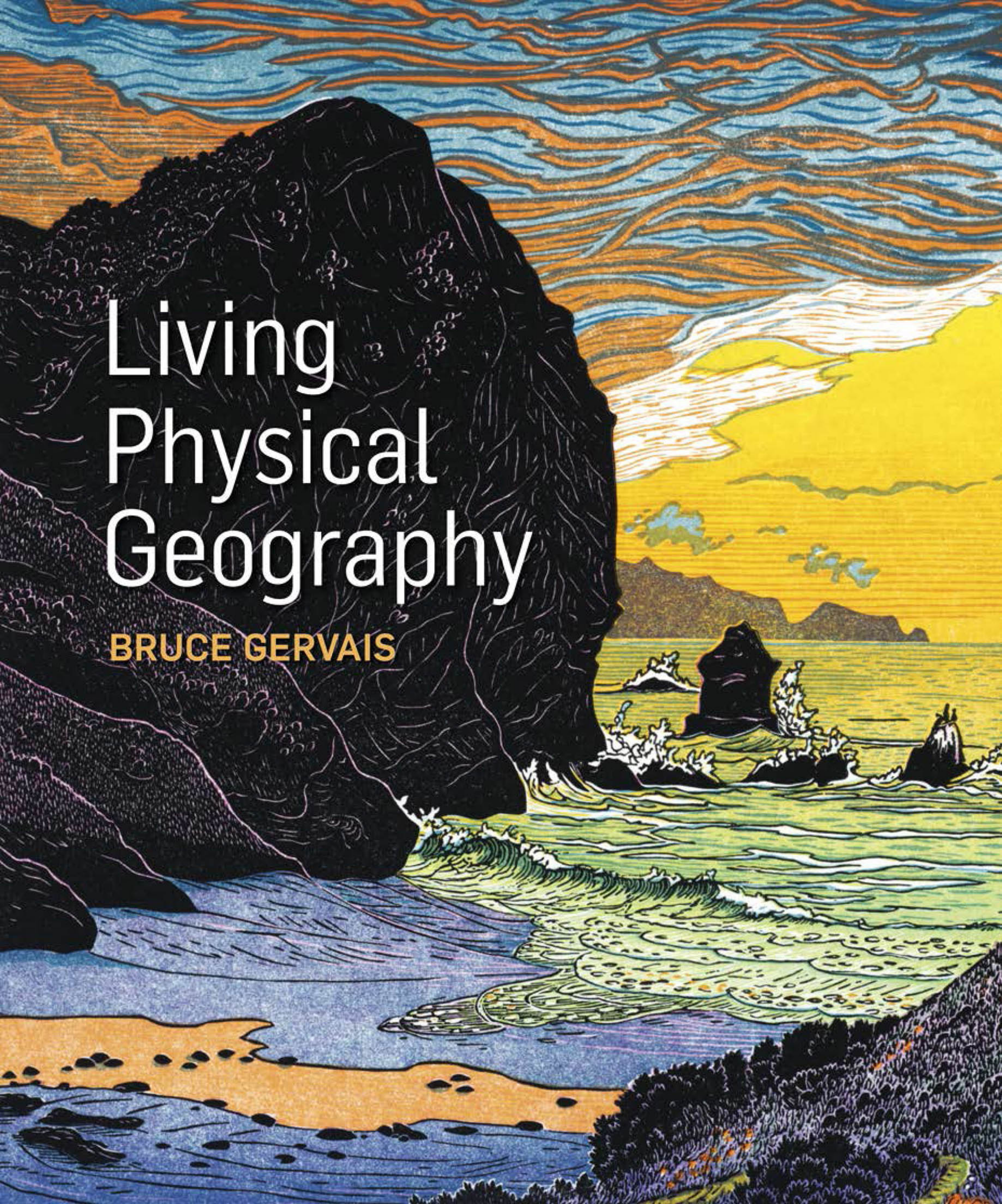
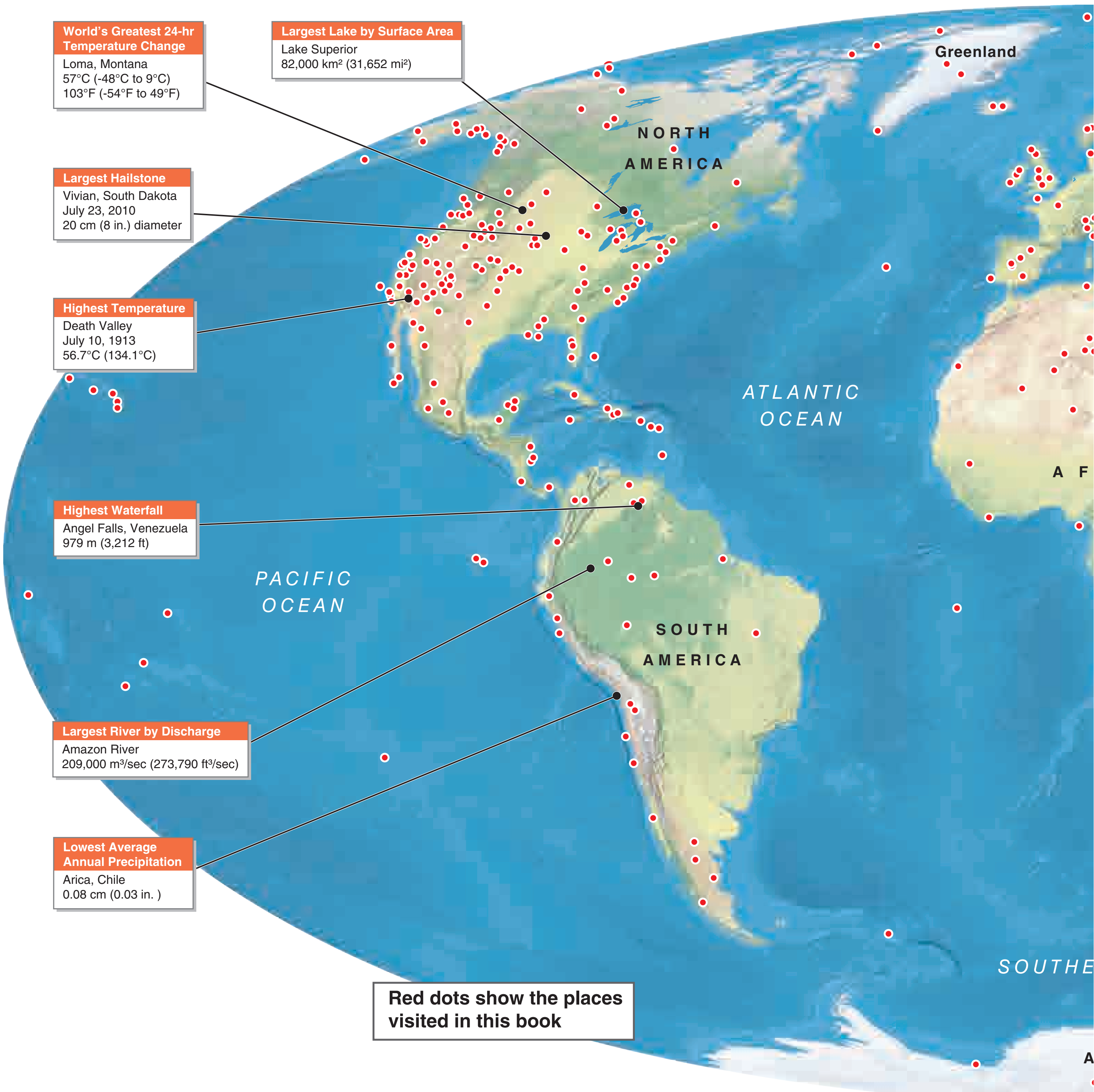
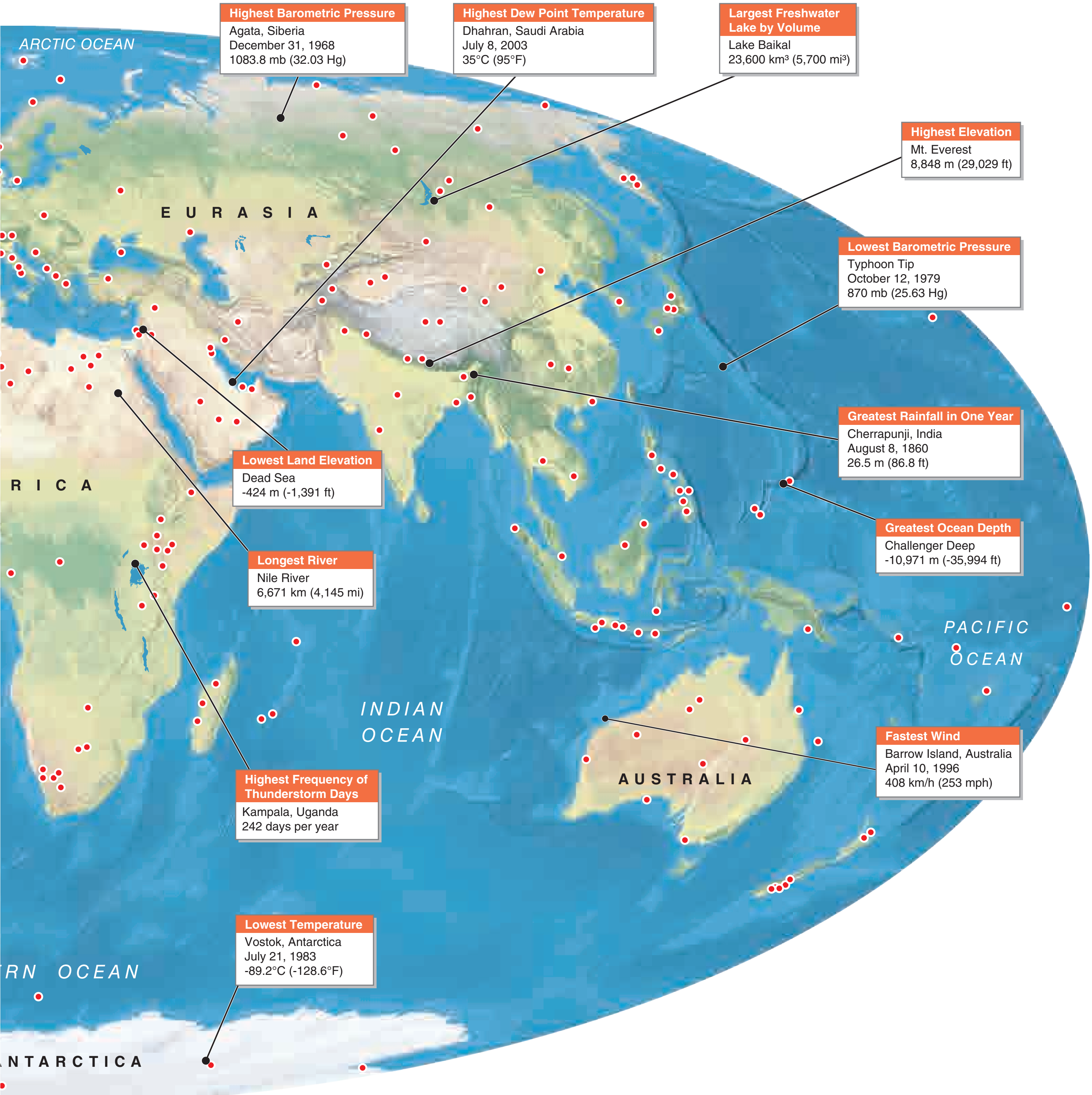
Living Physical Geography

