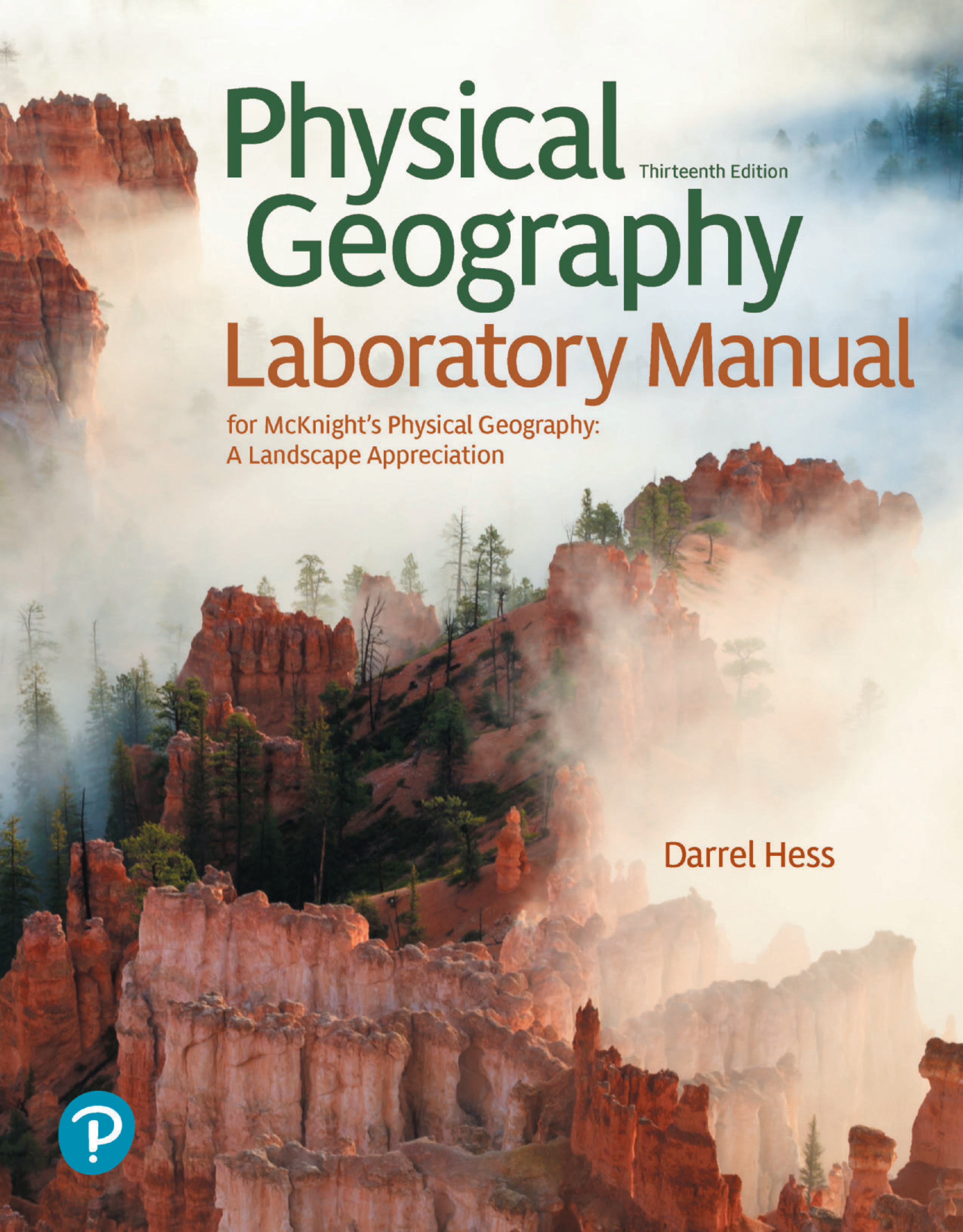

Physical Geography Laboratory Manual

Thirteenth Edition

for McKnight's Physical Geography: A Landscape Appreciation

Darrel Hess

World – Physical

Great Basin	Land features
Caribbean Sea	Water bodies
Aleutian Trench	Underwater features

40°W
20°W
0°
20°E
40°E
60°E
80°E
100°E
120°E
140°E
160°E
ARCTIC OCEAN
80°N
Svalbard
Franz Josef Land
Cape Zhelaniya
Kara Sea
Taymyr Peninsula
Laptev Sea
New Siberian Is.
East Siberian Sea
Greenland Sea
Norwegian Sea
Novaya Zemlya
Barents Sea
North Cape
Lapland
Arctic Circle
Iceland
Faroe Is.
Scandinavia
SIBERIA
Central Siberian Plateau
VERKHOYANSK RANGE
KOLYMA RANGE
Ridge
North Sea
Lake Ladoga
URAL MTS.
West Siberian Plain
Ob R.
Yenisey R.
Lena R.
60°N
Kamchatka Peninsula
Sea of Okhotsk
Ireland
Great Britain
Northern European Plain
Volga R.
EURASIA
ASIA
YABLONOVY RANGE
Amur R.
Cape Lopatka
Sakhalin
EUROPE
Lake Baikal
Kuril Is.
Biscay Plain
ALPS
Mt. Elbrus 18,510 ft (5,642 m)
Caspian Depression
ALTAY MTS.
Kuril Tr.
Emperor Seamounts
Danube R.
Aral Sea
Corsica
Balkan Peninsula
Black Sea
CAUCASUS MTS.
Qizilqum
Gobi
Hokkaido
Azores
Iberian Peninsula
Sardinia
Sicily
Anatolia
Caspian Sea
Garagum
TIAN SHAN
Taklimakan Desert
Huang (Yellow) R.
Sea of Japan (East Sea)
Korea
Japan Trench
40°N
Northwest Pacific Basin
Shatsky Rise
Madeira Is.
ATLAS MTS.
Mediterranean Sea
Tigris R.
ZAGROS MTS.
HINDU KUSH
Honshu
Canary Is.
Euphrates R.
HIMALAYAS
Mt. Everest 29,035 ft (8,850 m)
Indus R.
East China Sea
Kyushu
Qattara Depression
Cape Verde Plain
SAHARA
Red Sea
Persian Gulf
Great Indian Desert
Ganges R.
Chang Jiang (Yangtze R.)
Ryukyu Trench
PACIFIC OCEAN
Tropic of Cancer
Ahaggar
Tibesti
Nile R.
Arabian Peninsula
Taiwan
Mariana Is.
Kyushu-Palau Ridge
Mid-Pacific Mountains
20°N
Air
SAHEL
WESTERN GHATS
Mekong R.
Hainan
South China Sea
Bay of Bengal
Cape Verde Is.
Cape Verde
Niger R.
Lake Chad
Marra Mts.
Arabian Sea
Gulf of Aden
Indochina Peninsula
Philippine Islands
Philippine Trench
Guam
Mariana Trench
Marshall Is.
AFRICA
Great Rift Valley
Cape Gwardafuy
Somali Pen.
Cape Comorin
Sri Lanka (Ceylon)
Palau
MICRONESIA
Ethiopian Highlands
Maldive Is.
Malay Peninsula
Caroline Islands
Cape Palmas
Bioko
Somali Basin
Central Pacific Basin
Equator
Gilbert Is.
0°
São Tomé
Congo R.
MITUMBA MTS.
Lake Victoria
Congo Basin
Mid-Indian Basin
Borneo
Kilimanjaro 19,340 ft (5,895 m)
Seychelles
Sumatra
Sulawesi (Celebes)
MELANESIA
New Guinea
Tuvalu
Mid-Atlantic Ridge
L. Tanganyika
Mascarene Plateau
Mid-Indian Ridge
Ninetyeast Ridge
INDONESIA
Solomon Is.
Ascension
INDIAN OCEAN
Java
Java Trench
Timor
Cape York
Angola Plain
Katanga Plateau
Comoro Is.
Lake Nyasa
Cocos Is.
Coral Sea
Vanuatu
Fiji Is.
St. Helena
Zambezi R.
Madagascar
GREAT DIVIDING RANGE
New Hebrides Tr.
20°S
Namib Desert
Kalahari Desert
Mauritius
Reunion
Great Sandy Desert
New Caledonia
Tropic of Capricorn
Western Plateau
AUSTRALIA
Simpson Desert
ATLANTIC OCEAN
Walvis Ridge
Mozambique Channel
Great Victoria Desert
DRAKENSBERG
Cape Plain
Perth Basin
Madagascar Basin
Broken Ridge
Mt. Kosciusko 7,310 ft (2,228 m)
Tasman Sea
Tristan da Cunha Group
Cape of Good Hope
Great Australian Bight
North Is.
Agulhas Plateau
Southwest Indian Ridge
Tasman Plain
Crozet Basin
Southeast Indian Ridge
South Australian Basin
South Is.
Crozet Is.
Tasmania
Agulhas Basin
Kerguelen Is.
Prince Edward Is.
Campbell Plateau
Macquarie Ridge
South Sandwich Trench
Atlantic-Indian Ridge
Kerguelen Plateau
South Indian Basin
Enderby Plain
America-Antarctic Ridge
60°S
SOUTHERN OCEAN
Weddell Plain
Antarctic Circle
ANTARCTICA
80°S

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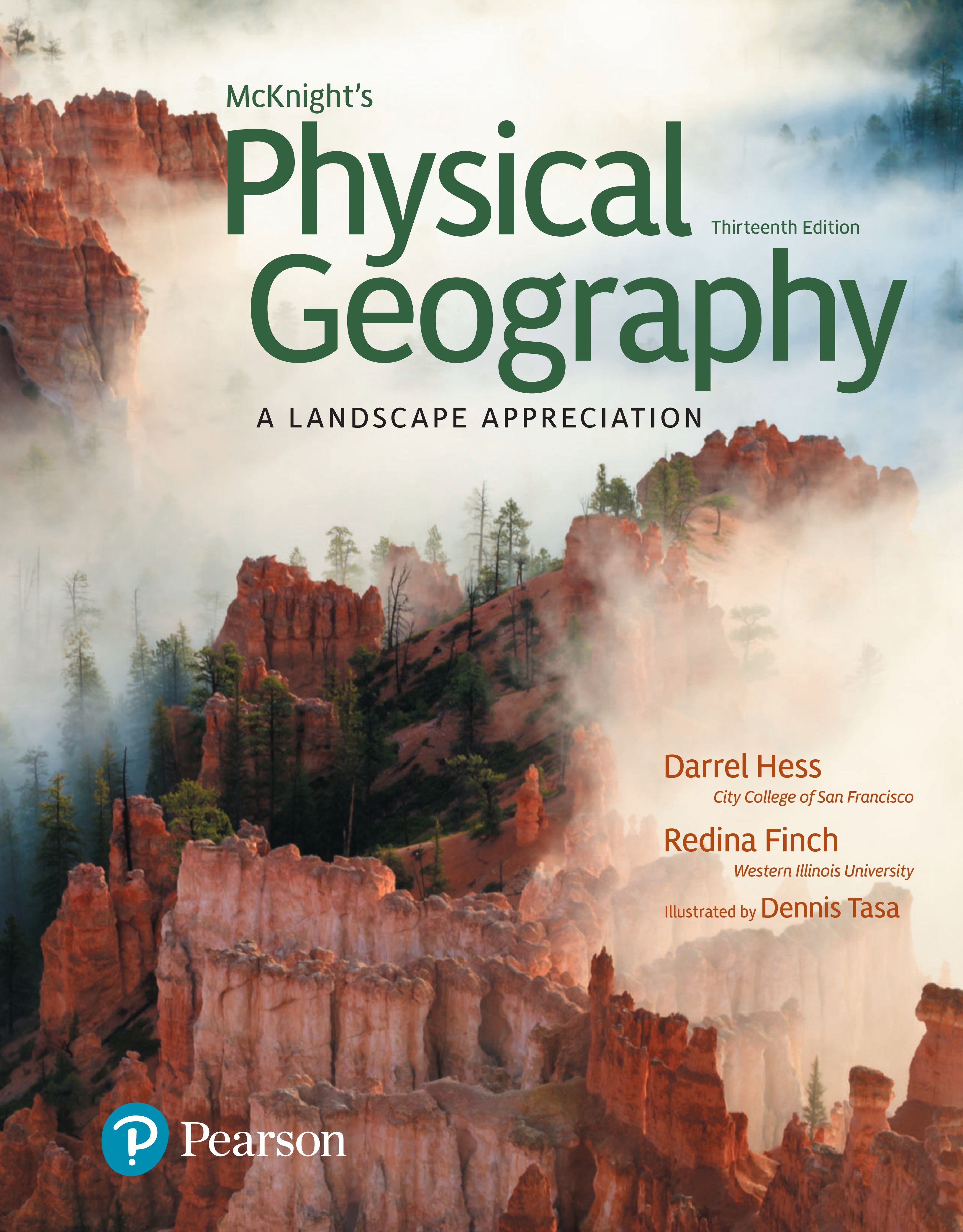

McKnight's

Physical Geography

Thirteenth Edition

A LANDSCAPE APPRECIATION

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Pearson

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Geoscience Animations

Covering the most difficult-to-visualize topics in physical geography, students can access the Geoscience Animations by clicking on the related Pearson links in the book or through the **Mastering Geography™** Study Area. Teachers can assign these media with assessments in **Mastering Geography™**.

