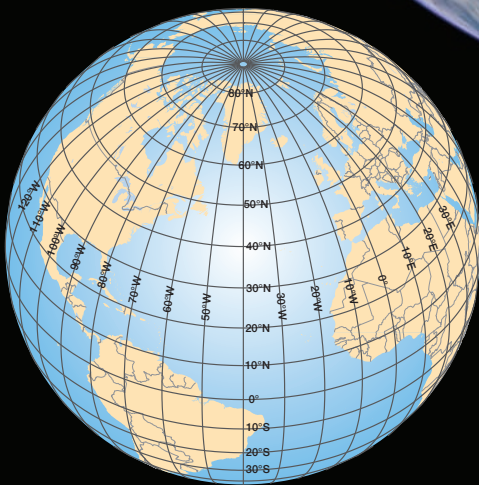
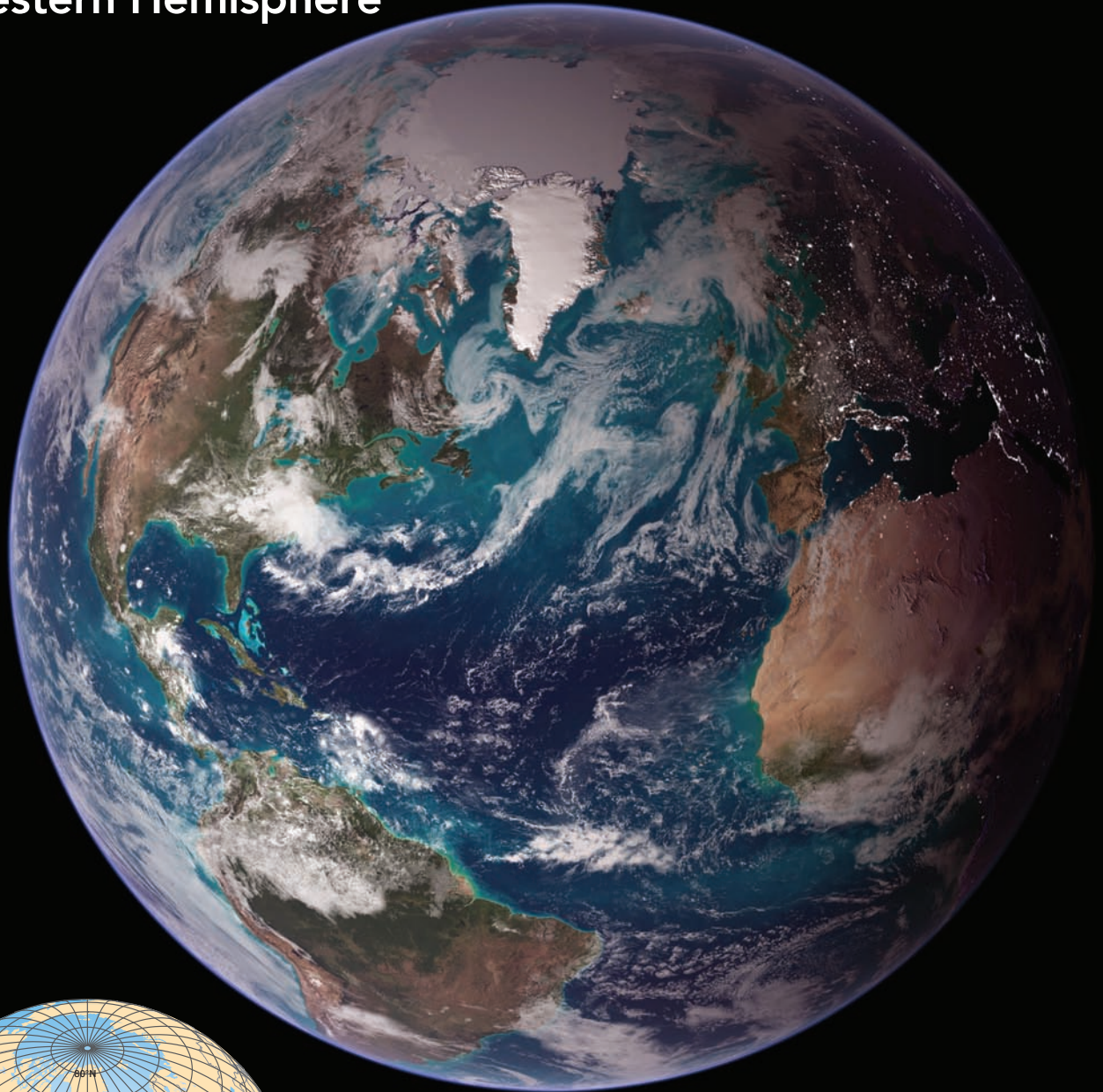


Fourth Canadian Edition

# Geosystems

**Robert W. Christopherson**  
**Ginger H. Birkeland**  
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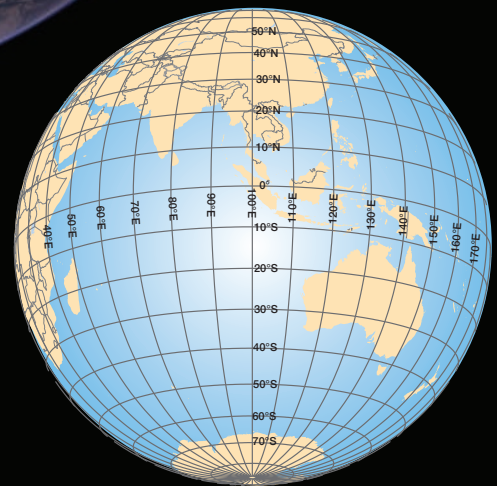
# Western Hemisphere



Multiple images from satellites *Terra*, *Aqua*, *Radarsat*, and *Defense Meteorological Satellite*, and from Space Shuttle *Endeavor*'s radar data of topography, all merge in a dramatic composite to show the Western Hemisphere and Eastern Hemisphere of Earth. What indications do you see on these images that tell you the time of year? These are part of NASA's Blue Marble Next Generation image collection.

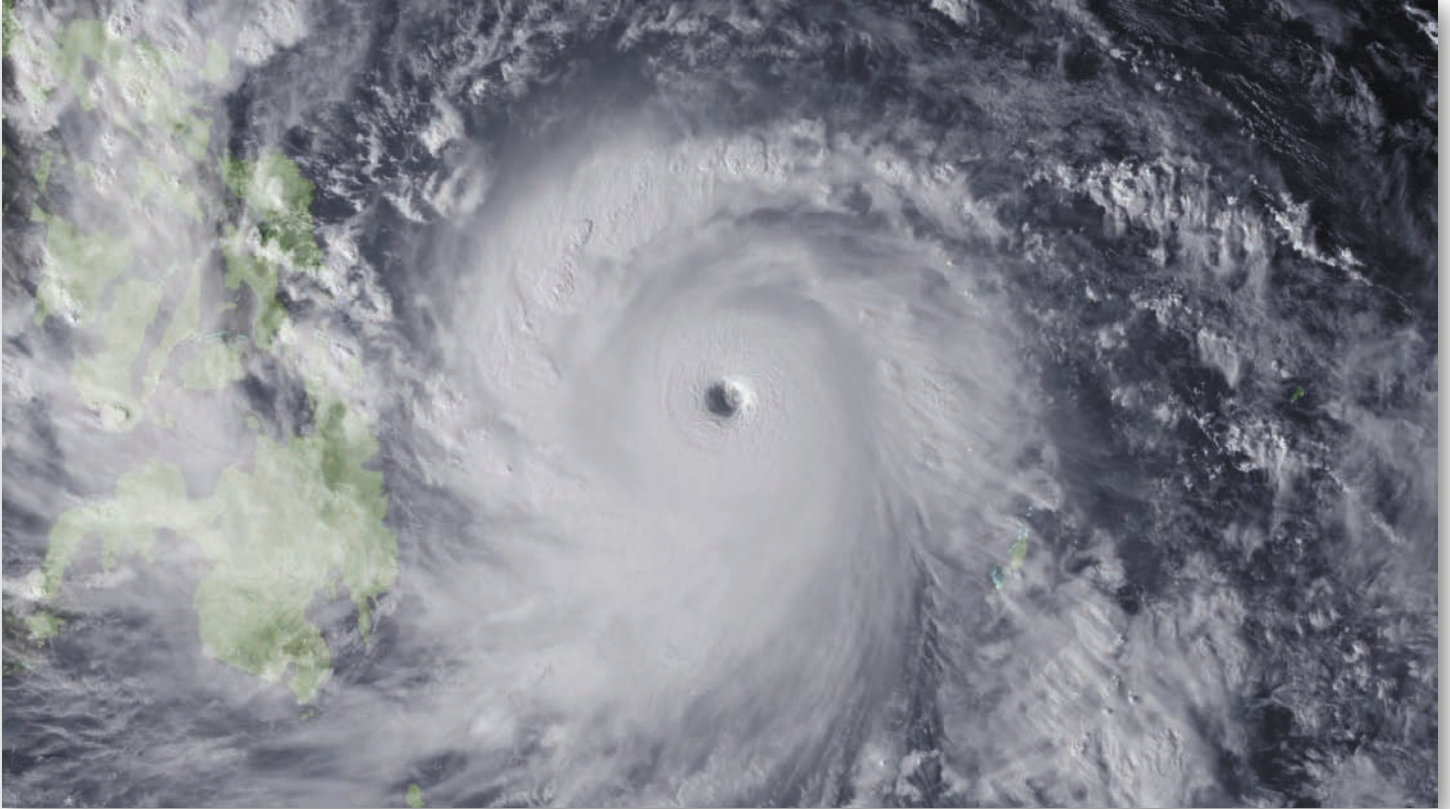
[NASA images by Reto Stöckli, based on data from NASA and NOAA.]

# Eastern Hemisphere



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# Geosystems



Super Typhoon Haiyan made landfall in the central Philippines on the morning of November 7, 2013, with sustained winds over  $306 \text{ km} \cdot \text{h}^{-1}$ , the strongest ever recorded for a tropical cyclone at landfall using satellite measurements. In *Geosystems*, we discuss tropical cyclones and other severe weather events on Earth in Chapter 8. [NOAA Forecast Systems Laboratory.]



Tanquary Fjord, Ellesmere Island, Nunavut, Canada. [Wayne Lynch/Getty Images.]

AN INTRODUCTION TO PHYSICAL GEOGRAPHY

Fourth Canadian Edition

# Geosystems

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## dedication

To the students and teachers of Earth, and  
to all the children and grandchildren, for it  
is their future and home planet.

---

*The land still provides our genesis,  
however we might like to forget that our  
food comes from dank, muddy Earth, that  
the oxygen in our lungs was recently  
inside a leaf, and that every newspaper  
or book we may pick up is made from the  
hearts of trees that died for the sake of  
our imagined lives. What you hold in your  
hands right now, beneath these words, is  
consecrated air and time and sunlight.*

—Barbara Kingsolver

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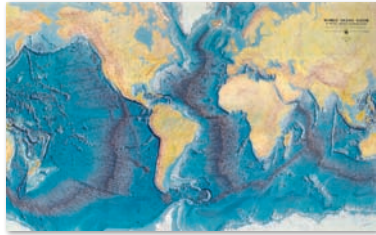
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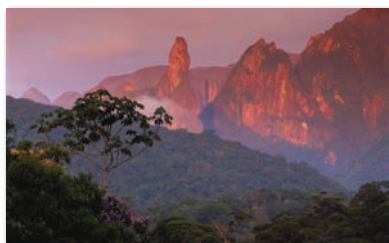
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# preface

Welcome to the Fourth Canadian Edition of *Geosystems*. This edition marks the addition of Dr. Ginger Birkeland as a coauthor to Robert Christopherson, Mary-Louise Byrne, and Philip Giles. The Fourth Canadian Edition features significant revision, with a new chapter on climate change, new features, updated content, and many new photos, maps, and illustrations. We continue to build on the success of the previous editions, as well as the companion texts, *Geosystems*, now in its Ninth Edition, and *Elemental Geosystems*, Eighth Edition. Canadian students and instructors appreciate the systems organization, scientific accuracy, integration of figures and examples specific to Canada while maintaining an international flavour throughout. The clarity of the summary and review sections, and overall relevancy to what is happening to Earth systems in real time are valued by all who use the *Geosystems*, Fourth Canadian Edition text. *Geosystems* continues to tell Earth's story in student-friendly language.

The goal of physical geography is to explain the spatial dimension of Earth's dynamic systems—its energy, air, water, weather, climate, tectonics, landforms, rocks, soils, plants, ecosystems, and biomes. Understanding human–Earth relations is part of physical geography as it seeks to understand and link the planet and its inhabitants. Welcome to physical geography!

