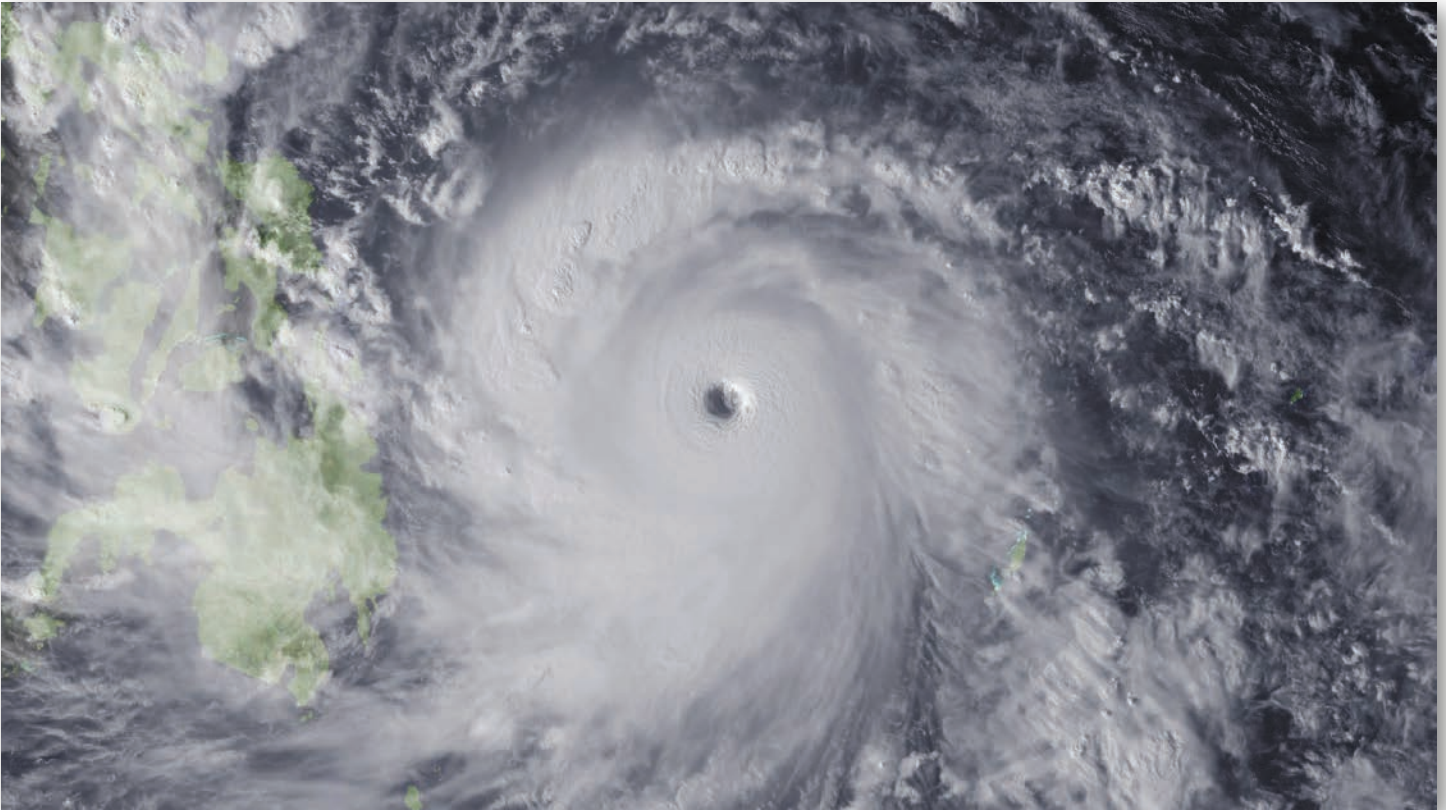


# Geosystems



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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# brief contents

**1** Essentials of Geography 2

## **PART I The Energy–Atmosphere System** 40

**2** Solar Energy to Earth and the Seasons 42

**3** Earth’s Modern Atmosphere 64

**4** Atmosphere and Surface Energy Balances 90

**5** Global Temperatures 116

**6** Atmospheric and Oceanic Circulations 142

## **PART II The Water, Weather, and Climate Systems** 178

**7** Water and Atmospheric Moisture 180

**8** Weather 206

**9** Water Resources 240

**10** Global Climate Systems 274

**11** Climate Change 306

## **PART III The Earth–Atmosphere Interface** 344

**12** The Dynamic Planet 346

**13** Tectonics, Earthquakes, and Volcanism 382

**14** Weathering, Karst Landscapes, and Mass Movement 422

**15** River Systems 452

**16** Oceans, Coastal Systems, and Wind Processes 490

**17** Glacial and Periglacial Landscapes 532

## **PART IV Soils, Ecosystems, and Biomes** 568

**18** The Geography of Soils 570

**19** Ecosystem Essentials 604

**20** Terrestrial Biomes 640

**Appendix A** Maps in This Text and Topographic Maps **A-1**

**Appendix B** The 12 Soil Orders of the U.S. Soil Taxonomy **A-6**

**Appendix C** The Köppen Climate Classification System **A-10**

**Appendix D** Common Conversions **A-13**



Preface xviii  
 Digital and Print Resources xxii  
 Book and MasteringGeography  
 Walkthrough xxii



## 1 Essentials of Geography 2

KEY LEARNING **concepts** 2  
 GEOSYSTEMS**now** Canada's Borders, Not Just Lines  
 on a Map 3  
**The Science of Geography** 5  
 The Geographic Continuum 7  
 Geographic Analysis 7  
 The Scientific Process 7  
 Human–Earth Interactions in the 21st Century 8  
**Earth Systems Concepts** 11  
 Systems Theory 11  
 Systems Organization in Geosystems 14  
 Earth's Dimensions 19

**Location and Time on Earth** 20  
 Latitude 20  
 Longitude 22  
 Great Circles and Small Circles 23  
 Meridians and Global Time 23  
**Maps and Cartography** 25  
 The Scale of Maps 26  
 Map Projections 26  
**Modern Tools and Techniques for Geoscience** 30  
 Global Positioning System 30  
 Remote Sensing 31  
 Geographic Information Systems 33  
 GEOSYSTEMS **connection** 37  
 KEY LEARNING **concepts review** 37  
**geosystems in action 1** Exploring Earth Systems 16  
**CRITICAL THINKING 1.1** What Is Your Footprint? 11  
**CRITICAL THINKING 1.2** Latitudinal Geographic Zones  
 and Temperature 21  
**CRITICAL THINKING 1.3** Where Are You? 23  
**CRITICAL THINKING 1.4** Find and Compare Map Scales 26  
**CRITICAL THINKING 1.5** Test Your Knowledge about  
 Satellite Imagery 34  
 A **Quantitative** SOLUTION: **Map Scales** 36  
 GEO**reports**: 7 REPORTS