BRUCE GERVAIS



WORLD PHYSICAL MAP





Highest Barometric Pressure
Agata, Siberia
December 31, 1968
1083.8 mb (32.03 Hg)
Highest Dew Point Temperature
Dhahran, Saudi Arabia
July 8, 2003
35°C (95°F)
Largest Freshwater Lake by Volume
Lake Baikal
23,600 km³ (5,700 mi³)
Highest Elevation
Mt. Everest
8,848 m (29,029 ft)
Lowest Barometric Pressure
Typhoon Tip
October 12, 1979
870 mb (25.63 Hg)
Greatest Rainfall in One Year
Cherrapunji, India
August 8, 1860
26.5 m (86.8 ft)
Greatest Ocean Depth
Challenger Deep
-10,971 m (-35,994 ft)
Lowest Land Elevation
Dead Sea
-424 m (-1,391 ft)
Longest River
Nile River
6,671 km (4,145 mi)
Highest Frequency of Thunderstorm Days
Kampala, Uganda
242 days per year
Fastest Wind
Barrow Island, Australia
April 10, 1996
408 km/h (253 mph)
Lowest Temperature
Vostok, Antarctica
July 21, 1983
-89.2°C (-128.6°F)
ARCTIC OCEAN
E U R A S I A
R I C A
INDIAN OCEAN
PACIFIC OCEAN
AUSTRALIA
RN OCEAN
NTARCTICA

Living Physical Geography

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For Nancy, Katherine, and Natalie

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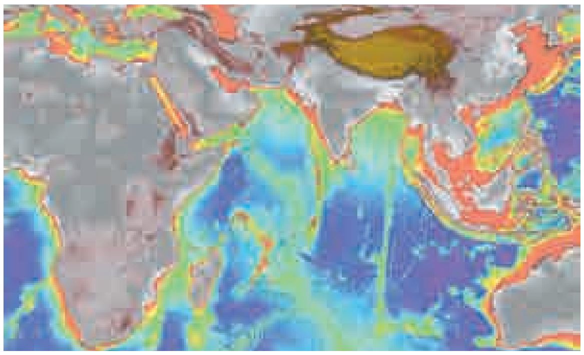

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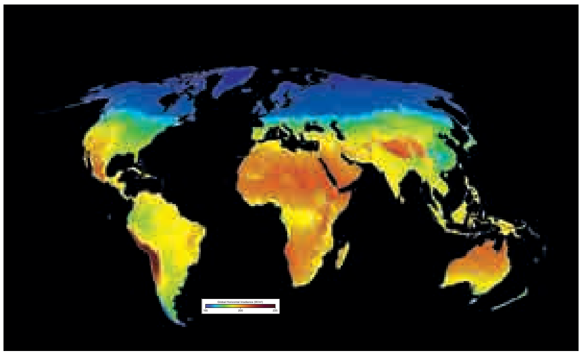

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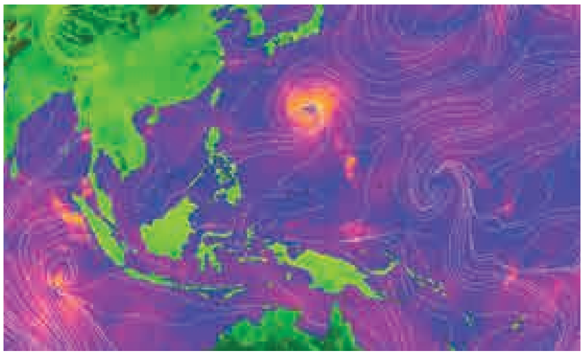
(NASA/JPL)


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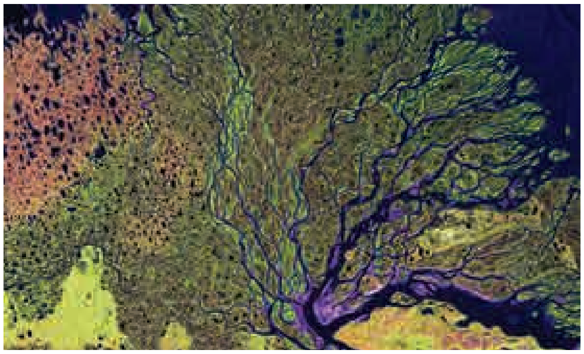

(EROS Center, U.S. Geological Survey)

(© Dr. Juerg Alean/Science Source)

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Preface

Living Physical Geography: The Big Picture

We are all living physical geography. Weather and climate strongly influence where we live and the types of crops farmers can grow. Almost half the world's population lives within 150 km (93 mi) of the coast, mostly in large cities situated in bays and estuaries at the mouths of major rivers. Floods and drought, cold snaps and heat waves, volcanic eruptions and earthquakes, soil development and landslides all influence human beings. Physical geography is now more relevant to society than ever. Changes in air quality and climate, losses of habitat and species, soil and water resource demands, and burgeoning renewable energy technologies are all topics that are in the news daily and are all central to the science of physical geography.

The idea for this book originated with my desire to highlight the relevance of physical geography to students' daily lives and to address the most pressing environmental and resource issues that people face today. *Living Physical Geography* is unique in that it emphasizes how people change, and are changed by, Earth's physical systems. This approach creates a student-friendly context in which to understand Earth systems science and reveals the connections between Earth and people.

Three major themes are woven throughout this book:

1. **Earth is composed of interacting physical systems.** The atmosphere, the biosphere, water, and Earth's crust are major physical systems that interact with and affect one another. Energy from the Sun and energy from Earth's interior change these systems.

2. **Earth is always changing.** The physical Earth is in a constant state of change on many different time scales. The weather changes within minutes, tides ebb and flow over hours, rivers shift their channels across centuries, and over millions of years species evolve, mountains grow and are worn down, and whole continents move.

3. **The influence of people is important.** Earth's land surface, atmosphere, life, and oceans are extensively changed by people. It is not possible to study modern physical geography without considering the influences of human activity.

There are other important themes that also provide the foundation for and enliven the study of physical geography in this book:

Spatial and temporal relationships underpin geographic thinking. Geographers often ask why things occur where they do and how they change through time. For example, why do deserts and rainforests occur where they do? How long have they been in their present locations? How are they changing now? *Living Physical Geography* examines Earth's physical features and processes through the lens of geographic space and time.

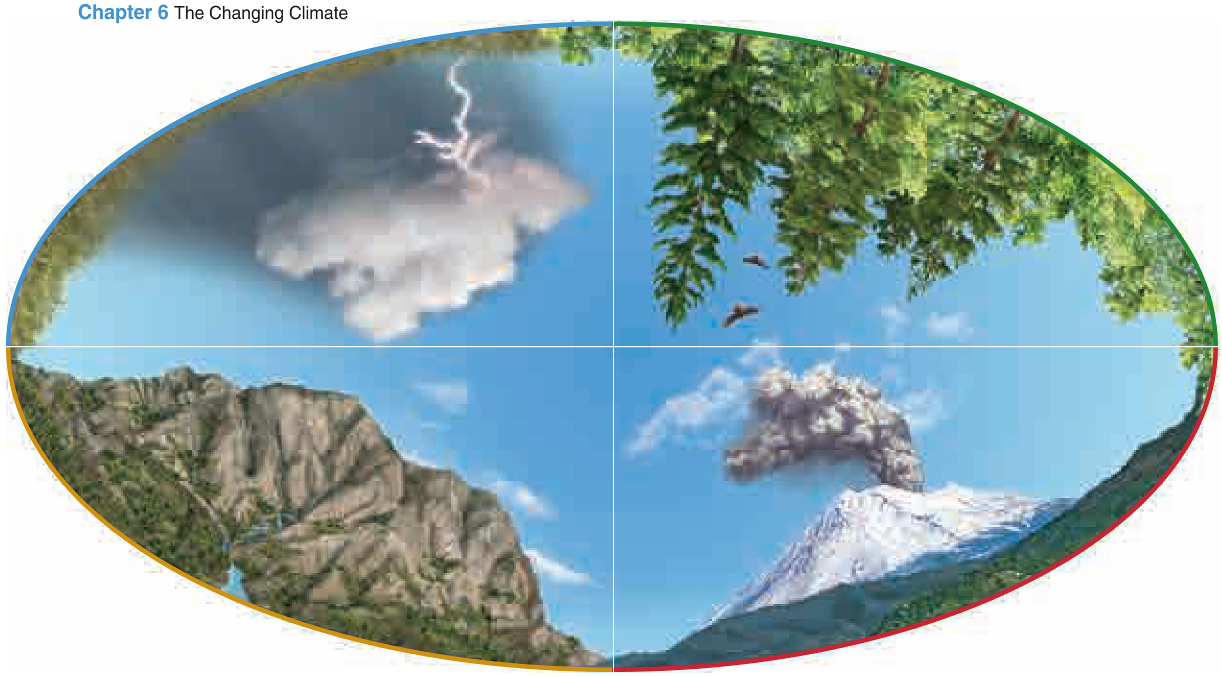
People depend on Earth's natural resources. From the energy we use, to the materials in the things we acquire, to the food we eat, people depend on natural resources from Earth's physical systems.

People are influenced by physical geography. Volcanic eruptions and earthquakes, the development of rich agricultural soils with river flooding, severe weather and climate change, storm protection of coastal cities by wetlands, freshwater supplies from groundwater and streams are a few examples of physical phenomena that influence the lives of people.

