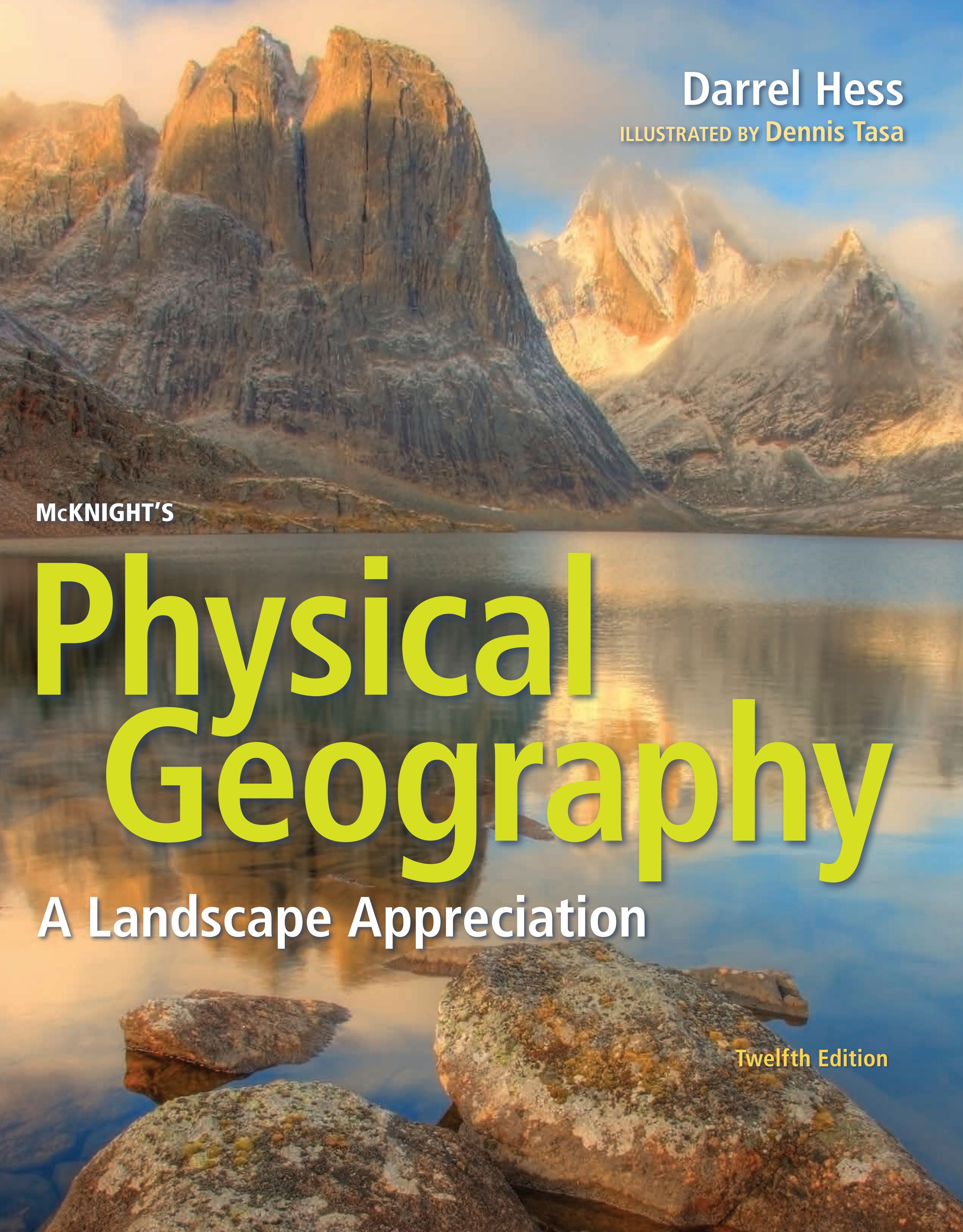


Darrel Hess
ILLUSTRATED BY Dennis Tasa

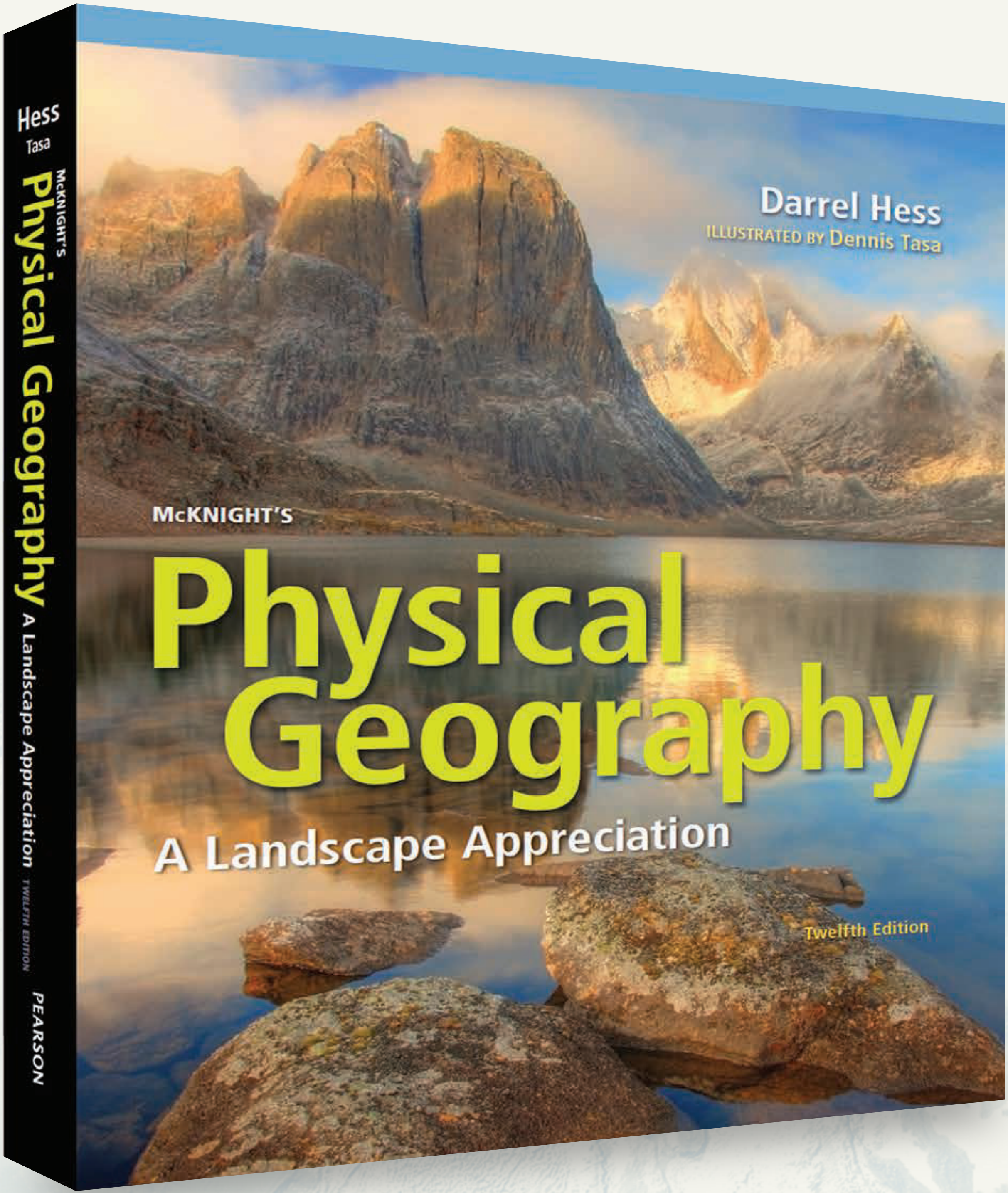
McKNIGHT'S

Physical Geography

A Landscape Appreciation

Twelfth Edition

Explore the Changing Global Environment
with Real-World Applications & Mobile Field Trips



PEARSON

Exploring the Changing Global Environment

NEW! Global Environmental Change features written by expert contributors present brief case studies on natural and human-caused environmental change, exploring important contemporary events and implications for the future.

global environmental change

Growing a City in the Desert

Bradley Shellito, Youngstown State University

At the end of 2015, the world population was an estimated 7.3 billion people, up from 5 billion in 1987. As a result of this tremendous growth, extensive demand is under way to provide housing, industries, and amenities for everyone across the planet—sometimes in the unlikeliest of environments. For instance, in Saudi Arabia, crops are grown in the desert, while China's Pearl River Delta, which was mostly rural only 30 years ago, is now the world's largest urban area.

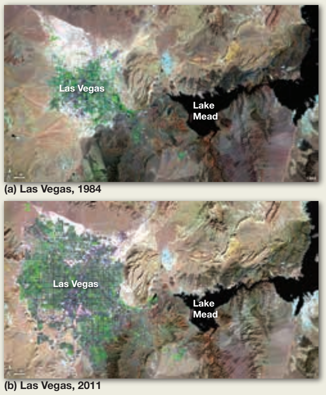
Viva Las Vegas: For several years, Las Vegas, Nevada, has been one of the fastest-growing cities in the United States. According to the U.S. Census Bureau, the Las Vegas area grew to over 1.1 million persons by 2014, almost a 300 percent growth rate from 1990. In addition, visitors in 2014 numbered over 41 million, about double the number in 1990. That's a huge amount of people living, working, and touring in a city built in the middle of a desert ecosystem. Las Vegas sits within a basin in the Mojave Desert, and sidewalks in new housing developments at the city's edges lead straight into the desert.

This level of urban development in a desert environment brings plenty of challenges and questions, particularly concerning water usage and sustainability. Water levels in a reservoir of the Colorado River at Lake Mead, the main source of water for the region, have been dropping. Water conservation efforts are now in place to aid sustainability, including returning indoor wastewater consumption to the lake, limits and prohibitions on the planting of turf grass, and watering restrictions in public places.

Geospatial technologies can be used to examine the "big picture" of the growth of Las Vegas and its environs and provide the monitoring needed to maintain sustainable growth measures. Satellite remote sensing allows us to view the expansion of urban development spatially, so we can see where the city is growing and at what rates. For instance, the Landsat satellite archive, stretching back over 40 years for intervals of every 16 days, allows us to keep a constant eye on urban growth within fragile ecosystems. Landsat imagery of Las Vegas in 1984 and 2011 (Figure 2-A) gives a dramatic look at the growth in urban developments (including houses, shops, utilities, and tourist locations) necessary to accommodate the growing population and visitors. With this monitoring, we can then use geographic information systems (GIS; discussed later in this chapter) to analyze different planning and water management strategies for the city.

Artificial Archipelago: Las Vegas is not the only site for which geospatial technologies can help in monitoring and planning. For example, the Palm Islands in the Persian Gulf, just off the coast of Dubai in the desert country of the United Arab Emirates, is an archipelago that was built for touristry. Building a series of islands out of sand and rocks to be used as resorts and hotels brings with it a series of environmental challenges, but their growth can be monitored through remote sensing technologies (Figure 2-B). Remote sensing is especially useful for monitoring environmental conditions such as water quality in the region as well as documenting urbanization and the environmental consequences of development. For example, see the growth of the Palm Islands at http://earthobservatory.nasa.gov, NASA's Earth Observatory (search for "World of Change: Urbanization of Dubai"). Similarly, the Timelapse app (http://world.time.com/timelapse/) allows you to view yearly Landsat imagery from 1984 until 2012 of locations around Earth (including Las Vegas and Dubai).

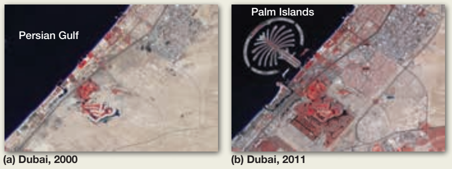
Looking Ahead: Earth's population is expected to climb to 9 billion people by 2040 and to continue to grow. This dramatic growth will carry with it a variety of environmental impacts all around the world. Remote sensing satellites will allow us to monitor these kinds of impacts and growth; GIS will let us analyze the patterns. By looking through the lens of geospatial technologies, we can understand global environmental impacts and plan for a sustainable future.



▲ Figure 2-A Las Vegas in (a) 1984 and (b) 2011 as viewed by the Landsat 5 TM sensor.

Questions

1. How can city officials use satellite imagery taken at regular intervals to make decisions for smart growth or sustainability strategies?
2. What other types of sustainability challenges do urban developments in desert and coastal ecosystems face? How can remote sensing be used to address them?



▲ Figure 2-B Satellite imagery of Dubai in (a) 2000 and (b) 2011. Here vegetation appears in red.

EnvironmentalAnalysis Cloud Climatology

DATA MG
Cloud Climatology
https://goo.gl/9EFghL

The International Satellite Cloud Climatology Project (ISCCP) collects cloud data from weather satellites of several nations to help us understand the role of clouds in climate.

Activities

Go to http://isccp.giss.nasa.gov/products/browsed2.html, the ISCCP website. Retain the variable "Total Cloud Amount (%)" and time period "Mean Annual"; then click "View."

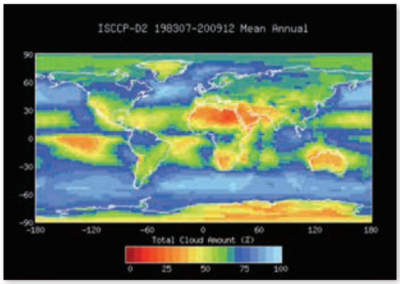
1. The map indicates the average annual percentage of cloud-covered sky. What is the range of cloud cover amounts in the far north? In the far south?
2. In general, is cloud cover higher over oceans or land? What would cause this?

Go back and select the variable "Mean Precipitable Water for 1000–680 mb"; then click "View."

3. The map indicates how much moisture is available for precipitation in the lower half of the troposphere. How much precipitable water is available in the far north?
4. Notice that precipitable water amounts are high in equatorial regions and decrease poleward, as do temperatures. Why are precipitable water and temperature related in this way?

Go back and select the variable "Mean Precipitable Water for 680–310 mb"; then click "View."

5. The map indicates how much moisture is available for precipitation in the upper half of the troposphere. Again, precipitable water is most abundant in equatorial regions. What type of cloud is likely to form there?
6. Recall the patterns of cloud cover (Activity 1) and precipitable water (Activity 3) in the far north. What types of clouds are most likely to form in the far north? It may help to refer to Figure 6-14.



NEW! Environmental Analysis Activities at the end of each chapter send students online to use a variety of interactive science resources and data sets to perform data analysis and critical thinking tasks.

Mobile-Ready Media Brings Geography to Life

NEW! *Mobile Field Trip* Videos have students accompany acclaimed photographer and pilot Michael Collier in the air and on the ground to explore iconic landscapes of North America and beyond. Readers scan Quick Response (QR) links in the book to access the 20 videos as they read. Also available within MasteringGeography.

NEW! *Project Condor* Quadcopter Videos take students out into the field through narrated and annotated quadcopter footage, exploring the physical processes that have helped shape North American landscapes. Also available within MasteringGeography.

Structured Learning to Guide Students

UPDATED! Key Questions frame the big ideas and important topics of each chapter, and inform the Learning Outcomes in the MasteringGeography item library.

As you study this chapter, think about these **Key**Questions:

- **How is a map different from a globe?**
- **What is meant by the *scale* of a map?**
- **What are the differences between *equivalent* ("equal area") maps and *conformal* maps?**
- **Why are different map projections needed?**
- **How do *isolines* convey information on a map?**
- **How does a GPS unit know where we are?**
- **What is *remote sensing*?**
- **How does GIS help us analyze geographic data?**

UPDATED! Learning Checks integrated throughout chapter sections give students a chance to stop and check their understanding as they read. Answers are available at the back of the book.

LearningCheck **2-9** **How does a digital elevation model convey the topography of Earth's surface?**

LearningCheck **2-10** **How does GPS determine locations?**

LearningCheck **2-11** **What are the differences between near infrared and thermal infrared images, and what kinds of features might be studied with each?**

UPDATED! Seeing Geographically questions at the beginning and end of each chapter ask students to perform visual analysis and critical thinking tasks that test their initial assumptions before they read the chapter and their understanding of key chapter concepts after they have read the chapter.

SeeingGeographically

Look again at the photograph of the tornado at the beginning of the chapter (p. 174). How might the topography of this region influence the likelihood of tornadoes? Why are spring and early summer the most common times for tornadoes? Why does the funnel cloud look different near the cloud base than where it comes in contact with the ground?

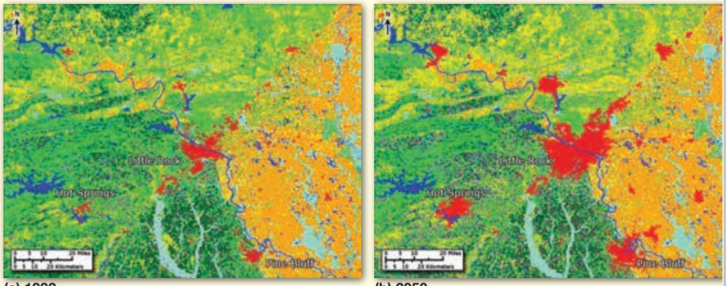
Real-World Applications of Physical Geography

focus

GIS for Geographic Decision Making

▸ Keith Clarke, University of California–Santa Barbara

A coastal engineer wishes to know what will be the future impact of sea-level rise and increased storm surge on coastal wetlands. An emergency manager needs to know how best to evacuate residents during a hurricane. A city planner wants to know the future impact that land-use changes will have on the emission of carbon dioxide and other greenhouse gases. In each case, geographic information systems (GIS) can help bring together geographic facts that are relevant to decisions about natural and built environments. Such a system first assimilates and brings together spatial data—data that include geographic location or coordinates—from multiple sources, which may include government data clearinghouses, state agencies, and field measurements. It then overlays all of the data in a common reference frame of coordinates as layers (see Figure 2-26).



(a) 1992 (b) 2050

▲ Figure 2-D Land use in Little Rock, Arkansas, (a) in 1992; (b) as predicted for 2050 by GIS modeling. (Red = developed; orange = cropland; yellow = pasture; dark green = evergreen forest.)

UPDATED! Focus features, many written by expert contributors, present in-depth case studies of special applied topics in physical geography.

NEW! Practicing Geography photo features highlight the real-world people and professions in geography and science today.

UPDATED! Energy for the 21st Century features provide coverage of renewable and nonrenewable energy resources, authored by expert contributors.

energy for the 21st century

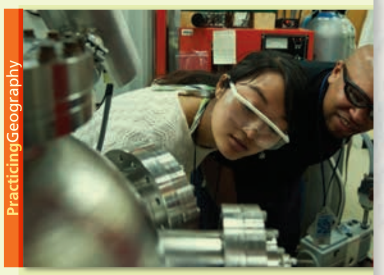
Transitioning from Fossil Fuels

▸ Michael E. Mann, Penn State University

Fossil fuels (coal, oil, and natural gas) are the product of millions of years of accumulated energy from sunlight, absorbed in plant life and trapped as hydrocarbon matter beneath Earth's surface. Although fossil fuels have been the primary energy source powering human civilization since the dawn of the industrial revolution, a transition to newer, cleaner forms of energy is now underway.

Historical Significance of Fossil Fuels: Before the use of fossil fuels, people did most mechanical work by using their own muscle power and that of animals, both ultimately derived from the Sun's energy stored in plants through photosynthesis and plant-eating animals (discussed in Chapter 10). The shift to fossil fuels led to machinery that ran without the force of muscle power, such as steam engines, and eventually to electrical power generation and automobiles. This change allowed for dramatic gains in labor productivity and the growth of transportation networks. Moreover, the increasing reliance on fossil fuels freed up thousands of acres that which required scrubbers in factory smoke stacks to remove SO_2 emissions, has largely alleviated that problem. However, a more fundamental environmental threat arises from the fact that all fossil fuel use emits carbon dioxide (CO_2), the primary human-produced greenhouse gas causing global climate change (discussed in Chapter 4). Moreover, the uneven distribution of fossil fuels creates geopolitical conflict over access to, and control over, energy resources. Although this problem is most visible in conflicts over oil (as in the Middle East), other areas of contention include natural gas pipelines in the Ukraine and North America and "fracking" (see Chapter 13) and mountaintop coal mining in the United States.

Alternative Energy: Support for switching to *alternative energy* has been growing among scientists, policymakers, and the public in recent decades. Most alternatives to fossil fuels generate electricity. Electricity is primarily generated by the combustion of coal or gas to create steam



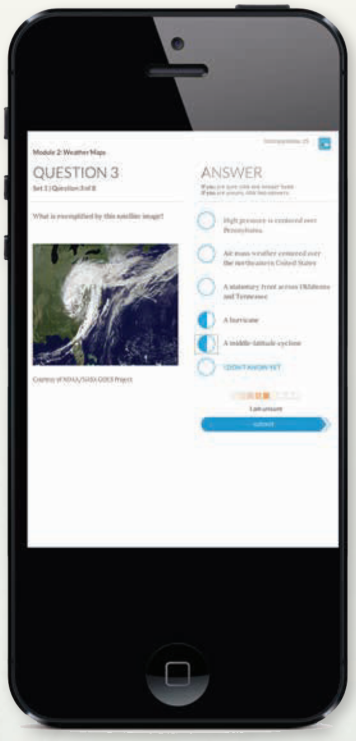
▲ Figure 3-E National Renewable Energy Laboratory scientists experimenting with ways to make solar cells more efficient..

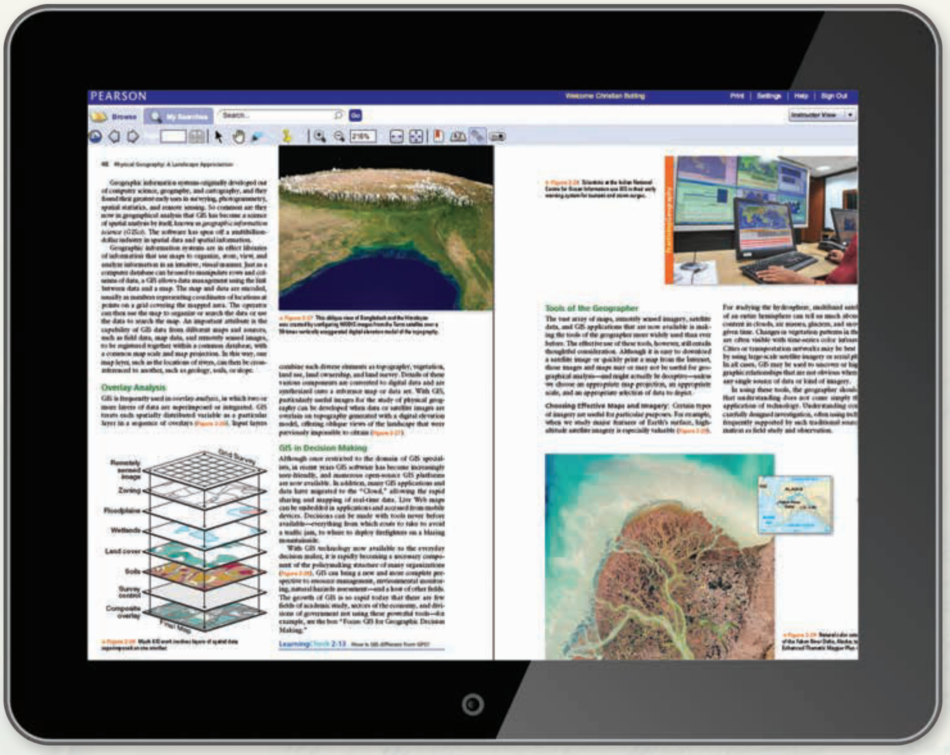
to generate electricity ultimately depends on when the wind blows. Solar power harnesses direct sunlight to generate electricity through either photovoltaic cells or the boiling of water to create steam (see Chapter 4).