## New to the Fourth Canadian Edition

Nearly every page of *Geosystems*, Fourth Canadian Edition, presents updated material, new Canadian and international content in text and figures, or new features. A sampling of new features includes:

- A **new chapter on climate change**. Although climate change science affects all systems and is discussed to some extent in every chapter of *Geosystems*, we now present a stand-alone chapter covering this topic—Chapter 11, Climate Change. This chapter covers paleoclimatology and mechanisms for past climatic change (expanding on topics covered in Chapter 17 in the previous edition), climate feedbacks and the global carbon budget, the evidence and causes of present climate change, climate models and projections, and actions that we can take to moderate Earth's changing climate. This new Chapter 11 expands on the climate change discussion that was formerly part of Chapter 10, Climate Systems and Climate Change, in the previous edition. Canadian content has been added, including Canada's decision to withdraw from the Kyoto Protocol in 2012.
- A new ***Geosystems in Action*** feature focusing on key topics, processes, systems, or human–Earth connections. In every chapter, *Geosystems in Action* is a one-to-two-page highly visual presentation of a topic central

to the chapter, with active learning questions and links to media in *MasteringGeography*, as well as a GeoQuiz to aid student learning. Throughout each part of the *Geosystems in Action* figure, students are asked to analyze, explain, infer, or predict based on the information presented. Topics include Earth–Sun Relations (Chapter 2), Air Pollution (Chapter 3), Earth–Atmosphere Energy Balance (Chapter 4), The Global Carbon Budget (Chapter 11), Glaciers As Dynamic Systems (Chapter 17), and Biological Activity in Soils (Chapter 18).

- A new feature, ***The Human Denominator***, that links chapter topics to human examples and applications. At the end of Chapters 2 through 20, this new feature includes maps, photos, graphs, and other diagrams to provide visual examples of many human–Earth interactions. This feature replaces and expands on the former Chapter 21 in previous *Geosystems* editions, called *Earth and the Human Denominator*.
- New and revised illustrations and maps to improve student learning. More than 250 new photos and images bring real-world scenes into the classroom. Our photo and remote sensing program, updated for this edition, exceeds 500 items, integrated throughout the text.
- New images and photos for the 20 chapter openers, and redesigned schematics and photos for the 4 part openers.
- **Learning Catalytics**, a “bring your own device” student engagement, assessment, and classroom intelligence system, integrated with *MasteringGeography*.

## Continuing in the Fourth Canadian Edition

- Twenty-two **Focus Studies**, with either updated or new content, explore relevant applied topics in greater depth and are a popular feature of the *Geosystems* texts. In this edition, these features are grouped by topic into five categories: Pollution, Climate Change, Natural Hazards, Sustainable Resources, and Environmental Restoration.

Ten new Focus Study topics include:

Heat Waves (Chapter 5)  
Hurricanes Katrina and Sandy: Storm Development and Links to Climate Change (Chapter 8)  
Thawing Methane Hydrates—Another Arctic Methane Concern (Chapter 11)  
Earthquakes in Haiti, Chile, and Japan: A Comparative Analysis (Chapter 13)  
Stream Restoration: Merging Science and Practice (Chapter 15)

Flooding in Southern Alberta in 2013 (Chapter 15)  
 The 2011 Japan Tsunami (Chapter 16)  
 Snow Avalanches (Chapter 17)  
 Wildfire and Fire Ecology (Chapter 19)  
 Global Conservation Strategies (Chapter 20)

- The chapter-opening *Geosystems Now* case study feature presents current issues in geography and Earth systems science. These original, unique essays, updated for the Fourth Canadian Edition, immediately engage readers into the chapter with relevant, real-world examples of physical geography. New *Geosystems Now* topics in this edition include Canada's December 2013 claim to extend its boundary in the Arctic to the edge of the continental shelf (Chapter 1), getting water from the air in arid climates (Chapter 7), a large-scale look at Vancouver Island's climate (Chapter 10), and the effects of proposed dams on rivers in China (Chapter 15). Many of these features emphasize linkages across chapters and Earth systems, exemplifying the *Geosystems* approach.
- *GeoReports* continue to describe timely and relevant events or facts related to the discussion in the chapter, provide student action items, and offer new sources of information. The 84 *GeoReports* in the Fourth Canadian Edition, placed along the bottom of pages, are updated, with many new to this edition. Example topics include:

Did light refraction sink the *Titanic*? (Chapter 4)  
 Yukon and Saskatchewan hold records for extreme temperatures (Chapter 5)  
 Stormy seas and maritime tragedy (Chapter 8)  
 Water use in Canada (Chapter 9)  
 Satellite GRACE enables groundwater measurements (Chapter 9)  
 Tropical climate zones advance to higher latitudes (Chapter 10)  
 Sinkhole collapse in Ottawa caused by human activities (Chapter 14)  
 Surprise waves flood a cruise ship (Chapter 16)  
 Greenland ice sheet melting (Chapter 17)  
 Overgrazing effects on Argentina's grasslands (Chapter 18)

- *Critical Thinking* exercises are integrated throughout the chapters. These carefully crafted action items bridge students to the next level of learning, placing students in charge of further inquiry. Example topics include:

Applying Energy-Balance Principles to a Solar Cooker  
 What Causes the North Australian Monsoon?  
 Identify Two Kinds of Fog  
 Analyzing a Weather Map  
 Allocating Responsibility and Cost for Coastal Hazards  
 Tropical Forests: A Global or Local Resource?

- The *Geosystems Connection* feature at the end of each chapter provides a preview “bridge” between chapters, reinforcing connections between chapter topics.

- At the end of each chapter is *A Quantitative Solution*. This feature leads students through a solution to a problem, using a quantitative approach. Formerly called *Applied Physical Geography*, several of these were expanded or updated for this edition, and a new one was added (Map Scales, in Chapter 1).
- *Key Learning Concepts* appear at the outset of each chapter, many rewritten for clarity. Each chapter concludes with *Key Learning Concepts Review*, which summarizes the chapter using the opening objectives.
- *Geosystems* continues to embed Internet URLs within the text. More than 200 appear in this edition. These allow students to pursue topics of interest to greater depth, or to obtain the latest information about weather and climate, tectonic events, floods, and the myriad other subjects covered in the book.
- The *MasteringGeography*<sup>TM</sup> online homework and tutoring system delivers self-paced tutorials that provide individualized coaching, focus on course objectives, and are responsive to each student's progress. Instructors can assign activities built around Geoscience Animations, *Encounter* “Google Earth<sup>TM</sup> Explorations”, MapMaster interactive maps, *Thinking Spatially and Data Analysis* activities, new *GeoTutors* on the most challenging topics in physical geography, end-of-chapter questions, and more. Students also have access to a text-specific Study Area with study resources, including an optional Pearson eText version of *Geosystems*, Geoscience Animations, MapMaster<sup>TM</sup> interactive maps, new videos, Satellite Loops, Author Notebooks, additional content to support materials for the text, photo galleries, *In the News* RSS feeds, web links, career links, physical geography case studies, flashcard glossary, quizzes, and more—all at [www.masteringgeography.com](http://www.masteringgeography.com).

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**From Robert:** I give special gratitude to all the students during my 30 years teaching at American River College, for it is in the classroom crucible that the *Geosystems* books were forged. I appreciate our Canadian staff at Pearson and the skilled Canadian educators that coauthored this edition, Mary-Lou Byrne and Philip Giles, who I am honoured to call my colleagues. The Canadian environment is under accelerating climate-change stress that exceeds that occurring in the lower latitudes. For this reason, *Geosystems*, Fourth Canadian Edition, takes on an important role to educate and, hopefully, provoke actions toward a slower rate of climate change and a more sustainable future.

Thanks and admiration go to the many authors and scientists who published research that enriches this work. Thanks for all the dialogue received from students and teachers shared with me through e-mails from across the globe.

I offer a special thanks to Ginger Birkeland, Ph.D., our new coauthor on this edition and previous collaborator and developmental editor, for her essential work, attention to detail, and geographic sense. The challenge of such a text project is truly met by her strengths and talents.

As you read this book, you will learn from many beautiful photographs made by my wife, photographer, and expedition partner, Bobbé Christopherson. Her contribution to the success of *Geosystems* is obvious.

**From Ginger:** Many thanks to my husband, Karl Birkeland, for his ongoing patience, support, and inspiration throughout the many hours of work on this book. I also thank my daughters, Erika and Kelsey, who endured my absence throughout a ski season and a rafting season as I sat at my desk. My gratitude also goes to William Graf, my academic advisor from so many years ago, for always exemplifying the highest standard of research and writing, and for helping transform my love of rivers into a love of science and all things geography. Special thanks to Robert Christopherson, who took a leap of faith to bring me on this *Geosystems* journey. It is a privilege to work with him.

**From Mary-Louise:** The incredible journey continues and once again I need to thank so many for their help. I owe my greatest thanks to my immediate family—my husband, Alain Pinard, and our children, Madeleine and Julianne, who continue to be curious about the world around them. To my extended family I am indebted to your honest comments and criticisms.

*Geosystems* is an amazing textbook, and I am so pleased to participate in its development. I thank all my colleagues in the geographic community in Canada who, by comment, communication, or review, helped to shape the contents of this text. I am forever indebted to Brian McCann for teaching me to look at physical processes from many perspectives and to integrate these perspectives in order to form an explanation. He is sadly missed.

To all the students with whom I had contact in 24 years of teaching at Wilfrid Laurier University, your enthusiasm and curiosity keep me focused on the goal of explaining planet Earth. I have had the pleasure of communicating with several current students from across the country that have had positive and constructive criticism about the book. I took your comments seriously and have addressed them where appropriate. It is amazing to hear from you and I encourage you to continue to communicate. To future students, our planet is in your hands: Care for it.

**From Philip:** I am very pleased and grateful to continue as part of the author team on *Geosystems*, Fourth Canadian Edition. For many years I admired the choice of content and writing style, as well as the presentation quality, in *Geosystems*. When selected to join the team for the Third Canadian Edition, it was an honour to know that I would be contributing to the preparation of this textbook which will play an important role for so many students in learning about physical geography. I knew quite early that I wanted to make physical geography my career, so to reach this stage and be playing this role as an author on a successful and influential textbook is extremely satisfying.

As an undergraduate and graduate student, one is influenced by many people. All of my course instructors and advisors helped me to learn and develop academically, and collectively they deserve recognition. In particular, like Mary-Lou, I also had the pleasure and



good fortune to have been taught and advised by Brian McCann during my time at McMaster University. Mary-Lou completed her Ph.D. while I was in the B.Sc. and M.Sc. programs at McMaster; we were both supervised by Brian for our thesis research on coastal sand dunes.

To Yvonne, my parents, and my colleagues in the Department of Geography and Environmental Studies at Saint Mary's University, thank you all for your support over the years.

Whether you are taking this course as a requirement for your major or as an elective, I hope this textbook will help you find pleasure as you develop a better understanding of the physical environment. Robert, Ginger, Mary-Lou, and I each have a deep passion for this subject and one of the goals of this book is to inspire the same passion in you, our readers.

**From all of us:** Physical geography teaches us a holistic view of the intricate supporting web that is Earth's environment and our place in it. Dramatic global change is underway in human–Earth relations as we alter physical, chemical, and biological systems. Our attention to climate change science and applied topics is in response to the impacts we are experiencing and the future we are shaping. All things considered, this is a critical time for

you to be enrolled in a physical geography course! The best to you in your studies—and *carpe diem!*

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# digital and print resources

## For Students and Teachers

**MasteringGeography** for *Geosystems* is the most effective and widely used tutorial, homework, and assessment system for the sciences. The Mastering system empowers students to take charge of their learning through activities aimed at different learning styles, and engages them in learning science through practice and step-by-step guidance—at their convenience, 24/7. MasteringGeography™ offers:

- **Assignable activities** that include Geoscience Animations, *Encounter* Google Earth™ Explorations, MapMaster™ interactive maps, *Thinking Spatially and Data Analysis* activities, *GeoTutors* on the most challenging topics in Physical Geography, end-of-chapter questions, reading questions, and more.
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**Television for the Environment Earth Report Geography Videos on DVD (0321662989)**. This three-DVD set helps students visualize how human decisions and behaviour 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-ROM (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 geology, physical geography, oceanography, meteorology, and earth science. The animations are provided as Flash files and preloaded into PowerPoint(R) slides for both Windows and Mac.

**Practicing Geography: Careers for Enhancing Society and the Environment** by Association of American Geographers (0321811151). This book examines career opportunities for geographers and geospatial professionals in 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 Association of American Geographers (0136054471). This two-part resource provides a starting point for becoming an effective geography teacher from the very first day of class. Part One addresses “nuts-and-bolts” teaching issues. Part Two explores being an effective teacher in the field, supporting critical thinking with GIS and mapping technologies, engaging learners in large geography classes, and promoting awareness of international perspectives and geographic issues.

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

## For Students

**Applied Physical Geography—Geosystems in the Laboratory, Ninth Edition (0321987284)** by Charlie Thomsen and

Robert Christopherson. A variety of exercises provides flexibility in lab assignments. Each exercise includes key terms and learning concepts linked to *Geosystems*. The ninth edition includes new exercises on climate change, a fully updated exercise on basic GIS using ArcGIS online, and more integrated media, including Google Earth and Quick Response (QR) codes. Supported by a website with media resources needed for exercises, as well as a downloadable Solutions Manual for teachers.