1 Introduction to Earth
Solar System Formation
Earth-Sun Relations

2 Portraying Earth
Map Projections

3 Introduction to the Atmosphere
Coriolis Effect
Ozone Depletion

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
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North Atlantic Deep Water Circulation
Arctic Sea Ice Decline
Groundwater Cone of Depression
The Water Table

10 Cycles and Patterns in the Biosphere
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Isostasy

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Plate Boundaries
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Breakup of Pangaea
Subduction Zones
Collision of India with Eurasia
Transform Faults and Boundaries
Hot Spot Volcano Tracks
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Volcanoes
Formation of Crater Lake
The Eruption of Mount St. Helens
Igneous Features
Folding
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Mass Wasting
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18 The Topography of Arid Lands
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19 Glacial Modification of Terrain
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Isostasy
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Glacial Processes
Orbital Variations and Climate Change

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Movement of a Barrier Island
Coastal Stabilization Structures
Seamounts & Coral Reefs

Videos

Students can access videos providing engaging visualizations and real-world examples of physical geography concepts by clicking on the related Pearson links in the book or through the **Mastering Geography™** Study Area. Teachers can assign these media with assessments in **Mastering Geography™**.

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

2 Portraying Earth
Studying Fires Using Multiple Satellite Sensors

3 Introduction to the Atmosphere
NPS: Science in the Park: Denali
Coriolis Effect Merry Go Round
Ozone Hole
NASA: Exploring Earth

4 Insolation and Temperature
Seasonal Radiation Patterns
Ocean Circulation Patterns—Subtropical Gyres
Seasonal Changes in Temperature
NPS: Outside Science: Isle Royale

5 Atmospheric Pressure and Wind
NPS: Point Reyes Wilderness
El Niño
El Niño Triggers Disease
La Niña
Mobile Field Trip: El Niño

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

7 Atmospheric Disturbances
NPS: Lightening Safety at Grand Canyon
NPS: Outside Science: Keeping an Eye on the Everglades
NPS: Climate Change: Everglades
2005 Hurricane Season
NASA: Hurricane Michael as Seen from Space

8 Climate and Climate Change
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18,000 Years of Pine Pollen
Temperature and Agriculture

9 The Hydrosphere
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NPS: Hidden Waters—Grand Canyon in Depth
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Mobile Field Trip: Mammoth Cave

10 Cycles and Patterns in the Biosphere
Global Carbon Uptake by Plants
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Project Condor: Monoclines
Project Condor: Anticlines and Synclines
Project Condor: Faulting versus Joints

15 Weathering and Mass Wasting
Project Condor: Joints and Faults
NPS: Geology of Arches
NPS: Rock Fall
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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
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NPS: Yellowstone: Geysers

18 The Topography of Arid Lands
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Mobile Field Trip: Desert Geomorphology
NPS: Death Valley Explorer (E2)

19 Glacial Modification of Terrain

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Mobile Field Trip: Climate Change in the Arctic
NASA: Operation IceBridge
NPS: Glacial Change at Kenai Fjords National Park
Mobile Field Trip: Yosemite
NPS: Experience Your Yosemite

20 Coastal Processes and Terrain

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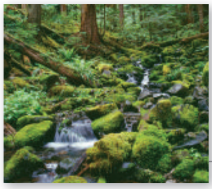

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Preface

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 time-proven approach to physical geography first presented by Tom McKnight more than 35 years ago and carried through 12 editions, now has a new focus in the 13th edition—that of this country's National Parks. The parks, monuments, seashores, and recreational areas that comprise our National Park system serve as a source of inspiration for anyone interested in experiencing natural landscapes. They also provide the prefect introduction to topics that range from Earth's physical features and the processes that form them, to the opportunities they provide for scientific research, and offer a lens through which to view climate change

FEATURES OF 13TH 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 As introduced in Chapter 1, each chapter includes at least one feature that explores a National Park. These include a ***Featured National Park*** that focuses on one particular aspect or ***Snapshots From Our National Parks*** that presents a series of images that relate to a particular topic.
- NEW In addition to the images incorporated into the National Park features, ***Our National Parks*** banners highlight more than 90 photographs that appear as numbered figures in the text, each accompanied by a locator map of the park. Also, highlighted with ***Science in the Field*** banners, photos highlight scientists and researchers at work, many in National Parks.
- NEW Each chapter now opens with the image of a National Park that is the subject of ***Seeing Geographically in Our National Parks***. This feature tests students ability to analyze and interpret what they see before they begin the chapter and then, at the end of the chapter, asks them to reassess their initial assumptions given what they have learned.

All the features originally introduced in the 12th edition, including many authored by outside contributors, have been retained and updated. These include the following:

- ***Global Environmental Change*** features written by expert contributors that present brief case studies on natural and human-caused environmental change, exploring important contemporary events and implications for the future. Topics include *Aerosol Plumes Circling the Globe* and *Changes in the South Asian Monsoon*.
- ***Energy for the 21st Century*** features cover *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*.
- ***Focus*** features focus on science and technology. Topics include *Multiyear Atmospheric and Oceanic Cycles; Soil Differences—They're All About Scale; Measuring Earth's Surface Temperature by Satellite; GOES Weather Satellites; Conveyor Belt Model of Midlatitude Cyclones; Weather Radar; and Earthquake Prediction.*
- ***People & the Environment*** features include *The Oso Landslide*; *The Great Pacific Garbage Patch*; and *The Future of the Mississippi River Delta*.

The pedagogical features that were a hallmark of the 12th edition have been retained and updated. These include the following:

- *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. "All 22 videos are" available within *Mastering Geography*.
- The entire art program was created by the geoscience illustrator Dennis Tasa and includes more than 800 diagrams and maps, done in Dennis's distinctive, accessible style.
- Each chapter includes a refined learning path, beginning with a series of **Key Questions** to help students prioritize key issues and concepts.
- Throughout each chapter, **Learning Check** questions periodically confirm student understanding of the material.
- The end-of-chapter **Learning Review** includes *Key Terms and Concepts*, *Study Questions*, and *Exercises* plus 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 media assets included in the 13th edition include:

- NEW More than 20 *NPS Videos* produced by the National Park Service are included with many of the National Park features and linked by short Urls. Also available within Mastering Geography.
- *Project Condor Quadcopter Videos*, take students out into the field through narrated quadcopter footage, exploring the physical processes that have helped shape North American landscapes.
- The book is supported by Mastering Geography™, 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.

Chapter updates for the 13th edition include the following:

- In Chapter 1, the introduction of the new national parks theme in a two-page feature *National Parks: Our Geographical Laboratories*.
- In Chapter 3, the chapter was reorganized, placing *Human-Caused Atmospheric Change* at the end of the chapter; data and satellite imagery has been updated.
- In Chapter 4, the material on the greenhouse effect has been updated to reflect current terminology; the figure illustrating adiabatic cooling and warming has been clarified; data and satellite imagery has been updated.
- In Chapter 6, the material on latent heat in the atmosphere has been clarified and now includes an illustration; data and satellite imagery has been updated.
- Chapter 7 includes clarifications in the Midlatitude Cyclones section and discussion and illustrations of some of the latest storms, including Hurricanes Harvey (2017), Michael (2018), and Dorian (2019).
- Chapter 8, Climate and Climate Change, has been thoroughly updated and revised with the latest data and applications.
- Chapter 9, the material on the cryosphere has been updated, along with other data and satellite.
- Chapter 10, image of the 2019 Camp Fire has been included.
- Chapter 11, the material and data on the tropical rainforest has been updated.
- Chapter 13, the Geologic Time Scale has been updated and a discussion of absolute and relative dating has been included in the NPS feature.
- Chapter 14, the new NPS feature includes a timeline of the ongoing eruptions of Kīlauea, including the eruption in 2018.
- Chapter 19, maps and data have been updated on glaciers and ice shelves.

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.
- *Science in the Field* 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 from a National Park that begins each chapter. The *Seeing Geographically in Our National Parks* 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 URLs that direct you to *Mobile Field Trips*, *Project Condor* Quadcopter Videos, online animations, and other videos. 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

I first want to formally welcome Redina Finch as coauthor of *McKnight's Physical Geography*. Her involvement with the textbook began as a major contributor to the previous edition. Now as coauthor, she took primary responsibility for the revisions of our chapters on atmospheric

science—although her mark is found throughout the book. It is a much better textbook because of her contributions and thoughtful critiques.

Once again Dennis Tasa has done a wonderful job on the illustrations. We've now worked together on four editions, and he continues to impress me with his ability to take rough ideas and turn them into effective and beautiful illustrations.

I am delighted that we are again including the *Mobile Field Trip* videos developed by photographer, writer, pilot, and educator, Michael Collier—many of his videos fit in perfectly with this new edition's focus on our National Parks.

A special nod of appreciation goes to my previous editor, Christian Botting, who first developed the idea of a National Parks emphasis for this new edition of the textbook.

Finally, I offer my deepest gratitude to Development Editor Mary Hill. Her sound advice and critical eye for detail all through the writing and production process has improved this book enormously.

As with previous editions, this book was a collaborative effort incorporating contributions of many scholars who wrote short boxed essays, problem sets, and activities for the book. Many thanks to all who offered their ideas for improvement for this edition, including:

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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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Matt Huber, *Syracuse University*
Paul Hudson, *University of Texas*
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Steven Jennings, *University of Colorado at Colorado Springs*
Ryan Jensen, *Brigham Young University*
Dorleen B. Jenson, *Salt Lake Community College*
Kris Jones, *Saddleback College*
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Scott Walker, *Northwest Vista College*
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Nancy Lee Wilkinson, *San Francisco State University*
Shawn Willsey, *College of Southern Idaho*
Donald Wuebbles, *University of Illinois at Urbana Champaign*
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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.

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I would like to thank my husband, Owen, for his support and patience as I worked some very late hours to complete this book.

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www.masteringgeography.com

FOR STUDENTS

Physical Geography Laboratory Manual, 13th 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 13th 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 Mastering Geography program. **www.masteringgeography.com.**

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- Encounter Physical Geography by Jess C. Porter and Stephen O'Connell (0321672526)
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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 *Mastering Geography*™.

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- 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

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Dedication

For my students over the last 30 years at

City College of San Francisco

D.H.

To my students, past, present, and future:

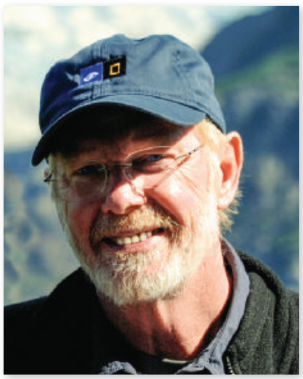
You inspire me!

R.L.F.

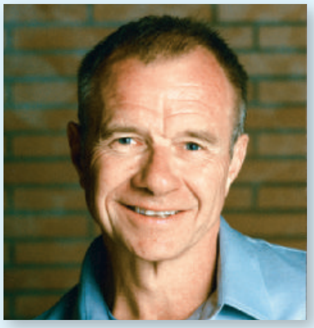
About the Authors

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. Along with the 9th edition, he developed the first of four special *California Editions* of the textbook. 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.