Continuous Learning
Before, During, and After Class

BEFORE CLASS

Mobile Media and Reading Assignments Ensure Students Come to Class Prepared.





NEW! Dynamic Study Modules personalize each student's learning experience. Created to allow students to acquire knowledge on their own and be better prepared for class discussions and assessments, this mobile app is available for iOS and Android devices.

Pearson eText in MasteringGeography gives students access to the text whenever and wherever they can access the internet. eText features include:

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

Pre-Lecture Reading Quizzes are easy to customize & assign

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

with MasteringGeography™

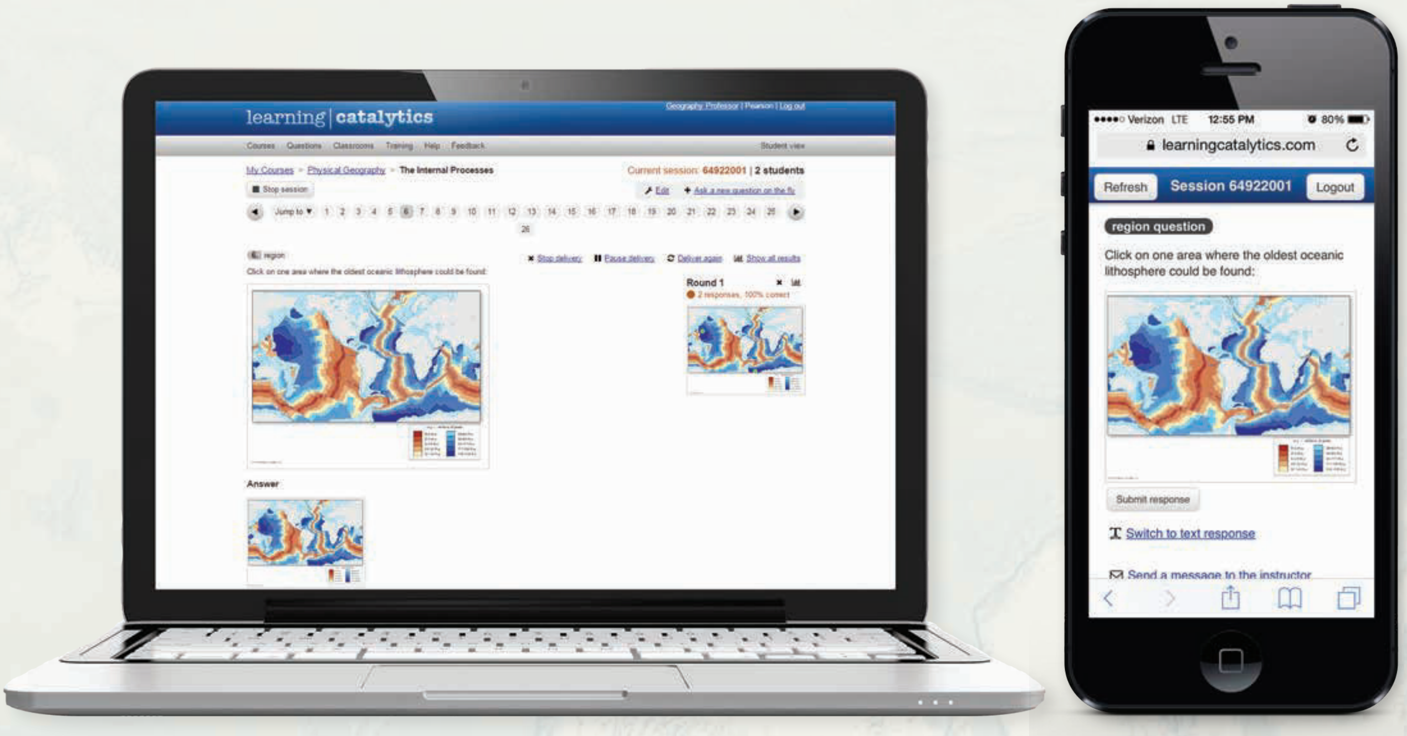
DURING CLASS

Learning Catalytics™ and Engaging Media

What has Teachers and Students excited? Learning Catalytics, a 'bring your own device' student engagement, assessment, and classroom intelligence system, allows students to use their smartphone, tablet, or laptop to respond to questions in class. With Learning Catalytics, you can:

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

> ***"My students are so busy and engaged answering Learning Catalytics questions during lecture that they don't have time for Facebook."***
>
> **Declan De Paor, *Old Dominion University***



Enrich Lecture with Dynamic Media

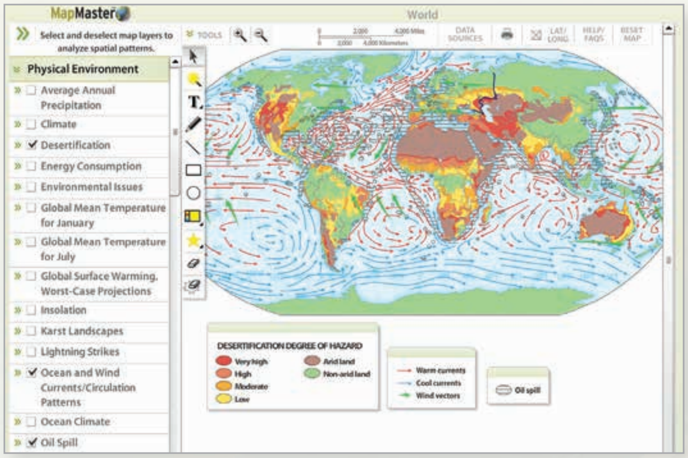
Teachers can incorporate dynamic media into lecture, such as Videos, *Mobile Field Trip* Videos, MapMaster Interactive Maps, *Project Condor* Quadcopter Videos, and Geoscience Animations.

Mastering Geography™

MasteringGeography delivers engaging, dynamic learning opportunities—focusing on course objectives and responsive to each student's progress—that are proven to help students absorb physical geography course material and understand challenging geography processes and concepts.

AFTER CLASS

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

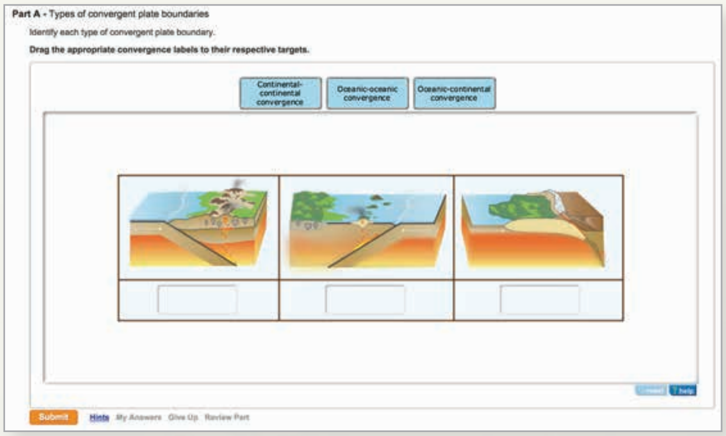


UPDATED! MapMaster Interactive Map Activities are inspired by GIS, allowing students to layer various thematic maps to analyze spatial patterns and data at regional and global scales. This tool includes zoom and annotation functionality, with hundreds of map layers leveraging recent data from sources such as NOAA, NASA, USGS, United Nations, and the CIA.

NEW! Geography Videos from such sources as the BBC and *The Financial Times* are now included in addition to the videos from Television for the Environment's *Life* and *Earth Report* series in **MasteringGeography**. Approximately 200 video clips for over 30 hours of footage are available to students and teachers in **MasteringGeography**.

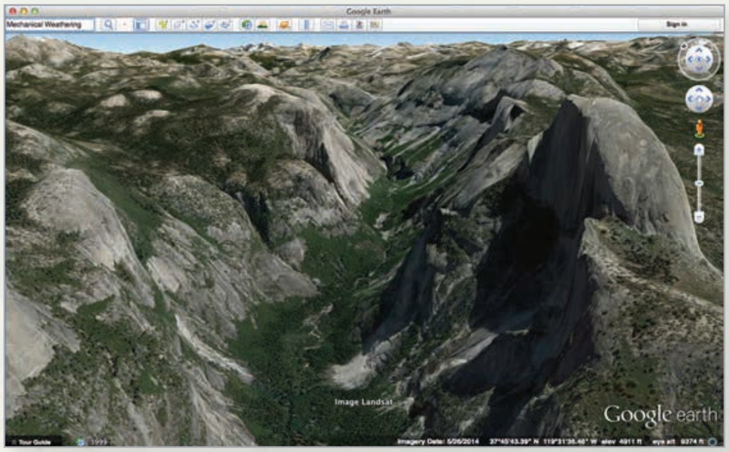
NEW! Mobile Field Trip Videos have students accompany acclaimed photographer and pilot Michael Collier in the air and on the ground to explore iconic landscapes of North America and beyond. Readers scan Quick Response (QR) links in the book to access the 20 videos as they read. Also available within **MasteringGeography** with assignable assessments.

www.MasteringGeography.com

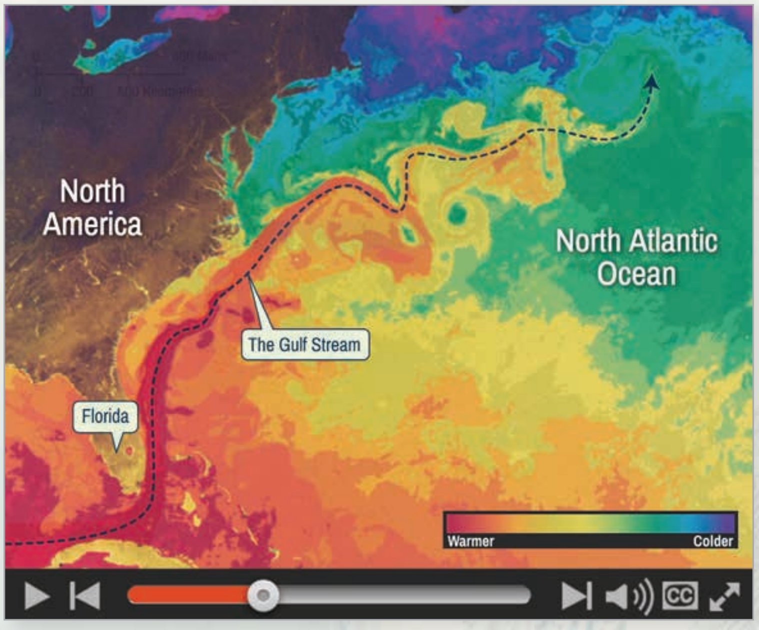


NEW and UPDATED! GeoTutors are highly visual and data-rich coaching items with hints and specific wrong answer feedback that help students master the toughest topics in geography.

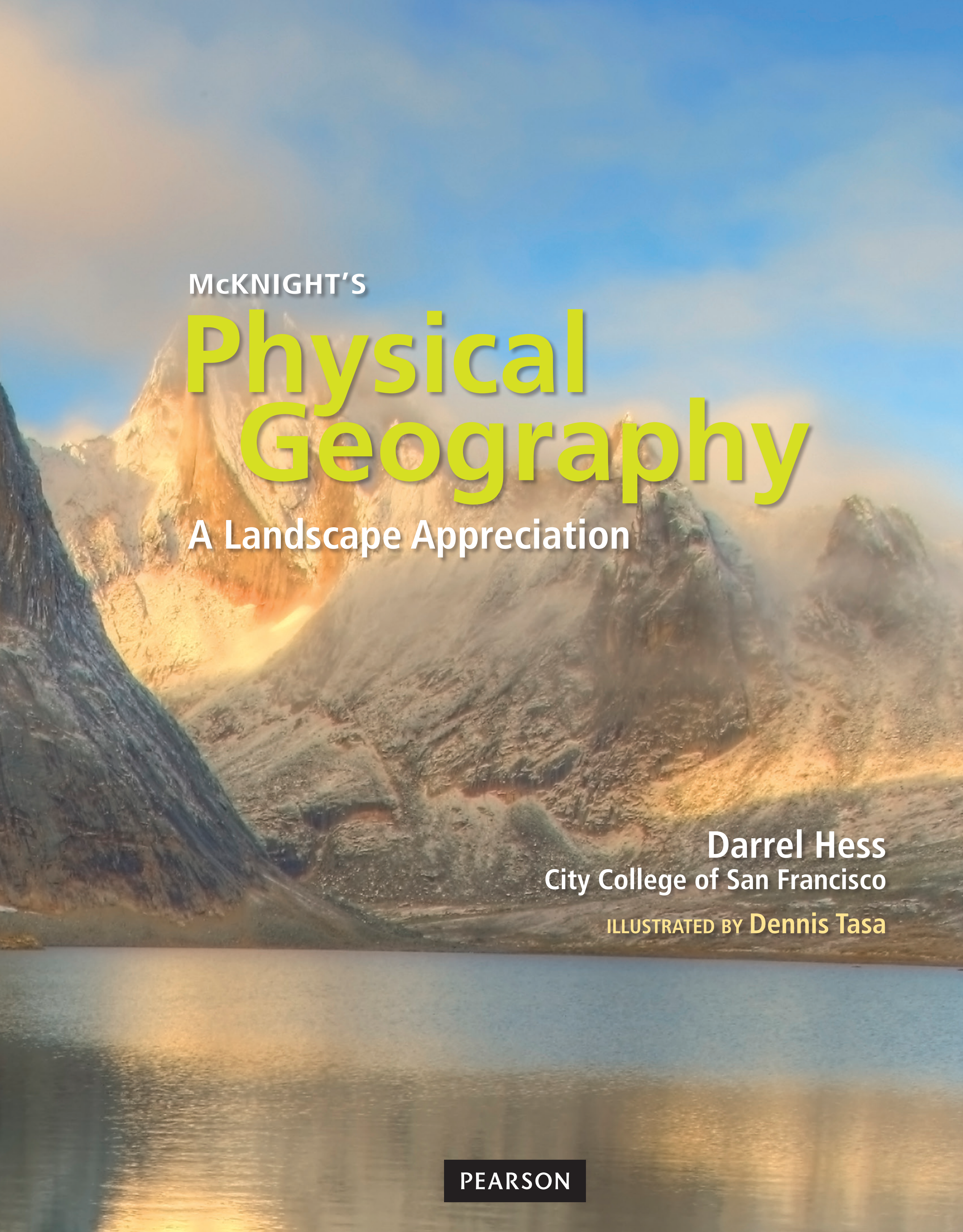
NEW! *Project Condor* Quadcopter Videos take students out into the field through narrated and annotated quadcopter video footage, exploring the physical processes that have helped shape North American landscapes.



UPDATED! Encounter (Google Earth) activities provide rich, interactive explorations of physical geography concepts, allowing students to visualize spatial data and tour distant places on the virtual globe.



Geoscience Animations help students visualize the most challenging physical processes in the physical geosciences with schematic animations that include audio narration. Animations include assignable multiple-choice quizzes with specific wrong answer feedback to help guide students toward mastery of these core physical process concepts.



McKNIGHT'S

Physical Geography

A Landscape Appreciation

Darrel Hess
City College of San Francisco
ILLUSTRATED BY Dennis Tasa

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BRIEF CONTENTS

GEOSCIENCE ANIMATIONS

Covering the most difficult-to-visualize topics in physical geography, the Geoscience Animations can be accessed by students with mobile devices through Quick Response Codes in the book, or through the MasteringGeography™ Study Area. Teachers can assign these media with assessments in MasteringGeography™.

ANIMATION MG
Gulf Stream
http://goo.gl/VxNztu

1 Introduction to Earth
Solar System Formation
Earth-Sun Relations

2 Portraying Earth
Map Projections

3 Introduction to the Atmosphere
Ozone Depletion
Coriolis Effect

4 Insolation and Temperature
Atmospheric Energy Balance
Gulf Stream
Global Warming

5 Atmospheric Pressure and Wind
Development of Wind Patterns
Coriolis Effect
Cyclones and Anticyclones
Global Atmospheric Circulation
The Jet Stream and Rossby Waves
Seasonal Pressure and Precipitation Patterns
El Niño

6 Atmospheric Moisture
Hydrologic Cycle
Water Phase Changes
Adiabatic Processes and Atmospheric Stability
Seasonal Pressure and Precipitation Patterns

7 Atmospheric Disturbances
Cold Fronts
Warm Fronts
Midlatitude Cyclones
Hurricanes
Hurricane Hot Towers
Tornadoes

8 Climate and Climate Change
Seasonal Pressure and Precipitation Patterns
End of the Last Ice Age
Orbital Variations and Climate Change

9 The Hydrosphere
Hydrologic Cycle
The Carbonate Buffering System
Tides
Tidal Cycle
Ocean Circulation Patterns—Subtropical Gyres
Ocean Circulation Patterns—Global Conveyor-Belt Circulation
North Atlantic Deep Water Circulation
Arctic Sea Ice Decline
The Water Table
Groundwater Cone of Depression

10 Cycles and Patterns in the Biosphere
Biological Productivity in Midlatitude Oceans
Net Primary Productivity

13 Introduction to Landform Study
Metamorphic Rock Foliation
Isostasy

14 The Internal Processes
Seafloor Spreading
Paleomagnetism
Convection and Plate Tectonics
Plate Boundaries
Divergent Boundaries
Subduction Zones
Collision of India with Eurasia
Transform Faults and Boundaries
Breakup of Pangaea
HotSpot Volcano Tracks
Terrane Formation
Volcanoes
Formation of Crater Lake
The Eruption of Mount St. Helens
Igneous Features
Folding
Faulting
Seismic Waves
Seismographs

15 Weathering and Mass Wasting
Mechanical Weathering
Mass Wasting
The Eruption of Mount St. Helens

16 Fluvial Processes
Stream Sediment Movement
Oxbow Lake Formation
Floods and Natural Levee Formation
Stream Terrace Formation

18 The Topography of Arid Lands
Wind Transportation of Sediment
Desert Sand Dunes

19 Glacial Modification of Terrain
End of the Last Ice Age
Isostasy
Flow of Ice within a Glacier
Glacial Processes
Orbital Variations and Climate Change

20 Coastal Processes and Terrain
Wave Motion
Wave Refraction
Tsunami
Tides
Coastal Sediment Transport
Movement of a Barrier Island
Coastal Stabilization Structures
Seamounts & Coral Reefs

VIDEOS

Videos providing engaging visualizations and real-world examples of physical geography concepts can be accessed by students with mobile devices through Quick Response Codes in the book, or through the MasteringGeography™ Study Area. Teachers can assign these media with assessments in MasteringGeography™.

VIDEO MG
Yosemite
https://goo.gl/iXSy3f

1 Introduction to Earth
Mobile Field Trip: Introduction to Physical Geography

2 Portraying Earth
Mobile Field Trip: Introduction to Physical Geography
Studying Fires Using Multiple Satellite Sensors

3 Introduction to the Atmosphere
Ozone Hole
Coriolis Effect Merry Go Round

4 Insolation and Temperature
Seasonal Radiation Patterns
Ocean Circulation Patterns—Subtropical Gyres
Seasonal Changes in Temperature

5 Atmospheric Pressure and Wind
El Niño
La Niña
Mobile Field Trip: El Niño

6 Atmospheric Moisture
Hydrological Cycle
Mobile Field Trip: Clouds: Earth's Dynamic Atmosphere

7 Atmospheric Disturbances
2005 Hurricane Season
Hurricane Sandy

8 Climate and Climate Change
Mobile Field Trip: Climate Change in the Arctic
18,000 Years of Pine Pollen
Temperature and Agriculture

9 The Hydrosphere
Hydrological Cycle
Mobile Field Trip: Moving Water Across California
Mobile Field Trip: Mammoth Cave

10 Cycles and Patterns in the Biosphere
Global Carbon Uptake by Plants
Mobile Field Trip: Forest Fires in the West

11 Terrestrial Flora and Fauna
Mobile Field Trip: Cloud Forest
Climate, Crops, and Bees

12 Soils
Mobile Field Trip: The Critical Zone
Maps of Soil Moisture
California Drought

13 Introduction to Landform Study
Mobile Field Trip: Yosemite
Mobile Field Trip: Oil Sands
Black Smokers

14 The Internal Processes
Mobile Field Trip: San Andreas Fault
Mobile Field Trip: Kīlauea Volcano
Project Condor: Cinder Cones and Basaltic Lava Flows
Project Condor: Monoclines of the Colorado Plateau
Project Condor: Identifying Anticlines and Synclines
Project Condor: Faults versus Joints

15 Weathering and Mass Wasting
Project Condor: Jointing
Mobile Field Trip: Landslide!

16 Fluvial Processes
Mobile Field Trip: Streams of the Great Smoky Mountains
Project Condor: Meandering Rivers
Mobile Field Trip: Mississippi Delta
Project Condor: River Terraces and Base Level

17 Karst and Hydrothermal Processes
Mobile Field Trip: Mammoth Cave

18 The Topography of Arid Lands
Project Condor: Characteristics of Alluvial Fans
Mobile Field Trip: Desert Geomorphology

19 Glacial Modification of Terrain
Mobile Field Trip: The Glaciers of Alaska
Mobile Field Trip: Climate Change in the Arctic

20 Coastal Processes and Terrain
Summertime/Wintertime Beach Conditions
Mobile Field Trip: Gulf Coast Processes
Movement of Sand in Beach Compartment
Mobile Field Trip: Cape Cod: Sculpted by Ice & Storm

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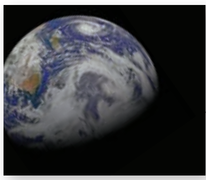

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16 Fluvial Processes 466

PREFACE

McKnight's Physical Geography: A Landscape Appreciation presents the concepts of physical geography in a clear, readable way to help students comprehend Earth's physical landscape. The 12th edition of the book has undergone a thorough revision, while maintaining the time-proven approach to physical geography first presented by Tom McKnight over 30 years ago.

