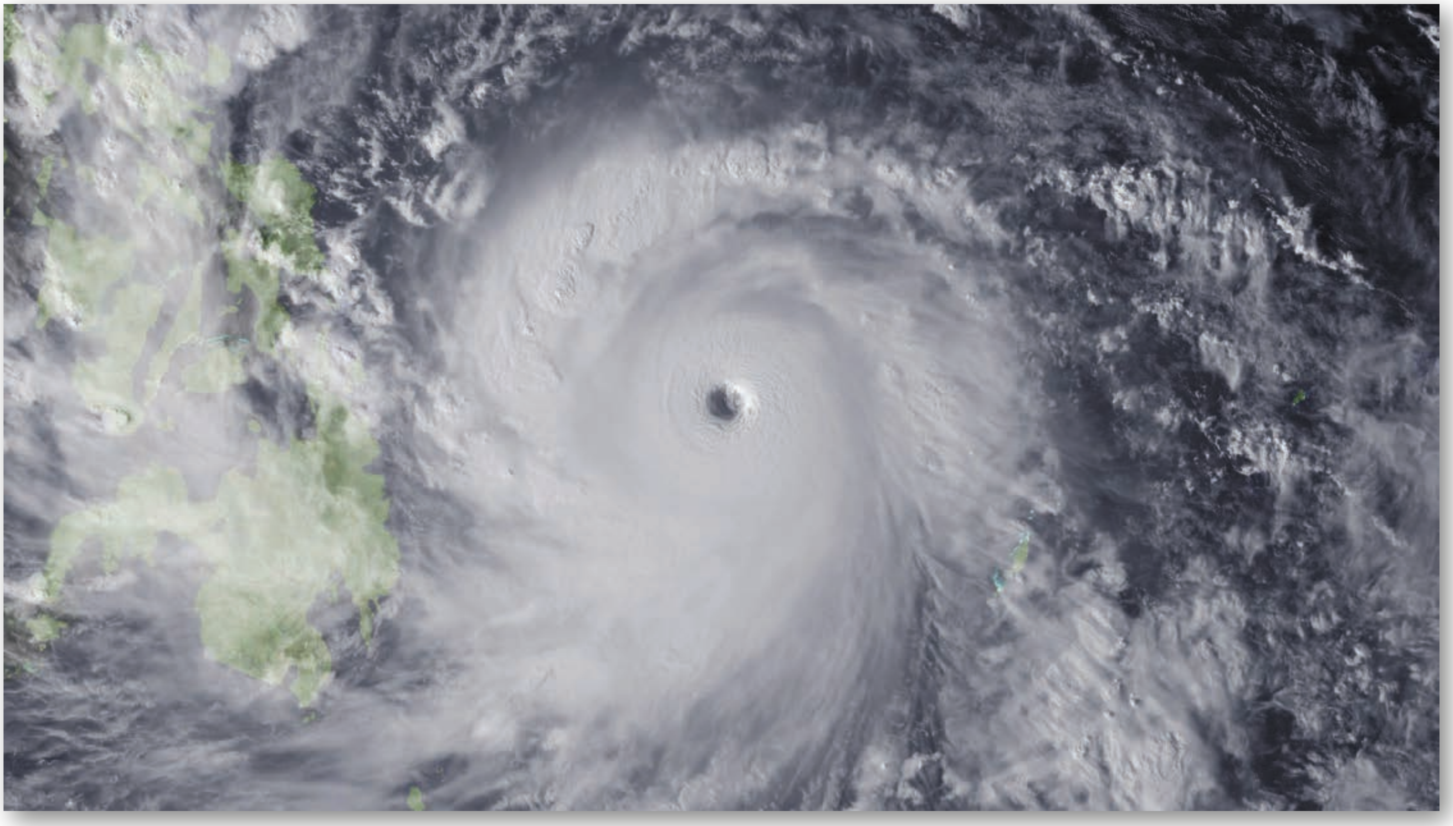