Redina L. Finch has been teaching introductory and advanced meteorology classes for almost 20 years. She earned a bachelor's degree in physics from the Florida Institute of Technology and a PhD in atmospheric sciences from the University of Illinois, Urbana-Champaign. Redina is involved in science education research and won the Western Illinois University College of Arts and Sciences award for Teaching with Technology in 2014. She is the current editor-in-chief for the National Association of Geoscience Teachers' education magazine, *In the Trenches*. Redina regularly contributes to community service activities, including Science Olympiad, Discovering the World through Science summer camp, Girl Scouts STEM program, and others. She is the Western Illinois University representative to the University Corporation for Atmospheric Research (UCAR), which runs the National Center for Atmospheric Research (NCAR). Redina is also a coauthor of *The Atmosphere: An Introduction to Meteorology*. In her spare time, Redina likes to do almost anything outdoors. People jokingly say that every picture Redina takes has clouds in it. She admits that's probably true! Redina and her husband, Owen, are lucky to have horses in the back yard and the Mississippi River right down the road.



Dennis Tasa attended the Minneapolis College of Art and Design and was then employed at a publishing company, working in book production, design, and illustration. While illustrating a geology textbook for the publisher, a close association with the author spurred an interest in the field of geology. After forming his own business, Tasa Graphic Arts, Inc., his interest in the geosciences continued, illustrating numerous textbooks including physical geography, physical geology, earth science, meteorology, historical geology, and mineralogy. From 1993 to 2018 he expanded his company to include computer software publishing. Working with noted college professors Dennis and his staff created and published award-winning educational programs in the geosciences. Now residing in Taos, New Mexico, in addition to book illustration under DK Tasa, Inc., he and his wife, Karen, enjoy camping, hiking, and painting.



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 Island*s; and *Introduction to Geography*, with Edward F. Bergman. Tom passed away in 2004—the geographic community misses him enormously.

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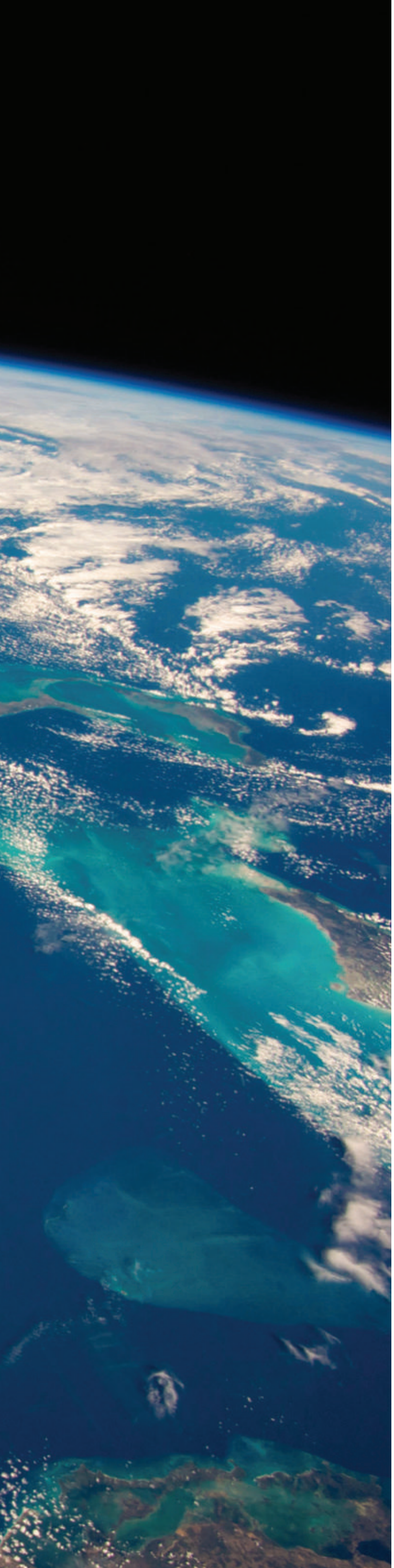
Seeing Geographically in Our National Parks

NASA Astronaut Terry Virts took this photograph of Florida from the International Space Station in 2015. Dry Tortugas National Park is the tiny horseshoe-shaped blue patch in the ocean west of the Florida Keys. What might explain the light color of the ocean here? From this distance above the surface, what evidence of human activity can you see?



Introduction to Earth

1

HAVE YOU EVER WONDERED how we know that human activity is changing global climate? Or why Seattle residents need to worry about earthquakes but Miami 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. Many examples come from one of our greatest resources for studying and protecting the natural environment: our National Parks—three are even visible in this image of Florida taken from space: Everglades, Biscayne, and Dry Tortugas.

By the time you finish this book, we hope you'll understand—in other words, appreciate—the landscape in new ways.

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

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

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.

Mobile Field Trip
Introduction to Physical Geography
https://media.pearsoncmg.com/ph/esm/esm_mcknight_physgeo_13/media/

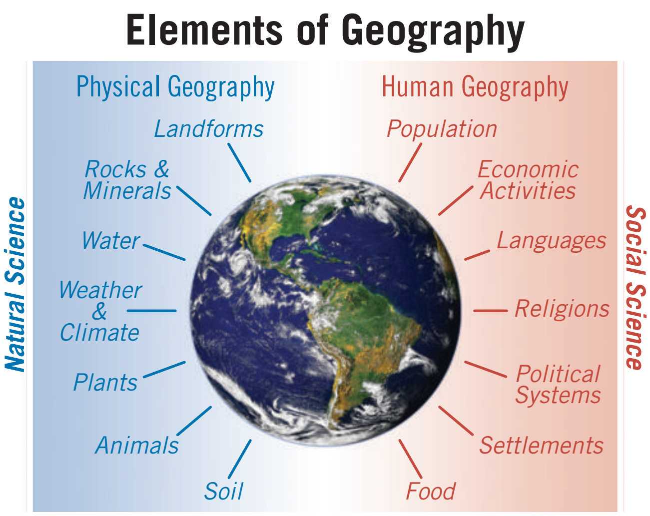
The Study of Geography

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 studies veered 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 activity; 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.

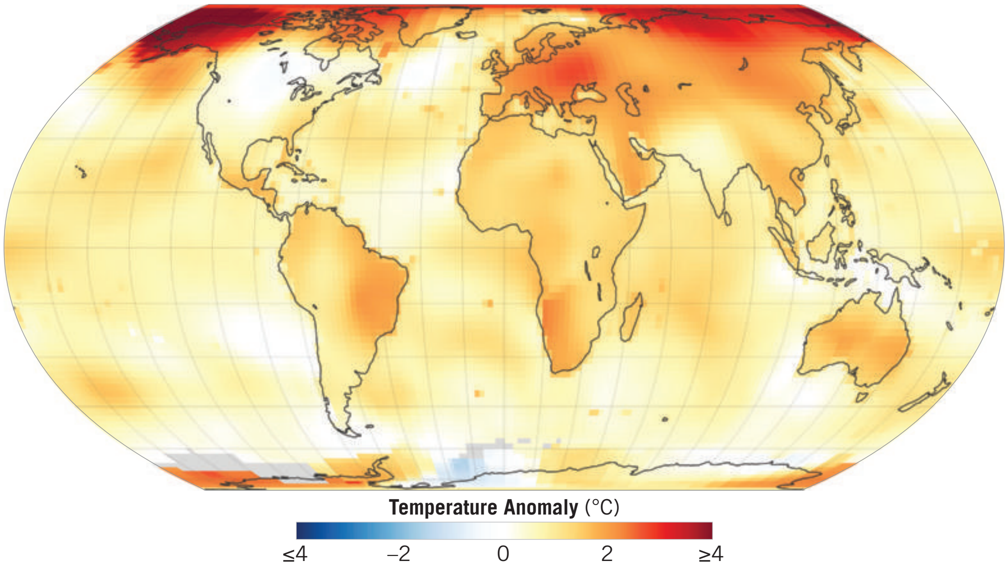
LearningCheck 1-1 **What are the differences between physical geography and human geography? (Answer on p. AK-1)**

Another basic characteristic of geography is its interest in interrelationships. We 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 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—with the global economy and human society.



◀ **Figure 1-2** Earth's climate is changing. This image shows the difference in temperature (the temperature anomaly in °C) during the year 2019 compared with the average temperatures for the baseline period 1951 to 1980. (NASA)

Furthermore, in many chapters 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, 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 older industrialized countries. The 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?**

Geography in the National Parks

A final theme running through this book is the role of National Parks as places to study, protect, and enjoy all facets of the natural environment. Throughout the book, you'll see many topics illustrated with examples from our National Park System. Every chapter begins with an image from a Park and each chapter includes at least one special box featuring a National Park. The first box is an overview of the National Park System itself—see the box *Featured National Parks: National Parks—Our Geographical Laboratories*.

▼ **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.

Featured National Parks

National Parks

Our Geographical Laboratories

The American writer Wallace Stegner once said that our National Parks are "the best idea we ever had." Although we can argue that our Bill of Rights, the Emancipation Proclamation, the Nineteenth Amendment, and the Civil Rights Act of 1964 rank higher in terms of American ideals, our National Park System did indeed begin with the distinctly American idea that there are places in our country that belong to all of us, and these places should be protected and preserved for all generations to come.

▲ **Figure 1-A** Yosemite in 1899. African American "Buffalo Soldiers" of the Twenty-Fourth Infantry were the first protectors of Yosemite National Park—before the National Park Service was established, the U.S. Army was responsible for administering National Parks.

History of the National Parks: The first step toward our present-day National Park System took place in 1864 when President Lincoln set aside Yosemite Valley and adjacent lands for California to protect (**Figure 1-A**). In 1872, President Grant signed the act that would lead to the creation of Yellowstone National Park—the first national park in the world (**Figure 1-B**). The 1906 Antiquities Act allowed a president—with simply a signature—to protect a specific natural, historic, or cultural feature as a National Monument. Over the decades, many National Monuments established in this way, such as Grand Canyon (**Figure 1-C**) and Death Valley, became full-fledged National Parks. In 1916, the Organic Act created the National Park Service (NPS) within the Department of the Interior, with the mission to

> *. . . conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations.*
>
> From the National Park Service *Organic Act* of 1916.

Today the National Park System has more than 400 units. The NPS oversees National Parks, National Monuments, National Seashores, National Recreation Areas, National Memorials, National Historic Parks, National Battlefields, and National Preserves, along with many other components. The differences among these designations relate to how each was established, its purpose, the types of activities permitted, and the kind of protection afforded. These sites range in size from a single house to areas twice the size of Maryland. In all, about 340,000 square kilometers (130,000 square miles) of land are administered by the National Park Service—an area greater than the entire country of Finland.

Although the mission of the NPS has not wavered over the last century, in some regards what we conserve and how we conserve our natural and historic heritage has evolved. Early on, the Parks were thought of primarily as wild places with little regard for the people originally living there—for example, Native Americans and their settlements were removed from Yosemite Valley by the 1960s. But over time, the NPS has come to acknowledge that even some of the darkest chapters of American history are as important for us to remember and preserve as are wild places; the National Park System now incorporates sites such as the Gettysburg battlefield of the Civil War, the Manzanar internment camp where Japanese Americans were imprisoned during World War II, and Little Rock Central High School where in 1957 nine African American students passed through an angry white crowd to desegregate a public school.

The Parks as Preserves: For physical geographers, the units of our National Park System offer some of the best places in the country to observe processes operating in the natural environment. In many Parks, large tracts of land have been set aside where the landscape is allowed to change with as little influence from people as possible. Parks provide some of the last sanctuaries for animals now gone from the rest of the country; there are expanses of natural grassland not yet tilled under for agriculture; coastlines not yet lined with houses; and

◀ **Figure 1-B** Yellowstone National Park. The Midway Geyser Basin with Excelsior Geyser and Grand Prismatic Spring seen from the air.

▲ **Figure 1-C** Grand Canyon National Park. Visitors at Mather Point along the South Rim.

there are Parks with truly dark skies where city dwellers can glimpse the Milky Way for perhaps the first time in their lives.

The Parks as Laboratories: In addition to being places where we can visit largely unspoiled landscapes, National Parks are also critical laboratories for the study of both natural and anthropogenic (human-caused) environmental change. Within our Parks, we can observe how forest health changes in the decades after a wildfire; how whole ecosystems are altered when a once-exterminated predator is reintroduced; and how a changing climate affects the size of glaciers, the distribution of birds, or the pattern of vegetation.

Because our National Parks include such a variety of environments—from the tropics to the Arctic, and from low deserts to high mountains—the research conducted here will only become more important in the years to come.