**Companion website for *Applied Physical Geography: Geosystems in the Laboratory*.** The website for lab manual provides online worksheets as well as KMZ files for all of the Google Earth™ exercises found in the lab manual. [www.mygeoscienceplace.com](http://www.mygeoscienceplace.com)

**Goode's World Atlas, 22nd Edition** (0321652002). *Goode's World Atlas* has been the world's premiere educational atlas since 1923—and for good reason. It features over 250 pages of maps, from definitive physical and political maps to important thematic maps that illustrate the spatial aspects of many important topics. The 22nd Edition includes 160 pages of 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 Geosystems* by Charlie Thomsen (0321636996)
- *Encounter World Regional Geography* by Jess C. Porter (0321681754)
- *Encounter Human Geography* by Jess C. Porter (0321682203)
- *Encounter Earth* by Steve Kluge (0321581296)

**Dire Predictions: Understanding Global Warming** by Michael Mann, Lee R. Kump (0133909778). Appropriate for any science or social science course in need of a basic understanding of the reports from the Intergovernmental Panel on Climate Change (IPCC). These periodic reports 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 still question the validity of climate change. In just over 200 pages, this practical text presents and expands upon the essential findings in a visually stunning and undeniably powerful way to the lay reader. Scientific findings that provide validity to the implications of climate change are presented in clear-cut graphic elements, striking images, and understandable analogies.

## For Teachers

**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*.

**Instructor Resource Manual** by Mary-Louise Byrne, Wilfrid Laurier University. Includes lecture outlines and key terms, additional source materials, teaching tips, and a complete annotation of chapter review questions.

**Computerized Test Bank** by Mary-Louise Byrne, Wilfrid Laurier University. Pearson's computerized test banks allow instructors to filter and select questions to create quizzes, tests, or homework. Instructors can revise questions or add their own, and may be able to choose print or online options. These questions are also available in Microsoft Word format.

**Lecture Outline PowerPoint™ Presentations** by Khaled Hamdan, Kwantlen Polytechnic University, outlines the concepts of each chapter with embedded art and can be customized to fit teachers' lecture requirements.

**Image Library** contains all textbook images as JPEGs for instructors to use when personalizing their PowerPoint™ Presentations.

These instructor resources are also available online via the Instructor Resources section of *MasteringGeography* and <http://catalogue.pearsoned.ca/>.

**Pearson Custom Library** For enrollments of at least 25 students, you can create your own textbook by choosing the chapters that best suit your own course needs. To begin building your custom text, visit [www.pearsoncustomlibrary.com](http://www.pearsoncustomlibrary.com). You may also work with a dedicated Pearson custom editor to create your ideal text—publishing your own original content or mixing and matching Pearson content. Contact your local Pearson representative to get started.

**Learning Solutions Managers** Pearson's Learning Solutions Managers work with faculty and campus course designers to ensure that Pearson technology products, assessment tools, and online course materials are tailored to meet your specific needs. This highly qualified team is dedicated to helping schools take full advantage of a wide range of educational resources, by assisting in the integration of a variety of instructional materials and media formats. Your local Pearson Education sales representative can provide you with more details on this service program.

# Exploring Earth's Dynamic Systems

Geosystems is organized around the natural flow of energy, materials, and information, presenting subjects in the same sequence in which they occur in nature—an organic, holistic Earth systems approach that is unique in this discipline. Offering current examples and modern science, Geosystems combines a structured learning path, student-friendly writing, current applications, outstanding visuals, and a strong multimedia program for a truly unique physical geography experience.

▼ **NEW! Chapter 11: Climate Change.** Incorporating the latest climate change science and data, this new chapter covers paleoclimatology and mechanisms for past climatic change, climate feedbacks and the global carbon budget, the evidence and causes of present climate change, climate forecasts and models, and actions that we can take to moderate Earth's changing climate.

## 11

### Climate Change



**GEOSYSTEMS**  
LOW

**KEY LEARNING**  
concepts

After reading the chapter, you should be able to:

- Describe scientific tools used to study paleoclimatology.
- Discuss several natural factors that influence Earth's climate, and describe climate feedbacks, using examples.
- List the key lines of evidence for present global climate change, and summarize the scientific evidence for anthropogenic forcing of climate.
- Discuss climate models, and summarize several climate projections.
- Describe several mitigation measures to slow rates of climate change.

In March 2013, scientists began the fifth year of Operation IceBridge, NASA's airborne, multi-instrument survey of Earth's rapidly changing polar ice. This view of Saundvik Island and Wolstenholme Fjord in northwest Greenland in April 2013 shows Arctic sea ice as air and ocean temperature warm. Thinner seasonal ice appears clearer in the foreground. Thicker multiyear ice appears whiter in the distance. Much of the Arctic Ocean is now dominated by seasonal ice, which melts rapidly every summer. Ice melt in the polar regions and at high altitudes is an important indicator of Earth's changing climate, the subject of this chapter. (NASA/Michael Studinger)

**Greenhouse Gases Awaken in the Arctic**

In the subarctic and tundra climate regions of the Northern Hemisphere, generally frozen soils and sediment, known as permafrost, cover about 24% of the land area. With Arctic air temperatures currently rising at a rate more than two times that of the midlatitudes, ground temperatures are increasing, causing permafrost thaw. This results in changes to land surfaces, primarily sinking and slumping, that damage buildings, forests, and coastlines. Permafrost thaw also leads to the decay of soil material, a process that releases vast amounts of carbon, in the form of the greenhouse gases carbon dioxide (CO<sub>2</sub>) and methane (CH<sub>4</sub>), into the atmosphere (Figure GN 11.1).

**Carbon in Permafrost Soils** Permafrost is, by definition, soil and sediment that have remained frozen for two or more consecutive years. The "active layer" is the seasonally frozen ground on top of subsurface permafrost. This thin layer of soil and sediment thaws every summer, providing substrate for seasonal grasses and other plants that absorb CO<sub>2</sub> from the atmosphere. In winter, the active layer freezes, trapping plant and animal material before it can decompose completely. Over hundreds of thousands of years, this carbon-rich material has become incorporated into permafrost and now makes up roughly half of all the organic matter stored in Earth's soils—twice the amount of carbon that is stored in the atmosphere. In terms of real numbers, the latest estimate of the amount of carbon stored in Arctic permafrost is 1550 gigatonnes (or 1550 billion tonnes).

**A Positive Feedback Loop** As summers become warmer in the Arctic, heat radiating through the ground thaws the permafrost layers. Microbial activity in these layers increases, enhancing the breakdown of organic matter. As this occurs, bacteria and other organisms release CO<sub>2</sub> into the atmosphere in a process known as microbial respiration. In anaerobic (oxygen-free) environments, such as lakes and wetlands, the process releases methane. Studies show that thousands of methane seeps can develop under a single lake, a huge amount when multiplied by hundreds of thousands of lakes across the northern latitudes (Figure GN 11.2).

Carbon dioxide and methane are major greenhouse gases, which absorb outgoing long-wave radiation and radiate it back toward Earth, enhancing the greenhouse effect and leading to atmospheric warming. Methane is especially important because, although its relative percentage is small in the atmosphere, it is over 20 times more effective than CO<sub>2</sub> at trapping atmospheric heat. Thus, a positive feedback loop forms: As temperatures rise, permafrost thaws, causing a release of CO<sub>2</sub> and CH<sub>4</sub> into the atmosphere, which causes more warming, leading to more permafrost thaw.

**Figure GN 11.1** Ice-rich permafrost melting on the Mackenzie Delta, Northwest Territories, Canada. (AP Photo/Rick Bowmer/CP Images)

**Figure GN 11.2** Methane lies under arctic lakebeds, and like natural gas, is highly flammable.

**Melting Ground Ice** In addition to frozen soil and sediment, ice, which melts as the permafrost thaws. When the supporting structure provided by the ice is removed, land surfaces collapse and slump. Subsurface soils are then exposed to sunlight, which speeds up microbial processes, and to water erosion, which moves organic carbon into streams and lakes, where it is mobilized into the atmosphere. Research suggests that this process may release bursts of CO<sub>2</sub> and CH<sub>4</sub> into the atmosphere, in contrast to the slower top-down melting of permafrost.

Permafrost soils are now warming at a rate faster than Arctic air temperatures, releasing vast amounts of "ancient" carbon into the atmosphere. Scientists are actively researching the locations and amounts of vulnerable permafrost, the current and projected rates of thaw, and the potential impacts to the permafrost-carbon positive feedback. The thawing Arctic is one of many immediate concerns we discuss in this chapter regarding the causes and impacts of changing climate on Earth systems.

Geosystems now online! Go to Chapter 11 on the MasteringGeography website ([www.masteringgeography.com](http://www.masteringgeography.com)) for more on the permafrost thaw and climate change. To learn about NASA's Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE), which measures CO<sub>2</sub> and CH<sub>4</sub> gas emissions in permafrost regions, go to [science.nasa.gov/missions/carve/](http://science.nasa.gov/missions/carve/) (the mission website) or [www.nasa.gov/topics/earth/features/020302main\\_carve.html](http://www.nasa.gov/topics/earth/features/020302main_carve.html) (mission background and early news).

► **NEW! The Human Denominator** summarizes Human-Earth relationships, interactions, challenges for the 21st century through dynamic visuals, including maps, photos, graphs, and diagrams.

## THE HUMAN DENOMINATOR 12 Earth Materials and Plate Tectonics

**ENDOGENIC PROCESSES** → HUMAN

- Endogenic processes cause natural hazards such as earthquakes and volcanic events that affect humans and ecosystems.
- Rocks provide materials for human use; geothermal power is a renewable resource.

HUMAN → **ENDOGENIC PROCESSES**

- Wells drilled into Earth's crust in association with oil.



Hydrothermal features and lava flows are common in Yellowstone National Park, Wyoming, which sits above a stationary hot spot in Earth's crust. Hydrothermal activity produces hot springs, fumaroles (steam vents), mud pots, and geysers. Grand Prismatic Spring, pictured here, is the largest hot spring in the United States, and the third largest in the world. (Edward R. Beal/RedUX.com)



The Mid-Atlantic Ridge system surfaces at Thetisfjell, Iceland, now a tourist destination. The rifts mark the divergent boundary separating the North American and Eurasian plates. (ARCTIC IMAGES/ANAP)



In April 2013, the Nevada Desert Peak Enhanced Geothermal System (EGS) became the first U.S. enhanced geothermal project to supply electricity to the power grid. (Top: Science/Alamy)



Uluru, also known as Ayers Rock, is probably Australia's best-known landmark. This steep-sided isolated sandstone feature, about 3.5 km long and 1.9 km wide, was formed from endogenic and exogenic processes, and has cultural significance for the Aboriginal peoples. (Photo: Travel/Alamy)

**ISSUES FOR THE 21ST CENTURY**

- Geothermal capacity will continue to be explored as an alternative energy source to fossil fuels.
- Mapping of tectonically active regions will continue to inform policy actions with regard to seismic hazards.

**GEOSYSTEMS CONNECTION**

We surveyed the internal structure of Earth and discussed the internal energy flow. Movement in Earth's crust results from these internal dynamics. Plate tectonics is the unifying theory that describes the lithosphere in terms of continent-sized migrating pieces of crust that can collide with other plates. Earth's present surface map is the result of these vast forces and motions. In Chapter 13, we focus more closely on the surface expressions of all this energy and matter in motion: the stress and strain of folding, faulting, and deformation; the building of mountains; and the sometimes dramatic activity of earthquakes and volcanoes.

# Visualizing Processes and Landscapes

▼ **NEW!** *Geosystems in Action* present highly-visual presentations of core physical processes and critical chapter concepts. These features include links to mobile-ready media and MasteringGeography, as well as GeoQuizzes and integrated active learning tasks that ask students to analyze, explain, infer, or predict based on the information presented.

geosystems in action 15 MEANDERING STREAMS

**15.1a PROFILE OF A MEANDERING STREAM**

The cross sections show how the location of maximum flow velocity shifts from the centre along a straight stretch of the stream channel to the outside bend of a meander. The oblique view shows how the stream erodes, or "scours," an undercut bank, or cutbank, on the outside of a bend, while depositing a point bar on the inside of the bend.

**Point bar deposition:** On a bend's inner side, stream velocity decreases, leading to deposition of sediment and forming a point bar.

**Undercut bank erosion:** Areas of maximum stream velocity (darker blue) have more power to erode, so they undercut the stream's banks on the outside of a bend.

**15.1b ACTIVE EROSION ALONG A MEANDER**

Notice how this stream in Iowa has eroded a steep cutbank on the outside of a bend.

**MasteringGeography™**

Visit the Study Area in MasteringGeography™ to explore meander and oxbow lake formation.