## PART I The Energy–Atmosphere System 40



## 2 Solar Energy to Earth and the Seasons 42

KEY LEARNING **concepts** 42  
 GEOSYSTEMS**now** Chasing the Subsolar Point 43  
**The Solar System, Sun, and Earth** 44  
 Solar System Formation 45  
 Dimensions and Distances 45

**Solar Energy: From Sun to Earth** 45  
 Solar Activity and Solar Wind 46  
 Electromagnetic Spectrum of Radiant Energy 47  
 Incoming Energy at the Top of the Atmosphere 49  
**The Seasons** 51  
 Seasonality 52  
 Reasons for Seasons 52  
 Annual March of the Seasons 55  
 GEOSYSTEMS **connection** 60  
 KEY LEARNING **concepts review** 61  
**geosystems in action 2** Earth–Sun Relations 56  
**CRITICAL THINKING 2.1** A Way to Calculate Sunrise  
 and Sunset 52  
**CRITICAL THINKING 2.2** Astronomical Factors Vary over  
 Long Time Frames 54

**CRITICAL THINKING 2.3** Use the Analemma to Find the Subsolar Point 58

THE **human**DENOMINATOR2: **Solar Energy and the Seasons** 59



### 3 Earth's Modern Atmosphere 64

KEY LEARNING **concepts** 64

GEOSYSTEMS **now** Humans Explore the Atmosphere 65

#### Atmospheric Composition, Temperature, and Function 66

Atmospheric Profile 66

Atmospheric Composition Criterion 67

Atmospheric Temperature Criterion 69

Atmospheric Function Criterion 71

#### Pollutants in the Atmosphere 73

Natural Sources of Air Pollution 73

A **Quantitative**SOLUTION: **Radiation and Temperature** 60

VISUAL **analysis 2**: **Dryland Agriculture** 63

GEOREPORTS: 4 REPORTS

Anthropogenic Pollution 76

Natural Factors That Affect Pollutants 80

Benefits of the Clean Air Act 81

GEOSYSTEMS **connection** 85

KEY LEARNING **concepts review** 87

**geosystems in action 3** Air Pollution 82

**Focus Study 3.1** Pollution 74

**Focus Study 3.2** Pollution 78

**CRITICAL THINKING 3.1** Where Is Your Tropopause? 71

**CRITICAL THINKING 3.2** Finding Your Local Ozone 72

**CRITICAL THINKING 3.3** Evaluating Costs and Benefits 84

THE **human**DENOMINATOR3: **The Shared Global Atmosphere** 85

A **Quantitative**SOLUTION: **Lapse Rates** 86

VISUAL **analysis 3**: **The Atmosphere and Inversion Layers** 89

GEOREPORTS: 5 REPORTS



### 4 Atmosphere and Surface Energy Balances 90

KEY LEARNING **concepts** 90

GEOSYSTEMS **now** Melting Sea Ice Opens Arctic Shipping Lanes, However . . . 91

#### Energy-Balance Essentials 92

Energy and Heat 92

Energy Pathways and Principles 94

#### Energy Balance in the Troposphere 98

The Greenhouse Effect and Atmospheric Warming 98

Earth–Atmosphere Energy Balance 99

#### Energy Balance at Earth's Surface 103

Daily Radiation Patterns 103

A Simplified Surface Energy Budget 104

The Urban Environment 107

GEOSYSTEMS **connection** 112

KEY LEARNING **concepts review** 113

**geosystems in action 4** Earth–Atmosphere Energy Balance 100

**Focus Study 4.1** Sustainable Resources 108

**CRITICAL THINKING 4.1** A Kelp Indicator of Surface Energy Dynamics 102

**CRITICAL THINKING 4.2** Applying Energy-Balance Principles to a Solar Cooker 105

**CRITICAL THINKING 4.3** Looking at Your Surface Energy Budget 111

THE **human**DENOMINATOR4: **Changes in Atmospheric and Surface Energy Budgets** 112