Featured National Parks: In this book we illustrate many aspects of physical geography with examples from our National Parks (a term we'll use rather broadly to include any unit in the National Park System). In addition to the many photographs, "Mobile Field Trips" and videos you'll see, we also provide a series of short case studies from the National Parks. These "Featured National Park" boxes encompass a wide range of topics, environments, and locations within the National Park System (**Figure 1-D**).

The examples in this book only scratch the surface of what you can see and learn about in our National Parks. To find out more about National Parks near you, visit *https://www.nps.gov/findapark*.

Questions

1. Which unit of the National Park System is closest to your home?
2. Why are National Parks important "laboratories" for studying environmental change?

▼ **Figure 1-D** Map showing the location of National Parks featured in this textbook.

Other Parks Included in This Book:

(NHP = National Historic Park, NM = National Monument, NMe = National Memorial, NP = National Park, NPr = National Preserve, NR = National River, NRA = National Recreation Area, NS = National Seashore)

Acadia NP, *ME*
Arches NP, *UT*
Big Bend NP, *TX*
Cape Hatteras NS, *NC*
Capitol Reef NP, *UT*
Congaree NP, *SC*
Craters of the Moon NM, *ID*
Devils Postpile NM, *CA*
Dry Tortugas NP, *FL*
Gates of the Arctic NP, *AK*
Gateway Arch NP, *MO*
Haleakalā NP, *HI*
Joshua Tree NP, *CA*
Katmai NP, *AK*
Kenai Fjords NP, *AK*
Lyndon B. Johnson NHP, *TX*
Mount Rushmore NMe, *SD*
National Marine Sanctuary of *American Samoa*
New River Gorge NR, *WV*
North Cascades NP, *WA*
Organ Pipe Cactus NM, *AZ*
Padre Island NS, *TX*
Rainbow Bridge NM, *UT*
Saguaro NP, *AZ*
Santa Monica Mountains NRA, *CA*
Sunset Crater NM, *AZ*
Theodore Roosevelt NP, *ND*
Voyageurs NP, *MN*
White Sands NP, *NM*
Wind Cave NP, *SD*
Wrangell–St. Elias NP, *AK*
Yukon–Charley Rivers NPr, *AK*
Zion NP, *UT*

Geography and Science

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

The Process of Science

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 or 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 phenomena 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 its stated conclusions. 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. However, this very uncertainty often compels scientists to push forward in the quest for knowledge and understanding.

In this book we present the fundamentals of physical geography as 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?**

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. 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.

TABLE 1-1 Unit Conversions—Quick Approximations

	S.I. to English Units	English to S.I. Units
Distance:	1 centimeter = a little less than ½ inch	1 inch = about 2½ centimeters
	1 meter = a little more than 3 feet	1 foot = about ⅓ meters
	1 kilometer = about ⅔ mile	1 yard = about 1 meter
		1 mile = about 1½ kilometers
Volume:	1 liter = about 1 quart	1 quart = about 1 liter
		1 gallon = about 4 liters
Mass:	1 gram = about 1/30 ounce	1 ounce = about 30 grams
	1 kilogram = about 2 pounds	1 pound = about ½ kilogram
Temperature:	1°C change = 1.8°F change	1°F change = about 0.6°C change

For exact conversion formulas, see Appendix I.

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*.

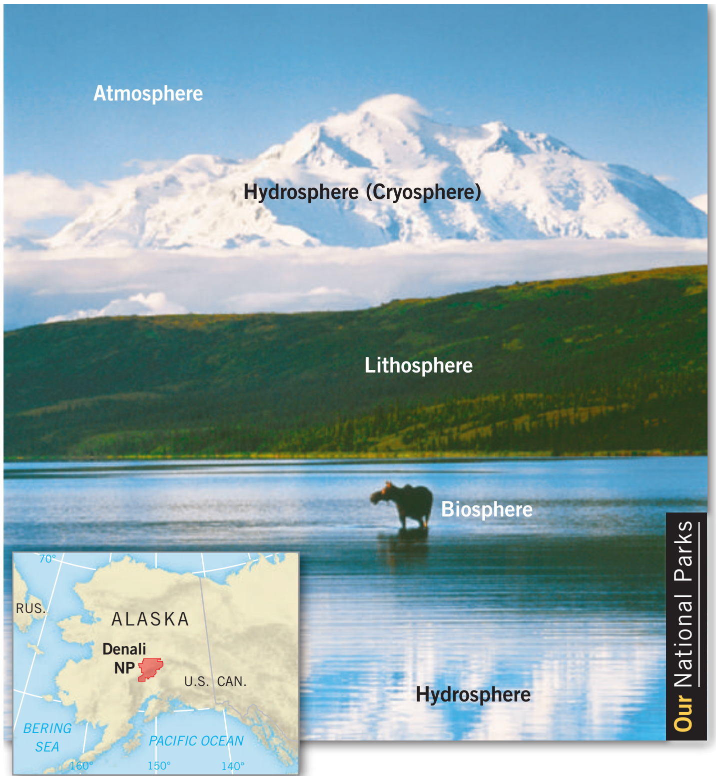
Earth's Environmental Spheres

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

The **biosphere** (*bios* 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*).



▲ **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.

These "spheres" are not discrete entities but rather are considerably interconnected. This intermingling is 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 material (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.

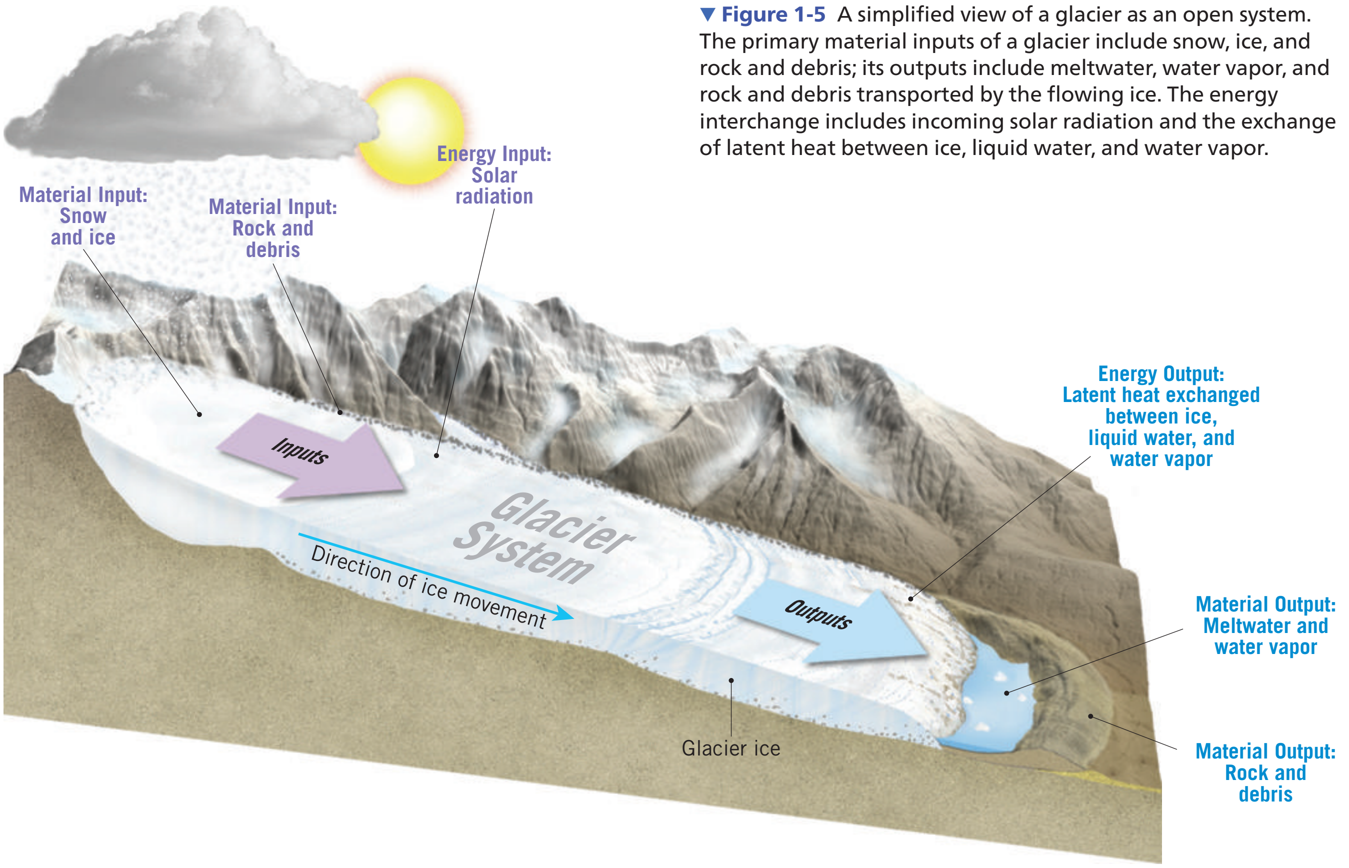
LearningCheck 1-4 **Briefly define the lithosphere, atmosphere, hydrosphere, cryosphere, and biosphere.**

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, constantly enters and exits the Earth system.

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 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.)



▼ **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.

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 example, a glacier remains 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 is 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 example, 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
Solar System Formation
https://media.pearsoncmg.com/ph/esm/esm_mcknight_physgeo_13/media/

The Solar System

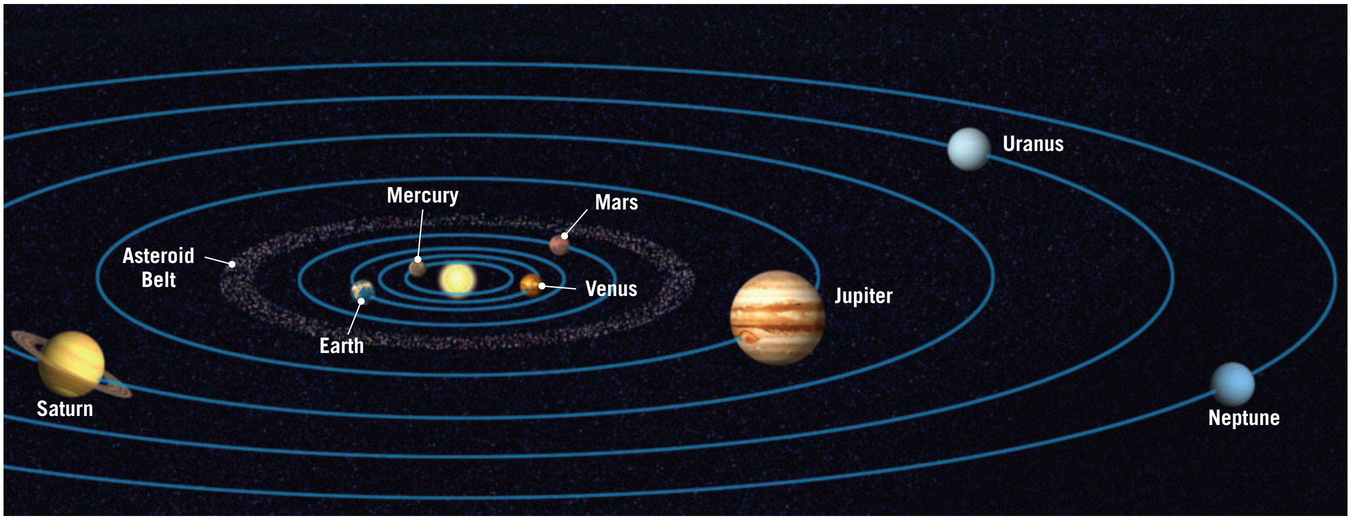
Earth is one of eight planets of our solar system, which also contains more than 200 natural satellites or "moons" revolving around the planets; an uncertain number of smaller *dwarf planets*, such as Pluto; scores of comets (bodies composed of frozen liquid and gases together with small pieces of rock and metallic minerals); more than 995,000 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 100 billion 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. Scientists generally accept 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 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 and other bodies.

All of the planets revolve around the Sun in elliptical orbits, with the Sun located at one focus. (If we look "down" on the



▲ **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.

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*. Several dozen yet-to-be-discovered plutoids and other dwarf planets may be 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 your 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 example, 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 trillion kilometers (25 trillion 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 8848 meters (29,029 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 about 19,881 meters (65,227 feet).[2]

Although prominent on a human scale of perception, the difference between the highest and lowest places is minor on the 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 is usually exaggerated 8 to 20 times—as are many diagrams used in this book. Furthermore, many diagrams illustrating features of the atmosphere also exaggerate relative sizes to convey important concepts.

