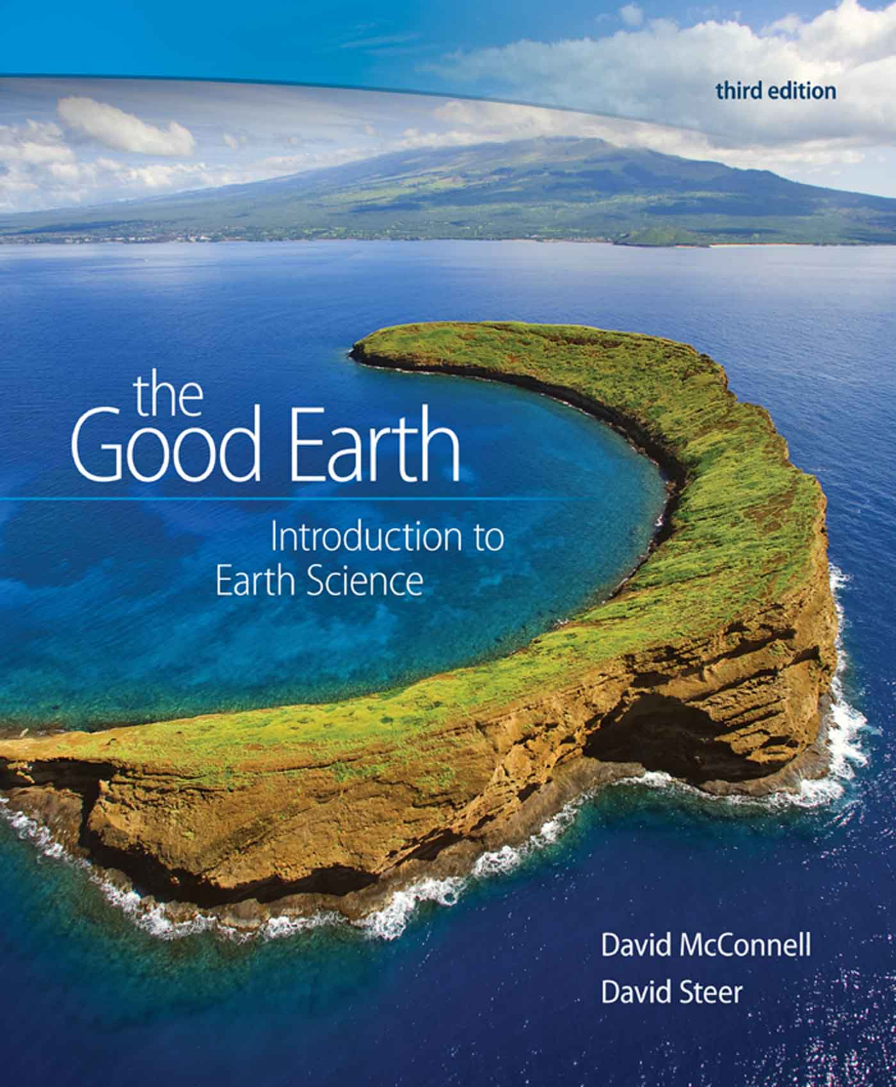

third edition

the Good Earth

Introduction to Earth Science

David McConnell
David Steer

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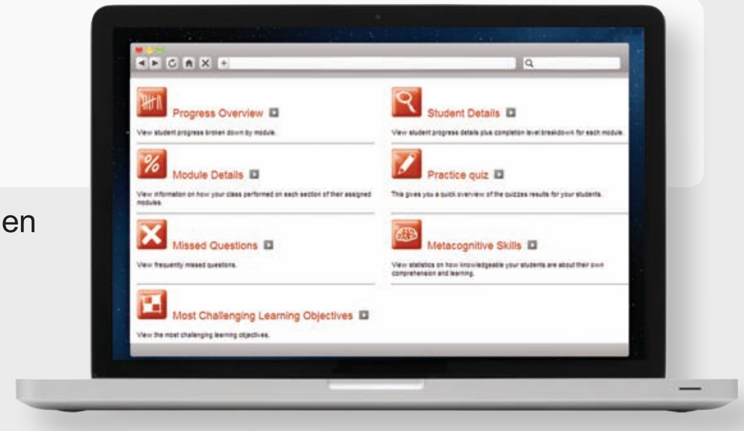

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the Good Earth

Introduction to Earth Science

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THE GOOD EARTH: INTRODUCTION TO EARTH SCIENCE

This book is printed on acid-free paper.

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Preface

Teaching earth science can be viewed as content instruction, covering the principles of science and earth systems. But can it also be considered as an opportunity to *engage* students in the nature of scientific inquiry?

> *A traditional science instructor concentrates on teaching factual knowledge, with the implicit assumption that expert-like ways of thinking about the subject come along for free or are already present. But that is not what cognitive science tells us. It tells us instead that students need to develop these different ways of thinking by means of extended, focused, mental effort.*
>
> *Carl Wieman*
> *Nobel Prize winner*

For many, the wonder of Earth and its features is enough to drive learning. For these happy few, a readable book with lots of attractive photographs is almost all that is required. *But for many—in fact most—learning takes more than pretty words and pictures.* Providing high-quality teaching is the most cost-effective, tangible, and timely effort that geoscience instructors can make to improve student engagement, increase attendance, and add majors.

But how do we do that? There is extensive literature describing what effective teaching looks like, but most science instructors have not had access to these articles and books. Further, few of us were ever explicitly taught the components of good teaching. Instead, we were left to figure it out for ourselves on the basis of our classroom experiences as students.

The Good Earth was published to support both the traditional earth science class ***and*** to serve as an accessible resource for instructors seeking to apply effective teaching strategies to enhance learning.

The Good Earth *Difference*

We wrote *The Good Earth* to support an active learning approach to teaching and to provide the necessary resources for instructors moving through the transition from passive to active learning. Like you, we want our students to walk away from this course with an appreciation for science and the ability to make life decisions based on scientific reasoning.

Our goal was to write a book that was engaging for students but that also included resources that illustrated for instructors how to use teaching practices that have been shown to support student learning. The materials and methods discussed in the text and the accompanying *Instructor's Manual* have been tried and tested in our own classes. Our research shows that the integration of the materials and pedagogy provided in this book not only improved students' understanding of earth science as measured by standardized national tests, but it can also improve students' logical thinking skills by twice as much as a typical "traditional" lecture class. Such methods are overwhelmingly preferred by students and increase student attendance and satisfaction with the course. Finally, a significant point for us is that these methods make teaching class more fun for the instructor.

> *I love the voice the authors use. Reading the text is like listening to a very intelligent but down-to-earth friend explain a difficult topic. The authors are excellent at organizing and presenting the material. . . . The illustrations are superior to other texts in all ways.*
>
> *Patricia Hartshorn*
> *University of Michigan–Dearborn*

Student-Centered Research

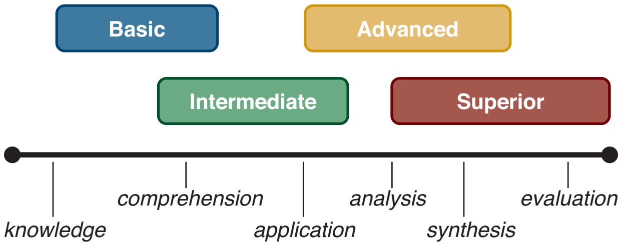
The Good Earth can be used as a text for a traditional, teacher-centered lecture-based course. In fact, we have taken great care to write a book that students would find more engaging than a typical text. But the greatest benefit will come when the book is used as part of an active-learning, student-centered course. For some instructors, it may simply be a matter of adding some of our exercises to an existing active-learning class environment. For others, the book and accompanying materials will give them an opportunity to add components as they gradually change their pedagogy. If you want a more interactive class, try one or all of the following three recommendations based on research findings:

1. Students learn key concepts better when they have opportunities to actively monitor their understanding during class. Rather than just standing up and talking, the instructor can break lectures into segments separated by brief exercises to make sure that students understand concepts before moving on. Students' understanding must be frequently challenged to provide an opportunity to identify misconceptions and replace them with improved, more realistic models.

   The Good Earth includes hundreds of Checkpoint exercises that can also be used as handout-ready PDF files (located on the text website along with answer keys). Practice makes perfect: the more opportunities students have to assess their learning and to practice the application of new skills, the better their performance. If you are concerned about reduced time for lecture, we have found that an emphasis on fostering deeper understanding and less content coverage in lecture, combined with greater student responsibility for reading, produced no decrease in content knowledge attainment and improved student comprehension of key concepts. Some exercises can be assigned as homework, and the answer key in the back of the book can help students to assess their self-directed-learning.

2. Students become better learners when we challenge them to answer questions that require the use of higher-order thinking skills (for example, analysis, synthesis, evaluation). Brain research shows that people become smarter when they experience cognitive challenges. However, it is important not to throw students into the deep end without any help. Instead, instructors need to step through a series of problems of increasing difficulty (scaffolding) so that they can train students to correctly apply their newly acquired thinking skills.

   Therefore, we have carefully created a series of color-coded **Checkpoint** exercises for each section of every chapter. The exercises are pitched at four skill levels: basic, intermediate, advanced, and superior, to give students and instructors an opportunity to scaffold student understanding of key concepts. The questions represent four levels of Bloom's taxonomy. Blue and green questions typically are comprehension and application-level questions. Yellow and red checkpoints typically require analysis, synthesis, or evaluation skills. It is not necessary to complete all the exercises; instructors can select the exercises that are most appropriate for their learning goals.