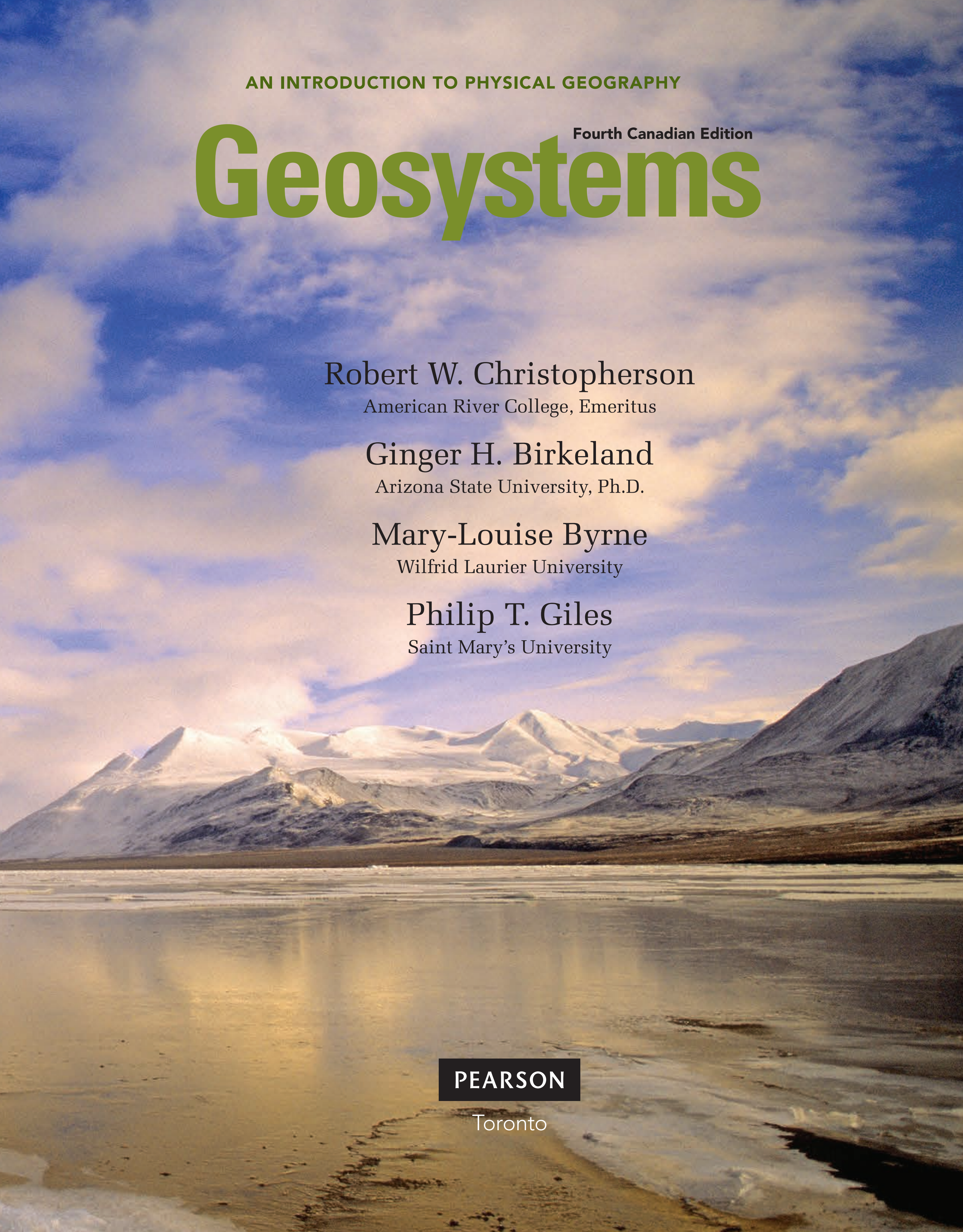
Geosystems