NEW TO THE 12TH EDITION

Users of earlier editions will see that the overall sequence of chapters and most topics remains the same, with material added and updated in several key areas. Changes to the new edition include the following:

- NEW *Global Environmental Change* features written by expert contributors present brief case studies on natural and human-caused environmental change, exploring important contemporary events and implications for the future.
- NEW *Mobile Field Trip Videos* have students accompany acclaimed photographer and pilot Michael Collier in the air and on the ground to explore iconic landscapes of North America and beyond. Readers scan Quick Response (QR) links in the book to access the 20 videos as they read. Also available within MasteringGeography.
- NEW *Project Condor Quadcopter Videos,* linked via QR codes, take students out into the field through narrated quadcopter footage, exploring the physical processes that have helped shape North American landscapes.
- Chapters now open with new "Have You Ever Wondered…?" questions to engage students in the everyday big-picture questions for that chapter.
- Updated *Seeing Geographically* features at the beginning and end of each chapter in the *Learning Review* ask students to perform visual analysis and critical thinking tasks that test their initial assumptions before they read the chapter and their understanding of key chapter concepts after they have read the chapter.
- New *Practicing Geography* photo features highlight the real-world people and professions in geography and science today.
- *Energy for the 21st Century* features have been updated with topics including *Transitioning from Fossil Fuels; Solar Energy; Wind Power; Strategies for Reducing Greenhouse Gas Emissions; Biofuels; Unconventional Hydrocarbons and the Fracking Revolution; Hydropower; Geothermal Energy;* and *Tidal Power.*
- New *Focus* features include *Citizens as Scientists; GIS for Geographic Decision Making; Multiyear Atmospheric and Oceanic Cycles; Soil Differences—They're All About Scale;* and *Death Valley's Extraordinary Basin-and-Range Terrain.*
- Updated and revised *Focus features include Measuring Earth's Surface Temperature by Satellite; GOES Weather Satellites; Conveyor Belt Model of Midlatitude Cyclones; Weather Radar; Signs of Climate Change in the Arctic; What's Killing Our Forests?; Changing Climate Affects Bird Populations; Earthquake Prediction;* and *Imperiled Coral Reefs.*
- Several new *People & the Environment* special content features have been added: *Invasive Species in Florida; Human Impacts of Recent Volcanic Eruptions;* and *The Oso Landslide. Several more have been revised for currency: The UV Index; The Great Pacific Garbage Patch; The Future of the Mississippi River Delta;* and *Disintegration of Antarctic Ice Shelves.*
- The entire art program has continued its thorough revision and updating by illustrator Dennis Tasa. Over 200 new diagrams, maps, and photographs are found throughout. Even the figures that have remained essentially the same have been updated with minor changes to improve usability.
- Each chapter includes a refined learning path, beginning with a series of new *Key Questions* to help students prioritize key issues and concepts.
- Throughout each chapter, new and revised *Learning Check* questions periodically confirm a student's understanding of the material.
- An expanded end-of-chapter *Learning Review* now includes a capstone activity called *Environmental Analysis* that sends students online to use a variety of interactive science resources and data sets to perform data analysis and critical thinking tasks.
- The findings of the IPCC's *Fifth Assessment Report* have been incorporated throughout.
- In Chapter 2, material on GPS and GIS has been updated and expanded.
- In Chapter 4, the material on the greenhouse effect has been updated and revised.
- New diagrams in Chapter 5 illustrate the consequences of El Niño.
- Chapter 7 includes discussion and illustrations of some of the latest storms, including 2015's Hurricane Patricia.
- Chapter 8, Climate and Climate Change, has been thoroughly updated and revised with the latest data and applications, fully incorporating the latest findings of the IPCC.
- Many new and revised diagrams appear in Chapter 14 to illustrate the internal processes.
- Over 130 Quick Response (QR) Codes are integrated throughout the book to enable students with mobile devices to access Mobile Field Trips, Condor Quadcopter Videos, and mobile-ready versions of the Geoscience Animations and other videos as they read, for just-in-time visualization and conceptual reinforcement. These media are also available in the Student Study Area of MasteringGeography, and many can also be assigned by teachers for credit and grading.
- The book is supported by MasteringGeography™, the most widely used and effective online homework, tutorial, and assessment system for the sciences. Assignable media and activities include Geoscience Animations, Videos, *Mobile Field Trip* Videos, *Project Condor* Quadcopter Videos, Encounter Physical Geography Google Earth™ Explorations, GIS-inspired MapMaster™ interactive maps, coaching activities on the toughest topics in physical geography, end-of-chapter questions and exercises, reading quizzes, and Test Bank questions.

TO THE STUDENT

Welcome to *McKnight's Physical Geography: A Landscape Appreciation*. Take a minute to skim through this book to see some of the features that will help you learn the material in your physical geography course:

- You'll notice that the book includes many diagrams, maps, and photographs. Physical geography is a visual discipline, so studying the figures and their captions is just as important as reading through the text itself.
- Many photographs have "locator maps" to help you learn the locations of the many places we mention in the book.
- A reference map of physical features of the world is found inside the front cover of the book, and a reference map of the countries of the world is found inside the back cover.
- *Practicing Geography* photo features highlight the real-world people and professions in geography and science today.
- Each chapter begins with a quick overview of the material, as well as a series of questions—think about these questions as you study the material in that chapter.
- Look at the photograph that begins each chapter. The *Seeing Geographically* questions for this photograph will get you thinking about the material in the chapter and about the kinds of things that geographers can learn by looking at a landscape.
- As you read through each chapter, you'll come across short *Learning Check* questions. These quick questions are designed to check your understanding of key information in the text section you've just read. Answers to the Learning Check questions are found in the back of the book.
- Each chapter concludes with a *Learning Review.* Begin with the *Key Terms and Concepts* questions—these will check your understanding of basic factual information and key terms (which are printed in bold type throughout the text). Then, answer the *Study Questions*—these will confirm your understanding of major concepts presented in the chapter. Finally, you can try the *Exercises*—for these problems you'll interpret maps or diagrams and use basic math to reinforce your understanding of the material you've studied.
- *Environmental Analysis* activities at the end of each chapter will direct you to interactive science resources and data sets for broader data analysis and critical thinking.
- Finish the chapter by answering the *Seeing Geographically* questions at the end of the Learning Review. To answer these questions, you'll put to use things you've learned in the chapter. As you progress through the book, you begin to recognize how much more you can "see" in a landscape after studying physical geography.
- The alphabetical glossary at the end of the book provides definitions for all of the key terms.
- All chapters include Quick Response (QR) codes/icons that direct you to *Mobile Field Trips*, *Project Condor* Quadcopter Videos, online animations, and other videos that you can access with your mobile device. Download free QR scanning apps from the app store for your mobile device. The animations and videos help explain important concepts in physical geography and also provide real-world case studies of physical geography in action. The animations and videos can also be accessed through the Student Study Area in MasteringGeography, and can also be assigned for credit by teachers.

ACKNOWLEDGMENTS

My special thanks goes to the three people most responsible for the improvements you see in this latest edition of *McKnight's Physical Geography*. First, I want to express my admiration and great appreciation for illustrator Dennis Tasa—now having worked together on three editions, he continues to impress me with his ability to take my poorly explained ideas and turn them into effective and impressive illustrations. Next, I extend my thanks to Michael Collier, who developed the *Mobile Field Trips* you find throughout the book—equal parts scientist, educator, story teller and artist, in these field trips he brings to life the excitement and wonder of the study of physical geography. Finally, and most importantly, I offer my gratitude to Executive Development Editor Karen Karlin—her unfailing sound advice, as well as her critical eye for every concept, every sentence, and every piece of art, helped me immeasurably as an author and has vastly improved this book.

More than any previous edition, this was a collaborative effort incorporating contributions of many scholars who wrote short boxed essays, problem sets, and activities for the book. My thanks to all of them, but especially to Redina Herman and Michael Pease for their often unheralded work:

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Over the years, scores of colleagues, students, and friends have helped me and the founding author of this book, Tom McKnight, update and improve this textbook. Their assistance has been gratefully acknowledged previously. Here we acknowledge those who have provided assistance in recent years by acting as reviewers of the text and animations that accompany it, or by providing helpful critiques and suggestions:

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Textbooks of this scope cannot be created without a production team that is as dedicated to quality as the authors. First of all, my thanks go to Pearson Senior Geography Editor Christian Botting, who provided skillful leadership and assembled the outstanding group of professionals with whom I worked. My thanks and admiration go to Project Manager Connie Long, who cheerfully kept me on track throughout the entire production process. Many thanks also to Development Editor Karen Karlin, Program Manager Anton Yakovlev, SPi Global Project Manager Rebecca Lazure, Photo Researcher Kristin Piljay, International Mapping Senior Project Manager Kevin Lear, Director of Development Jennifer Hart, Editorial Assistant Michelle Koski, Executive Marketing Manager Neena Bali, Senior Field Marketing Manager Mary Salzman, Marketing Assistant Ami Sampat, and Media Producers Tim Hainley and Ziki Dekel.

Finally, I wish to express my appreciation for my wife, Nora. Her help, understanding, and support have once again seen me through the long hours and many months of work that went into this book.

Darrel Hess
Earth Sciences Department
City College of San Francisco
50 Phelan Avenue
San Francisco, CA 94112
dhess@ccsf.edu

DIGITAL & PRINT RESOURCES

MasteringGeography™ with Pearson eText. The Mastering platform is the most widely used and effective online homework, tutorial, and assessment system for the sciences. It delivers self-paced tutorials that provide individualized coaching, focus on course objectives, and are responsive to each student's progress. The Mastering system helps teachers maximize class time with customizable, easy-to-assign, and automatically graded assessments that motivate students to learn outside of class and arrive prepared for lecture. MasteringGeography™ offers:

- Assignable activities that include GIS-inspired MapMaster™ interactive map activities, Encounter Google Earth™ Explorations, video activities, Geoscience Animation activities, *Mobile Field Trip* video activities, *Project Condor* Quadcopter video activities, map projections activities, GeoTutor coaching activities on the toughest topics in geography, Dynamic Study Modules that provide each student with a customized learning experience, end-of-chapter questions and exercises, reading quizzes, Test Bank questions, and more.
- A student Study Area with GIS-inspired MapMaster™ interactive maps, videos, Geoscience Animations, *Mobile Field Trip* videos, *Project Condor* Quadcopter videos, web links, glossary flashcards, *In the News* readings, chapter quizzes, PDF downloads of outline maps, an optional Pearson eText, and more.

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www.masteringgeography.com

Television for the Environment "Earth Report" Geography Videos, **DVD** (0321662989). This three-DVD set helps students visualize how human decisions and behavior have affected the environment and how individuals are taking steps toward recovery. With topics ranging from the poor land management promoting the devastation of river systems in Central America to the struggles for electricity in China and Africa, these 13 videos from Television for the Environment's global *Earth Report* series recognize the efforts of individuals around the world to unite and protect the planet.

Geoscience Animation Library, 5th edition, **DVD** (0321716841). Created through a unique collaboration among Pearson's leading geoscience authors, this resource offers over 100 animations covering the most difficult-to-visualize topics in physical geography, meteorology, oceanography, earth science, and physical geology.

Practicing Geography: Careers for Enhancing Society and the Environment by American Association of Geographers (0321811151). This book examines career opportunities for geographers and geospatial professionals in the business, government, nonprofit, and education sectors. A diverse group of academic and industry professionals shares insights on career planning, networking, transitioning between employment sectors, and balancing work and home life. The book illustrates the value of geographic expertise and technologies through engaging profiles and case studies of geographers at work.

Teaching College Geography: A Practical Guide for Graduate Students and Early Career Faculty by American Association of Geographers (0136054471). This two-part resource provides a starting point for becoming an effective geography teacher from the very first day of class. Part One addresses "nuts-and-bolts" teaching issues. Part Two explores being an effective teacher in the field, supporting critical thinking with GIS and mapping technologies, engaging learners in large geography classes, and promoting awareness of international perspectives and geographic issues.

Aspiring Academics: A Resource Book for Graduate Students and Early Career Faculty by American Association of Geographers (0136048919). Drawing on several years of research, this set of essays is designed to help graduate students and early career faculty start their careers in geography and related social and environmental sciences. Aspiring Academics stresses the interdependence of teaching, research, and service—and the importance of achieving a healthy balance of professional and personal life—while doing faculty work. Each chapter provides accessible, forward-looking advice on topics that often cause the most stress in the first years of a college or university appointment.

FOR STUDENTS

Physical Geography Laboratory Manual, 12th edition by Darrel Hess. This lab manual offers a comprehensive set of more than 45 lab exercises to accompany any physical geography class. The first half covers topics such as basic meteorological processes, the interpretation of weather maps, weather satellite images, and climate data. The second half focuses on understanding the development of landforms and the interpretation of topographic maps and aerial imagery. Many exercises have problems that use Google Earth™, and the lab manual website contains maps, images, photographs, satellite movie loops, and Google Earth™ KMZ files. The 12th edition of the lab manual includes both new and revised exercises, new maps, expanded use of Google Earth™, and is now supported by a full MasteringGeography program. **www.masteringgeography.com.**

***Goode's World Atlas,* 23rd Edition** (0133864642). Goode's World Atlas has been the world's premiere educational atlas since 1923—and for good reason. It features over 250 pages of maps, from definitive physical and political maps to important thematic maps that illustrate the spatial aspects of many important topics. The 23rd Edition includes over 160 pages of digitally produced reference maps, as well as thematic maps on global climate change, sea-level rise, CO_2 emissions, polar ice fluctuations, deforestation, extreme weather events, infectious diseases, water resources, and energy production.

Pearson's Encounter Series provides rich, interactive explorations of geoscience concepts through Google Earth™ activities, covering a range of topics in regional, human, and physical geography. For those who do not use *MasteringGeography*™, all chapter explorations are available in print workbooks, as well as in online quizzes at **www.mygeoscienceplace.com**, accommodating different classroom needs. Each exploration consists of a worksheet, online quizzes whose results can be emailed to teachers, and a corresponding Google Earth™ KMZ file.

- Encounter Physical Geography by Jess C. Porter and Stephen O'Connell (0321672526)
- Encounter World Regional Geography by Jess C. Porter (0321681754)
- Encounter Human Geography by Jess C. Porter (0321682203)

***Dire Predictions: Understanding Global Climate Change* 2nd Edition** by Michael Mann, Lee R. Kump (0133909778). Periodic reports from the Intergovernmental Panel on Climate Change (IPCC) evaluate the risk of climate change brought on by humans. But the sheer volume of scientific data remains inscrutable to the general public, particularly to those who may still question the validity of climate change. In just over 200 pages, this practical text presents and expands upon the essential findings of the IPCC's *Fifth Assessment Report* in a visually stunning and undeniably powerful way to the lay reader. Scientific findings that provide validity to the implications of climate change are presented in clear-cut graphic elements, striking images, and understandable analogies.

The Second Edition covers the latest climate change data and scientific consensus from the IPCC *Fifth Assessment Report* and integrates mobile media links to online media. The text is also available in various eText formats, including an eText upgrade option from MasteringGeography courses.

FOR TEACHERS

***Instructor Resource Manual* (Download)** (0134326385). The manual includes lecture outlines and key terms, additional source materials, teaching tips, and a complete annotation of chapter review questions. Available from www.pearsonhighered.com/irc and in the Instructor Resources area of *MasteringGeography*™.

***TestGen® Test Bank* (Download)** by Steve Stadler (0134326377). TestGen® is a computerized test generator that lets you view and edit Test Bank questions, transfer questions to tests, and print tests in a variety of customized formats. This Test Bank includes around 3000 multiple-choice, true/false, and short answer/essay questions. All questions are correlated against the National Geography Standards, textbook key learning concepts, and Bloom's Taxonomy. The Test Bank is also available in Microsoft Word® and importable into Blackboard. Available from **www.pearsonhighered.com/irc** and in the Instructor Resources area of *MasteringGeography*™.

Instructor Resource DVD (0134326369). The Instructor Resource DVD provides a collection of resources to help teachers make efficient and effective use of their time. All digital resources can be found in one well-organized, easy-to-access place. The IRDVD includes:

- All textbook images as JPEGs, PDFs, and PowerPoint™ Presentations
- Pre-authored Lecture Outline PowerPoint® Presentations, which outline the concepts of each chapter with embedded art and can be customized to fit teachers' lecture requirements
- CRS "Clicker" Questions in PowerPoint™
- The TestGen software, Test Bank questions, and answers for both Macs and PCs
- Electronic files of the Instructor Resource Manual and Test Bank

This Instructor Resource content is also available online via the Instructor Resources section of *MasteringGeography*™ and **www.pearsonhighered.com/irc**.

Learning Catalytics is a "bring your own device" student engagement, assessment, and classroom intelligence system. With Learning Catalytics, you can:

- Assess students in real time, using open-ended tasks to probe student understanding.
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Learning Catalytics is a technology that has grown out of twenty years of cutting-edge research, innovation, and implementation of interactive teaching and peer instruction. Available integrated with MasteringGeography™.

DEDICATION

For our nephews, Daniel, Kyle, and Nicholas

D. H.

ABOUT OUR SUSTAINABILITY INITIATIVES

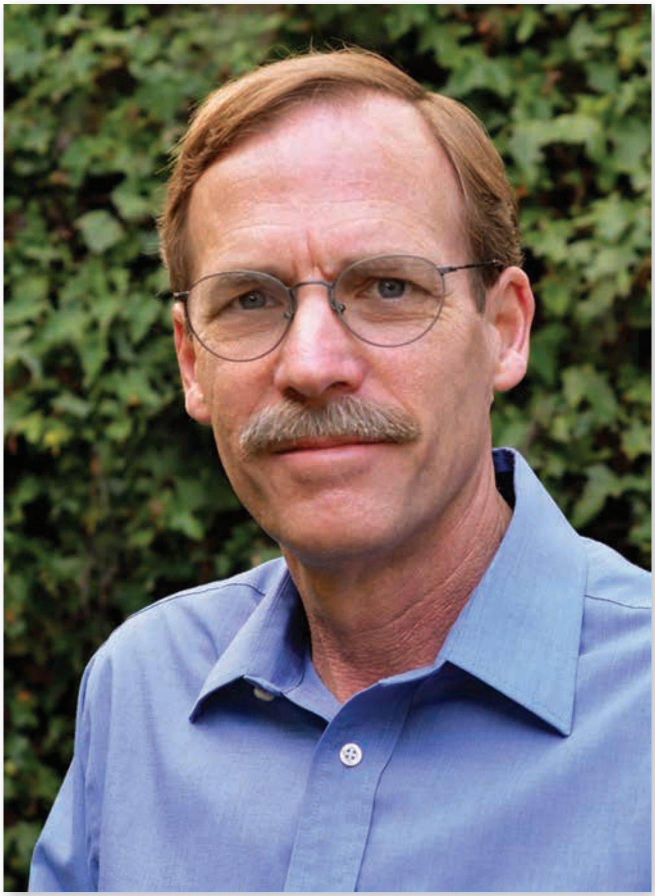
Pearson recognizes the environmental challenges facing this planet, as well as acknowledges our responsibility in making a difference. This book is carefully crafted to minimize environmental impact. The binding, cover, and paper come from facilities that minimize waste, energy consumption, and the use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

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

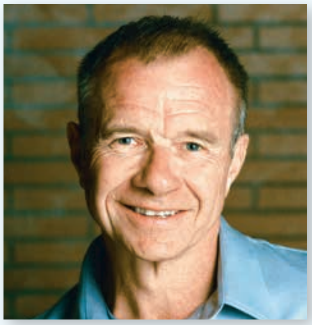
The future holds great promise for reducing our impact on Earth's environment, and Pearson is proud to be leading the way. We strive to publish the best books with the most up-to-date and accurate content, and to do so in ways that minimize our impact on Earth. To learn more about our initiatives, please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

PEARSON

ABOUT THE AUTHORS



Darrel Hess began teaching geography at City College of San Francisco in 1990 and served as chair of the Earth Sciences Department from 1995 to 2009. After earning his bachelor's degree in geography at the University of California, Berkeley, in 1978, he served for two years as a teacher in the Peace Corps on Jeju Island, Korea. Upon returning to the United States, he worked as a writer, photographer, and audiovisual producer. His association with Tom McKnight began as a graduate student at UCLA, where he served as one of Tom's teaching assistants. Their professional collaboration developed after Darrel graduated from UCLA with a master's degree in geography in 1990. He first wrote the *Study Guide* that accompanied the fourth edition of *Physical Geography: A Landscape Appreciation*, and then the *Laboratory Manual* that accompanied the fifth edition. Darrel continues to author the *Laboratory Manual,* along with the *California Edition* of this book, now in its fourth incarnation. In 1999 Tom asked Darrel to join him as coauthor of the textbook. Darrel was the 2014 recipient of the American Association of Geographers (AAG) Gilbert Grosvenor Geographic Education Honors. As did Tom, Darrel greatly enjoys the outdoor world. Darrel and his wife, Nora, are avid hikers, campers, and scuba divers.

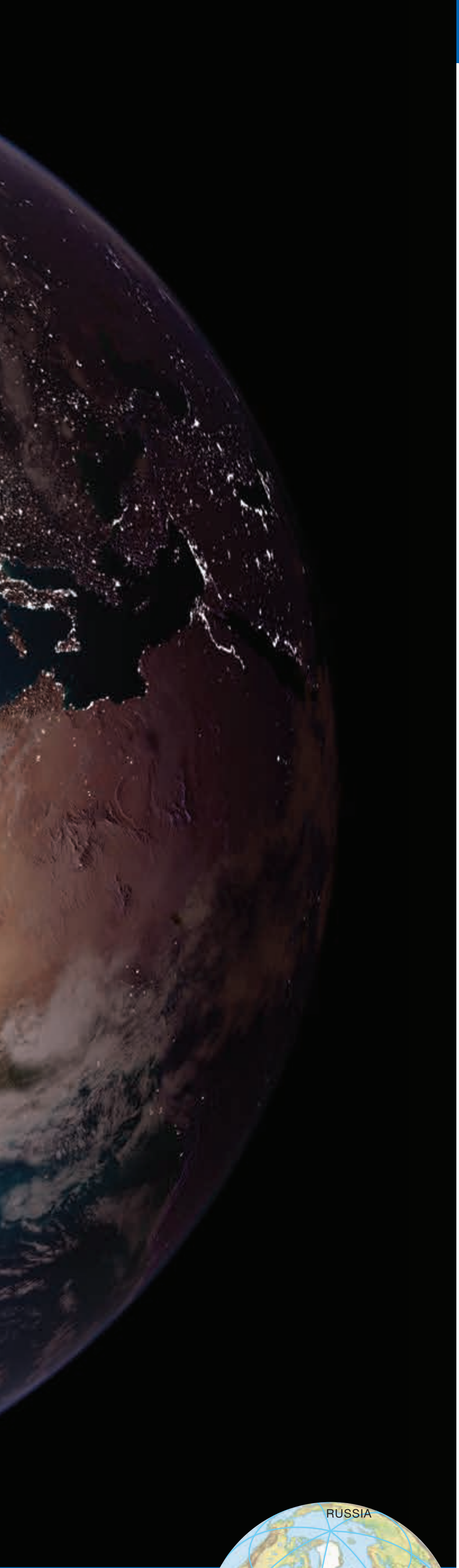


Tom L. McKnight taught geography at UCLA from 1956 to 1993. He received his bachelor's degree in geology from Southern Methodist University in 1949, his master's degree in geography from the University of Colorado in 1951, and his Ph.D. in geography and meteorology from the University of Wisconsin in 1955. During his long academic career, Tom served as chair of the UCLA Department of Geography from 1978 to 1983, and was director of the University of California Education Abroad Program in Australia from 1984 to 1985. Passionate about furthering the discipline of geography, he helped establish the UCLA/Community College Geography Alliance and generously funded awards for both undergraduate and graduate geography students. His many honors include the California Geographical Society's Outstanding Educator Award in 1988, and the honorary rank of Professor Emeritus upon his retirement from UCLA. In addition to *Physical Geography: A Landscape Appreciation*, his other college textbooks include *The Regional Geography of the United States and Canada*; *Oceania: The Geography of Australia, New Zealand, and the Pacific Islands*; and *Introduction to Geography*, with Edward F. Bergman. Tom passed away in 2004—the geographic community misses him enormously.

