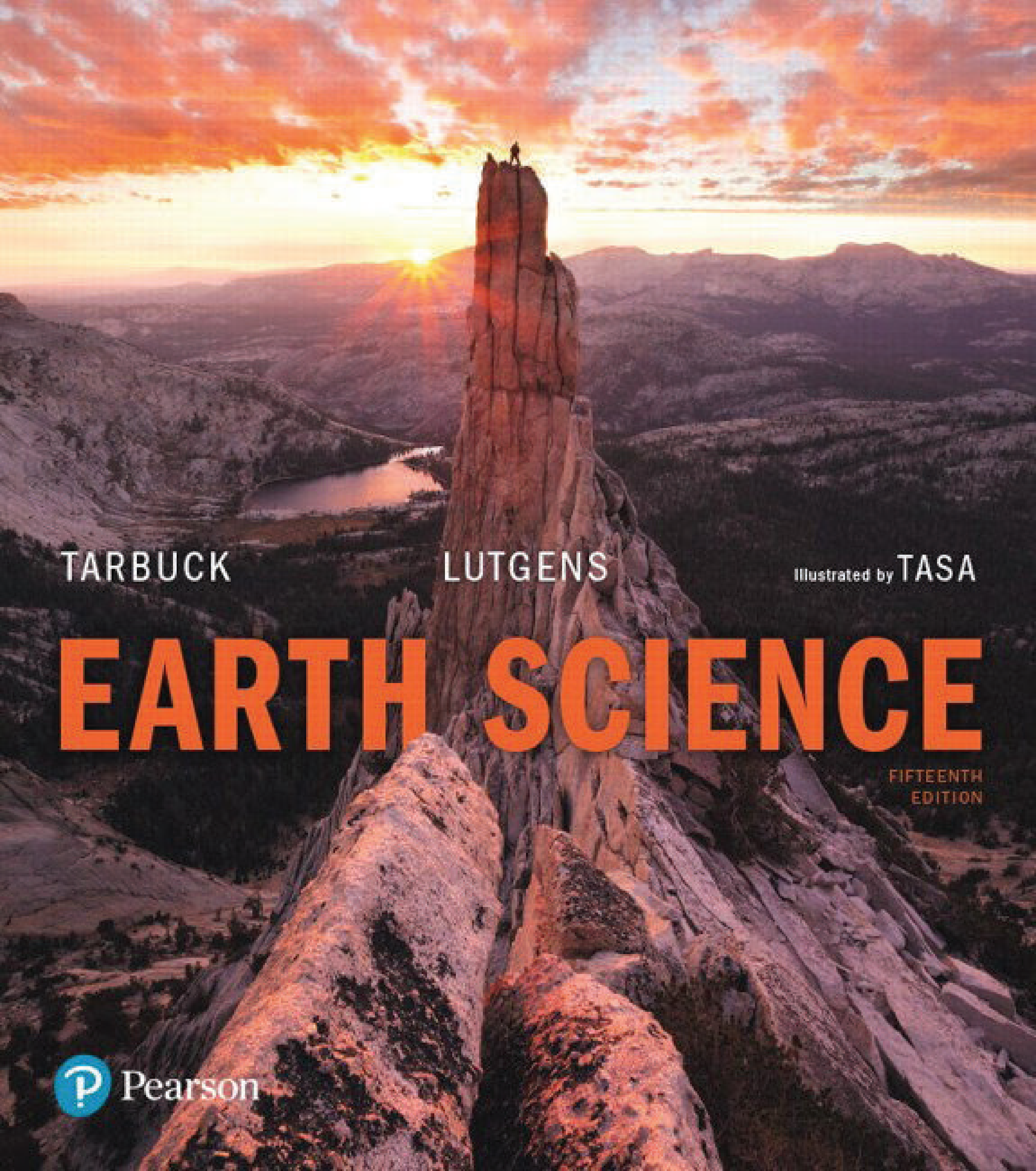


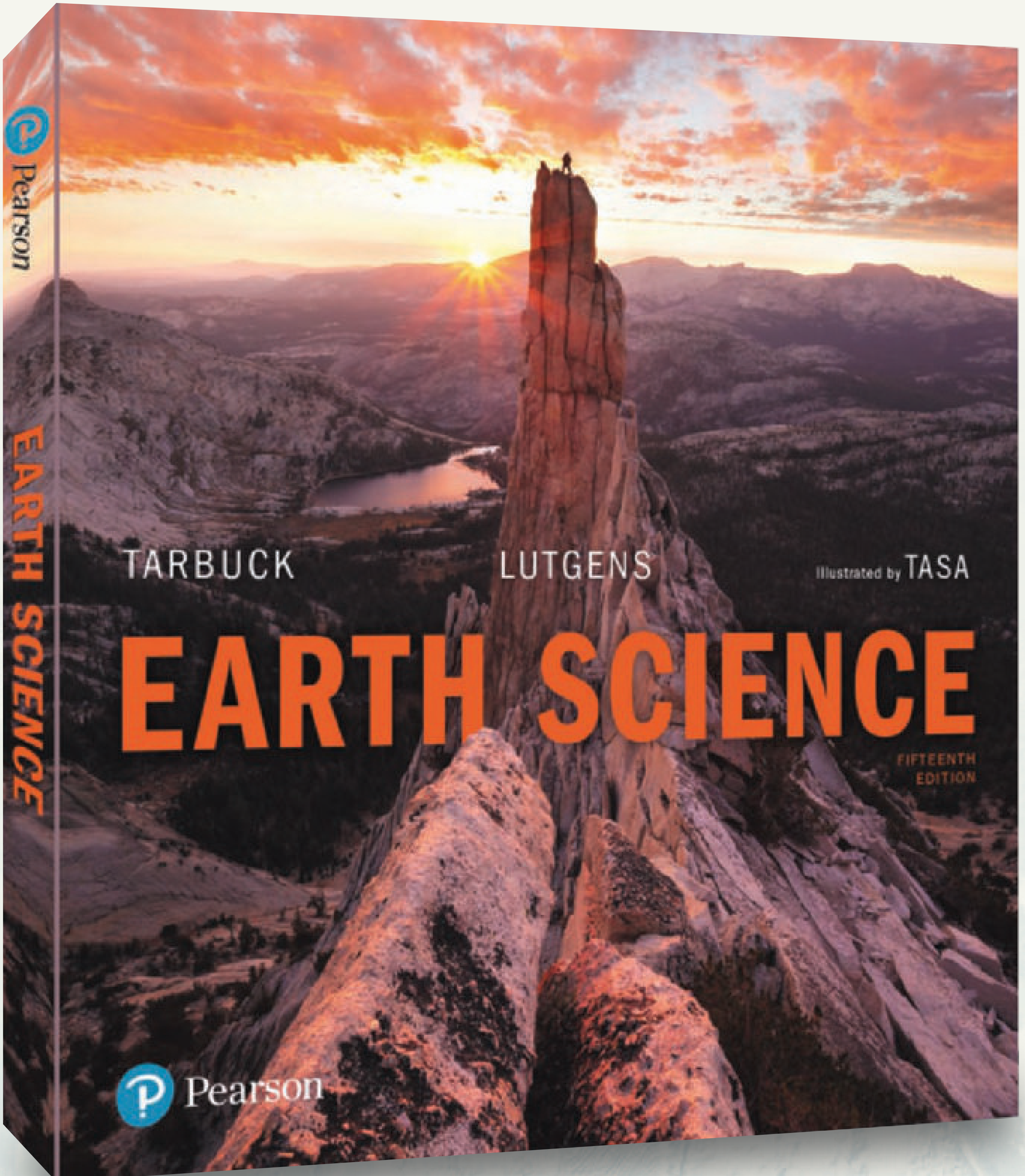
TARBUCK LUTGENS Illustrated by TASA

EARTH SCIENCE

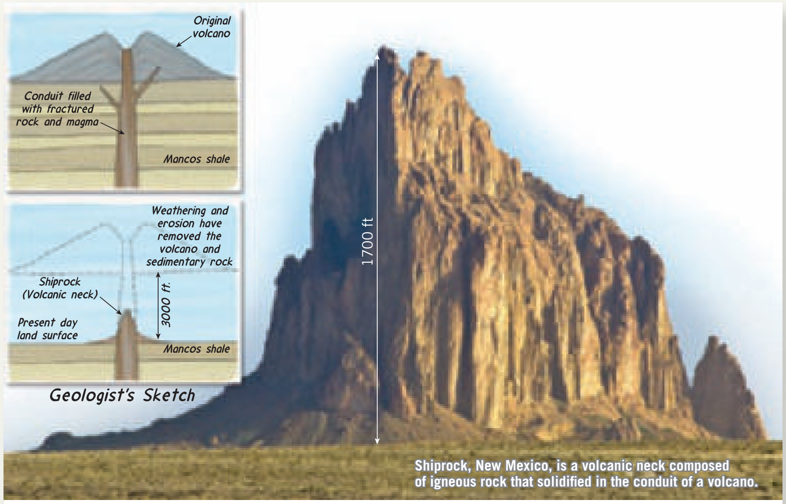
FIFTEENTH EDITION

Pearson

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

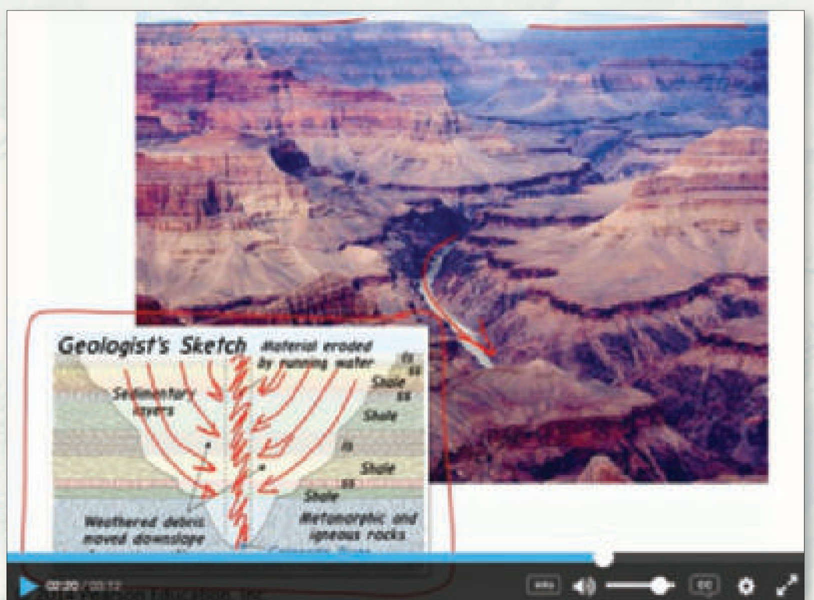
Bringing Earth Science to life for students, three geologists, using a quadcopter-mounted GoPro camera, have ventured into the field to film 10 key geologic locations and processes. These process-oriented videos, accessed through QR codes, are designed to bring the field to the classroom and improve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

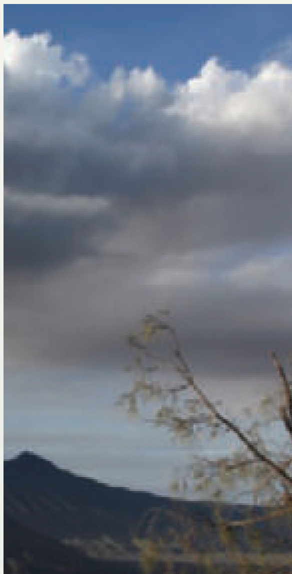
HALLMARK! SmartFigures: Tutorials
These brief tutorial videos present the student with a 3- to 4-minute feature (mini-lesson), most narrated and annotated by Professor Callan Bentley. Each lesson examines and explains the concepts illustrated by the figure. With over 150 SmartFigure Tutorials inside 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:

- **6.1** Compare and contrast the 1980 eruption of Mount St. Helens with the most recent eruption of Kilauea, which began in 1983.
- **6.2** Explain why some volcanic eruptions are explosive and others are quiescent.
- **6.3** List and describe the three categories of materials extruded during volcanic eruptions.
- **6.4** Draw and label a diagram that illustrates the basic features of a typical volcanic cone.
- **6.5** Summarize the characteristics of shield volcanoes and provide one example of this type of volcano.
- **6.6** Describe the formation, size, and composition of cinder cones.
- **6.7** List the characteristics of composite volcanoes and describe how they form.
- **6.8** Describe the major geologic hazards associated with volcanoes.
- **6.9** List volcanic landforms other than shield, cinder, and composite volcanoes and describe their formation.
- **6.10** Compare and contrast these intrusive igneous structures: dikes, sills, batholiths, stocks, and laccoliths.
- **6.11** Summarize the major processes that generate magma from solid rock.
- **6.12** Explain how the global distribution of volcanic activity is related to plate tectonics.