Science is driven by people. Scientific inquiry in the Earth sciences is driven by a fundamental curiosity about how the natural world works.

The Structure of *Living Physical Geography*

Living Physical Geography is divided into four main parts, focusing on the atmosphere, the biosphere, the building up of the lithosphere, and the wearing down of the lithosphere. Each part focuses on the flow and work of energy. Solar energy drives processes in the atmosphere, in the biosphere, and in the wearing down of the lithosphere. Earth's internal heat energy drives processes that build the lithosphere. Figure GT.11 (found on page 12), reprinted here, illustrates the book's organization.



Part I: Atmospheric Systems: Weather and Climate

All meteorological phenomena are powered by the Sun. For example, wind is solar powered because it derives its energy from the unequal heating of Earth's surface by the Sun. Similarly, rainfall is the result of evaporation of water from the oceans by the Sun.

Part II: The Biosphere and the Geography of Life

Solar energy fuels the biosphere. Life on Earth obtains its energy from the Sun (with the exception of the organisms around some hydrothermal vents on land and in the deep ocean). Plants convert solar energy to chemical energy. When plants are eaten, their chemical energy flows into the organism consuming them.

Part III: Tectonic Systems: Building the Lithosphere

Earth's internal heat energy (geothermal energy) lifts, buckles, and breaks the crust. Earth's internal heat also creates new rocks and moves the plates of the lithosphere, forming mountains, valleys, volcanoes, and ocean basins.

Part IV: Erosion and Deposition: Sculpting Earth's Surface

Solar energy sculpts the lifted crust. Sunlight evaporates water into the atmosphere. That water subsequently falls to the ground as precipitation, then returns to the oceans through flowing streams and flowing glaciers. These streams and glaciers erode the crust, reducing its height and smoothing it.

Living Physical Geography features discussion of the hydrosphere throughout the text as it naturally occurs rather than treating it as a separate entity. For example, water runs through and influences nearly all of Earth's physical systems, including the atmosphere, ecosystems and biomes, fluvial and glacial systems, and the crust's groundwater. Additionally, *Living Physical Geography* devotes an entire chapter to the oceans by examining their physical structure and the geographic patterns of life found in them.

The contents of this book follow a logical sequence, but each instructor approaches the discipline in a different way and may present topics in a different order. For this reason, each chapter is largely self-contained and makes cross-references to key information in other chapters only when needed.

Living Physical Geography: Innovations

Living Physical Geography was written to help instructors teach physical geography more effectively. In addition to emphasizing the interactions between physical geography and people, *Living Physical Geography* offers the following structural innovations:

- Humidity is covered before atmospheric pressure and wind. The release of heat energy through condensation drives many atmospheric phenomena and the winds they produce. The wind generated by hurricanes, for example, is the result of condensation of water vapor into liquid water in the atmosphere. To understand why a hurricane's winds are so strong, it is necessary to first understand the role of water vapor's latent heat. In this book, atmospheric weather systems are arranged by their spatial scales, from localized mountain breezes to the continent-wide Asian monsoon.
- Köppen climate types are covered alongside biomes. In most physical geography textbooks, Köppen climate types and biomes are covered in

two separate chapters. *Living Physical Geography* avoids this redundancy by combining these two compatible topics. In doing so, it establishes the natural link between climate and biomes and illustrates the interconnections of physical geography.

- The theory of plate tectonics undergirds all of Part III. Plate tectonics is covered before the topics of mountain building and rock formation, along with geohazards like earthquakes and eruptions, because all these geophysical phenomena are best contextualized within the paradigm of plate tectonics.
- Chapter 6, "The Changing Climate," is devoted to a scientific examination of climate change. Climate change is perhaps the fastest-moving topic in physical geography. The material presented in this book represents the most up-to-date examples, scientific research, and data on climate. Most students are deeply interested in climate change, and this chapter helps them to understand the current scientific consensus on this important topic and develop independent conclusions based on scientific data.
- Four chapters are devoted to the biosphere. The geography of the biosphere, including life in the oceans, receives extended coverage in *Living Physical Geography*. The theme of how people have changed the biosphere runs throughout Part II, "The Biosphere and the Geography of Life."
- A full chapter is devoted to the geography of life in the oceans. The physical and biological oceans are highly relevant to physical geography. Recent exploration and discoveries have improved scientific understanding of marine life, but scientists still know relatively little about the oceans. Chapter 10, "The Living Hydrosphere: Ocean Ecosystems," reflects recent advances in scientific knowledge of marine ecosystems and an awareness of the most pressing marine environmental issues.

Living Physical Geography Is Written for a Variety of Ways Students Learn

Living Physical Geography is written to engage students and hold their interest, especially those with little background in the Earth sciences. It uses a variety of learning tools to accommodate the different ways that students learn.

The art program and photography support the written text. Many figures illustrate processes in a step-by-step sequence. Basic geographic concepts, such as geographic scale and physical systems, are repeatedly developed throughout the book, reinforcing for students the major themes in physical geography.

Living Physical Geography Is an Integrated Textbook/Media Learning Solution

Living Physical Geography is an integrated learning system that combines a textbook with digital media to enhance the teaching and learning of physical geography. The following media components are part of this integrated system:

Exploring with Google Earth

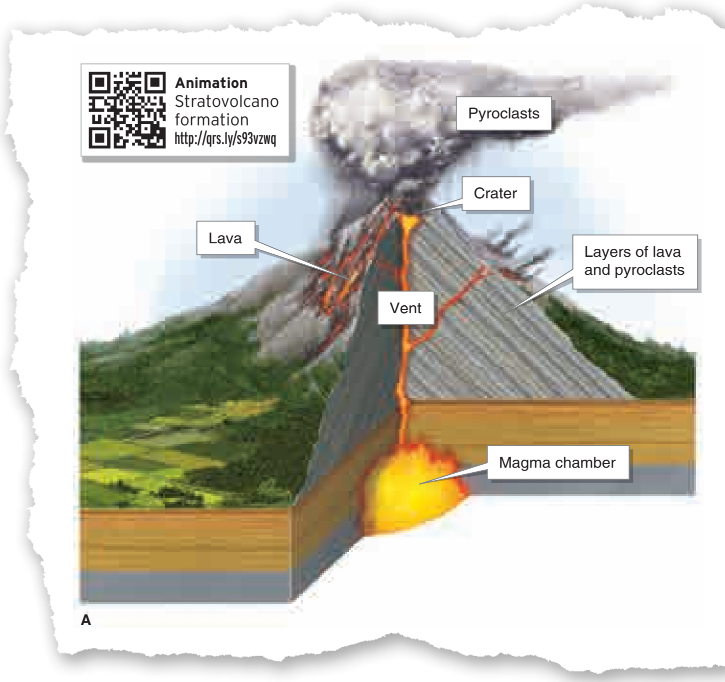
Google Earth is an important pedagogical tool in *Living Physical Geography*. An "Exploring with Google Earth" activity appears at the end of each chapter. The .kml files required to complete these activities are available on LaunchPad.

Students benefit from using Google Earth because it familiarizes them with the spatial relationships of physical and cultural features of Earth, vividly illustrating the spatial perspective that is essential to geography. Using these exercises, students will be able to quickly navigate to and interpret physical phenomena such as Mount Fuji, the Grand Canyon, the fjords of Greenland, the sand seas of Algeria, and the glaciers of New Zealand. (Answers to the Exploring with Google Earth questions are available in the Instructor's Manual.)

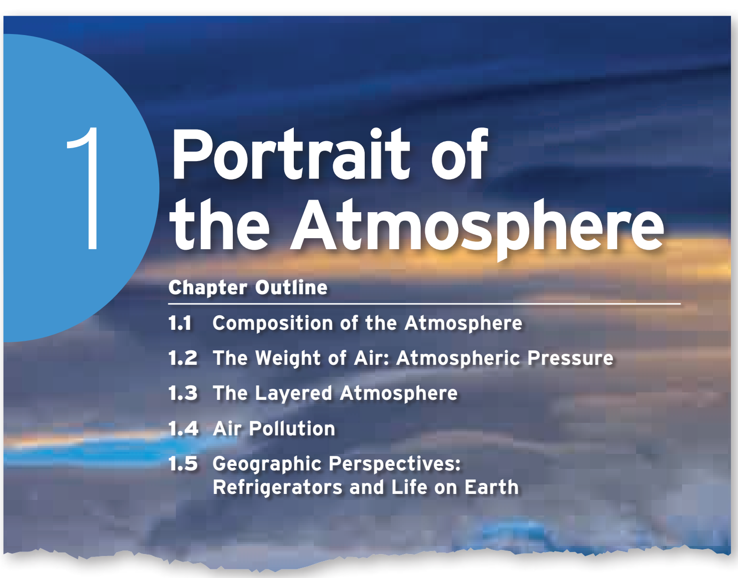
Animations and Videos

Animations are available for key figures throughout the book. The animations show the movement and development of select physical geography phenomena. For example, the formation of a stratovolcano as it grows by adding layers of ash and lava flows is animated to enhance student learning of this process.

These animations are accessible through LaunchPad, where they are accompanied by questions that assess students' understanding of the concepts. The animations are also available for immediate access with a smartphone using QR (Quick Response) codes that appear next to the relevant figures.



A library of short videos is also available. This collection is designed to support and further develop selected topics in each chapter. Select videos are conveniently accessible through QR codes in each chapter. The complete collection is also available, along with assessment questions, on LaunchPad.



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Learning Tools

The learning tools in *Living Physical Geography* have been carefully designed to provide a multimedia, multimodal approach to the teaching and learning of physical geography.

Chapter Opener with Chapter Outline

Each chapter begins with a two-page image or photo that relates to the contents of the chapter. Each image is briefly described, and reference to the appropriate section within the chapter is provided to stimulate students to seek further information about the image. A brief chapter outline allows the reader to preview the chapter's contents.

"Living Physical Geography" Questions

The chapter opener also includes a set of "Living Physical Geography" questions. This feature is designed to stimulate interest in the chapter material by asking questions that students may already have. Each question is repeated at the place in the chapter where students will find the answer. Brief versions of the answers to each question are provided at the end of the chapter.

LIVING PHYSICAL GEOGRAPHY

- What causes seasons?
- Does it snow in Hawai'i?
- Why are the sky blue and grass green?
- Why does the wind blow?

The Big Picture

At the beginning of each chapter, a brief description in a color band orients students to the chapter's main themes in one or two sentences.