**Visualize:** Study a geoscientific animation of meander and oxbow lake formation. **Assess:** Demonstrate understanding of meander and oxbow lake formation (if assigned by instructor).

**15.2a STREAM MEANDERING PROCESSES**

Over time, stream meanders migrate laterally across a stream valley, eroding the outside of bends and filling the insides of bends. Narrow areas between meanders are necks. When discharge increases, the stream may scour through the neck, forming a cutoff, as seen in the photograph.

**Stream valley landscape:** A neck has recently been eroded, forming a cutoff and straightening the stream channel. The bypassed portion of the stream may become a meander scar or an oxbow lake.

**15.2b FORMATION OF AN OXBOW LAKE**

The diagrams below show the steps often involved in forming an oxbow lake; this photo corresponds to Step 2, the formation of a cutoff. As stream channels shift, these processes leave characteristic landforms on a floodplain.

**Step 1:** A narrow neck is formed where a lengthening meander loops back on itself.

**Step 2:** The neck narrows even more due to undercutting of its banks.

**Step 3:** The stream erodes through the neck, forming a cutoff.

**Step 4:** An oxbow lake forms as sediment fills the area between the new stream channel and its old meander.

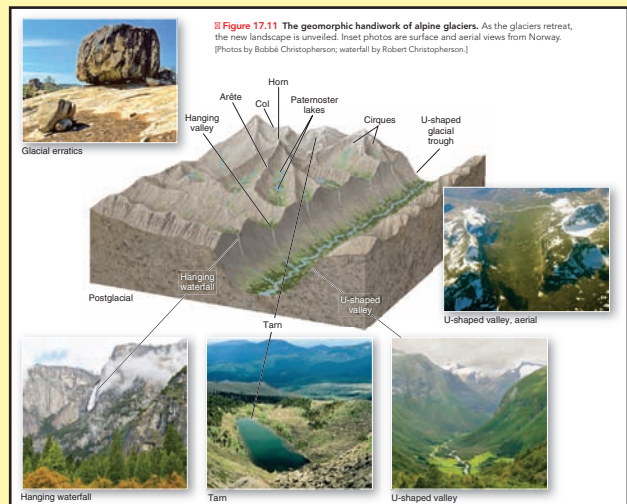
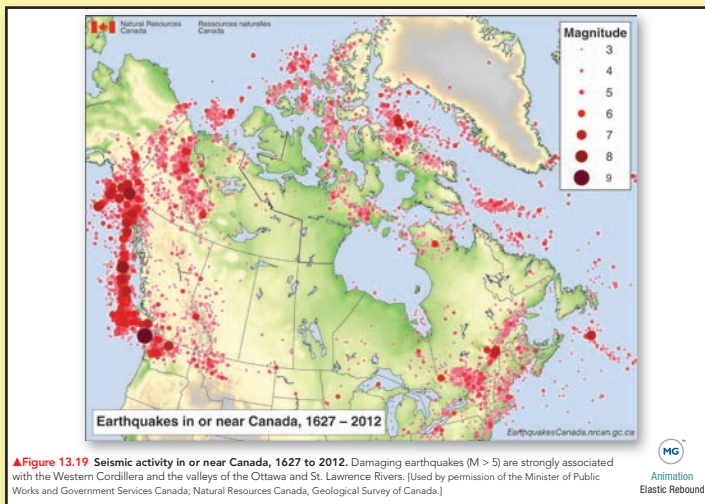
**Follow up:** In your own words, describe the sequence of steps in the process that forms an oxbow lake.

**GEOquiz**

1. Explain: Explain the processes that cause a gentle bend along a stream to become a deeply looping meander. 2. Summarize: Summarize the process by which a stream, over time, could produce the landscape in the GIA 15.2a photograph.

geosystems in action 15 MEANDERING STREAMS

An unparalleled visual program includes a variety of illustrations, maps, photographs, and composites, providing authoritative examples and applications of physical geography and Earth systems science.



# Physical Geography in the Real World

**Geosystems** integrates current real events and phenomena and presents the most thorough and integrated treatment of systems trends and climate change science, giving students compelling reasons for learning physical geography.

▼ **Geosystems Now** open each chapter with interesting, current applications of physical geography and Earth systems science. New **Geosystems Now Online** features direct students online to related resources.

▼ **Focus Studies** present detailed discussions of critical physical geography topics, emphasizing the applied relevance of physical geography today.

GEOSYSTEMS NOW

## Humans Explore the Atmosphere

**Kittinger's Record-Setting Jump** In an earlier era, before orbital flights, scientists did not know how a human could survive in space or how to produce an artificial atmosphere inside a space suit. In 1960, Air Force Captain Joseph Kittinger, Jr., stood at the opening of a small, unpressurized compartment, floating at 31.3 km altitude, dangling from a helium-filled balloon. The air pressure was barely measurable—the altitude is considered the beginning of space in experimental-aircraft testing.

Kittinger then leaped into the stratosphere void, at tremendous personal risk, for an experimental reentry into the atmosphere (Figure GN 3.2). He carried an instrument pack on his seat, his main chute, and pure oxygen for his breathing mask. Initially frightened, he heard nothing, no rushing sound, for there was not enough air to produce any sound. The fabric of his pressure suit did not flutter, for there was not enough air to create friction against the cloth. His speed was remarkable, quickly accelerating to 988 km/h—nearly the speed of sound at sea level—owing to the lack of air resistance in the stratosphere.

When his free fall reached the stratosphere and its ozone layer, the frictional drag of denser atmospheric gases slowed his body. He then dropped into the lower atmosphere, finally falling below airplane flying altitudes.

Kittinger's free fall lasted 4 minutes and 37 seconds to the opening of his main chute at 5500 m. The parachute lowered him safely to Earth's surface. This remarkable 13-minute, 35-second voyage through 99% of the atmospheric mass remained a record for 52 years.

**Recent Jumps Break the Record** On October 14, 2012, Felix Baumgartner ascended by helium balloon to 39.0 km altitude and then jumped (Figure GN 3.3). Guided by Colonel Kittinger's voice from mission control, Baumgartner survived an out-of-control spin early in his fall, reaching a top free-fall speed of 1342 km/h. Watched live online by millions around the globe, his fall lasted 4 minutes, 20 seconds—faster than Kittinger's free fall by 17 seconds.

On October 24, 2014, computer scientist Alan Eustace set a



**Figure GN 3.1** Astronaut Mark Lee, un tethered, on a working spacewalk in 1994. (NASA.)



**Figure GN 3.3** Felix Baumgartner's jump set free-fall height and speed records. Alan Eustace set a new height record in 2014. (Red Bull/Stratosurf Images.)

## Focus Study 13.1 Natural Hazards


### Tectonic Setting of the Pacific Coast of Canada

The Pacific Coast is the most seismically active region of Canada. This region is one of the few areas in the world where divergent, convergent, and transform plate boundaries occur in proximity to one another (Figure 13.1), resulting in significant earthquake activity. More than 100 earthquakes of magnitude 5 or greater (capable of causing damage) were recorded offshore in the past 75 years.

The oceanic Juan de Fuca plate, which extends from the northern tip of Vancouver Island to northern California (Figure 13.1), is moving east toward North America. The Juan de Fuca plate is sliding beneath the North American plate within the Cascadia subduction zone at a convergence rate of about 40 mm per year. Earthquake activity in this region is unusual in that instruments record few small (low magnitude) earthquakes and infrequent large magnitude events (Figure 13.1.2). A magnitude 7.3 earthquake that occurred in June 1946 on central Vancouver Island (Figure 13.1.3a) caused considerable structural damage in communities on Vancouver Island and resulted in two deaths.


Further north, in a region extending from northern Vancouver Island to Haida Gwaii (Queen Charlotte Islands), the oceanic Pacific plate is sliding northward relative to North America at a rate of 60 mm per year (Figure 13.1). The transform boundary separating the Pacific and North American plates is known as the Queen Charlotte fault, the Canadian equivalent of the San Andreas fault. A magnitude 8.1 earthquake, Canada's largest earthquake in recorded history, occurred on this fault in August 1949 (Figure 13.1.3b). Limited structural damage in mainland communities such as Prince Rupert resulted.

The Canadian and American governments have established a network of Global Positioning System (GPS) receivers to monitor the motion of the Earth's surface in response to compression and shearing occurring along convergent plate boundaries (Cascadia subduction zone) and transform plate boundaries (San Andreas fault–Queen Charlotte fault, that separates the Pacific and North American plates), respectively. The Western Canada Deformation Array (WCDA), a network of eight GPS stations in southwestern British Columbia, is linked to the Pacific Northwest Geodetic Array (PANGA), which operates in the northwestern United States. Data from these networks indicate that the Cascadia subduction zone is currently locked ([www.seismescanada.mcgill.ca/toner/westcan-eng.php](http://www.seismescanada.mcgill.ca/toner/westcan-eng.php)) and that Vancouver Island is being compressed at a rate of 10 mm per year. Earth scientists believe that the energy currently being stored along the Cascadia subduction zone will be released in a future megathrust earthquake.



**Figure 13.1.1** Plate tectonic setting of western North America. The Juan de Fuca plate is currently being subducted beneath the North American continent; the convergent plate boundary is indicated by the Cascadia subduction zone along the eastern margin of the Juan de Fuca plate. The blue arrow indicates the movement of this plate. A divergent plate boundary (indicated by green arrows) marks the western margin of the Juan de Fuca plate. This region is characterized by active volcanism and seismic activity. The San Andreas Fault–Queen Charlotte fault lies adjacent to the coastline of western North America. Blue arrows indicate movement along this fault. Seismic activity along this fault produces infrequent, large-magnitude (megathrust) earthquakes. (Reproduced with the permission of Natural Resources Canada, 2011. Courtesy of the Geological Survey of Canada.)

► **GeoReports** offer a wide variety of brief interesting facts, examples, and applications to complement and enrich the chapter reading.



### GEOREPORT 8.2 Mountains Cause Record Rains

Mount Waialeale, on the island of Kauai, Hawaii, rises 1569 m above sea level. On its windward slope, rainfall averaged 1234 cm a year for the years 1941–1992. In contrast, the rain-shadow side of Kauai received only 50 cm of rain annually. If no islands existed at this location, this portion of the Pacific Ocean would receive only an average 63.5 cm of precipitation a year. (These statistics are from established weather stations with a consistent record of weather data; several stations claim higher rainfall values, but do not have dependable measurement records.)


Cherrapunji, India, is 1313 m above sea level at 25° N latitude, in the Assam Hills south of the Himalayas. Summer monsoons pour in from the Indian Ocean and the Bay of Bengal, producing 930 cm of rainfall in one month. Not surprisingly, Cherrapunji is the all-time precipitation record holder for a single year, 2647 cm, and for every other time interval from 15 days to 2 years. The average annual precipitation there is 1143 cm, placing it second only to Mount Waialeale.

Record precipitation occurrences in Canada exist for locations along the Pacific Coast, on the windward side of the mountains. Henderson Lake, on Vancouver Island, is the wettest location in Canada, with an average annual precipitation of 666 cm.



### GEOREPORT 13.3 Large Earthquakes Affect Earth's Axial Tilt

Scientific evidence is mounting that Earth's largest earthquake events have a global influence. Both the 2004 Sumatran–Andaman quake and the 2011 Tohoku quake in Japan caused Earth's axial tilt to shift several centimetres. NASA scientists estimate that the redistribution of mass in each quake shortened daylength by 6.8 millionths of a second for the 2004 event and 1.8 millionths of a second for the 2011 event.



### GEOREPORT 20.2 Plant Communities Survive under Glacial Ice

Glacial retreat has exposed communities of bryophytes that lived 400 years ago, during the warmer interglacial period known as the Little Ice Age. Recently, scientists collected and dated samples of these communities in the Canadian Arctic. They also successfully cultured the plants in a laboratory, using a single cell of the exhumed material to regenerate the entire original organism. Thus, bryophytes can survive long periods of burial under thick glacial ice, and under the right conditions, potentially recolonize a landscape after glaciation.

# Tools for Structured Learning

Geosystems provides a structured learning path that helps students achieve a deeper understanding of physical geography through active learning.

## KEY LEARNING concepts

After reading the chapter, you should be able to:

- **Sketch** a basic drainage basin model, and **identify** different types of drainage patterns by visual examination.
- **Explain** the concepts of stream gradient and base level, and **describe** the relationship between stream velocity, depth, width, and discharge.
- **Explain** the processes involved in fluvial erosion and sediment transport.
- **Describe** common stream channel patterns, and **explain** the concept of a graded stream.
- **Describe** the depositional landforms associated with floodplains and alluvial fan environments.
- **List** and **describe** several types of river deltas, and **explain** flood probability estimates.

► A *Quantitative Solution* at the end of each chapter leads students through an exercise by using a quantitative approach to solve a problem.

▼ *Key Learning Concepts Review* at the end of each chapter concludes the learning path and features summaries, narrative definitions, a list of key terms with page numbers, and review questions.

## KEY LEARNING concepts review

- **Sketch** a basic drainage basin model, and **identify** different types of drainage patterns by visual examination.