Eruption of ash from Mount Bromo Volcano, 2011, in Java, Indonesia.
(Photo provided by Richard Roscoe/Stocktrek 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?

USGS

EXAMINING THE EARTH SYSTEM

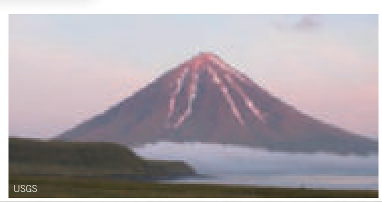
1 Speculate about some of the possible consequences that a great and prolonged increase in explosive volcanic activity might have on each of Earth's four spheres.

Jon A Helgason/Yay Micro/AGE Fotostock

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.

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

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 of 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?

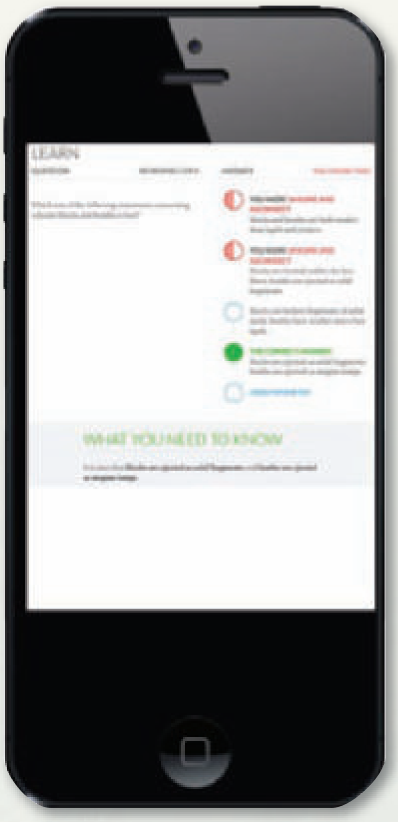
Go to "Shrinking Aral Sea" on NASA's Earth Observatory site (https://earthobservatory.nasa.gov/Features/WorldOfChange/aral_sea.php).

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?

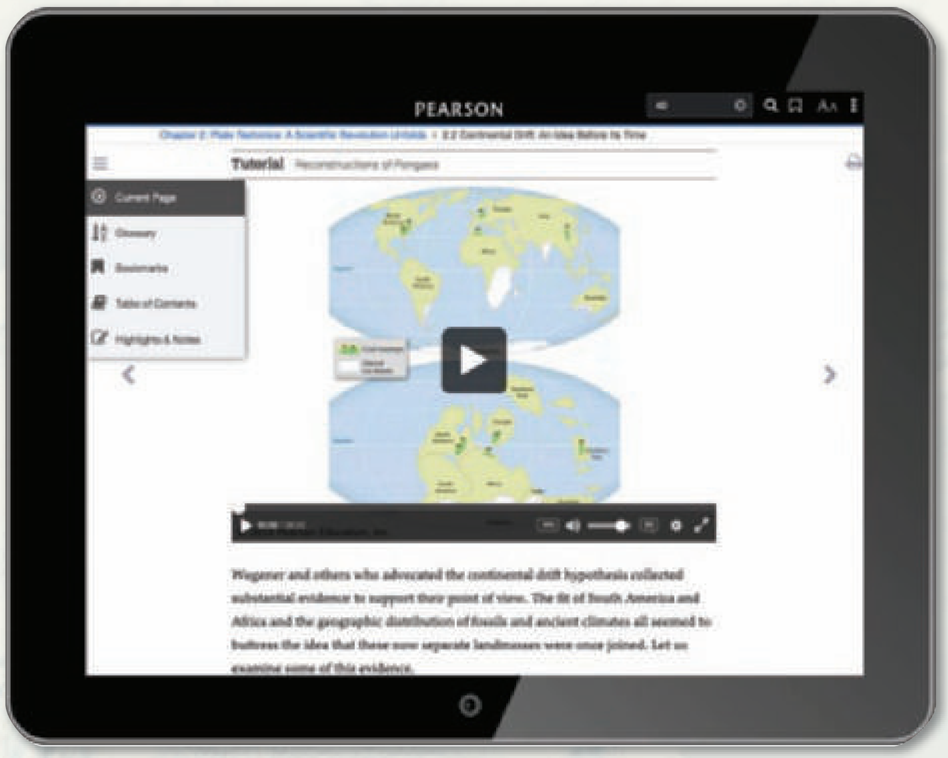
Continuous Learning
Before, During, and After Class

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

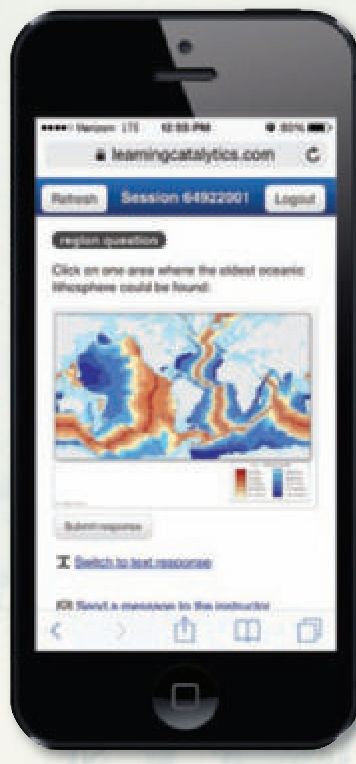
Engage students with Learning Catalytics

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."

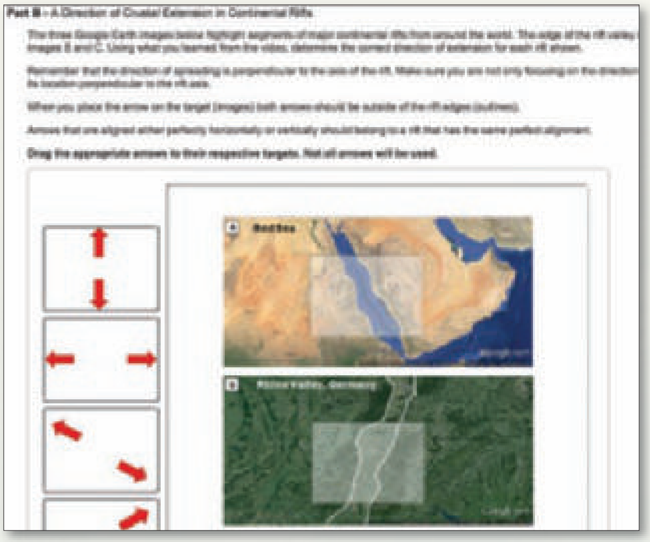
Declan De Paor, Old Dominion University



MasteringGeology™

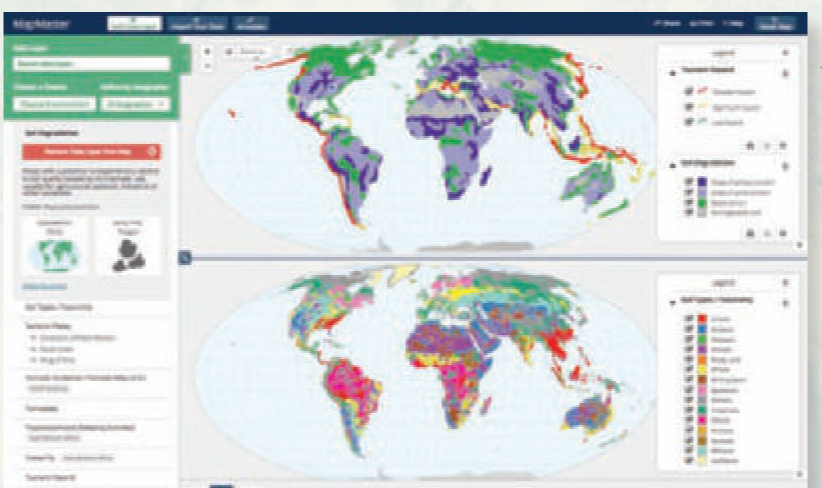
AFTER CLASS

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



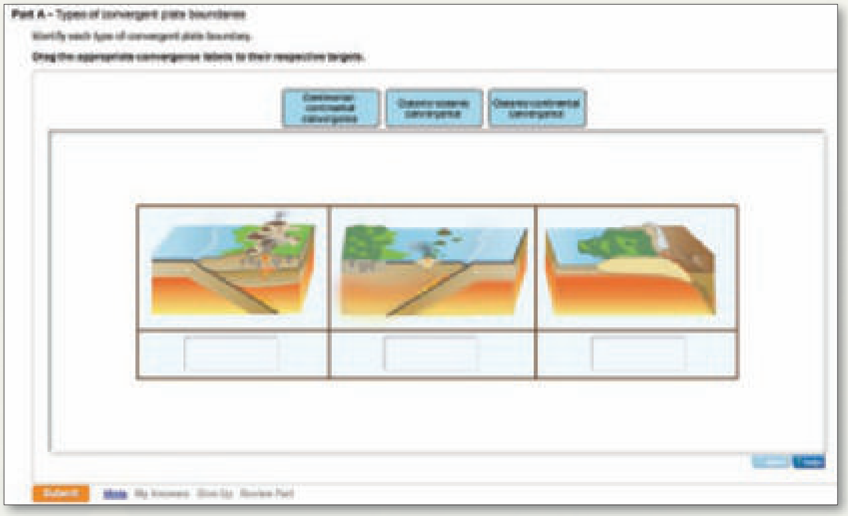
NEW! Project Condor Quadcopter Videos
A series of quadcopter videos with annotations, sketching, and narration help improve the way students learn about monoclines, streams and terraces, and so much more. In MasteringGeology™, these videos are accompanied by assessments to test student understanding.

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.