THE BIG PICTURE *Earth's hot interior and its moving crust create volcanoes and earthquakes. These phenomena shape the surface of the crust and present hazards for people.*

Learning Goals

At the start of each chapter, a list of learning goals is provided. Each numbered section of the chapter begins with a repetition of the relevant learning goal. These learning goals break each chapter down into manageable units while helping instructors focus on the learning outcomes that are important to them.

LEARNING GOALS *After reading this chapter, you will be able to:*

- **2.1** Explain what causes seasons and give the major characteristics of the four seasons.
- **2.2** Understand the difference between temperature and heat.
- **2.3** Describe Earth's surface temperature patterns and explain what causes them.
- **2.4** Describe solar energy and its different wavelengths.
- **2.5** Explain Earth's energy budget and why the atmosphere circulates.
- **2.6** Assess the role of sunlight as a clean energy source.

The Human Sphere

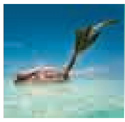
Each chapter opens with a section titled "The Human Sphere." This opening story briefly explores the relationship between people and a physical phenomenon or process. The key goals of this feature are to illustrate the importance of people to physical geography and to demonstrate the relevance of physical geography to students' daily lives. Some examples of the Human Sphere topics include air pollution in Wyoming, Asian dust storms, EF5 tornadoes, non-native species, tsunamis, weathering on Mount Rushmore, and collecting mammoth remains from thawing permafrost.

THE HUMAN SPHERE: Exotic Invaders

FIGURE 7.1 **A Nile perch.** *The non-native Nile perch has inflicted serious ecological damage in Lake Victoria. It preys on the lake's native cichlid fish and has driven about 300 cichlid species to extinction or near-extinction. Nile perch grow to nearly 2 m (6.5 ft) and can weigh 200 kg (440 lb).* (© Walter Astrada/AFP/Getty Images)

NON-NATIVE (or *exotic*) organisms are those that have been moved outside their original geographic range by people. **Some non-native organisms cause ecological damage by preying on or taking resources in their new ranges from native organisms (those that were there originally).** In many areas where non-natives are successful, their natural predators are missing. For example, the Nile perch (*Lates niloticus*) **(Figure 7.1)**, which was intentionally brought into Lake Victoria in eastern Africa in the 1950s as a food resource for local communities, has had significant negative effects on native fish species in the lake.

Today, non-native species are implicated in extinctions worldwide. About 50,000 non-native species have been introduced into the United States (although not all of them are harmful). Among the U.S. states, Hawai'i has a particularly serious problem with non-native organisms. Hawai'i has no native reptiles (such as snakes and lizards), no native amphibians (such as frogs), no native parrots, no native ants, and only one native mammal—a bat. Today, Hawai'i has many non-native organisms introduced by people, including escaped garden plants, wild pigs, piranhas, game, bass, trout, chickens, rats,



GEOGRAPHIC PERSPECTIVES

7.6 Journey of the Coconut

Assess the relationship between people and the coconut palm and apply that knowledge to other organisms used by people.

Geographic Perspectives

Each chapter concludes with a section titled "Geographic Perspectives." These sections are mini-case studies that show students how to think like geographers. Some topics explored in the Geographic Perspectives sections are renewable wind and solar energy, the functional value of plant dispersal, strategies to address climate change, the pros and cons of fracking for natural gas, the pros and cons of dams on rivers, the consequences of rising sea level, and the importance of soils. Geographic Perspectives encourage critical thought and assessment in four ways:

1. By providing context for and developing a broader understanding of the material presented in the chapter
2. By illustrating the connections among seemingly disparate topics within a chapter and across chapters
3. By providing instructors with self-contained, manageable units that they can use to facilitate their teaching and stimulate classroom discussion
4. By presenting a balanced view of contemporary environmental issues to encourage critical discussion, reflection, and independent conclusions

Scientific Inquiry

Each chapter has a feature titled "Scientific Inquiry" that reveals why scientists do what they do, how they assess what they know, and how they collect and interpret scientific data. The goal of this feature is to dispel the percep-

FIGURE 7.4 **SCIENTIFIC INQUIRY: How do scientists track animal movement?** *Different animals require different means of tracking. GPS is important in many, but not all, tracking methods. (Butterfly, © Will & Deni McIntyre/Photo Researchers/Getty Images; fish, Eric Orbesen/NOAA Fisheries; goose, © FLPA/Mark Newman/age fotostock; wolf, Oregon Dept. of Fish & Wildife.)*

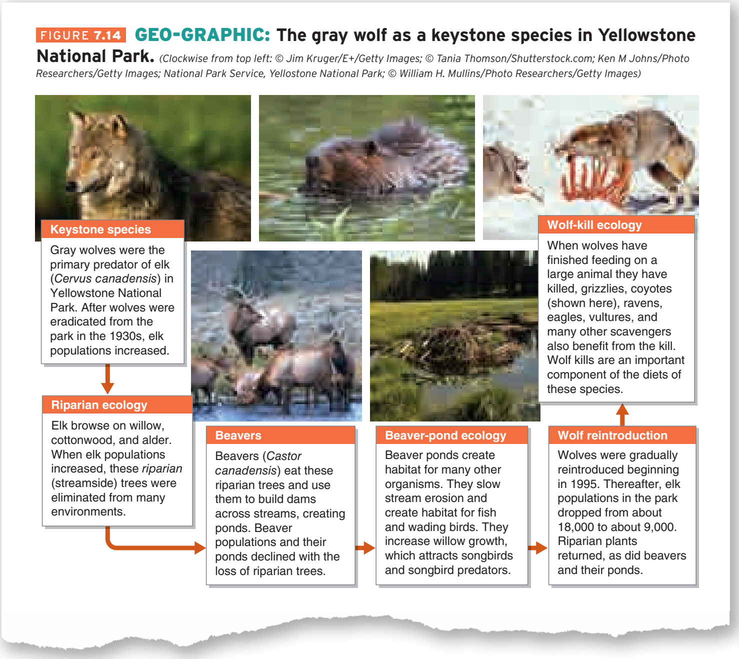


FIGURE 7.14 **GEO-GRAPHIC: The gray wolf as a keystone species in Yellowstone National Park.** *(Clockwise from top left: © Jim Kruger/E+/Getty Images; © Tania Thomson/Shutterstock.com; Ken M Johns/Photo Researchers/Getty Images; National Park Service, Yellowstone National Park; © William H. Mullins/Photo Researchers/Getty Images)*

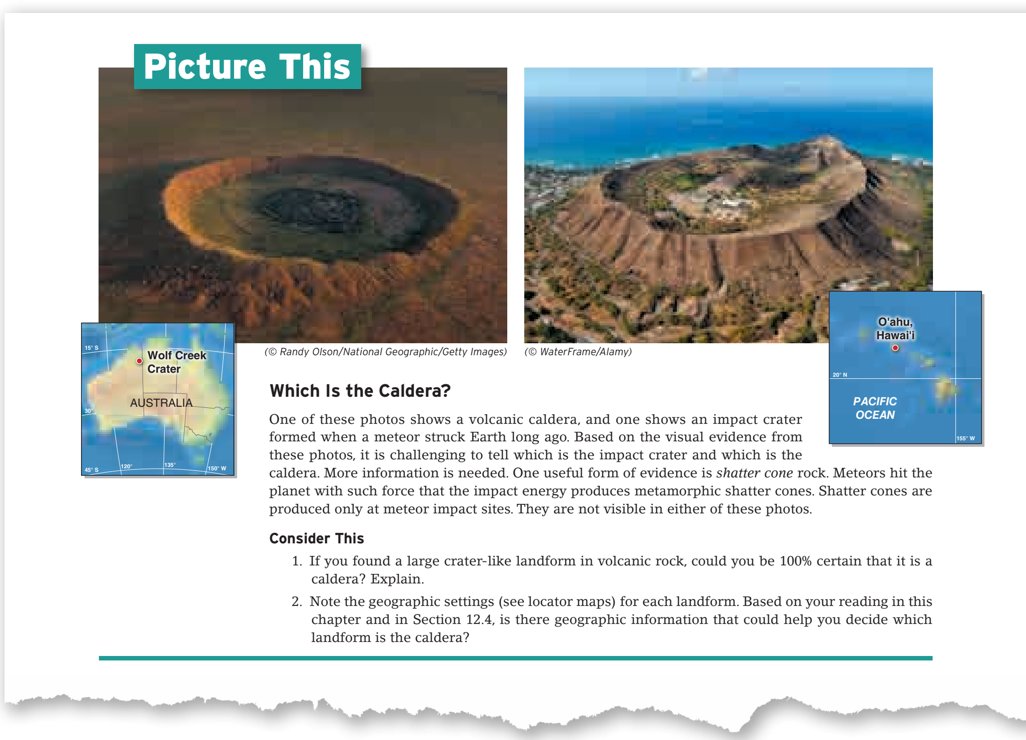
tion of science as something disconnected from students' daily lives or career options. Topics range from how stream gauges work and why they are important, to how data are collected from marine buoys and weather balloons to forecast hurricane threats, to how data are collected from ice cores for research into ancient atmospheric chemistry.

Geo-Graphics

The Geo-Graphic feature is a pedagogical tool that combines imagery with narrative. Geo-Graphics develop the text narrative without repeating information from the main text. A key goal of this feature is to provide an image-based avenue of learning for students who learn visually. Clear labels guide students through each Geo-Graphic in a logical sequence.

Picture This

In each chapter, the Picture This feature delivers pertinent and intriguing content that supplements the main text and illustrates a relevant principle. The wettest place on Earth, extreme climate events, coal mining, and collapse sinkholes are examples of topics visited in this feature. Each Picture This includes two or three Consider This questions that students can answer by reading supporting text within the feature or the text just preceding it. (Answers to the Consider This questions are available in the Instructor's Manual.)