> *This was kind of a neat idea, and the questions [Checkpoints] do get quite challenging at higher orders. I feel these are good things for students to do while studying, with the idea that if they understand the higher order questions they will understand concepts better for exams. I thought these checkpoints have some very well-formulated questions in the chapters I reviewed.*
>
> *Swarndeep Gill*
> *California University of Pennsylvania*

> *I like the fact that the authors are mindful and well versed in science education research and pedagogy. This aspect of the author's background is evident in the design of the Checkpoint questions.*
>
> *The use of Concept Maps and Venn Diagrams is fairly cutting edge for introductory Earth Science textbooks that I am familiar with. This is probably the most innovative aspect of this book and distinguishes it from similar texts, even though the content is presented very similarly to other texts.*
>
> *Jeffrey Templeton*
> *Western Oregon University*

Sort …

Checkpoint 11.1

basic advanced intermediate superior

Sort the following 12 terms into six pairs of terms that most closely relate to one another. Explain your choices.

groundwater
stream
rainfall
gas
plants
ice
precipitation
meltwater
transpiration
infiltration
water vapor
runoff

Match the lettered responses …

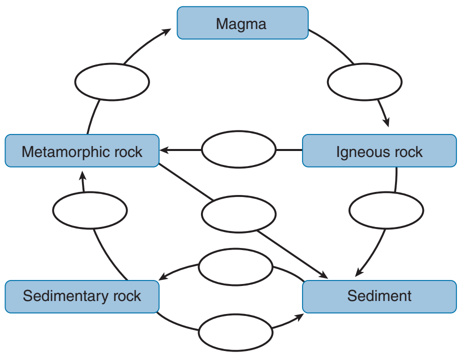
Checkpoint 7.22

basic advanced intermediate superior

Rock Cycle Diagram

The following diagram illustrates some of the interactions of the rock cycle. Match the lettered responses to the blank ovals on the diagram. (*Note:* Some letters are used more than once.) Example: If you believe that metamorphic rock is converted to magma by cementation and compaction, enter "a" in the top left oval.

a) Cementation and compaction (lithification)
b) Heat and pressure
c) Weathering, transportation, deposition
d) Cooling and solidification
e) Melting



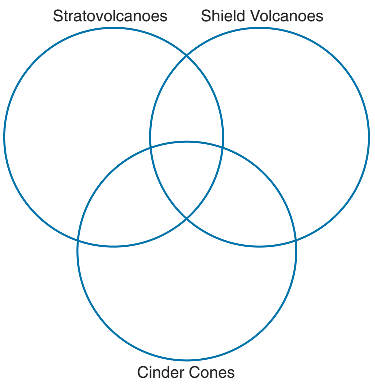
Checkpoint 6.19

basic advanced intermediate superior

Venn Diagram: Shield Volcanoes, Stratovolcanoes, and Cinder Cones

Use the Venn diagram provided here to compare and contrast the three principal types of volcanoes. Place the number corresponding to features unique to each type in the larger areas of the circles; note features they share in the overlap area in the center of the image. Five items are provided; identify at least 12 more.

1. Associated with subduction zones
2. Have a triangular shape in profile
3. Example: Mount Hood, Oregon
4. Mild eruptions
5. High-silica magma



Compare and contrast …

Evaluate the five most important factors …

Checkpoint 12.12

basic advanced intermediate superior

Groundwater Evaluation Rubric

You are asked to help locate a new aquifer that will supply your town with water. In examining the potential sites, you recognize that several different factors will influence groundwater availability and at no single site are all of the factors optimal. You decide to create a scoring scheme to evaluate the five most important factors that will influence the availability of groundwater. The location that scores the highest according to the rubric will be selected for the well field. One factor is included as an example in the table below; identify five more.

Factors	Poor (1 point)	Moderate (2 points)	Good (3 points)
Depth to water table	Deep	Intermediate	Shallow

> *I have to compliment you on putting together Checkpoint 3.3. This was probably the best evaluation tool I have seen for determining whether a student really understands the meaning of the words we use to describe the scientific methods (hypothesis, prediction, etc.).*
>
> *Neil Lundberg*
> *Florida State University*

3. Knowledge is socially constructed and people learn best in supportive social settings. Students do not enter our classrooms as empty vessels to be filled with knowledge. Instead, they actively construct mental models that assimilate new information with previous experiences. This construction of knowledge happens most readily when students work in small collaborative groups (three to four students), where they can talk and listen to peers as they build their understanding of new concepts. Students must be provided with opportunities to be self-reflective about their learning and to help them learn how to learn. Our research confirmed that students in classes where small groups worked to solve challenging problems outperformed students in classes where they worked on the same problems independently.

> *It is set up very user friendly and will make it easy for instructors to create an interactive learning environment. Also, the way the chapters and questions are laid out, students will know exactly what they should be getting from the chapter and how to test their knowledge and skills.*
>
> *Jessica Kapp*
> *University of Arizona*

Whether you choose to use informal groups ("turn and talk to your neighbors") or formal groups determined by experiences (for example, number of science classes, scores on pretests, academic rank), collaborative learning is a powerful mechanism for maintaining attendance, increasing student-instructor dialogue, and enhancing learning. The Checkpoint exercises (especially advanced and superior level) and conceptests (conceptual multiple choice questions) provided with the book will give you many assignments that you can use as the basis for group work.

For detailed information regarding concept maps, Venn diagrams, Bloom's taxonomy, assessment, and so forth, please consult the *Instructor's Manual* on the text website: http://www.mhhe.com/thegoodearth3e

Tools for Teaching and Learning Science Literacy

Science can be thought of in three ways: as a body of knowledge, as the processes that people employ to explain the universe, and as a set of attitudes and values possessed by those who "do science." This latter aspect is often overlooked in college science textbooks. For each chapter of *The Good Earth*, the *Instructor's Manual* gives suggestions for incorporating into class discussion science attitudes and values such as open-mindedness, skepticism, persistence, and curiosity.

Additionally, the discussion of the **scientific method** is woven throughout the text. We emphasize three scientific themes throughout the text: 1) scientific literacy, 2) earth science and human experience, and 3) the science of global change. Numerous examples of human interaction with Earth serve as introductions to each chapter. Each chapter includes examples of the connection between science and technology, and builds on a context or event familiar to the student. We believe that links to students' past knowledge and experience are essential foundations upon which to build deeper understanding.

In addition to the theme of global change permeating the text, we devote a full chapter to the topic and do not duck the tough issues related to it. We use data and evidence to help students build their own understanding and assist them to realize that *"Much of what lies ahead for the good Earth is up to us. Know, care, act."*

> *I am pleased to see the final chapter on global change; most students assume that climate change is a political debate, so it is nice to see a textbook that discusses the science behind the news.*
>
> *Bryan C. Wilbur*
> *Pasadena City College*

Ways to Direct Learning

Rather than put key vocabulary terms in bold, we put **key concepts** in bold font. Our rationale is that conceptual understanding is the goal; vocabulary terms alone may not lead to the understanding that we desire. Research suggests that listing key terms encourages the memorization of those terms, rather than the understanding of the associated concepts—rather like learning words in a foreign language but being unable to put together a sentence. To make students fluent in science, we chose to focus on a vocabulary that builds students' conceptual understanding of major ideas in earth science. These ideas were recommended by standards-setting groups, such as the American Association for the Advancement of Science (AAAS).

Students can use the Checkpoint surveys to self-evaluate their comprehension of the major concepts in the section. Self-evaluation is a life skill that persists far longer than the evaluation imposed by an outside party (that is, the instructor). We believe in ongoing assessment tied to each key concept while ideas are still fresh. In contrast, other texts may provide tools for assessment only at the end of the chapter, after all of the content has been covered.

National Committee on Science Education Standards and Assessment

National Research Council

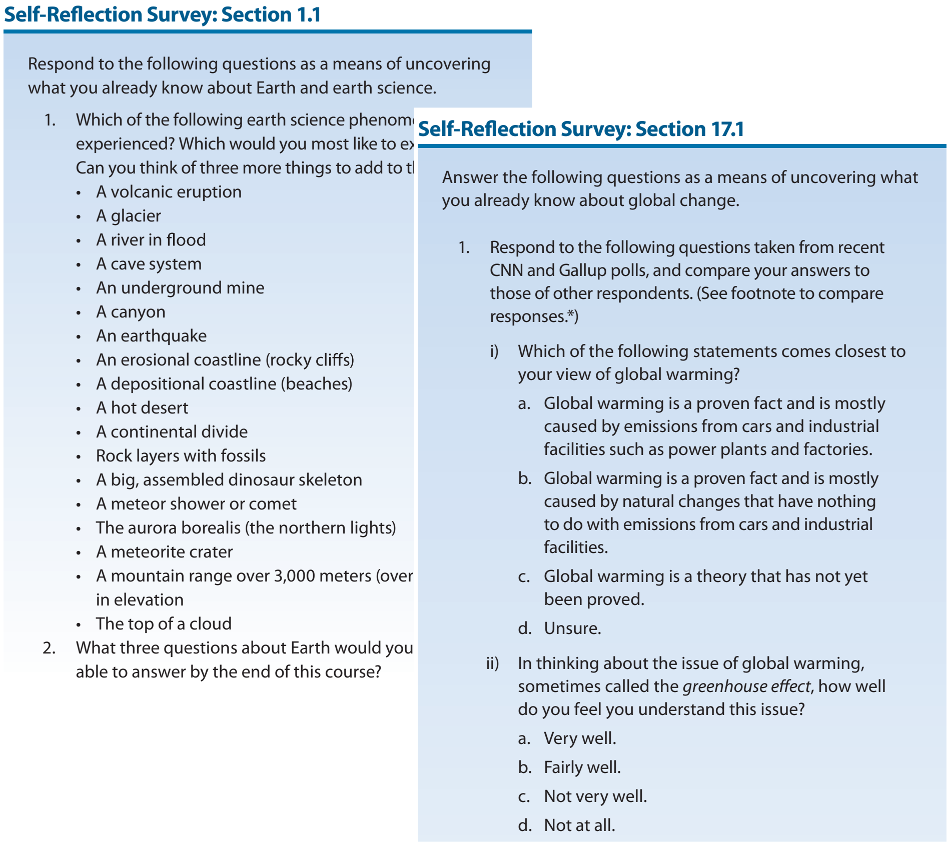
LEARNING SCIENCE IS AN ACTIVE PROCESS. Learning science is something students do, not something that is done to them. In learning science, students describe objects and events, ask questions, acquire knowledge, construct explanations of natural phenomena, test those explanations in many different ways, and communicate their ideas to others. Science teaching must involve students in inquiry-oriented investigations in which they interact with their teachers and peers.