1

SeeingGeographically

NASA created this natural-color, composite satellite image of Earth. What evidence of human presence do you see here? What might cause the different colors of the ocean areas? The different colors of the land areas? What relationship might exist between the color of land surfaces and the presence or absence of cloud cover?



Introduction to Earth

Have You Ever Wondered how we know that human activity is changing global climate? Or why Seattle residents need to worry about earthquakes but Minneapolis residents don't? Or why kangaroos are native to Australia but not to China? Or even why the days are longer in summer than in winter? These are the kinds of questions we answer in physical geography.

If you opened this book expecting that the study of geography was going to be memorizing names and places on maps, you'll be surprised to find that geography is much more than that. Geographers study the location and distribution of things—tangible things such as rainfall, mountains, and trees, as well as less tangible things such as language, migration, and voting patterns. In short, geographers look for and explain patterns in the physical and human landscape.

In this book you learn about fundamental processes and patterns in the natural world—the kinds of things you can see whenever you walk outside: clouds in the sky, mountains, streams and valleys, and the plants and animals that inhabit the landscape. You also learn about human interactions with the natural environment—how events such as hurricanes, earthquakes, and floods affect our lives and the world around us, as well as how human activities are increasingly altering our global environment. By the time you finish this book, you'll understand—in other words, you'll appreciate—the landscape in new ways.

As you study this chapter, think about these **KeyQuestions**:

- **How do geographers study the world?**
- **How do we make sense of different environments on Earth?**
- **How does Earth fit in with the solar system?**
- **How do we describe location on Earth?**
- **Why do the seasons change?**
- **How do global time zones work?**

MOBILE FIELD TRIP MG
Introduction to Physical Geography
https://goo.gl/B2xTBh

Mobile Field Trip videos, created by renowned Earth Science writer, photographer, and pilot Michael Collier, are virtual field trips that explore physical geography from the air and ground. This first Mobile Field Trip introduces you to the study of physical geography.

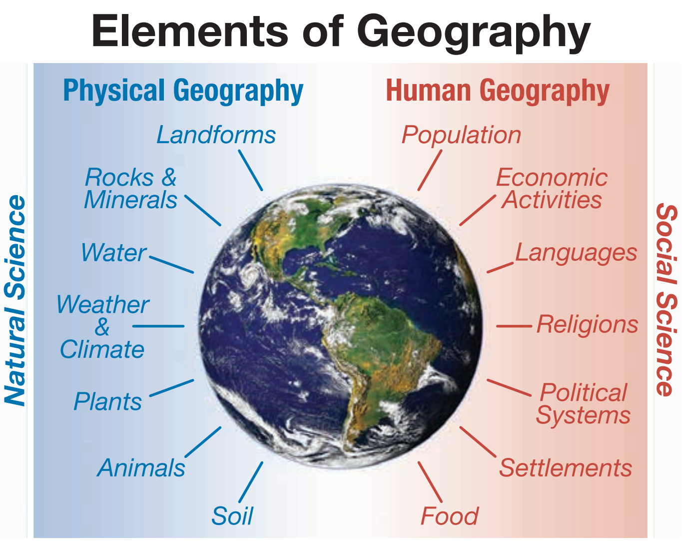
Geography and Science

The word **geography** comes from the Greek words meaning "Earth description." Several thousand years ago many scholars were indeed "Earth describers," and therefore geographers, more than anything else. Nonetheless, over the centuries there was a trend away from generalized Earth description toward more specialized disciplines—such as geology, meteorology, economics, and biology—so geography as a field of study was somewhat overshadowed. Over the last few hundred years, however, geography reaffirmed its place in the academic world, and today geography is an expanding and flourishing field of study.

Studying the World Geographically

Geographers study how things differ from place to place—the distributional and locational relationships of things around the world (what is sometimes called the "spatial" aspect of things). Figure 1-1 shows the kinds of "things" geographers study, divided into two groups representing the two principal branches of geography. The elements of **physical geography** are natural in origin, and for this reason physical geography is sometimes called *environmental geography*. The elements of **human geography** are those of human endeavor; this branch includes such subfields as *cultural geography*, *economic geography*, *political geography*, and *urban geography*. The almost unlimited possible combinations of these various elements create the physical and cultural landscapes of the world that geographers study.

All of the items shown in Figure 1-1 are familiar to us, and this familiarity highlights a basic characteristic of geography as a field of learning: geography doesn't have its own body of facts or objects that only geographers study. The focus of geology is rocks, the attention of economics is economic systems, demography examines human population, and so on. Geography, on the other hand, is much broader in scope than most other disciplines, "borrowing" its objects of study from related fields. Geographers, too, are interested in rocks and economic systems and population—especially in describing and understanding their location and distribution. We sometimes say that geography asks the fundamental question, "Why is what where, and so what?"



▲ **Figure 1-1** The elements of geography can be grouped into two broad categories. Physical geography primarily involves the study of natural science, whereas human geography primarily entails the study of social science.

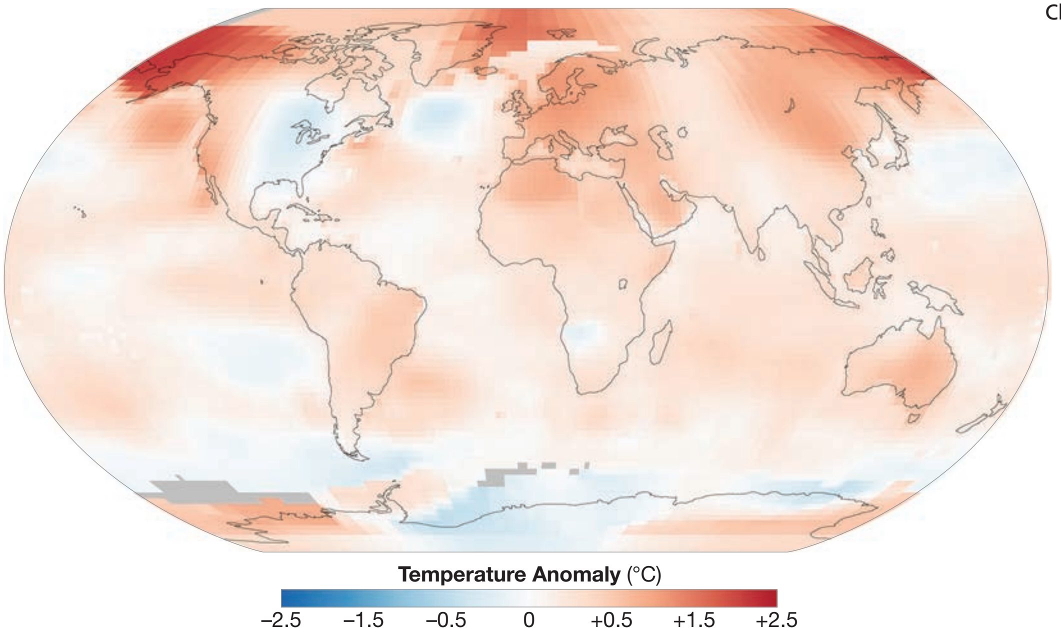
LearningCheck 1-1 **What are the differences between physical geography and human geography?** (Answer on p. AK-1)

Another basic characteristic of geography is its interest in interrelationships. One cannot understand the distribution of soils, for example, without knowing something about the rocks from which the soils were derived, the slopes on which the soils developed, and the climate and vegetation under which they developed. Similarly, it is impossible to comprehend the distribution of agriculture without an understanding of climate, topography, soil, drainage, population, economic conditions, technology, historical development, and many other factors, both physical and cultural. Because of its wide scope, geography bridges the academic gap between natural science and social science, studying all of the elements in Figure 1-1 in an intricate web of geographic interrelationships.

In this book we concentrate on the physical elements of the landscape, the processes involved in their development, their distribution, and their basic interrelationships. As we proceed from chapter to chapter, this notion of landscape development by natural processes and landscape modification by humans serves as a central focus. We pay attention to elements of human geography when they help to explain the development or patterns of the physical elements—especially the ways in which humans influence or alter the physical environment.

Global Environmental Change: Several broad geographic themes run through this book. One of these themes is *global environmental change*—both the human-caused and natural processes that are currently altering the landscapes of the world. Some of these changes can take place over a period of just a few years, whereas others require many decades or even thousands of years (Figure 1-2). We pay special attention to the accelerating impact of human activities on the global environment: in the chapters on the atmosphere we discuss such issues as human-caused climate change, ozone depletion, and acid rain, whereas in later chapters we look at issues such as rainforest removal and coastal erosion.

Rather than treat global environmental change as a separate topic, we integrate this theme throughout the book. To help with this integration, we supplement the main text with short boxed essays, such as those titled "People & the Environment" that focus on specific cases of human interaction with the natural environment, as well as boxes titled "Energy for the 21st Century" that focus on the challenge of supplementing—and perhaps eventually replacing—fossil fuels with renewable sources of energy. These essays



◀ **Figure 1-2** Earth's climate is changing. This image shows the difference in temperature (the *temperature anomaly* in °C) during the year 2014 compared with the average temperatures for the baseline period 1951 to 1980. *(NASA)*

serve to illustrate the connections between many aspects of the environment—such as the relationships between changing global temperatures, changing sea level, changing quantities of polar ice, and the changing distribution of plant and animal species—and the global economy and human society.

Furthermore, in each chapter you'll see boxed essays titled "Global Environmental Change." These essays introduce special topics and include activities and questions that will help you understand the scope of both natural and human-caused environmental changes.

Globalization: A related but less obvious theme running through this book is *globalization*. In the broadest terms, globalization refers to the processes and consequences of an increasingly interconnected world—connections among the economies, cultures, and political systems of the world. Although globalization is most commonly associated with the cultural and economic realms of the world, it is important to recognize the environmental components of globalization as well. For example, the loss of tropical rainforest for timber or commercial agriculture in some regions of the world is driven in part by growing demand for commodities in countries far from the tropics (**Figure 1-3**). Similarly, rapid economic growth in newly industrialized countries is contributing to the already high atmospheric greenhouse gas emissions of industrialized countries—the interconnected economies of the world are thus interconnected in their influence on the natural environment.

Because of geography's global perspective and its interest in both the natural and human landscapes, geographers are able to offer insights into many of the world's most pressing problems—problems too complex to address from a narrower perspective. For example, the detrimental consequences of climate change cannot be addressed if we ignore the economic, social, historical, and political aspects of the issue. Similarly, global inequities of wealth and political power cannot be addressed if we ignore environmental and resource issues.

Just about everything in the world is in one way or another connected with everything else! Geography helps us understand these connections.

LearningCheck 1-2 **Why are physical geographers interested in globalization?**

▼ **Figure 1-3** Deforestation in some parts of the tropics is influenced by consumer demand in other parts of the world. This logging operation is in Sarawak, Borneo, Malaysia.

The Process of Science

Because physical geography is concerned with processes and patterns in the natural world, knowledge in physical geography is advanced primarily through the study of science. It is useful for us to say a few words about science in general.

Science is often described—although somewhat simplistically—as a process that follows the *scientific method*:

1. Observe phenomena that stimulate a question or problem.
2. Offer an educated guess—a *hypothesis*—about the answer.
3. Design an experiment to test the hypothesis.
4. Predict the outcome of the experiment if the hypothesis is supported and if the hypothesis is not supported.
5. Conduct the experiment and observe what actually happens.
6. Draw a conclusion or formulate a simple generalized "rule" based on the results of the experiment.

In practice, however, science doesn't always work through experimentation; in many fields of science, data collection through observation of a phenomenon is the basis of knowledge. In some regards science is best thought of as a process—or perhaps even as an attitude—for gaining knowledge. The scientific approach is based on observation, experimentation, logical reasoning, skepticism of unsupported conclusions, and the willingness to modify or even reject long-held ideas when new evidence contradicts them. For example, up until the 1950s most Earth scientists thought it impossible that the positions of continents could change over time. However, as we see in Chapter 14, by the late 1960s enough new evidence had been gathered to convince them that their earlier ideas were wrong—the configuration of continents has changed and continues to change!

Although the term "scientific proof" is sometimes used by the general public, strictly speaking, science does not "prove" ideas. Instead, science works by eliminating alternative explanations—eliminating explanations that aren't supported by evidence. In fact, in order for a hypothesis to be "scientific," there must be some test or possible observation that could *disprove* it. If there is no way to disprove an idea, then that idea simply cannot be supported by science.

The word "theory" is often used in everyday conversation to mean a "hunch" or conjecture. However, in science a *theory* represents the highest order of understanding for a body of information—a logical, well-tested explanation that encompasses a wide variety of facts and observations. Thus, the "theory of plate tectonics" presented in Chapter 14 represents an empirically supported, broadly accepted, overarching framework for understanding processes that operate within Earth.

The acceptance of scientific ideas and theories is based on a preponderance of evidence, not on "belief" and not on the pronouncements of "authorities." New observations and new evidence often cause scientists to revise their conclusions and theories or those of others. Much of this self-correcting process for refining scientific knowledge takes place through peer-reviewed journal articles. Peers—that is, fellow scientists—scrutinize a scientific report for sound reasoning, appropriate data collection, and solid evidence before it is published; reviewers need not agree with the author's conclusions, but they strive to ensure that the research meets rigorous standards of scholarship before publication.

Because new evidence may prompt scientists to change their ideas, good science tends to be somewhat cautious in the conclusions that are drawn. For this reason, the findings of many scientific studies are prefaced by phrases such as "the evidence suggests" or "the results most likely show." In some cases, different scientists interpret the same data quite differently and so disagree in their conclusions. Frequently, studies find that "more research is needed." The kind of uncertainty sometimes inherent in science may lead the general public to question the conclusions of scientific studies—especially when presented with a simple, and perhaps comforting, nonscientific alternative. It is, however, this very uncertainty that often compels scientists to push forward in the quest for knowledge and understanding!

In this book we present the fundamentals of physical geography as it is supported by scientific research and evidence. In some cases, we describe how our current understanding of a phenomenon developed over time; in other cases we point out where uncertainty remains, where scientists still disagree, or where intriguing questions still remain.

LearningCheck 1-3 **Why is the term "theory" sometimes misunderstood by the general public?**

With the widespread use of cell phones and other mobile devices, nonprofessionals are increasingly able to contribute to scientific studies. Volunteer "citizen scientists" collect data and report their observations or images of various phenomena to researchers—see the box *Focus: Citizens as Scientists*.

Numbers and Measurement Systems

Because so much of science is based on observation and measurable data, any thorough study of physical geography entails the use of mathematics. Although this book introduces physical geography primarily in a conceptual way without the extensive use of mathematical formulas, numbers and measurement systems are nonetheless important for us. Throughout the book, we use numbers and simple formulas to help illustrate concepts—the most obvious of which are numbers used to describe distance, size, weight, or temperature.

Two quite different measurement systems are used today. In the United States, much of the general public is most familiar with the *English System* of measurement—with measurements such as miles, pounds, and degrees Fahrenheit.

focus

Citizens as Scientists

▶ Christopher J. Seeger, Iowa State University

Snap a photo of an insect, a bird, or a landscape while you are hiking in a park; track the temperature of a neighborhood stream; record sounds in the forest; or document some other aspect of the environment as you interact with it—and you could contribute your data to a *participatory science* research project. By sharing your findings through educational websites, interactive atlases, or wikis, such as http://greatnatureproject.org, you can become involved in environmental monitoring, inventorying of species, or conservation planning and management. Although these projects use data collected by trained experts, information is also provided by average citizens interacting with the environment (Figure 1-A). Participants are often referred to as *citizen scientists* as they collectively help build repositories of scientific data.

Volunteered Geographic Information (VGI): This process of voluntarily creating and sharing data that include geographic information is referred to as *volunteered geographic information* (VGI) and is a form of *geospatial crowdsourcing*. Today's integration of GPS-enabled smartphones and online mapping tools, allowing citizens to overlay spatial information on satellite imagery, makes it easy to create and share data. VGI is a valuable tool that allows individuals who may not be trained as professionals in a specific field to contribute to large research projects, sharing personal observations or perceptions to allow for more informed decision making or provide on-the-ground updates during natural disasters or times of civil unrest.

Data Validity: With VGI data, we can acquire large quantities of up-to-date information locally and quickly. *Facilitated-VGI* (f-VGI) builds upon VGI by providing a collection mechanism that sets parameters as to the type and location of the data. F-VGI can also provide reliability by requiring the data to be collected on-site or by a contributor who is local to the area of interest. Reliability is further established by having multiple people submit information about a location.

Examples: Participatory science projects can vary greatly in purpose and scope. For instance, the Appalachian Mountain Club (www.outdoors.org/conservation/mountainwatch/vizvols-how.cfm) invites volunteers to submit pictures of mountains so that scientists can study air quality and haze pollution. The Did You Feel It? program (http://earthquake.usgs.gov/earthquakes/dyfi/) invites users to describe their experience in and the effects and extent of damage of an earthquake event (Figure 1-B).

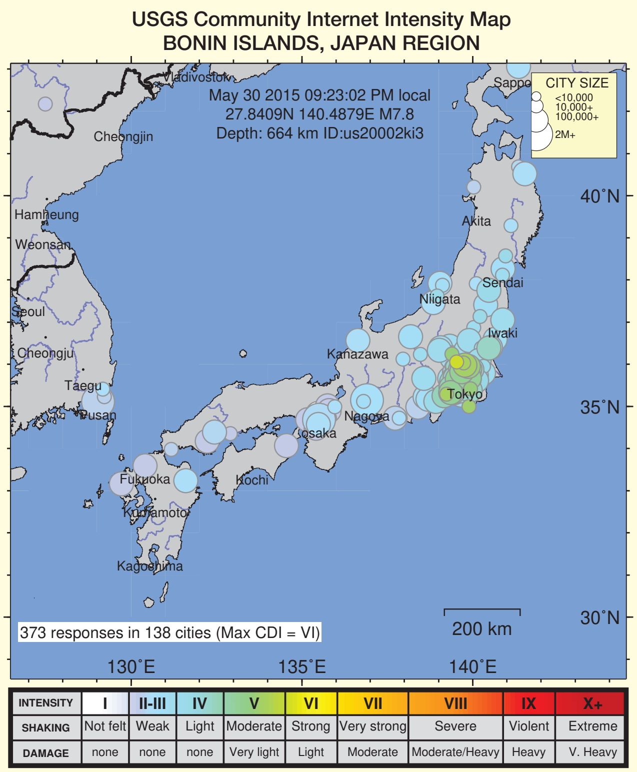
VGI is a significant aid in mapping biodiversity. For example, citizen scientists submit sightings of plants and animals at local, regional, or national levels to the Atlas of Living Australia (www.ala.org.au). The Unified Butterfly Recorder app (www.reimangardens.com/collections/insects/unified-butterfly-recorder-app/) is a tool for recording butterfly sightings that ties the data to location, time of day, and weather. The What Do Birds Eat? project (www.whatdobirdseat.com) invites volunteers to submit geo-tagged photos that an expert can verify before the data are added to a map.

VGI can also provide assistance in disaster recovery. In such *crisis mapping*, data gathered by a large number of individuals across an impacted region can aid responders by allowing them to display and analyze the data information in near real time. During the 2015 earthquakes around Nepal, thousands of "volunteer mappers" provided humanitarian support. By digitizing the data from aerial imagery or collecting data from users on the ground and applying it to local maps, they helped fill in gaps.

The Future of VGI: The ability to provide near-instant sharing of relevant geographic information is having a significant impact on those involved in geographic science. As more people become equipped with geospatially enabled devices, the notion of *citizens as sensors* will become more commonplace.

Questions

1. Provide an example of how VGI might be implemented for monitoring weather.
2. When might VGI data *not* provide valid information?



▲ **Figure 1-B** Map of Japan, showing shaking intensity reports to the U.S. Geological Survey "Did You Feel It?" website for a May 2015 earthquake.

PracticingGeography

▲ **Figure 1-A** Volunteers count albatross nests on Midway Atoll, in the Pacific.

TABLE 1-1 Unit Conversions—Quick Approximations

	S.I. to English Units	English to S.I. Units
Distance:	1 centimeter = a little less than $\frac{1}{2}$ inch	1 inch = about $2\frac{1}{2}$ centimeters
	1 meter = a little more than 3 feet	1 foot = about $\frac{1}{3}$ meters
	1 kilometer = about $\frac{2}{3}$ mile	1 yard = about 1 meter
		1 mile = about $1\frac{1}{2}$ kilometers
Volume:	1 liter = about 1 quart	1 quart = about 1 liter
		1 gallon = about 4 liters
Mass:	1 gram = about $\frac{1}{30}$ ounce	1 ounce = about 30 grams
	1 kilogram = about 2 pounds	1 pound = about $\frac{1}{2}$ kilogram
Temperature:	1°C change = 1.8°F change	1°F change = about 0.6°C change

For exact conversion formulas, see Appendix I.

However, most of the rest of the world—and the entire scientific community—uses the **International System** of measurement (abbreviated **S.I.** from the French *Système International*; also called the "metric system")—with measurements such as kilometers, kilograms, and degrees Celsius.

This book gives measurements in both S.I. and English units. Table 1-1 provides some quick approximations of the basic equivalents in each; detailed tables of conversion formulas between English and S.I. units appear in Appendix I.

Environmental Spheres and Earth Systems

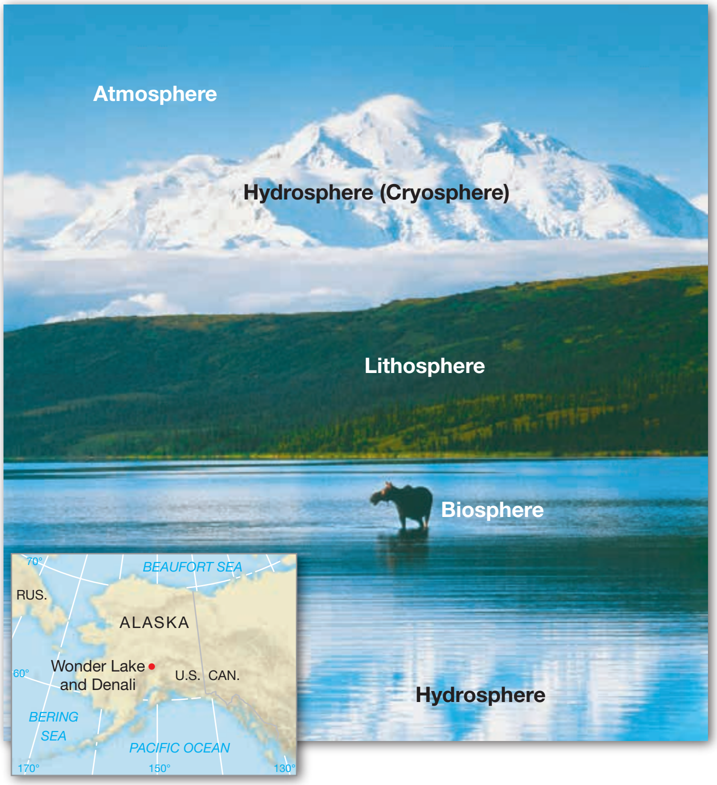
From the standpoint of physical geography, the surface of Earth is a complex interface where four principal components of the environment meet and to some degree overlap and interact (Figure 1-4). These four components are often referred to as Earth's *environmental spheres*.