A **Quantitative**SOLUTION: **Zero-Dimensional Global Energy Balance Model** 113

GEOREPORTS: 3 REPORTS





## 5 Global Temperatures 116

KEY LEARNING **concepts** 116

GEOSYSTEMS **now** The Mystery of St. Kilda's Shrinking Sheep 117

**Temperature Concepts and Measurement** 119

Temperature Scales 119

Measuring Temperature 120

**Principal Temperature Controls** 122

Latitude 122

Altitude and Elevation 122

Cloud Cover 123

Land–Water Heating Differences 124

**Earth's Temperature Patterns** 130

January and July Global Temperature Maps 130

January and July Polar-Region Temperature Maps 132

Annual Temperature Range Map 133

**Recent Temperature Trends and Human Response** 134

Record Temperatures and Greenhouse Warming 134

Heat Stress and the Heat Index 136

GEOSYSTEMS **connection** 139

KEY LEARNING **concepts review** 140

**geosystems in action** 5 Heat Waves 121

**Focus Study 5.1 Climate Change** 136

**CRITICAL THINKING 5.1** Compare and Explain Coastal and Inland Temperatures 127

**CRITICAL THINKING 5.2** Begin a Full Physical Geography Profile of Your Area 132

THE **human** DENOMINATOR 5: **Global Temperatures** 139

A **Quantitative** SOLUTION: **Humidex** 140

GEOREPORTS: 4 REPORTS



## 6 Atmospheric and Oceanic Circulations 142

KEY LEARNING **concepts** 142

GEOSYSTEMS **now** Ocean Currents Bring Invasive Species 143

**Wind Essentials** 145

Air Pressure 145

Wind: Description and Measurement 146

**Driving Forces within the Atmosphere** 148

Pressure Gradient Force 148

Coriolis Force 148

Friction Force 150

Summary of Physical Forces on Winds 151

High- and Low-Pressure Systems 151

**Atmospheric Patterns of Motion** 151

Primary Pressure Areas and Associated Winds 151

Upper Atmospheric Circulation 158

Monsoonal Winds 160

Local Winds 162

**Oceanic Currents** 163

Surface Currents 163

Thermohaline Circulation—The Deep Currents 165

**Natural Oscillations in Global Circulation** 168

El Niño–Southern Oscillation 168

Pacific Decadal Oscillation 170

North Atlantic and Arctic Oscillations 171

GEOSYSTEMS **connection** 172

KEY LEARNING **concepts review** 174

**geosystems in action** 6 Atmospheric Circulation 156

**Focus Study 6.1 Sustainable Resources** 166

**CRITICAL THINKING 6.1** Measure the Wind 148

**CRITICAL THINKING 6.2** What Causes the North Australian Monsoon? 162

**CRITICAL THINKING 6.3** Construct Your Own Wind-Power Assessment Report 163

THE **human** DENOMINATOR 6: **Global Circulation** 172

A **Quantitative** SOLUTION: **Wind Regimes** 173

VISUAL **analysis** 6: **Atmospheric Circulation** 177

GEOREPORTS: 5 REPORTS

## PART II The Water, Weather, and Climate Systems 178



### 7 Water and Atmospheric Moisture 180

KEY LEARNING **concepts** 180

GEOSYSTEMS**now** Getting Water from the Air in Arid Climates 181

**Water's Unique Properties** 182

Phase Changes and Heat Exchange 183

Latent Heat Transfer under Natural Conditions 185

**Humidity** 186

Relative Humidity 186

Specialized Expressions of Humidity 188

Instruments for Measuring Humidity 189

**Atmospheric Stability** 190

Adiabatic Processes 190

Stable and Unstable Atmospheric Conditions 191

**Clouds and Fog** 194

Cloud Formation Processes 194

Cloud Types and Identification 194

Processes That Form Fog 197

GEOSYSTEMS**connection** 200

KEY LEARNING **concepts review** 203

**geosystems in action 7** Adiabatic Heating and Cooling 192

**CRITICAL THINKING 7.1** Iceberg Analysis 184

**CRITICAL THINKING 7.2** Changes in Temperature and Humidity 189

**CRITICAL THINKING 7.3** Identify Two Kinds of Fog 199

THE **human**DENOMINATOR7: **Atmospheric Moisture** 200

A **Quantitative**SOLUTION: **Measuring Relative Humidity and Dew-Point Temperature** 201

VISUAL **analysis 7: What type of fog is this?** 205

GEOREPORTS: 3 REPORTS



### 8 Weather 206

KEY LEARNING **concepts** 206

GEOSYSTEMS**now** What Is the Increasing Cost of Intense Weather? 207

**Air Masses** 208

Air Masses Affecting North America 208

Air Mass Modification 208

**Atmospheric Lifting Mechanisms** 209

Convergent Lifting 210

Convective Lifting 210

Orographic Lifting 211

Frontal Lifting (Cold and Warm Fronts) 212

**Midlatitude Cyclonic Systems** 216

Life Cycle of a Midlatitude Cyclone 217

Weather Maps and Forecasting 217

**Violent Weather** 220

Winter Storms and Blizzards 221

Thunderstorms 221

Damaging Winds 224

Tornadoes 225

Tropical Cyclones 226

GEOSYSTEMS**connection** 236

KEY LEARNING **concepts review** 237

**geosystems in action 8** Midlatitude Cyclones 218

**Focus Study 8.1 Natural Hazards** 230

**CRITICAL THINKING 8.1** Analyzing a Weather Map 222

**CRITICAL THINKING 8.2** Hazard Perception and Planning: What Seems to be Missing? 235

THE **human**DENOMINATOR8: **Weather** 236

A **Quantitative**SOLUTION: **Adiabatic Warming and the Rain Shadow** 237

VISUAL **analysis 8: Wildfire, clouds, climatic regions, and climate change** 239

GEOREPORTS: 5 REPORTS





## 9 Water Resources 240

KEY LEARNING **concepts** 240

GEOSYSTEMS**now** Water Resources and Climate Change in the Prairies 241

### Water on Earth 242

Worldwide Equilibrium 243

Distribution of Earth's Water Today 243

### The Hydrologic Cycle 244

Water in the Atmosphere 245

Water at the Surface 245

Water in the Subsurface 246

### Water Budgets and Resource Analysis 246

Components of the Water Budget 247

The Water-Budget Equation 250

Sample Water Budgets 251

Drought: The Water Deficit 251

### Surface Water Resources 253

Snow and Ice 254

Rivers and Lakes 254

Wetlands 256

### Groundwater Resources 256

The Groundwater Environment 257

Overuse of Groundwater 260

Pollution of Groundwater 262

### Our Water Supply 265

Water Supply in Canada 266

Water Withdrawal and Consumption 266

Future Considerations 268

GEOSYSTEMS**connection** 269

KEY LEARNING **concepts review** 271

**geosystems in action** 9 Groundwater 258

**Focus Study 9.1 Sustainable Resources** 262

**CRITICAL THINKING 9.1** Your Local Water Budget 251

**CRITICAL THINKING 9.2** Calculate Your Water Footprint 266

**CRITICAL THINKING 9.3** That Next Glass of Water 268

THE **human**DENOMINATOR<sup>9</sup>: **Water Use** 269

A **Quantitative**SOLUTION: **Thornthwaite Water Budget** 270

VISUAL**analysis 9: A weighing lysimeter** 273

GEOREports: 5 REPORTS



## 10 Global Climate Systems 274

KEY LEARNING **concepts** 274

GEOSYSTEMS**now** A Large-Scale Look at Vancouver Island's Climate 275

### Review of Earth's Climate System 276

#### Classifying Earth's Climates 276

Tropical Rain Forest Climates 282

Tropical Monsoon Climates 282

Tropical Savanna Climates 283

Humid Subtropical Hot-Summer Climates 285

Humid Subtropical Winter-Dry Climates 285

Marine West Coast Climates 287

Mediterranean Dry-Summer Climates 287

Humid Continental Hot-Summer Climates 289

Humid Continental Mild-Summer Climates 292

Subarctic Climates 293

Tundra Climates 295

Ice-Cap and Ice-Sheet Climates 295

Polar Marine Climates 295

Characteristics of Dry Climates 297

Tropical, Subtropical Hot Desert Climates 297

Midlatitude Cold Desert Climates 297

Tropical, Subtropical Hot Steppe Climates 298

Midlatitude Cold Steppe Climates 298

### Climate Regions and Climate Change 300

GEOSYSTEMS**connection** 302

KEY LEARNING **concepts review** 304

**geosystems in action** 10 Earth's Climate System 278

**CRITICAL THINKING 10.1** Finding Your Climate 282

THE **human**DENOMINATOR<sup>10</sup>: **Climate Regions** 302

A **Quantitative**SOLUTION: **Temperature and Degree-Days** 303

GEOREports: 3 REPORTS



## 11 Climate Change 306

KEY LEARNING **concepts** 306

GEOSYSTEMS**now** Greenhouse Gases Awaken in the Arctic 307

**Population Growth and Fossil Fuels—The Setting for Climate Change** 308

**Deciphering Past Climates** 310

- Methods for Long-Term Climate Reconstruction 311
- Earth's Long-Term Climate History 313
- Methods for Short-Term Climate Reconstruction 315
- Earth's Short-Term Climate History 317