**Hydrology** is the science of water and its global circulation, distribution, and properties—specifically, water at and below Earth's surface. **Fluvial** processes are stream-related. The basic fluvial system is a **drainage basin**, or **watershed**, which is an open system. **Drainage divides** define the catchment (water-receiving) area of a drainage basin. In any drainage basin, water initially moves downslope in a thin film of **sheetflow**, or **overland flow**. This surface runoff concentrates in **rills**, or small-scale downhill grooves, which may develop into deeper **gullies** and a stream course in a valley. High ground that separates one valley from another and directs sheetflow is an **interfluvium**. Extensive mountain and highland regions act as **continental divides** that separate major drainage basins. Some regions, such as the Great Salt Lake Basin, have **internal drainage** that does not reach the ocean, the

only outlets being evaporation and subsurface gravitational flow.

**Drainage density** is determined by the number and length of channels in a given area and is an expression of a landscape's topographic surface appearance. **Drainage pattern** refers to the arrangement of channels in an area as determined by the steepness, variable rock resistance, variable climate, hydrology, relief of the land, and structural controls imposed by the landscape. Seven basic drainage patterns are generally found in nature: dendritic, trellis, radial, parallel, rectangular, annular, and deranged.

- hydrology (p. 454)
- fluvial (p. 454)
- drainage basin (p. 454)
- sheetflow (p. 455)
- continental divide (p. 455)
- internal drainage (p. 457)
- drainage density (p. 458)
- drainage pattern (p. 458)

► *Geosystems Connection* at the end of chapters help students bridge concepts between chapters, reminding them where they have been and where they are going.

## GEOSYSTEMSconnection

While following the flow of water through streams, we examined fluvial processes and landforms and the river-system outputs of discharge and sediment. We saw that a scientific understanding of river dynamics, floodplain landscapes, and related flood hazards is integral to society's ability to perceive hazards in the familiar environments we inhabit. In the next chapter, we examine the erosional activities of waves, tides, currents, and wind as they sculpt Earth's coastlines and desert regions. A significant portion of the human population lives in coastal areas, making the difficulties of hazard perception and the need to plan for the future, given a rising sea level, important aspects of Chapter 16.



## Key Learning Concepts

at the beginning of every chapter help students identify the key knowledge and skills they will acquire through study of the chapter.

## A Quantitative SOLUTION Flood Frequency Analysis

The degree to which any phenomenon is a hazard depends on its magnitude and its frequency of occurrence. The frequency with which a flood of a certain magnitude or higher can be expected to occur is called its recurrence interval. Recurrence intervals can be determined wherever long-term river-gauging records are available, and are given by the formula:

$$T_r = \frac{(n + 1)}{m}$$

where  $T_r$  is the recurrence interval,  $n$  is the number of years of record, and  $m$  is the number of floods of the given magnitude or higher during the years of record.

Table AQS 15.1 shows peak discharges for a river-gauging station for a period of record from 1980 to 2009. Note that each annual peak discharge is independent of other values in the table. The peak in one year does not influence the peak value in the next year.

If we want to calculate the recurrence of a flood of magnitude  $425 \text{ m}^3 \text{ s}^{-1}$  or higher, for example, we note in Table AQS 15.1 that  $\text{m}^3 \text{ s}^{-1}$  was exceeded four times in the 30-year period.

$$T_{425} = \frac{(30 + 1)}{4} \\ = 7.75 \\ = 7.8 \text{ years}$$

Statistically, we then expect a flood of magnitude  $425 \text{ m}^3 \text{ s}^{-1}$  (or higher) to occur on average once every 7 to 8 years. On average is emphasized, as it is incorrect to expect a flood of this magnitude or higher to occur on a regular cycle of once every 7 to 8 years. Sometimes the interval between floods of this magnitude or higher will be shorter than 7 to 8 years, and sometimes it will be longer. A recurrence interval cannot be used to predict when a flood of a certain magnitude will occur in the future.

The relationship can also be expressed as the probability of a flood of given magnitude occurring in any given year ( $P_r$ ). This is the reciprocal of the recurrence interval, expressed as a percentage:

$$P_{425} = \frac{m}{(n + 1)} \times 100 \\ = \frac{4}{31} \times 100 \\ = 12.9\%$$

For this river, based on these data, there is a 12.9% chance of a flood of magnitude  $425 \text{ m}^3 \text{ s}^{-1}$  or higher occurring in any given year.

TABLE AQS 15.1 Peak Discharges for a River, 1980–2009

Year	Peak Discharge ( $\text{m}^3 \text{ s}^{-1}$ )	Year	Peak Discharge ( $\text{m}^3 \text{ s}^{-1}$ )	Year	Peak Discharge ( $\text{m}^3 \text{ s}^{-1}$ )
1980	113	1990	227	2000	119
1981	71	1991	2407	2001	241
1982	170	1992	411	2002	112
1983	212	1993	198	2003	311
1984	85	1994	255	2004	184
1985	42	1995	311	2005	198
1986	297	1996	113	2006	991
1987	57	1997	595	2007	71
1988	1770	1998	212	2008	28
1989	57	1999	227	2009	283

▼ *Critical Thinking Activities* integrated throughout chapter sections give students an opportunity to stop, check, and apply their understanding.



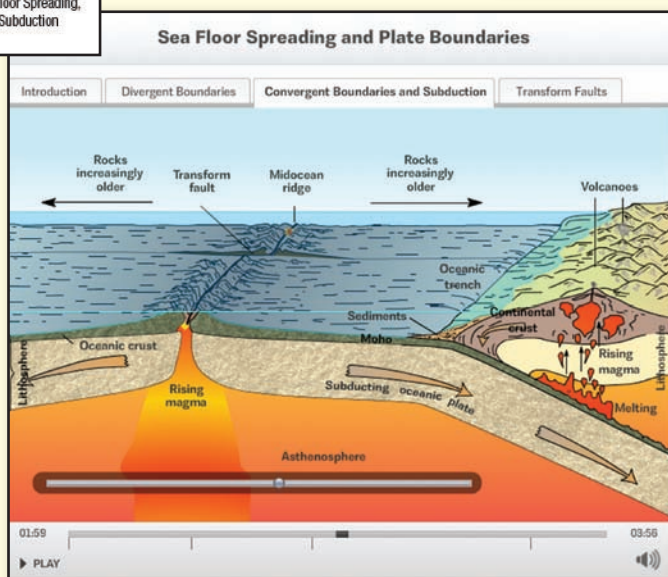
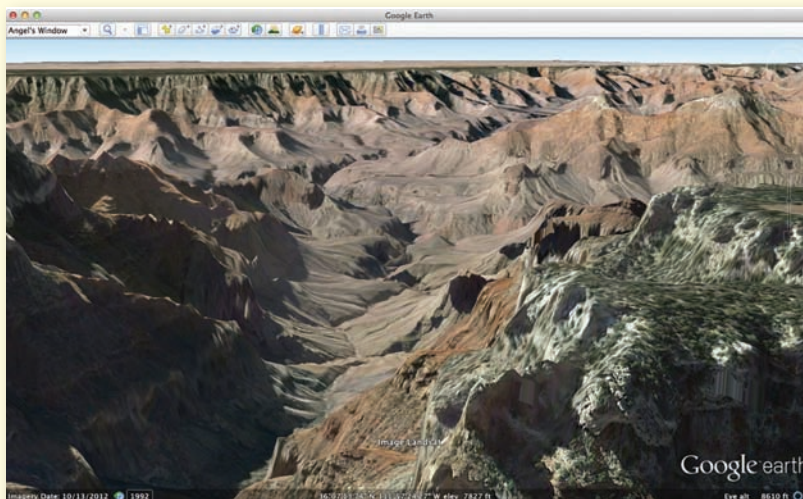
## CRITICALthinking 15.1 Locate Your Drainage Basin

Determine the name of the drainage basin within which your campus is located. Where are its headwaters? Where is the river's mouth? Use Figure 15.3 to locate the larger drainage basins and divides for your region, and then take a look at this region on Google Earth™. Investigate whether any regulatory organization oversees planning and coordination for the drainage basin you identified. Can you find topographic maps online that cover this region? ●

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

## Visualize the Processes and Landscapes That Form Earth’s Physical Environment

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



◄ **Geoscience Animations** illuminate the most difficult-to-visualize topics from across the physical geosciences, such as solar system formation, hydrologic cycle, plate tectonics, glacial advance and retreat, global warming, etc. Animations include audio narration, a text transcript, and assignable multiple-choice quizzes with specific wrong-answer feedback to help guide students toward mastery of these core physical process concepts. Icons integrated throughout the text indicate to students when they can login to the Study Area of MasteringGeography to access the animations.



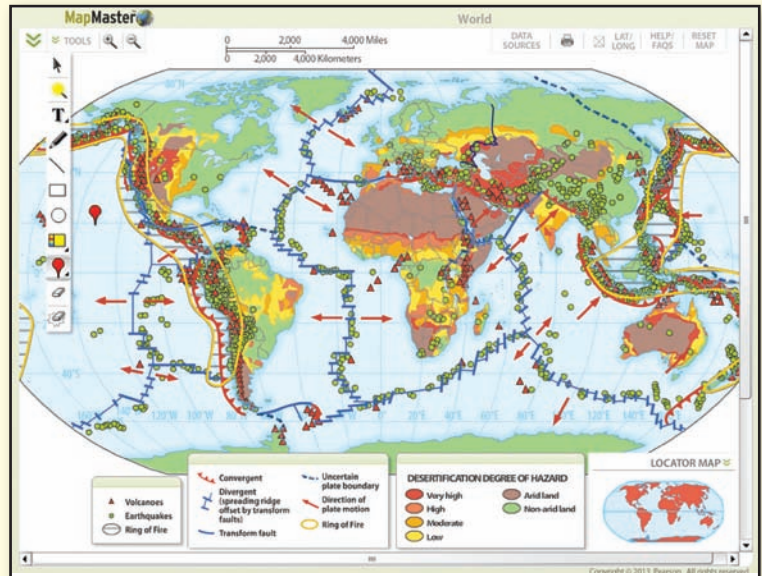


## Engage in Map Reading, Data Analysis, and Critical Thinking

**MapMaster™** is a powerful tool that presents assignable layered thematic and place name interactive maps at world and regional scales for students to test their geographic literacy, map reading, data analysis, and spatial reasoning skills.

► **MapMaster Layered Thematic Interactive Map Activities** allow students to layer various thematic maps to analyze spatial patterns and data at regional and global scales. Available with assignable and customizable multiple-choice and short-answer questions organized around the textbook topics and concepts. This GIS-like tool includes zoom and annotation functionality, with hundreds of map layers leveraging recent data from sources such as NOAA, NASA, USGS, U.S. Census Bureau, United Nations, CIA, World Bank, and the Population Reference Bureau.

▼ **Thinking Spatially & Data Analysis and NEW GeoTutor Activities** help students master the toughest geographic concepts and develop both spatial reasoning and critical thinking skills. Students identify and label features from maps, illustrations, graphs, and charts, examine related data sets, and answer higher-order conceptual questions, which include hints and specific wrong-answer feedback.



**Part B - Ingredients for Mass Movement**

The various types of mass movements are different in terms of the materials they constitute, and this difference results in a unique mark on the landscape for each type. You will label the five type of mass wasting in terms of the materials they carry.

Drag the appropriate labels to their respective targets. Each label will be used only once.

Unconsolidated sediments along a curved surface	Loose sediments with soil and plants on top	Sandstone layer above a clay layer	Boulders on a rocky cliff	Sometimes ash
---	---	------------------------------------	---------------------------	---------------

Slump	Slide	Flow	Creep	Fall
Material	Material	Material	Material	Material
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>

Submit Hints My Answers Give Up Review Part

▼ **Videos** provide students with a sense of place and allow them to explore a range of locations and topics. Covering physical processes and critical issues such as climate and climate change, renewable energy resources, economy and development, culture, and globalization, these video activities include assignable questions, with many including hints and specific wrong-answer feedback.