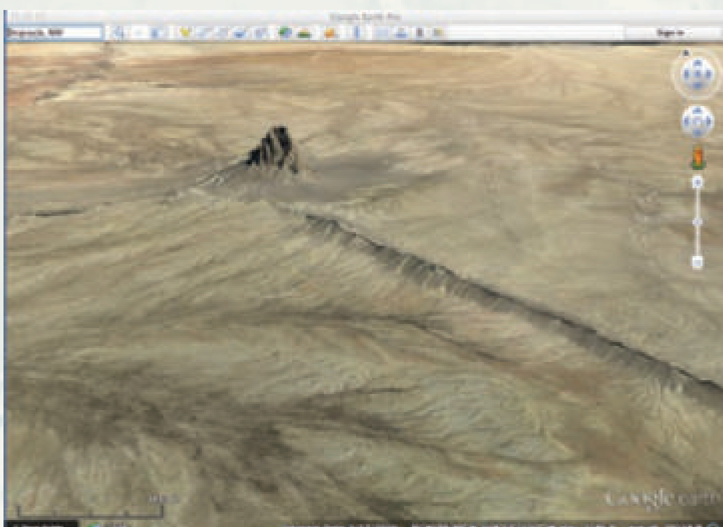
NEW! MapMaster 2.0 Activities
are inspired by GIS, allowing students to layer various thematic maps to analyze spatial patterns and data at regional and global scales. Now fully mobile, with enhanced analysis tools, such as split screen, the ability for students to geolocate themselves in the data, and 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.

www.masteringgeology.com



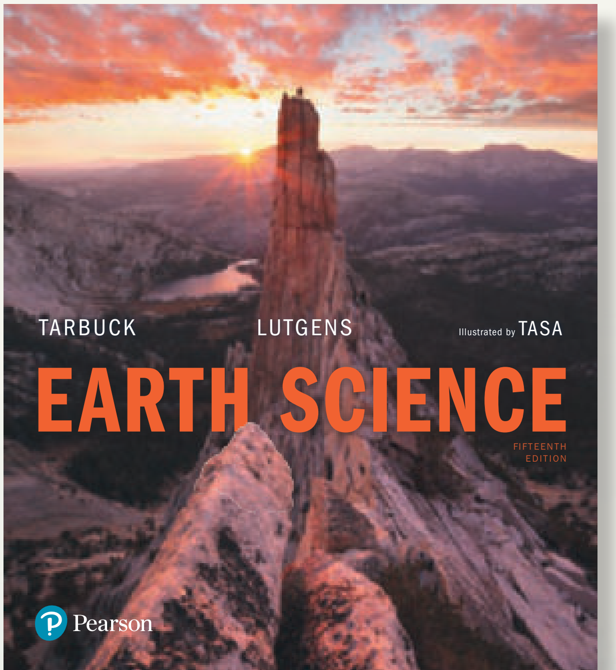
GeoTutors
These coaching activities help students master the most challenging physical geoscience concepts with highly visual, kinesthetic activities focused on critical thinking and application of core geoscience concepts.

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.



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

Pearson

330 Hudson Street, NY NY 10013

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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 carbonneutrality. 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.

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BRIEF CONTENTS

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9 Running Water and Groundwater 267

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

Chapter 2

Chapter 3

Chapter 4

Chapter 5

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Chapter 7

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Chapter 9

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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 narrations 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.

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Used each year by over 3 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*, 15^{th} edition, **MasteringGeology**™ offers tools for use before, during, and after class:

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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

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- 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 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

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- 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.

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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 us added at the start of "Causes of Floods" in Section 9.8; the description of the1889 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, 1731), 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 id 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 14^{th} edition figure is deleted (21.27).
- Two new *Give It Some Thought* questions are modified; two 14^{th} 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 *GeoGraphics* 22.1. Five 14^{th} edition figures are deleted (22.11, 22.22, 22.25, 22.35, 22.37).
- One 14^{th} 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 14^{th} edition 23.6), 23.13, 23.16, 23.18, 23.20, 23.21 (replaces 14^{th} edition 23.17), 23.27, 23.29. Ten 14^{th} edition figures are deleted: 23.4, 23.6, 23.9, 23.13, 23.16, 23.17–23.19, 23.22, 23.25.
- Two 14^{th} 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 14^{th} 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 14^{th} edition figures are deleted (24.3–24.7).
- Three 14^{th} edition *Give It Some Thought* questions are deleted; one *Examining the Earth System* question is deleted.

1 Introduction to Earth Science

FOCUS ON CONCEPTS

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

- **1.1** List and describe the sciences that collectively make up Earth science. Discuss the scales of space and time in Earth science.
- **1.2** Discuss the nature of scientific inquiry, including the construction of hypotheses and the development of theories.
- **1.3** Outline the stages in the formation of our solar system.
- **1.4** List and describe Earth's four major spheres. Define *system* and explain why Earth is considered to be a system.
- **1.5** List and describe the major features of the ocean basins and continents.

All four of Earth's major spheres are represented in this image from Jasper National Park in the Canadian Rockies. (Photo by Adam Burton/Getty Images)

THE SPECTACULAR ERUPTION OF A VOLCANO, the magnificent scenery of a rocky coast, and the destruction created by a hurricane are all subjects for an Earth scientist. The study of Earth science deals with many fascinating and practical questions about our environment. What forces produce mountains? Why is our daily weather variable? Is climate really changing? How old is Earth, and how is it related to other planets in the solar system? What causes ocean tides? What were the Ice Ages like, and will there be another? Where should we search for water?

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

1.1 What Is Earth Science?

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

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

Figure 1.1 Volcanic eruption Molten lava from Hawaii's Kilauea Volcano is spilling into the Pacific Ocean. Internal processes are those that occur beneath Earth's surface. Sometimes they lead to the formation of major features at the surface. (Photo by Russ Bishop/Alamy Stock Photo)

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

Geology

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

Physical geology examines the materials composing Earth and seeks to understand the many processes that operate beneath and upon its surface. Earth is a dynamic, ever-changing planet. Internal forces create earthquakes, build mountains, and produce volcanic structures (**Figure 1.1**). At the surface, external processes break rock apart and sculpt a broad array of landforms. The erosional effects of water, wind, and ice result in a great diversity of landscapes. Because rocks and minerals

form in response to Earth's internal and external processes, their interpretation is basic to an understanding of our planet.

In contrast to physical geology, the aim of *historical geology* is to understand the origin of Earth and the development of the planet through its 4.6-billion-year history (**Figure 1.2**). It strives to establish an orderly chronological arrangement of the multitude of physical and biological changes that have occurred in the geologic past. The study of physical geology logically precedes the study of Earth history because we must first understand how Earth works before we attempt to unravel its past.

Oceanography

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

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

Meteorology

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

▲ **SmartFigure 1.2**
Arizona's Grand Canyon The erosional work of the Colorado River along with other external processes created this natural wonder. For someone studying historical geology, hiking down the South Kaibab Trail in Grand Canyon National Park is a trip through time. These rock layers hold clues to millions of years of Earth history. (Photo by Michael Collier)

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

▲ **Figure 1.3 Earthquake in Ecuador** On April 16, 2016, a magnitude 7.8 earthquake struck coastal Ecuador. It was the strongest quake in that region in 40 years. There were nearly 700 fatalities and more than 7000 people injured. Natural hazards are *natural processes*. They become hazards only when people try to live where the processes occur. (Photo by Meridth Kohut/Bloomberg via Getty Images)

Astronomy

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

Earth Science Is Environmental Science

Earth science is an environmental science that explores many important relationships between people and the natural environment. Many of the problems and issues addressed by Earth science are of practical value to people.

Natural Hazards Natural hazards are a part of living on Earth. Every day they adversely affect literally millions of people worldwide and are responsible for staggering damages. Among the hazardous Earth processes studied by Earth scientists are volcanoes, floods, tsunamis, earthquakes, landslides, and hurricanes. Of course, these hazards are *natural* processes. They become hazards only when people try to live where these processes occur.

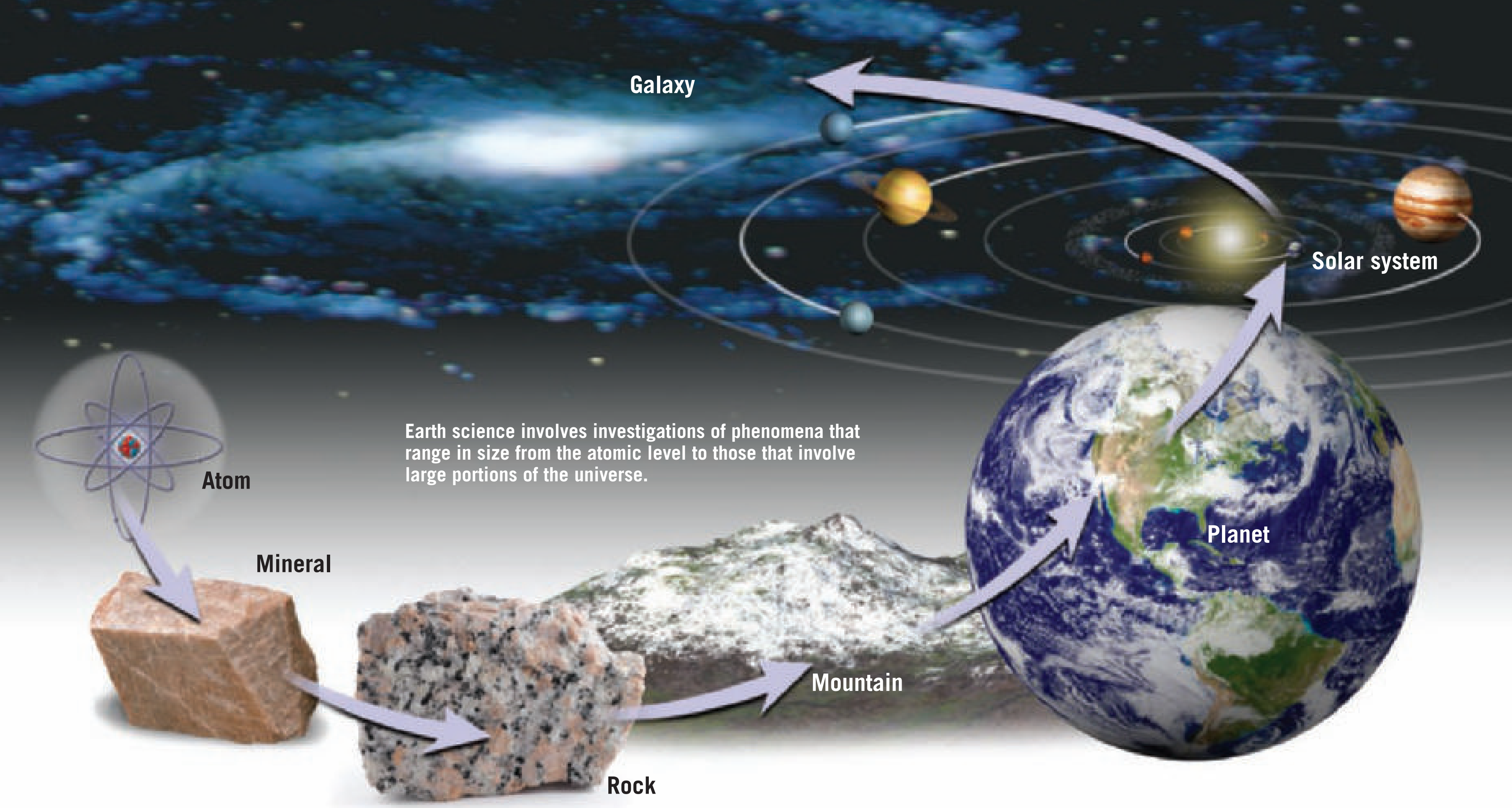
For most of history, most people lived in rural areas. However, today more people live in cities than in rural areas. This global trend toward urbanization concentrates millions of people into places that are vulnerable to natural hazards. Coastal sites are becoming more vulnerable because development often destroys natural defenses such as wetlands and sand dunes. In addition, there is a growing threat associated with human influences on the Earth system, such as sea level rise that is linked to global warming.* Other urban areas are exposed to seismic (earthquake) and volcanic hazards where inappropriate land use and poor construction practices, coupled with rapid population growth, increase vulnerability (**Figure 1.3**).

Resources Resources represent another important focus that is of great practical value to people. They include water and soil, a great variety of metallic and nonmetallic minerals, and energy. Together they form the very foundation of modern civilization. Earth science deals with the formation and occurrence of these vital resources and also with maintaining supplies and with the environmental impact of their extraction and use.

People Influence Earth Processes Not only do Earth processes have an impact on people, but we humans can dramatically influence Earth processes as well. Human activities alter the composition of the atmosphere, triggering air pollution episodes and causing global climate change (**Figure 1.4**). River flooding is natural, but the

*The idea of the Earth system is explored later in the chapter. Global climate change and its effects are a focus of Chapter 20.

▼ **Figure 1.4 People influence the atmosphere** China is plagued by frequent severe air pollution episodes. Fuel combustion from power plants, factories, and motor vehicles provide a high percentage of the pollutants. Meteorological factors determine whether pollutants remain trapped in the city or are dispersed. (Photo by AFP/Stringer/Getty Images)



▲ **Figure 1.5** **From atoms to galaxies** Earth science studies phenomena on many different scales.

magnitude and frequency of flooding can be changed significantly by human activities such as clearing forests, building cities, and constructing dams. Unfortunately, natural systems do not always adjust to artificial changes in ways that we can anticipate. Thus, an alteration to the environment that was intended to benefit society often has the opposite effect.