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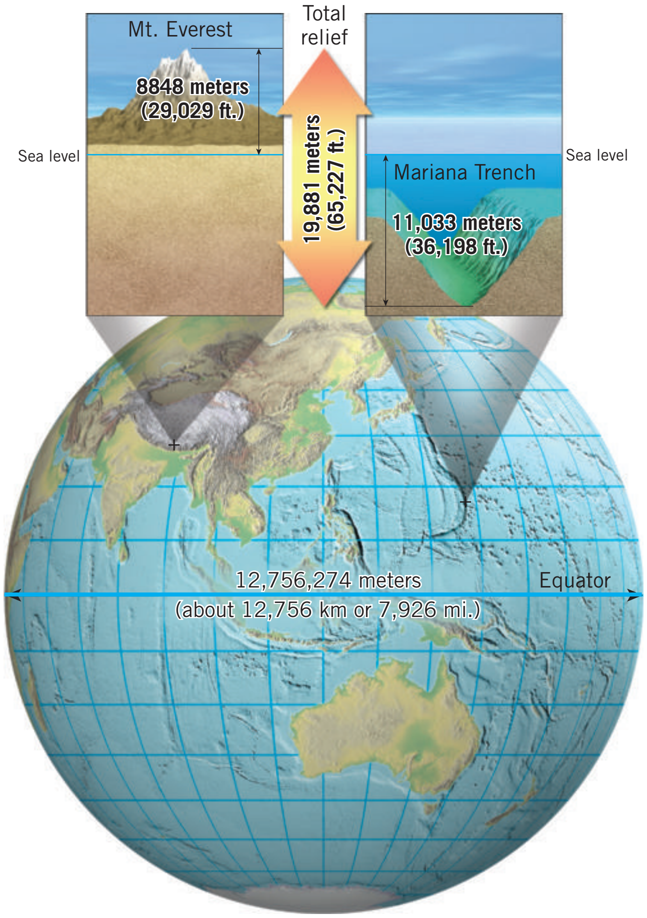
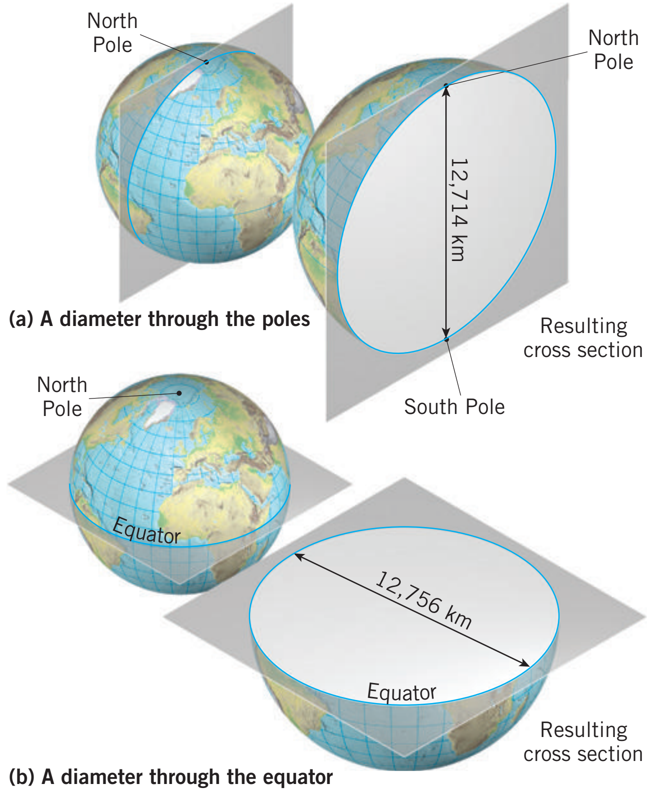
[2]As more precise data become available through the use of GPS (see Chapter 2), the accepted elevations of points on Earth can change. The "height modernization" program of the National Oceanic and Atmospheric Administration in the United States is scheduled for completion by 2023; once the new vertical "datum" is established, the precise elevations of some places may change—but only on paper!



▲ **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 19,881 meters (65,227 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.

More than 2600 years ago, Greek scholars correctly reasoned that Earth has 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 pliable enough 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.

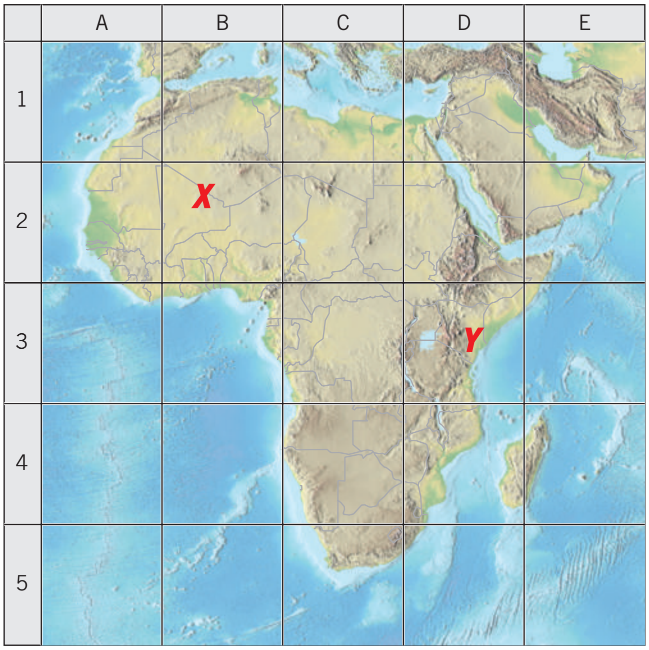
LearningCheck 1-8 **What are Earth's highest and lowest points, and what is the approximate elevation difference between them?**

The Geographic Grid—Latitude and Longitude

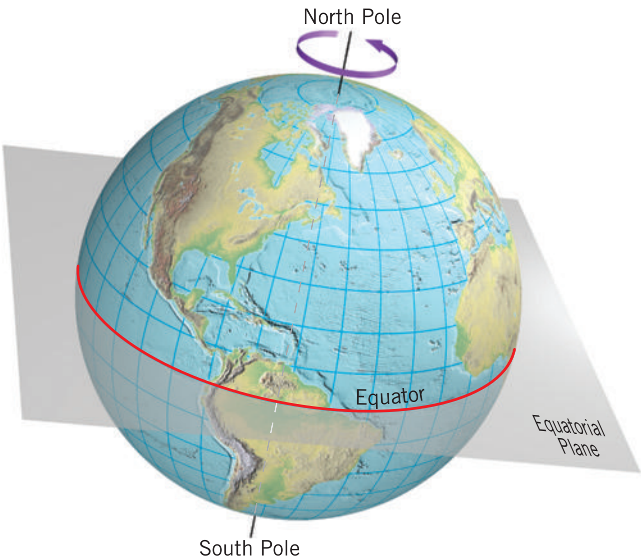
Any understanding of the distribution of geographic features over Earth's surface requires some system of accurate location. The simplest technique for achieving this is a grid system consisting of two sets of lines that intersect at right angles, allowing the location of any point on the surface to 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 wasn't rotating, 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 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



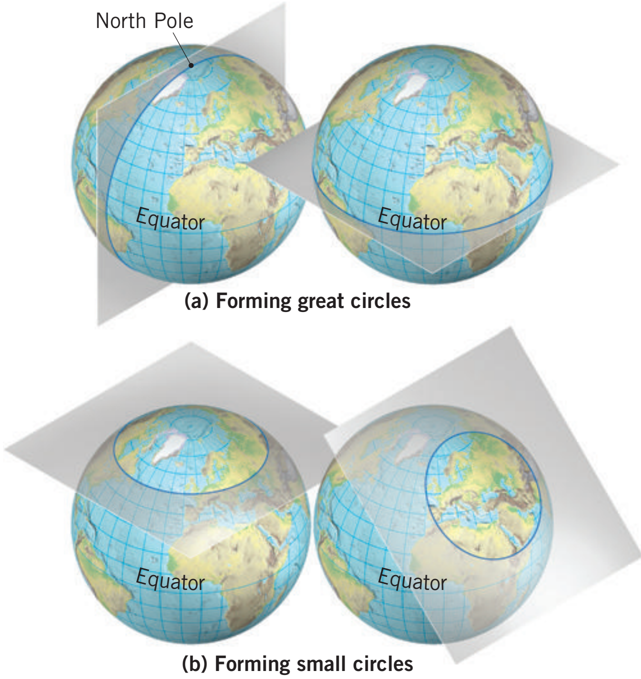
▲ **Figure 1-9** An example of a grid system. The location of point *X* can be described as 2B or as B2; the location of *Y* is 3D or D3.



▲ **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.

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.

Great Circles: Any plane that passes 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**).



▲ **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.

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.)

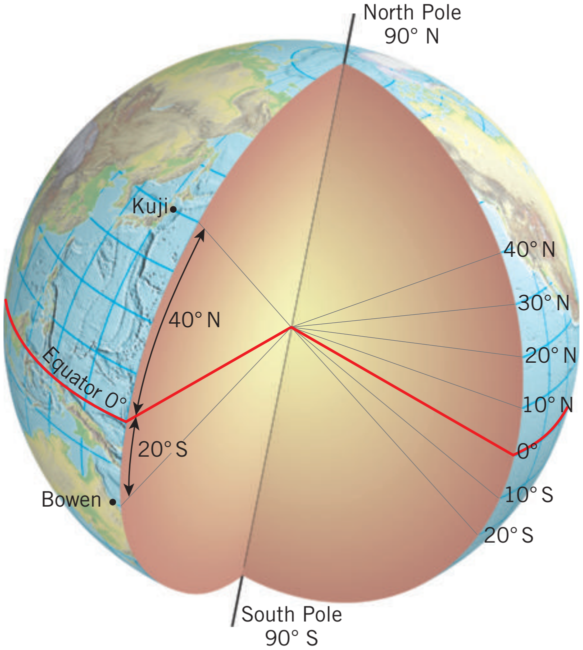
The geographic grid used as the locational system for Earth is based on the principles just discussed. This locational system is closely linked with the various positions of Earth in its orbit around the Sun. Earth's grid system, called a *graticule*, consists of lines of *latitude* and *longitude*.

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

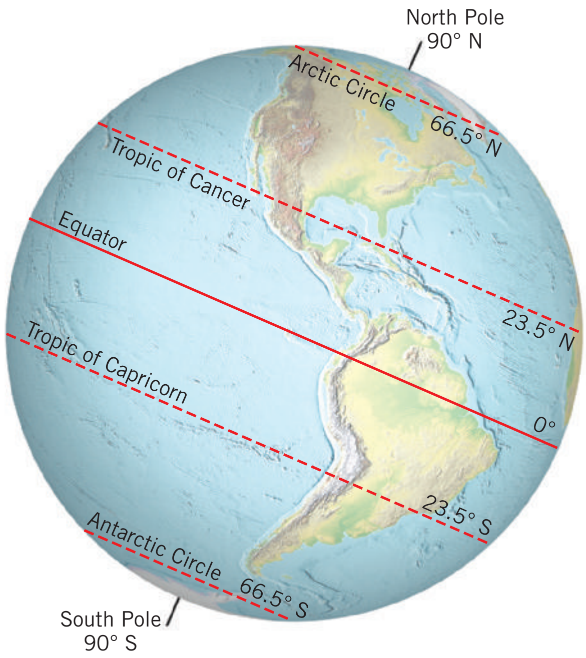
Latitude

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

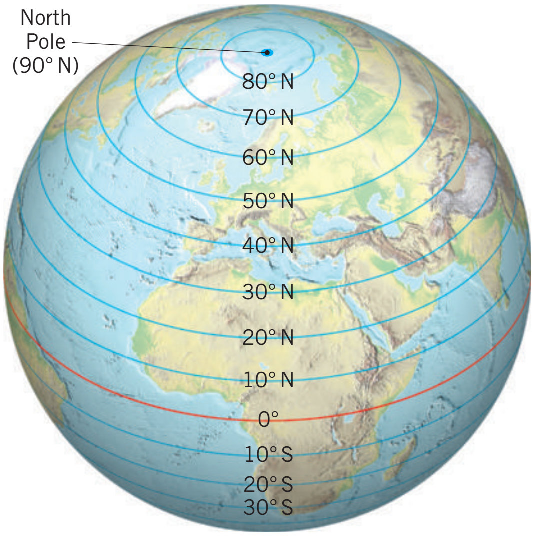
Latitude is expressed in *degrees*, *minutes*, and *seconds*. There are 360 degrees (°) in a circle, 60 minutes (′) in one degree, and 60 seconds (″) in one minute. With the advent of GPS navigation (discussed in Chapter 2) , it is increasingly common to see latitude and longitude designated using decimal 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).



