

McKnight's

# Physical Geography

A LANDSCAPE APPRECIATION

*Eleventh Edition*



**DARREL HESS**

Illustrated by  
**Dennis Tasa**

MCKNIGHT'S

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A Landscape Appreciation



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ELEVENTH EDITION

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A Landscape Appreciation

**DARREL HESS**

City College of San Francisco

Illustrated by **DENNIS TASA**

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*Icons for Focus, People and the Environment, and Energy for the 21st Century features:* Shutterstock

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Library of Congress Cataloging-in-Publication Data  
Hess, Darrel.

McKnight's physical geography : a landscape appreciation / Darrel Hess ; illustrated by Dennis Tasa. — 11th ed.  
p. cm.

Includes bibliographical references and index.

ISBN-13: 978-0-321-82043-3 (hardcover : alk. paper)

ISBN-10: 0-321-82043-6 (hardcover : alk. paper)

1. Physical geography. I. McKnight, Tom L. (Tom Lee). 1928–2004 Physical geography. II. Title. III. Title: Physical geography.

GB54.5.H47 2013

910'.02—dc23

2012039478

**PEARSON**

[www.pearsonhighered.com](http://www.pearsonhighered.com)

1 2 3 4 5 6 7 8 9 10—DOW—16 15 14 13 12

ISBN-10: 0-321-82043-6; ISBN-13: 978-0-321-82043-3 (Student Edition)

ISBN-10: 0-321-86404-2; ISBN-13: 978-0-321-86404-8 (Instructor's Review Copy)

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Animation  
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Video  
Hurricane  
Sandy



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Studying Fires Using Multiple Satellite Sensors

## 3 Introduction to the Atmosphere

Ozone Hole

Coriolis Effect Merry-Go-Round

## 4 Insolation and Temperature

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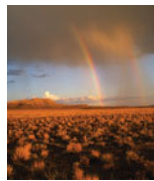
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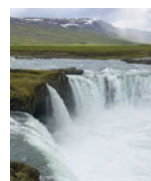
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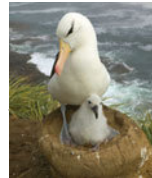
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# PREFACE

*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 11th edition of the book has undergone a thorough revision, while maintaining the time-proven approach to physical geography first presented by Tom McKnight nearly 30 years ago.

## NEW TO THE 11TH EDITION

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

- The entire art program has continued its thorough revision and updating by illustrator Dennis Tasa. Dozens of new diagrams, maps, and photographs are found throughout.
- Each chapter includes a new learning path, beginning with a series of new *Key Questions* to help students prioritize key issues and concepts.
- Chapters now open with new *Seeing Geographically* features that ask students observational questions about the chapter's opening image, and are revisited in the end-of-chapter *Learning Review*.
- Throughout each chapter, new *Learning Check* questions periodically confirm a student's understanding of the material.
- An expanded end-of-chapter *Learning Review* now includes new basic **quantitative Exercises**.
- The series of boxed essays called *Energy for the 21st Century* has been expanded from the 10th edition (where it was called *Renewable Energy*). The boxes have been updated and are now more closely tied to the main text. Contributed by professors from across the country, the essay topics include *Our Continuing Dependence on Fossil Fuels*; *Solar Energy*; *Wind Energy*; *Strategies for Reducing Greenhouse Gas Emissions*; *Fracking for Natural Gas*; *Geothermal Energy*; *Biofuels*; *Hydropower*; and *Tidal Power*.
- In Chapter 1, information on *Earth's Environmental Spheres* and *Earth Systems* has been greatly expanded.
- In Chapter 2, material on *contour lines* and *portraying the three-dimensional landscape* has been reorganized.
- Material on the *development of Earth's modern atmosphere* has been added to Chapter 3.
- In Chapter 3, the section on the *Coriolis effect* has been revised and reorganized to clarify the concept for students, and examples have been added of topics in later chapters for which understanding of the Coriolis effect is important.
- In Chapter 4, the material on *energy, heat, and temperature* has been revised and expanded.
- New diagrams in Chapter 5 illustrate the *Pacific Decadal Oscillation*.
- Chapter 8, *Climate and Climate Change*, has been thoroughly updated and revised with the latest data and applications, and more detailed explanations of *oxygen isotope analysis* and *radiocarbon dating*.
- The material on *rocks* has been expanded in Chapter 13, as has the discussion of *geologic time*.
- Material on *differential weathering* is now incorporated into Chapter 15.
- Chapter 18 on *desert landscapes* and Chapter 20 on *coastal processes and landforms* have been thoroughly reorganized for clarity.
- Some key material previously found in Focus Boxes has been integrated directly into the text. Updated and revised Focus Boxes include *The UV Index*; *Monitoring Earth's Radiation Budget*; *Forecasting El Niño*; *GOES Weather Satellites*; *Global Dimming*; *Lessons of Hurricane Katrina*; *The Great Pacific Garbage Patch*; *Bark Beetles Killing Forests in Western North America*; *Signs of Climate Change in the Arctic*; *Climate Change Affects Bird Populations*; *Rainforest Loss in Brazil*; *The La Conchita Landslides*; *The Changing Mississippi River Delta*; *Disintegration of Antarctic Ice Shelves*; *Shrinking Glaciers*; and *Imperiled Coral Reefs*.
- New Focus Boxes include *Using Remote Sensing Images to Study a Landscape*; *The Conveyor Belt Model of Midlatitude Cyclones*; *Weather Radar*; *The Devastating Tornadoes of 2011*; *Monitoring Groundwater Resources from Space*; *The 2010 Deepwater Horizon Oil Spill*; *Using Soil Profiles to Decipher Past Environmental Changes*; *The 2010 Haiti Earthquake*; *Earthquake Prediction*; *Desertification*; and *The 2011 Japan Earthquake and Tsunami*.
- Quick Response (QR) Codes are integrated throughout the book to enable students with mobile devices to access mobile-ready versions of the *Geoscience Animations* and new *videos* as they read, for just in time visualization and conceptual reinforcement. These media are also available in the Student Study Area of MasteringGeography, and many can also be assigned by teachers for credit and grading.
- The 11th edition is now supported by **MasteringGeography™**, the most widely used and effective online homework, tutorial, and assessment system for the sciences. Assignable media and activities include: *Geoscience Animations*, *Videos*, *Encounter Physical Geography Google Earth™ Explorations*, *MapMaster™* interactive maps, coaching activities on the toughest topics in physical geography, end-of-chapter questions and exercises, reading quizzes, and Test Bank questions.

## TO THE STUDENT

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

- You'll notice that the book includes many diagrams, maps, and photographs. Physical geography is a visual discipline, so studying the figures and their captions is just as important as reading through the text itself.
- Many photographs have “locator maps” to help you learn the locations of the many places we mention in the book.
- A reference map of physical features of the world is found inside the front cover of the book, and a reference map of the countries of the world is found inside the back cover.
- Each chapter begins with a quick overview of the material, as well as series of questions—think about these questions as you study the material in that chapter.
- Look at the photograph that begins each chapter. The *Seeing Geographically* questions for this photograph will get you thinking about the material in the chapter, and about the kinds of things that geographers can learn by looking at a landscape.
- As you read through each chapter, you'll come across short *Learning Check* questions. These quick questions are designed to check your understanding of key information in the text section you've just read. Answers to the Learning Check questions are found in the back of the book.
- Each chapter concludes with a *Learning Review*. Begin with the *Key Terms and Concepts* questions—these will check your understanding of basic factual information and key terms (key terms 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.
- 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.
- Most chapters include QR codes/icons that direct you to online animations and videos that you can access with your mobile device. The animations help explain important concepts in physical geography and include a written and an audio narration. The animations and videos can also be accessed through the Student Study Area in MasteringGeography, and animations can also be assigned for credit by teachers.

## THE TEACHING AND LEARNING PACKAGE

The author and publisher have been pleased to work with a number of talented people to produce an excellent instructional package.

## FOR TEACHERS AND STUDENTS

### MasteringGeography™ with Pearson eText

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

MasteringGeography offers:

- **Assignable activities** that include Geoscience Animation activities, *Encounter Physical Geography* Google Earth Explorations, Video activities, MapMaster™ Interactive Map activities, Map Projection activities, coaching activities on the toughest topics in physical geography, end-of-chapter questions and exercises, reading quizzes, Test Bank questions, and more.
- **Student Study Area** with Geoscience Animations, Videos, MapMaster™ interactive maps, web links, glossary flashcards, “In the News” RSS feeds, chapter quizzes, an optional Pearson eText (including versions for iPad and Android devices), and more.

**Pearson eText** gives students access to the text whenever and wherever they can access the Internet. The eText pages look exactly like the printed text, and include powerful interactive and customization functions, including links to the multimedia.

**Geoscience Animation Library on DVD 5th edition** (0321716841) This resource offers over 100 animations covering the most difficult-to-visualize topics in physical geography, physical geology, oceanography, meteorology, and Earth science. The animations are provided as Flash files and preloaded into PowerPoint slides for both Windows and Mac. This library was created through a unique collaboration among Pearson's leading geoscience authors—including Darrel Hess, Robert Christopherson, Frederick Lutgens, Aurora Pun, Gary Smith, Edward Tarbuck, and Alan Trujillo.

**Television for the Environment Earth Report Videos on DVD** (0321662989) This three-DVD set helps students visualize how human decisions and behavior have affected the environment, and how individuals are taking steps

toward recovery. With topics ranging from the poor land management promoting the devastation of river systems in Central America to the struggles for electricity in China and Africa, these 13 videos from Television for the Environment's global *Earth Report* series recognize the efforts of individuals around the world to unite and protect the planet.

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

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

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

## FOR THE TEACHER

- ***Instructor Resource Manual*** (032186400X) Available for download, this resource for both new and experienced teachers includes learning objectives, detailed chapter outlines, icebreakers to initiate classroom discussions, answers to end-of-chapter questions and a sample syllabus.
- ***TestGen/Test Bank®*** (0321863992) TestGen is a computerized test generator that lets teachers view and edit *Test Bank* questions, transfer questions to tests,

and print the test in a variety of customized formats. This *Test Bank* includes over 3000 multiple-choice, true/false, and short-answer/essay questions. Questions are correlated against learning outcomes as well as U.S. National Geography Standards and Bloom's Taxonomy to help teachers to better map the assessments against both broad and specific teaching and learning objectives. The *Test Bank* is also available in Microsoft Word®, and is importable into Blackboard and WebCT.