FOCUS AND SUPPORT INQUIRIES. Student inquiry in the science classroom encompasses a range of activities. Some activities provide a basis for observation, data collection, reflection, and analysis of firsthand events and phenomena. Other activities encourage the critical analysis of secondary sources—including media, books, and journals in a library.

ENCOURAGE AND MODEL THE SKILLS OF SCIENTIFIC INQUIRY, AS WELL AS THE CURIOSITY, OPENNESS TO NEW IDEAS, AND SKEPTICISM THAT CHARACTERIZE SCIENCE.

USE MULTIPLE METHODS AND SYSTEMATICALLY GATHER DATA ON STUDENT UNDERSTANDING AND ABILITY. Because assessment information is a powerful tool for monitoring the development of student understanding, modifying activities, and promoting student self-reflection, the effective teacher of science carefully selects and uses assessment tasks that are also good learning experiences.

Often students have some fundamental knowledge of earth science and, when reminded, are able to apply this information to the introduction of new concepts. Each chapter includes a **Self-Reflection Survey** to promote awareness of personal experiences.



Self-Reflection Survey: Section 1.1

Respond to the following questions as a means of uncovering what you already know about Earth and earth science.

1. Which of the following earth science phenom experienced? Which would you most like to ex Can you think of three more things to add to t
   - A volcanic eruption
   - A glacier
   - A river in flood
   - A cave system
   - An underground mine
   - A canyon
   - An earthquake
   - An erosional coastline (rocky cliffs)
   - A depositional coastline (beaches)
   - A hot desert
   - A continental divide
   - Rock layers with fossils
   - A big, assembled dinosaur skeleton
   - A meteor shower or comet
   - The aurora borealis (the northern lights)
   - A meteorite crater
   - A mountain range over 3,000 meters (over in elevation
   - The top of a cloud
2. What three questions about Earth would you able to answer by the end of this course?

Self-Reflection Survey: Section 17.1

Answer the following questions as a means of uncovering what you already know about global change.

1. Respond to the following questions taken from recent CNN and Gallup polls, and compare your answers to those of other respondents. (See footnote to compare responses.*)

   i) Which of the following statements comes closest to your view of global warming?

      a. Global warming is a proven fact and is mostly caused by emissions from cars and industrial facilities such as power plants and factories.

      b. Global warming is a proven fact and is mostly caused by natural changes that have nothing to do with emissions from cars and industrial facilities.

      c. Global warming is a theory that has not yet been proved.

      d. Unsure.

   ii) In thinking about the issue of global warming, sometimes called the *greenhouse effect*, how well do you feel you understand this issue?

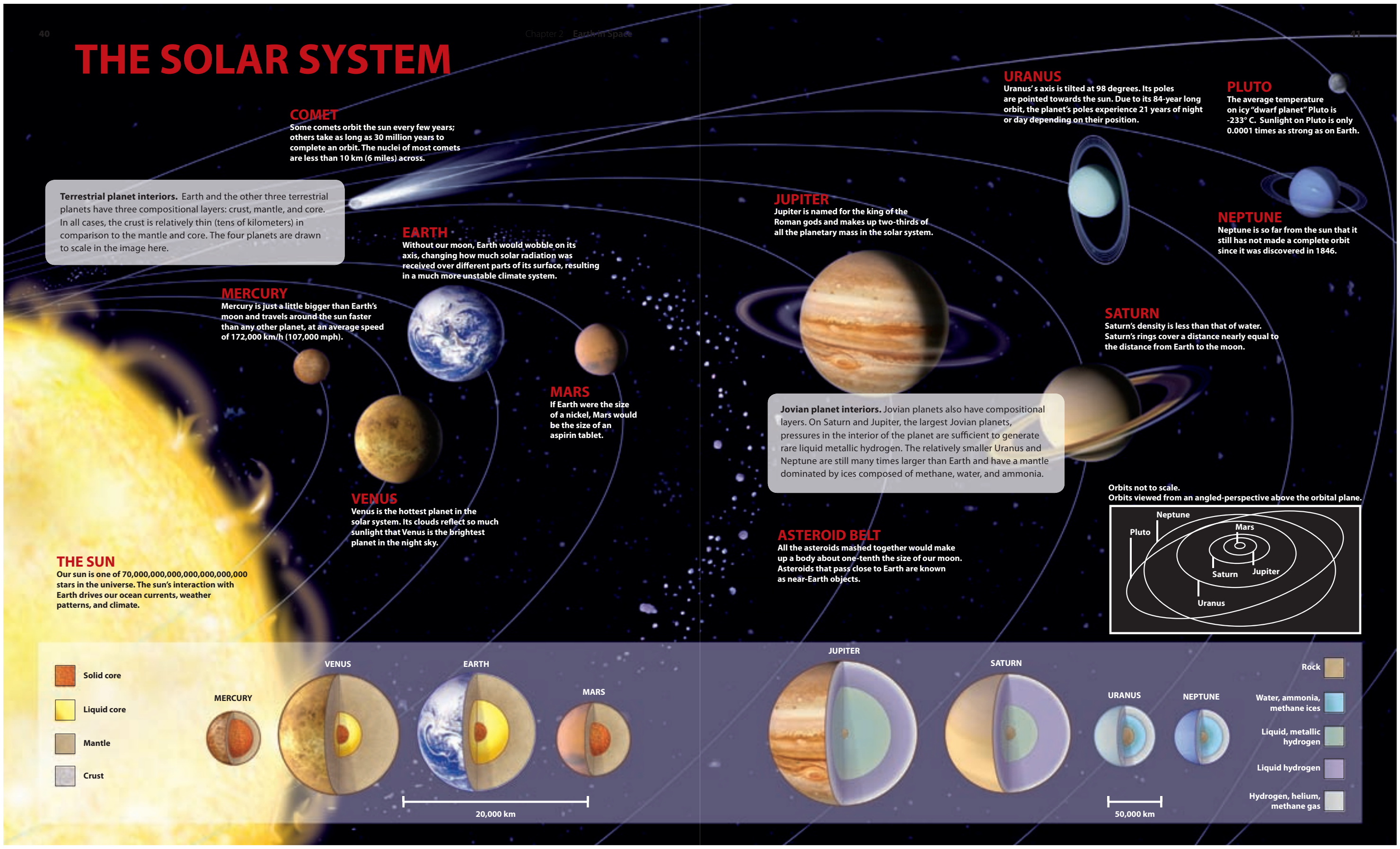
      a. Very well.

      b. Fairly well.

      c. Not very well.

      d. Not at all.

Visuals are of great importance for understanding earth science concepts. *The Good Earth* features two-page **Snapshots** to emphasize an important concept in every chapter.



THE SOLAR SYSTEM

COMET Some comets orbit the sun every few years; others take as long as 30 million years to complete an orbit. The nuclei of most comets are less than 10 km (6 miles) across.

Terrestrial planet interiors. Earth and the other three terrestrial planets have three compositional layers: crust, mantle, and core. In all cases, the crust is relatively thin (tens of kilometers) in comparison to the mantle and core. The four planets are drawn to scale in the image here.

EARTH Without our moon, Earth would wobble on its axis, changing how much solar radiation was received over different parts of its surface, resulting in a much more unstable climate system.

MERCURY Mercury is just a little bigger than Earth's moon and travels around the sun faster than any other planet, at an average speed of 172,000 km/h (107,000 mph).

MARS If Earth were the size of a nickel, Mars would be the size of an aspirin tablet.

VENUS Venus is the hottest planet in the solar system. Its clouds reflect so much sunlight that Venus is the brightest planet in the night sky.

THE SUN Our sun is one of 70,000,000,000,000,000,000,000 stars in the universe. The sun's interaction with Earth drives our ocean currents, weather patterns, and climate.

URANUS Uranus' s axis is tilted at 98 degrees. Its poles are pointed towards the sun. Due to its 84-year long orbit, the planet's poles experience 21 years of night or day depending on their position.

PLUTO The average temperature on icy "dwarf planet" Pluto is -233° C. Sunlight on Pluto is only 0.0001 times as strong as on Earth.

JUPITER Jupiter is named for the king of the Roman gods and makes up two-thirds of all the planetary mass in the solar system.

NEPTUNE Neptune is so far from the sun that it still has not made a complete orbit since it was discovered in 1846.

