



**Darrel Hess**

ILLUSTRATED BY **Dennis Tasa**

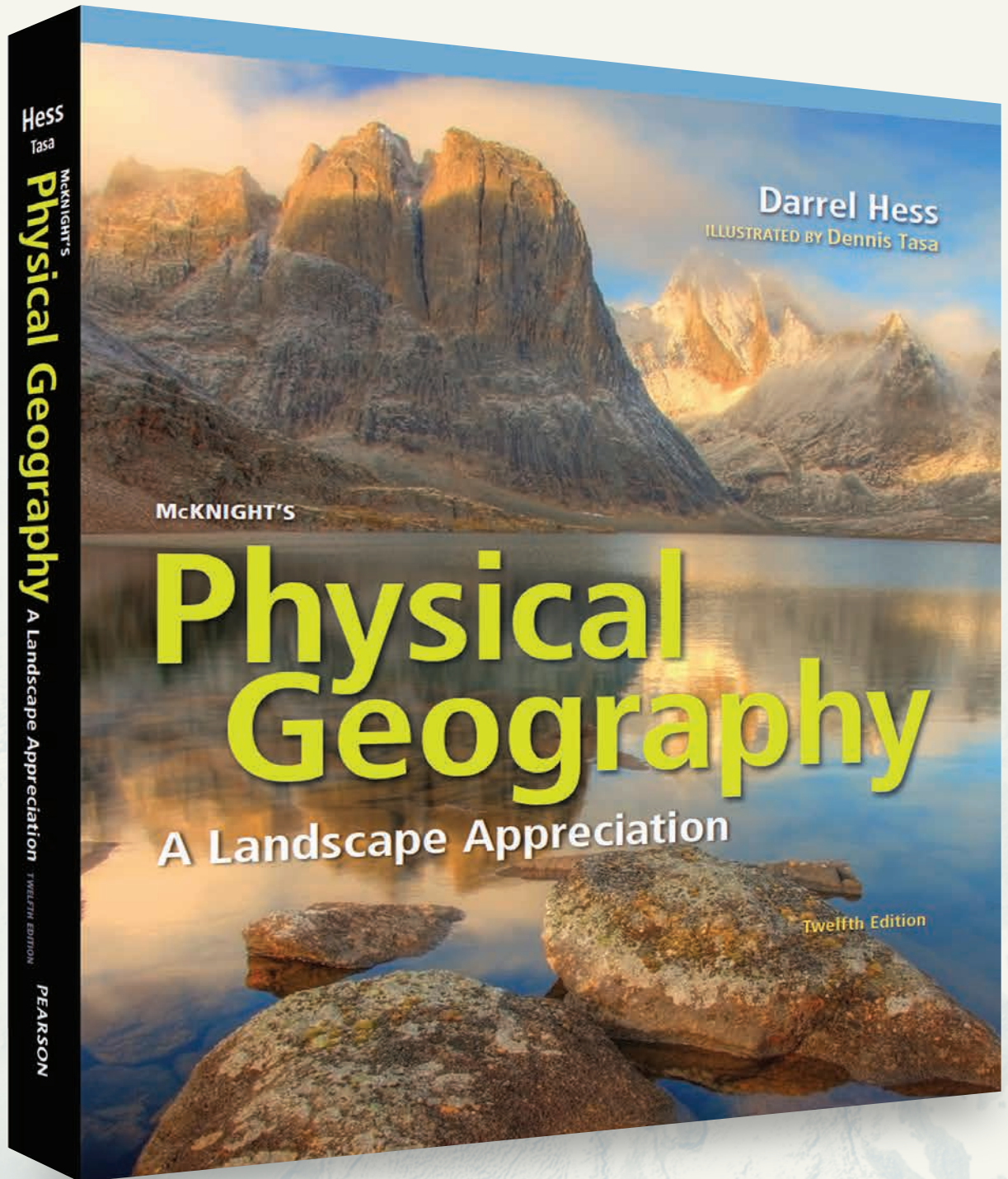
**McKNIGHT'S**

# Physical Geography

**A Landscape Appreciation**

**Twelfth Edition**

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



PEARSON

# Exploring the Changing Global Environment

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

## global environmental change



### Growing a City in the Desert

Bradley Shellito, Youngstown State University

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

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

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

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

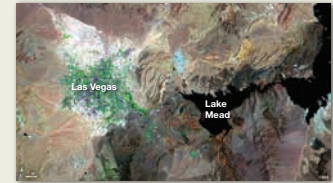
**Artificial Archipelago:** Las Vegas is not the only site for which geospatial technologies can help in monitoring and planning. For example, the Palm Islands in the Persian Gulf, just off the coast of Dubai in the desert country of the United Arab Emirates, is an archipelago that was built for tourism.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

**Looking Ahead:** Earth's population is expected to climb to 9 billion people by 2040 and to continue to grow. This dramatic growth will carry with it a variety of environmental impacts all around the world. Remote sensing satellites will allow us to monitor these kinds

of impacts and growth; GIS will let us analyze the patterns. By looking through the lens of geospatial technologies, we can understand global environmental impacts and plan for a sustainable future.

#### Questions

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



(a) Las Vegas, 1984



(b) Las Vegas, 2011

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



(a) Dubai, 2000



(b) Dubai, 2011

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

## Environmental Analysis Cloud Climatology



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

#### Activities

Go to <http://isccp.giss.nasa.gov/products/browse2.html>, the ISCCP website. Retain the variable "Total Cloud Amount (%)" and time period "Mean Annual"; then click "View."

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

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

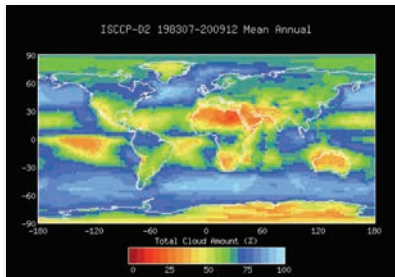
3. The map indicates how much moisture is available for precipitation in the lower half of the troposphere. How much precipitable water is available in the far north?

4. Notice that precipitable water amounts are high in equatorial regions and decrease poleward, as do temperatures. Why are precipitable water and temperature related in this way?

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

5. The map indicates how much moisture is available for precipitation in the upper half of the troposphere. Again, precipitable water is most abundant in equatorial regions. What type of cloud is likely to form there?

6. Recall the patterns of cloud cover (Activity 1) and precipitable water (Activity 3) in the far north. What types of clouds are most likely to form in the far north? It may help to refer to Figure 6-14.



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

# Mobile-Ready Media Brings Geography to Life

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



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



# Structured Learning to Guide Students

## UPDATED! Key Questions

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

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

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

## UPDATED! Learning Checks

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

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

---

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

---

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

---

## UPDATED! Seeing Geographically questions

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



## Seeing Geographically

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

# Real-World Applications of Physical Geography

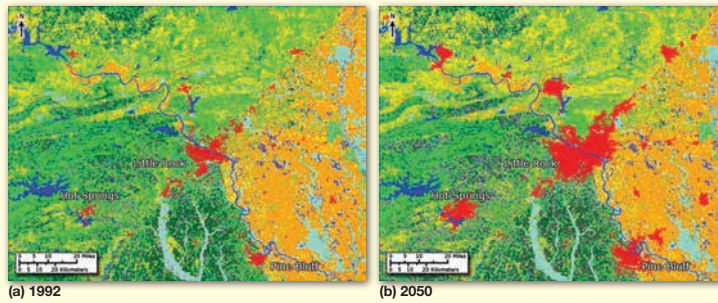
## focus



### GIS for Geographic Decision Making

► Keith Clarke, University of California–Santa Barbara

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



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

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

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



Practicing Geography



Practicing Geography

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

## energy for the 21st century



### Transitioning from Fossil Fuels

► Michael E. Mann, Penn State University

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

**Historical Significance of Fossil Fuels:** Before the use of fossil fuels, people did most mechanical work by using their own muscle power and that of animals, both ultimately derived from the Sun's energy stored in plants through photosynthesis and plant-eating animals (discussed in Chapter 10). The shift to fossil fuels led to machinery that ran without the force of muscle power, such as steam engines, and eventually to electrical power generation and automobiles. This change allowed for dramatic gains in labor productivity and the growth of transportation networks. Moreover, the increasing reliance on fossil fuels freed up thousands of acres that

which required scrubbers in factory smoke stacks to remove  $\text{SO}_2$  emissions, has largely alleviated that problem. However, a more fundamental environmental threat arises from the fact that all fossil fuel use emits carbon dioxide ( $\text{CO}_2$ ), the primary human-produced greenhouse gas causing global climate change (discussed in Chapter 4). Moreover, the uneven distribution of fossil fuels creates geopolitical conflict over access to, and control over, energy resources. Although this problem is most visible in conflicts over oil (as in the Middle East), other areas of contention include natural gas pipelines in the Ukraine and North America and "fracking" (see Chapter 13) and mountaintop coal mining in the United States.