At many places throughout this book, you will have opportunities to examine different aspects of our relationship with the physical environment. Moreover, significant parts of some chapters provide the basic knowledge and principles needed to understand environmental problems.

Scales of Space and Time in Earth Science

When we study Earth, we must contend with a broad array of space and time scales (**Figure 1.5**). Some phenomena are relatively easy for us to imagine, such as the size and duration of an afternoon thunderstorm or the dimensions of a sand dune. Other phenomena are so vast or so small that they are difficult to imagine. The number of stars and distances in our galaxy (and beyond!) or the internal arrangement of atoms in a mineral crystal are examples of such phenomena.

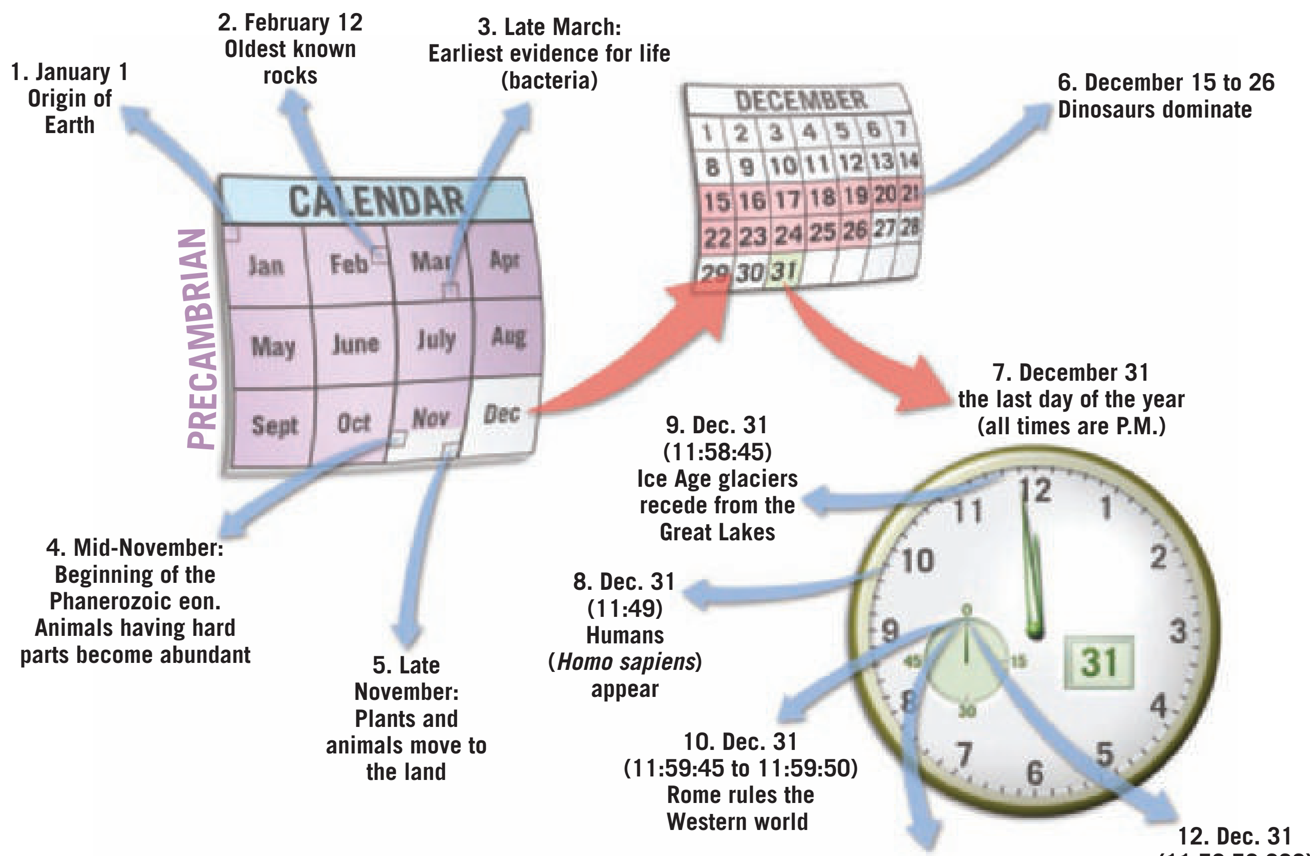
Some of the events we study occur in fractions of a second. Lightning is an example. Other processes extend over spans of tens or hundreds of millions of years. For example, the lofty Himalaya Mountains began forming nearly 50 million years ago, and they continue to develop today.

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

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

An appreciation for the magnitude of geologic time is important in the study of our planet because many processes are so gradual that vast spans of time are needed before significant changes occur. How long

What if we compress the 4.6 billion years of Earth history into a single year?



▶ **SmartFigure 1.6**
Magnitude of geologic time

TUTORIAL
https://goo.gl/V1WFRd

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

The preceding analogy is just one of many that have been conceived in an attempt to convey the magnitude of geologic time. Although helpful, all of them, no matter how clever, only begin to help us comprehend the vast expanse of Earth history. **Figure 1.6** provides another interesting way of viewing the age of Earth.

Over the past 200 years or so, Earth scientists have developed the *geologic time scale* of Earth history. It divides the 4.6-billion-year history of Earth into many different units and provides a meaningful time frame within which the events of the geologic past are arranged (see Figure 11.25, page 374). The principles used to develop the geologic time scale are examined in some detail in Chapter 11.

CONCEPT CHECKS 1.1

1. List and briefly describe the sciences that collectively make up Earth science.
2. List at least four different natural hazards. Aside from natural hazards, describe another important connection between people and Earth science.
3. List two examples of size/space scales in Earth science that are at opposite ends of the spectrum.
4. How old is Earth?
5. If you compress geologic time into a single year, how much time has elapsed since Columbus arrived in the New World?

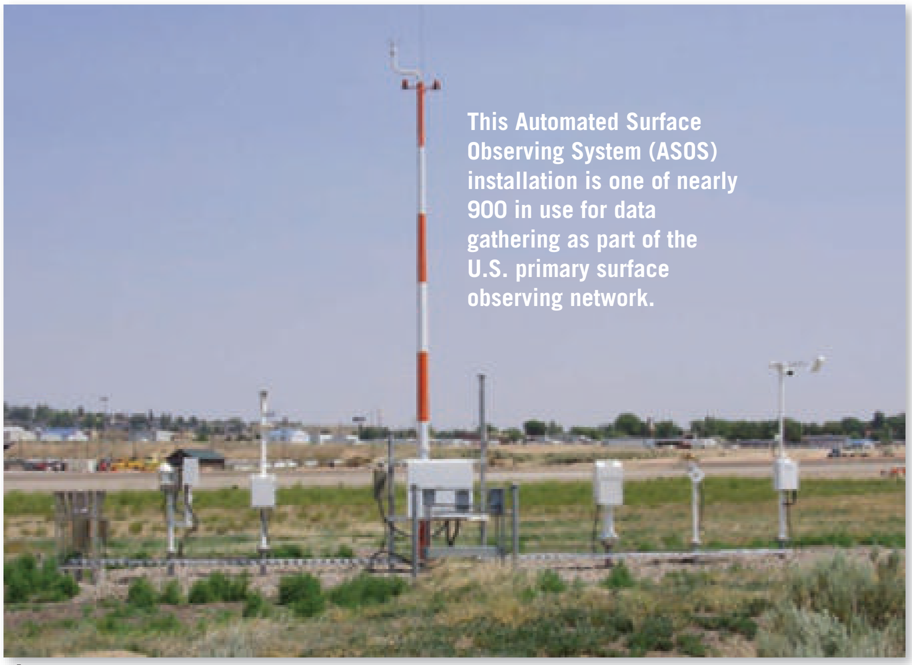
1.2 The Nature of Scientific Inquiry

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

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

All science is based on the assumption that the natural world behaves in a consistent and predictable manner that is comprehensible through careful, systematic study. The overall goal of science is to discover the underlying patterns in nature and then to use that knowledge to make predictions about what should or should not be expected, given certain facts or circumstances. For example, by understanding the circumstances and processes that produce certain cloud types, meteorologists are often able to predict the approximate time and place of their formation and the intensity of the associated weather.

The development of new scientific knowledge involves some basic logical processes that are universally accepted. To determine what is occurring in the natural world, scientists collect data through observation and measurement (**Figure 1.7**). The data collected often help answer well-defined questions about the natural world. Because some error is inevitable, the accuracy of a particular measurement



A.

B.

C.

Figure 1.7 Observation and measurement Gathering data and making careful observations are basic parts of scientific inquiry. **A.** This array of instruments automatically records and transmits basic weather data. (Photo by NASA/Science Source) **B.** The Earth sciences frequently involve fieldwork. (Photo by Robbie Shone/Science Source) **C.** In the lab, this researcher is using a special microscope to study the mineral composition of rock samples that were collected during fieldwork. (Photo by Jon Wilson/Science Source) or observation is always open to question. Nevertheless, these data are essential to science and serve as a springboard for the development of scientific hypotheses and theories.

Hypothesis

Once facts have been gathered and principles have been formulated to describe a natural phenomenon, investigators try to explain how or why things happened in the manner observed. They often do this by constructing a tentative (or untested) explanation, which is called a scientific **hypothesis**. It is best if an investigator can formulate more than one hypothesis to explain a given set of observations. If an individual scientist is unable to devise multiple hypotheses, others in the scientific community will almost always develop alternative explanations. A spirited debate frequently ensues. As a result, extensive research is conducted by proponents of opposing hypotheses, and the results are made available to the wider scientific community in scientific journals.

Before a hypothesis can become an accepted part of scientific knowledge, it must repeatedly pass objective testing and analysis. If a hypothesis cannot be tested, it is not scientifically useful, no matter how interesting it might seem. The verification process requires that *predictions* be made based on the hypothesis being considered and that the predictions be tested by being compared against objective observations of nature. Put another way, hypotheses must fit observations other than those used to formulate them in the first place. Hypotheses that fail rigorous testing are ultimately discarded. The history of science is littered with discarded hypotheses. One of the best known is the Earth-centered model of the universe—a proposal that was supported by the apparent daily motion of the Sun, Moon, and stars around Earth. As the mathematician Jacob Bronowski so ably stated, "Science is a great many things, but in the end they all return to this: Science is the acceptance of what works and the rejection of what does not."

Theory

When a hypothesis has survived extensive scrutiny and when competing hypotheses have been eliminated, it may be elevated to the status of a scientific **theory**. In everyday language, we might say, "That's only a theory." But a scientific theory is a well-tested and widely accepted view that the scientific community agrees best explains certain observable facts.

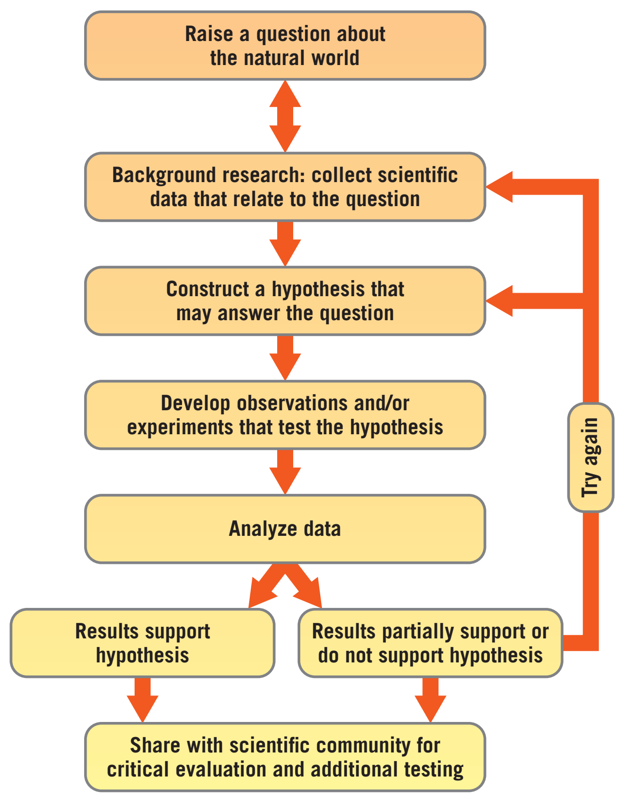
Some theories that are extensively documented and extremely well supported are comprehensive in scope and may incorporate several well-tested hypotheses. For example, the theory of plate tectonics provides the framework for understanding the origin of mountains, earthquakes, and volcanic activity. In addition, plate tectonics explains the evolution of the continents and the ocean basins through time—ideas that are explored in some detail in Chapters 4 through 7.