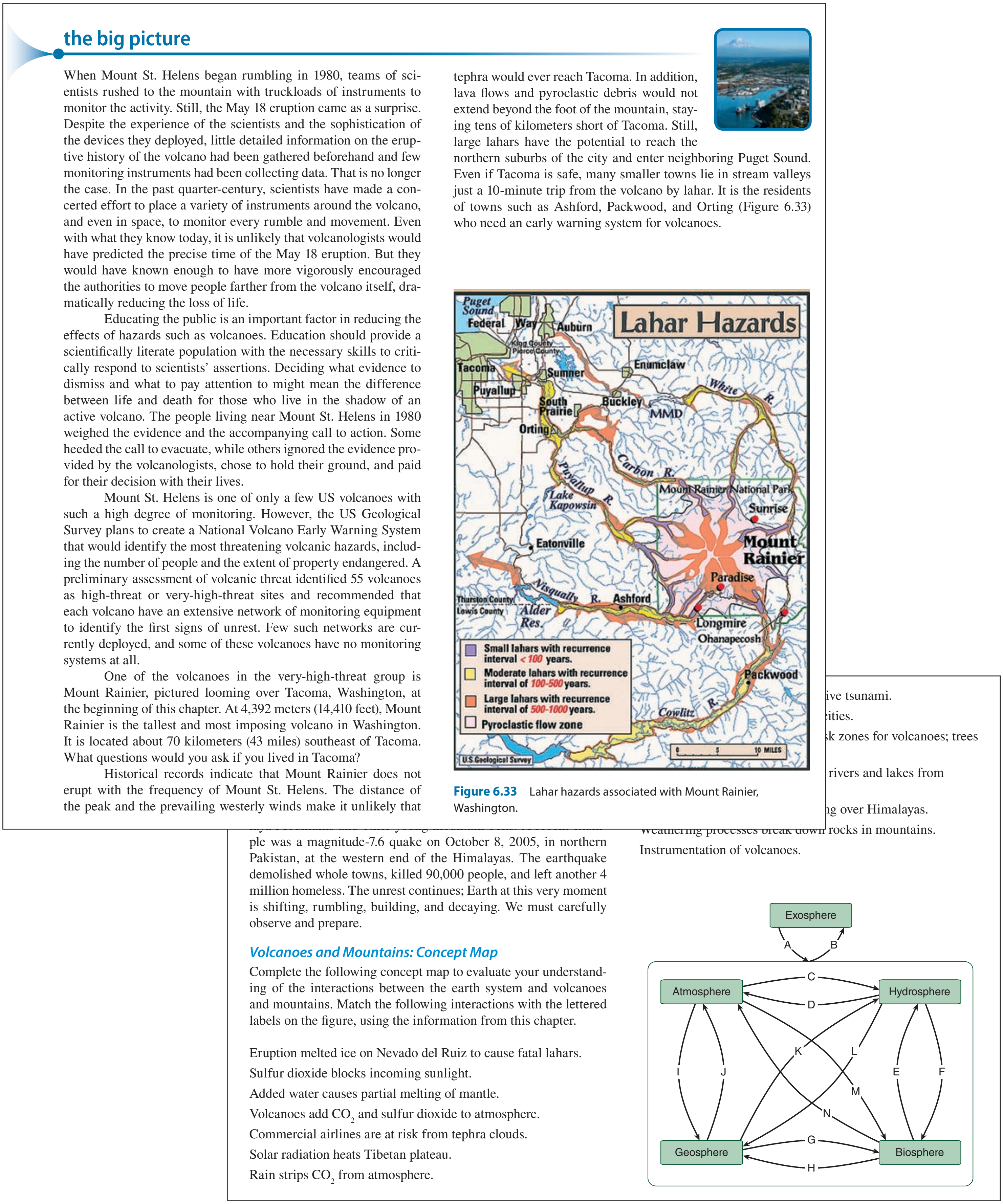
SATURN Saturn's density is less than that of water. Saturn's rings cover a distance nearly equal to the distance from Earth to the moon.

Jovian planet interiors. Jovian planets also have compositional layers. On Saturn and Jupiter, the largest Jovian planets, pressures in the interior of the planet are sufficient to generate rare liquid metallic hydrogen. The relatively smaller Uranus and Neptune are still many times larger than Earth and have a mantle dominated by ices composed of methane, water, and ammonia.

ASTEROID BELT All the asteroids mashed together would make up a body about one-tenth the size of our moon. Asteroids that pass close to Earth are known as near-Earth objects.

Orbits not to scale.
Orbits viewed from an angled-perspective above the orbital plane.

We frequently hear complaints that students don't get the **Big Picture** and become lost in the vocabulary or in trying to memorize facts. We responded to this concern by connecting a chapter-opening "Big Picture" question and photo to the end-of-chapter summary, titled **The Big Picture,** to help students link the key concepts before moving to a new chapter.



the big picture

When Mount St. Helens began rumbling in 1980, teams of scientists rushed to the mountain with truckloads of instruments to monitor the activity. Still, the May 18 eruption came as a surprise. Despite the experience of the scientists and the sophistication of the devices they deployed, little detailed information on the eruptive history of the volcano had been gathered beforehand and few monitoring instruments had been collecting data. That is no longer the case. In the past quarter-century, scientists have made a concerted effort to place a variety of instruments around the volcano, and even in space, to monitor every rumble and movement. Even with what they know today, it is unlikely that volcanologists would have predicted the precise time of the May 18 eruption. But they would have known enough to have more vigorously encouraged the authorities to move people farther from the volcano itself, dramatically reducing the loss of life.

Educating the public is an important factor in reducing the effects of hazards such as volcanoes. Education should provide a scientifically literate population with the necessary skills to critically respond to scientists' assertions. Deciding what evidence to dismiss and what to pay attention to might mean the difference between life and death for those who live in the shadow of an active volcano. The people living near Mount St. Helens in 1980 weighed the evidence and the accompanying call to action. Some heeded the call to evacuate, while others ignored the evidence provided by the volcanologists, chose to hold their ground, and paid for their decision with their lives.

Mount St. Helens is one of only a few US volcanoes with such a high degree of monitoring. However, the US Geological Survey plans to create a National Volcano Early Warning System that would identify the most threatening volcanic hazards, including the number of people and the extent of property endangered. A preliminary assessment of volcanic threat identified 55 volcanoes as high-threat or very-high-threat sites and recommended that each volcano have an extensive network of monitoring equipment to identify the first signs of unrest. Few such networks are currently deployed, and some of these volcanoes have no monitoring systems at all.

One of the volcanoes in the very-high-threat group is Mount Rainier, pictured looming over Tacoma, Washington, at the beginning of this chapter. At 4,392 meters (14,410 feet), Mount Rainier is the tallest and most imposing volcano in Washington. It is located about 70 kilometers (43 miles) southeast of Tacoma. What questions would you ask if you lived in Tacoma?

Historical records indicate that Mount Rainier does not erupt with the frequency of Mount St. Helens. The distance of the peak and the prevailing westerly winds make it unlikely that tephra would ever reach Tacoma. In addition, lava flows and pyroclastic debris would not extend beyond the foot of the mountain, staying tens of kilometers short of Tacoma. Still, large lahars have the potential to reach the northern suburbs of the city and enter neighboring Puget Sound. Even if Tacoma is safe, many smaller towns lie in stream valleys just a 10-minute trip from the volcano by lahar. It is the residents of towns such as Ashford, Packwood, and Orting (Figure 6.33) who need an early warning system for volcanoes.

▨ Small lahars with recurrence interval < 100 years.
🟨 Moderate lahars with recurrence interval of 100-500 years.
🟧 Large lahars with recurrence interval of 500-1000 years.
☐ Pyroclastic flow zone

Figure 6.33 Lahar hazards associated with Mount Rainier, Washington.

ple was a magnitude-7.6 quake on October 8, 2005, in northern Pakistan, at the western end of the Himalayas. The earthquake demolished whole towns, killed 90,000 people, and left another 4 million homeless. The unrest continues; Earth at this very moment is shifting, rumbling, building, and decaying. We must carefully observe and prepare.

Volcanoes and Mountains: Concept Map

Complete the following concept map to evaluate your understanding of the interactions between the earth system and volcanoes and mountains. Match the following interactions with the lettered labels on the figure, using the information from this chapter.

Eruption melted ice on Nevado del Ruiz to cause fatal lahars.
Sulfur dioxide blocks incoming sunlight.
Added water causes partial melting of mantle.
Volcanoes add CO_2 and sulfur dioxide to atmosphere.
Commercial airlines are at risk from tephra clouds.
Solar radiation heats Tibetan plateau.
Rain strips CO_2 from atmosphere.

ive tsunami.
ities.
sk zones for volcanoes; trees

rivers and lakes from

ng over Himalayas.
Weathering processes break down rocks in mountains.
Instrumentation of volcanoes.

Numerous diagrams, photos, and tables support visual processes and concepts.

Figure 6.15 Hawaiian lava. **a.** A lava tube transports hot, fluid, low-viscosity basalt lava toward the front of a lava flow on Kilauea volcano, Hawaii. **b.** Walter's Kalapana Store and Drive-in was burned and buried within a few weeks in 1990 as lava from the Kilauea volcano invaded communities along the southern coast of Hawaii. Note the height of the original sign. How deep is the lava at this location?