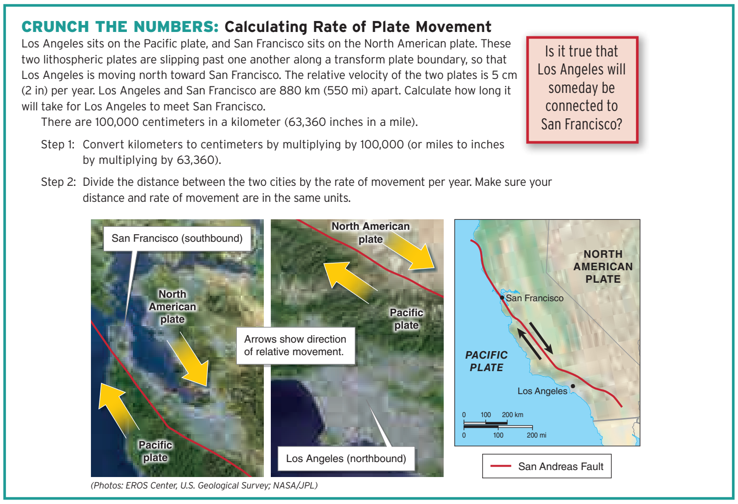
(© Randy Olson/National Geographic/Getty Images) (© WaterFrame/Alamy)

Which Is the Caldera?

One of these photos shows a volcanic caldera, and one shows an impact crater formed when a meteor struck Earth long ago. Based on the visual evidence from these photos, it is challenging to tell which is the impact crater and which is the caldera. More information is needed. One useful form of evidence is *shatter cone* rock. Meteors hit the planet with such force that the impact energy produces metamorphic shatter cones. Shatter cones are produced only at meteor impact sites. They are not visible in either of these photos.

Consider This

1. If you found a large crater-like landform in volcanic rock, could you be 100% certain that it is a caldera? Explain.
2. Note the geographic settings (see locator maps) for each landform. Based on your reading in this chapter and in Section 12.4, is there geographic information that could help you decide which landform is the caldera?



Crunch the Numbers

A feature titled "Crunch the Numbers" appears in each chapter at an appropriate point. These short quantitative reasoning exercises ask students to think about how the science of physical geography can be expressed in numbers as well as in words. (Answers to the Crunch the Numbers exercises are available in the Instructor's Manual.)

Key Information in Blue

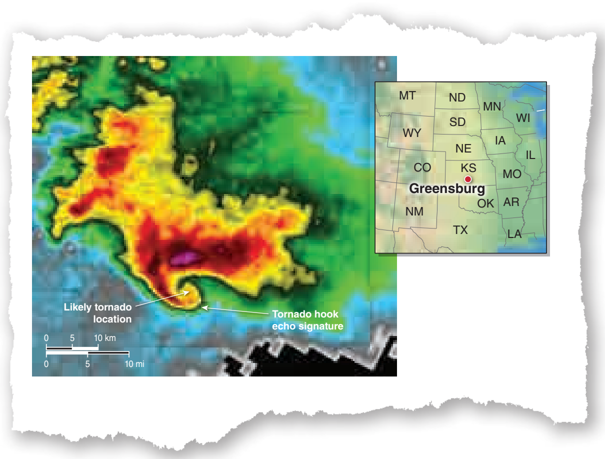
Within each chapter, sentences with key information are emphasized in blue. Collectively, these highlights provide a snapshot of the most essential ideas in the chapter.

Chapter Study Guide

Each chapter concludes with a comprehensive study guide. Included are an Exploring with Google Earth question set, Focus Points that summarize the chapter text, a Key Terms list with page references, Concept Review questions, Critical-Thinking questions, a 10-question Test Yourself quiz, a visual Picture This: Your Turn exercise, a brief Further Reading list, and the answers to the "Living Physical Geography" questions (from the chapter opener). Answers to the study guide questions are provided in the Instructor's Manual.

Locator Maps and Places Visited Index

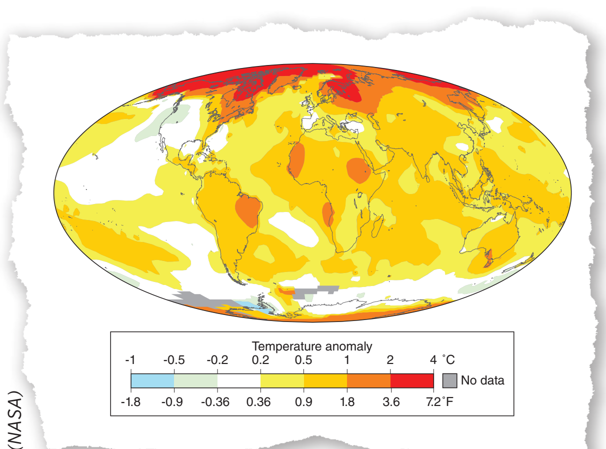
All photos whose subjects are located in real geographic space are accompanied by a locator map. The purpose of these locator maps is to emphasize and familiarize students with the locations and spatial relationships of places visited in the book. All places visited are listed in the Places Visited Index at the back of the book. The locations of the places visited are also shown on the world map on the inside front cover.



(National Weather Service, Dodge City, KS)

Consistent Use of the Mollweide Map Projection

The Mollweide map projection is used for most world maps in the text. This projection was chosen because it is an equal-area projection that preserves the true relative sizes of the continents. This quality is necessary so that the geographic extent of mapped features, such as regions of atmospheric warming or types of vegetation, can be meaningfully compared across different geographic regions. A consistent map projection fosters a more accurate understanding of spatial dimensions and relationships and greater geographic literacy.



(NASA)

LaunchPad: Resources for Students and Instructors

www.macmillanhighered.com/launchpad/gervais1e

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e-Book. A complete e-Book is provided within LaunchPad. The e-Book offers powerful study tools for students and easily customizable features for instructors. Embedded resources within the e-Book include animations, videos, and Exploring with Google Earth Activities.

Animations and Videos. Each animation and video (see page xx) is accompanied by a multiple-choice assessment quiz. Results are reported directly to the instructor's gradebook.

Exploring with Google Earth Activities and .kml Files. These activities are online versions of the "Exploring with Google Earth" activities found at the end of each chapter. Here, students can access the .kml files required to complete these activities. Instructors can assign these activities online; results are reported directly to the instructor's gradebook. A tour of select figures in the text is also provided for more in-depth learning of the featured location.

For Instructors

The following resources are available exclusively to instructors on LaunchPad:

Test Bank and **Instructor's Manual**, by Bruce Gervais. The test bank contains approximately 2,500 multiple-choice and true or false questions. Each question is tied to the chapter's learning objectives. The Instructor's Manual includes teaching tips for each chapter, along with the answers or solutions to all the exercises found in the textbook. The author's intimate familiarity with the text material maximizes the effectiveness of the Test Bank's questions and provides useful insight for teaching tips in the Instructor's Manual.

PowerPoint Classroom Presentations, by Nicole C. James. A ready-made PowerPoint presentation is available for each chapter in the textbook. These presentations concisely summarize the key concepts in the chapters.

Textbook Image PowerPoint Presentations. All images from each chapter are provided in PowerPoint format for easy customization.

Textbook Photos and Images. All images and photos from the textbook are available as high-quality electronic files.

Living Physical Geography in the Laboratory: Lab Manual to Accompany *Living Physical Geography*

Theodore Erski, McHenry County College

For schools that offer a physical geography laboratory, *Living Physical Geography in the Laboratory* is the ideal lab manual to accompany *Living Physical Geography*. The manual contains 30 lab activities, each broken down into four problem-solving modules, thus permitting lab instructors to customize the manual to fit the amount of time they have for their lab period. Each lab activity contains the following:

- Recommended textbook reading before the laboratory activities
- Goals of the laboratory activities
- Key terms and concepts (from the textbook)
- Equipment required. Recognizing that many labs do not have access to expensive equipment, the manual focuses on activities that require only the most basic tools or equipment. Some problem-solving activities require more sophisticated equipment. Those activities are clearly separated into discrete modules so that instructors can skip them if the necessary equipment is not available.
- Four problem-solving modules
- Summary of key terms and concepts for each lab

The activities in *Living Physical Geography in the Laboratory* require critical thinking, map and image analysis, data analysis, and occasionally math.

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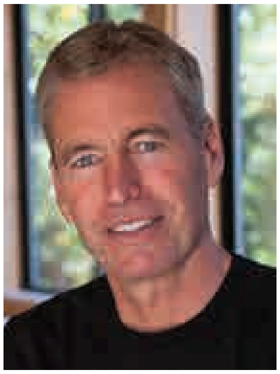
Bruce Gervais is a professor of geography at California State University, Sacramento. He holds a B.A. in geography from San Francisco State University, a master’s in geography from the University of California at Davis, and a doctorate in geography from the University of California at Los Angeles. Bruce’s research focus is in paleoclimatology. For his doctoral research at UCLA, he studied ancient climates by using tree rings and fossil pollen preserved in lake sediments on the Kola Peninsula in northwestern Russia. He has published 12 peer-reviewed research papers detailing his work in Russia and California. Bruce enjoys spending his free time mountaineering, backpacking, and with his family. He welcomes your comments and can be reached at gervais@csus.edu.

(Bruce Gervais)

The author and his wife, Nancy, and their two daughters, Katherine and Natalie, at Mono Lake in eastern California. Katherine holds an air-filled volcanic rock called pumice that is light enough to float on water. Turn to Section 14.1 to find out more about pumice and other volcanic features.

About the Book Team

The Cover Artist


(Max James Fallon)

Tom Killion grew up in Marin County, California, where the rugged landscape inspired him to create Japanese-style woodblock prints. Tom studied history at the University of California at Santa Cruz, and holds a doctorate in African history from Stanford University. He has taught at Bowdoin College, San Francisco State University, and as a Fulbright Professor at Asmara University in Eritrea. In 1975, he produced his first book of woodcut prints, *28 Views of Mount Tamalpais*. In 1977, he founded Quail Press, where he has printed five handmade art books and over 400 relief prints. In 2000, he published *The High Sierra* of California in collaboration with Pulitzer Prize–winning poet Gary Snyder. Tom is currently working on his third collaboration with Snyder, *California's Wild Edge*, and lives with his family in Point Reyes, California.

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(W. Andrew Recher)

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Mapping Specialists


(Peter Robertson)

Beth Robertson is a Senior Cartographer at Mapping Specialists, Ltd., a Madison, Wisconsin-based company that since 1984 has been leading the way in providing custom cartography for educational, trade, and travel publishers, as well as many other types of cartography and graphics for both print products and Web resources. Beth studied environmental geography at the University of Wisconsin–Milwaukee where her love of maps drew her toward a career in cartography. She has produced thousands of maps for clients such as the National Geographic Society, Bedford/Freeman/Worth, National Park Service, and dozens of other companies. In recent years, Beth has been continually expanding her knowledge of html (and previously Flash) to produce animated and interactive graphics. She is currently enrolled in the Penn State World Campus post-baccalaureate certificate in geographic information systems. When she is not making maps, Beth enjoys bicycling and spending time with her husband and young son.