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



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

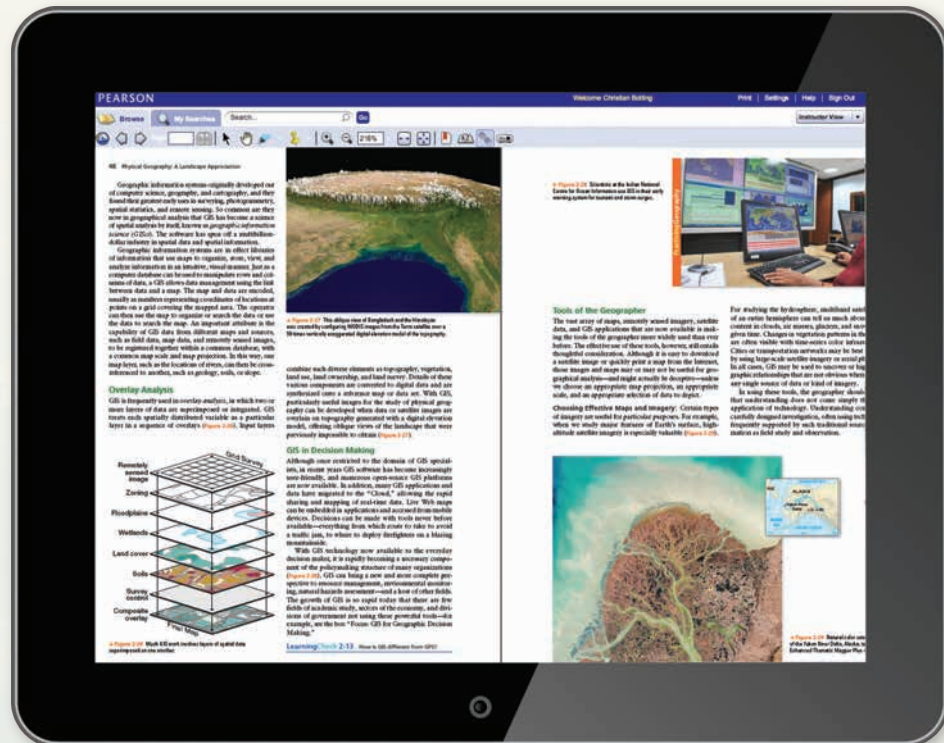
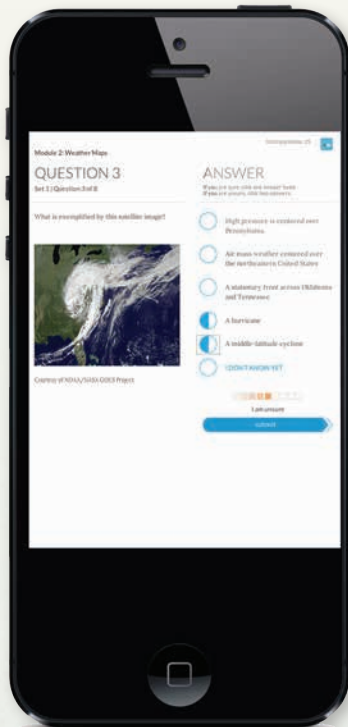
to generate electricity ultimately depends on when the wind blows. Solar power harnesses direct sunlight to generate electricity through either photovoltaic cells or the boiling of water to create steam (see Chapter 4).

Practicing Geography

# Continuous Learning Before, During, and After Class

## BEFORE CLASS

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



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

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

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

**Pre-Lecture Reading Quizzes are easy to customize & assign**

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

# with MasteringGeography™

## DURING CLASS

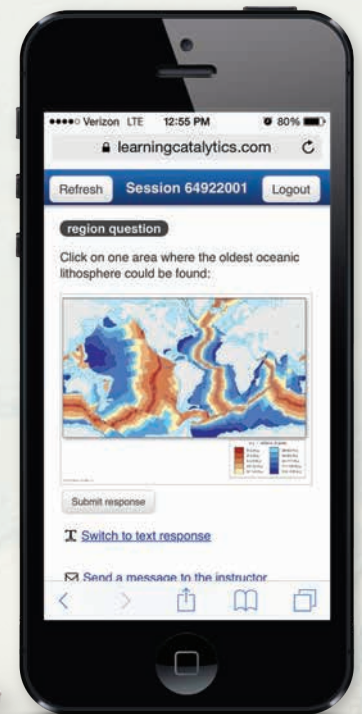
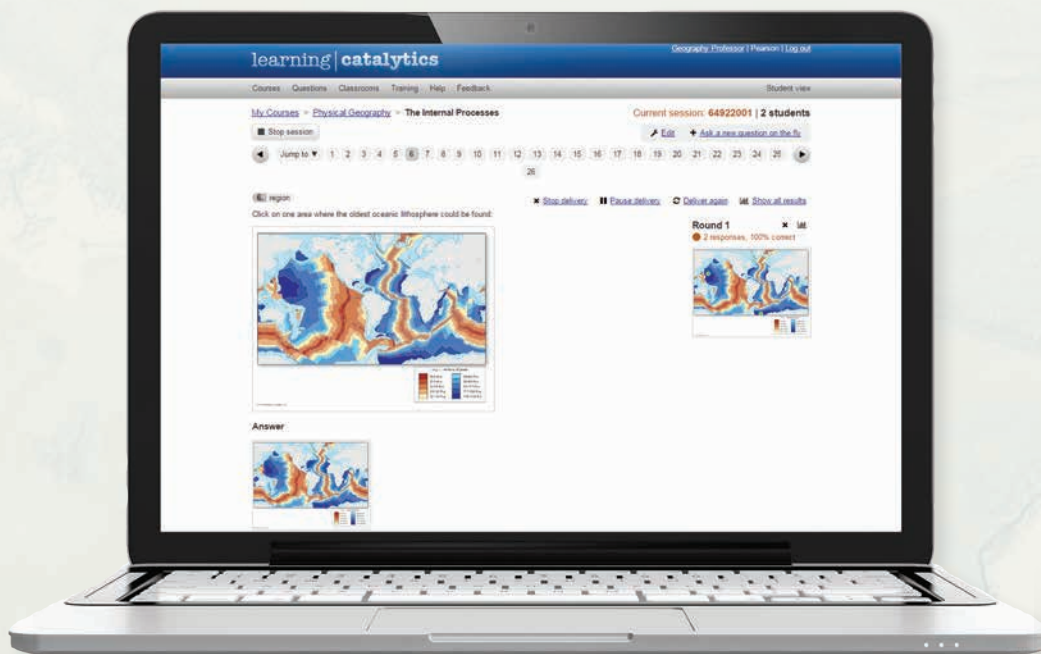
### Learning Catalytics™ and Engaging Media

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

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

*"My students are so busy and engaged answering Learning Catalytics questions during lecture that they don't have time for Facebook."*

*Declan De Paor, Old Dominion University*



### Enrich Lecture with Dynamic Media

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

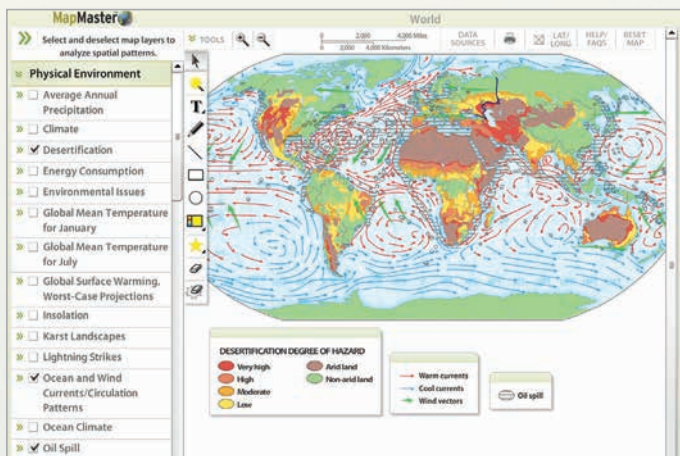


# Mastering Geography™

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

## AFTER CLASS

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

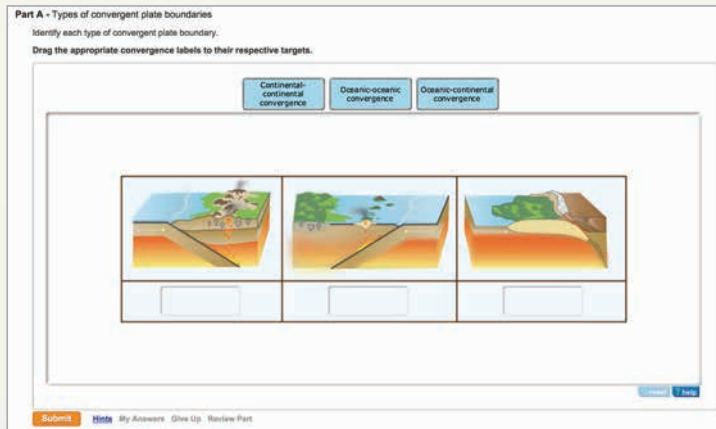


**UPDATED! MapMaster Interactive Map Activities** are inspired by GIS, allowing students to layer various thematic maps to analyze spatial patterns and data at regional and global scales. This tool includes zoom and annotation functionality, with hundreds of map layers leveraging recent data from sources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

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

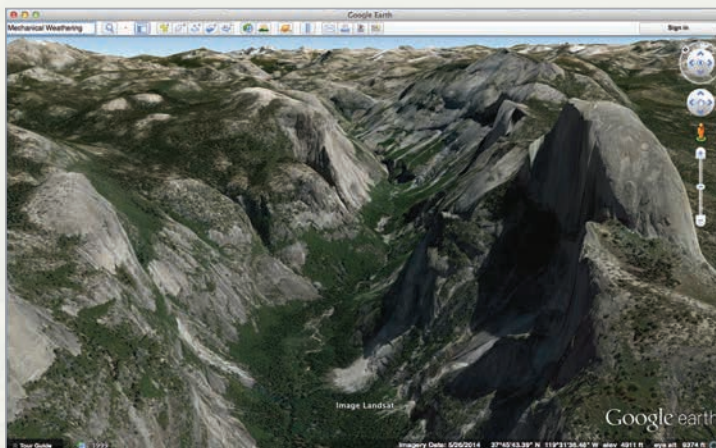


**NEW! Mobile Field Trip Videos** have students accompany acclaimed photographer and pilot Michael Collier in the air and on the ground to explore iconic landscapes of North America and beyond. Readers scan Quick Response (QR) links in the book to access the 20 videos as they read. Also available within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

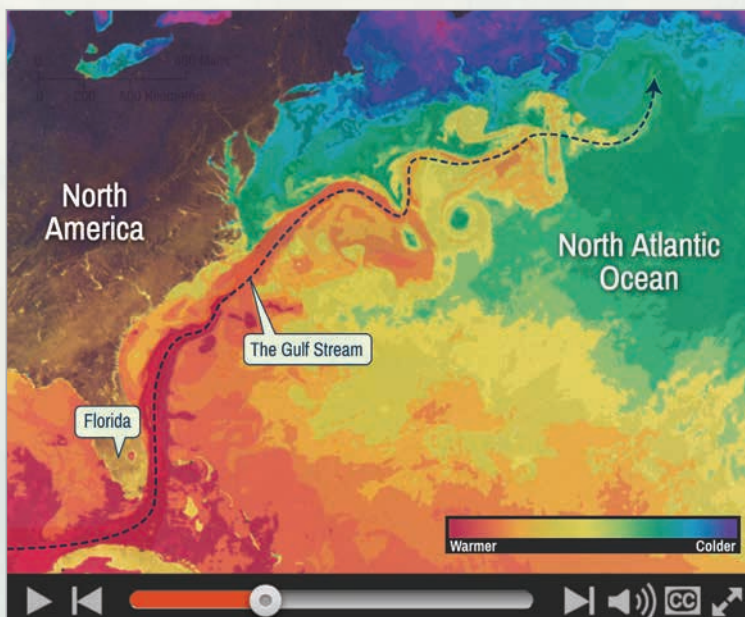


**NEW and UPDATED! GeoTutors** are highly visual and data-rich coaching items with hints and specific wrong answer feedback that help students master the toughest topics in geography.