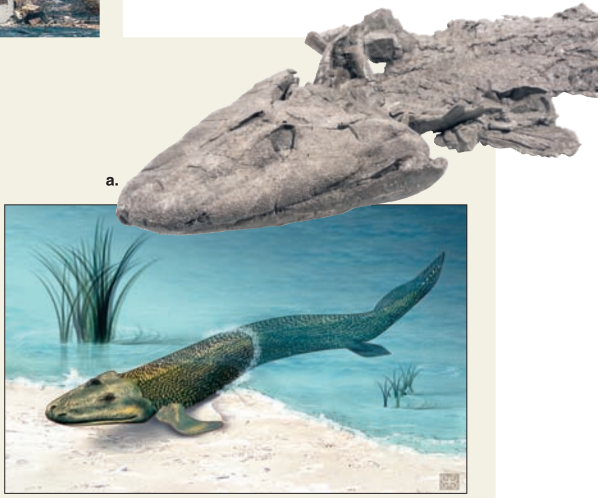
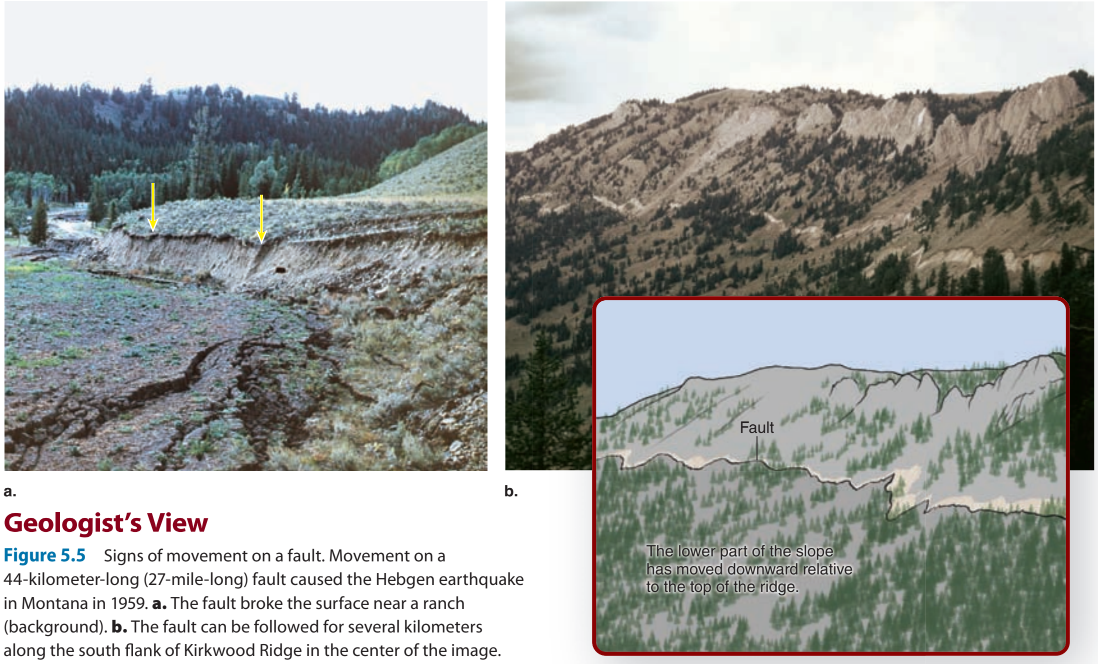


Figure 8.15 Recently discovered Tiktaalik fossil. **a.** This is a transitional fossil between fish and amphibians. The fossil was discovered on Ellesmere Island, Canada, in 375 million-year-old rocks. Several individuals were found, some up to nearly 3 meters (9 feet) long. **b.** A re-creation of what Tiktaalik may have looked like in life.

To further aid in the understanding of earth processes, many figures include a simple drawing to portray a **Geologist's View.**



Geologist's View

Figure 5.5 Signs of movement on a fault. Movement on a 44-kilometer-long (27-mile-long) fault caused the Hebgen earthquake in Montana in 1959. **a.** The fault broke the surface near a ranch (background). **b.** The fault can be followed for several kilometers along the south flank of Kirkwood Ridge in the center of the image.

How Is This Text Organized?

The Good Earth covers the primary topics included in other earth science texts. However, there are a few notable differences in its content compared to other textbooks.

The Good Earth begins with an introduction (Chapter 1), then takes up the topic of astronomy (Chapters 2, 3), and moves on to solid earth (Chapters 4, 5, 6, 7, 8) and the surficial processes (Chapters 9, 10, 11, 12), which overlap with the hydrosphere (Chapters 11, 12, 13), before dealing with the atmosphere (Chapters 14, 15, 16) and finishing with a wrap-up chapter on global change (Chapter 17) that incorporates elements of all the previous chapters.

Astronomy is dealt with early in the text (Chapters 2 and 3) from the context of Earth's position in space. By beginning with Earth's place in the universe, we give students a "big picture," set the context for looking at the uniqueness of this planet in contrast to our neighbors in space, and hopefully, inspire a bit of wonder in the reader. In both chapters, we grab the reader's attention by emphasizing space from a human perspective. We believe this provides a more appealing beginning to an earth science class than the traditional several weeks spent discussing minerals, rocks, and weathering. Chapter 2, in particular, guides students to see methods that scientists employ as they build our knowledge of the planet and its place in the universe.

Plate tectonics appears early (Chapter 4). We introduce this important unifying concept at the beginning of the text and then use it as a foundation to introduce other solid earth topics (for example, earthquakes, volcanoes). Because an understanding of plate tectonics is pivotal to all the content that follows in subsequent chapters, we revisit this concept several times in subsequent chapters, thereby showing students the interrelationships among the other solid earth topics, such as rock formation, earthquakes, and volcanoes.

Driven by recent research findings, we have chosen to emphasize some topics that are discussed briefly or not at all in other earth science texts. We have included chapters on the threat of a collision with near-Earth objects (Chapter 3), Earth's climate system (Chapter 16), and global change (Chapter 17). In addition, the continuing debate about the teaching of creationism in the public schools has lead us to address this topic head-on in our treatment of geologic time (Chapter 8).

New in This Edition

One major change evident throughout the text is the addition of Chapter Learning Outcomes at the beginning of each chapter and the identification of key Learning Objectives at the start of each section in the chapter.

Additional updates to this edition include:

- Figures have been updated and/or replaced throughout the text to better illustrate key concepts and to provide updated data.
- References and discussions to recent significant events have been added:
  - the massive 2010 oil spill in the Gulf of Mexico after the blowout of the Deepwater Horizon drilling platform
  - the major earthquake and tsunami in Japan in 2011
  - east coast damage from superstorm (hurricane) Sandy in 2012
  - the destructive tornado that struck Moore, Oklahoma, in 2013
- Recent data on the human toll and economic costs of recent earthquakes
- Information about the recent sightings of Near Earth Objects
- New discussion on tools used by Earth Scientists
- Rewritten content on extra-solar planets and how planets formed
- A new more detailed account of the rejection of Wegener's drift hypothesis
- Addition of Harry Hess's contribution to the Seafloor Spreading Theory
- Expanded discussion on early earth evolution
- New statistics on weather hazards
- Updated information on recent changes in Arctic Ocean ice coverage
- Updated climate and emissions data
- Increased coverage on the factors affecting density of seawater
- An analogy of a water balloon is used to further explain the concept of Tidal Bulge

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about the authors

The original version of The Good Earth was a product of a team of educators from the geosciences, science education, and cognitive psychology whose combined expertise created this text to teach essential earth science content in an engaging and cognitively supportive way. We wish to thank our colleagues Kathie Owens, Cathy Knight, and Lisa Park to their contributions to the textbook through the first two editions. The writing team has been reduced to the two principal authors for the third edition of the book.

David McConnell grew up in Londonderry, Northern Ireland, and was hooked on geology when he took his first course in high school with an inspirational teacher. His earliest geological exercises involved examining rocks along the rugged coastlines of Ireland. He graduated with a degree in geology from Queen's University, Belfast, before moving to the US to obtain graduate degrees from Oklahoma State and Texas A&M Universities. David spent much of his career at the University of Akron, Ohio, where he met David Steer, beginning a research partnership that eventually resulted in the book you are now holding. David relocated to North Carolina State University to build a geoscience education research group that continues to examine how to improve the student learning experience in large general education science classes.

David has taught a dozen different courses from introductory geoscience classes to advanced graduate courses. He has received several teaching awards, and he and his collaborators and graduate students have made many presentations and published articles on their educational research. When pressed for some personal information, David will tell you that he loves collecting vinyl records, is way too attached to Tottenham Hotspur football club, and enjoys spending weeks each summer hiking trails through a mountain range somewhere.

David Steer was fascinated with rocks as a child in Ohio. That interest was nurtured by his participation in a National Science Foundation–sponsored geology field camp for high school students that took him to the Black Hills of South Dakota. David's plan to become a geologist had to wait when he accepted an appointment to West Point and then served for a decade as an Army Corps of Engineers officer. While in the military, David attended Cornell University, earning a Master's of Engineering degree. He was then assigned to West Point Military Academy, where he taught physics. After leaving the service, David returned to Cornell University to pursue his early geological interests at the Ph.D. level, albeit in the field of geophysics. He began his appointment at the University of Akron in 1999.

Several years ago, David began employing student-centered learning techniques in his large introductory earth science classes. He has extensive experience in using conceptual questions, physical models, and other active learning techniques. His education research, allowing him to identify at-risk students very early in the course so that effective intervention can occur, has produced scholarly publications in the *Journal of Geoscience Education* and numerous national and regional conference presentations. David has been recognized for his extensive research and teaching scholarship at the institutional and national levels. He and David McConnell were recognized together as National Association of Geoscience Teachers Distinguished Speakers and travel the country making presentations about their educational research.

On a more personal note, David frequently experiments with using golf clubs as seismic energy sources and travels the country with his family with a goal of visiting every national park in the continental United States. David brings military discipline to the team and is one of the principal geoscience content writers. David made this comment about his participation: "Writing this text has been both rewarding and humbling. That endeavor constantly reminded me how much I still have to learn about our planet."

Contributing Authors

Catharine Knight originally hails from Minneapolis, Minnesota. Cathy began her career in teaching while a teenager, achieving national recognition in training her Shelties for obedience competition. Cathy has become an expert in effective teaching and learning, and in cognitive support of learning for humans, as well. With a master's degree and clinical certification in speech science and audiology from St. Cloud State University, Cathy brings a facility in the concepts of "hard science" to the science of learning and teaching: pedagogy. Her Ph.D. research in educational psychology and human development at Arizona State University and her research in cognitive development as a postdoctoral National Institutes of Health Research Fellow at the University of Denver began her dedication to making the science of cognitive development accessible, practical, and applicable to teachers and instructors in the real world.