Scientific Methods

The process just described, in which researchers gather facts through observations and formulate scientific hypotheses and theories, is called the **scientific method**. Contrary to popular belief, the scientific method is not a standard recipe that scientists apply in a routine manner to unravel the secrets of our natural world. Rather, it is an endeavor that involves creativity and insight. Rutherford and Ahlgren put it this way: "Inventing hypotheses or theories to imagine how the world works and then figuring out how they can be put to the test of reality is as creative as writing poetry, composing music, or designing skyscrapers."†

There is no fixed path for scientists to follow that leads unerringly to scientific knowledge. However, many scientific investigations involve the steps outlined in **Figure 1.8**. In addition, some scientific discoveries result from purely theoretical ideas that stand up to extensive examination. Some researchers use high-speed computers to create models that simulate what is happening in the "real" world. These models are useful when dealing with natural processes that occur on very long time scales or take place in extreme or inaccessible locations.

†F. James Rutherford and Andrew Ahlgren, *Science for All Americans* (New York: Oxford University Press, 1990), p. 7.



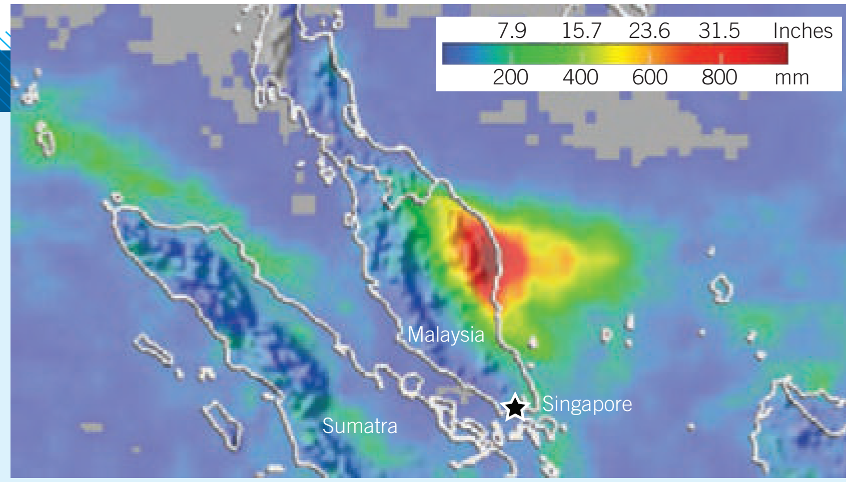
▲ **Figure 1.8 Steps frequently followed in scientific investigations** The diagram depicts the steps involved in the process many refer to as the *scientific method*.

EYE ON EARTH 1.1

This image shows rainfall data for December 7–13, 2004, in Malaysia. More than 800 millimeters (32 inches) of rain fell along the east coast of the peninsula (darkest red area). The extraordinary rains caused extensive flooding. The data for this image are from NASA's *Tropical Rainfall Measuring Mission* (*TRMM*). This is just one of hundreds of satellites that provide scientists with all kinds of data about our planet.

QUESTION 1 *Suggest some advantages that satellites provide to scientists in terms of gaining information about Earth.*

QUESTION 2 *Gathering data is a basic part of scientific inquiry. Aside from satellites, list at least two ways that Earth scientists gather data.*



NASA Headquarters

Still other scientific advancements are made when a totally unexpected happening occurs during an experiment. These serendipitous discoveries are more than pure luck, for as the nineteenth-century French scientist Louis Pasteur said, "In the field of observation, chance favors only the prepared mind."

Scientific knowledge is acquired through several avenues, so it might be best to describe the nature of scientific inquiry as the *methods of science* rather than as the *scientific method*. In addition, it should always be remembered that even the most compelling scientific theories are still simplified explanations of the natural world.

In this book, you will discover the results of centuries of scientific work. You will see the end product of millions of observations, thousands of hypotheses, and hundreds of theories. We have distilled all of this to give you a "briefing" on Earth science.

Bear in mind that our knowledge of Earth is changing daily, as thousands of scientists worldwide make satellite observations, analyze drill cores from the seafloor, measure earthquakes, develop computer models to predict climate, examine the genetic codes of organisms, and discover new facts about our planet's long history. This new knowledge often updates hypotheses and theories. Expect to see many new discoveries and changes in scientific thinking in your lifetime.

CONCEPT CHECKS 1.2

1. How is a scientific hypothesis different from a scientific theory?
2. Summarize the basic steps followed in many scientific investigations.

1.3 Early Evolution of Earth

Outline the stages in the formation of our solar system.

This section describes the most widely accepted views on the origin of our solar system. The theory summarized here represents the most consistent set of ideas available to explain what we know about our solar system today. **GEOgraphics 1.1** provides a useful perspective on size and scale in the solar system.

The Universe Begins

Our scenario begins about 13.7 billion years ago, with the *Big Bang*, an almost incomprehensible event in which space itself, along with all the matter and energy of the universe, exploded in an instant from tiny to huge dimensions. As the universe continued to expand, subatomic particles condensed to form hydrogen and helium gas, which later cooled and clumped to form the first stars and galaxies. It was in one of these galaxies, the Milky Way, that our solar system, including planet Earth, took form.

The Solar System Forms

Earth is one of eight planets that, along with dozens of moons and numerous smaller bodies, revolve around the Sun. The orderly nature of our solar system helped scientists determine that Earth and the other planets formed at essentially the same time and from the same primordial material as the Sun. The **nebular theory** proposes that the bodies of our solar system evolved

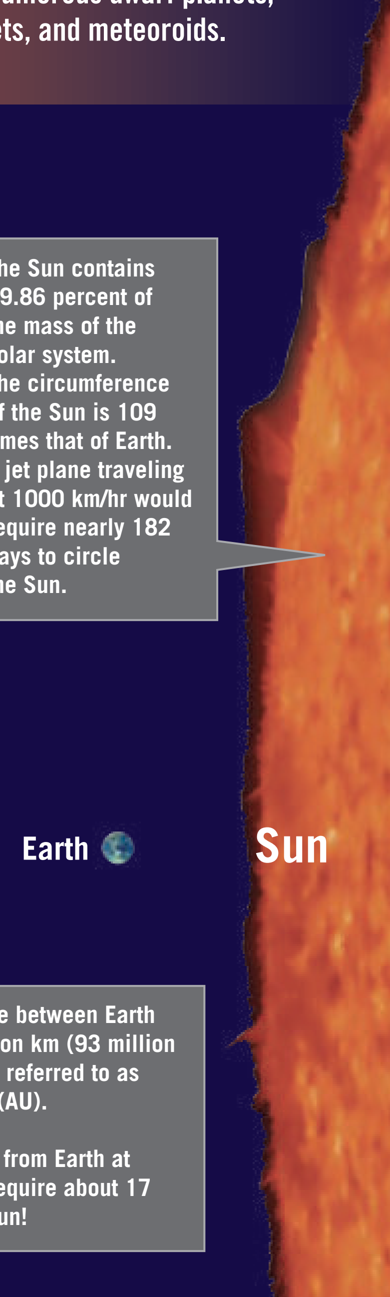
GEOGRAPHICS 1.1

Solar System: Size and Scale

The Sun is the center of a revolving system trillions of miles across, consisting of eight planets, their satellites, and numerous dwarf planets, asteroids, comets, and meteoroids.

1
- The circumference of Earth is slightly more than 40,000 km (nearly 25,000 mi). It would take a jet plane traveling at 1000 km/hr (620 mi/hr) 40 hours (1.7 days) to circle the planet.

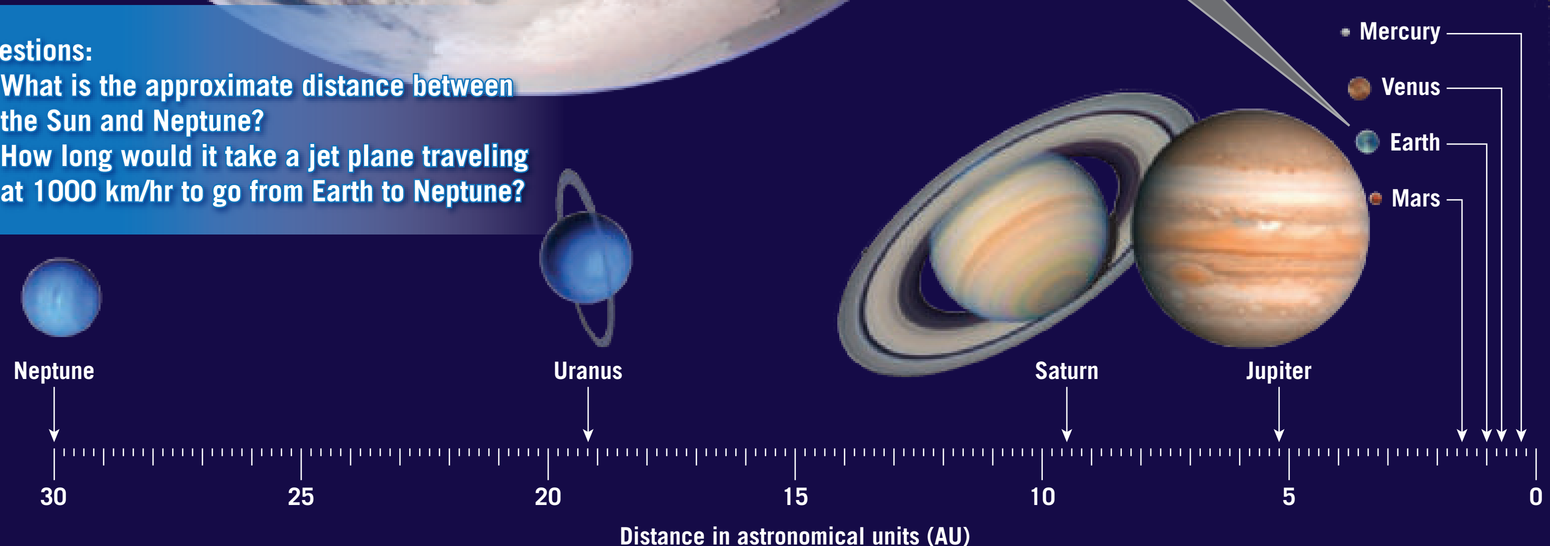
2
- The Sun contains 99.86 percent of the mass of the solar system.
- The circumference of the Sun is 109 times that of Earth.
- A jet plane traveling at 1000 km/hr would require nearly 182 days to circle the Sun.



3
- The average distance between Earth and Sun is 150 million km (93 million mi). This distance is referred to as 1 astronomical unit (AU).
- A jet plane traveling from Earth at 1000 km/hr would require about 17 years to reach the Sun!

?