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



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



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





McKNIGHT'S

# Physical Geography

A Landscape Appreciation

**Darrel Hess**  
City College of San Francisco

ILLUSTRATED BY **Dennis Tasa**

PEARSON

*Senior Geography Editor:* Christian Botting  
*Executive Product Marketing Manager:* Neena Bali  
*Senior Field Marketing Manager:* Mary Salzman  
*Program Manager:* Anton Yakovlev  
*Project Manager:* Connie Long  
*Executive Development Editor:* Karen Karlin  
*Development Manager:* Jennifer Hart  
*Program Management Team Lead:* Kristen Flathman  
*Project Management Team Lead:* David Zielonka  
*Production Management:* Rebecca Lazure/SPI Global

*Compositor:* SPi Global  
*Design Manager:* Mark Ong  
*Interior & Cover Designer:* Preston Thomas  
*Rights & Permissions Management:* Rachel Youdelman  
*Photo Researcher:* Kristin Piljay  
*Copyeditor:* Laura Patchkofsky  
*Manufacturing Buyer:* Maura Zaldivar-Garcia  
*Cover Photo Credit:* Tombstone Territorial Park, Yukon, Canada  
*Credit:* Robert Postma/All Canada Photos/Corbis

Copyright © 2017, 2014, 2011, 2008, 2005 Pearson Education, Inc. All Rights Reserved. Printed in the United States of America. This publication is protected by copyright, and permission should be obtained from the publisher prior to any prohibited reproduction, storage in a retrieval system, or transmission in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise. For information regarding permissions, request forms and the appropriate contacts within the Pearson Education Global Rights & Permissions department, please visit [www.pearsoned.com/permissions/](http://www.pearsoned.com/permissions/).

Acknowledgements of third party content appear on pages C-2–C-4, which constitutes an extension of this copyright page. PEARSON, ALWAYS LEARNING, MasteringGeography are exclusive trademarks in the U.S. and/or other countries owned by Pearson Education, Inc. or its affiliates. Unless otherwise indicated herein, any third-party trademarks that may appear in this work are the property of their respective owners and any references to third-party trademarks, logos or other trade dress are for demonstrative or descriptive purposes only. Such references are not intended to imply any sponsorship, endorsement, authorization, or promotion of Pearson's products by the owners of such marks, or any relationship between the owner and Pearson Education, Inc. or its affiliates, authors, licensees or distributors.

#### Library of Congress Cataloging-in-Publication Data

Names: Hess, Darrel. | McKnight, Tom L. (Tom Lee). 1928–2004 Physical geography.  
Title: McKnight's physical geography : a landscape appreciation / Darrel Hess  
; illustrated by Dennis Tasa.  
Description: Twelfth edition. | Hoboken, NJ : Pearson, 2016.  
Identifiers: LCCN 2016001401 | ISBN 9780134195421  
Subjects: LCSH: Physical geography.  
Classification: LCC GB54.5 .H47 2016 | DDC 910/.02—dc23  
LC record available at <http://lcn.loc.gov/2016001401>

1 2 3 4 5 6 7 8 9 10—V356—18 17 16 15

**PEARSON**

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

ISBN 10: 0-134-19542-6; ISBN 13: 978-0-134-19542-1 (Student edition)

ISBN 10: 0-134-32635-0; ISBN 13: 978-0-134-32635-1 (Instructor's Review Copy)

# BRIEF CONTENTS

- 1** Introduction to Earth 2
- 2** Portraying Earth 28
- 3** Introduction to the Atmosphere 54
- 4** Insolation and Temperature 76
- 5** Atmospheric Pressure and Wind 108
- 6** Atmospheric Moisture 138
- 7** Atmospheric Disturbances 174
- 8** Climate and Climate Change 204
- 9** The Hydrosphere 250
- 10** Cycles and Patterns in the Biosphere 278
- 11** Terrestrial Flora and Fauna 306
- 12** Soils 342
- 13** Introduction to Landform Study 372
- 14** The Internal Processes 398
- 15** Weathering and Mass Wasting 444
- 16** Fluvial Processes 466
- 17** Karst and Hydrothermal Processes 498
- 18** The Topography of Arid Lands 514
- 19** Glacial Modification of Terrain 538
- 20** Coastal Processes and Terrain 568

**Learning Check Answers** AK-1

**Appendix I** The International System of Units (SI) A-1

**Appendix II** U.S. Geological Survey Topographic Maps A-3

**Appendix III** Meteorological Tables A-8

**Appendix IV** The Weather Station Model A-13

**Appendix V** Köppen Climate Classification A-19

**Appendix VI** Biological Taxonomy A-21

**Appendix VII** The Soil Taxonomy A-23

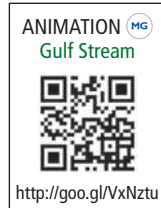
**Glossary** G-1

**Credits** C-2

**Index** I-1

# GEOSCIENCE ANIMATIONS

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



## 1 Introduction to Earth

Solar System Formation  
Earth-Sun Relations

## 2 Portraying Earth

Map Projections

## 3 Introduction to the Atmosphere

Ozone Depletion  
Coriolis Effect

## 4 Insolation and Temperature

Atmospheric Energy Balance  
Gulf Stream  
Global Warming

## 5 Atmospheric Pressure and Wind

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

## 6 Atmospheric Moisture

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

## 7 Atmospheric Disturbances

Cold Fronts  
Warm Fronts  
Midlatitude Cyclones  
Hurricanes  
Hurricane Hot Towers  
Tornadoes

## 8 Climate and Climate Change

Seasonal Pressure and  
Precipitation Patterns

End of the Last Ice Age  
Orbital Variations and  
Climate Change

## 9 The Hydrosphere

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

## 10 Cycles and Patterns in the Biosphere

Biological Productivity in  
Midlatitude Oceans  
Net Primary Productivity

## 13 Introduction to Landform Study

Metamorphic Rock  
Foliation  
Isostasy

## 14 The Internal Processes

Seafloor Spreading  
Paleomagnetism  
Convection and Plate  
Tectonics  
Plate Boundaries  
Divergent Boundaries  
Subduction Zones  
Collision of India with  
Eurasia  
Transform Faults and  
Boundaries  
Breakup of Pangaea  
HotSpot Volcano Tracks  
Terrane Formation  
Volcanoes  
Formation of Crater Lake

The Eruption  
of Mount  
St. Helens

Igneous Features  
Folding  
Faulting  
Seismic Waves  
Seismographs

## 15 Weathering and Mass Wasting

Mechanical Weathering  
Mass Wasting  
The Eruption of Mount St.  
Helens

## 16 Fluvial Processes

Stream Sediment Movement  
Oxbow Lake Formation  
Floods and Natural Levee  
Formation  
Stream Terrace Formation

## 18 The Topography of Arid Lands

Wind Transportation of  
Sediment  
Desert Sand Dunes

## 19 Glacial Modification of Terrain

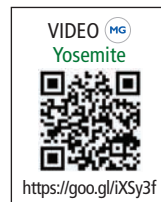
End of the Last Ice Age  
Isostasy  
Flow of Ice within a Glacier  
Glacial Processes  
Orbital Variations and  
Climate Change

## 20 Coastal Processes and Terrain

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

# VIDEOS

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



- 1 Introduction to Earth**  
Mobile Field Trip: Introduction to Physical Geography
- 2 Portraying Earth**  
Mobile Field Trip: Introduction to Physical Geography  
Studying Fires Using Multiple Satellite Sensors
- 3 Introduction to the Atmosphere**  
Ozone Hole  
Coriolis Effect Merry Go Round
- 4 Insolation and Temperature**  
Seasonal Radiation Patterns  
Ocean Circulation Patterns—Subtropical Gyres  
Seasonal Changes in Temperature
- 5 Atmospheric Pressure and Wind**  
El Niño  
La Niña  
Mobile Field Trip: El Niño
- 6 Atmospheric Moisture**  
Hydrological Cycle  
Mobile Field Trip: Clouds: Earth's Dynamic Atmosphere
- 7 Atmospheric Disturbances**  
2005 Hurricane Season  
Hurricane Sandy
- 8 Climate and Climate Change**  
Mobile Field Trip: Climate Change in the Arctic  
18,000 Years of Pine Pollen  
Temperature and Agriculture
- 9 The Hydrosphere**  
Hydrological Cycle  
Mobile Field Trip: Moving Water Across California  
Mobile Field Trip: Mammoth Cave
- 10 Cycles and Patterns in the Biosphere**  
Global Carbon Uptake by Plants  
Mobile Field Trip: Forest Fires in the West
- 11 Terrestrial Flora and Fauna**  
Mobile Field Trip: Cloud Forest  
Climate, Crops, and Bees
- 12 Soils**  
Mobile Field Trip: The Critical Zone  
Maps of Soil Moisture  
California Drought
- 13 Introduction to Landform Study**  
Mobile Field Trip: Yosemite  
Mobile Field Trip: Oil Sands  
Black Smokers
- 14 The Internal Processes**  
Mobile Field Trip: San Andreas Fault  
Mobile Field Trip: Kilauea Volcano  
Project Condor: Cinder Cones and Basaltic Lava Flows  
Project Condor: Monoclines of the Colorado Plateau  
Project Condor: Identifying Anticlines and Synclines  
Project Condor: Faults versus Joints
- 15 Weathering and Mass Wasting**  
Project Condor: Jointing  
Mobile Field Trip: Landslide!
- 16 Fluvial Processes**  
Mobile Field Trip: Streams of the Great Smoky Mountains  
Project Condor: Meandering Rivers  
Mobile Field Trip: Mississippi Delta  
Project Condor: River Terraces and Base Level
- 17 Karst and Hydrothermal Processes**  
Mobile Field Trip: Mammoth Cave
- 18 The Topography of Arid Lands**  
Project Condor: Characteristics of Alluvial Fans  
Mobile Field Trip: Desert Geomorphology
- 19 Glacial Modification of Terrain**  
Mobile Field Trip: The Glaciers of Alaska  
Mobile Field Trip: Climate Change in the Arctic
- 20 Coastal Processes and Terrain**  
Summertime/Wintertime Beach Conditions  
Mobile Field Trip: Gulf Coast Processes  
Movement of Sand in Beach Compartment  
Mobile Field Trip: Cape Cod: Sculpted by Ice & Storm