**Mechanisms of Natural Climate Fluctuation** 319

- Solar Variability 319
- Earth's Orbital Cycles 319
- Continental Position and Topography 320
- Atmospheric Gases and Aerosols 320

**Climate Feedbacks and the Carbon Budget** 320

- Earth's Carbon Budget 321
- Water-Vapour Feedback 321
- Carbon–Climate Feedback 321
- CO<sub>2</sub>–Weathering Feedback 321

**Evidence for Present Climate Change** 324

- Temperature 324

- Ice Melt 325
- Sea-Level Rise 326
- Extreme Events 326

**Causes of Present Climate Change** 328

- Contributions of Greenhouse Gases 328
- Sources of Radiative Forcing 331
- Scientific Consensus 333

**Climate Models and Forecasts** 335

- Radiative Forcing Scenarios 335
- Future Temperature Scenarios 336
- Sea-Level Projections 336

**The Path Ahead** 337

- Taking a Position on Climate Change 338
- Action Now Means “No Regrets” 338
- Mitigating Climate Change: What Can You Do? 339

GEOSYSTEMS**connection** 340

KEY LEARNING **concepts review** 342

**geosystems in action 11** The Global Carbon Budget 322

**Focus Study 11.1 Climate Change** 332

**CRITICAL THINKING 11.1** Crossing the 450-ppm Threshold for Carbon Dioxide 310

**CRITICAL THINKING 11.2** Thinking through an Action Plan to Reduce Human Climate Forcing 332

**CRITICAL THINKING 11.3** Consider Your Carbon Footprint 339

THE **human**DENOMINATOR11: **Taking Action on Climate Change** 340

A **Quantitative**SOLUTION: **Climate-Change Index** 341

GEOREPORTS: 3 REPORTS

## PART III The Earth–Atmosphere Interface 344



## 12 The Dynamic Planet 346

KEY LEARNING **concepts** 346

GEOSYSTEMS**now** Earth's Migrating Magnetic Poles 347

**The Pace of Change** 348

**Earth's Structure and Internal Energy** 350

- Earth's Core and Mantle 350
- Earth's Crust 351
- The Asthenosphere and Lithosphere 352

Adjustments in the Crust 353

Earth's Magnetism 353

**Earth Materials and the Rock Cycle** 355

- Igneous Processes 355
- Sedimentary Processes 357
- Metamorphic Processes 360
- The Rock Cycle 361

**Plate Tectonics** 363

- Continental Drift 363
- Seafloor Spreading 363
- Subduction 366
- Plate Boundaries 367
- Earthquake and Volcanic Activity 369
- Hot Spots 370

**The Geologic Cycle** 375

GEOSYSTEMS**connection** 378

KEY LEARNING **concepts review** 379

- geosystems in action 12** The Geologic Cycle 376
- Focus Study 12.1** Natural Hazards 370
- Focus Study 12.2** Sustainable Resources 372
- CRITICAL THINKING 12.1** Thoughts about an “Anthropocene Epoch” 350
- CRITICAL THINKING 12.2** Tracking Your Location Since Pangaea 367
- CRITICAL THINKING 12.3** How Fast Is the Pacific Plate Moving? 375



## 13 Tectonics, Earthquakes, and Volcanism 382

- KEY LEARNING concepts** 382
- GEOSYSTEMS now** The San Jacinto Fault Connection 383
- Earth’s Surface Relief** 384
- Studying Earth’s Topography 384
  - Orders of Relief 384
  - Earth’s Hypsometry 385
  - Earth’s Topographic Regions 385
- Crustal Formation** 387
- Continental Shields 387
  - Building Continental Crust and Accretion of Terranes 388
- Crustal Deformation** 389
- Folding and Broad Warping 390
  - Faulting 392
- Orogenesis (Mountain Building)** 394
- Types of Orogenesis 397
  - The Appalachian Mountains 397
  - The Western Cordillera 400
  - The Innuitian Mountains 400
  - World Structural Regions 400



- THE human DENOMINATOR 12: Earth Material and Plate Tectonics** 378
- A Quantitative SOLUTION: Radioactivity: Earth’s Time Clock** 379
- VISUAL analysis 12: Transform faults** 381
- GEOreports: 5 REPORTS**

- Earthquakes** 400
- Earthquake Anatomy 402
  - Earthquake Intensity and Magnitude 402
  - Fault Mechanics 404
  - Earthquake Forecasting 408
  - Earthquake Planning 410

- Volcanism** 410
- Settings for Volcanic Activity 410
  - Volcanic Materials 411
  - Volcanic Landforms 412
  - Effusive Eruptions 412
  - Explosive Eruptions 413
  - Canadian Volcanoes 416
  - Volcano Forecasting and Planning 416

**GEOSYSTEMS connection** 418

**KEY LEARNING concepts review** 419

**geosystems in action 13** Mountain Building 398

**Focus Study 13.1** Natural Hazards 404

**Focus Study 13.2** Natural Hazards 406

**CRITICAL THINKING 13.1** Comparing Topographic Regions at Different Scales 386

**CRITICAL THINKING 13.2** Ocean-Floor Tectonics Tour 416

**THE human DENOMINATOR 13: Tectonics** 418

**A Quantitative SOLUTION: The Sizes of Earthquakes** 419

**VISUAL analysis 13: Ageless Mount Etna on the Isle of Sicily** 421

**GEOreports: 4 REPORTS**

## 14 Weathering, Karst Landscapes, and Mass Movement 422

**KEY LEARNING concepts** 422

**GEOSYSTEMS now** Human-Caused Scarification in the Athabasca Region of Alberta 423

**Landmass Denudation** 424

- Dynamic Equilibrium Approach to Understanding Landforms 425
- Slopes 428



**Weathering Processes** 428  
 Factors Influencing Weathering Processes 429  
 Physical Weathering Processes 430  
 Chemical Weathering Processes 432

**Karst Topography** 435  
 Formation of Karst 436  
 Features of Karst Landscapes 436  
 Caves and Caverns 437

**Mass-Movement Processes** 440  
 Mass-Movement Mechanics 441  
 Classes of Mass Movements 441  
 Humans as a Geomorphic Agent 446