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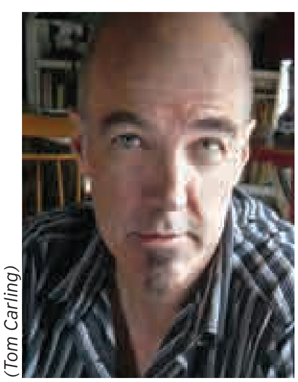
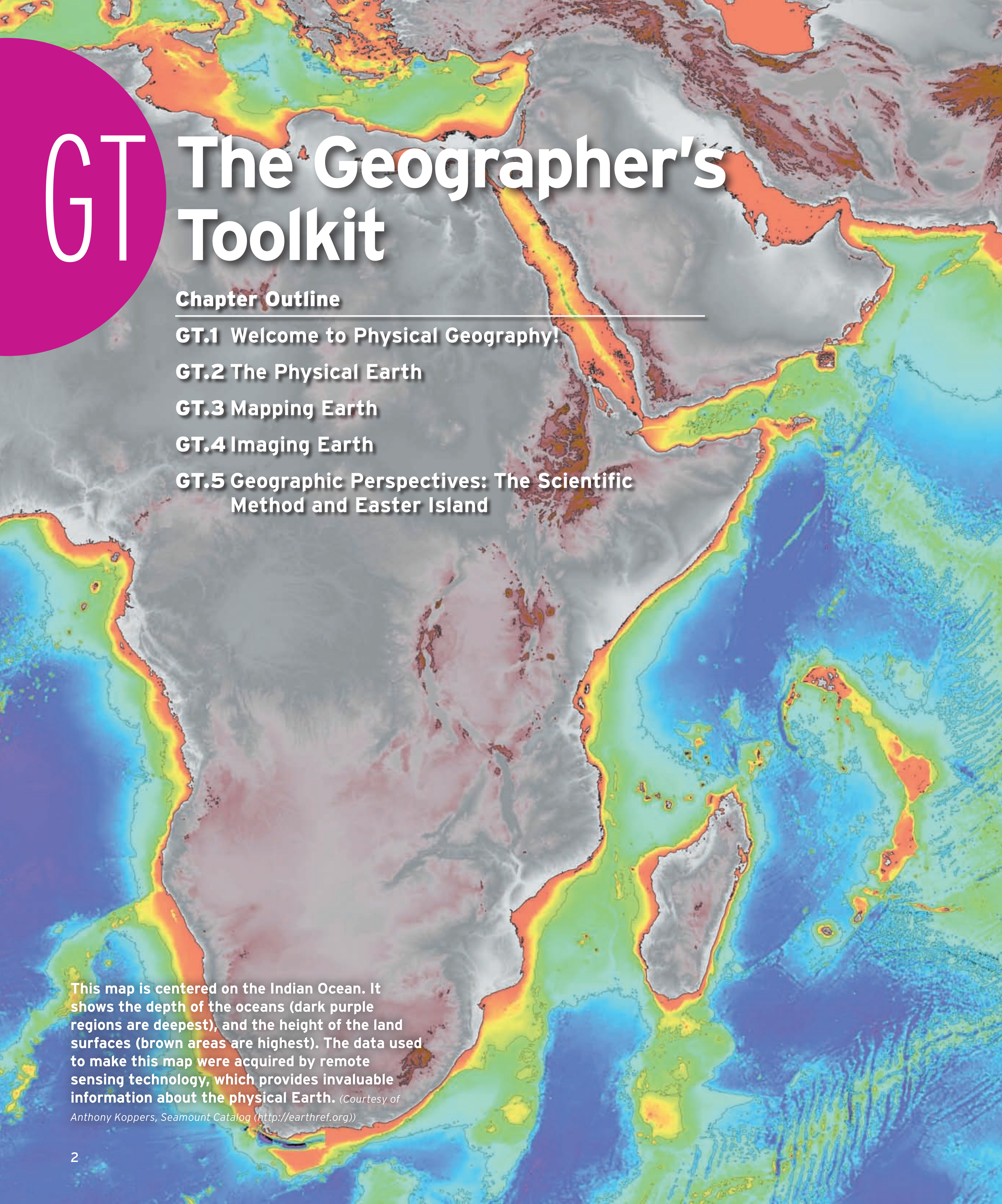

(Tom Carling)

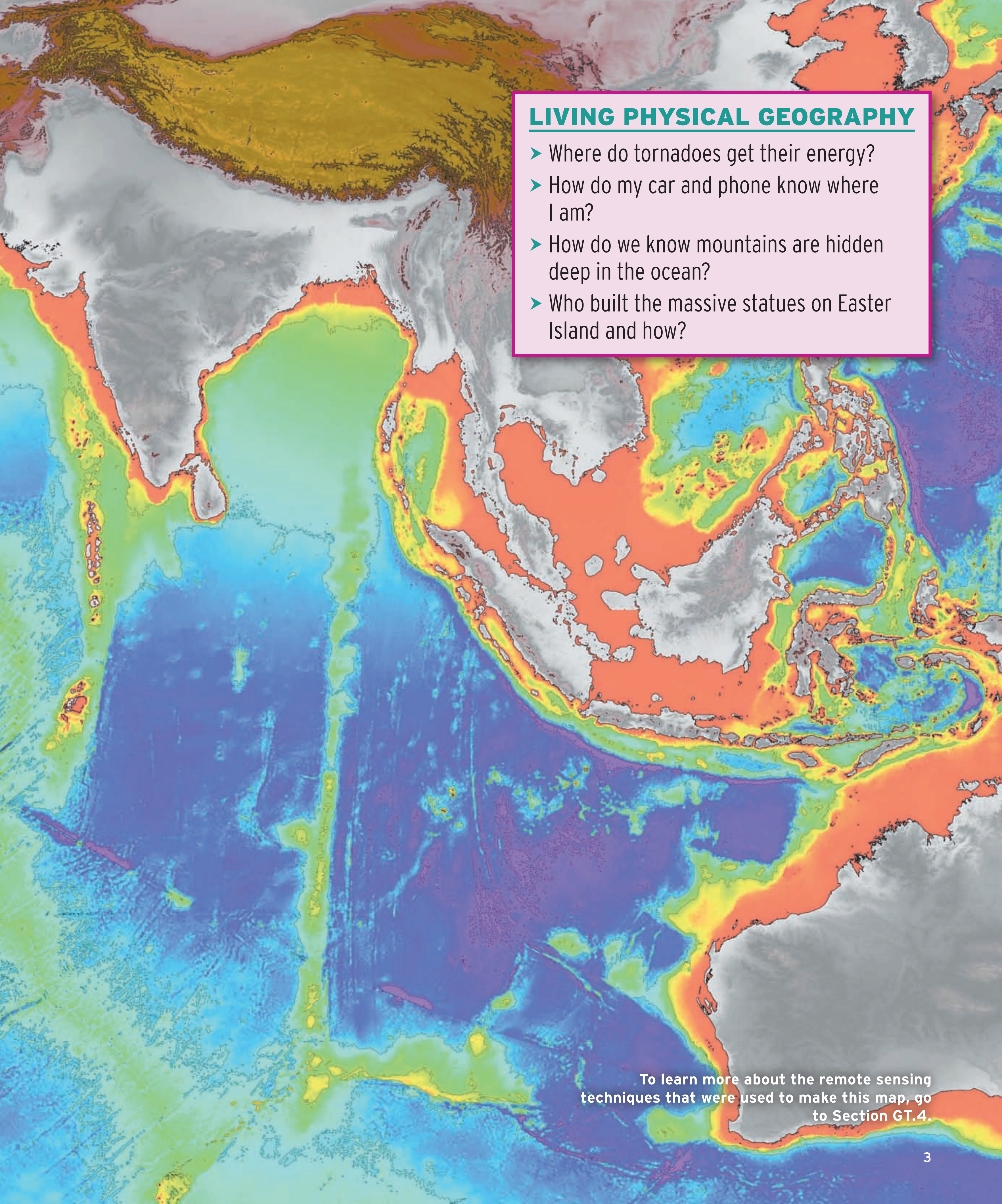
Tom Carling is the principal of Carling Design, a New York-based editorial design firm specializing in magazines, books, and custom-content publications. In recent years, Tom has designed numerous college-level titles for Macmillan Education in both the sciences and humanities. His approach to college textbook design is informed by his roots in trade magazines for clients such as *Sports Illustrated* and Lucasfilm as well as extensive experience in children's/young adult, nonfiction book design for DK Books, Scholastic, and many others. Several of his children's books have been recommended by the American Library Association for reluctant readers. Tom holds a BFA in art history from Syracuse University.

GT The Geographer's Toolkit



Chapter Outline

This map is centered on the Indian Ocean. It shows the depth of the oceans (dark purple regions are deepest), and the height of the land surfaces (brown areas are highest). The data used to make this map were acquired by remote sensing technology, which provides invaluable information about the physical Earth. *(Courtesy of Anthony Koppers, Seamount Catalog (http://earthref.org))*



LIVING PHYSICAL GEOGRAPHY

- Where do tornadoes get their energy?
- How do my car and phone know where I am?
- How do we know mountains are hidden deep in the ocean?
- Who built the massive statues on Easter Island and how?

To learn more about the remote sensing techniques that were used to make this map, go to Section GT.4.

THE BIG PICTURE *Physical geography studies how Earth's natural systems function, how they change naturally through space and time, and how people change them.*

LEARNING GOALS *After reading this chapter, you will be able to:*

- **GT.1** ◎ Define physical geography and explain different scales of geographic inquiry.
- **GT.2** ◎ Describe Earth's major physical systems and their characteristics.
- **GT.3** ◎ Use the geographic grid coordinate system to identify locations on Earth's surface and distinguish among different types of maps often employed in physical geography.
- **GT.4** ◎ Discuss how technologies such as satellite sensors and radar are used to study and portray Earth systems and processes.
- **GT.5** ◎ Apply the scientific method to Easter Island to study its history of human settlement.

GT.1 Welcome to Physical Geography!

◎ Define physical geography and explain different scales of geographic inquiry.

Have you ever wondered why deserts are barren and dry and tropical rainforests are lush and wet? Why Hawai'i has such delightfully pleasant winters but Alaska's are brutally cold? Why there is winter and summer? How millions of tons of water can be held aloft in a thunderstorm, then fall to the ground as rain? Why tornadoes form? Whether humans are causing climate change? Why there are no polar bears in the Southern Hemisphere or penguins in the Northern Hemisphere? Why mountains form and how they are worn down? The causes of volcanoes and earthquakes? These questions all stem from a fundamental curiosity about the natural world around us. They are all questions about Earth's physical geography, and they are all questions explored in this book.