She has devoted more than 25 years to the study of how students learn and develop, and how instructors can effectively teach, given the characteristics of both students and the concepts and content to be learned. This collaboration of earth science and pedagogical science results in a powerful tool to support teaching and learning in fundamentally new and excitingly effective ways.

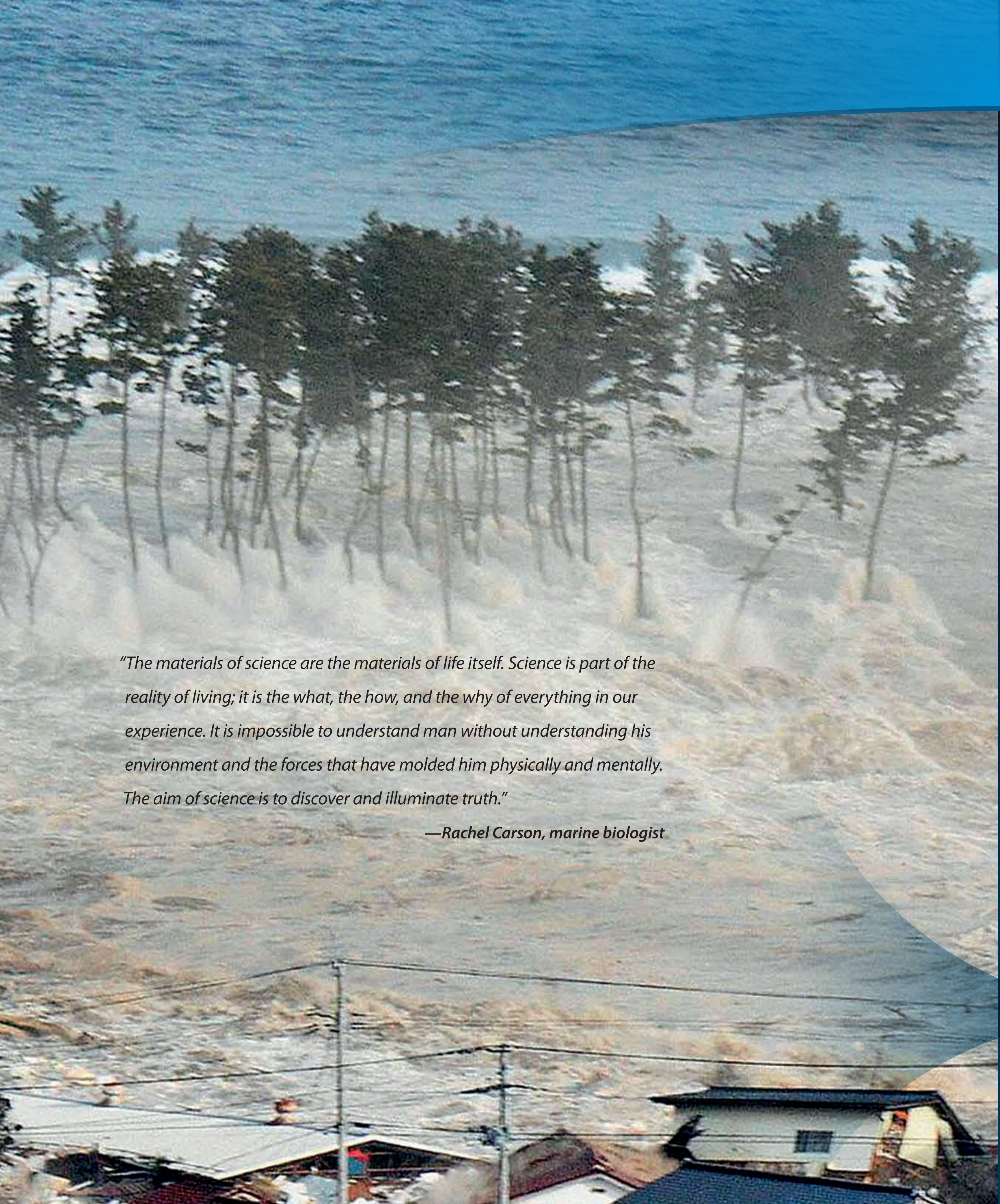
When Cathy can grab some spare time from teaching, research, and writing, she kicks back with her Shelties or her cello, or best of all, on a Caribbean cruise ship where the only "requirement" is to do nothing!

Katharine Owens or Kathie, as she's called informally, is the other education member of the team. Kathie says that being a member of *The Good Earth* writing team is one of the highlights of her long career in education. Kathie started out teaching mathematics in junior high and, after getting her master's degree in science education at Texas A&M University where she learned a lot of geology, quickly found another love—teaching science in middle schools both in New York State and in Mississippi (Ed.D., University of Southern Mississippi). She reports that her interest in science began when she watched the *Apollo 8* astronauts circle the moon and greet everyone on "the good Earth" from their vantage point millions of miles away. When she was chosen as a Mississippi finalist in the Teacher in Space program and later as a Christa McAuliffe Fellow, she knew that for the rest of her teaching career, earth science would dominate. Currently, Kathie focuses on teacher education in science at the University of Akron, where she teaches methods courses to future teachers and develops science and technology lessons for the Akron Global Polymer Academy.

Kathie is convinced that how a subject is taught is equally as important as what is taught and that, if the instructor's methods make the content dull and boring or the students are not challenged to think through the content, much is lost. When she's away from her teaching job and education projects, she's traveling around the United States to add to her rock collection, tending her garden, playing with her grandchildren, or whipping up some goodies in the kitchen.

The Good Earth

Although we have long understood Earth's position in space, the unique nature of our planet was not fully appreciated until we were able to look at our home from some distance. The astronauts aboard the *Apollo 8* spacecraft were the first people to travel to the moon and were the first to glimpse our home planet from distant space. This view of Earth, commonly known as "Earthrise," was one of the most well-known images of the twentieth century. The photograph was taken by astronaut William Anders during *Apollo 8's* fourth orbit of the moon on Christmas Eve 1968. (The original image was actually rotated so that the moon's surface was near-vertical and to the right of Earth.) A few hours after snapping the photograph, the Apollo crew read the first 10 verses of the book of Genesis during a broadcast to Earth. At the end of the reading, Commander Frank Borman closed communications with ". . . Merry Christmas, and God bless all of you, all of you on the good Earth." For many at home, those early views of the planet from the inky darkness of space illustrated the unique wonders of the fragile environment we share on spaceship Earth.



> *"The materials of science are the materials of life itself. Science is part of the reality of living; it is the what, the how, and the why of everything in our experience. It is impossible to understand man without understanding his environment and the forces that have molded him physically and mentally. The aim of science is to discover and illuminate truth."*
>
> ***—Rachel Carson, marine biologist***

Chapter 1

Introduction to Earth Science

Chapter Outline

the big picture

Tsunami coming onshore following the Tohoku earthquake, Japan, 2011.

See The Big Picture at the end of this chapter for the full story on this image.

1.1 Earth Science and the Earth System

Chapter Learning Outcomes

- Students will evaluate claims in a science-based argument.
- Students will describe the relationships among science, society, and government.
- Students will recognize that Earth is a complex system of interacting rock, water, air, and life.

The fourth-largest earthquake ever recorded buckled the seafloor east of Japan, at 2.46 P.M. on March 11, 2011. Within seconds the tremor was registered on the dense array of instruments, and alerts were issued to millions of citizens throughout the nation. Residents experienced severe shaking within a couple of minutes. Soon a tsunami warning was issued for coastal locations, giving people about 15 minutes to make it to safety. As earthquake-damaged structures blocked streets, people fled on foot, seeking higher ground. Katherine Heasley, an American teaching high school English in the harbor city of Kamaishi, didn't have classes that day. The long-lasting shaking alerted her to the need to move to a safer location. This is how she described what happened next:

> *An official-looking man was at the head of the column, directing us up the steep road to a recreation center. . . From the parking lot, I could see the estuary, the port and the long spit of land ending in a pier that separated the two. The first thing that concerned me was that the river was running very rapidly out to sea. Usually, even during low tide, the river was sluggish where it met the bay. The second thing that concerned me was that it wasn't the only thing running fast. Many of the larger fishing boats were absolutely speeding out of the harbor.*
>
> *Perhaps fifteen minutes after we got to the rec center, the tide turned. Kamaishi has a very sheltered bay, with the deepest breakwater in the world. The tsunami couldn't come in as the classic white-topped wave. But nothing could stop that much water. The water began flowing back, reversing the river's flow. It rose faster than I'd have thought possible. Soon, the pier was swamped. Those of us at the rec center watched helplessly as the water picked up an entire parking lot of cars on the pier and threw them into a building. And the water kept coming. It rose over the marina where the small fishing boats were kept. Then it swamped the area under the highway. Then it flowed into the parking lot of the keisatsu, or the main police station, just down the street from my apartment. And it kept. On. Coming. It threw the police cars into the keisatsu building. It began to hit houses, and the noise was indescribable as it lifted them off their foundations. It flowed across the highway and started rising up the hill we'd come up. There was a deafening crash as, across the bay, the derrick they used to load ships with Nippon Steel products was knocked down. Think about that: A derrick that regularly lifted tons of steel was no match for the tsunami. The water had turned into some kind of malevolent beast. Some days later, I thought about the Japanese Godzilla mythos, how a creature rises from the depths of the sea and destroys whole cities on land. I can't help but think I now know where that comes from in the collective unconscious of the Japanese people. They depend on the sea; they came across it to find their land, and many make their living off it. But once in a while, the sea comes to take back from the land. When that happens, there is nothing anyone can do except run. The tsunami broke down seawalls and ignored breakwaters. Nothing could stop it. Nothing.*