Super Typhoon Haiyan made landfall in the central Philippines on the morning of November 7, 2013, with sustained winds over 306 km · 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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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*™ 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™ 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™ 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.

Author Acknowledgments

The authors and publishers wish to thank all reviewers who have participated in reading material at various stages during development of *Geosystems* for previous editions, most recently those who reviewed manuscript for the Fourth Canadian Edition: Norm Catto, Memorial University of Newfoundland; Michele Wiens, Simon Fraser University; James Voogt, University of Western University; Nancy McKeown, MacEwan University; Trudy Kavanagh, University of British Columbia; and Denis Lacelle, University of Ottawa. And we extend continued thanks to reviewers of the previous three editions.

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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:

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- **Student study area** with Geoscience Animations, MapMaster™ 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, a glossary, self-quizzing, an optional Pearson eText and more. http://www.masteringgeography.com
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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

***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_2 emissions, polar ice fluctuations, deforestation, extreme weather events, infectious diseases, water resources, and energy production.

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

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

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

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/.

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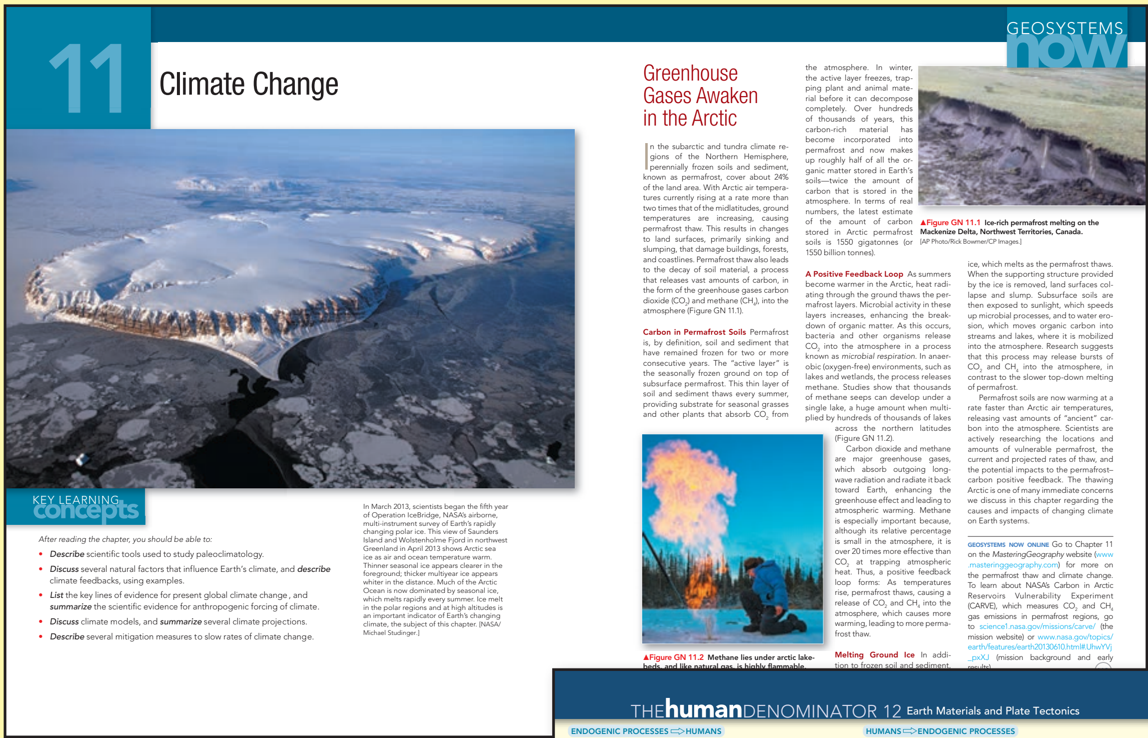
Exploring Earth's Dynamic Systems

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 now

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 Saunders 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, perennially 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_2) and methane (CH_4), 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_2 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 soils is 1550 gigatonnes (or 1550 billion tonnes).

▲**Figure GN 11.1** **Ice-rich permafrost melting on the Mackenize Delta, Northwest Territories, Canada.** [AP Photo/Rick Bowmer/CP Images.]

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_2 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 longwave 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_2 at trapping atmospheric heat. Thus, a positive feedback loop forms: As temperatures rise, permafrost thaws, causing a release of CO_2 and CH_4 into the atmosphere, which causes more warming, leading to more permafrost thaw.

▲**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_2 and CH_4 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) for more on the permafrost thaw and climate change. To learn about NASA's Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE), which measures CO_2 and CH_4 gas emissions in permafrost regions, go to science1.nasa.gov/missions/carve/ (the mission website) or www.nasa.gov/topics/earth/features/earth20130610.html#.UhwYVj_pxXJ (mission background and early results).

▶ **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 ⇨ HUMANS

- 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.

HUMANS ⇨ ENDOGENIC PROCESSES

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

12a Hydrothermal features and travertine deposits 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 third largest in the world. [Edward Fielding/Shutterstock.]

12b The Mid-Atlantic Ridge system surfaces at Thingvellir, Iceland, now a tourist destination. The rifts mark the divergent boundary separating the North American and Eurasian plates. [ARCTIC IMAGES/Alamy.]

12c 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. [Penny Tweedie/Alamy.]

12d 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. [Inga Spence/Alamy.]

[NOAA/NGDC.]