- ***Instructor Resource DVD*** (0321863909) Everything teachers need, where they want it. The *Instructor Resource DVD* helps make teachers more effective by saving them time and effort. All digital resources can be found in one well-organized, easy-to-access place, and include:

*Figures*—All textbook images as JPGs, PDFs, and PowerPoint Slides

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 format correlated against U.S. National Geography Standards, chapter specific learning outcomes, and Bloom's Taxonomy

*TestGen*—The TestGen software, questions, and answers for both MACs and PCs

*Electronic Files* of the *Instructor Resource Manual* and *Test Bank*

This Instructor Resource content is also available completely online via the Instructor Resources section of [www.pearsonhighered.com/irc](http://www.pearsonhighered.com/irc).

- ***Answer Key to Laboratory Manual*** (0321864026) Available for download, the answer key provides answers to problem sets presented in the Laboratory Manual: [www.pearsonhighered.com/irc](http://www.pearsonhighered.com/irc).
- ***AAG Community Portal for Aspiring Academics and Teaching College Geography***: This website is intended to support community-based professional development in geography and related disciplines. Here you will find activities providing extended treatment of the topics covered in both books. The activities can be used in workshops, graduate seminars, brown bags, and mentoring programs offered on campus or within an academic department. You can also use the discussion boards and contributions tool to share advice and materials with others: [www.pearsonhighered.com/aag/](http://www.pearsonhighered.com/aag/).
- ***Course Management***: Pearson is proud to partner with many of the leading course management system providers on the market today. These partnerships enable us to provide our testing materials already formatted for easy importation into the powerful Blackboard course management system. Please contact your local Pearson representative for details: [www.pearsonhighered.com/elearning/](http://www.pearsonhighered.com/elearning/).

## FOR THE STUDENT

- **Physical Geography Laboratory Manual, 11th edition** by Darrel Hess (0321863968) 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 11th edition of the lab manual includes both new and revised exercises, new maps, and expanded use of Google Earth™. [www.mygeoscienceplace.com](http://www.mygeoscienceplace.com)
- **Goode's World Atlas** (0321652002) *Goode's World Atlas* has been the world's premiere educational atlas since 1923, and for good reason. It features over 250 pages of maps, from definitive physical and political maps to important thematic maps that illustrate the spatial aspects of many important topics. The 22nd edition includes 160 pages of new, digitally produced reference maps, as well as new thematic maps on global climate change, sea level rise, CO<sub>2</sub> emissions, polar ice fluctuations, deforestation, extreme weather events, infectious diseases, water resources, and energy production.
- **Dire Predictions** by Michael Mann and Lee Kump (0136044352) Periodic reports from the Intergovernmental Panel on Climate Change (IPCC) evaluate the risk of climate change brought on by humans. But the sheer volume of scientific data remains inscrutable to the general public, particularly to those who may still question the validity of climate change. In just over 200 pages, this practical text presents and expands upon the essential findings in a visually stunning and undeniably powerful way to the lay reader. Scientific findings that provide validity to the implications of climate change are presented in clear-cut graphic elements, striking images, and understandable analogies.

## PEARSON'S ENCOUNTER SERIES

Pearson's Encounter series provides rich, interactive explorations of geoscience concepts through Google Earth™ activities, exploring a range of topics in regional, human, and physical geography. For those who do not use MasteringGeography, all chapter explorations are available in print workbooks as well as in online quizzes, at [www.mygeoscienceplace.com](http://www.mygeoscienceplace.com), accommodating different classroom needs. Each exploration consists of a worksheet, online quizzes, and a corresponding Google Earth™ KMZ file:

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

- **Encounter Geosystems** Workbook and Website by Charlie Thomsen (0321636996)
- **Encounter Earth** Workbook and Website by Steve Kluge (0321581296)
- **Encounter Human Geography** Workbook and Website by Jess C. Porter (0321682203)
- **Encounter World Regional Geography** Workbook and Website by Jess C. Porter (0321681754)

## ACKNOWLEDGMENTS

I offer my great appreciation to illustrator Dennis Tasa. Now in our second edition working together, my admiration for his ability to take my ideas and sketches and turn them into effective and impressive illustrations has only grown.

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:

Victoria Alapo, *Metropolitan Community College*  
 Casey Allen, *Weber State University*  
 Sergei Andronikov, *Austin Peay State University*  
 Greg Bierly, *Indiana State University*  
 Mark Binkley, *Mississippi State University*  
 Peter Blanken, *University of Colorado*  
 Margaret Boorstein, *Long Island University*  
 James Brey, *University of Wisconsin Fox Valley*  
 David Butler, *Texas State University*  
 Karl Byrand, *University of Wisconsin*  
 Sean Cannon, *Brigham Young University—Idaho*  
 Wing Cheung, *Palomar College*  
 Jongnam Choi, *Western Illinois University*  
 Glen Conner, *Western Kentucky University*  
 Carlos E. Cordova, *Oklahoma State University*  
 Richard A. Crooker, *Kutztown University of Pennsylvania*  
 Mike DeVivo, *Grand Rapids Community College*  
 Bryan Dorsey, *Weber State University*  
 Don W. Duckson, Jr., *Frostburg State University*  
 Tracy Edwards, *Frostburg State University*  
 Steve Emerick, *Glendale Community College*  
 Doug Foster, *Clackamas Community College*  
 Basil Gomez, *Indiana State University*  
 Jerry Green, *Miami University—Oxford*  
 Michael Grossman, *Southern Illinois University—Edwardsville*  
 Perry J. Hardin, *Brigham Young University*

Ann Harris, *Eastern Kentucky University*  
 Miriam Helen Hill, *Jacksonville State University*  
 Barbara Holzman, *San Francisco State University*  
 Robert M. Hordon, *Rutgers University*  
 Paul Hudson, *University of Texas*  
 Catherine Jain, *Palomar College*  
 Steven Jennings, *University of Colorado at Colorado Springs*  
 Dorleen B. Jenson, *Salt Lake Community College*  
 Kris Jones, *Saddleback College*  
 Ryan Kelly, *Lexington Community College*  
 Rob Kremer, *Metropolitan State College of Denver*  
 Kara Kuvakas, *Hartnell College*  
 Steve LaDochy, *California State University*  
 Michael Madsen, *Brigham Young University—Idaho*  
 Kenneth Martis, *West Virginia University*  
 William (Bill) Monfredo, *University of Oklahoma*  
 Mandy Munro-Stasiuk, *Kent State University*  
 Paul O'Farrell, *Middle Tennessee State University*  
 Thomas Orf, *Las Positas College*  
 Michael C. Pease, *University of New Mexico*  
 Stephen Podewell, *Western Michigan University*  
 Nick Polizzi, *Cypress College*  
 Robert Rohli, *Louisiana State University*  
 Anne Saxe, *Saddleback College*  
 Randall Schaetzl, *Michigan State University*  
 Jeffrey Schaffer, *Napa Valley College*  
 John H. Scheufler, *Mesa College*  
 Robert A. Sirk, *Austin Peay State University*  
 Dale Splinter, *University of Wisconsin—Whitewater*  
 Stephen Stadler, *Oklahoma State University*  
 Herschel Stern, *Mira Costa College*  
 Jane Thorngren, *San Diego State University*  
 Timothy Warner, *West Virginia University*  
 Shawn Willsey, *College of Southern Idaho*

My thanks go out to contributors of new and revised short boxed essays included in this edition: Ted Eckmann of Bowling Green State University, Matt Huber of Syracuse University, Ryan Jensen of Brigham Young University, Michael C. Pease of Central Washington University, Nancy Wilkinson of San Francisco State University, Jennifer Rahn, Samford University, Birmingham, Alabama, Valerie Sloan, University of Colorado at Boulder, and Kenneth Zweibel of George Washington University. Thanks also to Randall Schaetzl of Michigan State University, who contributed a new boxed essay, as well as a detailed review of the material on soils and geomorphology.

Special thanks go to Karl Byrand of the University of Wisconsin Colleges and Stephen Stadler of Oklahoma

State University. In addition to contributing essays to this edition, both have long shared their expertise by providing student- and teacher-support materials for this textbook series. I would also like to thank Jess Porter of University of Arkansas at Little Rock, Stephen O'Connell of the University of Central Arkansas, Jason Allard of Valdosta State University, Richard Crooker of Kutztown University, Chris Sutton of Western Illinois University, and Andrew Mercer of Mississippi State University for their contributions to *MasteringGeography* and other supporting material.

Many of my colleagues at City College of San Francisco offered valuable suggestions on sections of the previous and current edition of the book: Carla Grandy, Dack Lee, Joyce Lucas-Clark, Robert Manlove, Kathryn Pinna, Todd Rigg-Carriero, Carole Toebe, and Katryn Wiese. I especially want to thank Chris Lewis, who reviewed large sections of this book for clarity and accuracy. I also extend my appreciation to my many students over the years—their curiosity, thoughtful questions, and cheerful acceptance of my enthusiasm for geography have helped me as a teacher and as a textbook author.

Textbooks of this scope cannot be created without a production team that is as dedicated to quality as the authors. First of all, my thanks go to Pearson Geography Editor Christian Botting, who provided skillful leadership and assembled the outstanding group of professionals with whom I worked. My thanks and admiration go to Senior Project Editor Crissy Dudonis, who cheerfully kept me on track throughout the entire production process. Many thanks also to Project Manager Anton Yakovlev, Senior Project Manager Katy Gabel, Production Project Liaison Ed Thomas, Photo Researcher Kristin Piljay, Art Development Editor Jay McElroy, Senior Project Manager Kevin Lear, Assistant Editor Kristen Sanchez, Editorial Assistant Bethany Sexton, Senior Marketing Manager Maureen McLaughlin, Marketing Assistant Nicola Houston, Copyeditor Nicole Schlutt, and Media Producers Tim Hainley and Ziki Dekel. Special thanks go to Marcia Youngman, who has worked as copyeditor or proofreader with me on so many books that I can't imagine sending a book to press before she's looked at it. I offer my greatest appreciation to Executive Development Editor Jonathan Cheney, who provided me with unwavering support and sound advice on every aspect of this book.

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

**Darrel Hess**

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## DEDICATION

For my wife, Nora

D.H.