# CONTENTS

GEOSCIENCE ANIMATIONS xiv

VIDEOS xv

PREFACE xxv

DIGITAL & PRINT RESOURCES xxviii

DEDICATION xxx

ABOUT THE AUTHORS xxxi



## 1 Introduction to Earth 2

**Geography and Science** 4

Studying the World Geographically 4

The Process of Science 6

Numbers and Measurement Systems 6

**FOCUS ► Citizens as Scientists** 7

**Environmental Spheres and Earth Systems** 8

Earth's Environmental Spheres 8

Earth Systems 9

**Earth and the Solar System** 10

The Solar System 10

The Size and Shape of Earth 11

**The Geographic Grid—Latitude and Longitude** 12

Latitude 13

Longitude 15

Locating Points on the Geographic Grid 16

**Earth–Sun Relations and the Seasons** 17

Earth Movements 17

The Annual March of the Seasons 19

Seasonal Transitions 20

Significance of Seasonal Patterns 22

**Telling Time** 22

Standard Time 22

International Date Line 23

**GLOBAL ENVIRONMENTAL CHANGE ► Images of Earth at Night** 25

Daylight-Saving Time 25

**LearningReview** 25

**EnvironmentalAnalysis** 27



## 2 Portraying Earth 28

**Maps and Globes** 30

Maps 30

**Map Scale** 30

Scale Types 30

Large-Scale and Small-Scale Maps 32

**Map Projections and Properties** 32

Map Projections 33

Map Properties 33

**Families of Map Projections** 34

Cylindrical Projections 34

Planar Projections 35

Conic Projections 36

Pseudocylindrical Projections 36

**Conveying Information on Maps** 37

Map Essentials 37

Isolines 37

Portraying the Three-Dimensional Landscape 39

**GNSS—Global Navigation Satellite System** 40

**Remote Sensing** 41

Aerial Photographs 41

**GLOBAL ENVIRONMENTAL CHANGE ► Growing a City in the Desert** 42

Visible Light and Infrared Sensing 43

Thermal Infrared Sensing 43

Multispectral Remote Sensing 44

**Geographic Information Systems (GIS)** 47

Overlay Analysis 48

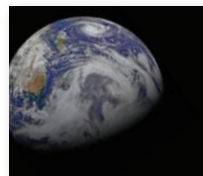
GIS in Decision Making 48

Tools of the Geographer 49

**FOCUS ► GIS for Geographic Decision Making** 50

**LearningReview** 51

**EnvironmentalAnalysis** 52



## 3 Introduction to the Atmosphere 54

**Size and Composition of the Atmosphere** 56

Size of Earth's Atmosphere 56

Development of Earth's Modern Atmosphere 56

Composition of the Modern Atmosphere 57

Permanent Gases	57
Variable Gases	57
Particulates (Aerosols)	58
<b>Vertical Structure of the Atmosphere</b>	<b>59</b>
Thermal Layers	59
Pressure	60
Composition	61
<b>Human-Caused Atmospheric Change</b>	<b>62</b>
Depletion of the Ozone Layer	62
Air Pollution	64
<b>PEOPLE &amp; THE ENVIRONMENT ► The UV Index</b>	<b>65</b>
<b>GLOBAL ENVIRONMENTAL CHANGE ► Aerosol Plumes Circling the Globe</b>	<b>66</b>
Energy Production and the Environment	67
<b>Weather and Climate</b>	<b>67</b>
Weather	67
<b>ENERGY FOR THE 21ST CENTURY ► Transitioning from Fossil Fuels</b>	<b>68</b>
Climate	69
The Elements of Weather and Climate	69
The Controls of Weather and Climate	69
The Coriolis Effect	71
<b>LearningReview</b>	<b>73</b>
<b>EnvironmentalAnalysis</b>	<b>74</b>



## 4 Insolation and Temperature 76

The Impact of Temperature on the Landscape	78
<b>Energy, Heat, and Temperature</b>	<b>78</b>
Energy	78
Temperature and Heat	79
Measuring Temperature	79
<b>Solar Energy</b>	<b>80</b>
Electromagnetic Radiation	80
<b>ENERGY FOR THE 21ST CENTURY ► Solar Power</b>	<b>81</b>
Insolation	83
<b>Basic Warming and Cooling Processes in the Atmosphere</b>	<b>83</b>
Radiation	83
Absorption	84
Reflection	84
Scattering	84
Transmission	85
Conduction	87
Convection	87
Advection	87
Adiabatic Cooling and Warming	87
Latent Heat	88
<b>Earth's Solar Radiation Budget</b>	<b>88</b>
Long-Term Energy Balance	88
Global Energy Budget	89

<b>Variations in Insolation by Latitude and Season</b>	<b>90</b>
Latitudinal and Seasonal Differences	90
Latitudinal Radiation Balance	91
<b>Land and Water Temperature Contrasts</b>	<b>92</b>
Warming of Land and Water	93
Cooling of Land and Water	93
Implications	93
<b>Mechanisms of Global Energy Transfer</b>	<b>94</b>
Atmospheric Circulation	94
Oceanic Circulation	94
<b>Vertical Temperature Patterns</b>	<b>97</b>
Environmental Lapse Rate	97
Average Lapse Rate	97
Temperature Inversions	97
<b>Global Temperature Patterns</b>	<b>98</b>
Prominent Controls of Temperature	98
Seasonal Patterns	99
Annual Temperature Range	100
Measuring Global Temperatures	100
Urban Heat Islands	100
<b>GLOBAL ENVIRONMENTAL CHANGE ► The Deadly Heat Waves of 2015</b>	<b>101</b>
<b>FOCUS ► Measuring Earth's Surface Temperature by Satellite</b>	<b>102</b>
<b>Climate Change and Global Warming</b>	<b>103</b>
Temperature Change Over the Last Century	103
Increasing Greenhouse Gas Concentrations	103
Intergovernmental Panel on Climate Change (IPCC)	105
<b>LearningReview</b>	<b>105</b>
<b>EnvironmentalAnalysis</b>	<b>107</b>



## 5 Atmospheric Pressure and Wind 108

The Impact of Pressure and Wind on the Landscape	110
<b>The Nature of Atmospheric Pressure</b>	<b>110</b>
Factors Influencing Atmospheric Pressure	110
Mapping Pressure with Isobars	112
<b>The Nature of Wind</b>	<b>112</b>
Direction of Movement	112
Wind Speed	114
<b>Cyclones and Anticyclones</b>	<b>115</b>
<b>ENERGY FOR THE 21ST CENTURY ► Wind Power</b>	<b>116</b>
<b>The General Circulation of the Atmosphere</b>	<b>117</b>
Idealized Circulation Patterns	117
Seven Components of the General Circulation	118
Subtropical Highs	119

Trade Winds 121  
 Intertropical Convergence Zone (ITCZ) 122  
 The Westerlies 122  
 Polar Highs 124  
 Polar Easterlies 124  
 Polar Front 124  
 Vertical Patterns of the General Circulation 125

**Modifications of the General Circulation 125**

Seasonal Variations in Location 125  
 Monsoons 126

**Localized Wind Systems 127**

Sea and Land Breezes 127

**GLOBAL ENVIRONMENTAL CHANGE ► Changes in the South Asian Monsoon 129**

Valley and Mountain Breezes 130  
 Katabatic Winds 130  
 Foehn and Chinook Winds 130  
 Santa Ana Winds 131

**El Niño–Southern Oscillation 131**

Effects of El Niño 131  
 Normal Pattern 132  
 El Niño Pattern 132  
 La Niña 133  
 Causes of ENSO 133  
 Teleconnections 134

**FOCUS ► Multiyear Atmospheric and Oceanic Cycles 135**

**LearningReview 136**

**EnvironmentalAnalysis 137**



## 6 Atmospheric Moisture 138

The Impact of Atmospheric Moisture on the Landscape 140

**The Nature of Water: Commonplace but Unique 140**

The Hydrologic Cycle 140  
 The Water Molecule 140  
 Important Properties of Water 141

**Phase Changes of Water 142**

Latent Heat 142  
 Importance of Latent Heat in the Atmosphere 144

**Water Vapor and Evaporation 144**

Evaporation and Rates of Evaporation 144  
 Evapotranspiration 145

**Measures of Humidity 145**

Actual Water Vapor Content 145  
 Relative Humidity 146  
 Related Humidity Concepts 147

**GLOBAL ENVIRONMENTAL CHANGE ► Extreme Dew Point Temperatures 148**

**Condensation 149**

The Condensation Process 149

**Adiabatic Processes 149**

Dry and Saturated Adiabatic Rates 149  
 Significance of Adiabatic Temperature Changes 151

**Clouds 151**

Classifying Clouds 151  
 Fog 154  
 Dew 155  
 Clouds and Climate Change 155

**Atmospheric Stability 155**

Buoyancy 155  
 The Stability of Air 155  
 Determining Atmospheric Stability 156

**Precipitation 157**

The Processes 158  
 Forms of Precipitation 160

**Atmospheric Lifting and Precipitation 161**

**FOCUS ► GOES Weather Satellites 162**

Convective Lifting 163  
 Orographic Lifting 163  
 Frontal Lifting 164  
 Convergent Lifting 164

**Global Distribution of Precipitation 165**

Regions of High Annual Precipitation 165  
 Regions of Low Annual Precipitation 165  
 Seasonal Precipitation Patterns 166  
 Precipitation Variability 167

**Acid Rain 167**

Sources of Acid Precipitation 168

**LearningReview 171**

**EnvironmentalAnalysis 173**



## 7 Atmospheric Disturbances 174

The Impact of Storms on the Landscape 176

**Air Masses 176**

Characteristics 176  
 Origin 176  
 Classification 176  
 Movement and Modification 176  
 North American Air Masses 177

**Fronts 178**

Types of Fronts 178  
 Cold Fronts 179  
 Warm Fronts 179  
 Stationary Fronts 179  
 Occluded Fronts 179  
 Air Masses, Fronts, and Major Atmospheric Disturbances 179