### Student Study Area Resources in MasteringGeography:

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



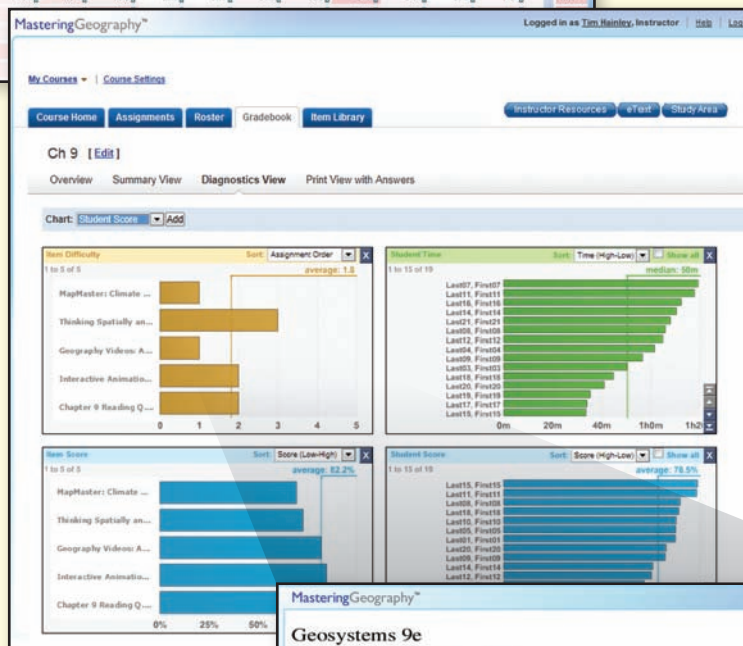
# MasteringGeography™

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

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

NAME	Intro.d.gy	Ch 2	Ch 3	Lab 2	Ch 4	Ch 5	Ch 6	Ch 7a	Chapter 7b	Lab 4	Ch 8	Ch 9	Ch 12	TOTAL
Class Average	76.4	66.0	62.6	68.1	69.5	66.7	61.6	63.7	60.0	68.4	77.7	71.4	72.5	68.9
Last01, First01...	84.4	73.3	83.3	100	89.9	0.0	95.8	101	100	0.0	87.4	46.9	26.2	26.2
Last02, First02...	70.3	64.9	83.9	88.0	49.5	66.2	72.9	47.5	80.8	86.9	66.3	27.0	27.0	27.0
Last03, First03...	71.6	48.0	61.9	104	102	84.8	66.0	106	95.6	99.7	87.3	30.3	30.3	30.3
Last04, First04...	72.5	53.6	0.0	34.3	68.3	65.3	60.0	63.4	60.0	99.2	67.6	31.9	31.9	31.9
Last05, First05...	78.8	69.3	78.6	89.0	97.0	95.2	62.5	34.6	95.0	98.3	67.7	31.9	31.9	31.9

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



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

**Geosystems 9e**

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

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

ANSWER:

- Ethiopia
- India
- China
- Yemen
- Uganda

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

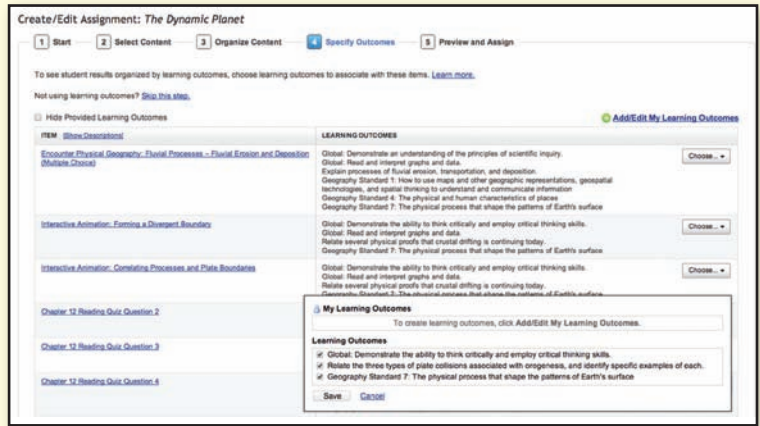
Wrong Answers for MBDEMOGRADES

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

## Learning Outcomes

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

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



NEW!

## Easy to customize

Customize publisher-provided items or quickly add your own. MasteringGeography makes it easy to edit any questions or answers, import your own questions, and quickly add images, links, and files to further enhance the student experience. Upload your own video and audio files from your hard drive to share with students, as well as record video from your computer's webcam directly into MasteringGeography—no plugins required. Students can download video and audio files to their local computer or launch them in Mastering to view the content.



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 or standalone.

# 18

## The Geography of Soils



**KEY LEARNING CONCEPTS**

After reading the chapter, you should be able to:

- Define soil and soil science, and list four components of soil.
- Describe the principal soil-formation factors, and describe the horizons of a typical soil profile.
- Describe the physical properties used to classify soils: colour, texture, structure, cohesiveness, porosity, and soil moisture.
- Explain basic soil chemistry, including cation-exchange capacity, and relate these concepts to soil fertility.
- Discuss human impacts on soils, including desertification.
- Describe the principal pedogenic processes that lead to the formation of soils under different environmental conditions.
- Describe the Global Index of the Canadian System of Soil Classification, and explain the general occurrence of these orders.

### Desertification: Declining Soils and Agriculture in Earth's Drylands

On September 2012, on the edge of the Gobi Desert in the town Mingyite, Inner Mongolia Province of China, a group of ecologists planted the millionth tree in an attempt to fight desertification. The degradation of drylands is a major environmental problem, and desertification is the most serious threat to the world's food security. In 2002, a global assessment found that a private corporation since 2002 plants trees linearly from the sea to the Pacific, or perhaps, moisture water availability for growth, and reduces constraints about the importance of trees for preventing erosion, protecting regions, and testing carbon dioxide by the sea, in the Sahelian Desert of central Asia, where global trees are declining with ongoing drought (Figure 18.1).

Desertification is defined by the United Nations (UN) as “the persistent degradation of dryland ecosystems by human activities and climate change.” This process along the margins of arid and semi-arid lands is caused in part by human abuse of soil structure and fertility—one of the subjects of this chapter (see a map of global desertification risk in Figure 18.2).

**Central Asia** Throughout the world, the combination of soil erosion combined with drought in the Aral Sea, formerly one of the world's largest lakes, has led to the steady shrink in size since the 1960s, when steadily more were dammed for irrigation (see Figure 18.2). In the end of this chapter, the sediment and what that can do for the future may lead to have become available for water pollution, leading to massive dust storms. This sediment combined fertilizers and other pollutants from agricultural runoff, as the population and demand for the land has caused crop drought and human health problems, including neurological diseases.

**Africa's Sahel** In Africa, the Sahel is the transitional zone between the Sahara Desert and the tropical rain forests. The world's largest expanse of desert conditions through portions of the Sahel region has left many African people on the edge of their existence (see Figure 18.2). The climate change is only part of the story. Other factors contributing to desertification in the Sahel are population pressure, land degradation, and overgrazing. The combination of overgrazing, deforestation, and the lack of a secure environmental policy.

**A. Drought** Problem: The UN estimates that degraded lands include more than 1.5 billion hectares and affect 1.5 billion people. Because of soil erosion, many millions of additional people are added each year. The primary cause of desertification is overgrazing, unsustainable agricultural practices, and forest removal. However, desertification is

Pearson eText gives students access to *Geosystems Fourth Canadian Edition* whenever and wherever they can access the Internet. The eText pages look exactly like the printed text, and include powerful interactive and customization functions. Users can create notes, highlight text in different colors, create bookmarks, zoom, click hyperlinked words and phrases to view definitions, and view as a single page or as two pages. Pearson eText also links students to associated media files, enabling them to view an animation as they read the text, and offers a full-text search and the ability to save and export notes. The Pearson eText also includes embedded URLs in the chapter text with active links to the Internet.

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# Geosystems

# 1

# Essentials of Geography



## KEY LEARNING concepts

After reading the chapter, you should be able to:

- **Define** geography in general and physical geography in particular.
- **Discuss** human activities and human population growth as they relate to geographic science, and **summarize** the scientific process.
- **Describe** systems analysis, open and closed systems, and feedback information, and **relate** these concepts to Earth systems.
- **Explain** Earth's reference grid: latitude and longitude and latitudinal geographic zones and time.
- **Define** cartography and mapping basics: map scale and map projections.
- **Describe** modern geoscience techniques—the Global Positioning System (GPS), remote sensing, and geographic information systems (GIS)—and **explain** how these tools are used in geographic analysis.

A snow avalanche roars down mountain slopes at Rogers Pass in Glacier National Park in the Selkirk Mountains, British Columbia. Between 1885 and 1950, nearly one hundred lives were lost in the pass due to avalanches burying the Canadian Pacific railway line. In 1910, 58 railway workers died in Rogers Pass in Canada's largest avalanche incident. This tragedy, previous deaths, and difficulties Canadian Pacific was having with the steep grade led to digging tunnels through the mountains for the railway (the Connaught Tunnel opened in 1916 and the Mount Macdonald Tunnel opened in 1988). When the Trans-Canada Highway was built through the pass from 1956-1962, static defences against avalanches were constructed, such as earth mounds, dykes and snowsheds. In addition, snow and avalanche observations began and the world's largest mobile avalanche control program using live artillery was established between Parks Canada and the Canadian Armed Forces in order to keep the Trans-Canada Highway and Canadian Pacific Railway corridor open and safe during winter. Potentially unstable snowpacks that threaten the transportation corridor are dislodged before they reach critical status by using a 105 mm C-3 Howitzer. [J. Bradford White/Alpenstock.]

## Canada's Borders, Not Just Lines on a Map

Canada is often called the land “north of the 49th” parallel, which marks the international boundary between Canada and the United States from Lake of the Woods at the Manitoba–Ontario border, westward to British Columbia (Figure GN 1.1). However, the 49th parallel is not the international boundary in eastern North America, where the border dips southward in Ontario to 41° 41' N, roughly splits the Great Lakes, and then winds around the New England states on through to the Bay of Fundy.

How did this become the southern border? What is its geographic significance and how is it maintained? Because there is no single natural feature that clearly marks the boundary between Canada and the United States, the eastern part of the border was negotiated and documented by treaty in the

1700s as land was settled by Europeans. Importantly, in all the editions of *Geosystems* since 1992, the author prepared maps with both countries presented, since the environment does not abruptly change at the unnatural U.S.–Canadian boundary!

With continued westward movement, following the lead of hunters and trappers trekking into the interior, the need arose for a boundary to separate British territories to the north from the new country to the south. As European settlements moved westward, various treaties were negotiated between Great Britain, on behalf of Canada, and the United States.

The 49th parallel in western North America was first referenced in Hudson Bay Company documents at the beginning of the 18th century. Westward U.S. expansion pressed the need for a clearly marked border. The “Convention of 1818” began the resolution of Canada–United States border issues and specified that the 49th parallel from Lake of the Woods to the Strait of Georgia would serve as the border. However, in 1844 the United States made claims to territory west of the Rockies, placing the border of the Oregon Territory at 54° 40' N. Britain countered with a desire to set the boundary along the Columbia River instead. The 49th parallel became the compromise location in 1846 with the Oregon Treaty.

The International Boundary Commission (IBC) was established in 1908 and made a permanent organization in 1925, although some 20 treaties and agreements preceded this commission. The International Boundary Commission Act, passed in Canada in 1960 and recognised by the United States, firmly established not only the boundary, but the government agencies on each side of the border that maintained it. The act was necessary because of deterioration of boundary markers that had been erected in the first half of the 19th century. Today, in each country, a commissioner serves as a ministerial chief to oversee staff, equipment, and budgets.

In Canada, this commissioner reports to the Minister for Foreign Affairs, and in the United States, the commissioner reports to the Secretary of State. The Canadian Boundary Commission is in the Surveyor General Branch of the

Department of Natural Resources. Essentially, commissioners of the IBC are charged with:

- Inspecting the border;
- Repairing and rebuilding monuments and placing new monuments;
- Keeping “boundary vistas” open; nearly 2200 km is forested;
- Regulating all construction within 3 m of the boundary;
- Defining the boundary in any legal situation involving the border;
- Implementing an operational GIS in support of IBC operations.

When you walk along most segments of this border you notice that there is no physical barrier. Instead, thousands of markers, or buoys when the boundary is in water, are set to make the boundary a visible reference line. The IBC guides boundary-marker placement on the advice of geospatial surveys. This is part of the longest nonmilitarised border in the world and Canada’s only land border with another country—an incredible line some 6416 km in total length (2878 km on land and 3538 km in water), of which 3013 km lie along the 49th parallel. The border with Alaska adds another 2475 km to the total; together these are Canada’s only land borders with another country. On a map of North America, find the Strait of Juan de Fuca and Passamaquoddy Bay, respectively, the western and eastern ends of this boundary. Note the vast distance traversed by this line.

The work of geographers is important when it comes to demarcating the border. There are over 8000 monuments and reference points to inspect and maintain. Each is tied into 1000 survey control points that allow accurate mapping and location of the border. Physically maintaining the border markers and buoys is a continuing challenge. Portions of the international border fall in waterways such as the St. Croix River (Figure GN 1.2).

In the Arctic, Canada presently has an exclusive economic zone extending 370 km from land masses, but in December 2013 a claim was submitted to the United Nations to extend its boundaries westward to the edge of the continental shelf in the Arctic Ocean ([www.international.gc.ca/arctic-arctique/continental/summary-resume.aspx?lang=eng](http://www.international.gc.ca/arctic-arctique/continental/summary-resume.aspx?lang=eng)).