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### ABOUT OUR SUSTAINABILITY INITIATIVES

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

Along with developing and exploring digital solutions to our market's needs, Pearson has a strong commitment to achieving carbon-neutrality. As of 2009, Pearson became the first carbon- and climateneutral publishing company. Since then, Pearson remains strongly committed to measuring, reducing, and offsetting our carbon footprint.

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

**PEARSON**



## ABOUT THE AUTHORS



**Darrel Hess** began teaching geography at City College of San Francisco in 1990 and served as chair of the Earth Sciences Department from 1995 to 2009. After earning his bachelor's degree in geography at the University of California, Berkeley, in 1978, he served for two years as a teacher in the Peace Corps on the Korean island of Jeju-do (see Figure 2-24). Upon returning to the United States, he worked as a writer, photographer, and audiovisual producer. His association with Tom McKnight began as a graduate student at UCLA, where he served as one of Tom's teaching assistants. Their professional collaboration developed after Darrel graduated from UCLA with a master's degree in geography in 1990. He first wrote the *Study Guide* that accompanied the fourth edition of *Physical Geography: A Landscape Appreciation*, and then the *Laboratory Manual* that accompanied the fifth edition. Darrel has been authoring both works ever since. In 1999 Tom asked Darrel to join him as coauthor of the textbook. As did Tom, Darrel greatly enjoys the outdoor world. Darrel and his wife, Nora, are avid hikers, campers, and scuba divers.



**Tom L. McKnight** taught geography at UCLA from 1956 to 1993. He received his bachelor's degree in geology from Southern Methodist University in 1949, his master's degree in geography from the University of Colorado in 1951, and his Ph.D. in geography and meteorology from the University of Wisconsin in 1955. During his long academic career, Tom served as chair of the UCLA Department of Geography from 1978 to 1983, and was director of the University of California Education Abroad Program in Australia from 1984 to 1985. Passionate about furthering the discipline of geography, he helped establish the UCLA/Community College Geography Alliance and generously funded awards for both undergraduate and graduate geography students. His many honors include the California Geographical Society's Outstanding Educator Award in 1988, and the honorary rank of Professor Emeritus upon his

retirement from UCLA. In addition to *Physical Geography: A Landscape Appreciation*, his other college textbooks include *The Regional Geography of the United States and Canada*; *Oceania: The Geography of Australia, New Zealand, and the Pacific Islands*; and *Introduction to Geography*, with Edward F. Bergman. Tom passed away in 2004—the geographic community misses him enormously.



# A Learning Path Guides Students

Each chapter's learning tools form a path that gives students a consistent framework to learn about the processes and patterns that create our planet's landscape.

**NEW! Seeing Geographically questions** at the beginning and end of each chapter ask students to perform visual analysis and critical thinking to check their understanding of key chapter concepts and overcome any misconceptions.



## Seeing Geographically

This natural color satellite image of Baja, Mexico, was taken on November 27, 2011, with the MODIS (Moderate Resolution Imaging Spectroradiometer) instrument aboard NASA's Aqua satellite. Strong winds have caused dust to blow off of mainland Mexico and the Baja peninsula. From which direction were the winds blowing on this day? How do the mountaintops and sky conditions change as you look north of Mexico into the United States?

31

## Seeing Geographically

Look again at the image of Baja at the beginning of the chapter (p. 30). The Baja peninsula is about 160 kilometers (100 miles) wide in the north and about 80 kilometers (50 miles) wide at its southern tip. About how far has the dust blown to the west off of Baja? In what part of the image is the shape of the land least distorted? Most distorted? Could a single graphic map scale be used to accurately measure distances everywhere on this image? Why or why not?

**NEW! Key Questions** work as chapter-specific learning outcomes in the chapter opening pages, which connect to Learning Checks, End of Chapter Questions, and the Learning Outcomes in MasteringGeography.™

**NEW! Learning Checks** integrate review questions at the end of chapter sections, helping students check comprehension.

**Learning Check 2-5** Would a Mercator projection be a good choice for a map used to study the loss of forest cover around the world? Why or why not?

**Learning Check 3-6** Is photochemical smog considered a *primary pollutant* or a *secondary pollutant* in the atmosphere? Why?

**Learning Check 9-7** What are some of the consequences of thawing permafrost around the Arctic?

**Review and Study questions** appear at the end of every chapter, giving students the practice they need to learn and master the material. There are three exercise types.

- **Questions on Key Terms & Concepts** ensure students have a firm grasp of the essential vocabulary.
- **Study Questions** reinforce the main concepts in the chapter.
- **NEW! Exercises** offer optional mathematical treatments of chapter concepts, and are also available in MasteringGeography.

## KEY TERMS AND CONCEPTS

### The Nature of Water: Commonplace but Unique (p. 142)

1. Briefly describe how water moves through the **hydrologic cycle**.
2. What is a **hydrogen bond** between water molecules?
3. Describe what happens to the density of water as it freezes.
4. What is meant by **surface tension** of water?
5. What is **capillarity**?

## STUDY QUESTIONS

1. Why does ice float on liquid water?
2. Why is evaporation a "cooling" process and condensation a "warming" process?
3. What happens to the relative humidity of an unsaturated parcel of air when the temperature decreases? Why?
4. What happens to the relative humidity of an unsaturated parcel of air when the temperature increases? Why?
5. Why does a rising parcel of unsaturated air cool at a greater rate than a rising parcel of saturated air (in which condensation is taking place)?

## EXERCISES

1. Calculate the relative humidity for the following parcels of air:
  - a. If the specific humidity is 5 g/kg and the capacity is 20 g/kg: \_\_\_\_\_ %
  - b. If the specific humidity is 35 g/kg and the capacity is 40 g/kg: \_\_\_\_\_ %
2. Use Figure 6-8 to estimate the water vapor capacity (the saturation specific humidity in g/kg) of air at the following temperatures:
  - a. 0°C (32°F): \_\_\_\_\_ g/kg
  - b. 30°C (86°F): \_\_\_\_\_ g/kg
3. Using your answers for Exercise Problem 2 above, calculate the relative humidity of the following parcels of air at the temperature given:
  - a. If the specific humidity is 3 g/kg at a temperature of 0°C: \_\_\_\_\_ %

# Current, Compelling Applications Boost Comprehension

Expert contributors author many of the special *Focus*, *People and the Environment*, and *Energy for the 21st Century* features, sharing a variety of expertise and experience with students.

**NEW! Energy for the 21st Century** feature boxes provide balanced coverage of both renewable and non-renewable energy resources authored by expert contributors, including a new feature on *Our Continuing Dependence on Fossil Fuels* (Chapter 3) and *Fracking for Natural Gas* (Chapter 13).

**People and the Environment** boxes discuss the effects of human activity on the environment. New topics in the Eleventh Edition include *The Record Breaking Tornadoes of 2011* (Chapter 7) and the *2010 Haiti Earthquake* (Chapter 14).

**ENERGY FOR THE 21ST CENTURY**

**Our Continuing Dependence on Fossil Fuels**  
Matthew T. Huber, Syracuse University

Fossil fuels (coal, oil, and natural gas) are the product of millions of years of accumulated solar energy absorbed in plant life and trapped as hydrocarbon matter underneath Earth's surface.

**The Historical Significance of Fossil Fuels:** Before the use of fossil fuels, people did most mechanical work using their own muscle power and that of animals both ultimately derived from the energy of sunshine stored in plants through photosynthesis and the animals that consume plants (discussed in Chapter 10). The historic shift from solar energy to fossil fuels led to machinery that ran without the force of muscle power, such as steam engines, and eventually to electrical power generation and automobiles. This change allowed for dramatic gains in labor productivity and the growth of transportation networks. Moreover, the increasing reliance on fossil fuels freed up thousands of acres that were previously used for energy, such as farmland used to grow feed for working animals and forest land that provided wood and charcoal for heating, cooking, and metal production.

Because of these benefits, the world today derives around 80 percent of its energy from fossil fuels (Figure 3-C).

**The Consequences of Fossil Fuel Use:** Despite the benefits of fossil fuels, they are not without drawbacks. First, the combustion of coal, oil, and gas produces enormous amounts of pollution. For example, sulfur dioxide (SO<sub>2</sub>) from coal-fired power plants causes acid rain (discussed in Chapter 6). All fossil fuel use emits carbon dioxide (CO<sub>2</sub>), a greenhouse gas associated with global climate change (discussed in Chapter 6). Moreover, the uneven distribution of fossil fuels creates geopolitical conflict over access to, and control over, energy resources. Although this problem is most visible in conflicts over oil (as in the Middle East), it ultimately depends on when the wind blows. Solar power harnesses direct sunlight to generate electricity either through photovoltaic cells or the boiling of water to create steam (see Chapter 4). Like wind, solar is intermittent, and it is not available when it is dark or cloudy. Furthermore, unlike fossil fuels that can be easily transported anywhere, some alternatives such as geothermal (see Chapter 17) and tidal power (see Chapter 20), as well as large installations of wind and solar power generation, may only be available in locations far from population centers, such as deserts for solar and unstructured topography for wind.

Most importantly, the main barrier to an "energy transition" away from fossil fuels are political and economic (see Chapter 8). Historically, fossil fuels are simply much cheaper making it difficult for alternative energy to be economically viable when only short-term costs are considered. Fossil fuel energy companies are also some of the largest and most profitable corporations in the world, and some have used their political influence to inhibit policies that might spur a shift toward alternative energy.

**Alternative Energy:** Since at least the 1970s, support for switching to alternative energy has been growing among scientists, policymakers, and the public. Most alternatives to fossil fuels generate electricity. Most electricity today is generated by the combustion of coal or gas to create steam that turns a turbine. For now, the transportation sector runs mostly on liquid fuels derived from crude oil. The only liquid fuel alternatives are biofuels (see Chapter 10), often derived from crops grown on farmland, thus competing with food production.

Many alternative energy sources show promise but also have limitations. Nuclear power is the largest alternative energy source, but it brings risks of calamitous accidents, such as the Fukushima disaster in Japan following the tsunami of 2011 (see Chapter 20), and produces radioactive waste.

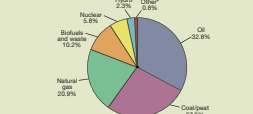


Figure 3-C Sources of global energy production in 2009. "Other" includes geothermal, solar, wind, and tidal power. (Source: International Energy Agency, 2011, *Key World Energy Statistics 2011*.)