What Is Physical Geography?

Physical geography is more than knowing the names of locations and places. **Physical geography** is the study of Earth's living and nonliving physical systems and how they change naturally through space and time or are changed by human activity. A **system** is a set of interacting parts or processes that function as a unit. Physical geography explores how Earth's natural physical landscapes have changed in the past and how they may change in the future.

Physical geography is nested within the larger discipline of **geography**: the study of the spatial relationships among Earth's physical and cultural features and how they develop and change through time. **Geography emphasizes the role of spatial relationships between people and the physical world to gain insight into cultural and physical phenomena.** Geography has several other subdisciplines. The counterpart to physical geography is *human geography*, which focuses on human phenomena, such as political voting patterns, human migration, transportation issues, and urban planning and development.

Often, physical geography and human geography overlap. In this book, for example, the role of people is never far from any topic. It is difficult to find regions or systems that are not at least in part **anthropogenic**: created or influenced by people. People modify Earth's physical landscapes to meet their needs, and in so doing, they are an active force of change. Earth's surface, its atmosphere, its oceans, and its organisms have been transformed in many ways by people in just the last few hundred years **(Figure GT.1)**.

All of our material goods are connected to natural resources derived from Earth's physical systems. The materials that meet our basic needs, such as our food, homes, cars, phones, computers, and clothing, were all once raw natural resources found in Earth's physical systems. In growing or manufacturing these materials, people modify Earth's natural environments.

People are also influenced by, and are a product of, Earth's physical systems and processes.

physical geography
The study of Earth's living and nonliving physical systems and how they change naturally through space and time or are changed by human activity.

system
A set of interacting parts or processes that function as a unit.

geography
The study of the spatial relationships among Earth's physical and cultural features and how they develop and change through time.

anthropogenic
Created or influenced by people.

FIGURE GT.1 Anthropogenic landscapes. *(A) Although wheat fields in Canada and the city of New York may not look alike, each has been completely transformed by people. The wheat fields of Saskatchewan, Canada, were once prairie grassland composed of a rich diversity of plant and animal species. (Note that locator maps, shown here, are used throughout this book to illustrate the geographic settings of photographs.) (B) Manhattan, New York, was once deciduous forest and coastal estuaries. (C) This composite image of night lights in North America was assembled from satellite data collected in April and October of 2012. Multiple images were combined to avoid cloudy skies. Night lights indicate where people live. The eastern United States and southern Canada are brighter and more populated than the arid western United States and mountainous Canadian provinces. Note that some lights are not related to populated centers, such as natural gas flares in North Dakota.* (A. Dave Reede/All CanadaPhotos/Getty Images; B. Michael S. Yamashita/NationalGeographic/Getty Images; C. NASA)

A

B

C

Our evolutionary history is a result of Earth's changing land surface, ocean currents, and climate patterns. Changing climate and interactions with other organisms led to the evolution of bipedalism (walking upright) about 4 million years ago in eastern Africa. Through time, human intelligence has increased, as has our technological sophistication.

Physical geography explores the human transformation of Earth's physical landscapes through science. Science is fundamental to the discipline of physical geography and to all aspects of this book. Later in this chapter, Geographic Perspectives (Section GT.5) explores the fallen civilization of Easter Island to illustrate the process of science.

GEOGRAPHIC PERSPECTIVES

The health and well-being of the human species are intertwined with Earth's natural and anthropogenic environments. This book is a journey through the physical geography of Earth and the place humans now occupy there.

Scales of Inquiry

There are two types of scale that geographers often employ: spatial scale and temporal scale. Different spatial and temporal scales provide varied perspectives on physical phenomena. **Spatial scale** refers to the physical size, length, distance, or area of an object such as a cloud or a rainforest. Spatial scale also pertains to the physical space occupied by a process such as migration of a species or movement of sand along a coastline. (A *process* is a stepwise progression of events.) **Temporal scale** refers to the window of time used to examine phenomena and processes as well as the length of time over which they develop or change.

spatial scale
The physical size, length, distance, or area of an object or the physical space occupied by a process.

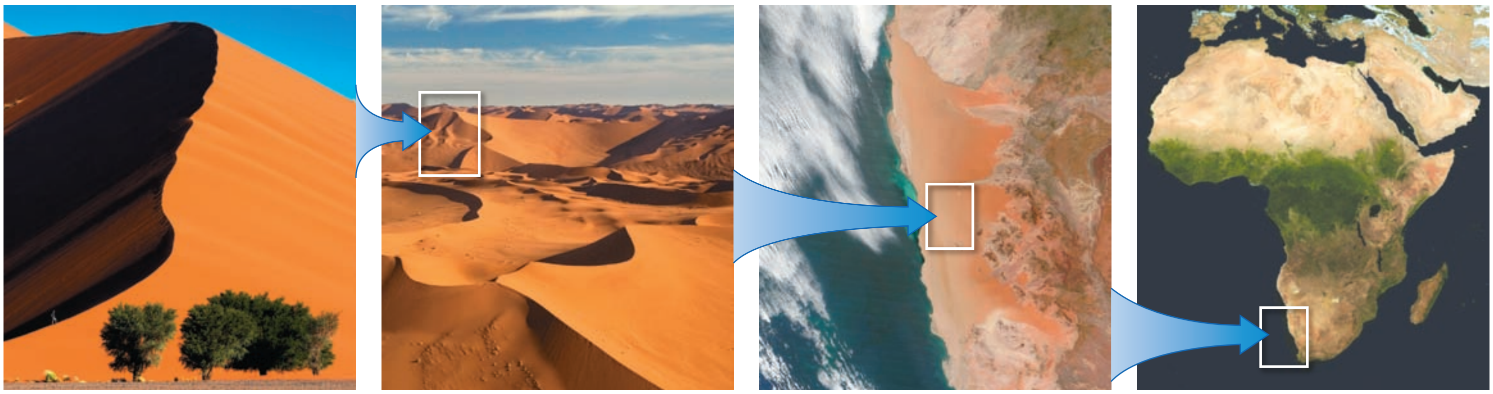
temporal scale
The window of time used to examine phenomena and processes or the length of time over which they develop or change.

FIGURE GT.2 **Spatial scale.** *Our perspective on the Namib Desert in southwestern Africa changes as spatial scale changes. Different spatial scales reveal different geographic patterns and processes and stimulate different kinds of questions. Images 3 and 4 are both developed from satellites.* *(1. Johnny Haglund/Lonely PlanetImages/Getty Images; 2. imagebroker.net/SuperStock; 3. NASA; 4. NASA)*

Video
Spatial scale
http://qrs.ly/es3wdr1

SPATIAL SCALE

Large scale — Small scale



1 Do sand dunes move? How deep is this sand dune? Why is there no vegetation on the dunes?

2 How does the wind form these dune patterns? Where did the sand come from? Are sand dunes found only in deserts?

3 Why does this desert occur near the ocean? Why is southwestern Africa arid?

4 Why is desert found north and south of central Africa but not in central Africa, which is green and fertile? Does this pattern occur on other continents?

The study of space and time underpins the study of physical geography. Together, spatial and temporal scales reveal important information about Earth's physical systems. Using the two scales together provides a unique perspective.

Spatial Scale: Perspective in Space

Imagine your college campus or your neighborhood. You are probably thinking on a local spatial scale. On a more regional spatial scale, imagine the city where you live, or the state, or even the entire country or continent. These are all examples of different spatial scales. Thinking on local spatial scales involves more detail, such as what building a classroom is in or where a house in a neighborhood is found. On broader spatial scales, there is less local detail, but more geographic space is covered with a clearer view of the bigger picture and of context.

A **map** is a flat two-dimensional representation of Earth's surface. A map can be drawn at any spatial scale. **Large-scale** perspectives make geographic features large to show more detail. **Small-scale** perspectives make geographic features small to cover broad regions. A map at a local scale, such as a college campus map that shows individual buildings, is a large-scale map. A small-scale map includes a large area of Earth's surface, such as a continent or a hemisphere. **Figure GT.2** shows how different spatial scales lead to different perspectives and different levels of inquiry.

It is easy to know what a thing is at a large spatial scale (such as a sand dune), but seeing the small-scale patterns and processes that produced

map
A flat two-dimensional representation of Earth's surface.

large scale
A geographic scale that pertains to a geographically restricted area and makes geographic features large to show more detail.

small scale
A geographic scale that makes geographic features small to cover a large area of Earth's surface.

FIGURE GT.3 **Spatial scales used in geography.** *The phenomena studied in physical geography occur across a wide range of spatial scales. Large-scale features, such as a cliff face, occupy little geographic space, and small-scale features, such as a continent, occupy immense spaces. Use of different spatial scales to gain different perspectives underpins the study of physical geography.*

Spatial Scales of Physical Geography

Meters	Kilometers	Tens of kilometers	Thousands of kilometers	Tens of thousands of kilometers
Cliff face	Mountain	Mountain range	Continent	Earth

it is difficult from that perspective. At a small spatial scale, a geographic pattern begins to emerge: The Namib Desert is part of a broader pattern of aridity around the world. Global atmospheric flow results in this geographic pattern.

This shift in spatial scale provides a way of seeing how phenomena or processes are situated in relation to one another. Physical geography focuses on phenomena that range in size from meters to the entire planet **(Figure GT.3)**.

Temporal Scale: Time as a Perspective

It is difficult to see clouds moving in the sky unless you keep your eyes fixed on them. Time-lapse video, however, shows clouds as roiling and billowing rapidly across the sky. Earth's physical landscapes today are merely one frame in a continuing landscape of change. On human time scales, most landscapes appear to be *static* (unchanging). On longer time scales, such as hundreds to thousands or millions of years, landscapes change and evolve. Mountains are lifted up, then eroded away; continents split apart as new ocean basins form. Natural climate cooling creates massive ice sheets that cover whole continents, and once-vegetated regions turn to barren desert. Most of the Sahara, for example, is barren today, without surface water and vegetation. Some 7,000 years ago, however, that desert was a *savanna* woodland (see Section 8.2) with many large lakes and was home to many animals, including crocodiles, hippos, giraffes, lions, and humans **(Figure GT.4)**.