Much of what happened in Japan was eerily similar to what had occurred just seven years earlier in southeast Asia (Figure 1.1). The third-largest earthquake ever recorded buckled the seafloor

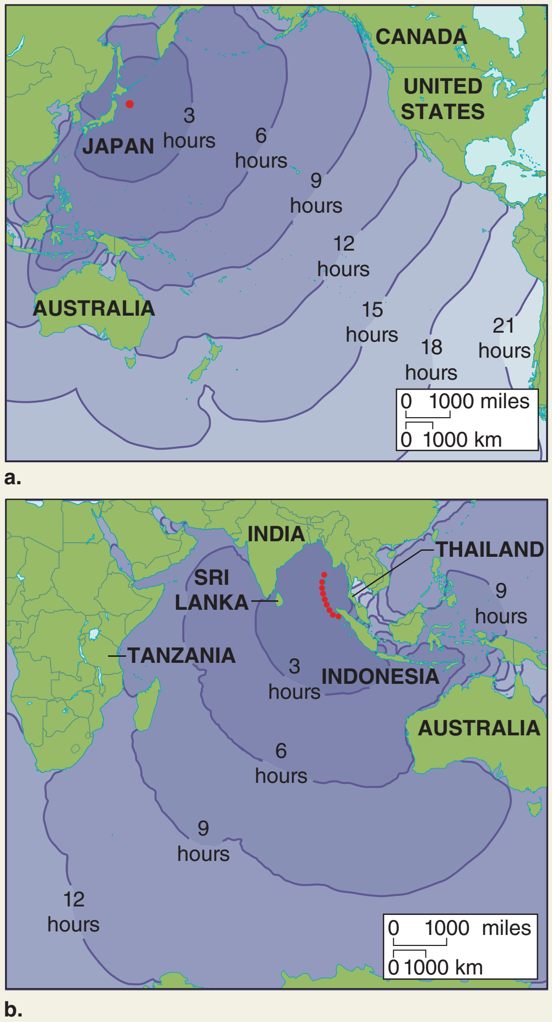


Figure 1.1 Travel times for recent tsunami. **a.** Time taken for 2011 tsunami to travel to locations along the margins of the Pacific Ocean. **b.** Time taken for 2004 tsunami to travel to locations along the margins of the Indian Ocean.

west of Sumatra, Indonesia, at 7:58 A.M. on the day after Christmas 2004. Hundreds of miles away, just before 10 A.M., Penny Smith saw her 10-year-old daughter, Tilly, staring at the sea off Mai Kao beach on the north end of Phuket Island, Thailand. The Smiths were enjoying a warm-weather vacation away from the cold, damp English winter. Tilly noticed that instead of the steady rhythm of breaking waves, the water was flowing down the beach—moving out to sea and not coming back in again. As the beach grew in size, everyone stood to watch, wondering just what strange natural phenomenon they were observing. Tilly knew. She remembered a recent school lesson about tsunami, a series of fast-moving, potentially dangerous ocean waves. Soon Tilly was yelling at her parents to get off the beach.

Meanwhile, about 30 kilometers (16 miles) south, Rick Von Feldt was passing the popular Patong beach in a taxi on his way to his hotel. He noticed people staring out to sea and wondered what they were looking at. A whale? Maybe some dolphins? He too noticed that the water had receded. Soon he was standing on an outdoor balcony of his hotel with a commanding view of the beach below and the bay beyond. He could see boats grounded on the beach and people milling about as if they were not quite sure what to do. This is how he described what happened next on his blog:

> *Suddenly—in front of our eyes—the bay begin(s) to fill. Rapidly. As if someone had turned on giant faucets—and it just seemed to rush in. In about 10–15 minutes this entire HUGE bay filled in. And then we saw the swell. It was perplexing—because the day was nice and sunny—and we could not figure out—or actually believe what was happening in front of our lives. But it did. The swell came—and we saw it rushing over the wall. And it kept risin(g)—and went higher than the palm trees along the edge. Local people started to cry—for they knew what it meant. We all stood there, stunned. People came running up the road—shrieking. "Water—the water" they were crying. The water receded slightly—and then, again with a vengeance. Rushed forward—rose again—and the 18 feet wall rolled over the front of the beach—the shops and everything in its path. We stood there in disbelief—not understanding WHY—but realizing that one of the most awful things that could happen—just had. But it wasn't over. It just keep coming and coming. It would recede—and then come again—rushing over the seawall.*

In both examples, images of the tsunami's destruction were soon being broadcast around the globe. The world looked on in horror as images of whole towns were wiped off the land (Figure 1.2). Piles of debris could be traced around the rim of the Indian Ocean or up and down the east coast of Japan. Before 2004, few would have anticipated the potential for tsunami linked to massive earthquakes as only three of these mega-earthquakes had ever been recorded worldwide. These types of destructive tsunami are so unusual in the modern era that earth science textbooks written 20 years ago would have briefly mentioned tsunami as part of the chapter on earthquakes, but here we are leading off the book comparing and contrasting two recent dramatic examples. As you can see from the first-hand descriptions above, there were similarities to the way the tsunami came on land, sweeping up all before them. However, there were also contrasts in the consequences of these events, mainly as a result of the awareness of the local populations and the warning systems that were in place.

Even though the earthquakes were of almost the same magnitude, the Japanese Tohoku earthquake resulted in about one-tenth of the casualties of the Indian Ocean earthquake. More than 230,000 people were missing or dead following the Indian Ocean tsunami; in contrast the death toll from the Japanese event

Figure 1.2 Destruction in Banda Aceh, Sumatra, Indonesia, from the Indian Ocean tsunami. The shoreline has been heavily eroded, and buildings have been almost completely destroyed.

Table 1.1 **Human Toll and Economic Costs of Selected Recent Earthquakes**

Date	Earthquake Location	Earthquake Magnitude	Deaths	Displaced	Economic Losses ($ Billions)
February 22, 2011	Christchurch, New Zealand	6.3	185	70,000	12
March 11, 2011	Tohoku, Japan	9.0	20,896	131,000	300
February 27, 2010	Maule, Chile	8.8	525	1,500,000	15–30
January 12, 2010	Haiti	7.0	316,000	1,300,000	7–14
September 30, 2009	Sumatra, Indonesia	7.5	1,117	451,000	2.3
May 12, 2008	Sichuan, China	7.9	87,587	>5,000,000	86
October 8, 2005	Kashmir, Pakistan	7.6	86,000	2,500,000	5
December 26, 2004	Sumatra, Indonesia	9.1	230,000	1,700,000	4.5
January 16, 1995	Kobe, Japan	6.9	5,502	31,000	200
January 17, 1994	Northridge, California	6.7	72	22,000	20

was closer to 21,000 (Table 1.1). Much of this can be ascribed to the extensive earthquake and tsunami warning systems that are in place in Japan. In contrast, in 2004 there was no tsunami early warning system in the Indian Ocean. The lack of effective communication systems in poor regions meant that thousands were killed along the coasts of India and Sri Lanka several hours after waves had already obliterated coastal towns in Indonesia. Economic losses were estimated to be more than 20 times higher in Japan than in Indonesia, largely as a consequence of the much more developed and industrialized Japanese coastline. The 2011 earthquake and tsunami produced the costliest natural disaster in history (~$300 billion). The resulting damage shut down industries for weeks, leading to a global slowdown in automobile manufacturing. The tsunami flooded the Fukushima nuclear power plant, resulting in both a meltdown in three of its six nuclear reactors and the release of dangerous radioactive gases. The disaster put a serious dent in the prospect of a nuclear-powered future as governments in many nations started backing away from plans for building new power plants. This destruction occurred in a country that is better prepared to deal with earthquakes than any nation on the planet. Much of the Japanese coastline is protected by 10-meter-high (33-foot-high) seawalls, specifically to protect against tsunami. Unfortunately, the seawalls were designed to protect against waves produced by earthquakes of smaller magnitude, the type and size that happen quite frequently along the coast of Japan.

Are you smarter than a fifth-grader such as Tilly Smith? What type of natural disaster are you most likely to experience in your lifetime? Are you ready? Will you, like Tilly, know what to do? How much responsibility do individuals have to protect themselves? How many resources should be devoted to trying to predict these events? What type of information should government agencies collect to protect their citizens from such hazards? How can this information be quickly communicated to those at risk? If we are to successfully answer these questions, we must understand the science of how Earth works and how to effectively integrate scientific findings with the needs of society. Scientists collect data on natural phenomena such as tsunami, but it is often politicians (and, indirectly, the people who elect them) who determine what actions should be taken to protect the public.

Your Introduction to Earth Science

In the remainder of this chapter, we will define *science* and describe how it is done by trained people doing basic research using an array of skills. These scientists ask questions and analyze data; some create maps or collect fossils, while others use sophisticated technologies to search for oil and gas, track ocean currents, or measure changes in the chemistry of Earth's atmosphere. We will explain the principles that scientists use to conduct investigations that weave together data collected from experiments and observations of the natural world. We will discuss the principal roles of the earth sciences in our lives, from finding ways to protect us from natural hazards to investigating the implications of climate changes for the future of humanity.

We finish the chapter by introducing the concept of global change and humans' impact on Earth. Global change is an idea that is currently generating research in a wide variety of disciplines relating to all components of the earth system, including geology, ecology, oceanography, and climatology. This work involves thousands of scientists across the globe and has implications for the

✓ Checkpoint 1.1

✓ basic ✓ advanced
✓ intermediate ✓ superior

Good questions often produce answers that lead to yet more questions. Review the following statement and suggest some related questions that could clarify or expand the topic.

Students who work together in groups often learn more than students in the same class who work alone.