Earth's Environmental Spheres

The solid, inorganic portion of Earth is sometimes called the **lithosphere**[1] (*litho* is Greek for "stone"), comprising the rocks of Earth's crust as well as the unconsolidated particles of mineral matter that overlie the solid bedrock. The lithosphere's surface is shaped into an almost infinite variety of landforms, both on the seafloors and on the surfaces of the continents and islands.

The gaseous envelope of air that surrounds Earth is the **atmosphere** (*atmo* is Greek for "air"). It contains the complex mixture of gases needed to sustain life. Most of the atmosphere is close to Earth's surface, being densest at sea level and rapidly thinning with increased altitude. It is a very dynamic sphere, kept in almost constant motion by solar energy and Earth's rotation.

The **hydrosphere** (*hydro* is Greek for "water") comprises water in all its forms. The oceans contain the vast majority of the water found on Earth and are the moisture source for most precipitation. A subcomponent of the



▲ **Figure 1-4** Earth's physical landscape is composed of four overlapping, interacting systems called "spheres." The atmosphere is the air we breathe. The hydrosphere is the water of rivers, lakes, and oceans, the moisture in soil and air, as well as the snow and ice of the cryosphere. The biosphere is the habitat of all life, as well as the life-forms themselves. The lithosphere is the soil and bedrock that cover Earth's surface. This scene shows Wonder Lake and Denali (formerly Mt. McKinley) in Denali National Park, Alaska.

[1]As we will see in Chapter 13, in the context of *plate tectonics* and our study of landforms, the term "lithosphere" is used specifically to refer to large "plates" consisting of Earth's crustal and upper mantle rock.

hydrosphere is known as the **cryosphere** (*cry* comes from the Greek word for "cold")—water frozen as snow and ice.

The **biosphere** (*bio* is Greek for "life") encompasses all the parts of Earth where living organisms can exist; in its broadest and loosest sense, the term also includes the vast variety of earthly life-forms (properly referred to as *biota*).

These "spheres" are not discrete entities but rather are considerably interconnected. This intermingling is readily apparent when we consider an ocean—a body that is clearly a major component of the hydrosphere yet may contain a vast quantity of fish and other organisms that are part of the biosphere. An even better example is soil, which is composed largely of bits of mineral matter (lithosphere) but also contains life-forms (biosphere), along with air (atmosphere), soil moisture (hydrosphere), and perhaps frozen water (cryosphere) in its pore spaces.

The environmental spheres can help us broadly organize concepts for the systematic study of Earth's physical geography and are used that way in this book.

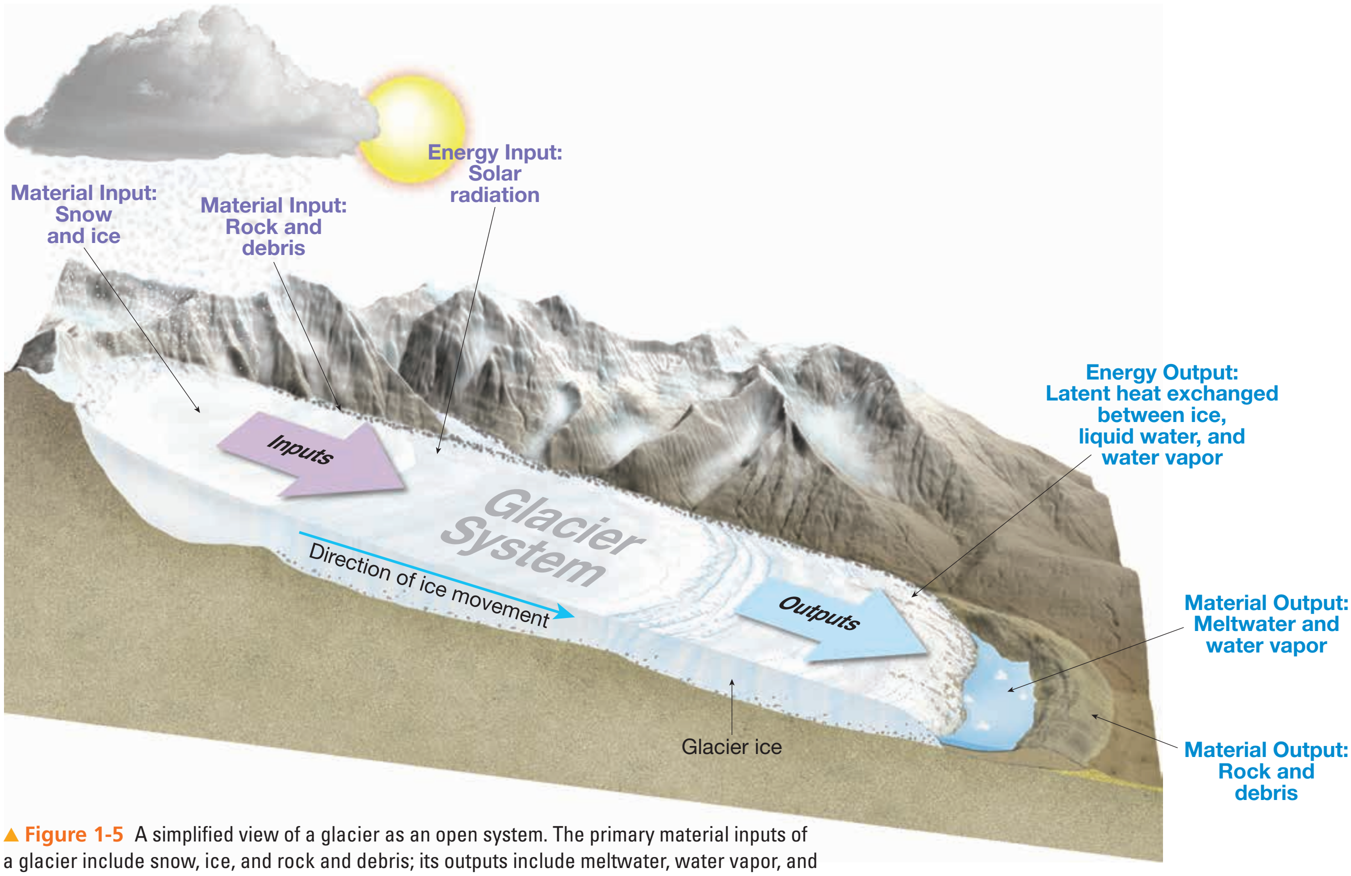
LearningCheck 1-4 **Briefly define the lithosphere, atmosphere, hydrosphere, cryosphere, and biosphere.**

Earth Systems

Earth's environmental spheres operate and interact through a complex of *Earth systems*. By "system" we mean a collection of things and processes that are connected and operate as a whole. In the human realm, for example, we talk of a global "financial system" that encompasses the exchange of money between institutions and individuals, or of a "transportation system" that involves the movement of people and commodities. In the natural world, systems entail the interconnected flows and storage of energy and matter.

Closed Systems: Effectively self-contained systems, which are therefore isolated from influences outside that system, are called *closed systems*. It is rare to find closed systems in nature. Earth as a whole is essentially a closed system with regard to matter—currently there is no significant increase or decrease in the amount of matter (the "stuff") of Earth, although relatively small but measurable amounts of meteoric debris arrives from space, and tiny amounts of gas are lost to space from the atmosphere. Energy, on the other hand, does enter and exit the Earth system constantly.

Open Systems: Most Earth systems are *open systems*—both matter and energy are exchanged across the system boundary. Matter and energy that enter the system are called *inputs*, and losses from the system to its surroundings are called *outputs*. For example, as we see in Chapter 19, a glacier behaves as an open system (Figure 1-5). The material inputs to a glacier include water in the form of snow and ice, along with rocks and other debris picked up by the moving ice; the material outputs of a glacier include the meltwater and water vapor lost to the atmosphere, as well



▲ **Figure 1-5** A simplified view of a glacier as an open system. The primary material inputs of a glacier include snow, ice, and rock and debris; its outputs include meltwater, water vapor, and rock and debris transported by the flowing ice. The energy interchange includes incoming solar radiation and the exchange of latent heat between ice, liquid water, and water vapor.

as the rock and debris transported and eventually deposited by the ice. The most obvious energy input into a glacial system is solar radiation, which melts the ice by warming the surrounding air and by direct absorption into the ice itself. But also at work are less obvious exchanges of energy that involve *latent heat*—energy stored by water during melting and evaporation, and released during freezing and condensation. (Latent heat is discussed in detail in Chapter 6.)

Equilibrium: When inputs and outputs balance over time, the conditions within a system remain the same; we describe such a system as being in *equilibrium*. For instance, a glacier will remain the same size over many years if its inputs of snow and ice are balanced by the loss of an equivalent amount of ice through melting. If, however, the balance between inputs and outputs changes, equilibrium will be disrupted—increasing snowfall for several years, for example, can cause a glacier to grow until a new equilibrium size is reached.

Interconnected Systems: In physical geography we study the myriad of interconnections among Earth's systems and subsystems. Continuing with our example of a glacier: the system of an individual glacier is interconnected with many other Earth systems, including Earth's solar radiation budget (discussed in Chapter 4), wind and pressure patterns (discussed in Chapter 5), and the hydrologic cycle (discussed in Chapter 6). If inputs or outputs in those systems change, a glacier may also change. For instance, if air temperature increases through a change in Earth's solar radiation budget, both the amount of water vapor available to precipitate as snow and the rate of melting of that snow may change, causing an adjustment in the size of the glacier.

LearningCheck 1-5 **What does it mean when we say a system is in equilibrium?**

Feedback Loops: Some systems produce outputs that "feed back" into that system, reinforcing change. As we see in Chapter 8, over the last few decades increasing temperatures in the Arctic have reduced the amount of highly reflective summer sea ice. As the area of sea ice has diminished, the darker, less reflective ocean has absorbed more solar radiation, contributing to the temperature increase—which in turn has reduced the amount of sea ice even more, further reducing reflection and increasing absorption. Were Arctic temperatures to decrease, an expanding cover of reflective sea ice would reduce absorption of solar radiation and so reinforce a cooling trend. These are examples of *positive feedback loops*—change within a system continuing in one direction.

Conversely, *negative feedback loops* tend to inhibit a system from changing—in this case, increasing a system input tends to *decrease* further change, keeping the system in equilibrium. For example, an increase in air temperature may increase the amount of water vapor in the air; the extra water vapor may in turn condense and increase the cloud cover—which can reflect incoming solar radiation and so prevent a further temperature increase.

Although systems may resist change through negative feedback loops, a system may reach a *tipping point* or *threshold*. Beyond that point, the system becomes unstable and changes abruptly until it reaches a new equilibrium. For instance, as we see in Chapter 9, the increasing freshwater runoff from melting glaciers in the Arctic could one day disrupt the energy transfer of the slow deep ocean *thermohaline circulation* in the Atlantic Ocean, triggering a sudden change in climate.

The preceding examples are not intended to confuse you but rather to illustrate the great complexity of Earth's interconnected systems! Because of this complexity, in this book we often first describe one process or Earth system in isolation before we present its interconnections with other systems.

LearningCheck 1-6 **What is the difference between a positive feedback loop and a negative feedback loop?**

Earth and the Solar System

Earth is part of a larger *solar system*—an open system with which Earth interacts. Earth is an extensive rotating mass of mostly solid material that orbits the enormous ball of superheated gases we call the Sun. The geographer's concern with spatial relationships properly begins with the relative location of this "spaceship Earth" in the universe.

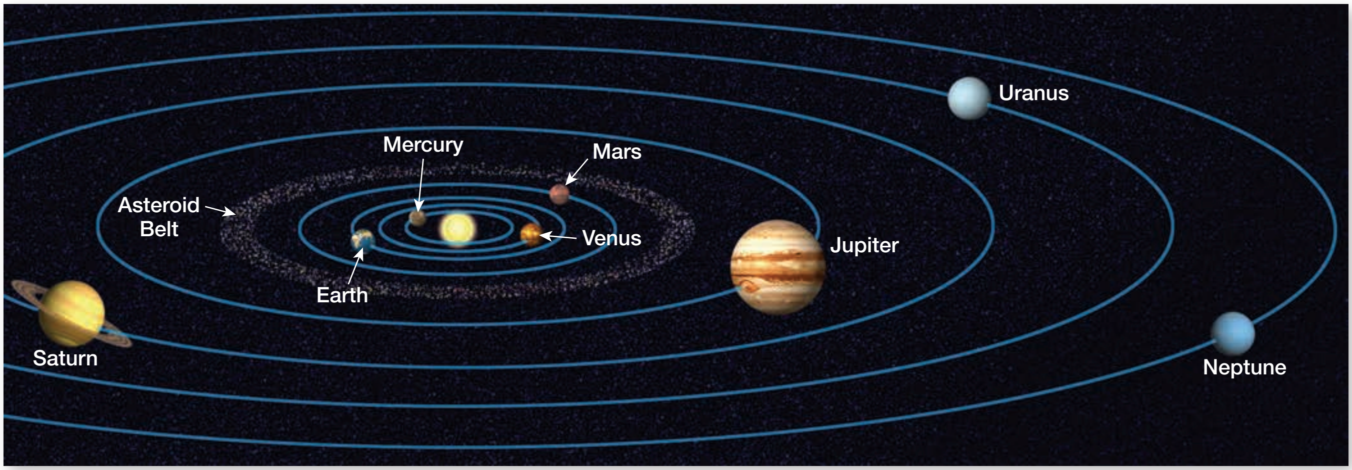
ANIMATION MG
Solar System Formation
http://goo.gl/alti7U

The Solar System

Earth is one of eight planets of our solar system, which also contains more than 160 natural satellites or "moons" revolving around the planets; an uncertain number of smaller *dwarf planets*, such as Pluto; scores of comets (bodies composed of frozen liquid and gases together with small pieces of rock and metallic minerals); more than 500,000 asteroids (small, rocky, and sometimes icy objects, mostly less than a few kilometers in diameter); and millions of meteoroids (most of them the size of sand grains).

The medium-massed star we call the Sun is the central body of the solar system and makes up more than 99.8 percent of its total mass. The solar system is part of the Milky Way Galaxy, which consists of at least 200,000,000,000 stars arranged in a disk-shaped spiral that is about 100,000 light-years in diameter and 10,000 light-years thick at the center. (One light-year equals the distance a beam of light travels over a period of one year—about 9.5 trillion kilometers.) The Milky Way Galaxy is only one of hundreds of billions of galaxies in the universe.

Origins: The origin of Earth, and indeed of the universe, is incompletely understood. It is generally accepted that the universe began with a cosmic event called the *big bang*. The most widely held view is that the big bang took place about 13.7 billion years ago—similar to the age of the oldest known stars. The big bang began in a fraction of a second



▲ **Figure 1-6** The solar system (not drawn to scale). The Sun is not exactly at the center of the solar system—the planets revolve around the Sun in elliptical orbits. The Kuiper Belt, which includes dwarf planets such as Pluto, begins beyond Neptune.

as an infinitely dense and infinitesimally small bundle of energy containing all of space and time started to expand in all directions at extraordinary speeds, pushing out the fabric of space and filling the universe with the energy and matter we see today.

Our solar system originated between 4.5 and 5 billion years ago when a *nebula*—a huge, cold, diffuse cloud of gas and dust—began to contract inward due to gravitational collapse, forming a hot, dense *protostar*. This hot center became our Sun, and the cold revolving disk of gas and dust around it eventually condensed and coalesced to form the planets.

All of the planets revolve around the Sun in elliptical orbits, with the Sun located at one focus. (If we look "down" on the solar system from a vantage point high above the North Pole of Earth, the planets appear to orbit in a counterclockwise direction around the Sun.) All the planetary orbits are in nearly the same plane (Figure 1-6), perhaps revealing their relationship to the original spinning direction of the nebular disk.

The Planets: The four inner *terrestrial planets*—Mercury, Venus, Earth, and Mars—are generally smaller, denser, and less oblate (more nearly spherical) than the four outer *Jovian planets*—Jupiter, Saturn, Uranus, and Neptune. The inner planets are composed principally of mineral matter and, except for airless Mercury, have diverse but relatively shallow atmospheres. The four large Jovian planets are more massive (although they are less dense) and less perfectly spherical because they rotate more rapidly. The Jovian planets have deep atmospheres and are mostly composed of elements such as hydrogen and helium—liquid near the surface, but frozen toward the interior—as well as ices of compounds such as methane and ammonia.

It was long thought that tiny Pluto was the ninth and outermost planet in the solar system. However, astronomers have discovered other icy bodies that are similar to Pluto and orbit the Sun beyond Neptune in what is known as the *Kuiper Belt* or *trans-Neptunian region*. In June 2008 the International Astronomical Union reclassified Pluto as a special type of dwarf planet known as a *plutoid*. There may be several dozen yet-to-be-discovered plutoids and other dwarf planets in the outer reaches of our solar system.

LearningCheck 1-7 **Contrast the characteristics of the terrestrial and Jovian planets in our solar system.**

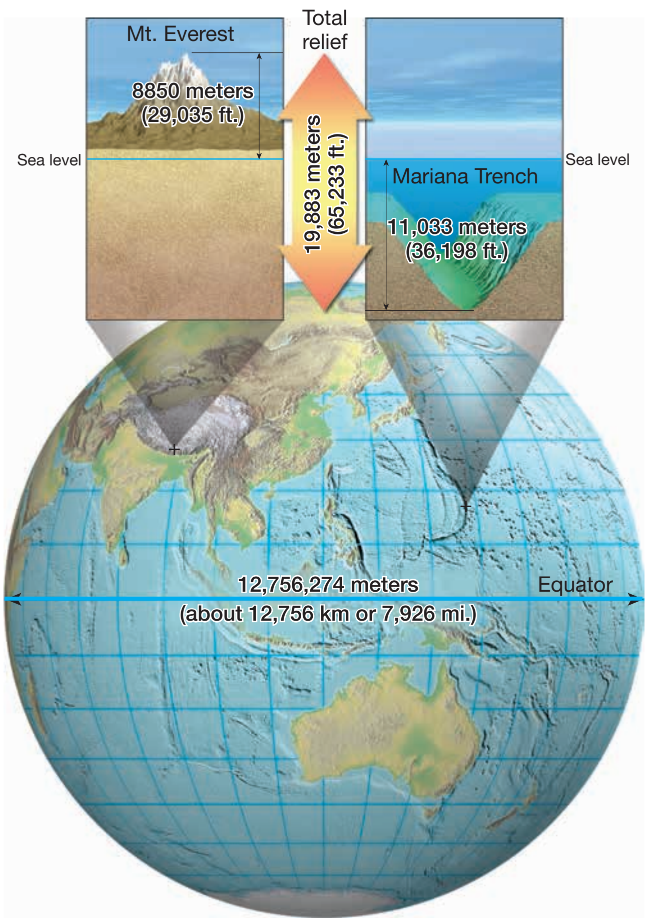
The Size and Shape of Earth

Is Earth large or small? The answer to this question depends on one's frame of reference. If the frame of reference is the universe, Earth is almost infinitely small. The diameter of our planet is only about 13,000 kilometers (7900 miles), a tiny distance at the scale of the universe—for instance, the Moon is 385,000 kilometers (239,000 miles) from Earth, the Sun is 150,000,000 kilometers (93,000,000 miles) away, and the nearest star is 40,000,000,000,000 kilometers (25,000,000,000,000 miles) distant.

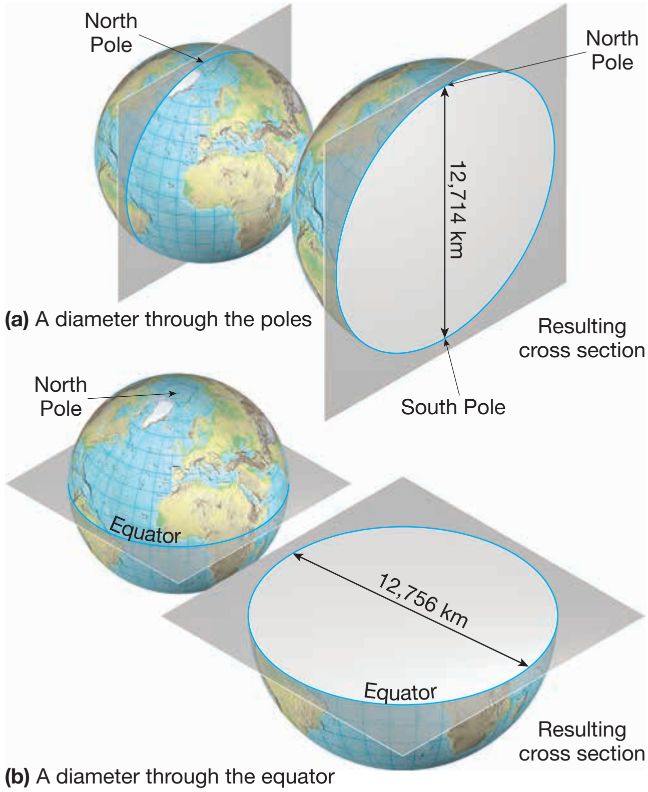
The Size of Earth: In a human frame of reference, however, Earth is impressive in size. Its surface varies in elevation from the highest mountain peak, Mount Everest, at about 8850 meters (29,035 feet) above sea level, to the deepest oceanic trench, the Mariana Trench of the Pacific Ocean, at about 11,033 meters (36,198 feet) below sea level—a total difference in elevation of 19,883 meters (65,233 feet).

Although prominent on a human scale of perception, this difference is minor on a planetary scale (Figure 1-7). If Earth were the size of a basketball, Mount Everest would be an imperceptible pimple no greater than 0.17 millimeter (about 7 thousandths of an inch) high. Similarly, the Mariana Trench would be a tiny crease only 0.21 millimeter (about 8 thousandths of an inch) deep—this represents a depression smaller than the thickness of a sheet of paper.

Our perception of the relative size of topographic irregularities on Earth is often distorted by maps and globes that emphasize such landforms. To portray any noticeable appearance of topographic variation, the vertical dimension on such maps are usually exaggerated 8 to 20 times—as are many diagrams used in this book. Furthermore,



▲ **Figure 1-7** Earth is large relative to the size of its surface features. Earth's maximum relief (the difference in elevation between the highest and lowest points) is 19,883 meters (65,233 feet) or about 20 kilometers (12 miles) from the top of Mount Everest to the bottom of the Mariana Trench in the Pacific Ocean.