▲ **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.



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

◀ **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.

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.[3] 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

[3]North latitudes are sometimes designated with positive numbers and south latitudes with negative numbers; east longitudes are designated with positive numbers and west longitudes with negative numbers.

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?**

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 30° S
- *Midlatitude*—between about 30° and 60° N and 30° and 60° S
- *High latitude*—latitudes greater than about 60° N and 60° 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 25°–30° 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.

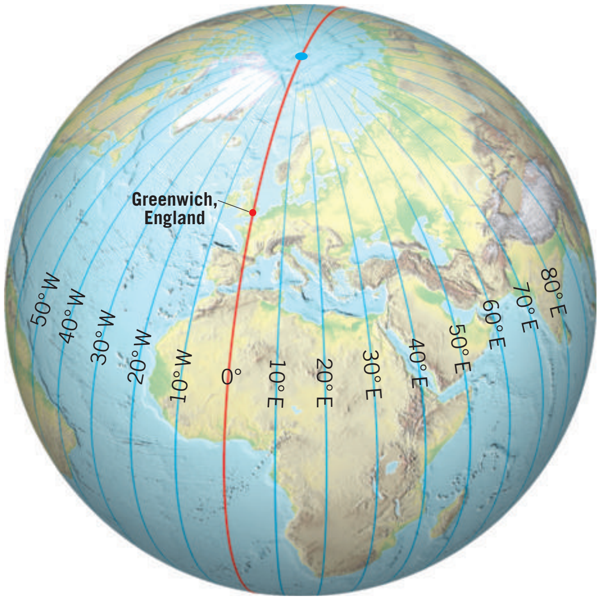
Longitude

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

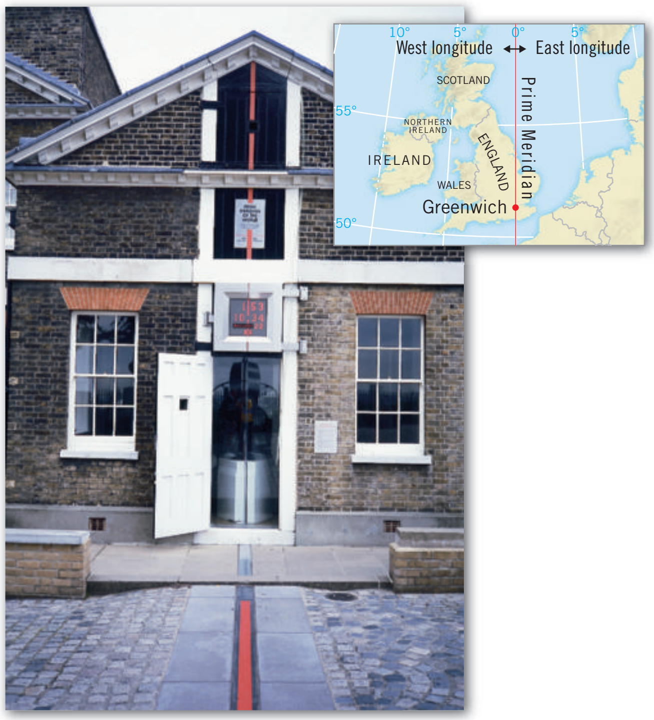
Longitude is represented by imaginary lines extending from pole to pole and crossing all parallels at right angles. These lines, called **meridians**, are not parallel to one another except where they cross the equator. Notice that any pair of meridians is farthest apart at the equator, becoming increasingly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

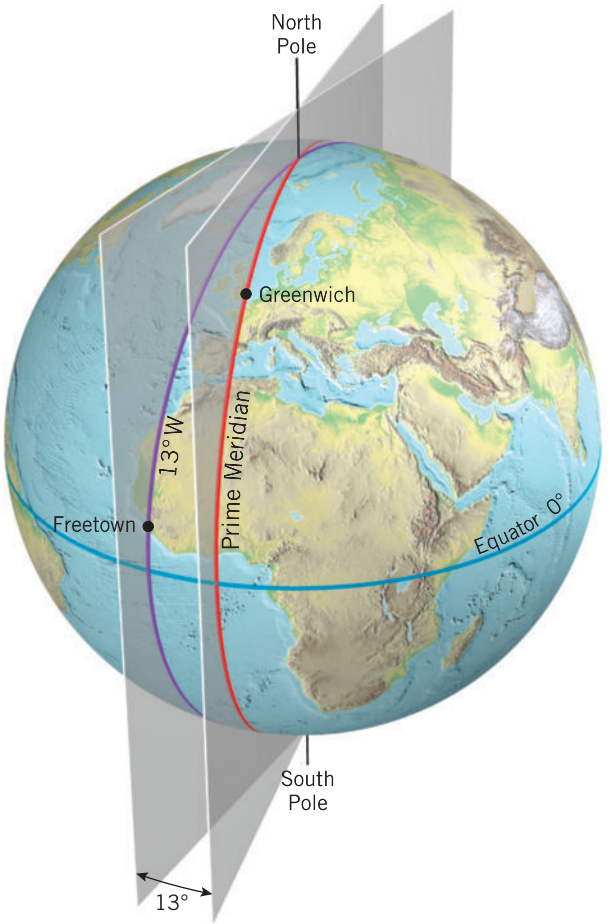
In 1884, an international conference was convened in Washington, D.C., to establish global time zones and select a single prime meridian. After weeks of debate, the conference chose the meridian passing through the Royal Observatory at Greenwich, England, just east of central London, as the **prime meridian** 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.



▲ **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.

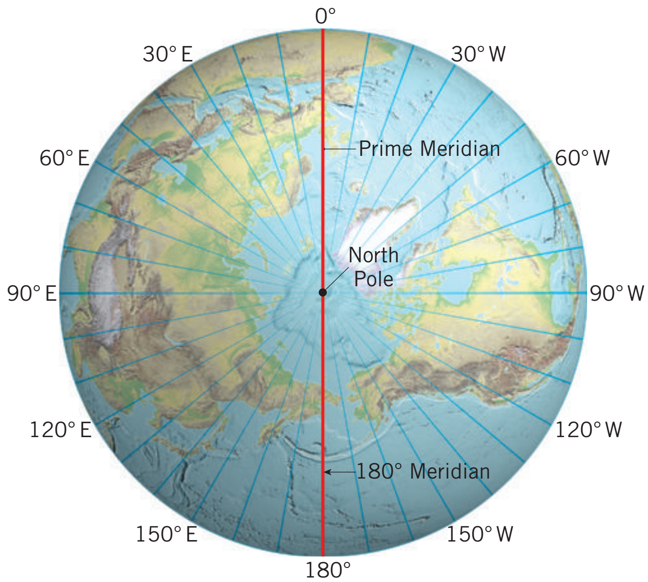


▲ **Figure 1-18** The meridians that mark longitude are defined by intersecting imaginary planes passing through the poles. Shown here are the planes for the prime meridian through Greenwich, England, and the meridian through Freetown, Sierra Leone, at 13° west longitude.

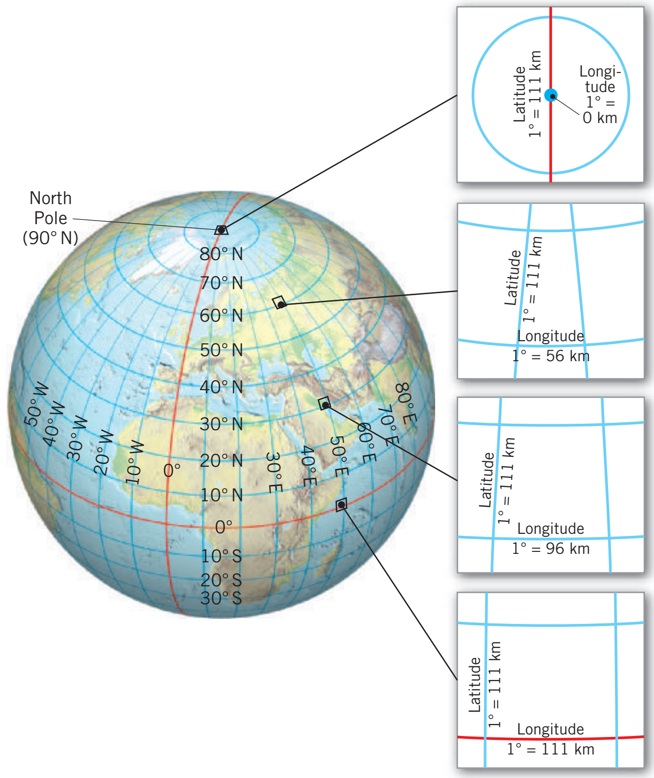
Thus, an imaginary north–south plane passing through Greenwich and through Earth's axis of rotation represents the plane of the prime meridian. The angle between this plane and a plane passed through any other point and the axis of Earth is a measure of longitude. For example, the angle between the Greenwich 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**).

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.



▲ **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 1-20** 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).

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°44′34.089″ N and 73°50′43.842″ 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?**

Earth–Sun Relations and the Seasons

Animation
Earth-Sun Relations
https://media.pearsoncmg.com/ph/esm/esm_mcknight_physgeo_13/media/

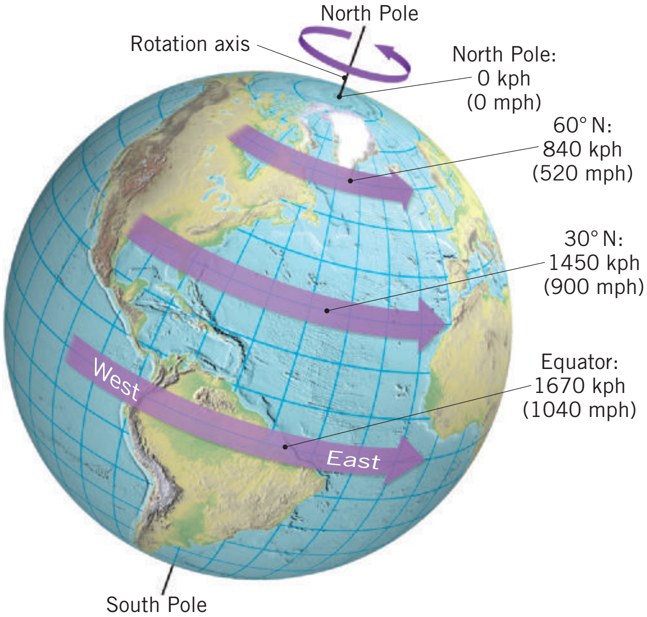
Nearly all life on Earth depends on solar energy; therefore, the relationship between Earth and the Sun is of vital importance. Because of the constant motions of Earth, this relationship does not remain the same throughout the year. We begin with a description of Earth movements and the relationship 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. This change produces 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.