**PEOPLE AND THE ENVIRONMENT**

**The Devastating Tornadoes of 2011**  
Ted Eckmann, Bowling Green State University

The tornadoes of 2011 shattered many long-standing records and demonstrated that despite advances in detection and warning technology, tornadoes still pose major threats. Prior to 2011, the record for largest number of tornadoes in a single month stood at 542, but April 2011 surpassed this in dramatic fashion with 758 tornadoes reported across the United States. The most active part of the month was from April 25 to April 28, and it included the deadliest tornado outbreak since modern record-keeping began. This outbreak produced 343 confirmed tornadoes and killed 321 people (Figure 7-6). Damage likely exceeded 10 billion dollars. Four of these tornadoes produced damage up to the EF-5 category—the first EF-5 tornadoes anywhere on Earth since 2008. However, these storms would not be the last tornadoes to reach EF-5 strength in this record-breaking year.

**EF-5 Tornadoes:** Although EF-5 is the rarest ranking for a tornado, EF-5s produce a disproportionately large share of overall tornado fatalities because they can destroy even well-built structures. Thus, even people in shelter who would be adequately protected from weaker tornadoes sometimes die in EF-5 strength winds, which can be the fastest on Earth. All four of the EF-5 tornadoes in Figure 7-6 occurred on the same day—April 27, 2011—that set a new record for the largest number of confirmed tornadoes in a 24-hour period: 199. The largest of the EF-5 tornadoes from April 27 remained on the ground for almost 3 hours, producing a damage path 172 kilometers (107 miles) long and up to 2 kilometers (1.25 miles) wide.

**Joplin Tornado:** Less than one month later, on May 22, another EF-5 tornado occurred, this time in Joplin, Missouri (Figure 7-7). In comparison to many of the tornadoes from the April outbreak, the EF-5 in Joplin was relatively compact, with a path length of only 36 kilometers (22 miles). However, the Joplin tornado reached its peak strength in a densely populated city of around 50,000 residents. Most of the areas affected in the April outbreak had substantially lower population densities, and although parts of urban areas like Tuscaloosa and Birmingham, Alabama, did experience EF-4 level damage, the EF-5 tornadoes in the April outbreak mostly occurred outside large cities.

The Joplin tornado's combination of EF-5 strength with a densely populated area produced catastrophic results. It killed 158 people and caused three billion dollars of damage, making it the most destructive and most deadly tornado since modern recordkeeping began. Tornadoes occurred in seven other states on the same day as the Joplin tornado, but the Joplin tornado was the day's only EF-5, and the totals for destruction and fatalities from that day remained well below the records set in the April outbreak a few weeks earlier.

**Lessons Learned:** By the end of 2011, tornadoes had killed 551 people in the United States—the largest total in 62 years of modern records. Even though weather forecasting and warning technologies have improved dramatically over the last 62 years, population densities have also increased, and studies have found that some people may even be taking tornadoes less seriously than they did in the past—education and communication about tornado hazards remains important components of public safety during severe storms.



Figure 7-6 Approximate paths of tornadoes from April 25 to April 28, 2011, color-coded by maximum intensity reached along the path.



Figure 7-7 Damage in Joplin, Missouri, two days after an EF-5 tornado devastated the city.

**Focus features** present in-depth case studies of special topics in physical geography. New topics in the Eleventh Edition include *Using Remote Sensing Images to Study a Landscape* (Chapter 2), *The Conveyor Belt Model of Midlatitude Cyclones* (Chapter 7), and *Monitoring Groundwater Resources from Space* (Chapter 9).

**FOCUS**

**Using Remote Sensing Images to Study a Landscape**  
Ryan Jensen, Brigham Young University

Remote sensing provides geographers and other researchers with a great amount of spatial information that can be analyzed to improve our understanding of landscapes. Geographers can study spatial features using data collected from both aerial platforms (airplanes or helicopters) and orbital platforms (satellites). Popular websites and programs provide much remote sensing data for anyone to examine at no cost. These programs, such as Google Earth™, MapQuest™, and the U.S. Geological Survey National Map, are valuable tools that display data at a variety of scales, depending on the "Zoom level" you select. Spatial resolution (the amount of detail you can see) becomes finer the further you zoom into a landscape. The usefulness of remote sensing will only increase as human activities and natural processes change Earth's surface.

**A Fluvial Landscape:** To see how remote sensing data can capture characteristics of Earth's surface, look at the images of fluvial features (features formed by flowing water) in Figure 2-A. Landsat 5 acquired the data for the Costa Marques, Brazil, area in June 1984 and again in September 2001. Costa Marques is located along the Guapore/Itenez River that forms the border between Brazil and Bolivia. Landsat data are typically acquired in 30 × 30 meter pixels. That is, each image pixel covers an area of 30 meters by 30 meters (98 feet by 98 feet), or 900 square meters (9687 square feet) over a surface area of 180 kilometers by 180 kilometers (111 miles by 111 miles). In each of the images, you can see fluvial features such as meanders, meander scars, oxbow lakes, and floodplain lakes.

The images can also be compared to study changes in the landscape. Notice that the river is much wider and there is more water on the floodplains in the 1984 scene than in the 2001 scene. Further, many of the oxbow lakes (Point A) had much more water in 1984 than in 2001. Meander scars that were very obvious in 1984 (Point B) are not obvious in 2001. Sand that was not visible in 1984 (Point C) is visible in 2001. The 2001 image also shows evidence of human expansion in Costa Marques and along parts of the Guapore/Itenez River (Points D and E).

**A More Detailed Look:** When more detail is needed, finer spatial resolutions may be used to study an area. Such data are available from commercial websites and programs such as Google Earth, MapQuest, and many others. For example, look at Point F in Figure 2-A. It is reasonable to assume that the river at that point will eventually create a new channel across the neck of the meander. This process cannot be clearly examined using the 30 × 30 meter Landsat data, but it can be examined using finer-resolution data. Figure 2-B shows a more-detailed image of the same meander neck at Point F. As you can see, there might be evidence of a new channel forming at Point F. In fact, in wet years, river water may flow through the meander neck.

Consider another example: Point B in Figure 2-B shows the same meander scars as the Landsat images in Figure 2-A (Point B). These features can be more fully examined using the detailed image in Google Earth, which can also be used to make measurements such as length and area. Knowing the area of the lake within the scar might be useful in determining how the lake changes from season to season or year to year.

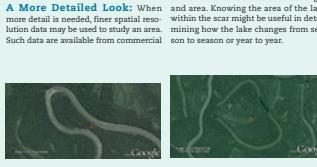


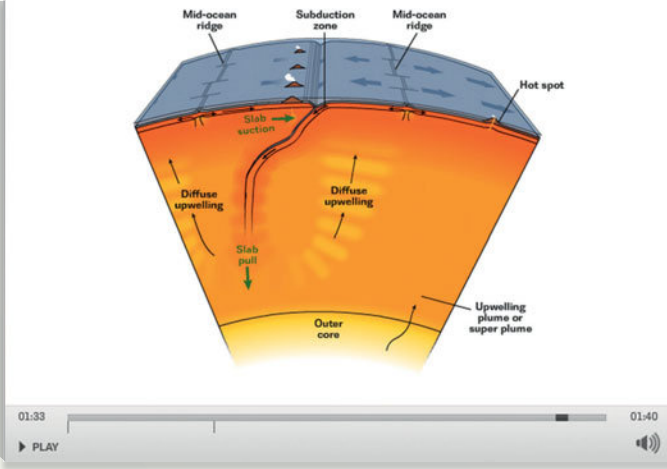
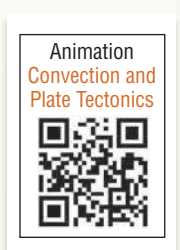
Figure 2-A Two Landsat images acquired over the Costa Marques, Brazil, area in 1984 and 2001.



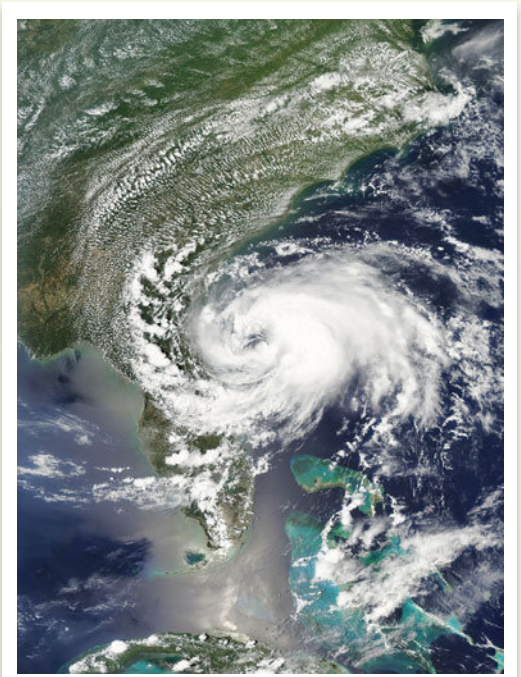
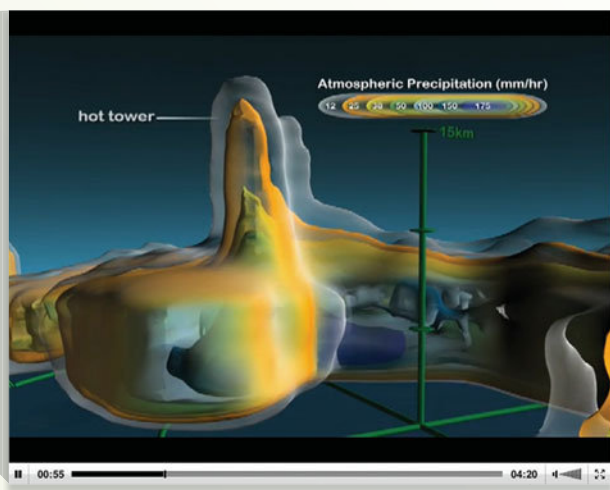
Figure 2-B Fine-spatial resolution data showing a meander neck and meander scars in the Costa Marques area.

# Dynamic Media to Engage Students

Multimedia resources are linked throughout the text and eText, bringing the concepts to life.



**NEW! Quick Response (QR) Codes** within the pages of the book link to a variety of animations and videos, providing students with just-in-time access to media resources tied to the book's concepts. Media are automatically linked in the eText and also available in the MasteringGeography™ study area.