▲ **Figure 1-8** Earth is not quite a perfect sphere. Its surface flattens slightly at the North Pole and the South Pole and bulges out slightly around the equator. Thus, (a) a cross section through the poles has a diameter slightly less than the diameter of (b) a cross section through the equator.

many diagrams illustrating features of the atmosphere also exaggerate relative sizes to convey important concepts.

More than 2600 years ago, Greek scholars correctly reasoned Earth to have a spherical shape. About 2200 years ago, Eratosthenes, the director of the Greek library at Alexandria, calculated the circumference of Earth trigonometrically. He determined the angle of the noon Sun's rays at Alexandria and at the city of Syene, 800 kilometers (500 miles) away. From these angular and linear distances, he was able to estimate an Earth circumference of almost 43,000 kilometers (26,700 miles), which is reasonably close to the actual figure of 40,000 kilometers (24,900 miles).

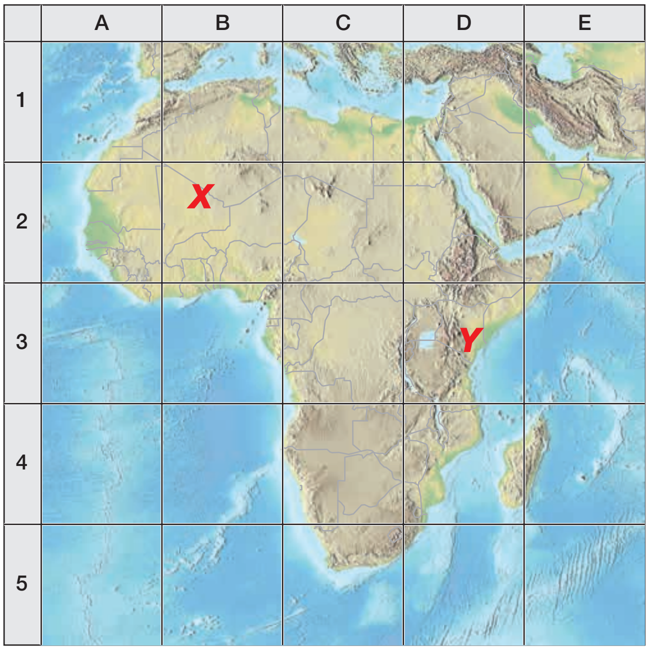
The Shape of Earth: Earth is not quite spherical. The cross section revealed by a cut through the equator would be circular, but a similar cut from pole to pole would be an ellipse rather than a circle. Any rotating body has a tendency to bulge around its equator and flatten at the polar ends of its rotational axis. Although the rocks of Earth may seem quite rigid, they are sufficiently pliable to allow Earth to develop a bulge around its middle. The slightly flattened polar diameter of Earth is 12,714 kilometers (7900 miles), whereas the slightly bulging equatorial diameter is 12,756 kilometers (7926 miles), a difference of only about 0.3 percent (Figure 1-8). Thus, our planet is properly described as an *oblate spheroid* rather than a true sphere. However, because this variation from true sphericity is exceedingly small, in most cases in this book we will treat Earth as if it were a perfect sphere.

LearningCheck 1-8 **What are Earth's highest and lowest points, and what is the approximate elevation difference between them?**

The Geographic Grid—Latitude and Longitude

Any understanding of the distribution of geographic features over Earth's surface requires some system of accurate location. The simplest technique for achieving this is a grid system consisting of two sets of lines that intersect at right angles, allowing the location of any point on the surface to be described by the appropriate intersection (Figure 1-9). Such a rectangular grid system has been reconfigured for Earth's spherical surface.

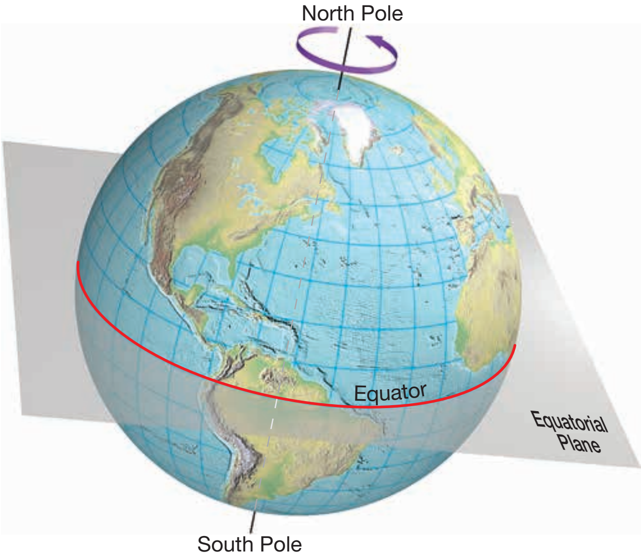
If our planet were a nonrotating body, the problem of describing location would be more difficult than it is: imagine trying to describe the location of a particular point on a perfectly round, perfectly clean ball. Because Earth does



▲ **Figure 1-9** An example of a grid system. The location of point X can be described as 2B or as B2; the location of Y is 3D or D3.

rotate, we can use its rotation axis as a starting point to describe locations.

Earth's rotation axis is an imaginary line passing through Earth that connects the points on the surface called the **North Pole** and the **South Pole** (Figure 1-10). Furthermore, if we visualize an imaginary plane passing through Earth halfway between the poles and perpendicular to the axis of rotation, we have another valuable reference feature: the *plane of the equator*. Where this plane intersects Earth's surface is the imaginary midline of Earth, called simply the **equator**. We use the North Pole, South Pole, rotational axis, and equatorial plane as natural reference features for measuring and describing locations on Earth's surface.



▲ **Figure 1-10** Earth spins around its rotation axis, an imaginary line that passes through the North Pole and the South Pole. An imaginary plane bisecting Earth midway between the two poles defines the equator.

Great Circles: Any plane that is passed through the center of a sphere bisects that sphere (divides it into equal halves) and creates what is called a **great circle** where it intersects the surface of the sphere (Figure 1-11a). The equator is a great circle. Planes passing through any other part of the sphere produce what are called *small circles* where they intersect the surface (Figure 1-11b).

Great circles have two properties of special interest:

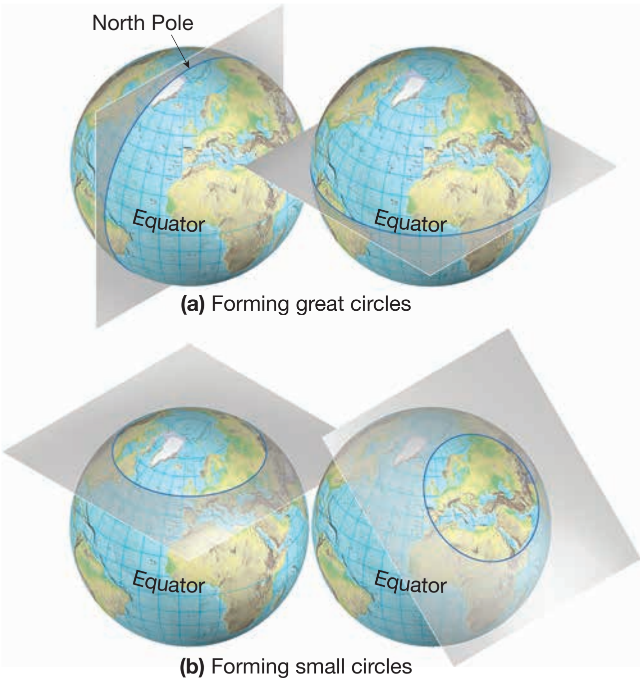
1. A great circle is the largest circle that can be drawn on a sphere, dividing its surface into two equal halves, or *hemispheres*. As we see later in this chapter, the dividing line between the daytime and nighttime halves of Earth is a great circle.
2. A path between two points along the arc of a great circle is always the shortest route between those points. Such routes on Earth are known as *great circle routes*. (We discuss great circle routes in more detail in Chapter 2.)

The geographic grid used as the locational system for Earth is based on the principles just discussed. This locational system is closely linked with the various positions assumed by Earth in its orbit around the Sun. Earth's grid system, called a *graticule*, consists of lines of latitude and longitude.

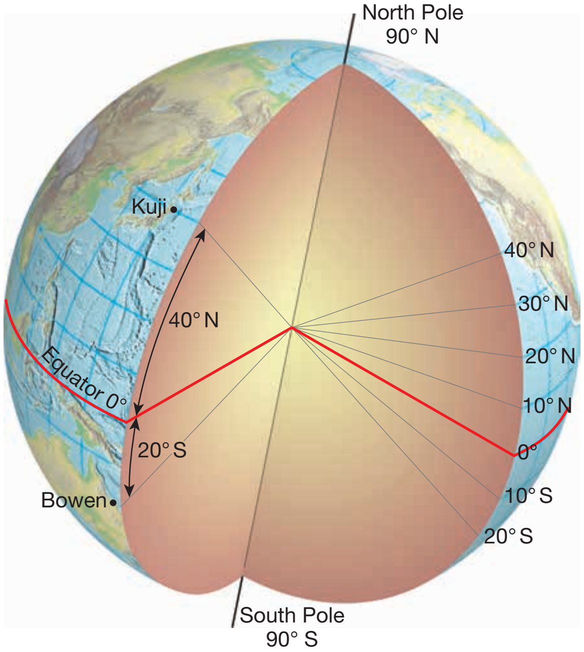
LearningCheck 1-9 **What is a great circle? Provide one example of a great circle.**

Latitude

Latitude is a description of location expressed as an angle north or south of the equator. As shown in Figure 1-12, we can project a line from any location on Earth's surface to



▲ **Figure 1-11** (a) A great circle results from the intersection of Earth's surface with any plane that passes through Earth's center. (b) A small circle results from the intersection of Earth's surface with any other plane.



▲ Figure 1-12 Measuring latitude. An imaginary line from Kuji, Japan, to Earth's center makes an angle of 40° with the equator. Therefore, Kuji's latitude is 40° N. An imaginary line from Bowen, Australia, to Earth's center makes an angle of 20°, giving this city a latitude of 20° S.

the center of Earth. The angle between this line and the equatorial plane is the latitude of that location.

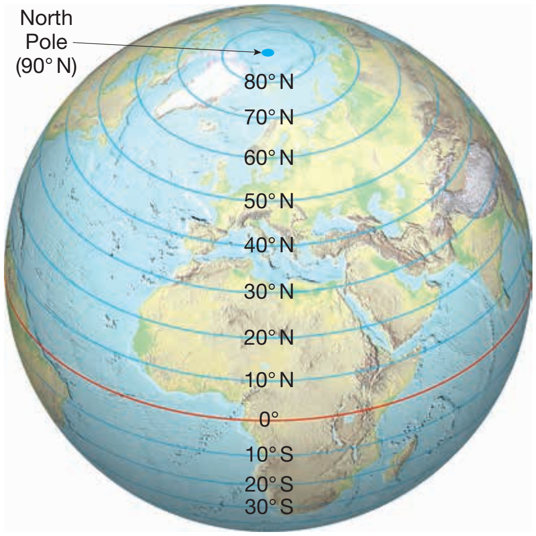
Latitude is expressed in degrees, minutes, and seconds. There are 360 degrees (°) in a circle, 60 minutes (′) in one degree, and 60 seconds (″) in one minute. With the advent of GPS navigation (discussed in Chapter 2), it is increasingly common to see latitude and longitude designated using decimal notation. For example, 38°22′47″ N can be written 38°22.78′ N (47" is 78 percent of one minute) or even 38.3797° N (22' 47" is 37.97 percent of one degree).

Latitude varies from 0° at the equator to 90° north at the North Pole and 90° south at the South Pole. Any position north of the equator is north latitude, and any position south of the equator is south latitude. The equator itself is simply assigned a latitude of 0°.

A line connecting all points of the same latitude is called a **parallel**—because it is parallel to all other lines of latitude (Figure 1-13). The equator is the parallel of 0° latitude, and it, alone of all parallels, constitutes a great circle. All other parallels are small circles—all aligned in true east–west directions on Earth's surface.

Although we could visualize an unlimited number of parallels, seven latitudes are of particular significance in a general study of Earth (Figure 1-14):

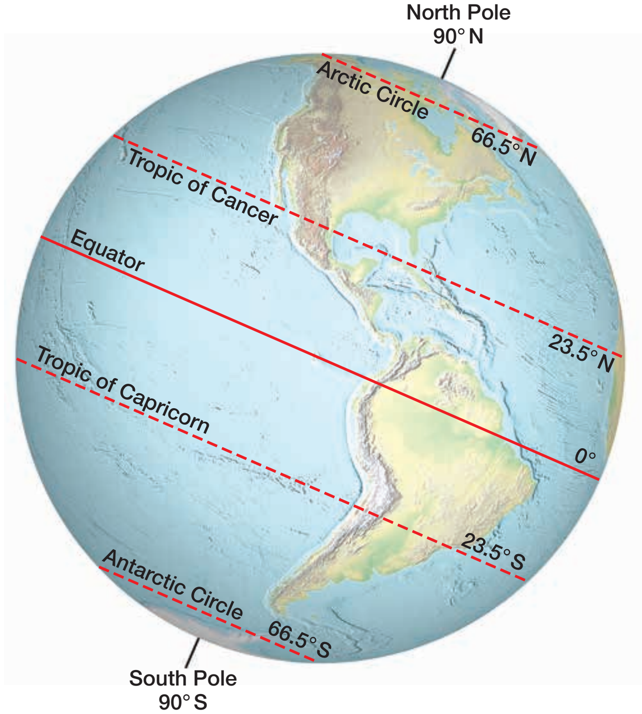
1. Equator, 0° (Figure 1-15)
2. Tropic of Cancer, 23.5° N
3. Tropic of Capricorn, 23.5° S
4. Arctic Circle, 66.5° N
5. Antarctic Circle, 66.5° S
6. North Pole, 90° N
7. South Pole, 90° S



▲ Figure 1-13 Lines of latitude indicate north–south location. They are called *parallels* because they are always parallel to each other.

The North Pole and South Pole are points rather than lines, but we can think of them as infinitely small parallels. The significance of these seven parallels is explained later in this chapter when we discuss the seasons.

LearningCheck 1-10 **Why are lines of latitude called parallels?**



▲ Figure 1-14 Seven important latitudes. As we will see when we discuss the seasons, these latitudes represent special locations where rays from the Sun strike Earth's surface on certain days of the year.

▲ Figure 1-15 The equator, like all other parallels of latitude, is an imaginary line. Here at Mitad del Mundo near Quito, Ecuador, its nearby location is commemorated by a monument.

Descriptive Zones of Latitude: Regions on Earth are sometimes described as falling within general bands or zones of latitude. The following common terms associated with latitude are used throughout this book (notice that some terms overlap):

- *Low latitude*—generally between the equator and 30° N and S
- *Midlatitude*—between about 30° and 60° N and S
- *High latitude*—latitudes greater than about 60° N and S
- *Equatorial*—within a few degrees of the equator
- *Tropical*—within the tropics (between 23.5° N and 23.5° S)
- *Subtropical*—slightly poleward of the tropics, generally around 25–30° N and S
- *Polar*—within a few degrees of the North or South Pole

Nautical Miles: Each degree of latitude on the surface of Earth covers a north–south distance of about 111 kilometers (69 miles). The distance varies slightly with latitude because of the flattening of Earth at the poles. The distance measurement of a *nautical mile*—and the description of speed known as a *knot* (one nautical mile per hour)—is defined by the distance covered by one minute of latitude (1′), the equivalent of about 1.15 statute ("ordinary") miles or about 1.85 kilometers.

Longitude

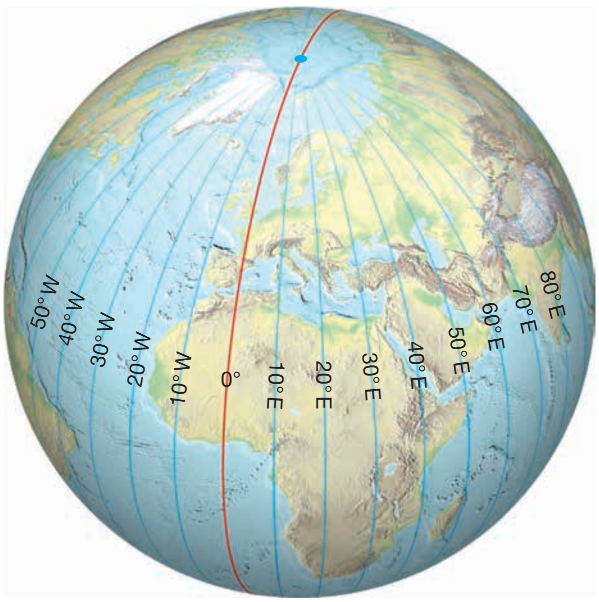
Longitude describes east–west location on Earth—like latitude, it is an angular description of location measured in degrees, minutes, and seconds.

Longitude is represented by imaginary lines extending from pole to pole and crossing all parallels at right angles. These lines, called **meridians**, are not parallel to one another except where they cross the equator. Notice that any pair of meridians is farthest apart at the equator, becoming increasingly close together northward and southward and finally converging at the poles (Figure 1-16).

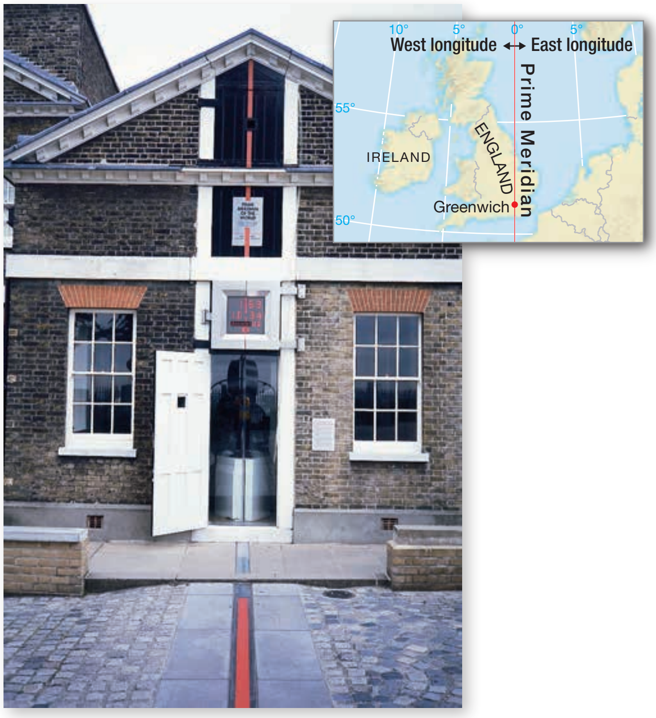
Establishing the Prime Meridian: The equator is a natural baseline from which to measure latitude, but no such natural reference line exists for longitude. Consequently, for most of recorded history, there was no accepted longitudinal baseline; each country selected its own "prime meridian" as the reference line for east–west measurement. At least 13 different prime meridians were in use in the 1880s.

In 1884 an international conference was convened in Washington, D.C., to establish global time zones and select a single prime meridian. After weeks of debate, the delegates chose the meridian passing through the Royal Observatory at Greenwich, England, just east of central London, as the **prime meridian** for all longitudinal measurement (Figure 1-17). The principal argument for adopting the Greenwich meridian as the prime meridian was a practical one: more than two-thirds of the world's shipping lines already used the Greenwich meridian as a navigational base.

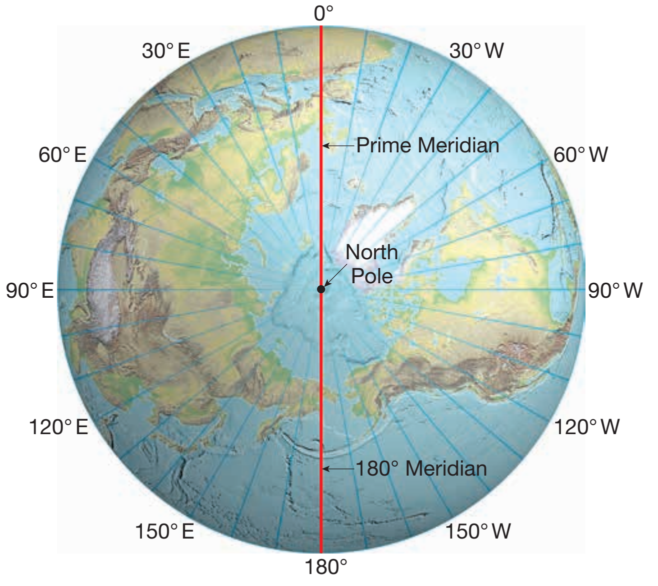
Thus, an imaginary north–south plane passing through Greenwich and through Earth's axis of rotation represents the plane of the prime meridian. The angle between this plane and a plane passed through any other point and the axis of Earth is a measure of longitude. For example, the angle between the Greenwich plane and a plane passing through the center of the city of Freetown (in the western African country of Sierra Leone) is 13 degrees, 15 minutes, and 12 seconds. Because the angle is formed west of the prime meridian, the longitude of Freetown is written 13°15′12″ W (Figure 1-18).



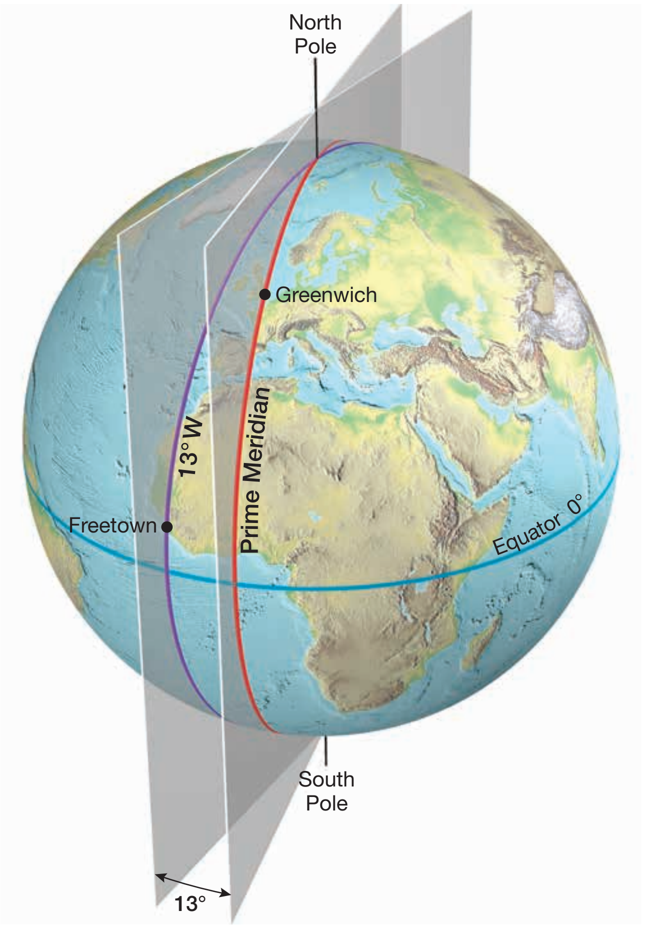
▲ Figure 1-16 Lines of longitude, or *meridians*, indicate east–west location and all converge at the poles.