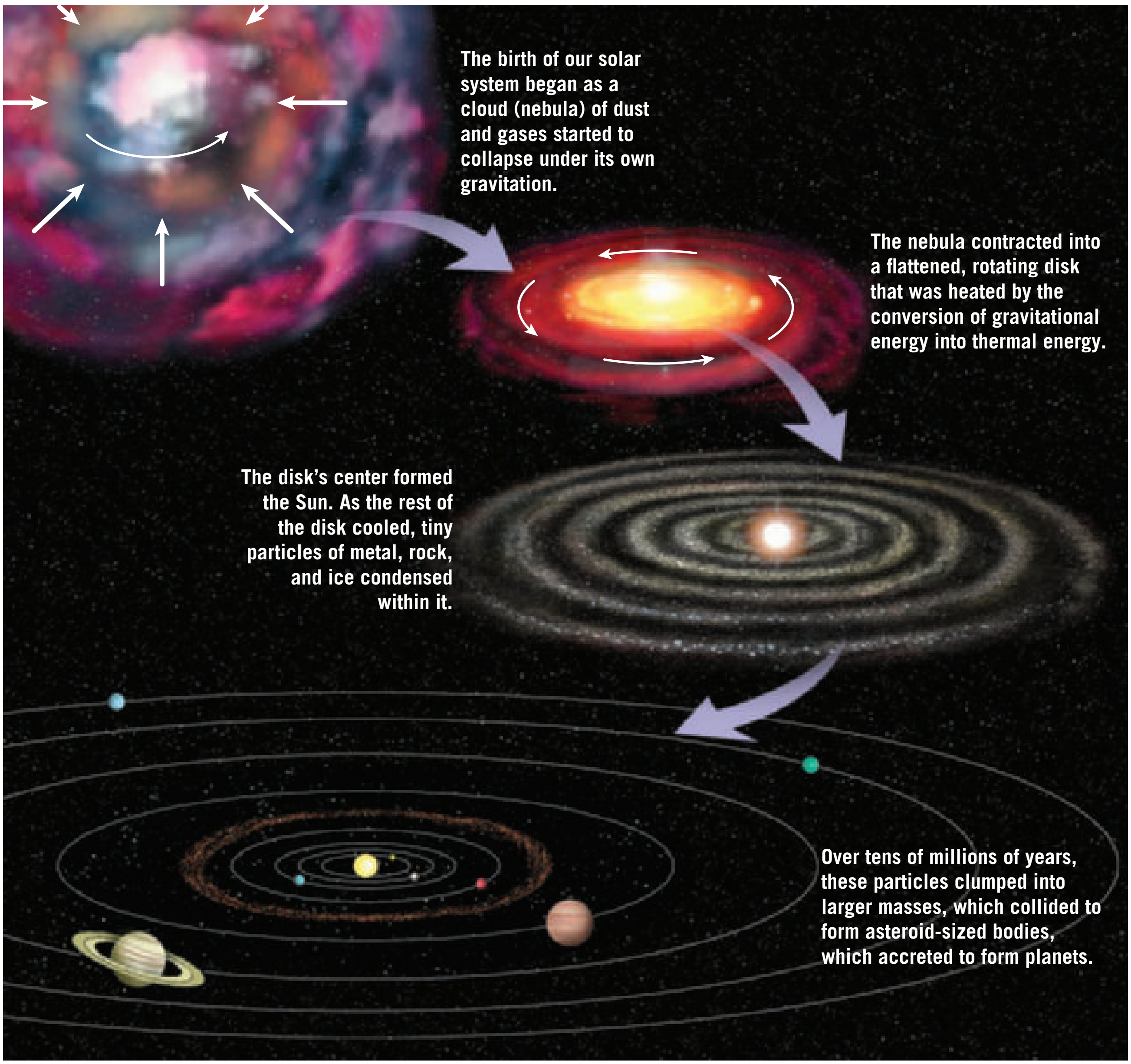
Questions:
1. What is the approximate distance between the Sun and Neptune?
2. How long would it take a jet plane traveling at 1000 km/hr to go from Earth to Neptune?



from an enormous rotating cloud called the solar nebula (**Figure 1.9**). Besides the hydrogen and helium atoms generated during the Big Bang, the solar nebula consisted of microscopic dust grains and other matter ejected ultimately from long-dead stars. (Nuclear fusion in stars converts hydrogen and helium into the other elements found in the universe.)

Nearly 5 billion years ago, something—perhaps a shock wave from an exploding star (*supernova*)—caused this nebula to start collapsing in response to its own gravitation. As it collapsed, it evolved from a huge, vaguely rotating cloud to a much smaller, fast-spinning disk. The cloud flattened into a disk for the same reason that it is easier to move along with a crowd of circling ice skaters than to cross their path. The orbital plane within the cloud that started out with the largest amount of matter gradually, through collisions and other interactions, incorporated gas and particles that originally had other orbits until all the matter orbited in one plane. The disk spun faster as it shrank, much as ice skaters spin faster when they draw their arms toward their bodies. Most of the cloud's matter ended up in the center of the disk, where it formed the *protosun* (pre-Sun). Astronomers have observed many such disks around newborn stars in neighboring regions of our galaxy.

The protosun and inner disk were heated by the gravitational energy of infalling matter. In the inner disk, temperatures became high enough to cause the dust grains to evaporate. However, at distances beyond the orbit of Mars, the temperatures probably remained



◀ **SmartFigure 1.9**
Nebular theory The nebular theory proposes the formation of the solar system.

TUTORIAL
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▶ **Figure 1.10 A remnant planetesimal** This image of Asteroid 21 Lutetia was obtained by special cameras aboard the *Rosetta* spacecraft on July 10, 2010. Spacecraft instruments showed that Lutetia is a primitive body (planetesimal) left over from when the solar system formed. (Image courtesy of European Space Agency)

quite low. At −200°C (−328°F), the tiny particles in the outer portion of the nebula were likely covered with a thick layer of frozen water, carbon dioxide, ammonia, and methane. The disk also contained appreciable amounts of the lighter gases hydrogen and helium.

The Inner Planets Form

The formation of the Sun marked the end of the period of contraction and thus the end of gravitational heating. Temperatures in the region where the inner planets now reside began to decline. The decrease in temperature caused substances with high melting points to condense into tiny particles that began to coalesce (join together). Materials such as iron and nickel and the elements of which the rock-forming minerals are composed—silicon, calcium, sodium, and so forth—formed metallic and rocky clumps that orbited the Sun (see Figure 1.9). Repeated collisions caused these masses to coalesce into larger asteroid-size bodies, called *planetesimals*, which in a few tens of millions of years accreted into the four inner planets we call Mercury, Venus, Earth, and Mars (**Figure 1.10**). Not all of these clumps of matter were incorporated into the planetesimals. Those rocky and metallic pieces that remained in orbit are called asteroids and meteors. Meteors become *meteorites* if they impact Earth's surface.

As more and more material was swept up by these growing planetary bodies, the high-velocity impact of nebular debris caused their temperatures to rise. Because of their relatively high temperatures and weak gravitational fields, the inner planets were unable to accumulate much of the lighter components of the nebular cloud. The lightest of these, hydrogen and helium, were eventually whisked from the inner solar system by the solar wind.

The Outer Planets Develop

At the same time that the inner planets were forming, the larger, outer planets (Jupiter, Saturn, Uranus, and Neptune), along with their extensive satellite systems, were also developing. Because of low temperatures far from the Sun, the material from which these planets formed contained a high percentage of ices—water, carbon dioxide, ammonia, and methane—as well as rocky and metallic debris. The accumulation of ices accounts in part for the large size and low density of the outer planets. The two most massive planets, Jupiter and Saturn, had a surface gravity sufficient to attract and hold large quantities of even the lightest elements—hydrogen and helium.

CONCEPT CHECKS 1.3

1. Name and briefly outline the theory that describes the formation of our solar system.
2. List the inner planets and the outer planets. Describe basic differences in size and composition.

1.4 Earth as a System

List and describe Earth's four major spheres. Define *system* and explain why Earth is considered to be a system.

Anyone who studies Earth soon learns that our planet is a dynamic body with many separate but interacting parts, or *spheres*. The hydrosphere, atmosphere, biosphere, and geosphere and all of their components can be studied separately. However, the parts are *not* isolated. Each is related in some way to the others, producing a complex and continuously interacting whole that we call the **Earth system**.

Earth's Spheres

The images in **Figure 1.11** are considered to be classics because they let humanity see Earth differently than ever before. These early views profoundly altered our conceptualizations of Earth and remain powerful images decades after they were first viewed. Seen from space, Earth is breathtaking in its beauty and startling in its solitude. The photos remind us that our home is, after all, a planet—small, self-contained, and in some ways even fragile.

As we look closely at our planet from space, it becomes apparent that Earth is much more than rock and soil. In fact, the most conspicuous features of Earth in Figure 1.11A are swirling clouds suspended above the surface of the vast global ocean. These features emphasize the importance of water on our planet.

The closer view of Earth from space shown in Figure 1.11B helps us appreciate why the physical environment is traditionally divided into three major parts: the water portion of our planet, the *hydrosphere*; Earth's gaseous envelope, the *atmosphere*; and, of course, the solid Earth, or *geosphere*. It needs to be emphasized that our environment is highly integrated and not dominated by rock, water, or air alone. Rather, it is characterized by continuous interactions as air comes in contact with rock, rock with water, and water with air. Moreover, the *biosphere*, which is the totality of all life on our planet, interacts with each of the three physical realms and is an equally integral part of the planet. Thus, Earth can be thought of as consisting of four major spheres: the hydrosphere, atmosphere, geosphere, and biosphere. All four spheres are represented in the chapter-opening photo.

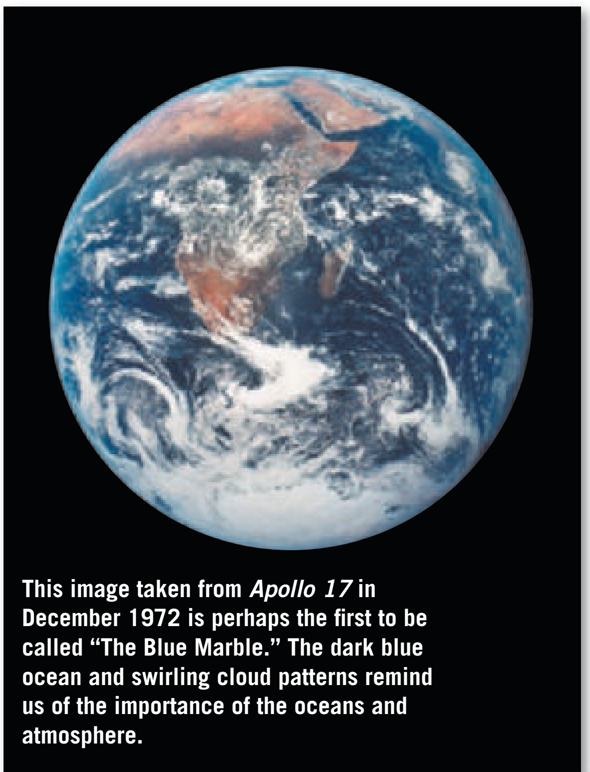
The interactions among Earth's spheres are incalculable. **Figure 1.12** provides one easy-to-visualize example. The shoreline is an obvious meeting place for rock, water, and air. In this scene, ocean waves created by the drag of air moving across the water are breaking against the rocky shore.

Hydrosphere

Earth is sometimes called the *blue* planet. Water, more than anything else, makes Earth unique. The **hydrosphere** is a dynamic mass of water that is continually on the move, evaporating from the oceans to the atmosphere, precipitating to the land, and running back to the ocean again. The global ocean is certainly the most prominent feature of the hydrosphere, blanketing nearly 71 percent of Earth's surface to an average depth of about 3800 meters (12,500 feet). It accounts for about

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

A.