▲ **Figure 3-24** The wind pattern within storms such as hurricanes is influenced by the deflection of the Coriolis effect. This image shows Tropical Storm Beryl in May 2012, just before making landfall.

**NEW! Additional satellite images, the latest science, statistics, and associated graphics** are integrated throughout the text. These resources provide a clear, relevant view of the planet as we understand it and encourage students to explore on their own.

# Stunning Graphics Visualize Earth's Landscape

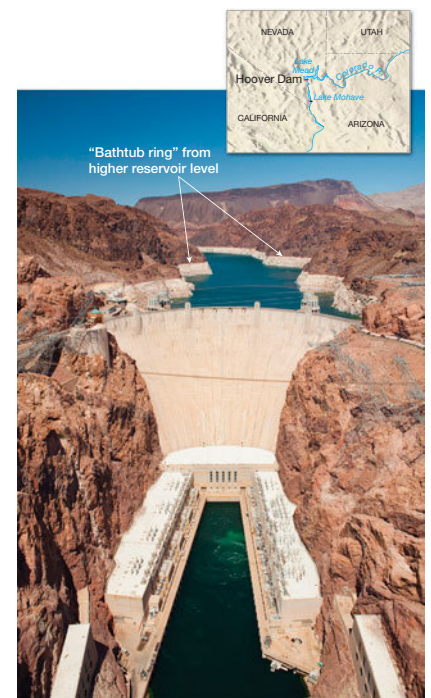
The excellent cartographic and illustration program by renowned geoscience illustrator Dennis Tasa helps students visualize and understand the concepts covered in this text.



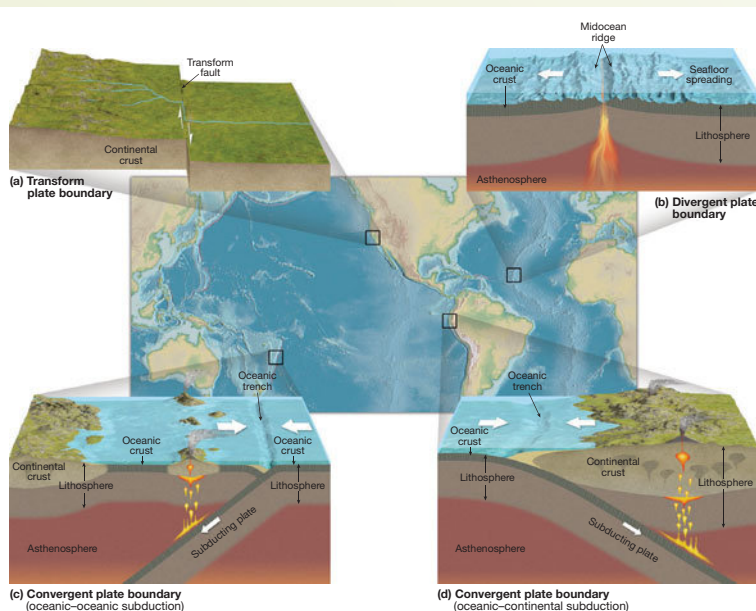
▲ **Figure 2-1** Different types of maps convey different kinds of information about the landscape, as shown in these four maps of a region near Salem, Massachusetts. (a) High-resolution orthophoto imagery (original scale 1:24,000). (b) Topographic map with elevation contour lines (original scale 1:24,000). (c) Geologic map showing rock types: orange = coarse glacial deposits; blue = glaciomarine deposits; green = glacial till; lavender = swamp deposits (original scale 1:50,000). (d) Google™ Map showing streets and highways.

**Hundreds of maps** include shaded relief where appropriate.

**Major photos** paired with locator maps to enhance geographic literacy.



▲ **Figure 9-24** Hoover Dam and Lake Mead on the Colorado River. The "bathtub ring" around the margin of the reservoir marks the water level when Lake Mead is at full capacity.



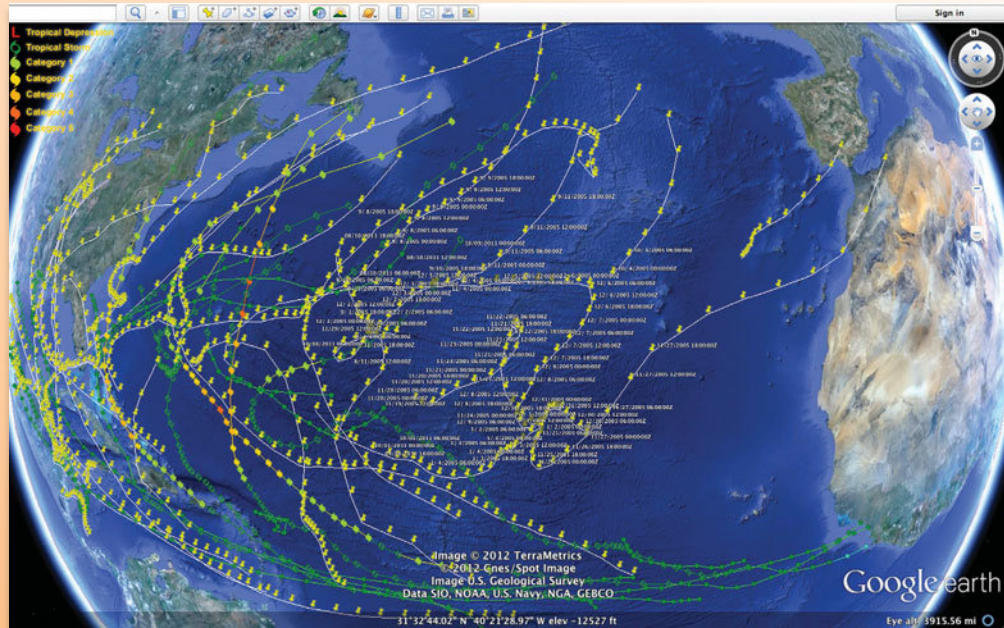
▲ **Figure 14-12** Three kinds of plate boundaries. The edges of lithospheric plates slide past each other along transform boundaries such as the San Andreas Fault system in California (a); move apart at divergent boundaries such as continental rift valleys and midocean ridges (b); and come together at convergent boundaries such as oceanic-oceanic plate subduction zones (c), oceanic-continental plate subduction zones (d), and continental collision zones.

**Line art** with numerous multi-part photorealistic illustrations capture sequence and evolution to help students understand various processes.

MasteringGeography delivers engaging, dynamic learning opportunities—focusing on course objectives and responsive to each student’s progress—that are proven to help students absorb physical geoscience course material and understand difficult geographic concepts.

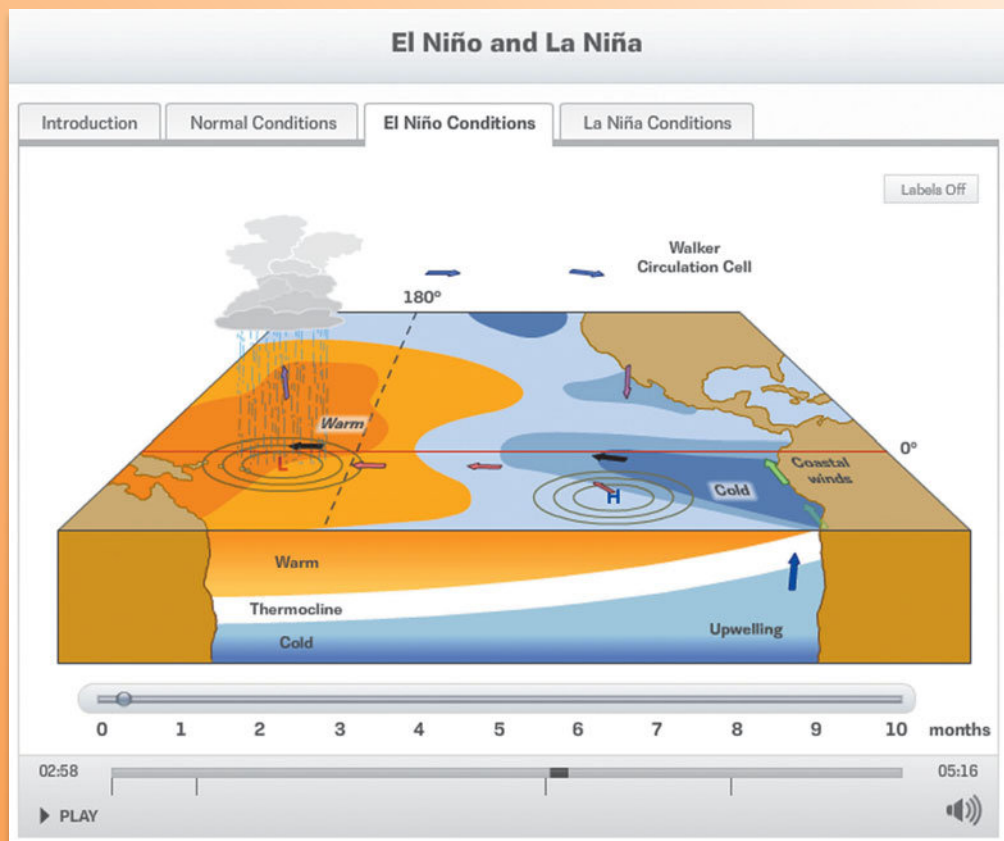
## Give students a sense of place and an understanding of physical concepts

**Encounter Activities** provide rich, interactive explorations of geography concepts using the dynamic features of **Google Earth™** to visualize and explore Earth’s physical landscape. Dynamic assessment includes multiple-choice and short-answer questions related to core physical geography concepts. All Explorations include corresponding Google Earth KMZ media files, and questions include hints and specific wrong-answer feedback to help coach students towards mastery of the concepts.



**Geoscience Animations** illuminate the most difficult-to-visualize topics from across the physical geosciences, such as solar system formation, hydrologic cycle, plate tectonics, glacial advance and retreat, global warming, etc. Animations include audio narration, a text transcript, and assignable multiple-choice quizzes with specific wrong-answer feedback to help guide students towards mastery of these core physical process concepts.

**NEW! Quick Response Codes** link to video and animation resources as a means to provide students with just-in-time access to visualization or indicate to students when they can login to the Study Area of MasteringGeography to access these media.