- Midlatitude Cyclones** 180  
 Characteristics 180  
 Movements 182  
 Life Cycle 182  
 Weather Changes with the Passing of a Midlatitude Cyclone 184  
 Occurrence and Distribution 184
- FOCUS ► Conveyor Belt Model of Midlatitude Cyclones** 185
- Midlatitude Anticyclones** 186  
 Characteristics 186  
 Relationships of Cyclones and Anticyclones 186
- Easterly Waves** 187
- Tropical Cyclones: Hurricanes** 187  
 Categories of Tropical Disturbances 187  
 Characteristics 188  
 Origin 189  
 Movement 189  
 Damage and Destruction 191  
 Hurricanes and Climate Change 193
- Localized Severe Weather** 194  
 Thunderstorms 194  
 Tornadoes 196
- GLOBAL ENVIRONMENTAL CHANGE ► Are Tornado Patterns Changing?** 197  
 Severe Storm Watches and Warnings 199
- FOCUS ► Weather Radar** 200
- LearningReview** 201
- EnvironmentalAnalysis** 203



## 8 Climate and Climate Change 204

- Climate Classification** 206  
 The Köppen Climate Classification System 206  
 Climographs 207  
 World Distribution of Major Climate Types 208
- Tropical Humid Climates (Group A)** 209  
 Tropical Wet Climate (Af) 209  
 Tropical Savanna Climate (Aw) 211  
 Tropical Monsoon Climate (Am) 213
- Dry Climates (Group B)** 214  
 Subtropical Desert Climate (BWh) 215  
 Midlatitude Desert Climate (BWk) 217
- Mild Midlatitude Climates (Group C)** 218  
 Mediterranean Climate (Csa, Csb) 219  
 Humid Subtropical Climate (Cfa, Cwa, Cwb) 220  
 Marine West Coast Climate (Cfb, Cfc) 222
- Severe Midlatitude Climates (Group D)** 223  
 Humid Continental Climate (Dfa, Dfb, Dwa, Dwb) 223  
 Subarctic Climate (Dfc, Dfd, Dwc, Dwd) 225

- Polar and Highland Climates (Groups E and H)** 226
- FOCUS ► Signs of Climate Change in the Arctic** 227  
 Tundra Climate (ET) 228  
 Ice Cap Climate (EF) 229  
 Highland Climate (Group H) 230  
 Global Patterns Idealized 231
- Global Climate Change** 232  
 Time Scales of Climate Change 233  
 Determining Climates of the Past 233  
 Dendrochronology 233  
 Oxygen Isotope Analysis 234  
 Ice Cores 235  
 Pollen Analysis 236  
 Remnant Glacial Landforms 236  
 Speleothems 236
- Causes of Climate Change** 236  
 Atmospheric Aerosols 236  
 Fluctuations in Solar Output 237  
 Variations in Earth–Sun Relations 238  
 Greenhouse Gas Concentrations 238  
 Feedback Mechanisms 239  
 The Roles of the Ocean 239
- Anthropogenic Climate Change** 240  
 Observed Current Climate Change 240  
 Natural or Anthropogenic Climate Change? 241
- Future Climate Change** 242  
 Using Models to Predict Future Climate 242  
 Projections of Future Climate 243
- Addressing Climate Change** 244
- GLOBAL ENVIRONMENTAL CHANGE ► Disappearing and Novel Climates** 245
- ENERGY FOR THE 21ST CENTURY ► Strategies for Reducing Greenhouse Gas Emissions** 246  
 International Climate Change Agreements 247  
 Newly Industrialized Countries 247  
 Mitigating and Adapting 247
- LearningReview** 248
- EnvironmentalAnalysis** 249



## 9 The Hydrosphere 250

- The Hydrologic Cycle** 252  
 Surface-to-Air Water Movement 252  
 Air-to-Surface Water Movement 253  
 Movement On and Beneath Earth's Surface 253  
 Residence Times 253  
 Energy Transfer in the Hydrologic Cycle 254
- The Oceans** 254  
 How Many Oceans? 254

Characteristics of Ocean Waters 255

**Movement of Ocean Waters** 256

Tides 257

Ocean Currents 258

**PEOPLE & THE ENVIRONMENT ► The Great Pacific**

**Garbage Patch** 260

Waves 261

**Permanent Ice—The Cryosphere** 261

Permafrost 262

**Surface Waters** 264

Lakes 264

Wetlands 267

Rivers and Streams 268

**Groundwater** 269

Movement and Storage of Groundwater 269

Zone of Aeration 270

Zone of Saturation 270

Waterless Zone 271

Groundwater Mining 271

**GLOBAL ENVIRONMENTAL CHANGE ► Monitoring**

**Groundwater Resources from Space** 273

**LearningReview** 275

**EnvironmentalAnalysis** 276



**10 Cycles and Patterns in the Biosphere** 278

The Impact of Plants and Animals on the Landscape 280

**The Geographic Approach to the Study of Organisms** 280

Biogeography 280

The Search for a Meaningful Classification Scheme 281

**Biogeochemical Cycles** 281

The Flow of Energy 282

The Hydrologic Cycle 284

The Carbon Cycle 284

**ENERGY FOR THE 21ST CENTURY ► Biofuels** 285

The Nitrogen Cycle 286

The Oxygen Cycle 287

Mineral Cycles 289

**Food Chains** 289

Food Pyramids 290

Pollutants in the Food Chain 290

**Biological Factors and Natural Distributions** 292

Evolutionary Development 292

Migration and Dispersal 293

**GLOBAL ENVIRONMENTAL CHANGE ► Honey Bees at Risk** 294

Reproductive Success 295

Population Die-off and Extinction 295

Plant Succession 296

**Environmental Factors** 297

The Influence of Climate 297

**FOCUS ► What's Killing Our Forests?** 299

Edaphic Influences 300

Topographic Influences 300

Wildfire 300

**Environmental Correlations** 302

The Example of Tropical Rainforest 302

**LearningReview** 304

**EnvironmentalAnalysis** 305



**11 Terrestrial Flora and Fauna** 306

**Ecosystems and Biomes** 308

Ecosystem: A Concept for All Scales 308

Biome: A Scale for All Biogeographers 308

**Terrestrial Flora** 309

Characteristics of Plants 309

Environmental Adaptations 310

Global Distribution of Plant Associations 311

Vertical Zonation 313

Local Variations 314

**Terrestrial Fauna** 314

Characteristics of Animals 315

Kinds of Animals 315

Environmental Adaptations 316

**FOCUS ► Changing Climate Affects Bird Populations** 318

Competition among Animals 320

Cooperation among Animals 320

**Zoogeographic Regions** 321

**The Major Biomes** 323

Tropical Rainforest 323

Tropical Deciduous Forest 324

Tropical Scrub 325

Tropical Savanna 325

Desert 327

Mediterranean Woodland and Shrub 328

Midlatitude Grassland 328

Midlatitude Deciduous Forest 329

Boreal Forest 330

Tundra 332

**Human Modification of the Biosphere** 333

Physical Removal of Organisms 333

Habitat Modification 333

**GLOBAL ENVIRONMENTAL CHANGE ► Rainforest Loss in Brazil and Southeast Asia** 335

Introduction of Exotic Species 336

Loss of Biodiversity 337

**PEOPLE & THE ENVIRONMENT ► Invasive Species in Florida** 338

**LearningReview** 339

**EnvironmentalAnalysis** 341



## 12 Soils 342

### Soil and Regolith 344

- Soil as a Component of the Landscape 344
- From Regolith to Soil 344

### Soil-Forming Factors 344

- The Geologic Factor 344
- The Climatic Factor 345
- The Topographic Factor 345
- The Biological Factor 346

### GLOBAL ENVIRONMENTAL CHANGE ► Invasive Earthworms Change Soils as We Know Them! 347

- The Time Factor 348

### Soil Components 348

- Inorganic Materials 348
- Organic Matter 349
- Soil Air 349
- Soil Water 349

### Soil Properties 351

- Color 351
- Texture 352
- Structure 352

### Soil Chemistry 353

- Colloids 353
- Cation Exchange 354
- Acidity/Alkalinity 354

### Soil Profiles 354

- Soil Horizons 354

### Pedogenic Regimes 356

- Laterization 356
- Podzolization 356
- Gleization 357
- Calcification 357
- Salinization 357
- Climate and Pedogenic Regimes 358

### Soil Classification 358

- The Soil Taxonomy 358

### FOCUS ► Soil Differences—They're All About Scale 359

- The Mapping Question 360

### Global Distribution of Major Soils 360

- Entisols (Very Little Profile Development) 362
- Inceptisols (Few Diagnostic Features) 362
- Andisols (Volcanic Ash Soils) 363
- Gelisols (Cold Soils with Permafrost) 363
- Histosols (Organic Soils on Very Wet Sites) 364
- Aridisols (Soils of Dry Climates) 364
- Vertisols (Swelling and Cracking Clays) 364
- Mollisols (Dark, Soft Soils of Grasslands) 365
- Alfisols (Clay-Rich B Horizons, High Base Status) 366
- Ultisols (Clay-Rich B Horizons, Low Base Status) 366

- Spodosols (Soils of Cool, Forested Zones) 367
- Oxisols (Highly Weathered and Leached) 367
- Distribution of Soils in the United States 368

### LearningReview 369

### EnvironmentalAnalysis 371



## 13 Introduction to Landform Study 372

### The Structure of Earth 374

- Earth's Hot Interior 374
- The Crust 374
- The Mantle 374
- The Inner and Outer Cores 375
- Plate Tectonics and the Structure of Earth 375

### The Composition of Earth 375

- Minerals 376
- Rocks 377
- Igneous Rocks 378
- Sedimentary Rocks 381
- Metamorphic Rocks 384

### ENERGY FOR THE 21ST CENTURY ► Unconventional Hydrocarbons and the Fracking Revolution 385

- The Rock Cycle 386
- Continental and Ocean Floor Rocks 387
- Isostasy 388
- Utilizing Earth's Mineral Resources 389

### The Study of Landforms 389

### GLOBAL ENVIRONMENTAL CHANGE ► Technological Gadgets and the Mining of Rare Earths 389

### Some Critical Concepts 390

- Internal and External Geomorphic Processes 390
- Uniformitarianism 391
- Geologic Time 392