ISSUES FOR THE 21ST CENTURY

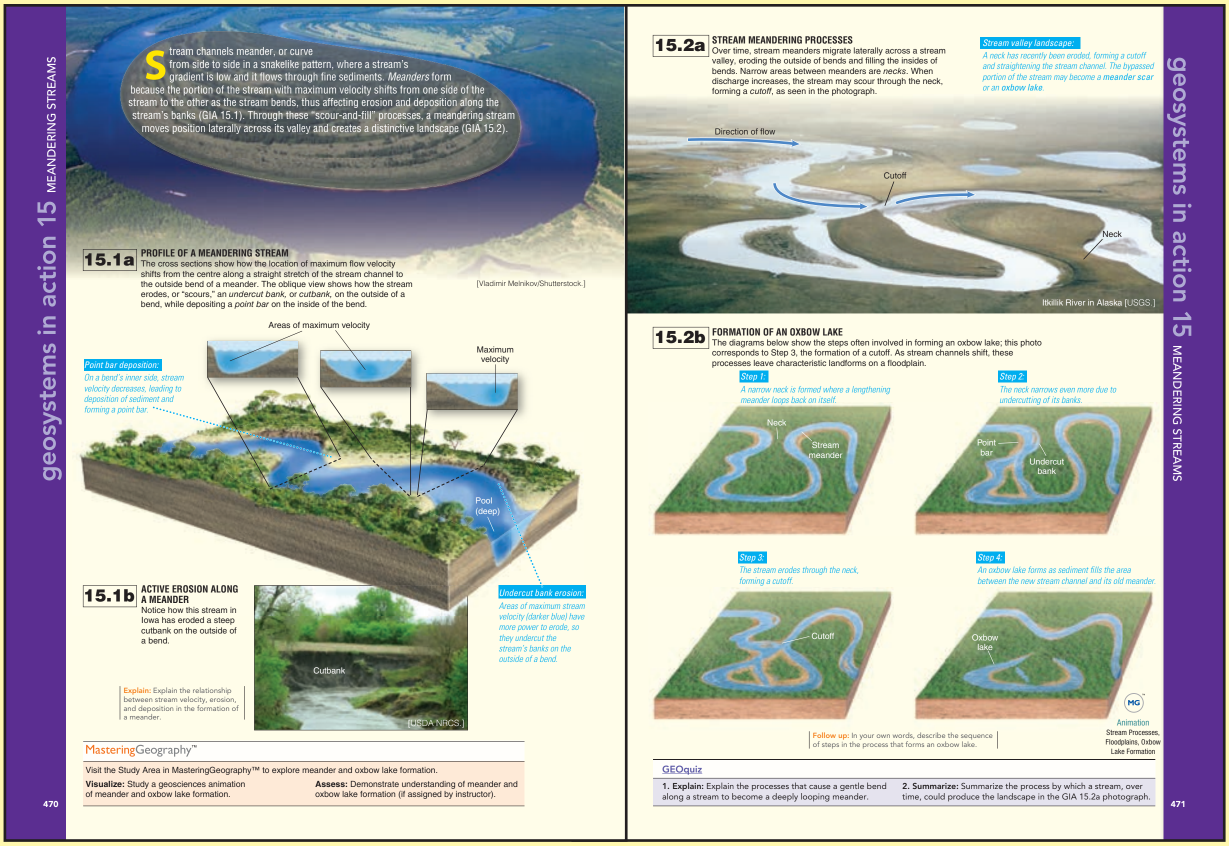
- Geothermal capacity will continue to be explored as an alternative energy source to fossil fuels.
- Mapping of tectonically active regions will continue to inform policy actions with regard to seismic hazards.

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

Stream channels meander, or curve from side to side in a snakelike pattern, where a stream's gradient is low and it flows through fine sediments. *Meanders* form because the portion of the stream with maximum velocity shifts from one side of the stream to the other as the stream bends, thus affecting erosion and deposition along the stream's banks (GIA 15.1). Through these "scour-and-fill" processes, a meandering stream moves position laterally across its valley and creates a distinctive landscape (GIA 15.2).

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.

[Vladimir Melnikov/Shutterstock.]

15.1b ACTIVE EROSION ALONG A MEANDER Notice how this stream in Iowa has eroded a steep cutbank on the outside of a bend.

Explain: Explain the relationship between stream velocity, erosion, and deposition in the formation of a meander.

MasteringGeography™

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

Visualize: Study a geosciences animation of meander and oxbow lake formation.

Assess: Demonstrate understanding of meander and oxbow lake formation (if assigned by instructor).

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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**.

Itkillik River in Alaska [USGS.]

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 3, 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.