▲Figure GN 1.1 Typical border marker. The Canada–U.S. border along the 49th parallel. [David R. Frazier Photolibrary, Inc./Alamy]



▲ **Figure GN 1.2** Canada–U.S. border along the St. Croix River. (a) The border separating New Brunswick and Maine includes a section that follows the course of the St. Croix River. (b) Ferry Point International Bridge crosses the St. Croix River between St. Stephen, New Brunswick (left), and Calais, Maine (right). The international border is approximately midchannel. [Fred J. Field.]

This application was made based on the UN Convention on the Law of the Sea. The claim will not result in a new boundary for many years, as other nations—United States, Russia, and Denmark—also have interests in the

Arctic seafloor and its resources. Accessing resources on the seafloor would be a monumental challenge, but establishing sovereignty is the current goal of the Canadian government.

**GEOSYSTEMS NOW ONLINE** To learn more about the Canada–U.S. border and the work of the International Boundary Commission in demarcating it, go to [www.internationalboundarycommission.org/index-eng.html](http://www.internationalboundarycommission.org/index-eng.html).

MG

Welcome to the Fourth Canadian Edition of *Geosystems* and the study of physical geography! In this text, we examine the powerful Earth systems that influence our lives and the many ways humans impact those systems. This is an important time to study physical geography, learning about Earth's environments, including the systems that form the landscapes, seascapes, atmosphere, and ecosystems on which humans depend. In this second decade of the 21st century, a century that will see many changes to our natural world, scientific study of the Earth and environment is more crucial than ever.

Consider the following events, among many similar ones we could mention, and the questions they raise for the study of Earth's systems and physical geography. This text provides tools for answering these questions and addressing the underlying issues.

- In June 2013, devastating floods hit southern Alberta, affecting one-quarter of the province. Several communities were placed under forced evacuation orders (Figure 1.1), and others were isolated for days. Parts of downtown Calgary were under water, and railway lines and roads were washed out. Environment Canada described the event as a super flood that is one of Canada's costliest natural disasters, with projected losses over 6 billion dollars. What sequence of preceding weather

conditions caused the flooding? How have residents and the government dealt with the aftermath? More about this event is found in *Geosystems Now* in Chapter 15, Focus Study 15.2.

- In October 2012, Hurricane Sandy made landfall along the U.S. East Coast, hitting New York and



▲ **Figure 1.1** Evacuation in High River, Alberta. Flooding on the Highwood River in June 2013 forced residents out of their homes and cost millions of dollars. [Lyle Aspinall/Calgary Sun/QMI Agency.]



New Jersey at high tide with hurricane force winds and record storm surges. The storm cost 110 human lives and caused damages approaching \$100 billion. What atmospheric processes explain the formation and movement of this storm? Why the unprecedented size and intensity? How is this storm related to record air and ocean temperatures?

- In March 2011, a magnitude 9.0 earthquake and resultant 10- to 20-m tsunami devastated Honshu Island, Japan—at \$340 billion (Canadian dollars), Earth’s most expensive natural disaster. Why do earthquakes occur in particular locations across the globe? What produces tsunami, and how far and fast do they travel? This event caused the worst multiple nuclear power plant catastrophe in history, with three core meltdowns, releasing dangerous quantities of radioactivity over land and into the atmosphere and ocean, and eventually reaching the food supply. How will prevailing winds and currents disperse the radiation across the globe?
- By the end of 2012, a project to restore a free-flowing river with the removal of two dams on the Elwha River in Washington was almost complete—the largest dam removals in the world to date. Meanwhile, controversial new hydroelectric dam projects are proposed or under construction. The proposed Site C Dam project on the Peace River in northeastern British Columbia would flood 5500 hectares, including 3800 hectares of farmland. In Brazil, construction of the controversial Belo Monte hydroelectric dam on the Xingu River continues, despite court orders and violent protests. The dam will displace nearly 20 000 people and, when completed, will be the world’s third largest hydroelectric project, one of 60 planned to generate power for Brazil’s rapidly expanding economy. How do dams change river environments?
- In 2013, humans emitted a record 36 billion metric tons of carbon dioxide (CO<sub>2</sub>) into the atmosphere, mainly from the burning of fossil fuels. China’s 1.3 billion people produce 10 billion tonnes of CO<sub>2</sub> annually; Canada produces 0.7 billion tonnes annually, with 36% of that amount in Alberta. This “greenhouse gas” contributes to climate change by trapping heat near Earth’s surface. Each year atmospheric CO<sub>2</sub> levels rise to a new record, altering Earth’s climate. What are the effects and what do climate forecasts tell us?

Physical geography uses a *spatial* perspective to examine processes and events happening at specific locations and follow their effects across the globe. Why does the environment vary from equator to midlatitudes, and between deserts and polar regions? How does solar energy influence the distribution of trees, soils, climates, and lifestyles? What produces the patterns of wind, weather, and ocean currents? Why are global sea levels on the rise? How do natural systems affect human populations, and, in turn, what impact are humans having on natural systems? Why are record levels of plants and animals facing extinction? In this book, we explore those questions, and more, through geography’s unique perspective.

Perhaps more than any other issue, climate change has become an overriding focus of the study of Earth systems. The past decade experienced the highest temperatures over land and water in the instrumental record. The year 2010 tied 2005 and were the warmest for global temperatures, until 2014 broke the record as the warmest year on record for land and ocean temperatures, surpassing these previous records. In response, the extent of sea ice in the Arctic Ocean continues to decline to record lows—the 2012 summer sea ice extent was the lowest since satellite measurements began in 1979. Between 1992 and 2011, melting of the Greenland and Antarctica ice sheets accelerated; together they now lose more than three times the ice they lost annually 20 years ago and contribute about 20% of current sea-level rise. Elsewhere, intense weather events, drought, and flooding continue to increase.

The Intergovernmental Panel on Climate Change (IPCC; [www.ipcc.ch/](http://www.ipcc.ch/)), the lead international scientific body assessing the current state of knowledge about climate change and its impacts on society and the environment, completed its *Fourth Assessment Report* in 2007, and released the *Fifth Assessment Report* in 2014. The overwhelming scientific consensus is that human activities are forcing climate change. The first edition of *Geosystems* in 1992 featured the findings of the initial *First Assessment Report* from the IPCC, and the current edition continues to survey climate change evidence and consider its implications. In every chapter, *Geosystems* presents up-to-date science and information to help you understand our dynamic Earth systems. Welcome to an exploration of physical geography!

**In this chapter:** Our study of geosystems—Earth systems—begins with a look at the science of physical geography and the geographic tools it uses. Physical geography uses an integrative spatial approach, guided by the scientific process, to study entire Earth systems. The role of humans is an increasingly important focus of physical geography, as are questions of global sustainability as Earth’s population grows.

Physical geographers study the environment by analyzing air, water, land, and living systems. Therefore, we discuss systems and the feedback mechanisms that influence system operations. We then consider location on Earth as determined by the coordinated grid system of latitude and longitude, and the determination of world time zones. Next, we examine maps as critical tools that geographers use to display physical and cultural information. This chapter concludes with an overview of new and widely accessible technologies that are adding exciting new dimensions to geographic science: Global Positioning System, remote sensing from space, and geographic information systems.

## The Science of Geography

A common idea about geography is that it is chiefly concerned with place names. Although location and place are important geographic concepts, geography as a

science encompasses much more. **Geography** (from *geo*, “Earth,” and *graphein*, “to write”) is the science that studies the relationships among natural systems, geographic areas, society, and cultural activities, and the interdependence of all of these, *over space*. These last two words are key, for geography is a science that is in part defined by its method—a special way of analyzing phenomena over space. In geography, the term **spatial** refers to the nature and character of physical space, its measurement, and the distribution of things within it.

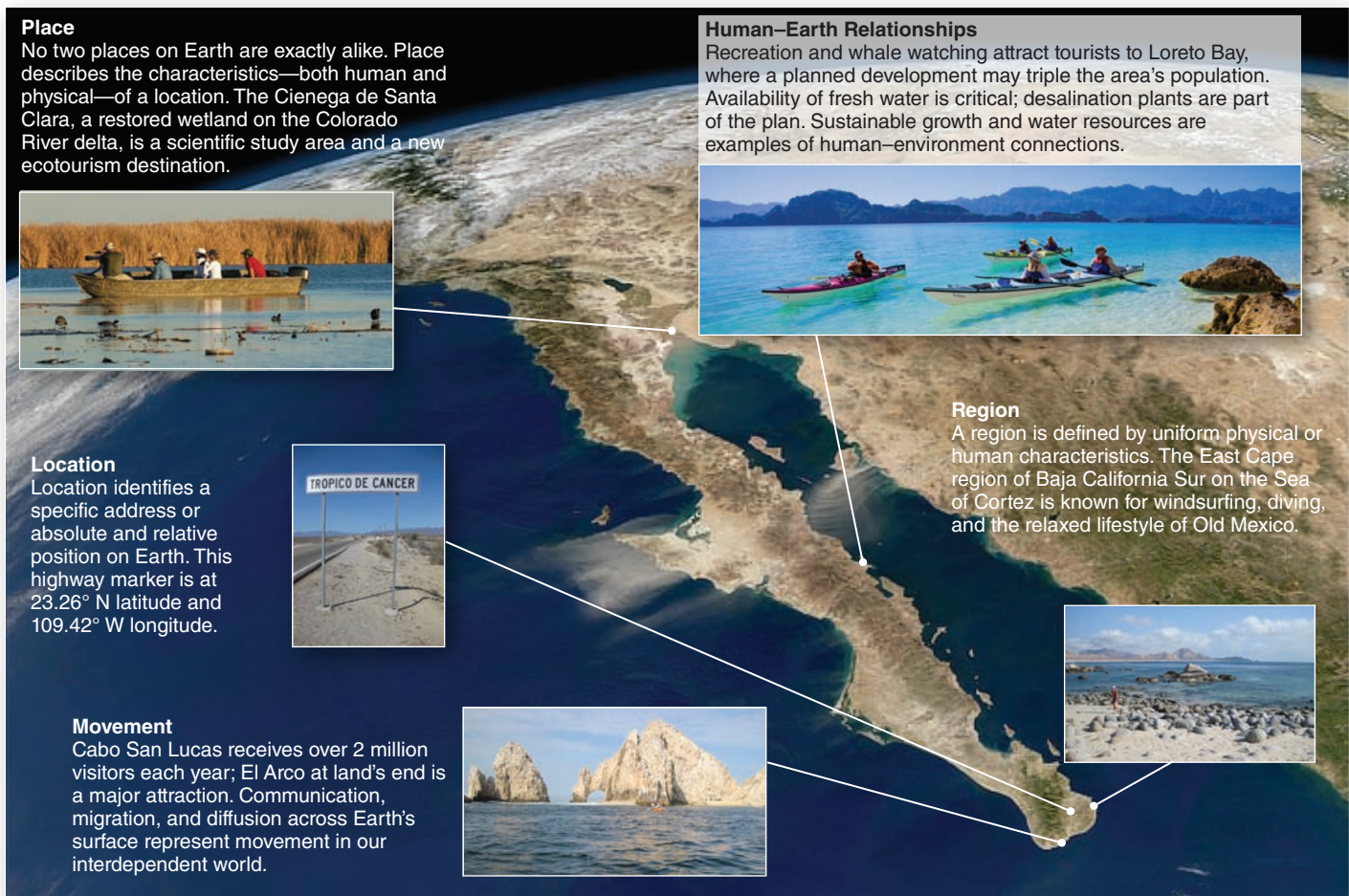
Geographic concepts pertain to distributions and movement across Earth. An example is the patterns of air and ocean currents over Earth’s surface, and how these currents affect the dispersal of pollutants, such as nuclear radiation or oil spills. Geography, then, is the spatial consideration of Earth processes interacting with human actions.

Although geography is not limited to place names, maps and location are central to the discipline and are important tools for conveying geographic data. Evolving technologies such as geographic information systems (GIS) and the Global Positioning System (GPS) are widely used for scientific applications and in today’s society as

hundreds of millions of people access maps and locational information every day on computers and mobile devices.

For educational purposes, the concerns of geographic science have traditionally been divided into five spatial themes: **location**, **region**, **human–Earth relationships**, **movement**, and **place**, each illustrated and defined in Figure 1.2. These themes, first implemented in 1984, are still used as a framework for understanding geographic concepts at all levels, and *Geosystems* draws on each. At the same time, the United States National Council for Geographic Education (NCGE)<sup>1</sup> has updated the geography education guidelines (most recently in 2012, [www.ncge.org/geography-for-life](http://www.ncge.org/geography-for-life)) in response to increasing globalization and environmental change, redefining the essential elements of geography and expanding their number to six: *the spatial world*, *places and regions*, *physical systems*, *human systems*, *environment and society*, and *uses of geography in today’s society*. These categories emphasize the spatial and environmental perspectives

<sup>1</sup>The National Council for Geographic Education ([www.ncge.org/](http://www.ncge.org/)) is a non-profit organization with a mission to enhance the status and quality of geographic teaching and learning.