Self-Reflection Survey: Section 1.1

Respond to the following questions as a means of uncovering what you already know about Earth and earth science.

1. Which of the following earth science phenomena have you experienced? Which would you most like to experience? Can you think of three more things to add to the list?
    - A volcanic eruption
    - A glacier
    - A river in flood
    - A cave system
    - An underground mine
    - A canyon
    - An earthquake
    - An erosional coastline (rocky cliffs)
    - A depositional coastline (beaches)
    - A hot desert
    - A continental divide
    - Rock layers with fossils
    - A big, assembled dinosaur skeleton
    - A meteor shower or comet
    - The aurora borealis (the northern lights)
    - A meteorite crater
    - A mountain range over 3,000 meters (over 10,000 feet) in elevation
    - The top of a cloud
2. What three questions about Earth would you like to be able to answer by the end of this course?

long-term quality of life for you and your families and is likely to require challenging social decisions within your lifetime. Future economic, cultural, and political choices in all the world's nations will depend on the rate and degree of change. We will follow the theme of global change through many of the chapters of *The Good Earth* and use it to show the links among the components of the earth system. As you will see, there is little that happens on Earth that doesn't involve multiple earth system components.

1.2 The Scope of (Earth) Science

Learning Objectives

- Describe the principal earth system components.
- Write a one-sentence definition of the term *science*.
- Identify examples of the tools that scientists use to learn about Earth.

Earth System Basics

In *The Good Earth*, we introduce you to the study of earth science. Earth is a complex system of interacting rock, water, air, and life where the components and interactions cycle energy and mass throughout the system. *Earth science* can be broadly defined as the investigation of interactions among the four parts of the earth system— the atmosphere (air, weather), hydrosphere (water, ice), biosphere (plants, animals), and geosphere (land, rocks) (Figure 1.3).

Figure 1.3 The four components of the earth system: atmosphere, hydrosphere, biosphere, and geosphere. All components interact with the solar radiation and other elements from space. How many components are featured in each image?

Together, these components form an elegant support system for life. In addition, the sun and assorted features from space, collectively termed the *exosphere*, interact with the earth system and are sometimes considered a fifth earth system component. The historic 2011 tsunami involved three of the components— the hydrosphere (ocean), geosphere (seafloor earthquake), and biosphere (people, plants, animals; Figure 1.4). Throughout this book, we will examine the characteristics of each of the components through the lens of human experience. We will look at how the earth system affects us over a wide range of timescales and how we, in turn, affect different earth system components. We will also be interested in how these components interact with one another and how changes in one component influence processes in the others. Representatives of the earth science community spent some time considering the essential principles or big ideas that everyone should appreciate about the earth system. They ended up with nine "big ideas" that can be divided into a series of secondary concepts. The big ideas were as follows:

- Earth is a complex system of interacting rock, water, air, and life.
- Earth scientists use repeatable observations and testable ideas to understand and explain our planet.
- Earth is 4.6 billion years old.
- Earth is continuously changing.
- Earth is the water planet.
- Life evolves on a dynamic Earth and continuously modifies Earth.
- Humans depend on Earth for resources.
- Natural hazards pose risks to humans.
- Humans significantly alter Earth.

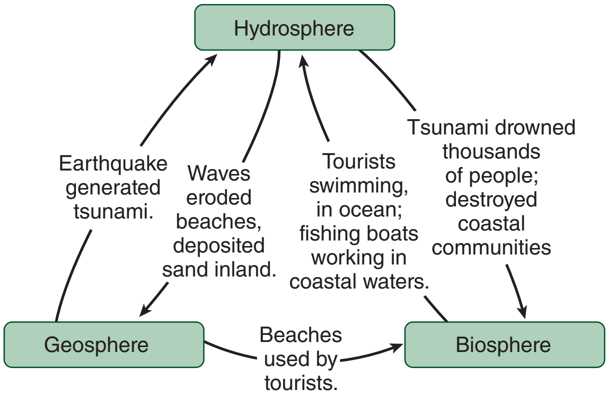


Figure 1.4 Interaction of earth system components involved in the tsunami described in this section. This diagram is a concept map. It includes key terms (in this case, three earth system components) and arrows that describe the interactions between the terms.

✓ Checkpoint 1.2

✓ basic ✓ advanced
✓ intermediate ✓ superior

Make a list of the multiple ways that you interact with each of the four components of the earth system.

We already introduced you to the first idea at the start of this section, and we discuss the second item on the list in the rest of this chapter. The remainder of the points will be discussed in several chapters throughout the book. Take a few moments after you read each chapter to reflect on how many of these big ideas were represented in the material you just read.

Science and Discovery

The second word in the term *earth science* is just as important to us as the first. Much of what you learn in college about science will happen in this and perhaps one other course. Therefore, we want you to have a firm understanding of what science is—and what it is not. Science is not a list of facts to be memorized that have no relevance to your life. Just ask Tilly Smith's parents. The only way to understand how to think like a scientist is to learn to use the skills of scientific reasoning. So in this chapter, and throughout the book, we will give you lots of examples to show that science is a process, a way of thinking about the natural world.

Why do we care what you think about science? The United States is a world leader in scientific research and development. Government and corporate science programs flourish because of substantial investment in innovation and the discovery of new ideas. Even though survey results show that Americans are supportive of scientific research, most people have only a shaky grasp of underlying scientific principles. The National Science Foundation has conducted surveys that reveal that less than one-third of the adult population can define what it means to study something scientifically. Even if you do not make a career in science, it is important that you understand how to use scientific reasoning skills to make wise decisions as an informed citizen to help solve daily problems.

Science is a process of discovery that increases our body of knowledge. Earth science is like all sciences; some of it is known and can be learned, and much of it is still waiting to be discovered. But science has another less tangible but equally important element—the innate curiosity of the scientists as they search for answers. Increasingly, individual citizens have the opportunity to become involved in a variety of scientific research projects that are too large to complete without the participation of a large number of talented amateur scientists. These projects can involve thousands of observations made by citizens over a limited time interval. They may involve volunteers with little or no training in collecting data or citizen researchers working with scientists in an online community. Examples of some of these projects follow. Which would you most like to be involved with?

- *Stardust*: Volunteers help scientists find a handful of interstellar dust particles brought to Earth by the *Stardust* spacecraft and hiding among a million online images.
- IceWatchUSA: This project by the Nature Abounds organization seeks to compile local climate records by making seasonal observations of ice conditions on water bodies.

- World Water Monitoring Day: Tens of thousands of people in more than 40 nations use simple sample kits to collect information on the characteristics of local streams and lakes. Data are then entered into an online database to be compared with results from subsequent years.
- Project Budburst: This project seeks to track the timing of the leafing and flowering of native vegetation around North America.
- FeederWatch: This data set yields information on the changes in native and alien species of birds using backyard bird feeders and can serve as a proxy indicator of environmental change.
- Weather observers: Eleven thousand volunteers in the National Weather Service's cooperative observer program collect daily temperature and precipitation readings to aid in weather forecasting and to help measure long-term climate change.
- Did You Feel It?: This US Geological Survey (USGS) online program uses reports from people who feel earthquakes and graphs the data to create Community Internet Intensity Maps. For example, a recent 5.8 magnitude earthquake in Virginia generated more nearly 150,000 citizen reports from people in states up and down the east coast.

Earth scientists combine their basic knowledge of facts and concepts with technical skills to explore Earth and solve its mysteries. It is tempting to view science as a list of facts to be memorized and repeated. But the real essence of science is a detective story in which teams of investigators piece together evidence to generate well-founded explanations of the workings of our planet. Scientists constantly refine or challenge these explanations, causing some to be discarded while others gain wide acceptance. Our imaginations and the physical laws of nature present the only limits to science. Throughout this book, we will strive to give you an inside look at how science is done and to initiate you in the process of discovery. Whenever possible, we will feature real-life situations and pose questions that place you in the role of the scientist.

Tools Used by Earth Scientists

Earth scientists use direct measurements, indirect information, and models to better understand Earth. Direct measurements are collected at field locations by scientists or trained technicians (Figure 1.5). For example, they might determine the type of rocks present (see Chapter 7) to create a geologic map, collect water samples from drinking water wells (see Chapter 12), or gather samples of gases erupting from volcanoes (see Chapter 6). Samples are carefully analyzed and cataloged with information about their original location, the conditions under which they were obtained, and any other data that could affect understanding of the importance of that sample. In these cases, the scientist is directly measuring exactly what she is interested in measuring. The actual measurements may be obtained in the field or in a laboratory.

Figure 1.5 This instrument consists of numerous bottles that are submerged to collect water samples from the ocean.

However, it is often not practical to measure some phenomena directly. In these cases, scientists use indirect measurements. Essentially, they measure something that they can then interpret to get a value for something else. For example, scientists cannot readily examine the features below the world's oceans, but they have been able to use a variety of methods to identify different properties of the rocks of the ocean floor. Measurements of the magnetic patterns of the ocean floor were used to determine that the age of the oceanic crust varied from place to place (see Chapter 4). Satellites measure variations in the height of the ocean surface which is related to the distribution of ridges and trenches on the ocean floor (see Chapter 13). Satellites can also make direct measurements of large regions that would be impossible to map on the surface. For example, scientists have used satellite measurements of Arctic sea ice coverage to show a steady decline over the last few decades (see Chapter 16).

Checkpoint 1.3

✓ basic ✓ advanced
✓ intermediate ✓ superior

Three of the big ideas listed near the start of this section detail the interaction of humans and the earth system: (1) Humans depend on Earth for resources; (2) natural hazards pose risks to humans; and (3) humans significantly alter Earth. Take a few minutes and write what you can in support of each of these statements. Consider revising your responses as you progress through the semester to see if you can add more items and/or more information.