### Scale and Pattern 394

- An Example of Scale 394
- Pattern and Process in Geomorphology 395

### LearningReview 396

### EnvironmentalAnalysis 397



## 14 The Internal Processes 398

- The Impact of Internal Processes on the Landscape 400

### From Rigid Earth to Plate Tectonics 400

- Wegener's Continental Drift 400

### The Theory of Plate Tectonics 402

- The Evidence 402
- Seafloor Spreading 402
- Plate Tectonic Theory 405

**Plate Boundaries 406**

- Divergent Boundaries 406
- Convergent Boundaries 408
- Transform Boundaries 409
- Plate Boundaries over Geologic Time 411

**Additions to Plate Tectonic Theory 412**

- Hot Spots and Mantle Plumes 412
- Accreted Terranes 415
- Remaining Questions 416

**Volcanism 416**

- Volcano Distribution 416
- Magma Chemistry and Styles of Eruption 418
- Lava Flows 418
- Volcanic Peaks 420

**Volcanic Hazards 423**

- Volcanic Gases 423
- Lava Flows 424
- Eruption Column and Ash Fall 424
- Pyroclastic Flows 424

**GLOBAL ENVIRONMENTAL CHANGE ► Have Volcanic Aerosols Offset Greenhouse Gas Warming? 425**

- Volcanic Mudflows (Lahars) 426
- Monitoring Volcanoes 426

**PEOPLE & THE ENVIRONMENT ► Human Impacts of Recent Volcanic Eruptions 428****Intrusive Igneous Features 429**

- Plutons 429

**Tectonism: Folding 430**

- The Process of Folding 430
- Types of Folds 431
- Topographic Features Associated with Folding 432

**Tectonism: Faulting 432**

- Types of Faults 433
- Landforms Associated with Normal Faulting 434
- Landforms Associated with Strike-Slip Faulting 435

**Earthquakes 436**

- Seismic Waves 436
- Earthquake Magnitude 437
- Shaking Intensity 437

**Earthquake Hazards 437**

- Ground Shaking 437
- Tsunami 438
- Earthquake Hazard Warnings 439

**Complexities of the Internal Processes—Example of the Northern Rockies 439****FOCUS ► Earthquake Prediction 440****LearningReview 441****EnvironmentalAnalysis 443**

## 15 Weathering and Mass Wasting 444

**Denudation 446**

- The Impact of Weathering and Mass Wasting on the Landscape 446

**Weathering and Rock Openings 446**

- Types of Rock Openings 446
- The Importance of Jointing 447

**Weathering Agents 447**

- Mechanical Weathering 448
- Chemical Weathering 450
- Biological Weathering 452
- Differential Weathering 453
- Climate and Weathering 453

**Mass Wasting 453**

- Factors Influencing Mass Wasting 454

**Types of Mass Wasting 454**

- Fall 454
- Slide 456

**GLOBAL ENVIRONMENTAL CHANGE ► Are Rockfalls Becoming More Common Around the World? 457**

- Flow 458

**PEOPLE & THE ENVIRONMENT ► The Oso Landslide 460 Creep 461****LearningReview 463****EnvironmentalAnalysis 464**

## 16 Fluvial Processes 466

- The Impact of Fluvial Processes on the Landscape 468

**Streams and Stream Systems 468**

- Streamflow and Overland Flow 468
- Valleys and Interfluves 468
- Drainage Basins 468
- Stream Orders 469

**ENERGY FOR THE 21ST CENTURY ► Hydropower 470****Fluvial Erosion and Deposition 471**

- Erosion by Overland Flow 471
- Erosion by Streamflow 471
- Transportation 472
- Deposition 472
- Perennial and Intermittent Streams 473
- Floods as Agents of Erosion and Deposition 473

**Stream Channels 475**

- Channel Flow 475
- Stream Channel Patterns 475

**Structural Relationships 477**

- Consequent and Subsequent Streams 477
- Antecedent and Superimposed Streams 477
- Stream Drainage Patterns 478

**The Shaping and Reshaping of Valleys 480**

- Valley Deepening 480
- Valley Widening 482
- Valley Lengthening 483
- Deposition in Valleys 485

- Floodplains** 486
  - Floodplain Landforms 486
  - Modifying Rivers for Flood Control 488
  - Flood Control on the Mississippi River 488

**Stream Rejuvenation** 490

**PEOPLE & THE ENVIRONMENT** ► **The Future of the Mississippi River Delta** 491

**GLOBAL ENVIRONMENTAL CHANGE** ► **Restoring Urban Streams** 492

**Theories of Landform Development** 494

- Davis's Geomorphic Cycle 494
- Penck's Theory of Crustal Change and Slope Development 495
- Equilibrium Theory 495

**LearningReview** 495

**EnvironmentalAnalysis** 497



## 17 Karst and Hydrothermal Processes 498

The Impact of Solution Processes on the Landscape 500

**Dissolution and Precipitation** 500

- Dissolution Processes 500
- Precipitation Processes 500

**Caverns and Related Features** 501

- Speleothems 501

**Karst Topography** 502

**GLOBAL ENVIRONMENTAL CHANGE** ► **Caverns Hold Evidence of Climate Change** 503

- Karst Landforms 504

**Hydrothermal Features** 507

- Hot Springs 507

**ENERGY FOR THE 21ST CENTURY** ► **Geothermal Energy** 508

- Geysers 509
- Fumaroles 509
- Hydrothermal Features in Yellowstone 510

**LearningReview** 512

**EnvironmentalAnalysis** 513



## 18 The Topography of Arid Lands 514

**A Specialized Environment** 516

- Special Conditions in Deserts 516

**Running Water in Waterless Regions** 517

- Surface Water in the Desert 517

- Fluvial Erosion in Arid Lands 519
- Fluvial Deposition in Arid Lands 521
- Climate Change and Deserts 522

**The Work of the Wind** 522

**GLOBAL ENVIRONMENTAL CHANGE** ► **Desertification** 523

- Aeolian Erosion 524
- Aeolian Transportation 524
- Aeolian Deposition 525
- Aeolian Processes in Nondesert Regions 527

**Characteristic Desert Landscape Surfaces** 529

- Erg—A Sea of Sand 529
- Reg—Stony Deserts 529
- Hamada—Barren Bedrock 530
- Two Representative Desert Landform Assemblages 530

**Basin-and-Range Landforms** 530

- The Ranges 530
- Piedmont Zone 531
- The Basins 531

**Mesa-and-Scarp Terrain** 532

**FOCUS** ► **Death Valley's Extraordinary Basin-and-Range Terrain** 533

- Structure of Mesa-and-Scarp Landforms 534
- Erosion of Escarpment Edge 534
- Arches and Natural Bridges 535
- Badlands 535

**LearningReview** 536

**EnvironmentalAnalysis** 537



## 19 Glacial Modification of Terrain 538

The Impact of Glaciers on the Landscape 540

**Types of Glaciers** 540

- Mountain Glaciers 540
- Continental Ice Sheets 540

**Glaciations Past and Present** 541

- Pleistocene Glaciation 541
- Indirect Effects of Pleistocene Glaciations 542
- Contemporary Glaciation 544

**Glacier Formation and Movement** 546

- Changing Snow to Ice 546

**PEOPLE & THE ENVIRONMENT** ► **Disintegration of Antarctic Ice Shelves** 547

- Glacier Movement 548
- Glacier Flow versus Glacier Advance 549

**The Effects of Glaciers** 549

- Erosion by Glaciers 549
- Transportation by Glaciers 550
- Deposition by Glaciers 550

**Continental Ice Sheets** 551

- Development and Flow 551
- Erosion by Ice Sheets 552



Deposition by Ice Sheets 553  
Glaciofluvial Features 555

**Mountain Glaciers** 556

Development and Flow of Mountain Glaciers 556

**GLOBAL ENVIRONMENTAL CHANGE ► Shrinking Glaciers** 557

Erosion by Mountain Glaciers 558  
Deposition by Mountain Glaciers 562

**The Periglacial Environment** 562

Patterned Ground 563  
Proglacial Lakes 563

**Causes of the Pleistocene Glaciations** 564

Climate Factors and the Pleistocene 565  
Are We Still in an Ice Age? 565

**LearningReview** 565

**EnvironmentalAnalysis** 567



## 20 Coastal Processes and Terrain 568

The Impact of Waves and Currents on the Landscape 570

**Coastal Processes** 570

The Role of Wind in Coastal Processes 570  
Coastlines of Oceans and Lakes 570

**Waves** 570

Wave Motion 570  
Wave Refraction 572  
Wave Erosion 572  
Tsunami 574

**Important Shoreline-Shaping Processes** 576

Tides 576  
Changes in Sea Level and Lake Level 576

**ENERGY FOR THE 21ST CENTURY ► Tidal Power** 577

Ice Push 578  
Organic Secretions 578

Stream Outflow 578

**GLOBAL ENVIRONMENTAL CHANGE ► Impact of Sea-Level Rise on Islands** 579

Coastal Sediment Transport 579

**Coastal Depositional Landforms** 580

Sediment Budget of Depositional Landforms 580  
Beaches 581  
Spits 581  
Barrier Islands 582  
Human Alteration of Coastal Sediment Budgets 584

**Shorelines of Submergence and Emergence** 585

Coastal Submergence 585  
Coastal Emergence 587

**Coral Reef Coasts** 588

Coral Polyps 588  
Coral Reefs 589

**FOCUS ► Imperiled Coral Reefs** 590

**LearningReview** 592

**EnvironmentalAnalysis** 593

**Learning Check Answers** AK-1

**Appendix I** The International System of Units (SI) A-1

**Appendix II** U.S. Geological Survey Topographic Maps A-3

**Appendix III** Meteorological Tables A-8

**Appendix IV** The Weather Station Model A-13

**Appendix V** Köppen Climate Classification A-19

**Appendix VI** Biological Taxonomy A-21

**Appendix VII** The Soil Taxonomy A-23

**Glossary** G-1

**Credits** C-2

**Index** I-1

# PREFACE

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

## NEW TO THE 12TH EDITION

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

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

## TO THE STUDENT

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

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

## ACKNOWLEDGMENTS

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

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

Sandra Arlinghaus, *University of Michigan*  
 Robert Bailis, *Stockholm Environment Institute*  
 Keith Clarke, *University of California–Santa Barbara*  
 Kristine L. DeLong, *Louisiana State University*  
 Robert A. Dull, *University of Texas at Austin*  
 Ted Eckmann, *University of Portland*  
 Matthew Fry, *University of North Texas*  
 Redina L. Herman, *Western Illinois University*  
 Christopher Groves, *Western Kentucky University*  
 Andrew J. Grundstein, *University of Georgia*  
 Ryan Longman, *University of Hawaii at Manoa*  
 Kerry Lyste, *Everett Community College*  
 Michael E. Mann, *Pennsylvania State University*  
 Michael C. Pease, *Central Washington University*  
 Natalie Peyronnin, *Mississippi River Delta Restoration*  
 Jennifer Rahn, *Samford University*  
 Christopher J. Seeger, *Iowa State University*  
 Diana Sammataro, *DianaBrand Honey Bee Research Services*  
 Randall Schaetzl, *Michigan State University*  
 Bradley A. Shellito, *Youngstown State University*  
 Stephen Stadler, *Oklahoma State University*  
 Pat Stevenson, *Natural Resources Department, Stillaguamish Tribe*  
 Paul Sutton, *University of South Australia*  
 Nancy Lee Wilkinson, *San Francisco State University*  
 Kyungsoo Yoo, *University of Minnesota*