GEOSYSTEMS **connection** 448  
 KEY LEARNING **concepts review** 449  
**geosystems in action** 14 Hillslopes As Open Systems 426  
**Focus Study 14.1 Natural Hazards** 445

**CRITICAL THINKING 14.1** Find a Slope; Apply the Concepts 428

THE **human**DENOMINATOR14: **Weathering, Karst, and Hillslopes** 448

A **Quantitative**SOLUTION: **The Role of Gravity in Landform Development** 449

GEOREPORTS: 5 REPORTS



**15 River Systems** 452

KEY LEARNING **concepts** 452  
 GEOSYSTEMS **now** Environmental Effects of Dams on the Nu River in China 453

**Drainage Basins and Drainage Patterns** 454  
 Drainage Divides 455  
 Drainage Basins as Open Systems 457  
 International Drainage Basins 457  
 Internal Drainage 457  
 Drainage Patterns 458

**Basic Fluvial Concepts** 459  
 Gradient 459  
 Base Level 459  
 Stream Discharge 459

**Fluvial Processes and Landforms** 462  
 Stream Channel Processes 462

Channel Patterns 465  
 Graded Streams 469  
 Depositional Landforms 473

**Floods and River Management** 478  
 Humans and Floodplains 479  
 Flood Protection 482  
 Flood Probability 483  
 Floodplain Management 483

GEOSYSTEMS **connection** 485  
 KEY LEARNING **concepts review** 486  
**geosystems in action** 15 Meandering Streams 470

**Focus Study 15.1 Environmental Restoration** 466  
**Focus Study 15.2 Natural Hazards** 480

**CRITICAL THINKING 15.1** Locate Your Drainage Basin 457

**CRITICAL THINKING 15.2** Identifying Drainage Patterns 459

THE **human**DENOMINATOR15: **Rivers, Floodplains, and Deltas** 485

A **Quantitative**SOLUTION: **Flood Frequency Analysis** 486

VISUAL **analysis 15: Horton River and Its Delta** 489

GEOREPORTS: 2 REPORTS



**16 Oceans, Coastal Systems, and Wind Processes** 490

KEY LEARNING **concepts** 490  
 GEOSYSTEMS **now** Coastal Communities Facing Changes 491

**Global Oceans and Seas** 492  
 Properties of Seawater 493  
 Physical Structure and Human Impacts 494

**Coastal System Components** 495  
 The Coastal Environment 496  
 Sea Level 498

**Coastal System Actions** 499  
 Tides 499  
 Waves 501

**Coastal System Outputs** 505  
 Coastal Erosion 505  
 Coastal Deposition 507  
 Barrier Beaches and Islands 511

Coral Formations	513
Coastal Wetlands	515
<b>Wind Processes</b>	<b>516</b>
Eolian Transport of Dust and Sand	517
Eolian Erosion	518
Desert Pavement	519
Eolian Deposition	520
<b>GEOSYSTEMSconnection</b>	<b>526</b>
<b>KEY LEARNINGconcepts review</b>	<b>528</b>
<b>geosystems in action 16</b>	<b>Wind-Blown Dune Forms 522</b>
<b>Focus Study 16.1 Pollution</b>	<b>496</b>
<b>Focus Study 16.2 Natural Hazards</b>	<b>506</b>



## 17 Glacial and Periglacial Landscapes 532

<b>KEY LEARNINGconcepts</b>	<b>532</b>
<b>GEOSYSTEMSnow</b>	<b>Tidewater Glaciers and Ice Shelves Give Way to Warming 533</b>
<b>Snow into Ice—The Basis of Glaciers</b>	<b>534</b>
Properties of Snow	534
Formation of Glacial Ice	535
<b>Types of Glaciers</b>	<b>535</b>
Alpine Glaciers	536
Continental Ice Sheets	538
<b>Glacial Processes</b>	<b>538</b>
Glacial Mass Balance	539
Glacial Movement	540
<b>Glacial Landforms</b>	<b>544</b>

<b>CRITICAL THINKING 16.1</b>	<b>Coastal Sensitivity to Sea-Level Rise 499</b>
<b>CRITICAL THINKING 16.2</b>	<b>Allocating Responsibility and Cost for Coastal Hazards 513</b>
<b>CRITICAL THINKING 16.3</b>	<b>The Nearest Eolian Features to You 525</b>
<b>THEhumanDENOMINATOR16:</b>	<b>Oceans, Coasts, and Dunes 526</b>
<b>AQuantitativeSOLUTION:</b>	<b>Coastal Sediment Budgets 527</b>
<b>VISUALanalysis 16:</b>	<b>Coastal Processes and Barrier Islands 531</b>
<b>GEOreports:</b>	<b>5 REPORTS</b>

Erosional Landforms	544
Depositional Landforms	547
<b>Periglacial Landscapes</b>	<b>550</b>
Permafrost and Its Distribution	550
Periglacial Processes	551
Humans and Periglacial Landscapes	553
<b>The Pleistocene Epoch</b>	<b>553</b>
Ice-Age Landscapes	554
Paleolakes	555
<b>Arctic and Antarctic Regions</b>	<b>558</b>
Recent Polar Region Changes	559
<b>GEOSYSTEMSconnection</b>	<b>562</b>
<b>KEY LEARNINGconcepts review</b>	<b>564</b>
<b>geosystems in action 17</b>	<b>Glaciers As Dynamic Systems 542</b>
<b>Focus Study 17.1 Natural Hazards</b>	<b>536</b>
<b>CRITICAL THINKING 17.1</b>	<b>Looking for Glacial Features 547</b>
<b>CRITICAL THINKING 17.2</b>	<b>A Sample of Life at the Polar Station 559</b>
<b>CRITICAL THINKING 17.3</b>	<b>The IPY Accomplishment Continues 561</b>
<b>THEhumanDENOMINATOR17:</b>	<b>Glaciers and Permafrost 562</b>
<b>AQuantitativeSOLUTION:</b>	<b>Glacier Mass Balance 563</b>
<b>VISUALanalysis 17:</b>	<b>Glacial Processes and Landforms 567</b>
<b>GEOreports:</b>	<b>4 REPORTS</b>

## PART IV SOILS, ECOSYSTEMS, AND BIOMES 568



## 18 The Geography of Soils 570

<b>KEY LEARNINGconcepts</b>	<b>570</b>
<b>GEOSYSTEMSnow</b>	<b>Desertification: Declining Soils and Agriculture in Earth's Drylands 571</b>