Animation Stream Processes, Floodplains, Oxbow Lake Formation

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

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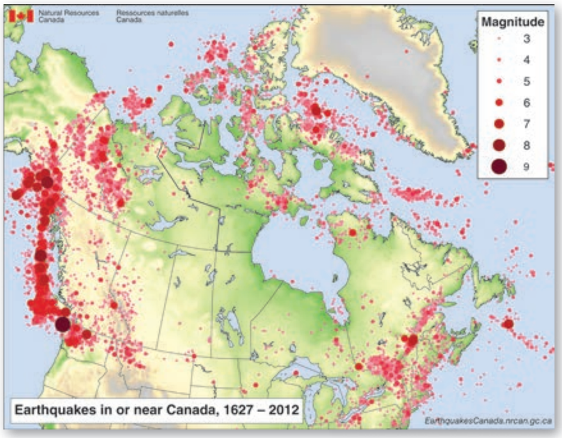
An unparalleled visual program includes a variety of illustrations, maps, photographs, and composites, providing authoritative examples and applications of physical geography and Earth systems science.



▲**Figure 13.19 Seismic activity in or near Canada, 1627 to 2012.** Damaging earthquakes (M > 5) are strongly associated with the Western Cordillera and the valleys of the Ottawa and St. Lawrence Rivers. [Used by permission of the Minister of Public Works and Government Services Canada; Natural Resources Canada, Geological Survey of Canada.]

Animation
Elastic Rebound

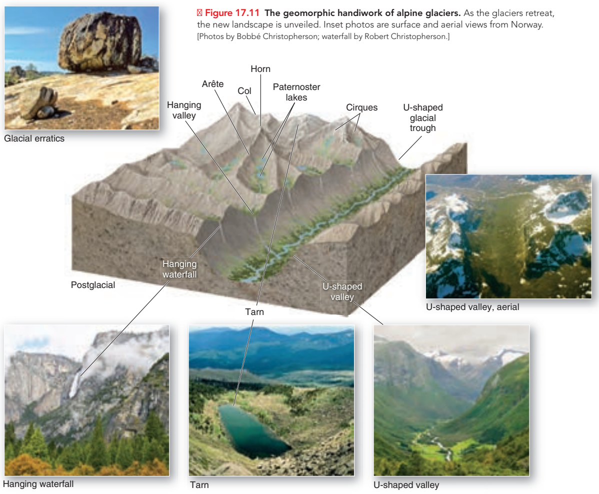


Figure 17.11 The geomorphic handiwork of alpine glaciers. As the glaciers retreat, the new landscape is unveiled. Inset photos are surface and aerial views from Norway. [Photos by Bobbé Christopherson; waterfall by Robert Christopherson.]

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.

GEOSYSTEMS now

Humans Explore the Atmosphere

Astronaut Mark Lee, on a spacewalk from the Space Shuttle *Discovery* in 1994 (mission *STS-64*), was 241 km above Earth's surface, in orbit beyond the protective shield of the atmosphere (Figure GN 3.1). He was travelling at 28 165 km·h^{-1}, almost nine times faster than a high-speed rifle bullet, the vacuum of space all around him. Where the Sun hit his spacesuit, temperatures reached +120°C; in the shadows, they dropped to –150°C. Radiation and solar wind struck his pressure suit. To survive at such an altitude is an obvious challenge, one that relies on the ability of National Aeronautics and Space Administration (NASA) spacesuits to duplicate the Earth's atmosphere.

Protection in a Spacesuit For human survival, a spacesuit must block radiation and particle impacts, as does the atmosphere. It must also protect the wearer from thermal extremes.

Earth's oxygen–carbon dioxide processing systems must also be replicated in the suit, as must fluid-delivery and waste-management systems. The suit must maintain an internal air pressure against the space vacuum; for pure oxygen, this is 32.4 kPa, which roughly equals the pressure that oxygen, water vapour, and CO_2 gases combined exert at sea level. All 18 000 parts of the modern spacesuit work to duplicate what the atmosphere does for us on a daily basis.

▲Figure GN 3.1 **Astronaut Mark Lee, untethered, on a working spacewalk in 1994.** [NASA.]

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 spacesuit. 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—this altitude is considered the beginning of space in experimental-aircraft testing.

Kittinger then leaped into the stratospheric 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.

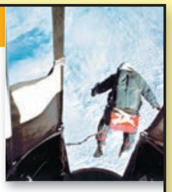
Initially frightened, he heard nothing, no rushing sound, for there was not enough air to produce any sound. The fabric of his pressure suit did not flutter, for there was not enough air to create friction against the cloth. His speed was remarkable, quickly accelerating to 988 km·h^{-1} nearly the speed 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^{-1}. 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 new free-fall height record of 41.4 km an altitude more than halfway to the top of the stratosphere. Eustace survived using a special pressure suit developed during 3 years of preparation by his scientific support team.



▲Figure GN 3.2 **A remotely triggered camera captures a stratospheric leap into history.** [National Museum of the U.S. Air Force.]