The temporal scale is particularly relevant to anthropogenic changes in Earth's environments. Rapid changes in Brazil's tropical rainforests, for example, have been well documented by satellite imagery through time, and that imagery has been crucial in monitoring losses of Amazon rainforest in South America. **Figure GT.5** provides two different satellite images that reveal the rapid changes in the Amazon rainforest.

Physical geography explores phenomena and processes across temporal scales that range from minutes to millions of years. As **Figure GT.6** on the next page shows, some phenomena, such as earthquakes, occur in minutes, while others, such as the development of mountain ranges, take millions of years. Some phenomena can occur over many time scales. Climate change, for example, occurs over decades to millions of years.

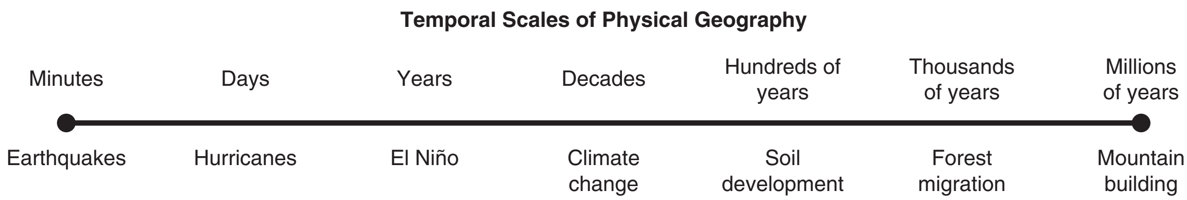
About the Metric System

You will notice as you use this book that two units of measurement are given. The *metric system* unit is provided first, and then the *U.S. customary*

FIGURE GT.4 Green Sahara. *This 7,000- to 9,000-year-old giraffe petroglyph (rock engraving) is in the Sahara Desert in Niger, Africa, where today it is very dry. Giraffes require woodlands, so the petroglyph's presence indicates that the climate was once much wetter. This petroglyph illustrates how temporal scale can provide a greater understanding of how environments change over long time spans.* (© Frans Lemmens/Lithium/age fotostock)

FIGURE GT.5 Rondônia deforestation. *These satellite images show deforestation in Rondônia, Brazil, between 1975 (left) and 2012 (right). The two images show the same location. Dark green areas are covered by forest. Light green and purple areas in the 2012 image have been cleared. Logging, agriculture, and cattle ranching are driving deforestation in the Amazon rainforest. Both spatial and temporal scales are evident in this image. In only 37 years (the temporal scale), large expanses (the spatial scale) of tropical rainforest habitat have been lost. The distance across each image is about 40 km (25 mi).* (EROS Data Center/Landsat/NASA)

FIGURE GT.6 **Temporal scales used in physical geography.** *Different physical phenomena or processes occur on different temporal scales.*



unit is provided in parentheses. Inches, feet, and miles are part of the U.S. customary system of weights and measurements, which also includes pounds, gallons, and degrees Fahrenheit. Centimeters, meters, and kilometers are metric system units of distance, and this system also includes kilograms, liters, and degrees Celsius.

The United States is the only industrialized country that still has a customary system in widespread use. The metric system is used in all formal scientific research in all countries, including the United States, and by the public in most of the rest of the world. The metric system is favored because of the ease of conversion between different units, as shown in **Table GT.1**.

TABLE **GT.1** AT A GLANCE: **The Metric System**

10 millimeters = 1 centimeter
100 centimeters = 1 meter
1,000 meters = 1 kilometer
1 cubic centimeter = 1 milliliter = 1 gram of water
1 calorie raises 1 gram of water 1°C
At sea level, water freezes at 0°C and boils at 100°C

GT.2 The Physical Earth

Describe Earth's major physical systems and their characteristics.

Earth is a large system, and it is therefore necessary to divide it into smaller systems to understand how it works. In this section, we examine the interaction between matter and energy, Earth's physical shape, and Earth's major physical systems.

Matter and Energy

The flow of energy through Earth's physical systems is central to most topics in physical geography. **Energy** is the capacity to do work on or to change the state of matter. **Matter** is any material that possesses mass and occupies space. Matter can exist in three states: solid, liquid, or gas. To change the state of matter (such as water), energy must be added to or removed from it **(Figure GT.7)**.

Several forms of energy influence Earth systems. **Radiant energy** is the energy of electromagnetic waves, such as light or X-rays. The Sun emits radiant energy that passes through Earth's atmosphere. A portion of that energy is absorbed by Earth's atmosphere and surface. When that radiant energy is absorbed, it is converted to heat. **Photosynthesis** is a process by which plants, algae, and some bacteria convert the Sun's radiant energy to stored chemical energy. **Chemical energy** is energy in a substance that can be released through a chemical reaction. All living organisms use chemical energy to move and to carry out metabolic functions. Gasoline is also a form of chemical energy. When burned, that energy works to move a car. **Geothermal energy** (heat from Earth's interior) moves entire continents and heaves and buckles mountain ranges. Lightning produced within a thunderstorm is *electrical energy*.

Two other important categories of energy in physical geography are *potential energy* and *kinetic energy* (both types of *mechanical energy*). Potential energy is stored in an object or material. A boulder perched over a cliff about to fall is an example of potential energy. Kinetic energy is the energy of movement. A boulder that is falling down a cliff and smashing into other rocks is an example of kinetic energy.

As energy flows through Earth's physical systems, it moves matter, and it changes its form in the process. **Figure GT.8** examines how the Sun's radiant energy changes from one form to another in Earth's physical systems.

Earth's Shape

From space, Earth looks like a perfect sphere, equal in all dimensions and perfectly smooth. Yet Earth is not a perfect sphere. Earth's true shape results from distortion by Earth's rotation, the vertical irregularities of Earth's surface, and gravitational

energy
The capacity to do work on or to change the state of matter.

matter
Any material that occupies space and possesses mass.

radiant energy
The energy of electromagnetic waves.

photosynthesis
The process by which plants, algae, and some bacteria convert the radiant energy of sunlight to chemical energy.

chemical energy
Energy in a substance that can be released through a chemical reaction.

geothermal energy
Heat from Earth's interior.

FIGURE GT.7 **States of matter.** *Mount Robson (elevation 3,954 m or 12,972 ft), in British Columbia, is the highest peak in the Canadian Rockies. Berg Glacier flows down the mountain and into Berg Lake. Here, water exists in its three phases: solid ice in Berg Glacier, liquid water in Berg Lake, and water vapor (a gas) that is invisible in the atmosphere. To change the state of water from solid ice to liquid water to water vapor, energy must be added to the water. To change its state from gas to liquid to solid, energy must be removed from water.* *(Jason Puddifoot/First Light/GettyImages)*

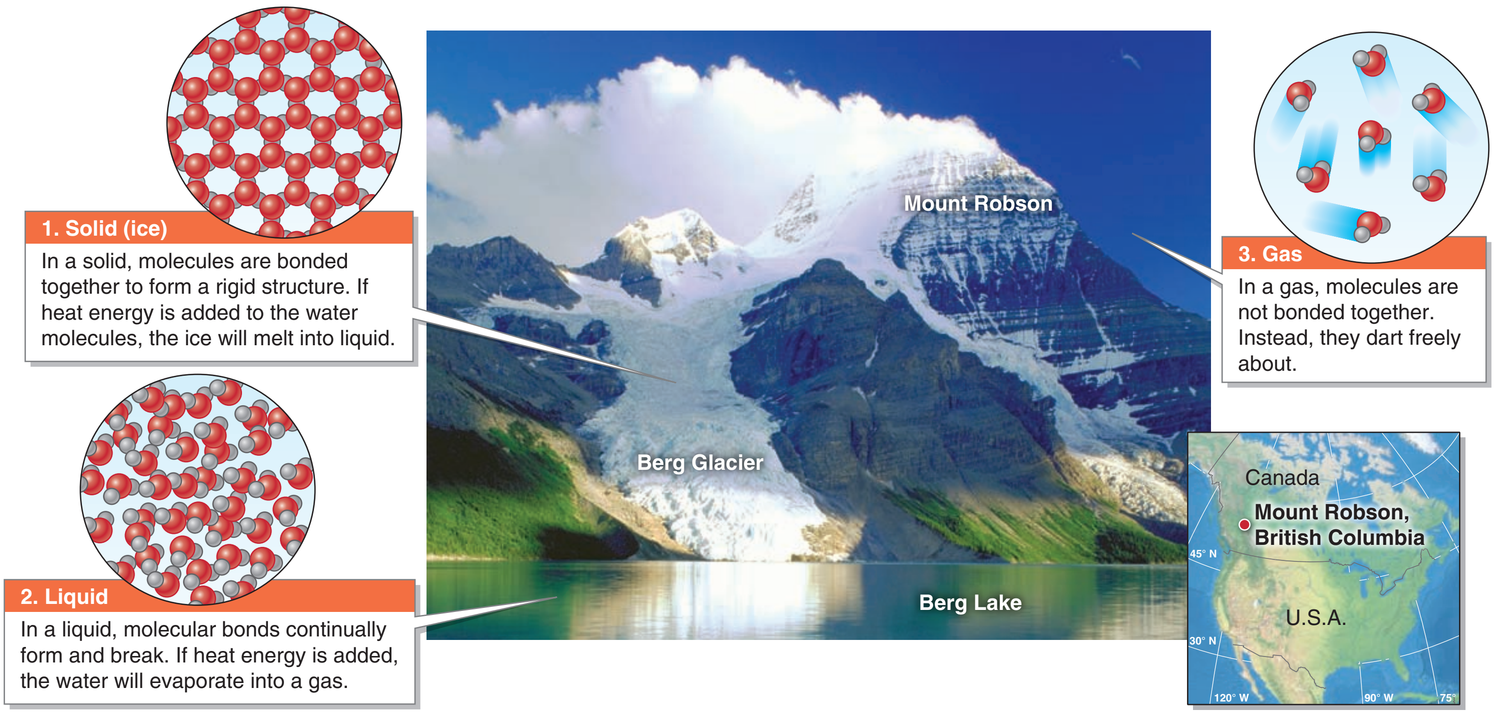


FIGURE GT.8 **GEO-GRAPHIC: A day in the life of solar energy.** *This graphic follows the path of solar radiant energy as it changes form and works on matter.* *(1. Evan Kafka/Getty Images; 2. Marco Brivio/age fotostock/GettyImages; 3. U.S. Dept. of the Interior-Bureau of Reclamation; 4. REBECCA COOK/Reuters/Newscom)*