<b>Soil-Formation Factors and Soil Profiles</b>	<b>572</b>
Natural Factors in Soil Development	572
Soil Horizons	573
<b>Soil Characteristics</b>	<b>574</b>
Physical Properties	574
Chemical Properties	578
<b>Human Impacts on Soils</b>	<b>579</b>
Soil Erosion	579
Desertification	581
<b>Soil Classification</b>	<b>582</b>
Diagnostic Soil Horizons	582
Pedogenic Regimes	582

The Canadian System of Soil Classification (CSSC) 582  
 Categories of Classification in the CSSC 583  
 Soil Horizons in the CSSC 583  
 The 10 Soil Orders of the CSSC 583  
 CSSC and Worldwide Soil Taxonomy 596

GEOSYSTEMS **connection** 600

KEY LEARNING **concepts review** 601

**geosystems in action 18** Biological Activity in Soils 577



## 19 Ecosystem Essentials 604

KEY LEARNING **concepts** 604

GEOSYSTEMS **now** Species' Distributions Shift with Climate Change 605

### Energy Flows and Nutrient Cycles 606

Converting Energy to Biomass 607

Elemental Cycles 610

Energy Pathways 613

### Communities and Species Distributions 619

The Niche Concept 619

Species Interactions 620

Abiotic Influences 621

Limiting Factors 622

Disturbance and Succession 623

**Focus Study 18.1 Pollution** 587

**CRITICAL THINKING 18.1** Soil Losses—What to Do? 582

**CRITICAL THINKING 18.2** Soil Observations 583

THE **human**DENOMINATOR18: **Soils and Land Use** 600

A **Quantitative**SOLUTION: **Soil Density and Porosity** 601

VISUAL **analysis 18: Soil as a fuel** 603

GEOREPORTS: 4 REPORTS

## Biodiversity, Evolution, and Ecosystem Stability 628

Biological Evolution Delivers Biodiversity 628

Biodiversity Fosters Ecosystem Stability 628

Biodiversity on the Decline 630

GEOSYSTEMS **connection** 635

KEY LEARNING **concepts review** 636

**geosystems in action 19** Coastal Dead Zones 614

**Focus Study 19.1 Natural Hazards** 624

**Focus Study 19.2 Environmental Restoration** 632

**CRITICAL THINKING 19.1** Mutualism? Parasitism? Where Do We Fit in? 621

**CRITICAL THINKING 19.2** Observe Ecosystem Disturbances 623

THE **human**DENOMINATOR19: **Ecosystems and Biodiversity** 635

A **Quantitative**SOLUTION: **Landscape Pattern Analysis** 636

VISUAL **analysis 19: Declining food, climate change impacts, and animal stress** 639

GEOREPORTS: 4 REPORTS



## 20 Terrestrial Biomes 640

KEY LEARNING **concepts** 640

GEOSYSTEMS **now** Invasive Species Arrive at Tristan da Cunha 641

### Biogeographic Divisions 642

Biogeographic Realms 642

Biomes 643

### Invasive Species 644

### Earth's Terrestrial Biomes 647

Tropical Rain Forest 647

Tropical Seasonal Forest and Scrub 651

Tropical Savanna 651

Midlatitude Broadleaf and Mixed Forest 654

Boreal and Montane Forest 655

Temperate Rain Forest 657

Mediterranean Shrubland 658

Midlatitude Grassland 659

Deserts 659

Arctic and Alpine Tundra 661

## Conservation, Management, and Human Biomes 662

Island Biogeography for Species Preservation 662

**Focus Study 20.1 Environmental Restoration** 663

Aquatic Ecosystem Management 664

Anthropogenic Biomes 665

GEOSYSTEMS **connection** 666

KEY LEARNING **concepts review** 668

**geosystems in action 20** Tropical Rain Forests and Amazon Deforestation 652



**CRITICAL THINKING 20.1** Reality Check 647

**CRITICAL THINKING 20.2** Tropical Forests: A Global or Local Resource? 651

**CRITICAL THINKING 20.3** A Shifting-Climate Hypothetical 662

THE **human**DENOMINATOR<sup>20</sup>: **Anthropogenic Environments** 666

A **Quantitative**SOLUTION: **Species Richness, Diversity, and Similarity** 667

**GEOREPORTS**: 5 REPORTS

**Appendix A** Maps in This Text and Topographic Maps **A-1**

**Appendix B** The 12 Soil Orders of the U.S. Soil Taxonomy **A-6**

**Appendix C** The Köppen Climate Classification System **A-10**

**Appendix D** Common Conversions **A-13**

**Glossary** **G-1**

**Index** **I-1**

# 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>™</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>™</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>™</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.
- **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>
- Pearson eText gives students access to the text wherever they have access to the Internet. Users can create notes, highlight text, and click hyperlinked words to view definitions. The Pearson eText also allows for quick navigation and provides full-text search.

We also offer prebuilt assignments for instructors to make it easy to assign this powerful tutorial and homework system. The Mastering platform is the only online tutorial/homework system with research showing that it improves student learning. A wide variety of published papers based on NSF-sponsored research and tests illustrate the benefits of the Mastering program. Results documented in scientifically valid efficacy papers are available at [www.masteringgeography.com/site/results](http://www.masteringgeography.com/site/results).

**CourseSmart** CourseSmart goes beyond traditional expectations—providing instant, online access to the textbooks and course materials you need at a lower cost for students. And even as students save money, you can save time and hassle with a digital eTextbook that allows you to search for the most relevant content at the very moment you need it. Whether it's evaluating textbooks or creating lecture notes to help students with difficult concepts, CourseSmart can make life a little easier. See how when you visit [www.coursesmart.com/instructors](http://www.coursesmart.com/instructors).

**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

### Greenhouse Gases Awaken in the Arctic

In the subarctic and tundra climate regions of the Northern Hemisphere, permafrost—frozen soil 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 soils 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.

**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 layers 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.

**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 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. (DeLay Michael Sudinger)

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

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

► **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.



Hydrothermal features and tuffaceous 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 Feilberg/Shutterstock)



In April 2013, the Nevada Desert Peak Enhanced Geothermal System (EDS) became the first U.S. enhanced geothermal project to supply electricity to the power grid. (Inga Siersch/Magnum)

### HUMANS ↔ ENDOGENIC PROCESSES

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



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)



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. (Perry Tassels/Magnum)

### 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 center 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.

**15.1b** ACTIVE EROSION ALONG A MEANDER

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

**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.

**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.

**Stream valley landscapes**

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.