▲**Figure 1.2** Five themes of geographic science. Drawing from your own experience, can you think of examples of each theme? This 2011 satellite image shows the entire length of Mexico’s Baja peninsula, including Earth’s curvature. [Photos by Karl Birkeland, except Place by Cheryl Zook/ National Geographic and Human–Earth by Gary Luhm/garyluhm.net. Image from Aqua satellite/Norman Kuring, Ocean Color Team. NASA/GSFC.]

within the discipline and reflect the growing importance of human–environment interactions.

## The Geographic Continuum

Because many subjects can be examined geographically, geography is an eclectic science that integrates subject matter from a wide range of disciplines.

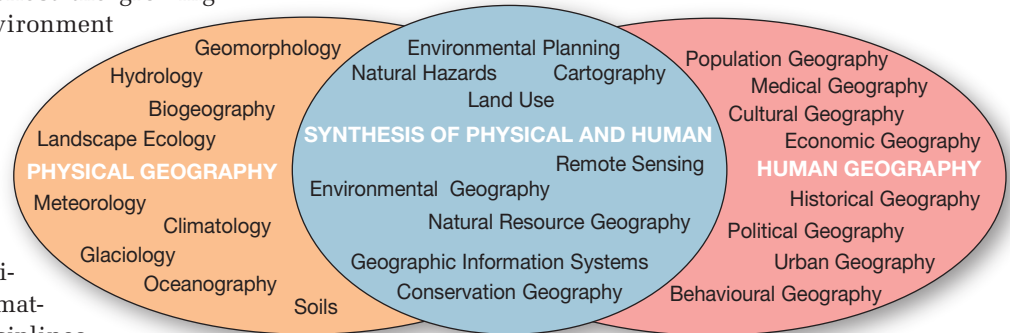
Even so, it splits broadly into two primary fields: *physical geography*, comprising specialty areas that draw largely on the physical and life sciences; and *human geography*, comprising specialty areas that draw largely on the social and cultural sciences. Prior to this century, scientific studies tended to fall onto one end of this continuum or the other. Humans tended at times to think of themselves as exempt from physical Earth processes—like actors not paying attention to their stage, props, and lighting.

However, as global population, communication, and movement increase, so does awareness that we all depend on Earth's systems to provide oxygen, water, nutrients, energy, and materials to support life. The growing complexity of the human–Earth relationship in the 21st century has shifted the study of geographic processes toward the centre of the continuum in Figure 1.3 to attain a more balanced perspective—such is the thrust of *Geosystems*. This more balanced synthesis is reflected in geographic subfields such as natural resource geography and environmental planning, and in technologies such as geographic information science (GISci), used by both physical and human geographers.

Within physical geography, research now emphasizes human influences on natural systems in all specialty areas, effectively moving this end of the continuum closer to the middle. For example, physical geographers monitor air pollution, examine the vulnerability of human populations to climate change, study impacts of human activities on forest health and the movement of invasive species, study changes in river systems caused by dams and dam removal, and examine the response of glacial ice to changing climate.

## Geographic Analysis

As mentioned earlier, the science of geography is unified more by its method than by a specific body of knowledge. The method is **spatial analysis**. Using this method, geography synthesizes (brings together) topics from many fields, integrating information to form a whole-Earth concept. Geographers view phenomena as occurring across spaces, areas, and locations. The language of geography reflects this spatial view: territory, zone, pattern, distribution, place, location, region, sphere, province, and distance. Geographers analyze the differences and similarities between places.



▲Figure 1.3 The content of geography. Geography synthesizes Earth topics and human topics, blending ideas from many different sciences. This book focuses on physical geography, but integrates pertinent human and cultural content for a whole-Earth perspective.

**Process**, a set of actions or mechanisms that operate in some special order, is a central concept of geographic analysis. Among the examples you encounter in *Geosystems* are the numerous processes involved in Earth's vast water–atmosphere–weather system; in continental crust movements and earthquake occurrences; in ecosystem functions; or in fluvial, glacial, coastal, and aeolian system dynamics. Geographers use spatial analysis to examine how Earth's processes interact through space or over areas.

Therefore, **physical geography** is the spatial analysis of all the physical elements, processes, and systems that make up the environment: energy, air, water, weather, climate, landforms, soils, animals, plants, microorganisms, and Earth itself. Today, in addition to its place in the geographic continuum, physical geography also forms part of the broad field of **Earth systems science**, the area of study that seeks to understand Earth as a complete entity, an interacting set of physical, chemical, and biological systems. With these definitions in mind, we now discuss the general process and methods used by scientists, including geographers.

## The Scientific Process

The process of science consists of observing, questioning, testing, and understanding elements of the natural world. The **scientific method** is the traditional recipe of a scientific investigation; it can be thought of as simple, organized steps leading toward concrete, objective conclusions. A scientist observes and asks questions, makes a general statement to summarize the observations, formulates a hypothesis (a logical explanation), conducts experiments or collects data to test the hypothesis, and interprets results. Repeated testing and support of a hypothesis lead to a scientific theory. Sir Isaac Newton (1642–1727) developed this method of discovering the patterns of nature, although the term *scientific method* was applied later.

While the scientific method is of fundamental importance in guiding scientific investigation, the real process of science is more dynamic and less linear, leaving room for questioning and thinking “out

of the box.” Flexibility and creativity are essential to the scientific process, which may not always follow the same sequence of steps or use the same methods for each experiment or research project. There is no single, definitive method for doing science; scientists in different fields and even in different subfields of physical geography may approach their scientific testing in different ways. However, the end result must be a conclusion that can be tested repeatedly and possibly shown as true, or as false. Without this characteristic, it is not science.

**Using the Scientific Method** Figure 1.4 illustrates steps of the scientific method and outlines a simple application examining cottonwood tree distributions. The scientific method begins with our perception of the real world. Scientists who study the physical environment begin with the clues they see in nature. The process begins as scientists question and analyze their observations and explore the relevant published scientific literature on their topic. Brainstorming with others, continued observation, and preliminary data collection may occur at this stage.

Questions and observations identify variables, which are the conditions that change in an experiment or model. Scientists often seek to reduce the number of variables when formulating a *hypothesis*—a tentative explanation for the phenomena observed. Since natural systems are complex, controlling or eliminating variables helps simplify research questions and predictions.

Scientists test hypotheses using experimental studies in laboratories or natural settings. Correlational studies, which look for associations between variables, are common in many scientific fields, including physical geography. The methods used for these studies must be reproducible so that repeat testing can occur. Results may support or disprove the hypothesis, or predictions made according to it may prove accurate or inaccurate. If the results disprove the hypothesis, the researcher will need to adjust data-collection methods or refine the hypothesis statement. If the results support the hypothesis, repeated testing and verification may lead to its elevation to the status of a *theory*.

Reporting research results is also part of the scientific method. For scientific work to reach other scientists and eventually the public at large, it must be described in a scientific paper and published in one of many scientific journals. Critical to the process is *peer review*, in which other members of the scientific or professional community critique the methods and interpretation of results. This process also helps detect any personal or political bias by the scientist. When a paper is submitted to a scientific journal, it is sent to reviewers, who may recommend rejecting the paper or accepting and revising it for publication. Once a number of papers are published with similar results and conclusions, the building of a theory begins.

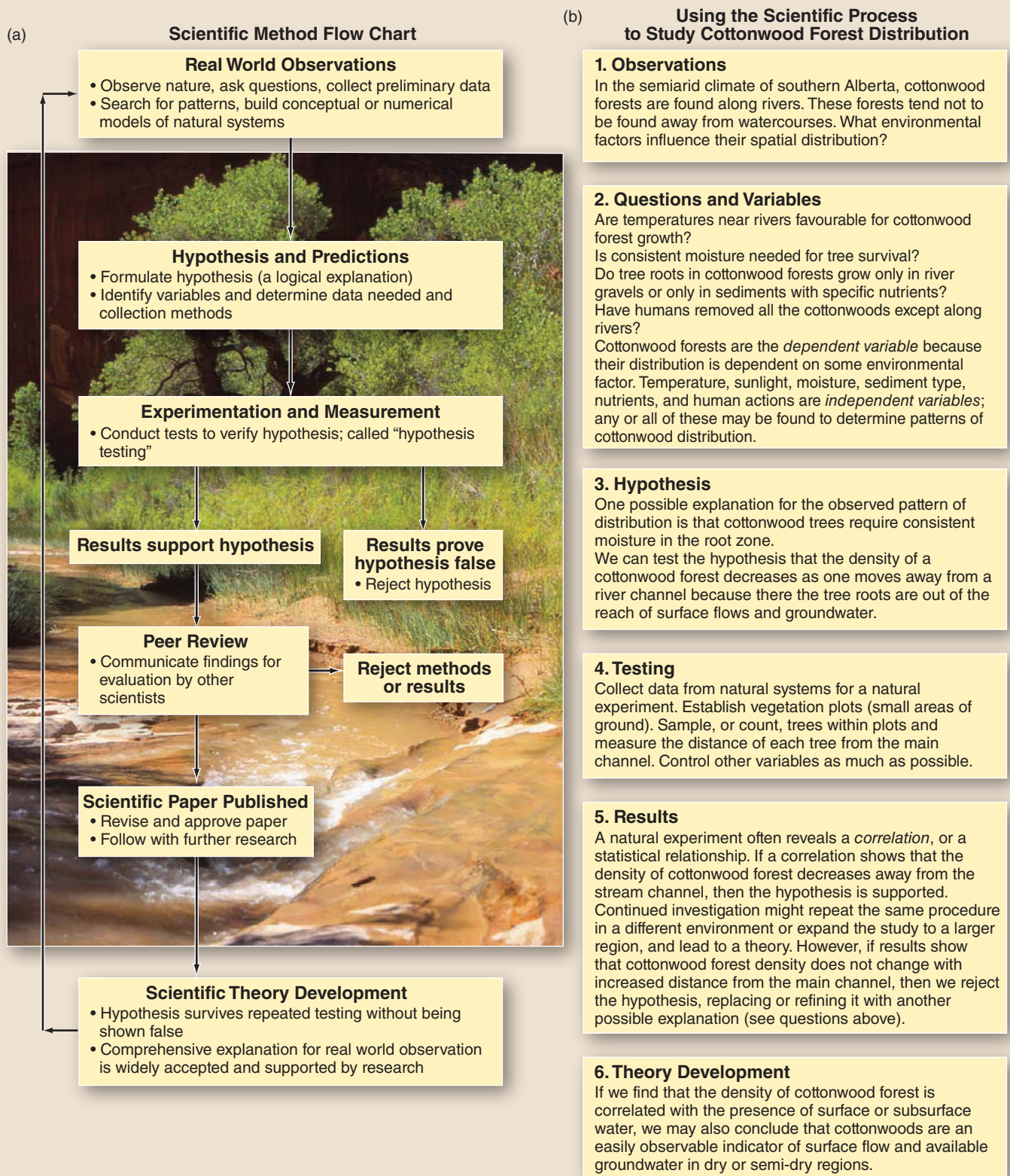
The word *theory* can be confusing as used by the media and general public. A scientific theory is constructed on the basis of several extensively tested hypotheses and can be reevaluated or expanded according to new evidence. Thus, a scientific theory is not absolute truth; the possibility always exists that the theory could be proved wrong. However, theories represent truly broad general principles—unifying concepts that tie together the laws that govern nature. Examples include the theory of relativity, theory of evolution, and plate tectonics theory. A scientific theory reinforces our perception of the real world and is the basis for predictions to be made about things not yet known. The value of a scientific theory is that it stimulates continued observation, testing, understanding, and pursuit of knowledge within scientific fields.

**Applying Scientific Results** Scientific studies described as “basic” are designed largely to help advance knowledge and build scientific theories. Other research is designed to produce “applied” results tied directly to real-world problem solving. Applied scientific research may advance new technologies, affect natural resource policy, or directly impact management strategies. Scientists share the results of both basic and applied research at conferences as well as in published papers, and they may take leadership roles in policy and planning. For example, the awareness that human activity is producing global climate change places increasing pressure on scientists to participate in decision making. Numerous editorials in scientific journals have called for such practical scientific involvement.

The nature of science is objective and does not make value judgments. Instead, pure science provides people and their institutions with objective information on which to base their own value judgments. Social and political judgments about the applications of science are increasingly important as Earth’s natural systems respond to the impacts of modern civilization.

## Human–Earth Interactions in the 21st Century

Issues surrounding the growing influence of humans on Earth systems are central concerns of physical geography; we discuss them in every chapter of *Geosystems*. Human influence on Earth is now pervasive. The global human population passed 6 billion in August 1999 and continued to grow at the rate of 82 million per year, adding another billion by 2011, when the 7 billion mark was passed. More people are alive today than at any previous moment in the planet’s long history, unevenly distributed among 193 countries and numerous colonies. Virtually all new population growth is in the less-developed countries (LDCs), which now possess 81%, or about 5.75 billion, of the total population. Over the span of human history, billion-mark milestones occurred at



▲Figure 1.4 The scientific process. (a) Scientific method flow chart and (b) example application to cottonwood forest distribution. [Ginger Birkeland photograph.]