▲ Figure 1-17 The prime meridian of the world, longitude 0°0′0″ at Greenwich, England, which is about 8 kilometers (5 miles) from the heart of London.



▲ Figure 1-19 A polar view of meridians radiating from the North Pole. Think of each line as the top edge of an imaginary plane passing through both poles. All the planes are perpendicular to the plane of the page.



▲ Figure 1-18 The meridians that mark longitude are defined by intersecting imaginary planes passing through the poles. Shown here are the planes for the prime meridian through Greenwich, England, and the meridian through Freetown, Sierra Leone, at 13° west longitude.

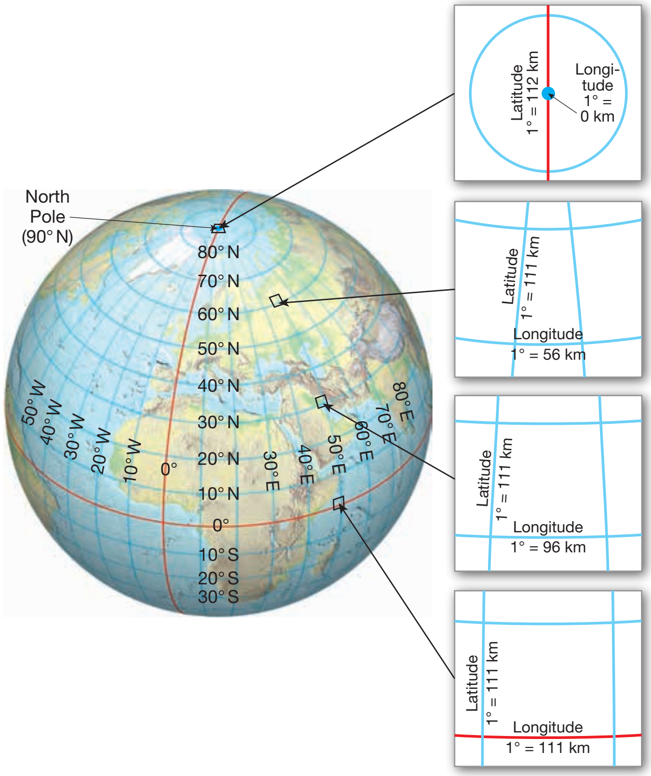
Measuring Longitude: Longitude is measured both east and west of the prime meridian to a maximum of 180° in each direction. Exactly halfway around the globe from the prime meridian, in the middle of the Pacific Ocean, is the 180° meridian (Figure 1-19). All places on Earth, then, have a location that is either east longitude or west longitude, except for points exactly on the prime meridian (described simply as 0° longitude) or exactly on the 180th meridian (described as 180° longitude).

The distance between any two meridians varies predictably. At the equator, the surface length of one degree of longitude is about the same as that of one degree of latitude. However, because meridians converge at the poles, the distance covered by one degree of longitude decreases poleward (Figure 1-20), diminishing to zero at the poles, where all meridians meet.

Locating Points on the Geographic Grid

The network of intersecting parallels and meridians creates a geographic grid over the entire surface of Earth (see Figure 1-20). The location of any place on Earth's surface can be described with great precision by reference to detailed latitude and longitude data. For example, at the 1964 World's Fair in New York City, a time capsule was buried. For reference purposes, the U.S. Coast and Geodetic Survey determined that the capsule was located at 40°28′34.089″ N and 73°43′16.412″ W. At some time in the future, if a hole were to be dug at the spot indicated by those coordinates, it would be within 15 centimeters (6 inches) of the capsule.

LearningCheck 1-11 **Are locations in North America described by east longitude or west longitude? Locations in China?**



▲ **Figure 1-20** The complete grid system of latitude and longitude—the *graticule*. Because the meridians converge at the poles, the distance of 1° of longitude is greatest at the equator and diminishes to zero at the poles, whereas the distance of 1° of latitude varies only slightly (due to the slight flattening of Earth at the poles).

Earth–Sun Relations and the Seasons

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Earth-Sun Relations
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Nearly all life on Earth depends on solar energy; therefore, the relationship between Earth and the Sun is of vital importance. Because of the perpetual motions of Earth, this relationship does not remain the same throughout the year. We begin with a description of Earth movements and the relationship of Earth's axis to the Sun, and then we offer an explanation of the change of seasons.

Earth Movements

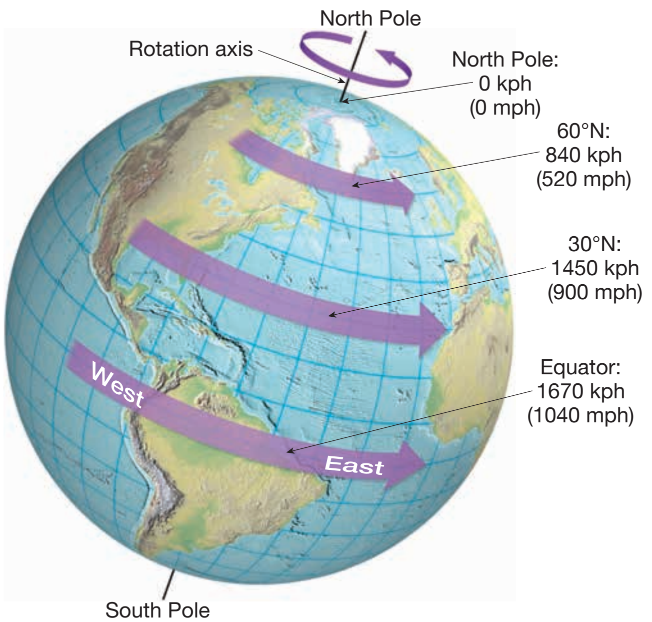
Two basic Earth movements—its daily rotation on its axis and its annual revolution around the Sun—along with the inclination and "polarity" of Earth's rotation axis, combine to change Earth's orientation to the Sun—and therefore produce the change of seasons.

Earth's Rotation on Its Axis: Earth rotates from west to east on its axis (Figure 1-21), a complete **rotation** requiring 24 hours. (From the vantage point of looking down at the North Pole from space, Earth is rotating counterclockwise.) The Sun, the Moon, and the stars appear to rise in the east and set in the west—this is, of course, an illusion created by the steady eastward spin of Earth.

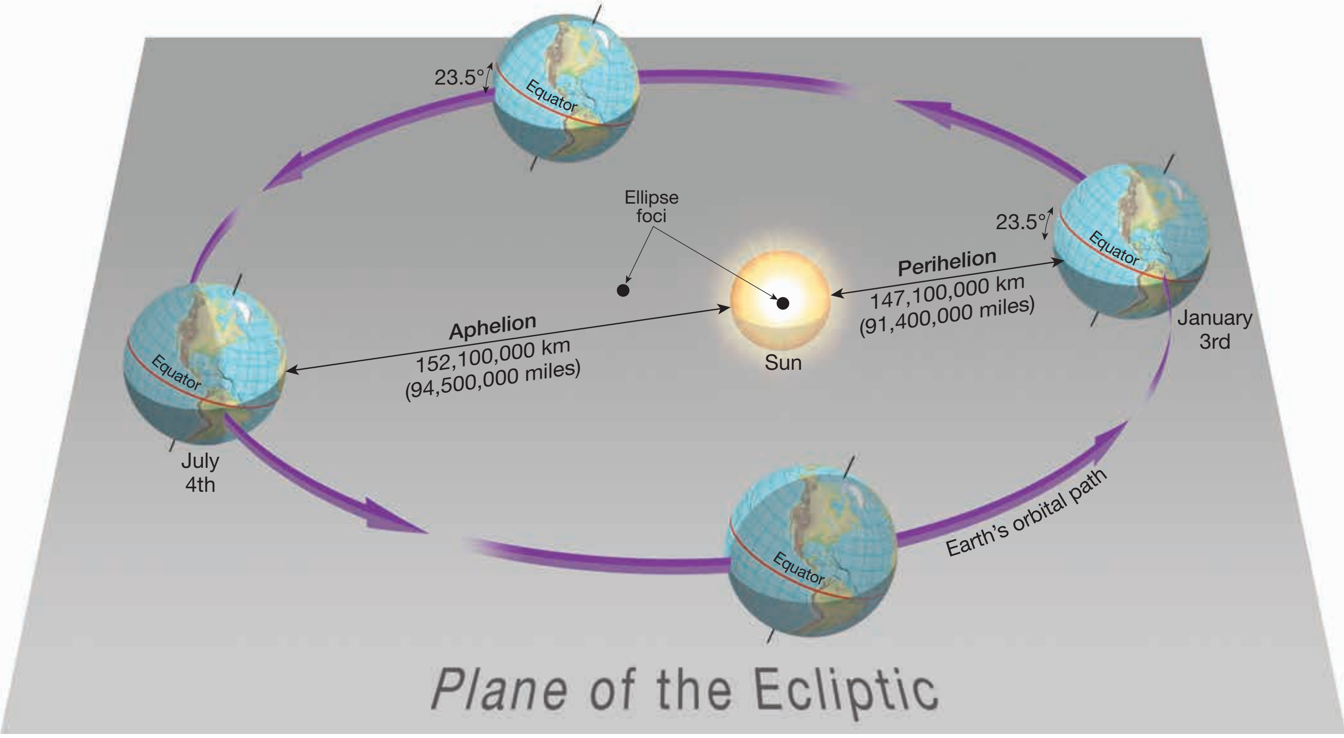
Rotation causes all parts of Earth's surface except the poles to move in a circle around Earth's axis. Although the speed of rotation varies by latitude (see Figure 1-21), it is constant at any given place on Earth; thus we experience no sense of motion. This is the same reason that we have little sense of motion on a smooth jet airplane flight at cruising speed—only when speed changes, such as during takeoff and landing, does motion become apparent.

Rotation has several important effects on the physical characteristics of Earth's surface:

1. The most obvious effect of Earth's rotation is the *diurnal* (daily) alternation of daylight and darkness, as portions of Earth's surface are turned first toward and then away from the Sun. This variation in exposure to sunlight greatly influences local temperature, humidity, and wind movements. Except for organisms that live in caves or in the deep ocean, nearly all forms of life have adapted to this sequential pattern of daylight and darkness. For example, we humans fare poorly when our *circadian* (24-hour cycle) rhythms are disrupted by long-distance, high-speed air travel, leaving us with a sense of fatigue known as "jet lag."
2. The rotation of Earth brings any point on the surface through the increasing and then decreasing gravitational pull of the Moon and the Sun. Although the land areas of Earth are too rigid to be significantly moved by these oscillating gravitational attractions, oceanic waters move onshore and then recede in a rhythmic pattern of *tides*, discussed further in Chapter 9.
3. Earth's constant rotation also causes an apparent deflection in the paths of both wind and ocean currents—to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. This phenomenon is called the *Coriolis effect* and is discussed in detail in Chapter 3.



▲ **Figure 1-21** Earth rotates from west to east. Looking down at the North Pole from above, Earth appears to rotate counterclockwise. The speed of Earth's rotation is constant but varies by latitude, being greatest at the equator and effectively diminishing to zero at the poles. The speed of rotation at different latitudes is shown in kilometers per hour (kph) and miles per hour (mph).



▲ **Figure 1-22** Earth reaches perihelion (its closest point to the Sun) on about January 3 and aphelion (its farthest point from the Sun) on about July 4. The plane of the ecliptic is the orbital plane of Earth. Because Earth's rotation axis is tilted, the plane of the ecliptic and the equatorial plane do not coincide. The path Earth follows in its revolution around the Sun is an ellipse with the Sun at one focus. (In this diagram the elliptical shape of Earth's orbit is greatly exaggerated.) Notice that Earth's axis always points in the same direction throughout its orbit.

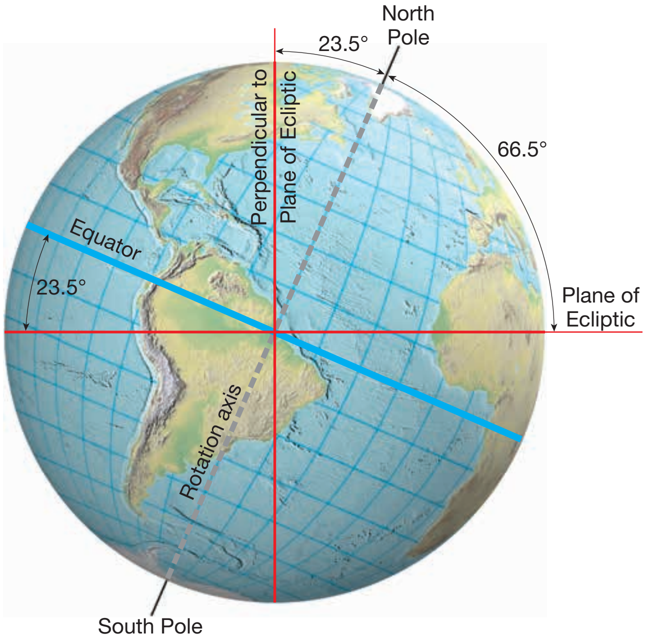
Earth's Revolution around the Sun: Another significant Earth motion is its **revolution** or orbit around the Sun. Each revolution takes 365 days, 5 hours, 48 minutes, and 46 seconds, or 365.242199 days. This is known officially as the *tropical year* and for practical purposes is usually simplified to 365.25 days.

The path followed by Earth in its journey around the Sun is not a true circle but an *ellipse* (Figure 1-22). Because of this elliptical orbit, the Earth–Sun distance is not constant. Rather, it varies from approximately 147,100,000 kilometers (91,400,000 miles) at the closest or **perihelion** position (*peri* is from the Greek and means "around" and *helios* means "Sun") on about January 3, to approximately 152,100,000 kilometers (94,500,000 miles) at the farthest or **aphelion** position (*ap* is from the Greek and means "away from") on about July 4. The average Earth–Sun distance is defined as one *astronomical unit* (1 AU)—about 149,597,871 kilometers (92,960,117 miles).

Earth is 3.3 percent closer to the Sun during the Northern Hemisphere winter than during the Northern Hemisphere summer, an indication that variations in the distance between Earth and the Sun do *not* cause the change of seasons. Instead, two additional factors in the relationship of Earth to the Sun—*inclination* and *polarity*—work together with rotation and revolution to produce the change of seasons.

LearningCheck 1-12 **Distinguish between Earth's rotation and its revolution.**

Inclination of Earth's Axis: Earth's rotation axis is not perpendicular to the imaginary plane defined by Earth's orbital path around the Sun, called the **plane of the ecliptic** (see Figure 1-22). Rather, the axis is tilted about 23.5° from the perpendicular (Figure 1-23) and maintains this tilt



▲ **Figure 1-23** Earth's rotation axis is inclined 23.5° from a line perpendicular to the plane of the ecliptic.

throughout the year. This tilt is referred to as the **inclination of Earth's axis**.

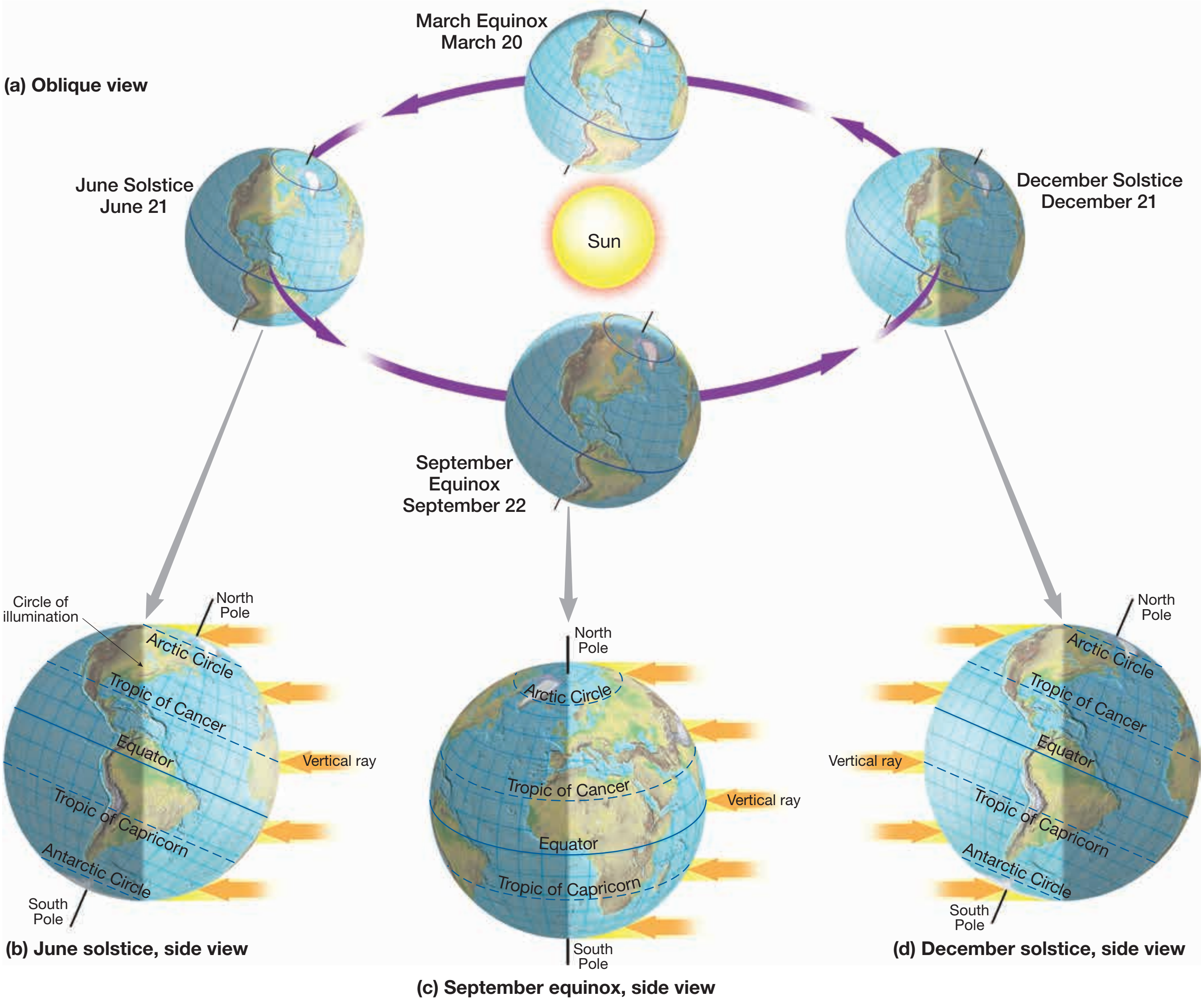
Polarity of Earth's Axis: Not only is Earth's rotation axis inclined relative to its orbital path, but also no matter where Earth is in its orbit around the Sun, the axis always points in the same direction relative to the stars—toward the North Star, Polaris (Figure 1-24). This characteristic is called the **polarity of Earth's axis** (or **parallelism**, because at any time of the year Earth's axis is parallel to its orientation at all other times).

The combined effects of rotation, revolution, inclination, and polarity result in the seasonal patterns experienced on Earth. Notice in Figure 1-24 that at one point in Earth's orbit, during the Northern Hemisphere summer, the North Pole is oriented most directly toward the Sun, whereas six months later, during the Northern Hemisphere winter, the North Pole is oriented most directly away from the Sun. This is the most fundamental feature of the annual march of the seasons.

LearningCheck 1-13 **Does the North Pole lean toward the Sun throughout the year? If not, how does the North Pole's orientation change during the year?**

The Annual March of the Seasons

During a year, the changing relationship of Earth to the Sun results in variations in day length and in the angle at which the Sun's rays strike the surface of Earth. These changes are most obvious in the mid- and high latitudes, but important variations take place within the tropics as well.



▲ **Figure 1-24** (a) The annual march of the seasons, showing Earth–Sun relations on the June solstice, September equinox, December solstice, and March equinox (the dates shown are approximate). (b) On the June solstice, the vertical rays of the noon Sun strike 23.5° N latitude. The circle of illumination is the dividing line between the daylight and nighttime halves of Earth. (c) On the March equinox and September equinox, the vertical rays of the noon Sun strike the equator. (d) On the December solstice, the vertical rays of the noon Sun strike 23.5° S latitude.

As we discuss the annual march of the seasons, we pay special attention to three conditions:

1. The latitude receiving the vertical rays of the Sun (rays striking the surface at a right angle), referred to as the **declination of the Sun**.
2. The **solar altitude** (the height of the noon Sun above the horizon) at different latitudes.
3. The length of day (number of daylight hours) at different latitudes.

Initially, we emphasize the conditions on four special days of the year: the March equinox, the June solstice, the September equinox, and the December solstice (see Figure 1-24a). As we describe the change of seasons, the significance of the "seven important parallels" discussed earlier in this chapter will become clear. We begin with the June solstice.

June Solstice: On the **June solstice**, which occurs on or about June 21 (the exact date varies slightly from year to year), Earth reaches the position in its orbit where the North Pole is oriented most directly toward the Sun. On this day, the vertical rays of the Sun strike the **Tropic of Cancer**, 23.5° north of the equator (Figure 1-24b). Were you at the Tropic of Cancer on this day, the Sun would be directly overhead in the sky at noon (in other words, the solar altitude would be 90°). The Tropic of Cancer marks the northernmost latitude reached by the vertical rays of the Sun during the year.

The dividing line between the daylight half of Earth and nighttime half of Earth is a great circle called the **circle of illumination**. On the June solstice, the circle of illumination bisects the equator (Figure 1-24b), so on this day the equator receives equal day and night—12 hours of daylight and 12 hours of darkness. However, as we move north of the equator, the portion of each parallel in daylight increases—in other words, day length increases. Conversely, day length decreases as we move south of the equator.

Notice in Figure 1-24b that on the June solstice, the circle of illumination reaches 23.5° *beyond* the North Pole to a latitude of 66.5° N. As Earth rotates, all locations north of 66.5° remain continuously in daylight and so experience 24 hours of daylight. By contrast, all points south of 66.5° S are always outside the circle of illumination and so have 24 continuous hours of darkness. These special parallels defining the equatorward limit of 24 hours of light and dark on the solstices are called the *polar circles*. The northern polar circle, at 66.5° N, is the **Arctic Circle**; the southern polar circle, at 66.5° S, is the **Antarctic Circle**.

The June solstice is called the *summer solstice* in the Northern Hemisphere and the *winter solstice* in the Southern Hemisphere. (These are commonly called the "first day of summer" and the "first day of winter" in their respective hemispheres.)

LearningCheck 1-14 **What is the latitude of the vertical rays of the Sun on the June solstice?**

September Equinox: Three months after the June solstice, on about September 22, Earth experiences the **September equinox**. Notice in Figure 1-24c that the vertical rays of the Sun strike the equator. Notice also that the circle of illumination just touches both poles, bisecting all other parallels—on this day all locations on Earth experience 12 hours of daylight and 12 hours of darkness. (The word "equinox" comes from the Latin, meaning "the time of equal days and equal nights.") At the equator—and only at the equator—*every* day of the year has virtually 12 hours of daylight and 12 hours of darkness; all other locations have equal day and night only on an equinox.