**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.

**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.

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

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

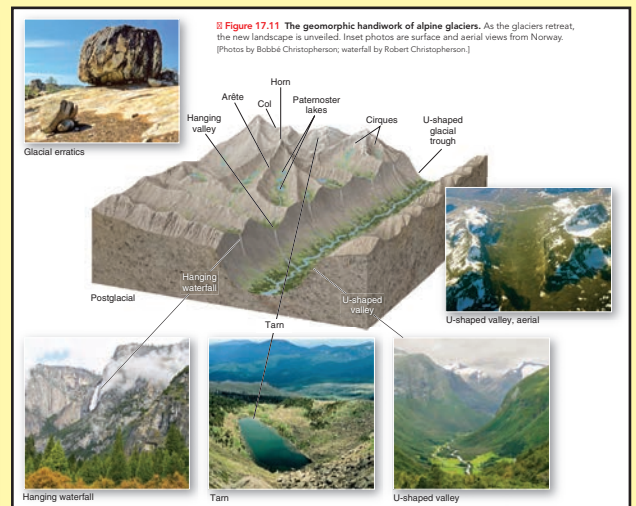
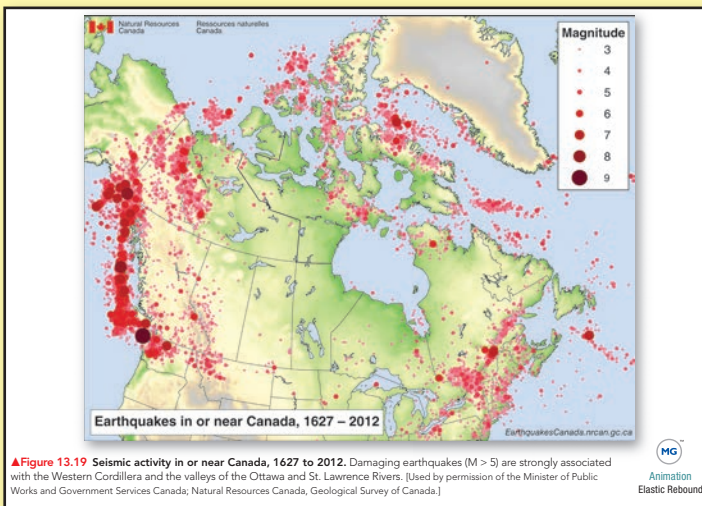
**Assess:** Demonstrate understanding of meander and oxbow lake formation (if assigned by instructor).

**Animation**  
Stream Processes, Floodplains, Oxbow Lake Formation

470

471

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

**A**stronaut Mark Lee, on a spacewalk from the Space Shuttle Discovery in 1996 (mission STS-54), was 241 km above Earth's surface, in orbit beyond the protective shield of the atmosphere (Figure GN 3.1). He was travelling at 28165 km/h<sup>1</sup>, 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<sub>2</sub> 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 1996. (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<sup>1</sup>—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 atmosphere's 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<sup>1</sup>. 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



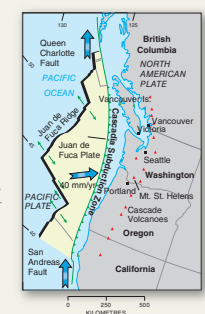
**Figure GN 3.2** A remotely triggered camera captures a stratospheric leap into history. (National Museum of the U.S. Air Force)

**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/APP 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 in 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 13.2). A magnitude 7.3 earthquake that occurred in June 1946 on central Vancouver Island (Figure 13.3a) 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 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

**Figure 13.1** 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.)

largest earthquake in recorded history, occurred on this fault in August 1949 (Figure 13.3b). 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/zones/western-eng.php](http://www.seismescanada.mcgill.ca/zones/western-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.

► **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.

► 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.

## 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.



## 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.

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

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:

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

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



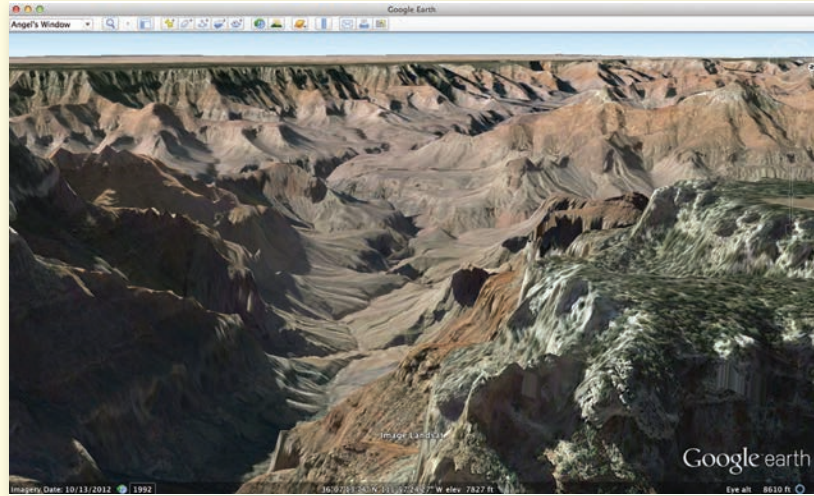
## CRITICALthinking 15.1 Locate Your Drainage Basin

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? ●

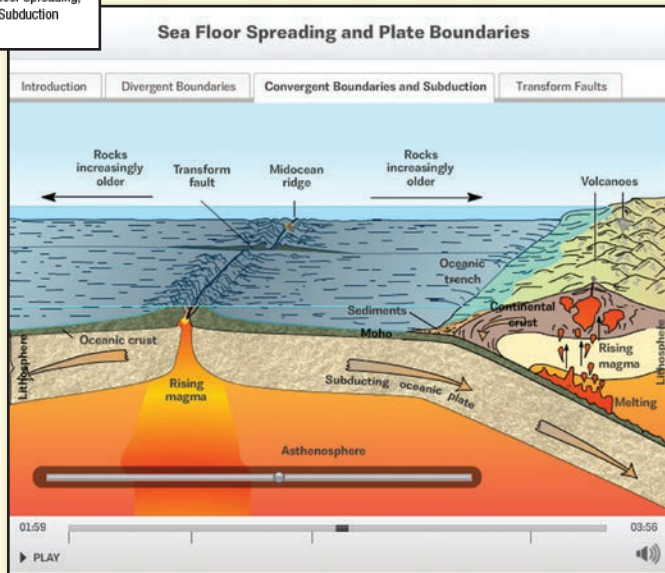
MasteringGeography delivers engaging, dynamic learning opportunities—focusing on course objectives and responsive to each student’s progress—that are proven to help students absorb geography course material and understand difficult physical processes and geographic concepts.