The experiences of these men illustrate the evolution of our understanding of upper-atmosphere survival. From events such as Kittinger's dangerous leap of discovery, the now routine spacewalks of astronauts such as Mark Lee, and the 2012 and 2014 record-breaking jumps, scientists have gained important information about the atmosphere. This chapter explores solar energy, the seasons, and our current knowledge of the atmosphere as it protects Earth's living systems.

GEOSYSTEMS NOW ONLINE Go to www.redbullstratos.com/ and vimeo.com/109992331 to watch the highlights of Baumgartner and Eustace jumps. Do you think these recent feats makes Kittinger's accomplishment less important? MG

▼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 Stratos/AP Images.]

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

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 13.1.1), 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 13.1.1), 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.

Farther north, in a region extending from northern Vancouver Island to Haida Gwaii (Queen Charlotte Islands), the oceanic Pacific plate is sliding northwestward relative to North America at a rate of 60 mm per year (Figure 13.1.1). 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.rncan.gc.ca/zones/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 Kaua'i, Hawai'i, 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 Kaua'i 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.

◄ ***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 $m^3 \cdot s^{-1}$ or higher, for example, we note in Table AQS 15.1 that $m^3 \cdot s^{-1}$ was exceeded four times in the 30-year period.

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

Statistically, we then expect a flood of magnitude 425 $m^3 \cdot s^{-1}$ (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:

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

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

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

Year	Peak Discharge ($m^3 \cdot s^{-1}$)	Year	Peak Discharge ($m^3 \cdot s^{-1}$)	Year	Peak Discharge ($m^3 \cdot s^{-1}$)
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

► 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 *interfluve*. 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)

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

CRITICAL**thinking 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? ●

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

GEOSYSTEMS**connection**

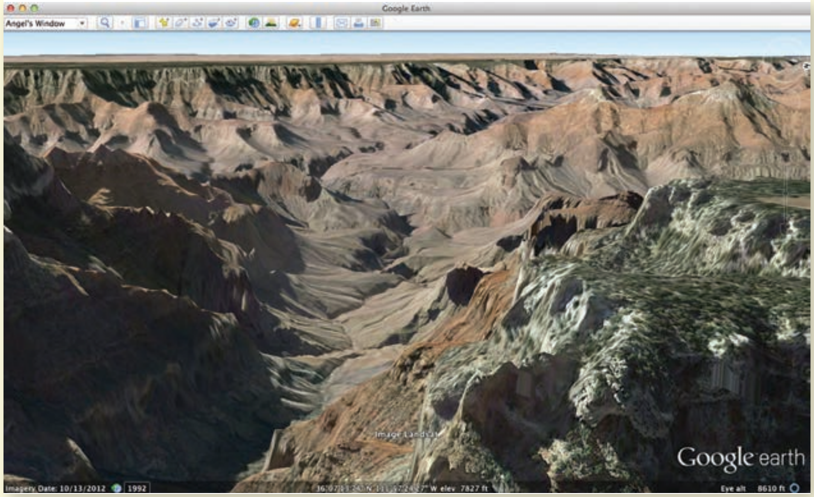
While following the flow of water through streams, we examined fluvial processes and landforms and the river-system outputs of discharge and sediment. We saw that a scientific understanding of river dynamics, floodplain landscapes, and related flood hazards is integral to society's ability to perceive 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.

Mastering Geography™

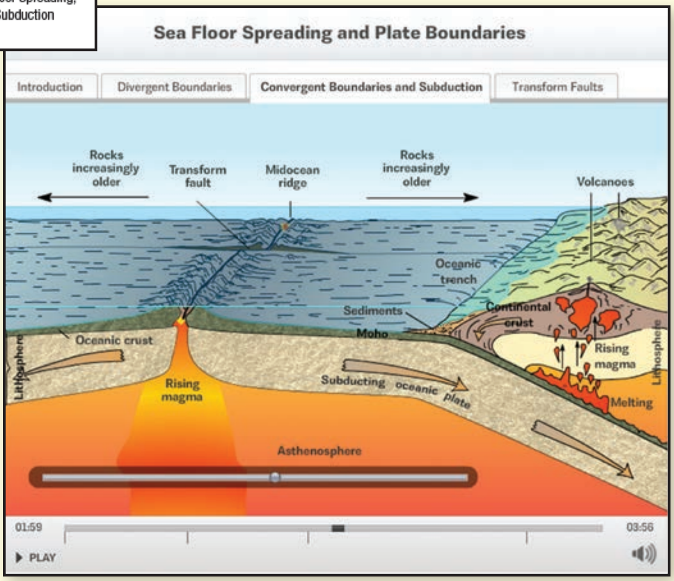
MasteringGeography delivers engaging, dynamic learning opportunities—focusing on course objectives and responsive to each student's progress—that are proven to help students absorb geography course material and understand difficult physical processes and geographic concepts.