The September equinox is called the *autumnal equinox* in the Northern Hemisphere and the *vernal equinox* in the Southern Hemisphere. (These are commonly called the "first day of fall" and the "first day of spring" in their respective hemispheres.)

December Solstice: On the **December solstice**, which occurs on about December 21, Earth reaches the position in its orbit where the North Pole is oriented most directly away from the Sun. The vertical rays of the Sun now strike 23.5° S, the **Tropic of Capricorn** (Figure 1-24d). Once again, the circle of illumination reaches to the far side of one pole and falls short on the near side of the other pole, so areas north of the Arctic Circle are in continuous darkness, whereas areas south of the Antarctic Circle are in daylight for 24 hours.

The relationships between Earth and the Sun on the June solstice and the December solstice are very similar; the conditions in each hemisphere are simply reversed. The December solstice is called the *winter solstice* in the Northern Hemisphere and the *summer solstice* in the Southern Hemisphere (the "first day of winter" and the "first day of summer," respectively).

March Equinox: Three months after the December solstice, on approximately March 20, Earth experiences the **March equinox**. The relationships of Earth and the Sun are virtually identical on the March equinox and the September equinox (Figure 1-24c). The March equinox is called the *vernal equinox* in the Northern Hemisphere and the *autumnal equinox* in the Southern Hemisphere (the "first day of spring" and the "first day of fall," respectively). Table 1-2 summarizes the conditions present during the solstices and equinoxes.

LearningCheck 1-15 **How much does day length at the equator change during the year?**

Seasonal Transitions

In the preceding discussion of the solstices and equinoxes, we emphasized the conditions on just four special days of the year. It is important to understand the transitions in day length and Sun angle that take place on other days as well.

Latitude Receiving the Vertical Rays of the Sun: The vertical rays of the Sun strike Earth only between the Tropic of Cancer and the Tropic of Capricorn. After the March equinox, the vertical rays of the Sun migrate north from the equator, striking the Tropic of Cancer on the June solstice

TABLE 1-2 Conditions on Equinoxes and Solstices

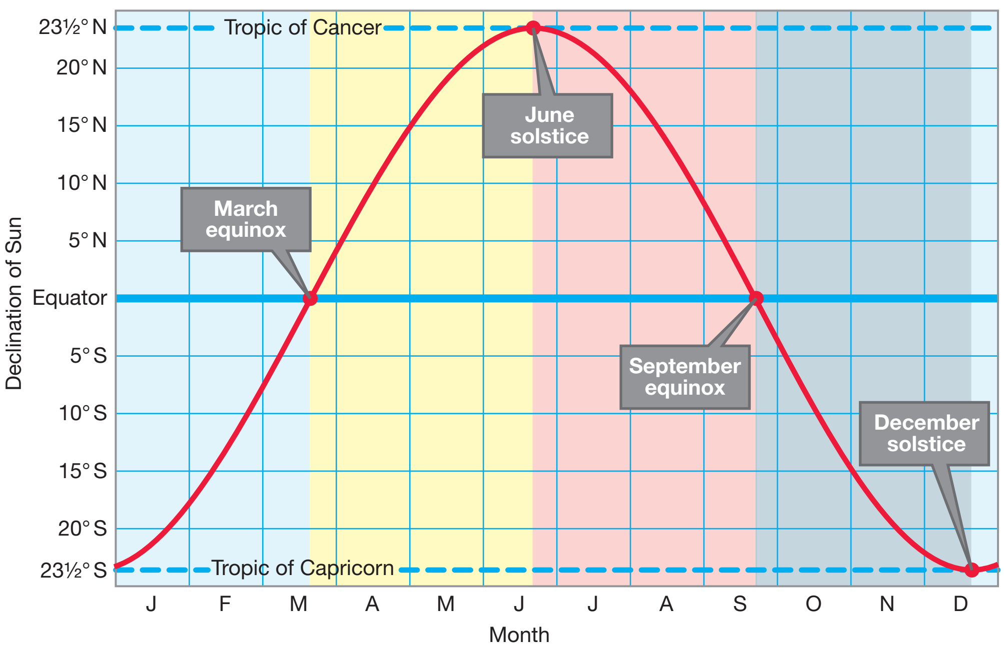
	March Equinox	June Solstice	September Equinox	December Solstice
Latitude of vertical rays of Sun	0°	23.5° N	0°	23.5° S
Day length at equator	12 hours	12 hours	12 hours	12 hours
Day length in midlatitudes of Northern Hemisphere	12 hours	Becomes longer with increasing latitude north of equator	12 hours	Day length becomes shorter with increasing latitude north of equator
Day length in midlatitudes of Southern Hemisphere	12 hours	Becomes shorter with increasing latitude south of equator	12 hours	Day length becomes longer with increasing latitude south of equator
24 hours of daylight	Nowhere	From Arctic Circle to North Pole	Nowhere	From Antarctic Circle to South Pole
24 hours of darkness	Nowhere	From Antarctic Circle to South Pole	Nowhere	From Arctic Circle to North Pole
Season in Northern Hemisphere	Spring	Summer	Autumn	Winter
Season in Southern Hemisphere	Autumn	Winter	Spring	Summer

(the day the Sun is highest in the sky for all latitudes north of the Tropic of Cancer). After the June solstice, the vertical rays migrate south, striking the equator again on the September equinox and reaching the Tropic of Capricorn on the December solstice (the day the Sun is lowest in the sky in the Northern Hemisphere). Following the December solstice, the vertical rays migrate northward, reaching the equator once again on the March equinox. The changing latitude of the vertical rays of the Sun during the year is shown graphically in **Figure 1-25**.

Day Length: Only at the equator is day length constant throughout the year—virtually 12 hours of daylight every day of the year.

For all regions in the Northern Hemisphere up to the latitude of the Arctic Circle, following the shortest day of the year on the December solstice, the number of hours of daylight gradually increases, reaching 12 hours on the March equinox. After the equinox, day length continues to increase until the longest day of the year, on the June solstice. (During this period, day length is diminishing in the Southern Hemisphere.)

Following the longest day of the year in the Northern Hemisphere, the June solstice, the pattern is reversed: the days get shorter in the Northern Hemisphere—reaching 12 hours on the September equinox. Day length continues to diminish until the shortest day of the year, on



◀ **Figure 1-25** The latitude receiving the vertical rays of the noon Sun (the *declination of the Sun*) throughout the year. The vertical rays strike the Tropic of Cancer on the June solstice and the Tropic of Capricorn on the December solstice, crossing the equator on the equinoxes.

TABLE 1-3 Day Length and Noon Sun Angle on the June Solstice

Latitude	Day Length	Noon Sun Angle (degrees above horizon)
90° N	24 h	23.5
60° N	18 h 53 min	53.5
30° N	14 h 05 min	83.5
0°	12 h 07 min	66.5
30° S	10 h 12 min	36.5
60° S	05 h 52 min	6.5
90° S	0	0

Source: After Robert J. List, *Smithsonian Meteorological Tables,* 6th rev. ed. Washington, D.C.: Smithsonian Institution, 1963, Table 171.

the December solstice. (During this period, day length is increasing in the Southern Hemisphere.)

Overall, the annual variation in day length is the least in the tropics and the greatest at high latitudes (Table 1-3).

LearningCheck 1-16 **On which days of the year do the vertical rays of the Sun strike the equator?**

Day Length in the Arctic and Antarctic: The patterns of day and night in the Arctic and Antarctic deserve special mention. For an observer exactly at the North Pole, the Sun rises on the March equinox and is above the horizon continuously for the next six months—circling the horizon higher and higher each day until the June solstice, after which it circles lower and lower until setting on the September equinox.

Week by week following the March equinox, a growing region surrounding the North Pole experiences 24 hours of daylight—until the June solstice, when the entire region from the Arctic Circle to the North Pole experiences 24 hours of daylight. Following the June solstice, the region of 24 hours of daylight diminishes week by week until the September equinox—when the Sun sets at the North Pole and remains below the horizon continuously for the next six months.

Week by week following the September equinox, the region around the North Pole experiencing 24 hours of darkness grows until the December solstice—when the entire region from the Arctic Circle to the North Pole experiences 24 hours of darkness. Following the December solstice, the region experiencing 24 hours of darkness diminishes week by week until the March equinox—when the Sun again rises at the North Pole.

In the Antarctic region of the Southern Hemisphere, these seasonal patterns are simply reversed.

Significance of Seasonal Patterns

Both day length and the angle at which the Sun's rays strike Earth determine the amount of solar energy received at any particular latitude. In general, the higher the Sun is in the sky, the more effective is the warming. Furthermore, short periods of daylight in winter and long periods of daylight in summer contribute to seasonal differences in temperature in the mid- and high-latitude regions.

Thus, the tropical latitudes are generally always warm because they have high Sun angles and consistent, near-12-hour days all year long. Conversely, the polar regions are consistently cold because they always have low Sun angles—even the 24-hour days in summer do not compensate for the low angle of incidence of sunlight. Seasonal temperature differences are large in the midlatitudes because of sizable seasonal variations in Sun angles and length of day. This topic will be explored further in Chapter 4.

LearningCheck 1-17 **For how many months of the year does the North Pole go without sunlight?**

Telling Time

To comprehend time around the world, we need an understanding of both (1) the geographic grid of latitude and longitude and (2) Earth–Sun relations.

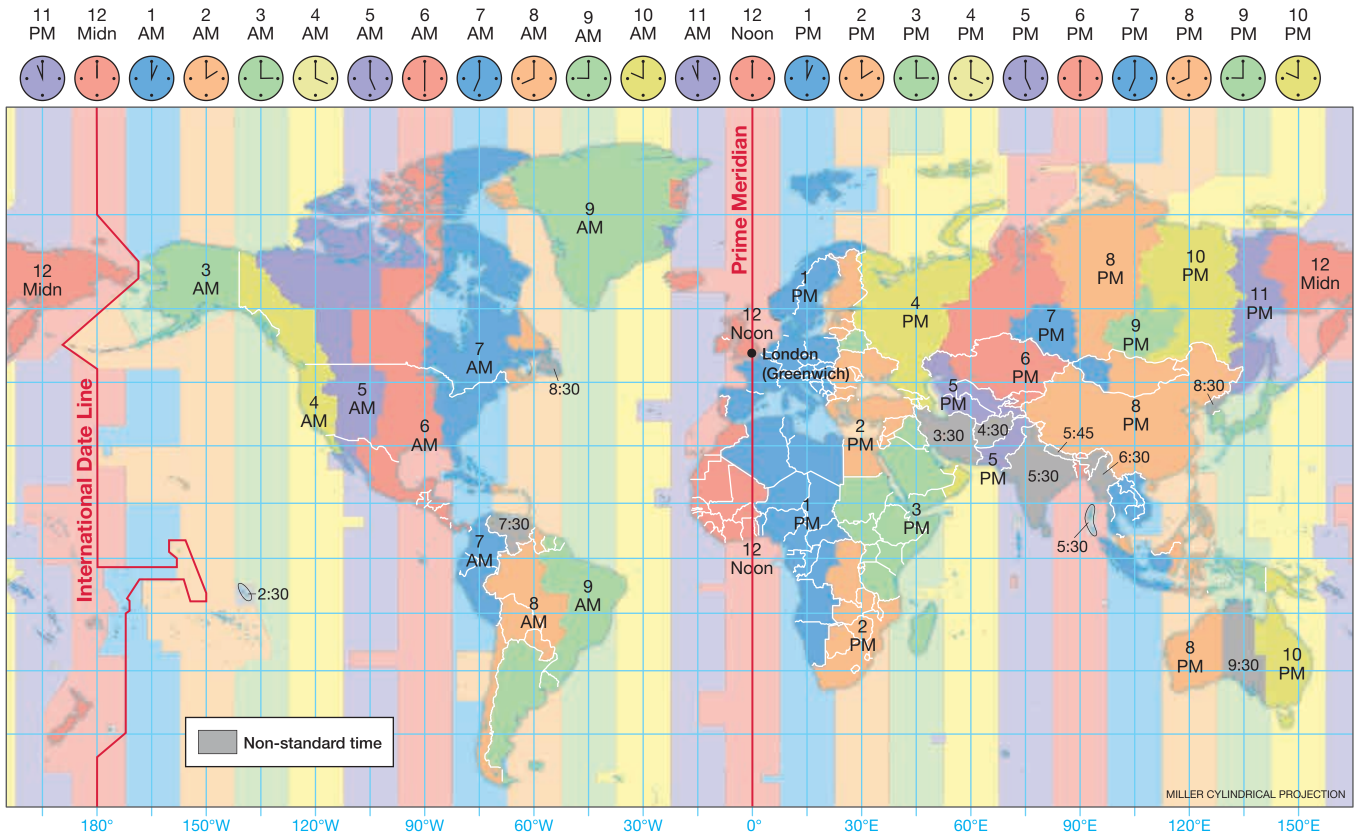
In prehistoric times, the rising and setting of the Sun were probably the principal means of telling time. Local *solar noon* was determined by watching for the moment when an object cast its shortest shadows. The Romans used sundials to tell time (Figure 1-26) and gave great importance to the noon position, which they called the *meridian*—the Sun's highest (*meri*) point of the day (*diem*). Our use of A.M. (*ante meridian*: "before noon") and P.M. (*post meridian*: "after noon") was derived from the Roman world.

When nearly all transportation was by foot, horse, or sailing vessel, it was difficult to compare time at different localities. Each community set its own time by correcting its local clocks to high noon at the moment of the shortest shadow.

Standard Time

As the telegraph and railroad began to speed words and passengers between cities, the use of many different local

▼ **Figure 1-26** A typical sundial. The edge of the vertical *gnomon* slants upward from the dial face at an angle equal to the latitude of the sundial, pointing toward the North Pole in the Northern Hemisphere and the South Pole in the Southern Hemisphere. As the Sun appears to move across the sky during the course of a day, the position of the shadow cast by the gnomon changes. The time shown on this sundial is about 2:00 P.M.



▲ **Figure 1-27** The time zones of the world, each based on central meridians spaced 15° apart. Especially over land areas, these boundaries have been significantly adjusted.

times created increasing problems. Eventually, the railroads stimulated the development of a standardized time system.

At the 1884 International Prime Meridian Conference in Washington, D.C., countries established 24 central meridians, 15° of longitude apart, in order to divide the world into standard **time zones**. The mean (averaged) local solar time of the Greenwich prime meridian was chosen as the standard for the entire system. The prime meridian became the center of a time zone that extends 7.5° of longitude to the west and 7.5° to the east of the prime meridian. Similarly, the meridians that are multiples of 15° both east and west of the prime meridian were set as the *central meridians* for the other time zones (Figure 1-27). When you cross into the next time zone from west to east, the time becomes one hour later.

Although **Greenwich Mean Time** (**GMT**) is now referred to as **Universal Time Coordinated** (**UTC**), the prime meridian is still the reference for standard time. To know the exact local time, we usually need to know only how many hours later or earlier our local time zone is compared with the time in Greenwich. Notice that a few countries, such as India, do not adhere to standard one-hour-interval time zones.

Most countries lie totally within a single time zone. However, some large countries may encompass several zones: Russia extends across time zones defined by 10 central meridians; including Alaska and Hawai‘i, the United States spreads over six (Figure 1-28a).

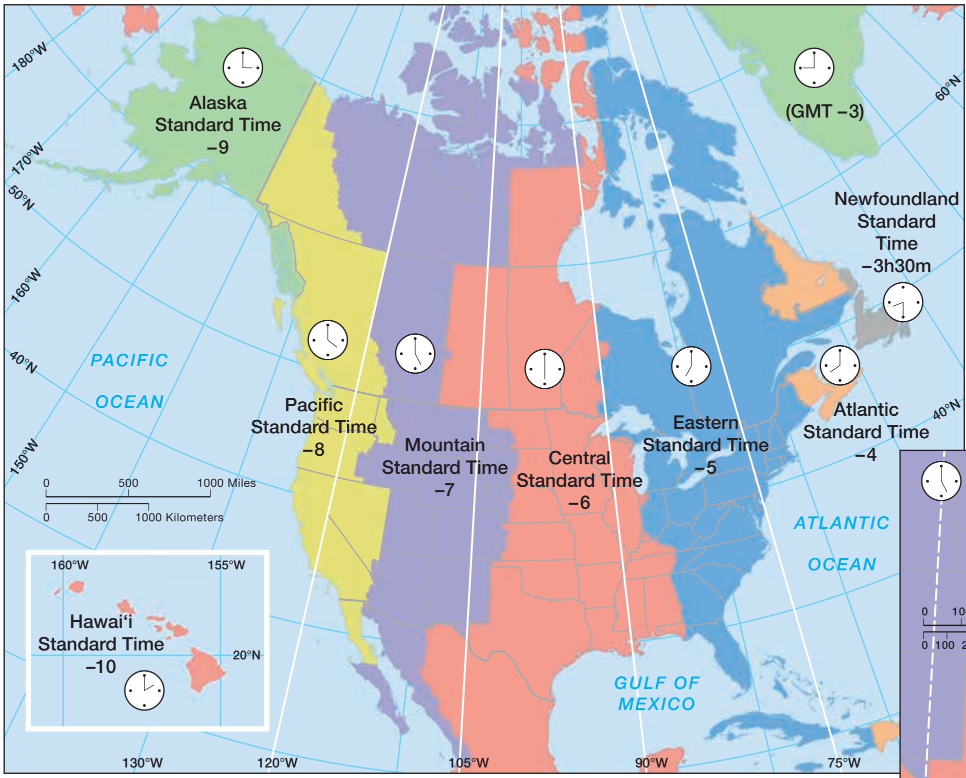
In international waters, time zones are exactly 15° wide. Over land areas, however, boundaries vary to coincide with political and economic boundaries. For example, the Central Standard Time Zone of the United States, centered on 90° W, extends all the way to 105° W (which is the central meridian of the Mountain Standard Time Zone) in Texas to keep most of that state within the same zone. But El Paso, Texas, is officially within the Mountain Standard Time Zone in accord with its role as a major market center for southern New Mexico, which observes Mountain Standard Time. At another extreme, China extends across four 15° zones, but the entire country, at least officially, observes the time of the 120° east meridian near Beijing.

In each time zone, the central meridian marks the location where clock time is the same as mean Sun time (i.e., the Sun reaches its highest point in the sky at 12:00 noon). On either side of that meridian, clock time does not coincide with Sun time. The deviation between the two is shown for one U.S. zone in Figure 1-28b.

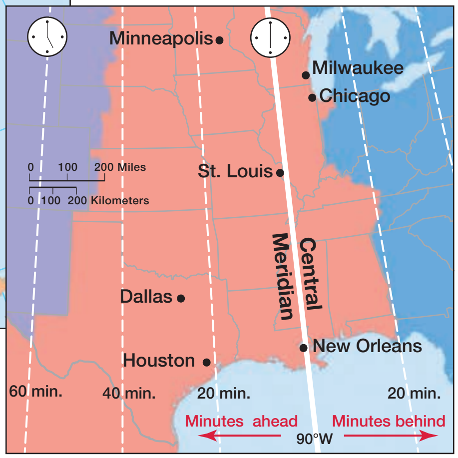
LearningCheck 1-18 What happens to the hour when you cross from one time zone to the next from west to east?

International Date Line

In 1519, Ferdinand Magellan set out westward from Spain, sailing for East Asia with 241 men in five ships. Three years later, the remnants of his crew (18 men in one ship) successfully completed the first circumnavigation of the globe. Although a careful log had been kept, the crew found that their calendar was one day short of the correct date. This was the first human experience with time change on a global scale, the realization of which eventually led to the establishment of the **International Date Line**.



(a) North American time zones



(b) Clock time versus Sun time

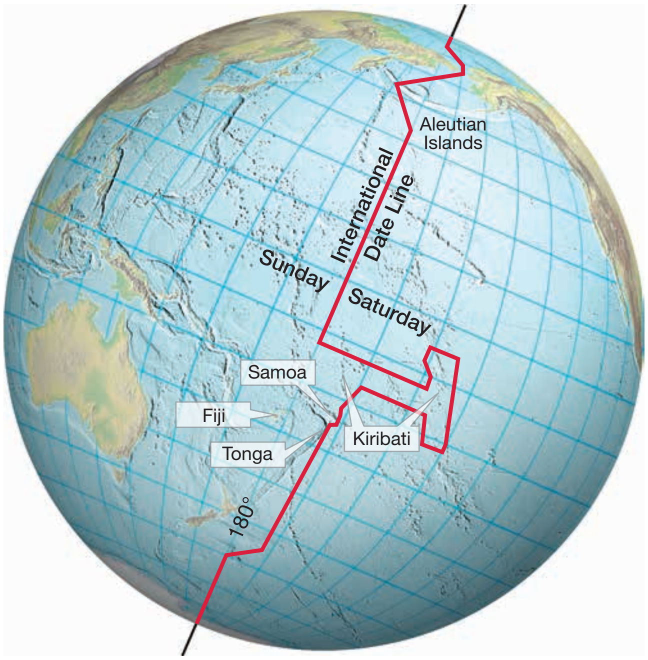
◀ **Figure 1-28** (a) Times zones for Canada, the United States, northern Mexico, and part of Greenland. The number in each time zone refers to the number of hours earlier than UTC (GMT). (b) Standard clock time versus Sun time. The Sun reaches its highest point in the sky at 12:00 noon in St. Louis and New Orleans because both cities lie on the central meridian. East of the central meridian, the Sun is highest in the sky a few minutes before standard time noon; to the west, local solar noon is a few minutes after. In Chicago, for instance, the Sun is highest in the sky at 11:50 A.M.; in Dallas, at 12:28 P.M.

One advantage of establishing the Greenwich meridian as the prime meridian is that its opposite arc is in the Pacific Ocean. The 180th meridian, transiting the sparsely populated mid-Pacific, was chosen as the meridian at which new days begin and old days exit from the surface of Earth. The International Date Line deviates from the 180th meridian in the Bering Sea to include all of the Aleutian Islands of Alaska within the same day and again in the South Pacific to keep islands of the same group—such as Fiji and Tonga—within the same day (**Figure 1-29**). The extensive eastern displacement of the date line in the central Pacific is due to the widely scattered locations of the many islands of the country of Kiribati.

The International Date Line is in the middle of the time zone defined by the 180° meridian. Consequently, there is no time (i.e., hourly) change when you cross the International Date Line—only the calendar day changes, not the clock. When you cross the International Date Line from west to east, it becomes one day earlier (e.g., from January 2 to January 1); when you move across the line from east to west, it becomes one day later (e.g., from January 1 to January 2).

LearningCheck 1-19 **What happens to the day when you cross the International Date Line from west to east?**

Satellite images of Earth can help us trace the expansion of human activities taking place day and night around the globe. Commerce, transportation, industry, and many aspects of urban life are no longer constrained by darkness or time differences between distant cities—see the box *Global Environmental Change: Images of Earth at Night.*



▲ **Figure 1-29** The International Date Line generally follows the 180th meridian, but it deviates around various island groups—most notably Kiribati. When you cross the International Date Line as you travel from west to east on Sunday, the day becomes Saturday; when you cross the International Date Line from east to west, Saturday becomes Sunday.