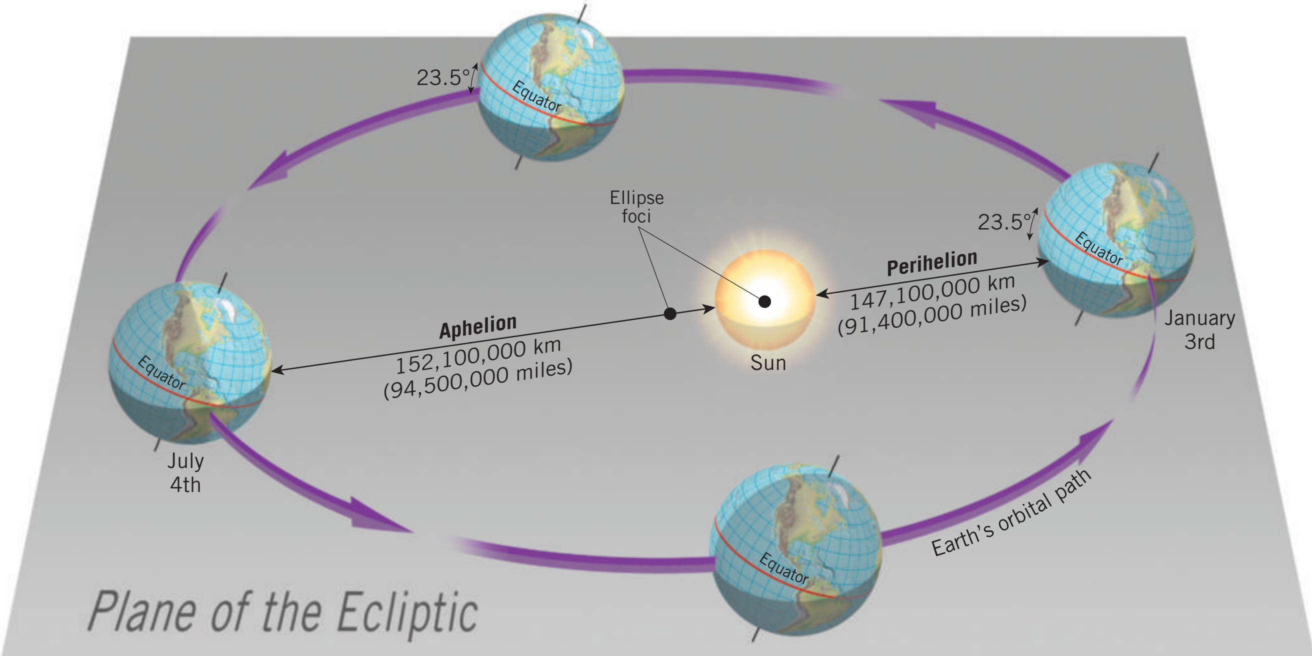


▲ **Figure 1-21** Earth rotates from west to east. Looking down at the North Pole from above, Earth appears to rotate counterclockwise. The speed of Earth's rotation is constant but varies by latitude, being greatest at the equator and effectively diminishing to zero at the poles. The speed of rotation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

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.

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 formally as



▲ **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 not exactly in the center. In this diagram the elliptical shape of Earth's orbit is greatly exaggerated. The Sun is actually much larger than Earth, but both are shown exaggerated in size. Notice that Earth's axis always points in the same direction throughout its orbit.

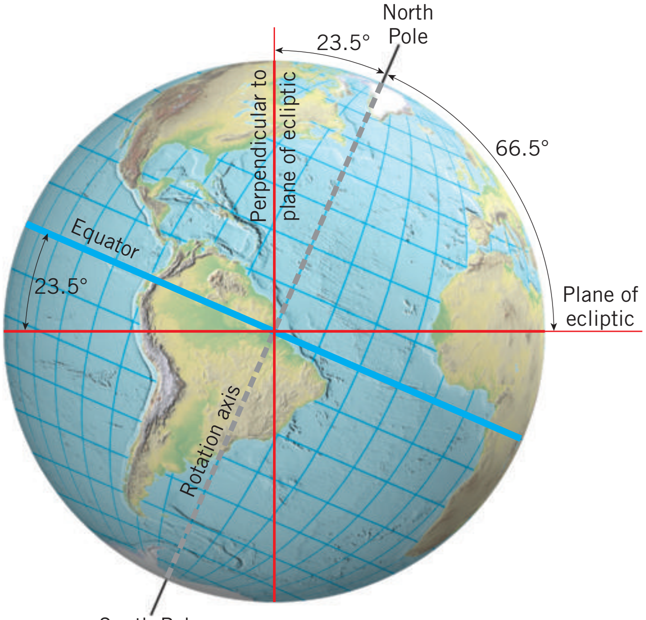
the *tropical year* and for practical purposes is usually simplified to 365.25 days.

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)—149,597,871 kilometers (92,960,117 miles).

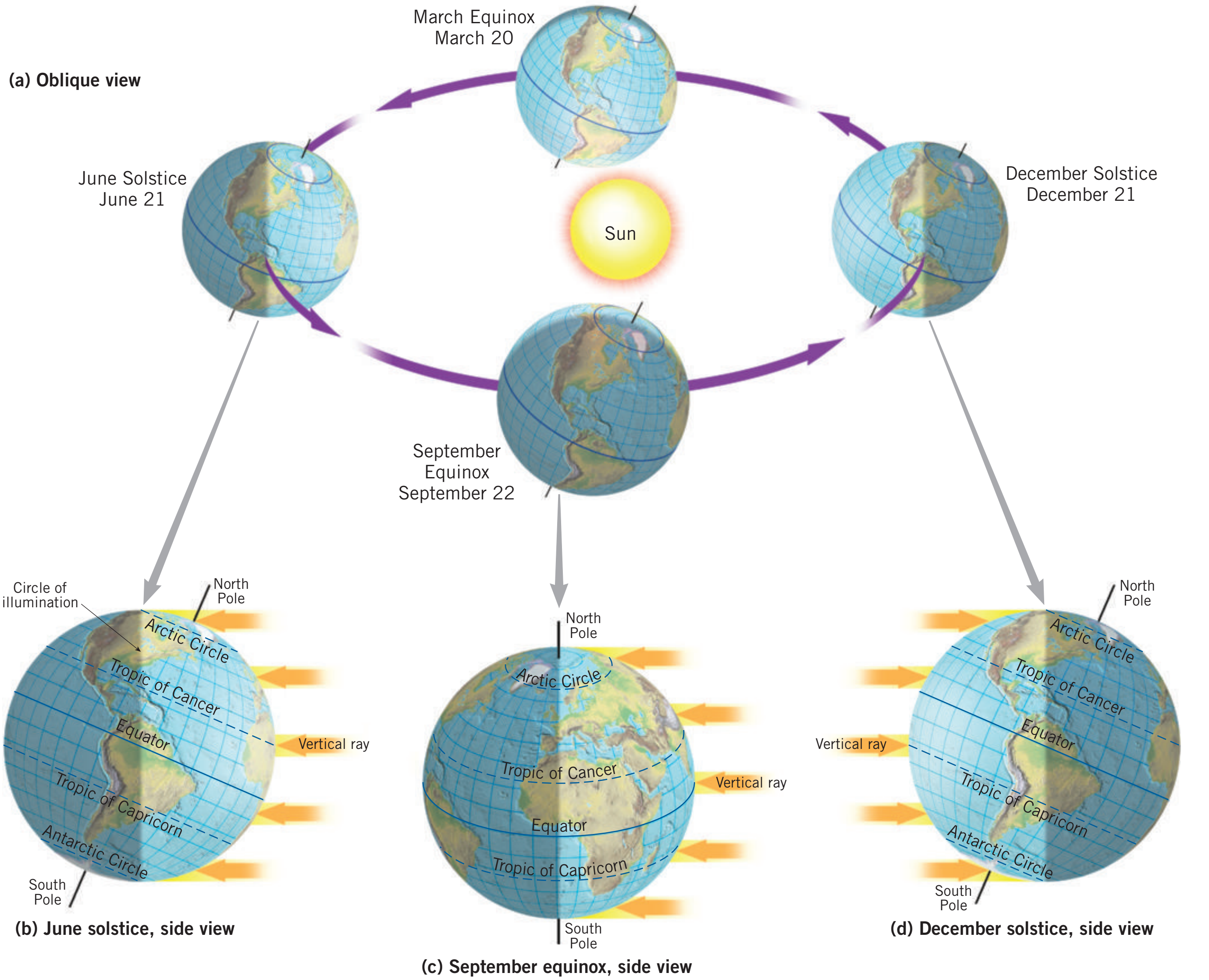
Earth is 3.3 percent closer to the Sun during the Northern Hemisphere winter than during the Northern Hemisphere summer, an indication that variations in the distance between Earth and the Sun do *not* cause the change of seasons. Instead, two additional factors in the relationship of Earth to the Sun—*inclination* 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 throughout the year. This tilt is referred to as the **inclination of Earth's axis**.



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



▲ **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.

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.

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

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 June solstice, the September equinox, the December solstice, and the March equinox (see Figure 1-24a and Table 1-2). 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 and September equinoxes (compare Figures 1-24a and 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).

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

Seasonal Transitions

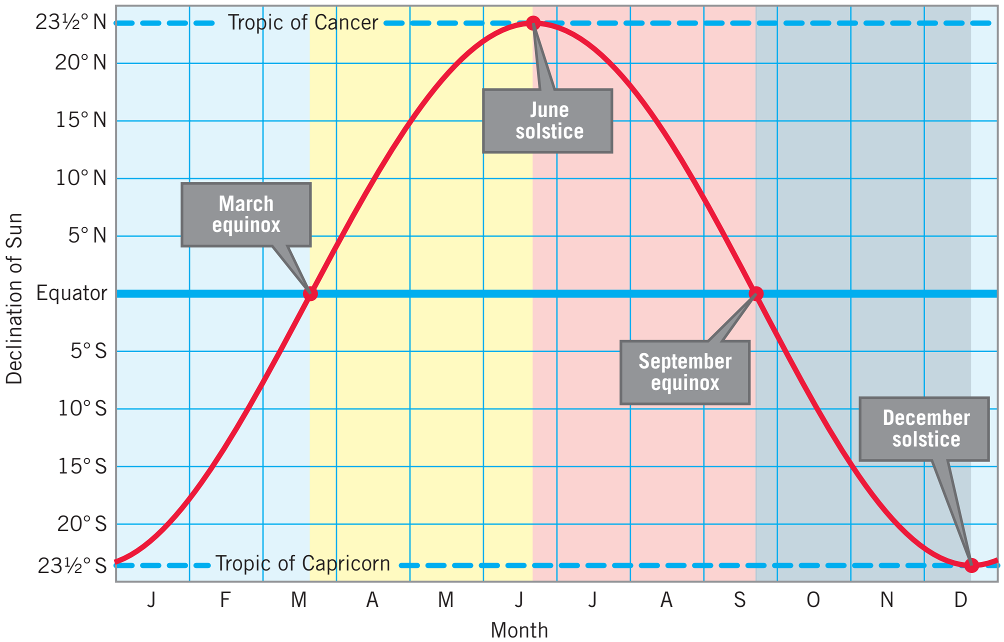
In the preceding discussion of the solstices and equinoxes, we emphasized the conditions on just four special days of the year. It is important to understand the transitions in day length and Sun angle that take place on other days as well.

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 (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 on 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



◀ **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.

to diminish until the shortest day of the year, on 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?