## 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.



**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.

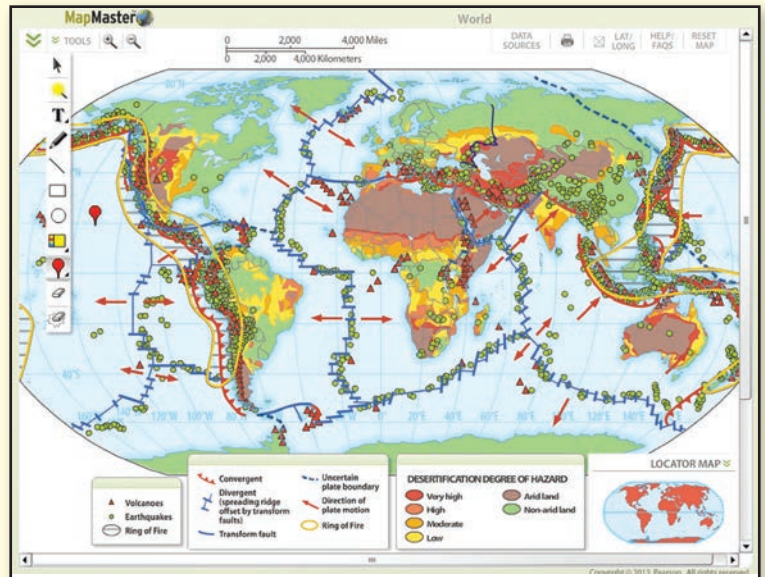




## Engage in Map Reading, Data Analysis, and Critical Thinking

**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.

**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

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



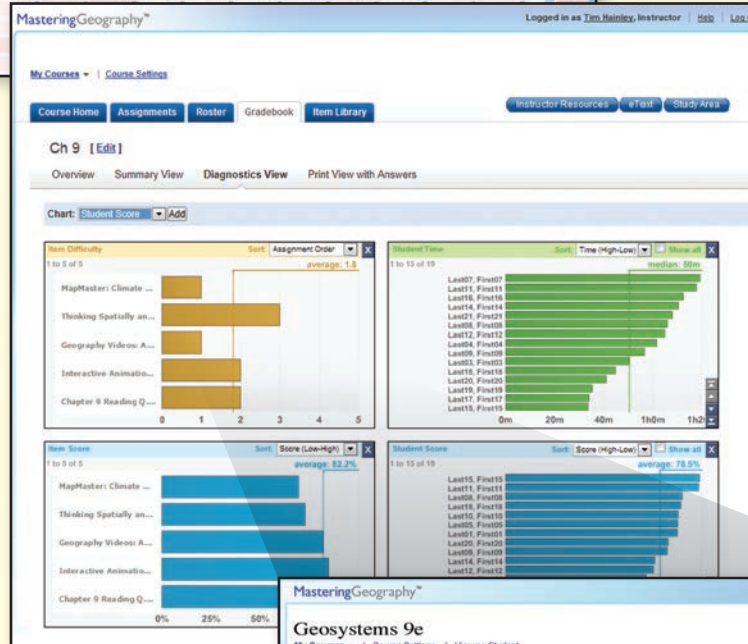
# MasteringGeography™

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.dg	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	62.0	88.1	89.5	86.7	91.6	83.7	90.0	88.4	77.7			24.5
Last01, First01	84.4	73.3	83.3	100	89.9	0.0	95.6	101	100	0.0	87.4			48.9
Last02, First02	70.3	64.9	83.9	88.0	49.5	86.2	72.9	47.5	80.0	88.9	66.3			28.2
Last03, First03	73.6	48.0	61.9	104	102	84.9	85.0	100	95.0	90.7	87.3			27.0
Last04, First04	72.5	53.8	80.0	34.3	86.3	65.3	80.0	83.4	90.0	99.2	87.0			36.3
Last05, First05	78.8	89.3	78.6	89.0	87.0	85.2	82.5	34.6	85.0	98.3	87.7			33.9

► 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**  
My Courses | Course Settings | View as Student

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

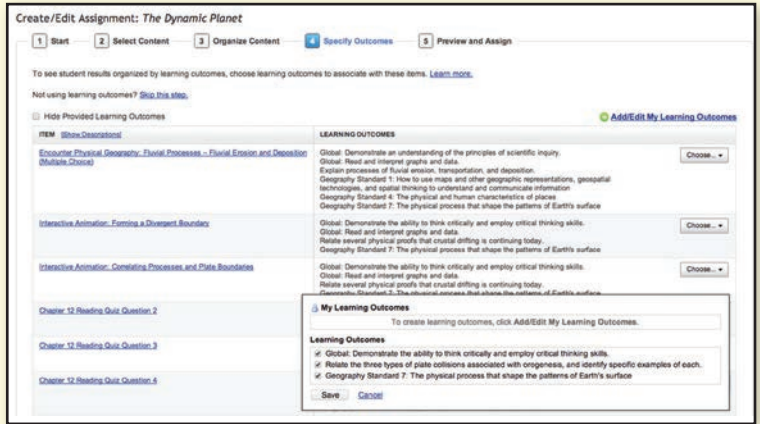
% Wrong	Answer	Response
38.1%	Ethiopia is projected to have an 88% population increase. Are there other countries that will have a higher increase?	
23.8%	Although India is expected to surpass China as the most highly populated country in the world, India is projected to have only a 36% population increase 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



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

**Central Asia** Throughout central Asia, over-exploitation of water resources has combined with drought to cause desertification. The Aral Sea, formerly one of the four largest lakes in the world, is nearly dried up. As the sea's following waters were channel for irrigation (see Figure 18.14 at the end of this chapter), the sea's water level has become available for wind deflation, leading to massive dust storms. The sediment contained fertilizers and pesticides from agricultural runoff, so its mobilization and spread over the land has caused crop damage and human health problems, including increased cancer rates.

**Africa's Sahel** In Africa, the Sahel is the transition region between the Sahara Desert to the north and the wetter equatorial regions. The accelerated degradation of desert conditions through portions of the Sahel region has led many African people on land that no longer can sustain the livelihood of their herds. Other factors contributing to desertification in the Sahel are population increases, land degradation from deforestation and overgrazing of cattle, poverty, and the lack of a coherent environmental policy.

**A Growing Problem** The UN estimates that degraded lands worldwide cover over 70 billion hectares and affect 1.3 billion people. The vast majority of degraded lands are located in the developing world. The primary causes of desertification include overgrazing, deforestation, and soil erosion. However, desertification is

**KEY LEARNING OBJECTIVES**

- 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, consistency, permeability, 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 12 soil orders of the Canadian System of Soil Classification, and explain the general occurrence of these orders.

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.



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