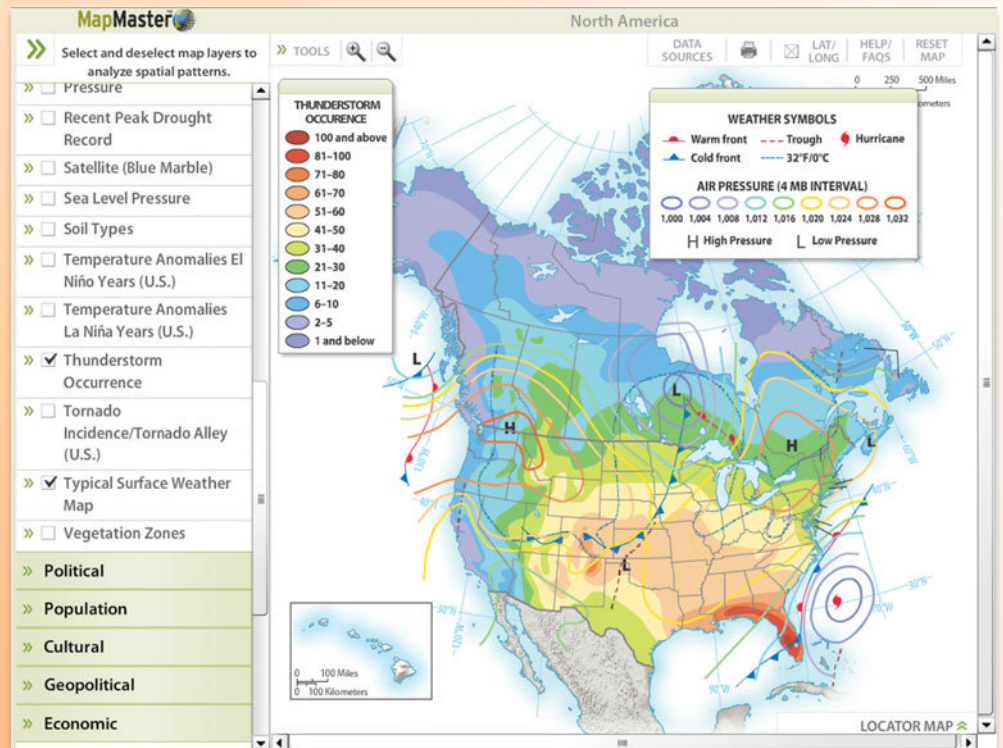
## Improve critical thinking and geographic literacy while exploring Earth's physical landscape

**MapMaster™** is a powerful tool that presents assignable layered thematic and place name interactive maps at world and regional scales for students to test their geographic literacy and spatial reasoning skills, and explore the modern geographer's tools.

**MapMaster Layered Thematic Interactive Map Activities** act as a mini-GIS tool, allowing students to layer various thematic maps to analyze spatial patterns and data at regional and global scales. Multiple-choice and short-answer questions are organized around the textbook topics and concepts.

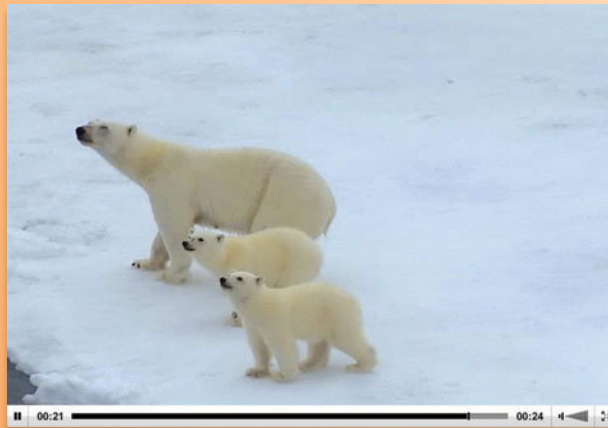
**NEW! MapMaster has been updated to include:**

- 90 new map layers
- Zoom and annotation functionalities
- Current U.S. Census, United Nations, and Population Reference Bureau Data



**NEW! Coaching Activities** are built around the toughest topics in physical geography.

**Geography videos** provide students a sense of place and allow them to explore a range of locations and topics related to physical geography. A variety of video clips cover diverse locations and physical geoscience concepts, with quiz questions to make these assignable and assessable. These video activities allow instructors to test students' understanding and application of concepts, and offer hints and wrong-answer feedback to guide students towards mastering the concepts.



### Student Resources in MasteringGeography

- Geoscience Animations
- MapMaster™ interactive maps
- Practice quizzes
- Geography videos
- "In the News" RSS feeds
- Glossary flashcards
- Optional Pearson eText and more

Callouts to MasteringGeography appear at the end of each chapter to direct students to extend their learning beyond the textbook.

With the Mastering gradebook and diagnostics, you'll be better informed about your students' progress than ever before. Mastering captures the step-by-step work of every student—including wrong answers submitted, hints requested, and time taken at every step of every problem—all providing unique insight into the most common misconceptions of your class.

## Quickly monitor and display student results

The **Gradebook** records all scores for automatically graded assignments. Shades of red highlight struggling students and challenging assignments.

NAME	Intro.d.gy	Ch 2	Ch 3	Lab 2	Ch 4	Ch 5	Ch 6	Ch 7a	Chapter 7b	Lab 4	Ch 8	Ch 9	Ch 12	TOTAL
Class Average	--	78.4	65.0	62.6	88.1	89.5	86.7	91.6	83.7	90.0	88.4	77.7		24.5
Last01, First0...	--	84.4	73.3	83.3	102	99.9	0.0	95.8	101	100	87.4			46.9
Last02, First0...	--	70.3	64.8	92.9	99.0	49.5	86.2	72.9	47.5	80.0	86.9	66.3		26.2
Last03, First0...	--	73.6	48.0	61.9	104	102	94.9	95.0	100	95.0	99.7	67.3		27.8
Last04, First0...	--	72.5	53.8	60.0	34.3	88.3	65.3	80.0	83.4	90.0	99.2	67.0		30.3
Last05, First0...	--	78.8	69.3	78.6	99.0	97.8	85.2	82.5	34.6	85.0	98.3	87.7		31.9
Last07, First0...	--	77.9	66.7	51.8	101	96.1	95.9	80.0	76.7	95.0	84.9	70.6		23.2
Last08, First0...	--	84.4	70.7	92.9	85.3	99.0	100	95.0	100	100	102	89.8		36.7
Last09, First0...	--	68.2	70.0	76										
Last10, First...	--	76.1	70.0	78										

**Diagnostics** provide unique insight into class and student performance. With a single click, charts summarize the most difficult questions, vulnerable students, grade distribution, and score improvement over the duration of the course.



With a single click, **Individual Student Performance Data** provides at-a-glance statistics into each individual student's performance, including time spent on the question, number of hints opened, and number of wrong and correct answers submitted.

Description: (a) Which country is expected to have the highest percentage of population increase for 2020?

Part A  
Which country is expected to have the highest percentage of population increase for 2020?

ANSWER:

Ethiopia  
 India  
 China  
 Yemen  
 Uganda

Answer Stats:	Students	% Correct	% Unfinished	% Req'd Solution	Wrong/student	Hints/student
Overall	10138	92.5%	6.8%	0.7%	0.6	0
MBDEMOGRADE5	25	100%	0%	0%	0.8	0

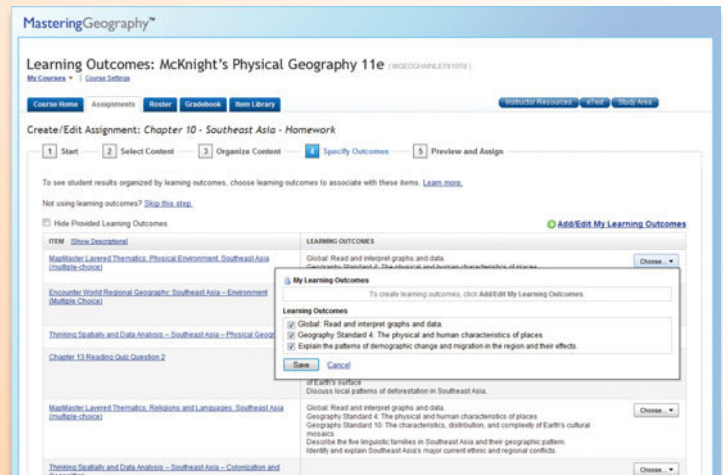
% Wrong	Answer	Response
38.1%	Ethiopia is projected to have an 88% population increase. Are there other countries that will have a higher increase?	
23.8%	Although India is expected to surpass China as the most highly populated country in the world, India is projected to have only a 36% population increase by 2020.	
23.8%	Are you thinking that China has the largest population in the world now? Its population policies have reduced the rate of population growth, and by 2020, China's population is expected to grow only about 13% (still a big number considering the size of China's population)	
14.3%	Yemen is anticipated to have a 96% population increase by 2020. Are there other countries that will have a higher increase?	

## Easily measure student performance against your Learning Outcomes

### Learning Outcomes

MasteringGeography provides quick and easy access to information on student performance against your learning outcomes and makes it easy to share those results.