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.



MG
Animation
Seafloor Spreading, Subduction

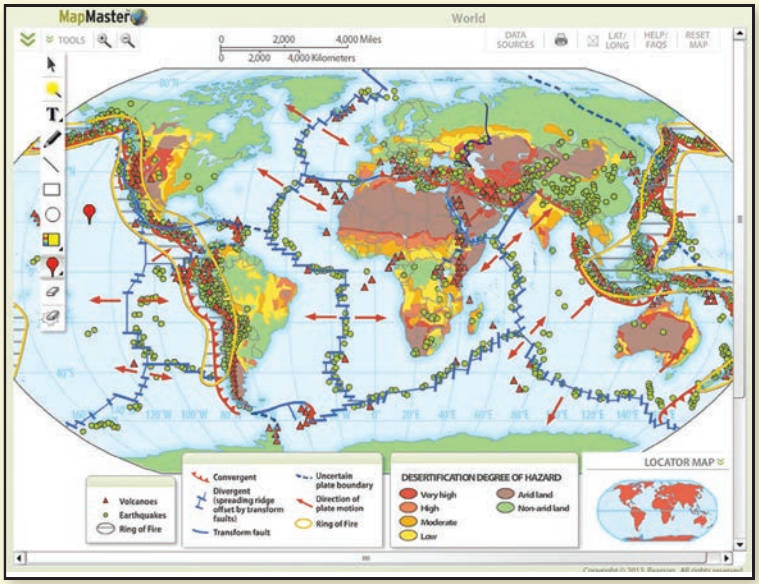


◄ **Geoscience Animations** illuminate the most difficult-to-visualize topics from across the physical geosciences, such as solar system formation, hydrologic cycle, plate tectonics, glacial advance and retreat, global warming, etc. Animations include audio narration, a text transcript, and assignable 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.

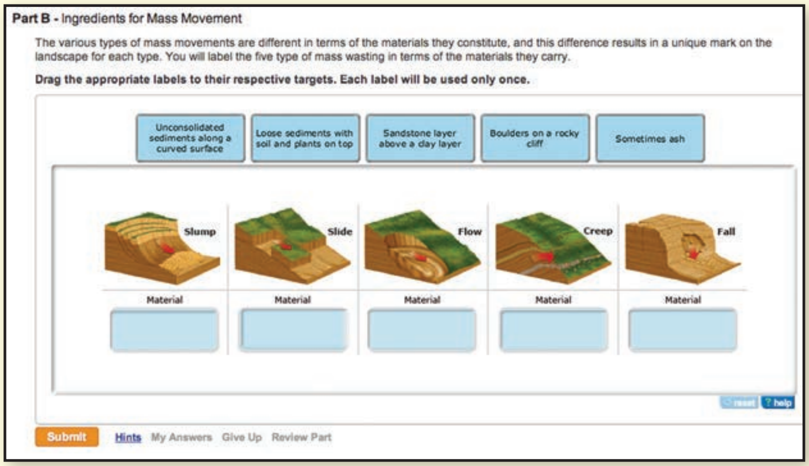
Engage in Map Reading, Data Analysis, and Critical Thinking

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.



▼ **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.

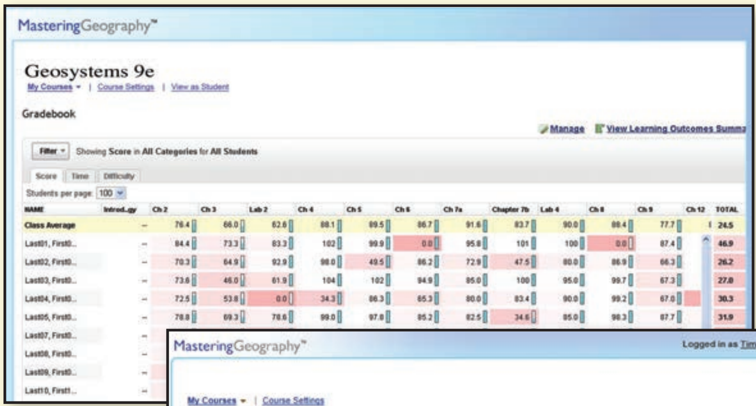
Student Study Area Resources in MasteringGeography:

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

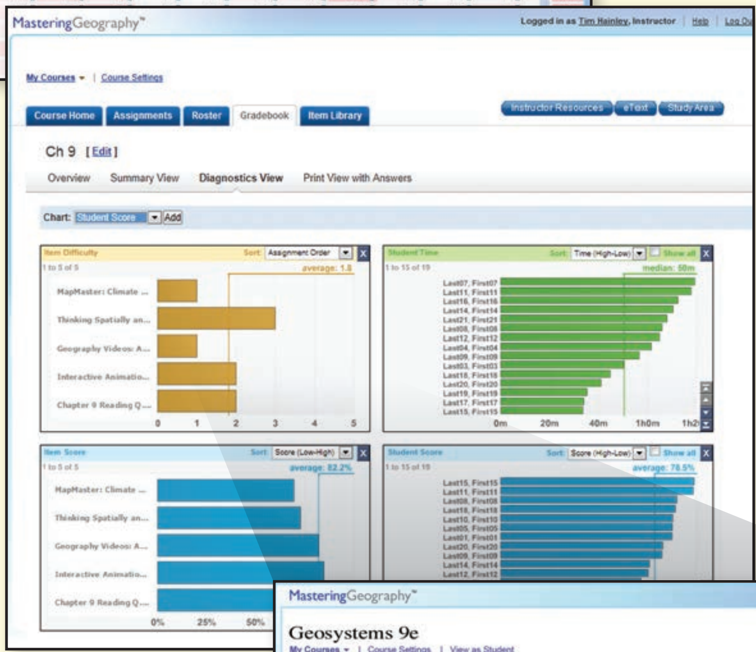
MasteringGeography™

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.

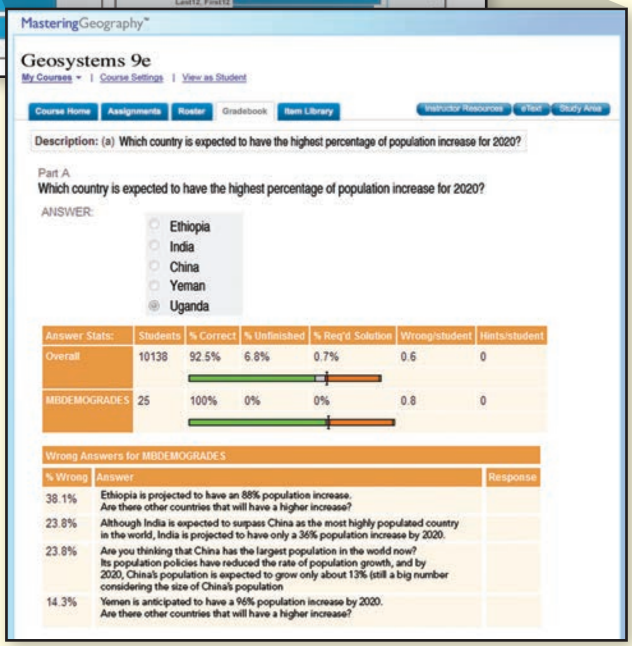
▶ The **Gradebook** records all scores for automatically graded assignments. Shades of red highlight struggling students and challenging **assignments.**



▶ **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.

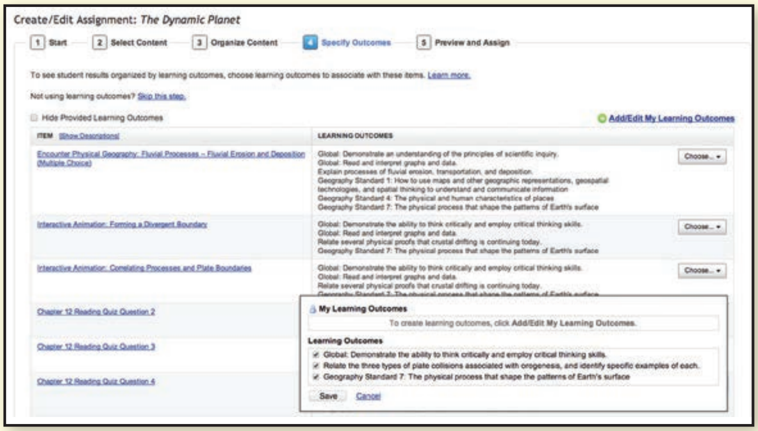


▸ Learning Outcomes

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

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.

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.

The Pearson eText app is a great companion to Pearson's eText browser-based book reader. It allows existing subscribers who view their Pearson eText titles on a Mac or PC to additionally access their titles in a bookshelf on the iPad and Android devices either online or via download.

Geosystems