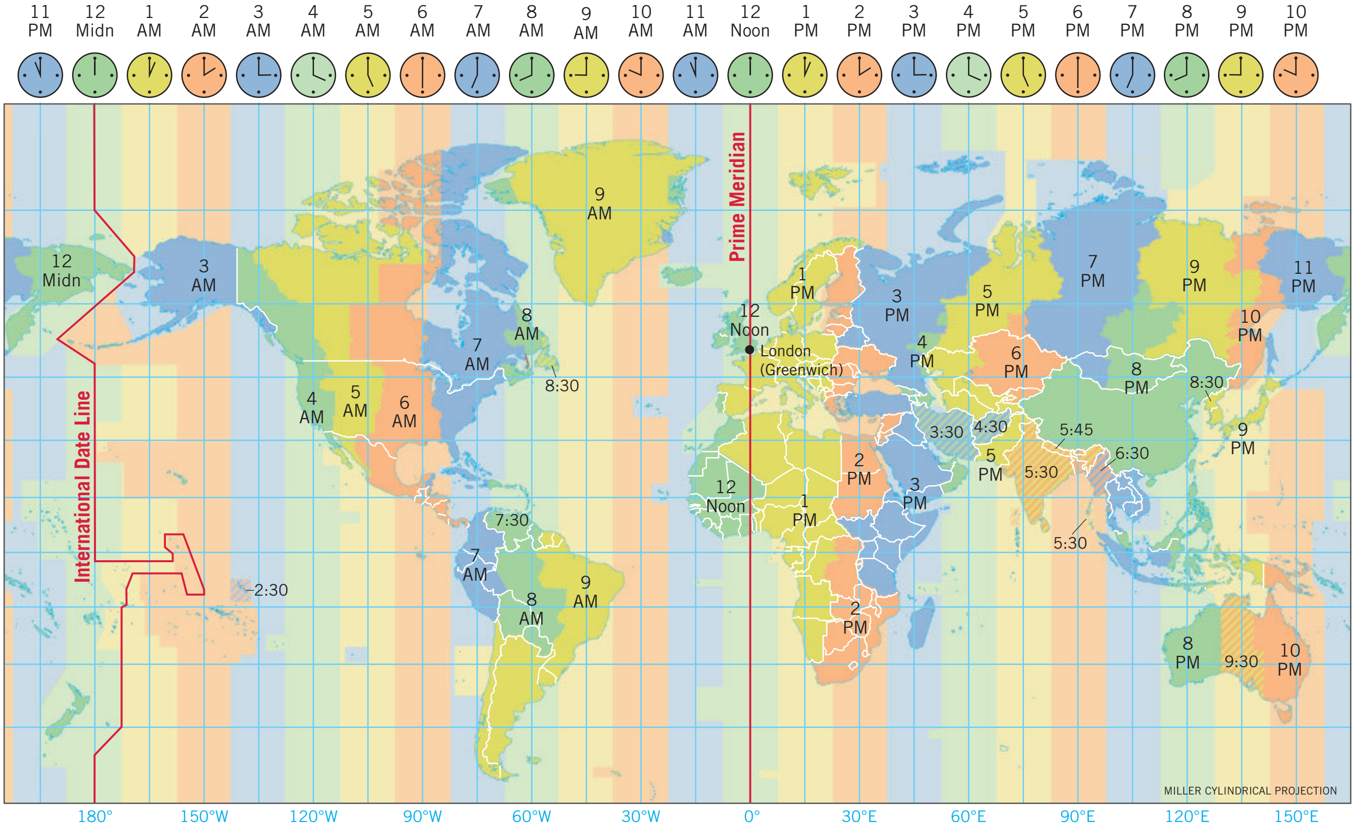
Telling Time

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 *meridiem*—the Sun's highest (*meri*) point of the day (*diem*). Our use of A.M. (ante meridiem: "before noon") and P.M. (post meridiem: "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.

▼ **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.

Standard Time

As the telegraph and railroad began to speed communications and passengers between cities, the use of many different local 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 **Coordinated Universal Time (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 11 time zones; including Alaska and Hawai‘i, the United States spreads over six (**Figure 1-28a**).

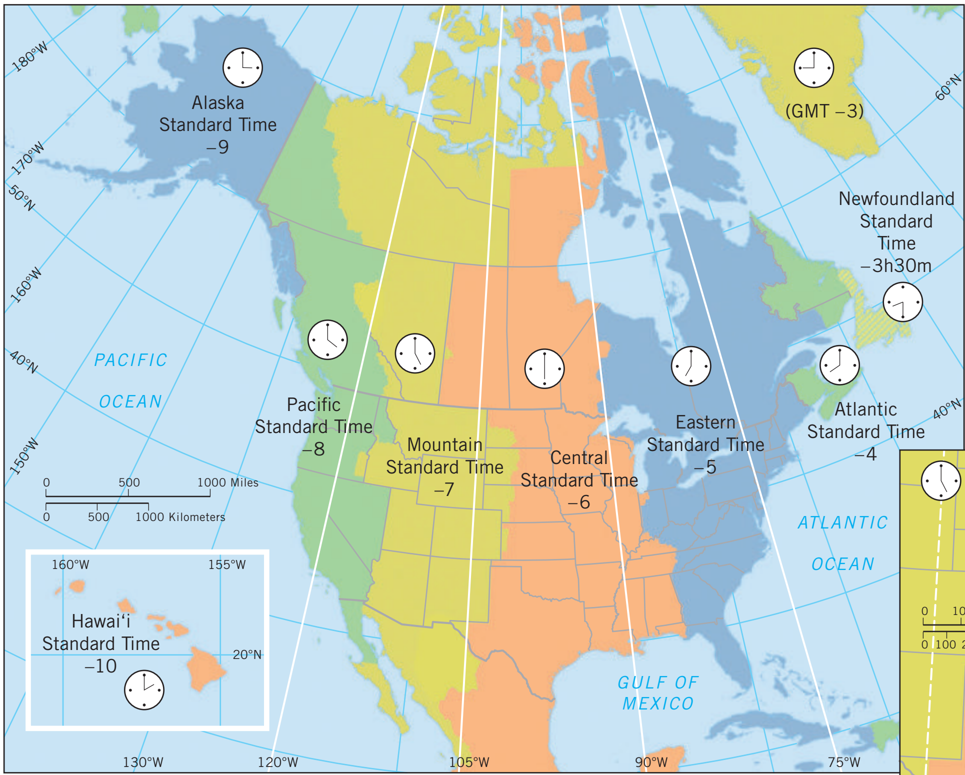
In international waters, time zones are exactly 15° wide. Over land areas, however, boundaries vary to coincide with political and economic boundaries. For example, the Central Standard Time Zone of the United States, centered on 90° W, extends all the way to 105° W (which is the central meridian of 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.**

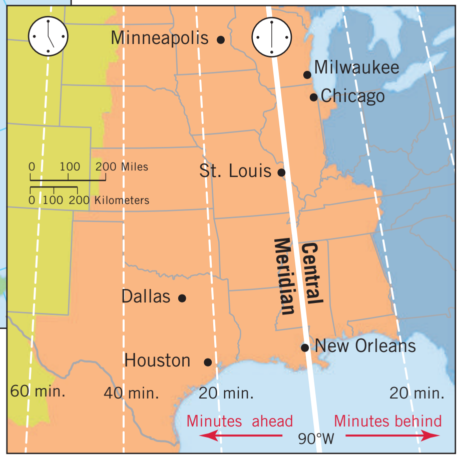
LearningCheck 1-18 **What happens to the hour when you cross from one time zone to the next from west to east?**

International Date Line

In 1519, Ferdinand Magellan set out westward from Spain, sailing for East Asia with 270 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



(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.

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**.

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?**

▲ **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.

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

Global Environmental Change

Images of Earth at Night

▲ **Figure 1-E** Satellite composite of Earth at night.

• **Paul Sutton,** University of South Australia

Images of Earth at night appear to map the world's largest cities (**Figure 1-E**). Imagine what these images would look like if you viewed Earth from space at night 100,000 years ago. Would there be clues of human presence? It is unlikely that human-made fires would be visible from space unless they were forest and grass fires lit as a land-use practice. Only in the last 200 years or so have we used nocturnal high-elevation perspectives to monitor human presence. Balloons were used during the U.S. Civil War to count enemy campfires. Most of the images you see today are from satellites or photos taken from the International Space Station (**Figure 1-F**)

The "Big Data" Reality: Most modern images of Earth at night are composites of many satellite images. There is no point in space or time in which you could take a "selfie" of the whole planet to show Earth as a rectangle. Because Earth is spherical, only half of it is in darkness (nighttime) at any moment. Satellites that observe Earth at night are typically about 800 kilometers (500 miles) above Earth's surface in a polar orbit; they do not "see" all of Earth at once. They record images in strips, much as you might wrap tape around a basketball. The image strips are processed and then reassembled into a complete mosaic.

▲ **Figure 1-F** Image of Europe at night showing city lights and aurora borealis taken by NASA astronaut Terry Virts from the International Space Station. (A portion of the solar panels that power the International Space Station appears in the upper right.)

What Do These Images Tell Us? Satellite imagery of Earth at night has been used to develop proxy measures of many human and nonhuman phenomena. Because the imagery is spatially and temporally referenced, we can use image processing techniques to produce maps of various features around the world, such as fires, lightning strikes, lantern fishing, or gas flaring, as well as human settlements or cities. These "maps" are digital data products that we can manipulate mathematically and statistically. By doing so, we can use a map of city lights as a model of human population density. Applying a different set of mathematical parameters to such data can produce a map of urban area, economic activity, energy consumption, ecological footprint, or carbon dioxide emissions. The myriad possibilities are still being explored.

Questions

1. Where in the universe could you take a photo to produce an image of Earth like that in Figure 1-E?
2. What does it mean to say that nighttime imagery is used as a proxy measure of energy consumption?

or time differences between distant cities—see the box *Global Environmental Change: Images of Earth at Night*.

Daylight-Saving Time

To conserve energy during World War I, Germany ordered all clocks set forward by an hour. This practice allowed the citizenry to "save" an hour of daylight by shifting the daylight period into the usual evening hours, thus reducing the consumption of electricity for lighting. The United States began a similar "summer time" policy in 1918, but Hawai'i and parts of Arizona have exempted themselves from observance of **daylight-saving time** under the Uniform Time Act.

Canada, Australia, New Zealand, and most of the nations of western Europe have also adopted daylight-saving time. In the Northern Hemisphere, many nations, such as the United States, begin daylight-saving time on the second Sunday in March (in spring we "spring forward" one hour) and resume standard time on the first Sunday in November (in fall we "fall back" one hour). In the tropics, the lengths of day and night change little seasonally, and there is not much twilight. Consequently, daylight-saving time would offer little or no savings there.

After studying this chapter, you should be able to answer the following questions. Key terms from each text section are shown in **bold type.** Definitions for key terms are also found in the glossary at the back of the book.

Learning Review 1

Key Terms and Concepts

The Study of Geography (*p. 4*)

1. What is the study of **geography**? Contrast **physical geography** and **human geography**.

Geography and Science (*p. 8*)

2. If an idea or a theory cannot be disproven by some possible observation, experiment, or test, can such an idea or theory be supported by science? Explain your reasoning.
3. What is the approximate English System of measurement equivalent of one kilometer in the **International System (S.I.)**?

Environmental Spheres and Earth Systems (*p. 9*)

4. Briefly describe the environmental "spheres": **atmosphere**, **hydrosphere**, **cryosphere**, **biosphere**, and **lithosphere**.
5. Contrast *closed systems* and *open systems*.
6. What does it mean when a system is in *equilibrium*?
7. How does a *positive feedback loop* differ from a *negative feedback loop*?

Earth and the Solar System (*p. 11*)

8. In what ways do the inner (terrestrial) and outer (Jovian) planets differ from each other?
9. Compare the size of Earth to that of its surface features and atmosphere.
10. Is Earth perfectly spherical? Explain.

The Geographic Grid—Latitude and Longitude (*p. 13*)

11. Define the following terms: **latitude**, **longitude**, **parallel**, **meridian**, and **prime meridian**.
12. Latitude ranges from _____° to _____° north and south, whereas longitude ranges from _____° to _____° east and west.
13. State the latitude (in degrees) of the following "special" parallels: **equator**, **North Pole**, **South Pole**, **Tropic of Cancer**, **Tropic of Capricorn**, **Arctic Circle**, and **Antarctic Circle**.
14. What is a **great circle**? A *small circle*? Provide examples of both.

Earth–Sun Relations and the Seasons (*p. 18*)

15. Describe and explain the four factors in Earth–Sun relations associated with the change of seasons: **rotation**, **revolution** around the Sun, **inclination of Earth's axis**, and **polarity (parallelism) of Earth's axis**.
16. Does the **plane of the ecliptic** coincide with the plane of the equator? Explain.
17. On which day of the year is Earth closest to the Sun (**perihelion**)? Farthest from the Sun (**aphelion**)?
18. Provide the approximate dates of the following special days of the year: **March equinox**, **June solstice**, **September equinox**, and **December solstice**.
19. What is the **circle of illumination**?
20. What is meant by the **solar altitude**?
21. Briefly describe Earth's orientation to the Sun during summer and winter in the Northern Hemisphere.
22. Beginning with the March equinox, describe the changing **declination of the Sun** during the year.
23. In the midlatitudes of the Northern Hemisphere, on which day of the year is the Sun highest in the sky? Lowest in the sky?
24. For the equator, describe the approximate number of daylight hours on the following days: March equinox, June solstice, September equinox, and December solstice.
25. What is the longest day of the year (the day with the greatest number of daylight hours) in the midlatitudes of the Northern Hemisphere? In the Southern Hemisphere?
26. For the North Pole, describe the approximate number of daylight hours on the following days: March equinox, June solstice, September equinox, and December solstice.
27. For how many months of the year does the North Pole have no sunlight at all?

Telling Time (*p. 23*)

28. What happens to the hour when you cross a **time zone** boundary from west to east?
29. What is meant by **UTC (Coordinated Universal Time)** and **Greenwich Mean Time (GMT)**?
30. What happens to the day when you cross the **International Date Line** from east to west?
31. When **daylight-saving time** begins in the spring, you would adjust your clock from 2:00 A.M. to _____.