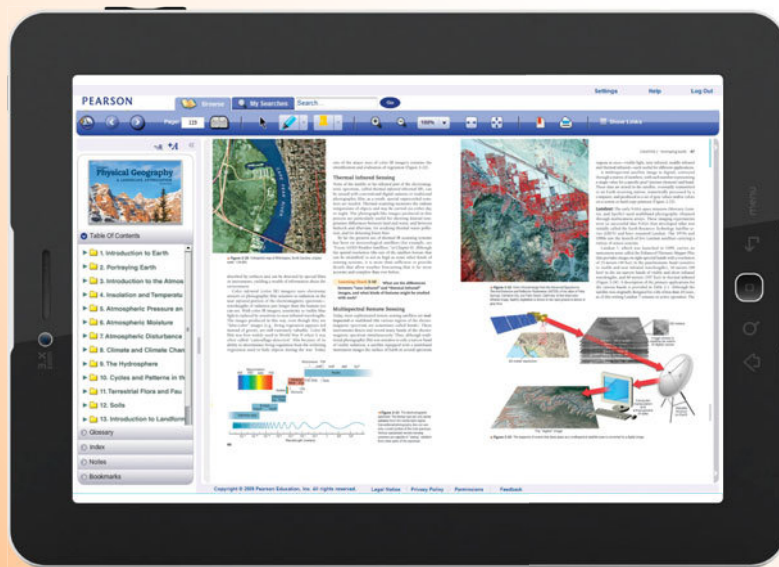
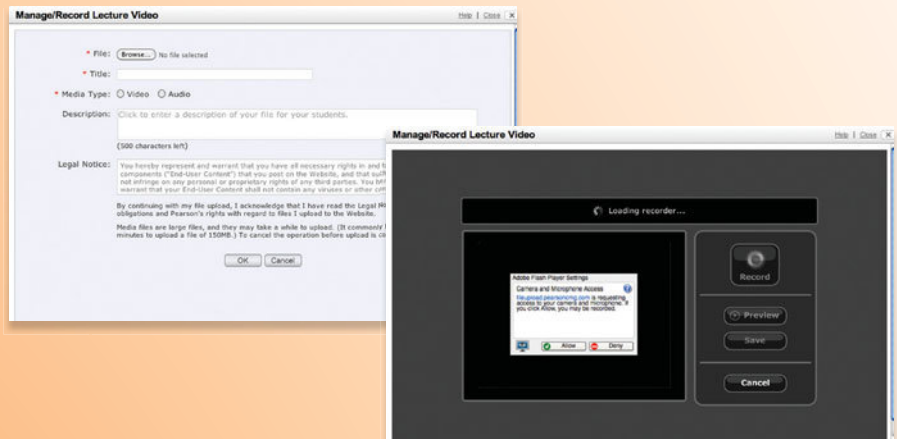
- Quickly add your own learning outcomes, or use publisher-provided ones, to track student performance and report it to your administration.
- View class and individual student performance against specific learning outcomes.
- Effortlessly export results to a spreadsheet that you can further customize and/or share with your chair, dean, administrator, and/or accreditation board.



### Easy to customize

**Customize publisher-provided items or quickly add your own.** MasteringGeography makes it easy to edit any questions or answers, import your own questions, and quickly add images, links, and files to further enhance the student experience.

**Upload your own video and audio files** from your hard drive to share with students, as well as record video from your computer's webcam directly into MasteringGeography—no plugins required. Students can download video and audio files to their local computer or launch them in Mastering to view the content.



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## 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'll 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'll 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 environment. By the time you finish this book you'll understand—in other words you'll appreciate—the landscape in new ways.

This opening chapter sets the stage for your study of physical geography. Here we introduce concepts and terms used throughout the book.

As you study this chapter, think about these key questions:

- **How do geographers study the world and use science to explain and understand the natural environment?**
- **What are the overlapping environmental “spheres” of Earth, and how does the concept of Earth systems help us understand the interrelationships of these spheres?**
- **How does Earth fit in with the solar system, and how does the size of Earth compare with the size of its surface features?**
- **How does the system of latitude and longitude describe location on Earth?**
- **What causes the annual change of seasons, and how do patterns of sunlight around Earth change during the year?**
- **How is the system of time zones used to establish times and dates around the world?**

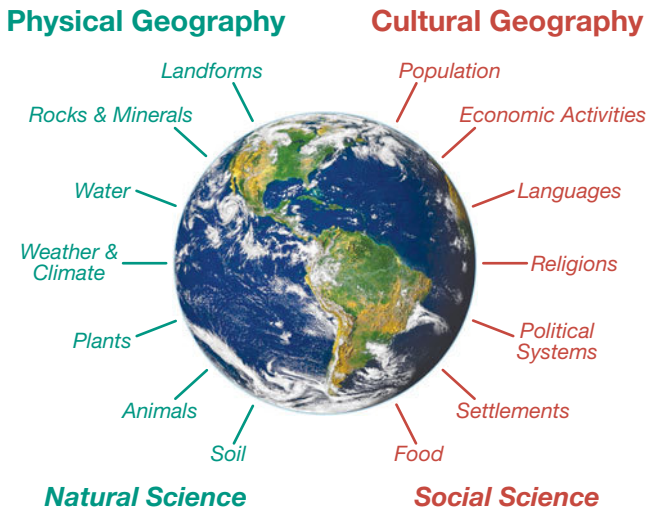
## GEOGRAPHY AND SCIENCE

The word *geography* comes from the Greek words meaning “Earth description.” Several thousand years ago many scholars were indeed “Earth describers,” and therefore geographers, more than anything else. Nonetheless, over the centuries there was a trend away from generalized Earth description toward more specialized disciplines—such as geology, meteorology, economics, and biology—and 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.

### Seeing Geographically

This is a natural color, composite satellite image of Earth created by NASA. In the image can you see any indications of human presence? What might explain the differences in the color of land areas? What might explain the differences in the color of ocean areas?

## Elements of Geography



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

### Studying the World Geographically

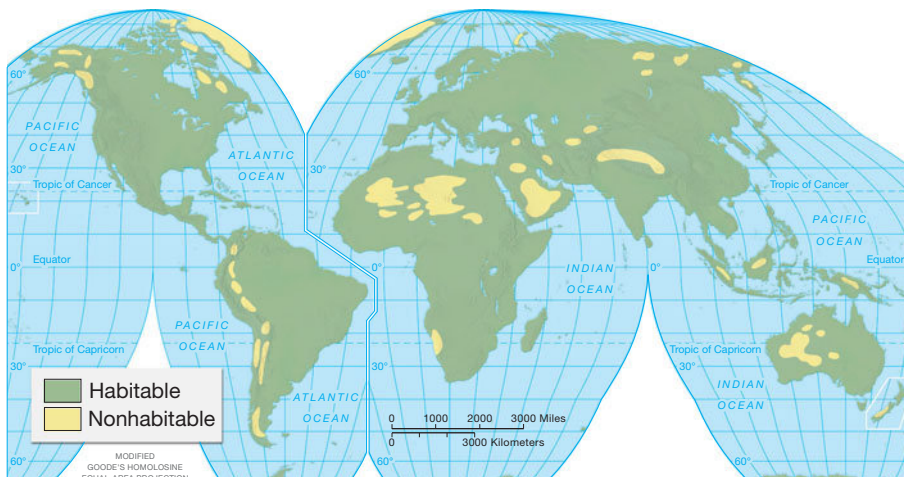
Geographers study how things differ from place to place—the distributional and locational relationships of things around the world (what is sometimes called the “spatial” aspect of things). Figure 1-1 shows the kinds of “things” geographers study, divided into two groups representing the two principal 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 **cultural geography** are those of human endeavor, so this branch is sometimes referred to as *human 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 what is where and so what?”

**Learning Check 1-1** What are the differences between physical geography and cultural geography? (Answer on p. AK-1)

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

In our study of physical geography, our emphasis is on understanding the surface environment of Earth and the ways in which humans utilize and alter this environmental home. The habitable environment for humans exists over almost the entire land surface of Earth (Figure 1-2). It is only in the most extremely dry, cold, and rugged places



◀ **Figure 1-2** Most of Earth’s land surface is habitable. The uninhabitable areas are too hot, too cold, too wet, too dry, or too rugged to support much human life—such as parts of the Arctic, most of Greenland, Antarctica, various mountainous regions, and several deserts.

that humans rarely venture, and even in such locations, other forms of life may be found. Earth's "life zone," encompassing oceanic, terrestrial, and atmospheric life, extends from the bottom of the deepest oceanic trench to the atmosphere above the highest mountain peaks—a zone perhaps 30 kilometers (20 miles) deep. It is primarily within this shallow life zone that geographers focus their interests and do their work.

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 will pay attention to elements of cultural geography only 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 1-3). 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.

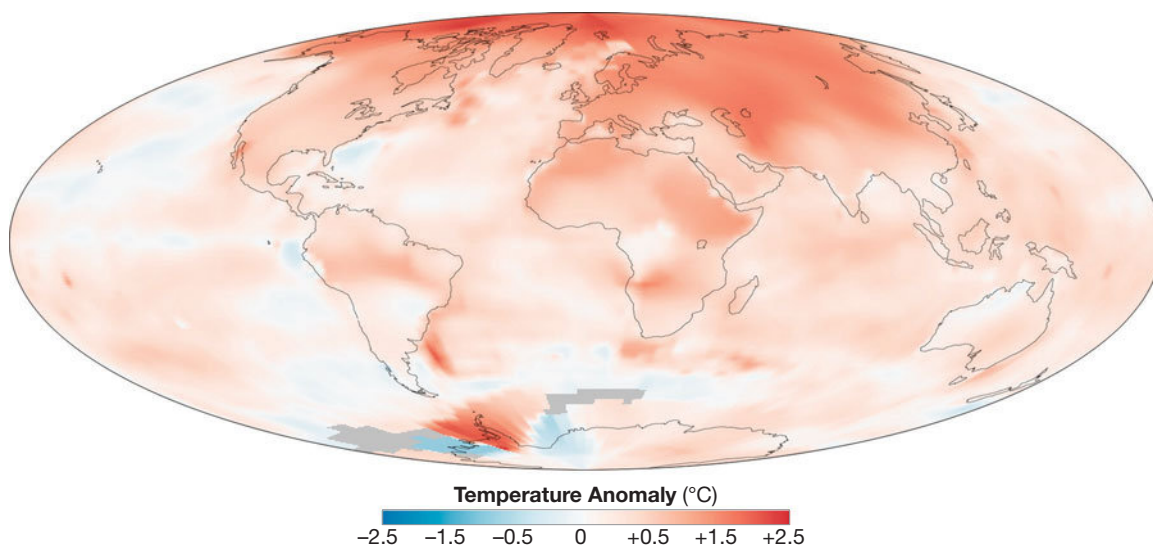
Rather than treat global environmental change as a separate topic, we integrate this theme throughout the book. To help with this integration, we supplement the main text with short boxed essays, such as those entitled "People and the Environment" that focus on specific cases of human interaction with the natural environment, as well as boxes entitled "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, and the global economy and human society.

**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 between the economies, cultures, and political systems of the world. Although globalization is most commonly associated with the cultural and economic realms of world, it is important to recognize the environmental components of globalization as well. For example, the loss of tropical rainforest for timber or commercial agriculture in some regions of the world is driven in part by growing demand for commodities in countries far away from the tropics (Figure 1-4). Similarly, rapid economic growth in newly industrialized countries is contributing to the already high atmospheric greenhouse gas emissions of industrialized countries—the interconnected economies of the world are thus interconnected in their influence on the natural environment.

Because of geography's global perspective and its interest in both the natural and human landscape, 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.