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*  
 Jason Allard, *Valdosta State University*  
 Casey Allen, *Weber State University*  
 Sergei Andronikov, *Austin Peay State University*  
 Christopher Atkinson, *University of North Dakota*  
 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*  
 Purba Fernandez, *De Anza College*  
 Jason Finley, *Los Angeles Pierce College*  
 Lynda Folts, *Richland College*  
 Doug Foster, *Clackamas Community College*  
 Basil Gomez, *Indiana State University*  
 Jerry Green, *Miami University–Oxford*  
 Michael Grossman, *Southern Illinois University–Edwardsville*  
 Andrew J. Grundstein, *University of Georgia*  
 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*  
 Matt Huber, *Syracuse University*  
 Paul Hudson, *University of Texas*  
 Catherine Jain, *Palomar College*  
 Steven Jennings, *University of Colorado at Colorado Springs*  
 Ryan Jensen, *Brigham Young University*  
 Dorleen B. Jenson, *Salt Lake Community College*  
 Kris Jones, *Saddleback College*  
 Ryan Kelly, *Lexington Community College*  
 Joseph Kerski, *ESRI*  
 John Keyantash, *California State University–Dominguez Hills*  
 Rob Kremer, *Metropolitan State College of Denver*  
 Kara Kuvakas, *Hartnell College*  
 Steve LaDochy, *California State University*  
 Colin Long, *University of Wisconsin–Oshkosh*  
 Michael Madsen, *Brigham Young University–Idaho*  
 Kenneth Martis, *West Virginia University*  
 Martin Mitchell, *Minnesota State University–Mankato*  
 William 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, *Central Washington University*  
 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*  
 Terry Shirley, *University of North Carolina–Charlotte*  
 Jorge Sifuentes, *Cuesta College*  
 Robert A. Sirk, *Austin Peay State University*  
 Valerie Sloan, *University of Colorado at Boulder*  
 Dale Splinter, *University of Wisconsin–Whitewater*  
 Stephen Stadler, *Oklahoma State University*  
 Herschel Stern, *Mira Costa College*  
 Jane Thorngren, *San Diego State University*  
 Christi Townsend, *San Diego State University*  
 Scott Walker, *Northwest Vista College*  
 Timothy Warner, *West Virginia University*  
 Shawn Willsey, *College of Southern Idaho*  
 Donald Wuebbles, *University of Illinois at Urbana Champaign*  
 Kenneth Zweibel, *George Washington University*

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 editions of the book: Ian Duncan, Carlos Jennings, Dack Lee, Chris Lewis, Joyce Lucas-Clark, Robert Manlove, Kathryn Pinna, Todd Rigg-Carrero, Kirstie Stramler, Carole Toebe, and Katryn Wiese. 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 Senior Geography Editor Christian Botting, who provided skillful leadership and assembled the outstanding group of professionals with whom I worked. My thanks and admiration go to Project Manager Connie Long, who cheerfully kept me on track throughout the entire production process. Many thanks also to Development Editor Karen Karlin, Program Manager Anton Yakovlev, SPi Global Project Manager Rebecca Lazure, Photo Researcher Kristin Piljay, International Mapping Senior Project Manager Kevin Lear, Director of Development Jennifer Hart, Editorial Assistant Michelle Koski, Executive Marketing Manager Neena Bali, Senior Field Marketing Manager Mary Salzman, Marketing Assistant Ami Sampat, and Media Producers Tim Hainley and Ziki Dekel.

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

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

# DIGITAL & PRINT RESOURCES

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

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

Pearson eText gives students access to the text whenever and wherever they can access the Internet. Features of Pearson eText include:

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

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

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

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

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

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

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

## FOR STUDENTS

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

*Goode's World Atlas, 23rd Edition* (0133864642). Goode's World Atlas has been the world's premiere educational atlas since 1923—and for good reason. It features over 250 pages of maps, from definitive physical and political maps to important thematic maps that illustrate the spatial aspects of many important topics. The 23rd Edition includes over 160 pages of digitally produced reference maps, as well as thematic maps on global climate change, sea-level rise, CO<sub>2</sub> emissions, polar ice fluctuations, deforestation, extreme weather events, infectious diseases, water resources, and energy production.

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

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

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

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

## FOR TEACHERS

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

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

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

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

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

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

- Assess students in real time, using open-ended tasks to probe student understanding.
- Understand immediately where students are and adjust your lecture accordingly.
- Improve your students' critical thinking skills.
- Access rich analytics to understand student performance.
- Add your own questions to make Learning Catalytics fit your course exactly.
- Manage student interactions with intelligent grouping and timing.

Learning Catalytics is a technology that has grown out of twenty years of cutting-edge research, innovation, and implementation of interactive teaching and peer instruction. Available integrated with *MasteringGeography*™.

# DEDICATION

For our nephews, Daniel, Kyle, and Nicholas

D. H.

---

## ABOUT OUR SUSTAINABILITY INITIATIVES

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

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

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

**PEARSON**



## ABOUT THE AUTHORS



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



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



# 1



## Seeing Geographically

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

# Introduction to Earth

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

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

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

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

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



**MOBILE  
FIELD TRIP** MG

**Introduction to  
Physical Geography**



<https://goo.gl/B2xTBh>

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

## Geography and Science

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

### Studying the World Geographically

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

All of the items shown in Figure 1-1 are familiar to us, and this familiarity highlights a basic characteristic of geography as a field of learning: geography doesn’t have its own body of facts or objects that only geographers study. The focus of geology is rocks, the attention of economics is economic systems, demography examines human population, and so on. Geography, on the

other hand, is much broader in scope than most other disciplines, “borrowing” its objects of study from related fields. Geographers, too, are interested in rocks and economic systems and population—especially in describing and understanding their location and distribution. We sometimes say that geography asks the fundamental question, “Why is what where, and so what?”

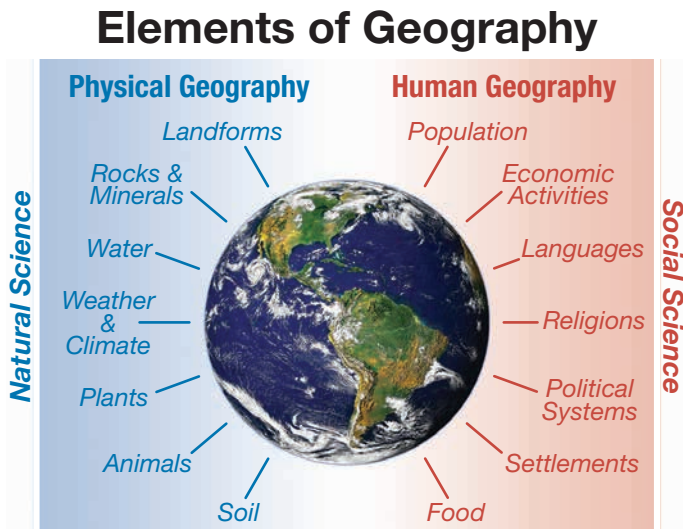
### LearningCheck 1-1 What are the differences between physical geography and human geography? (Answer on p. AK-1)

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

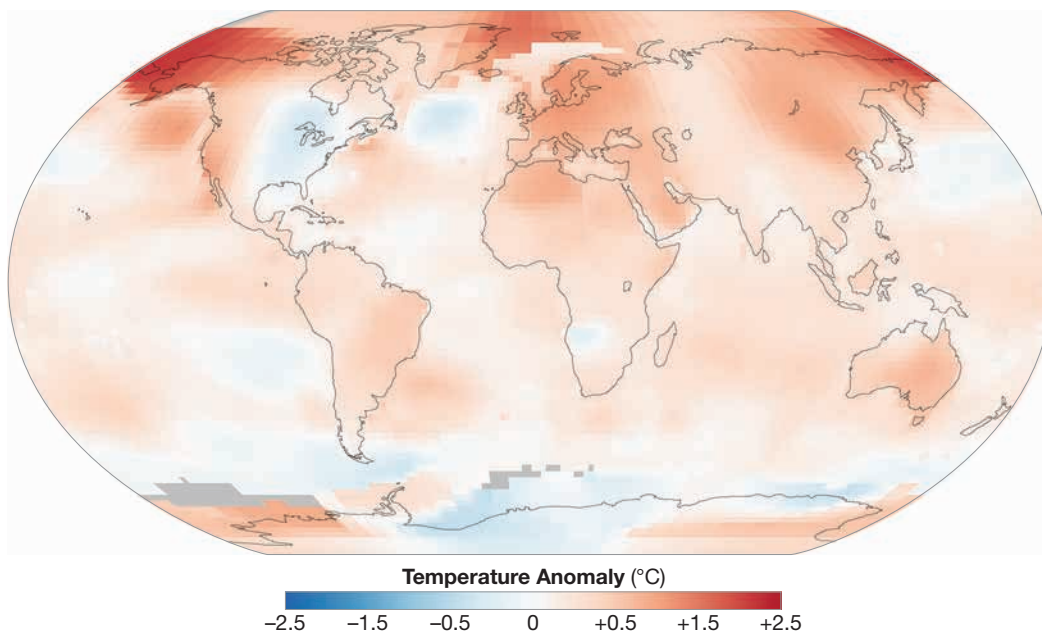
In this book we concentrate on the physical elements of the landscape, the processes involved in their development, their distribution, and their basic interrelationships. As we proceed from chapter to chapter, this notion of landscape development by natural processes and landscape modification by humans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

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

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



▲ **Figure 1-1** 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.