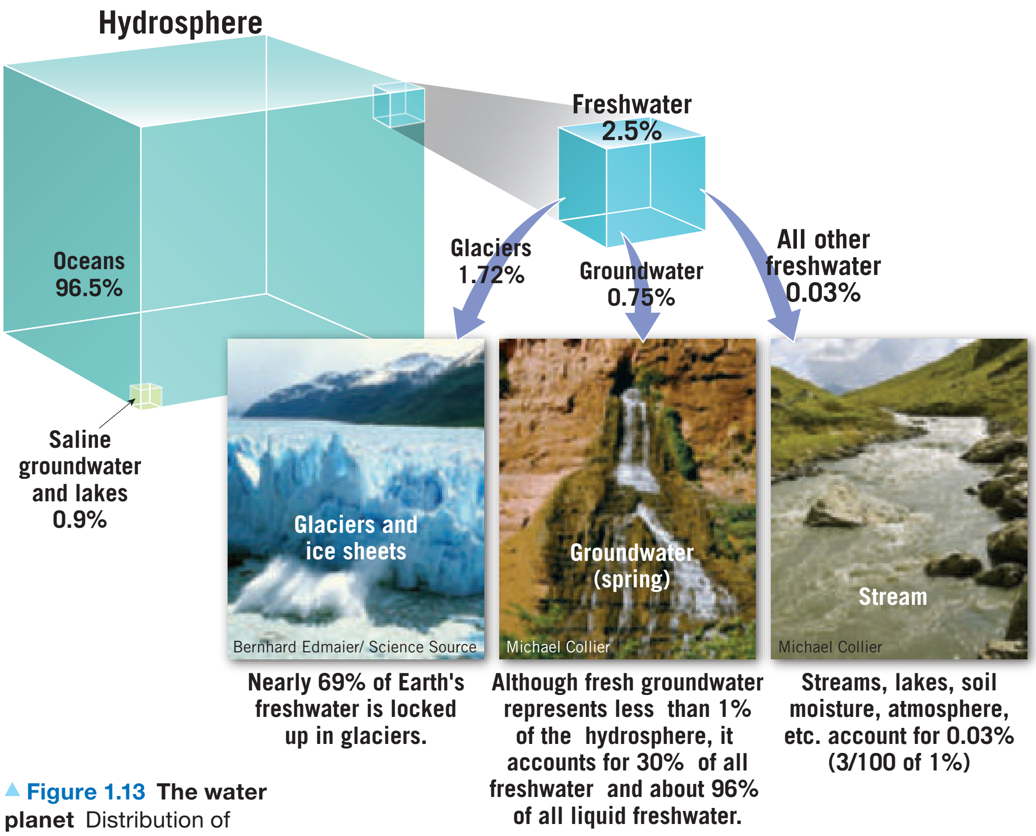
This image taken from *Apollo 17* in December 1972 is perhaps the first to be called "The Blue Marble." The dark blue ocean and swirling cloud patterns remind us of the importance of the oceans and atmosphere.

B.

▲ **SmartFigure 1.11 Two classic views of Earth from space** The accompanying video commemorates the 45th anniversary of *Apollo 8*'s historic flight by re-creating the moment when the crew first saw and photographed Earth rising from behind the Moon. (NASA)

VIDEO
https://goo.gl/AQKqaa

▼ **Figure 1.12**
Interactions among Earth's spheres The shoreline is one obvious interface—a common boundary where different parts of a system interact. In this scene, ocean waves (hydrosphere) that were created by the force of moving air (atmosphere) break against a rocky shore (geosphere). The force of the water can be powerful, and the erosional work that is accomplished can be great. (Photo by Michael Collier)



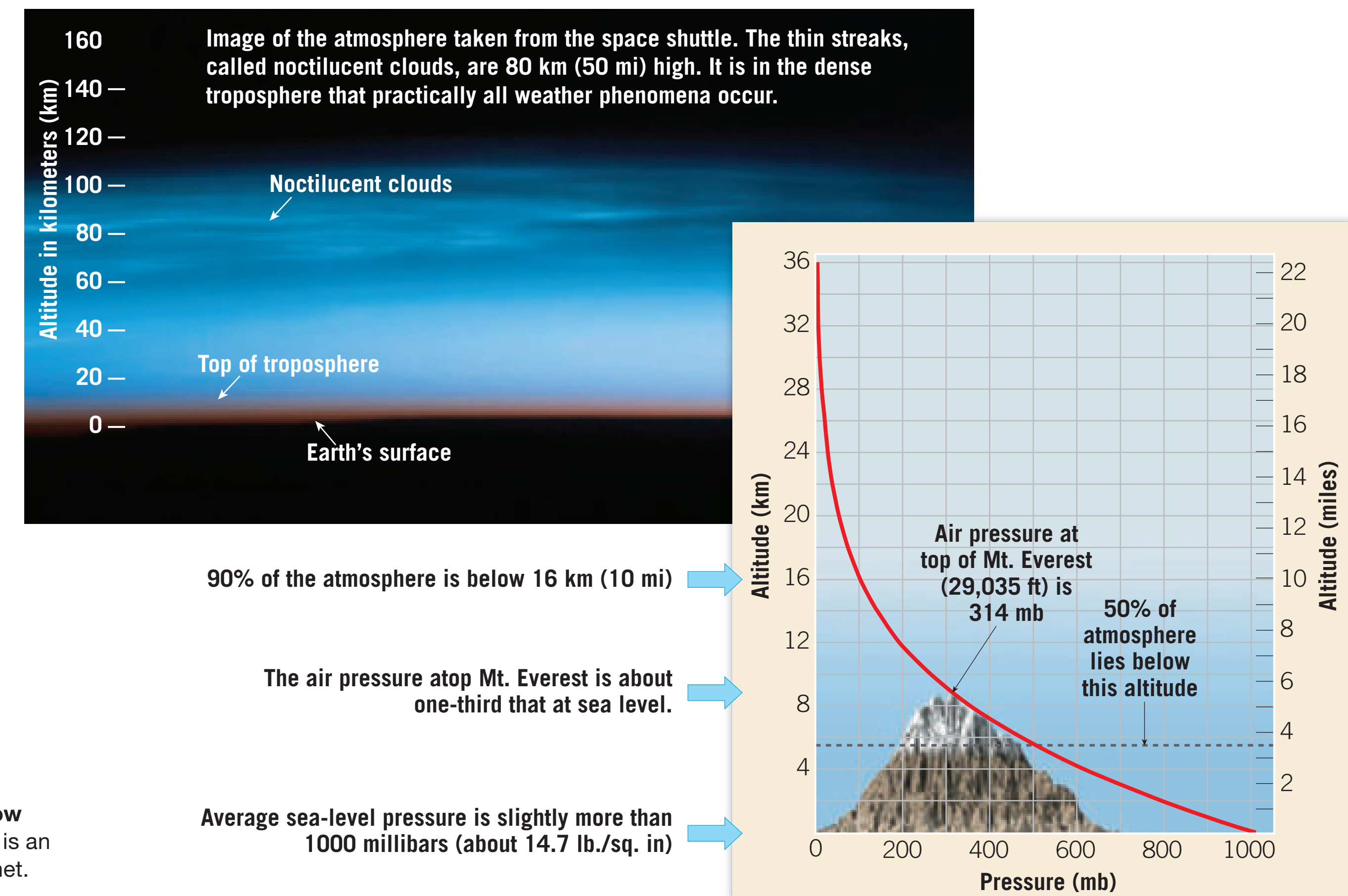
▲ **Figure 1.13 The water planet** Distribution of water in the hydrosphere.

97 percent of Earth's water (**Figure 1.13**). However, the hydrosphere also includes the freshwater found underground and in streams, lakes, and glaciers. Moreover, water is an important component of all living things.

Even though freshwater constitutes only a small fraction of Earth's hydrosphere, it plays an outsized role in Earth's external processes. Streams, glaciers, and groundwater sculpt many of our planet's varied landforms, and freshwater is vital for life on land.

Atmosphere

Earth is surrounded by a life-giving gaseous envelope called the **atmosphere** (**Figure 1.14**). When we watch a high-flying jet plane cross the sky, it seems that the atmosphere extends upward for a great distance. However, when compared to the thickness (radius) of the solid Earth (about 6400 kilometers [4000 miles]), the atmosphere is a very shallow layer. Despite its modest dimensions, this thin blanket of air is an integral part of the planet. It not only provides the air we breathe but also protects us from the Sun's intense heat and dangerous ultraviolet radiation. The energy exchanges that continually



▶ **Figure 1.14 A shallow layer** The atmosphere is an integral part of the planet. (NASA)

EYE ON EARTH 1.2

interlight/Shutterstock

This jet is cruising at an altitude of 10 kilometers (6.2 miles).

QUESTION 1 *Refer to the graph in Figure 1.14. What is the approximate air pressure at the altitude where the jet is flying?*

QUESTION 2 *About what percentage of the atmosphere is below the jet (assuming that the pressure at the surface is 1000 millibars)?*

occur between the atmosphere and Earth's surface and between the atmosphere and space produce the effects we call *weather* and *climate*. Climate has a strong influence on the nature and intensity of Earth's external processes. When climate changes, these processes respond.

If, like the Moon, Earth had no atmosphere, our planet would be lifeless, and many of the processes and interactions that make the surface such a dynamic place could not operate. Without weathering and erosion, the face of our planet might more closely resemble the lunar surface, which has not changed appreciably in nearly 3 billion years.

Biosphere

The **biosphere** includes all life on Earth (**Figure 1.15**). Ocean life is concentrated in the sunlit upper waters. Most life on land is also concentrated near the surface, with tree roots and burrowing animals reaching a few meters underground and flying insects and birds reaching a kilometer or so into the atmosphere. A surprising variety of life-forms are also adapted to extreme environments. For example, on the ocean floor, where pressures are extreme and no light penetrates, there are places where vents spew hot, mineral-rich fluids that support communities of exotic life-forms, as in Figure 1.15B. On land, some bacteria thrive in rocks as deep as 4 kilometers (2.5 miles) and in boiling hot springs. Moreover, air currents can carry microorganisms many kilometers into the atmosphere. But even when we consider these extremes, life still must be thought of as being confined to a narrow band very near Earth's surface.

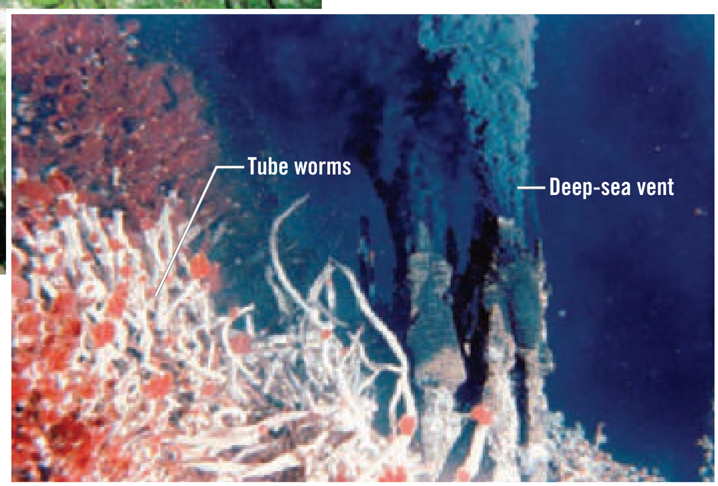
Plants and animals depend on the physical environment for the basics of life. However, organisms do not just respond to their physical environment. Through countless interactions, life-forms help maintain and alter the physical environment. Without life, the makeup and nature of the geosphere, hydrosphere, and atmosphere would be very different.