◀ **Figure 1-3** Earth's climate is changing. This image shows the difference in temperature (the *temperature anomaly* in °C) during the period 2000 to 2009 compared with the average temperatures for the baseline period 1951 to 1980. (NASA)



▲ **Figure 1-4** Deforestation in some parts of the tropics is influenced by consumer demand in other parts of the world. This logging operation is in Perak, Malaysia.

### Learning Check 1-2 Why are physical geographers interested in globalization?

## The Process of Science

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

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

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

In practice, however, science doesn’t always work through experimentation; in many fields of science, data collection through observation of a phenomenon is the basis of knowledge. In some regards science is best thought of as a process—or perhaps even as an attitude—

for gaining knowledge. The scientific approach is based on observation, experimentation, logical reasoning, skepticism of unsupported conclusions, and the willingness to modify or even reject long-held ideas when new evidence contradicts them. For example, up until the 1950s most Earth scientists thought it impossible that the positions of continents could change over time; however, as we’ll 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 operating within Earth.

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

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

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

**Learning Check 1-3** Why is the phrase “scientific proof” somewhat misleading?

## 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, and temperature.

Two quite different systems of measurement are used around the world today. In the United States much of the general public is most familiar with the so-called *English System* of measurement—using 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*

**TABLE 1-1** Unit Conversions—Quick Approximations

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

*For exact conversion formulas, see Appendix I.*

*International*; also sometimes called the “metric system”)—using measurements such as kilometers, kilograms, and degrees Celsius.

You will notice that this book gives measurements in both S.I. and English units. If you are not familiar with both systems, Table 1-1 provides some quick approximations to help you learn the basic equivalents in each; detailed tables of conversion formulas between English and S.I. units appear in Appendix I.

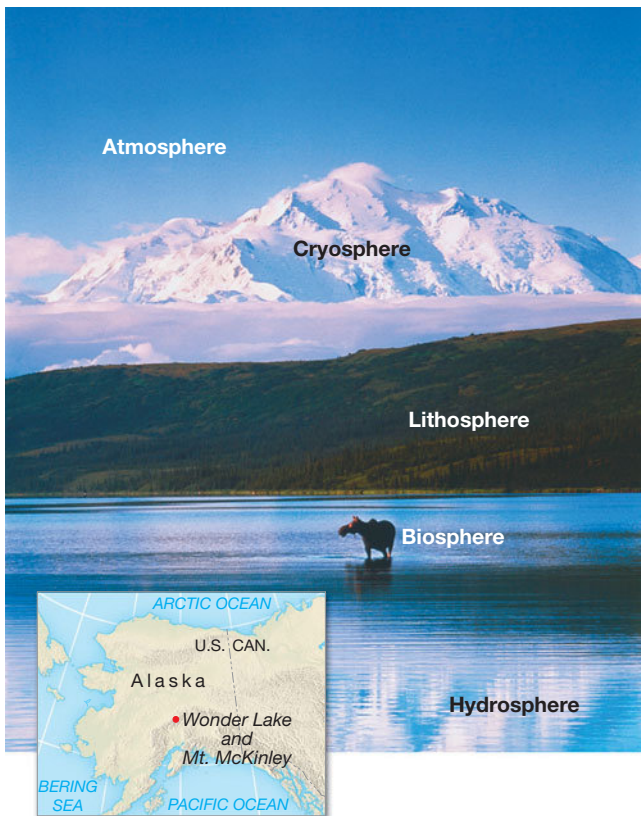
## ENVIRONMENTAL SPHERES AND EARTH SYSTEMS

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 1-5). 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**<sup>1</sup> (*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.

<sup>1</sup>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.



▲ **Figure 1-5** The physical landscape of Earth is composed of four overlapping and 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 earthly 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 Mt. McKinley (Denali) in Denali National Park, Alaska.

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

The **hydrosphere** (*hydro* is Greek for “water”) comprises water in all its forms. The oceans contain the vast majority of the water found on Earth and are the moisture source for most precipitation. A subcomponent of the hydrosphere is known as the **cryosphere** (*cry* comes from the Greek word for “cold”)—water frozen as snow and ice.

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

These “spheres” are not discrete and separated entities but rather are considerably interconnected. This intermingling is readily apparent when considering an ocean—a body that is clearly a major component of the

hydrosphere and yet may contain a vast quantity of fish and other organic life that are part of the biosphere. An even better example is soil, which is composed largely of bits of mineral matter (lithosphere) but also contains life forms (biosphere), along with air (atmosphere), soil moisture (hydrosphere), and perhaps frozen water (cryosphere) in its pore spaces.

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

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

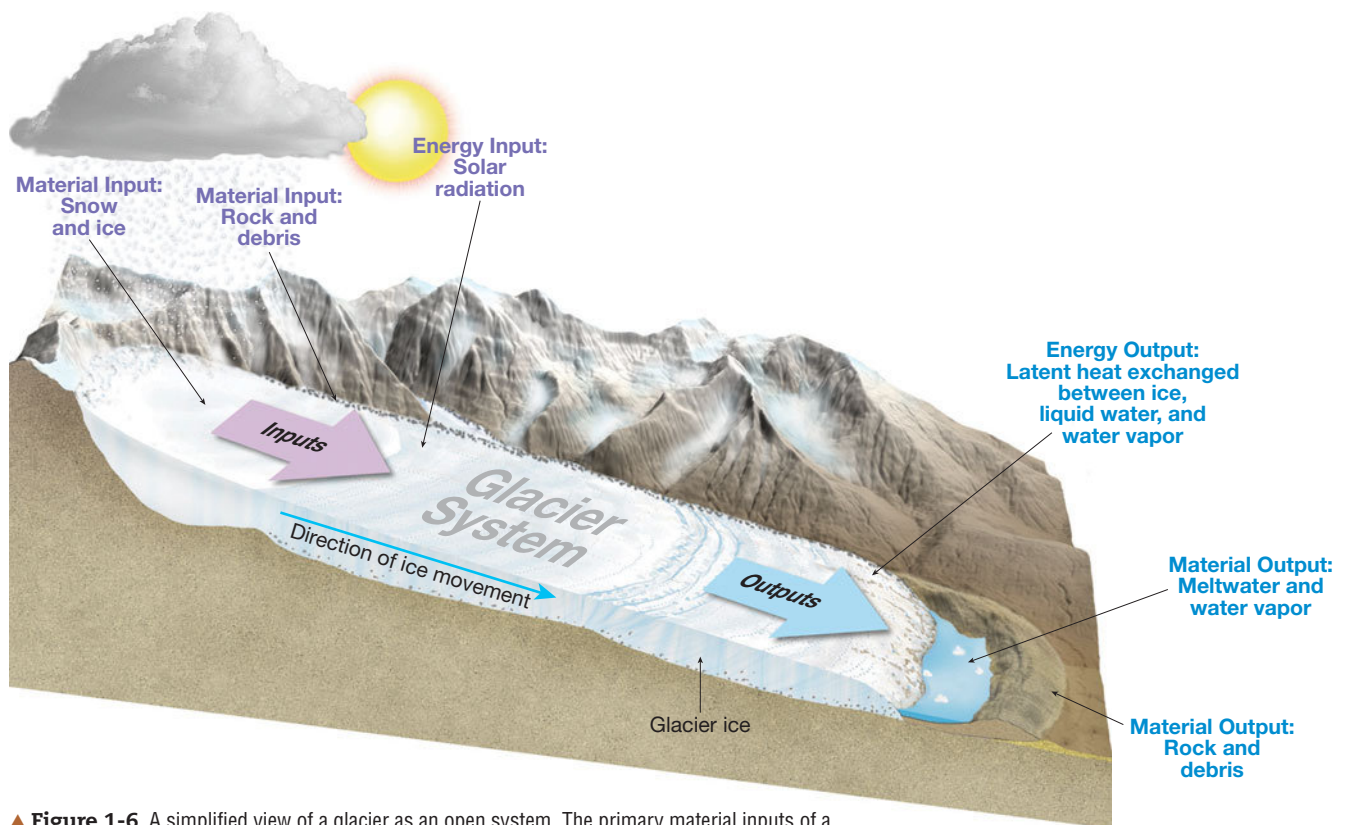
## Earth Systems

Earth’s environmental spheres operate and interact through a complex of *Earth systems*. By “system” we mean a collection of things and processes connected together and operating 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:** Some systems are effectively self-contained and therefore isolated from influences outside that system—and so are called *closed systems*. It is rare to find closed systems in nature. Earth as a whole is essentially a closed system with regard to matter—currently there is no significant increase or decrease in the amount of matter (the “stuff”) of Earth, although relatively small but measurable amounts of meteoric debris arrives from space, and tiny amounts of gas are lost to space from the atmosphere. Energy, on the other hand, does enter and exit the Earth system constantly.

**Open Systems:** Most Earth systems are *open systems*—both energy and matter 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’ll see in Chapter 19, a glacier behaves as an open system (Figure 1-6). The material inputs to a glacier include water in the form of snow and ice, along with rocks and other materials 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 transported and eventually deposited by the ice. The most obvious energy input into a glacial system is solar radiation that melts the ice by warming the surrounding air and by direct absorption into the ice itself. But also at work are less obvious exchanges of energy that involve *latent heat*—energy stored by water during melting and evaporation, and released during freezing and condensation (latent heat is discussed in detail in Chapter 6).

**Equilibrium:** When inputs and outputs are in balance over time, the conditions within a system remain the same; such a system can be described as being in *equilibrium*. For



▲ **Figure 1-6** A simplified view of a glacier as an open system. The primary material inputs of a glacier include snow, ice, and rock, whereas its outputs include meltwater, water vapor, and rock 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.

instance, a glacier will remain the same size over many years if its inputs of snow and ice are balanced by the loss of an equivalent amount of ice through melting. If, however, the balance between inputs and outputs changes, equilibrium will be disrupted—increasing snowfall for several years, for example, can cause a glacier to grow until a new equilibrium size is reached.

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

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

**Feedback Loops:** Some systems produce outputs that “feedback” into that system, reinforcing change. As we'll 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 reflectance 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; this greater amount of 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, at some point a system may reach a *tipping point* or *threshold* beyond which the system becomes unstable and changes abruptly until it reaches a new equilibrium. For instance, as we'll see in Chapter 9, it is possible that the increasing freshwater runoff from melting glaciers in the Arctic could disrupt the energy transfer of the slow, deep ocean *thermohaline circulation* in the Atlantic Ocean, triggering a sudden change in climate.