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

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

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

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

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

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

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

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



## The Process of Science

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

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

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

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

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

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

The acceptance of scientific ideas and theories is based on a preponderance of evidence, not on “belief” and not on the pronouncements of “authorities.” New observations

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

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

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

### LearningCheck 1-3 Why is the term “theory” sometimes misunderstood by the general public?

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

## Numbers and Measurement Systems

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

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



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

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

**Data Validity:** With VGI data, we can acquire large quantities of up-to-date information locally and quickly. *Facilitated-VGI* (f-VGI) builds upon VGI by providing a col-

lection mechanism that sets parameters as to the type and location of the data. F-VGI can also provide reliability by requiring the data to be collected on-site or by a contributor who is local to the area of interest. Reliability is further established by having multiple people submit information about a location.

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

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

VGI can also provide assistance in disaster recovery. In such *crisis mapping*, data gathered by a large number of individuals across

an impacted region can aid responders by allowing them to display and analyze the data information in near real time. During the 2015 earthquakes around Nepal, thousands of “volunteer mappers” provided humanitarian support. By digitizing the data from aerial imagery or collecting data from users on the ground and applying it to local maps, they helped fill in gaps.

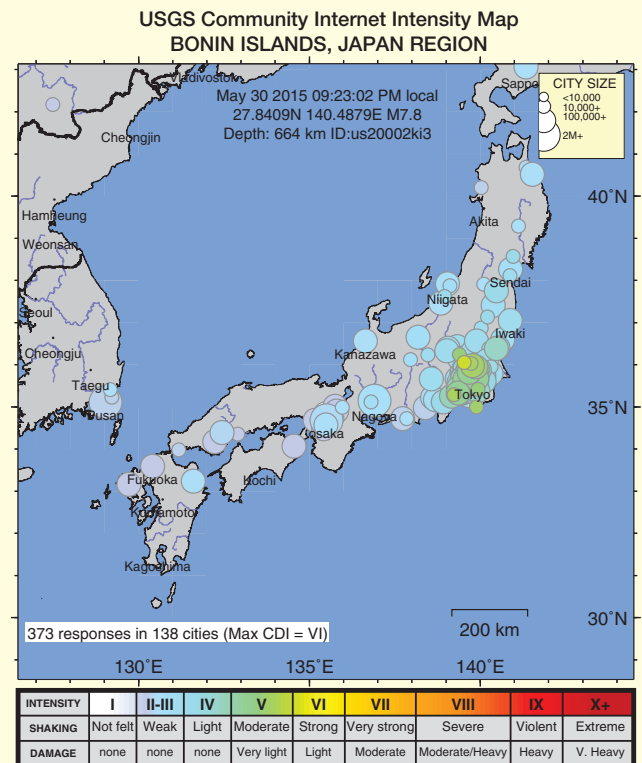
**The Future of VGI:** The ability to provide near-instant sharing of relevant geographic information is having a significant impact on those involved in geographic science. As more people become equipped with geospatially enabled devices, the notion of *citizens as sensors* will become more commonplace.

**Questions**

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



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



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

**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 $\frac{1}{2}$ inch	1 inch = about $2\frac{1}{2}$ centimeters
	1 meter = a little more than 3 feet	1 foot = about $\frac{1}{3}$ meters
	1 kilometer = about $\frac{2}{3}$ mile	1 yard = about 1 meter
<b>Volume:</b>	1 liter = about 1 quart	1 mile = about $1\frac{1}{2}$ kilometers
		1 quart = about 1 liter
		1 gallon = about 4 liters
<b>Mass:</b>	1 gram = about $\frac{1}{30}$ ounce	1 ounce = about 30 grams
	1 kilogram = about 2 pounds	1 pound = about $\frac{1}{2}$ 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.

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

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

## Environmental Spheres and Earth Systems

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

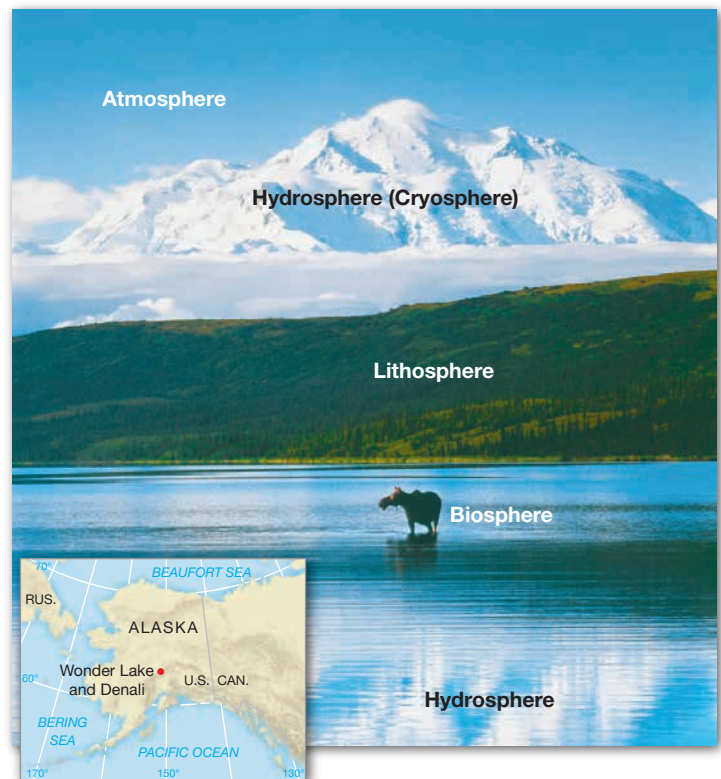
### Earth’s Environmental Spheres

The solid, inorganic portion of Earth is sometimes called the **lithosphere**<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.

The gaseous envelope of air that surrounds Earth is the **atmosphere** (*atmo* is Greek for “air”). It contains the complex mixture of gases needed to sustain life. Most of the atmosphere is close to Earth’s surface, being densest at sea

level and rapidly thinning with increased altitude. It is a very dynamic sphere, kept in almost constant motion by solar energy and Earth’s rotation.

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



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

<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.

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

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

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

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

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

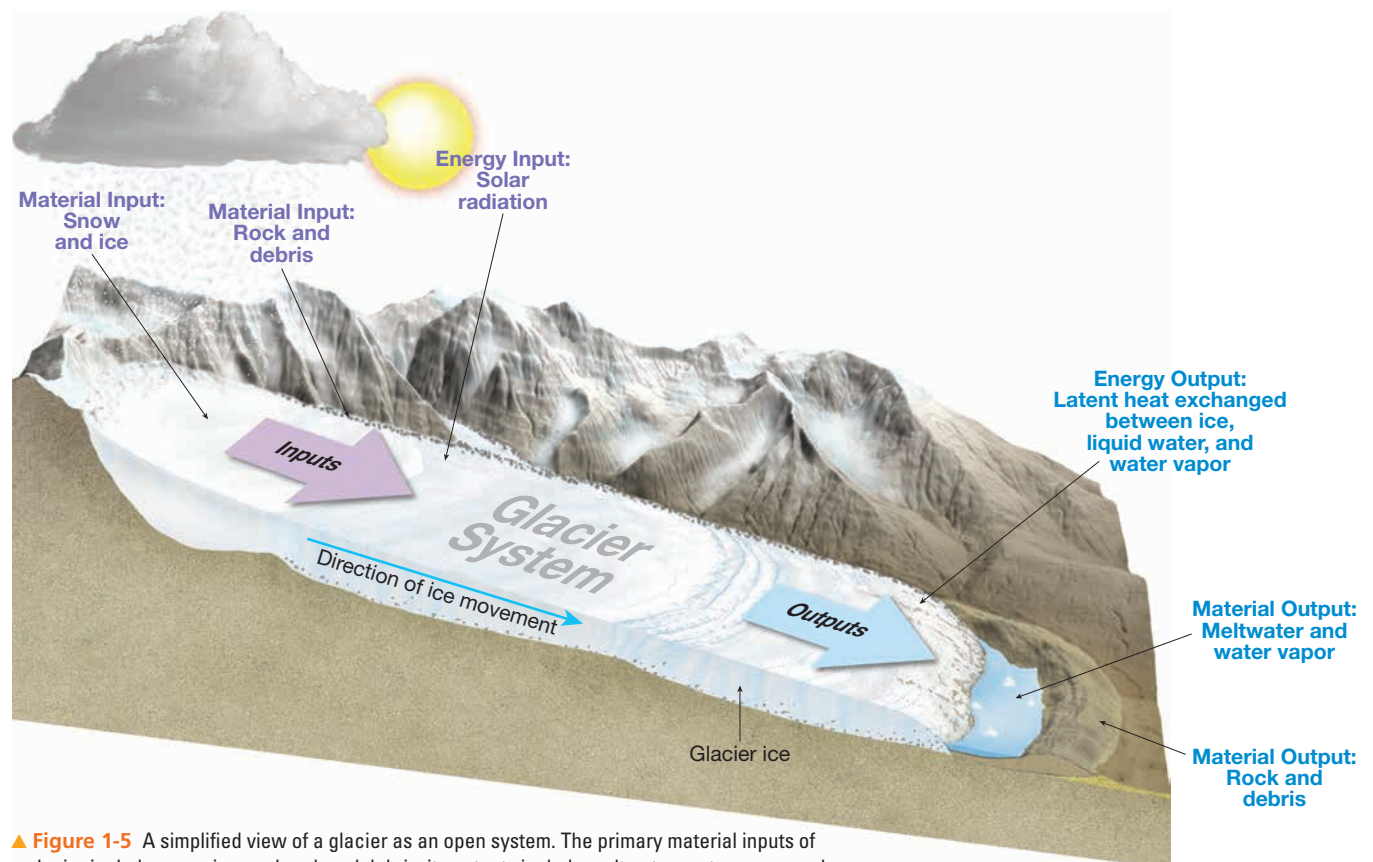
## Earth Systems

Earth’s environmental spheres operate and interact through a complex of *Earth systems*. By “system” we mean a collection of things and processes that are connected and

operate as a whole. In the human realm, for example, we talk of a global “financial system” that encompasses the exchange of money between institutions and individuals, or of a “transportation system” that involves the movement of people and commodities. In the natural world, systems entail the interconnected flows and storage of energy and matter.

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

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



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