Geosphere

Lying beneath the atmosphere and the ocean is the solid Earth or **geosphere**, extending from the surface to the center of the planet at a depth of nearly

Figure 1.15 The biosphere The biosphere, one of Earth's four spheres, includes all life. **A.** Tropical rain forests are teeming with life and occur in the vicinity of the equator. (Photo by AGE Fotostock/SuperStock) **B.** Some life occurs in extreme environments such as the absolute darkness of the deep ocean. (Photo by Fisheries and Oceans Canada/Verena Tunnicliffe/Newscom)

A. Tropical rain forests are characterized by hundreds of different species per square kilometer.

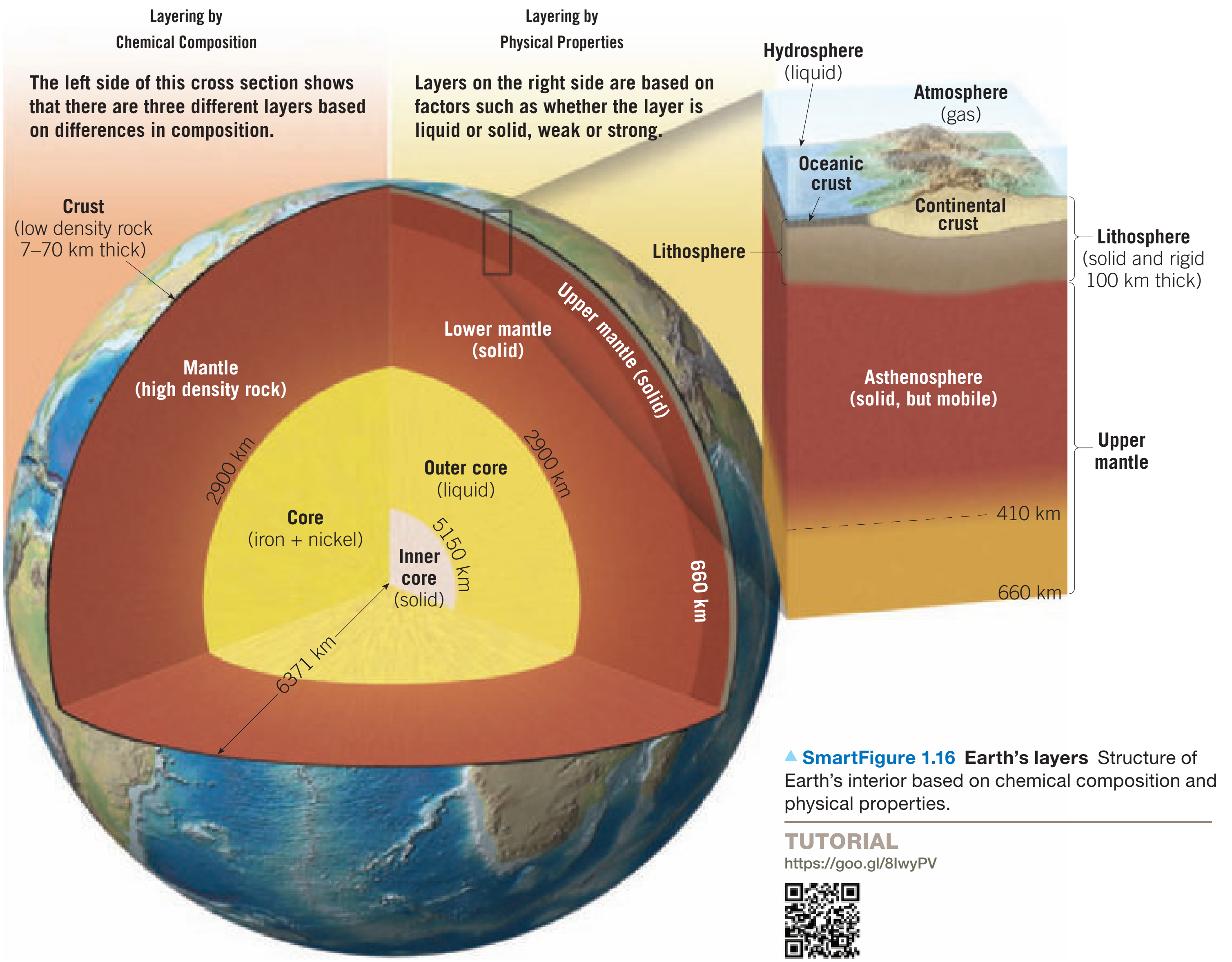


B. Microorganisms are nourished by hot, mineral-rich fluids spewing from vents on the deep-ocean floor. The microbes support larger organisms such as tube worms.

6400 kilometers (4000 miles)—by far the largest of Earth's spheres. Much of our study of the solid Earth focuses on the more accessible surface and near-surface features, but it is worth noting that many of these features are linked to the dynamic behavior of Earth's interior. Earth's interior is layered. As Figure 1.16 shows, we can think of this layering as being due to differences in both *chemical composition* and *physical properties*. On the basis of chemical composition, Earth has three layers: a dense inner sphere called the **core**; the less dense **mantle**; and the **crust**, which is the light and very thin outer skin of Earth. The crust is not a layer of uniform thickness. It is thinnest beneath the oceans and thickest where continents exist. Although the crust may seem insignificant when compared with the other layers of the geosphere, which are much thicker, it was created by the same general processes that formed Earth's present structure. Thus, the crust is important in understanding the history and nature of our planet.

The layering of Earth in terms of physical properties reflects the way Earth's materials behave when various forces and stresses are applied. The term **lithosphere** refers to the rigid outer layer that includes the crust and uppermost mantle. Beneath the rigid rocks that compose the lithosphere, the rocks of the **asthenosphere** are weak and able to slowly flow in response to the uneven distribution of heat deep within Earth.

The two principal divisions of Earth's surface are the continents and the ocean basins. The most obvious difference between these two provinces is their relative vertical levels. The average elevation of the continents above sea level is about 840 meters (2750 feet), whereas the average depth of the oceans is about 3800 meters (12,500 feet). Thus, the continents stand on average 4640 meters (about 4.6 kilometers, or nearly 3 miles) above the level of the ocean floor.



▲ SmartFigure 1.16 **Earth's layers** Structure of Earth's interior based on chemical composition and physical properties.

TUTORIAL
https://goo.gl/8IwyPV

◀ **Figure 1.17 Deadly debris flow** This image provides an example of interactions among different parts of the Earth system. Extraordinary rains triggered this debris flow (popularly called a mudslide) on March 22, 2014, near Oso, Washington. The mass of mud and debris blocked the North Fork of the Stillaguamish River and engulfed an area of about 2.6 square kilometers (1 square mile). Forty-three people perished. (Photo by Michael Collier)

Soil, the thin veneer of material at Earth's surface that supports the growth of plants, may be thought of as part of all four spheres. The solid portion is a mixture of weathered rock debris (geosphere) and organic matter from decayed plant and animal life (biosphere). The decomposed and disintegrated rock debris is the product of weathering processes that require air (atmosphere) and water (hydrosphere). Air and water also occupy the open spaces between solid particles.

Earth System Science

A simple example of the interactions among different parts of the Earth system occurs every winter, as moisture evaporates from the Pacific Ocean and subsequently falls as rain in the mountains of Washington, Oregon, and California, triggering destructive debris flows. The processes that move water from the hydrosphere to the atmosphere and then to the solid Earth have a profound impact on the plants and animals (including humans) that inhabit the affected regions (**Figure 1.17**).

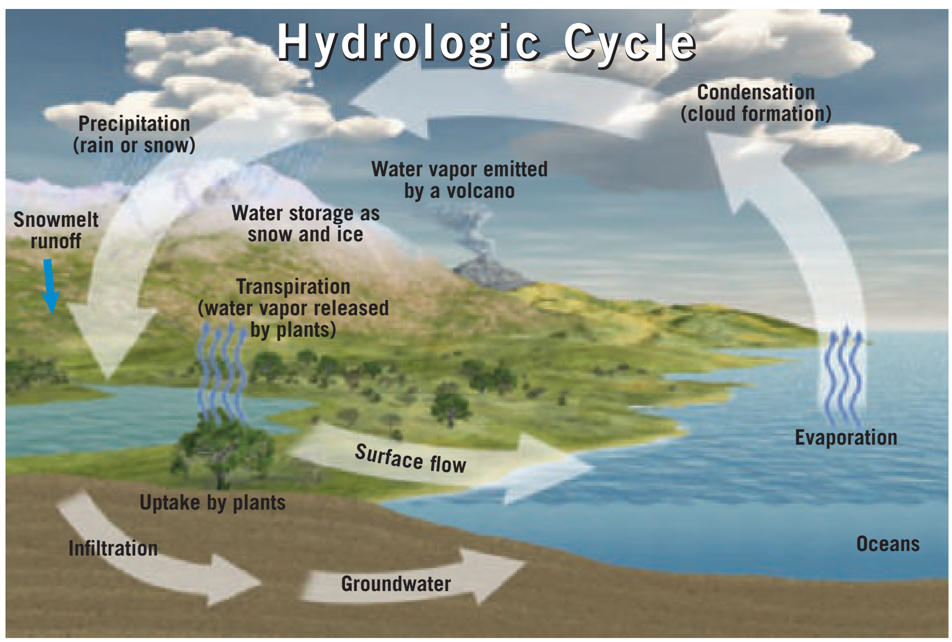
Scientists have recognized that in order to more fully understand our planet, they must learn how its individual components (land, water, air, and life-forms) are interconnected. This endeavor, called **Earth system science**, aims to study Earth as a *system* composed of numerous interacting parts, or *subsystems.* Rather than look through the limited lens of only one of the traditional sciences—geology, atmospheric science, chemistry, biology, and so on—Earth system science attempts to integrate the knowledge of many academic fields. Using an interdisciplinary approach, those engaged in Earth system science attempt to achieve the level of understanding necessary to comprehend and solve many of our global environmental problems.

A **system** is a group of interacting, or interdependent, parts that form a complex whole. Most of us hear and use the term *system* frequently. We may service our car's cooling *system*, make use of the city's transportation *system*, and be a participant in the political *system*. A news report might inform us of an approaching weather *system*. Further, we know that Earth is just a small part of a larger system known as the *solar system*, which in turn is a subsystem of an even larger system called the Milky Way Galaxy.

The Earth System

The Earth system has a nearly endless array of subsystems in which matter is recycled over and over. One familiar loop, or subsystem, is the *hydrologic cycle*. It represents the unending circulation of Earth's water among the hydrosphere, atmosphere, biosphere, and geosphere (**Figure 1.18**). Water enters the atmosphere through evaporation from Earth's surface and transpiration from plants. Water vapor condenses in the atmosphere to form clouds, which in turn produce precipitation that falls back to Earth's surface. Some of the rain that falls onto the land sinks in and then is taken up by plants or becomes groundwater, and some flows across the surface toward the ocean.

▼ **Figure 1.18 The hydrologic cycle** Water readily changes state from liquid, to gas (vapor), to solid at the temperatures and pressures occurring on Earth. This cycle traces the movements of water among Earth's four spheres. It is one of many subsystems that collectively make up the Earth system.



Viewed over long time spans, the rocks of the geosphere are constantly forming, changing, and re-forming. The loop that involves the processes by which one rock changes to another is called the *rock cycle* and is discussed at some length in Chapter 3. The cycles of the Earth system are not independent of one another. To the contrary, there are many places where the cycles come in contact and interact.

The Parts Are Linked The parts of the Earth system are linked so that a change in one part can produce changes in any or all of the other parts. For example, when a volcano erupts, lava from Earth's interior may flow out at the surface and block a nearby valley. This new obstruction influences the region's drainage system by creating a lake or causing streams to change course. The large quantities of volcanic ash and gases that can be emitted during an eruption might be blown high into the atmosphere and influence the amount of solar energy that can reach Earth's surface. The result could be a drop in air temperatures over the entire hemisphere.

Where the surface is covered by lava flows or a thick layer of volcanic ash, existing soils are buried. This causes the soil-forming processes to begin anew to transform the new surface material into soil (**Figure 1.19**). The soil that eventually forms will reflect the interactions among many parts of the Earth system—the volcanic parent material, the climate, and the impact of biological activity. Of course, there would also be significant changes in the biosphere. Some organisms and their habitats would be eliminated by the lava and ash, and new settings for life, such as a lake formed by a lava dam, would be created. The potential climate change could also impact sensitive life-forms.

Time and Space Scales The Earth system is characterized by processes that vary on spatial scales from fractions of millimeters to thousands of kilometers. Time scales for

▲ **Figure 1.19 Change is a geologic constant** When Mount St. Helens erupted in May 1980 (inset photo), the area shown here was buried by a volcanic mudflow. Now plants are reestablished, and new soil is forming. (Photo by Terry Donnelly/Alamy Images; inset photo by USGS)