

# CONTENTS

## Prologue | Introducing Physical Geography 2

### Introducing Geography 6

Human and Physical Geography 7

Tools in Geography 9

Understanding Physical Geography 14

### Spheres, Scales, Systems, and Cycles 14

The Spheres—Four Great Earth Realms 14

Scale, Pattern, and Process 15

Systems in Physical Geography 16

Time Cycles 16

### Physical Geography, Environment, and Global Change 16

Global Climate Change 18

The Carbon Cycle 18

Biodiversity 18

Pollution 19

Extreme Events 19

## 1 | The Earth as a Rotating Planet 22

### The Shape of the Earth 24

#### Earth Rotation 26

Environmental Effects of Earth Rotation 26

#### The Geographic Grid 26

*Focus on Remote Sensing 1.1 • The Global Positioning System 27*

Parallels and Meridians 28

Latitude and Longitude 28

#### Map Projections 30

Polar Projection 30

Mercator Projection 30

Goode Projection 32

#### Global Time 32

Standard Time 33

*Geographer's Tools 1.2 • Geographic Information Systems 34*

World Time Zones 36

International Date Line 37

Daylight Saving Time 38

Precise Timekeeping 38

### The Earth's Revolution Around the Sun 38

Tilt of the Earth's Axis 38

Solstice and Equinox 39

Equinox Conditions 41

Solstice Conditions 41

#### A Closer Look:

*Geographer's Tools 1.3 • Focus on Maps 45*



## 2 | The Earth's Global Energy Balance 50

### Electromagnetic Radiation 52

Radiation and Temperature 54

Solar Radiation 54

Characteristics of Solar Energy 55

Longwave Radiation from the Earth 56

The Global Radiation Balance 56

### Insolation over the Globe 57

Insolation and the Path of the Sun in the Sky 57

Daily Insolation through the Year 60

Annual Insolation by Latitude 61

### World Latitude Zones 61

### Composition of the Atmosphere 62

Ozone in the Upper Atmosphere 62

### Sensible Heat and Latent Heat Transfer 63

### The Global Energy System 63

Solar Energy Losses in the Atmosphere 63

*Eye on Global Change 2.1 • The Ozone Layer—Shield to Life* 64

Albedo 65

Counterradiation and the Greenhouse Effect 66

### Global Energy Budgets of the Atmosphere and Surface 67

Incoming Shortwave Radiation 67

Surface Energy Flows 67

*Focus on Remote Sensing 2.2 • CERES—Clouds and the Earth's Radiant Energy System* 68

Energy Flows to and from the Atmosphere 68

Climate and Global Change 69

### Net Radiation, Latitude, and the Energy Balance 69

*Eye on the Environment 2.3 • Solar Power* 72

### A Closer Look:

*Geographer's Tools 2.4 • Remote Sensing for Physical Geography* 77

## 3 | Air Temperature 86

### Surface Temperature 89

### Air Temperature 89

Measurement of Air Temperature 89

### The Daily Cycle of Air Temperature 91

Daily Insolation and Net Radiation 91

Daily Temperature 91

Temperatures Close to the Ground 92

Environmental Contrasts: Urban and Rural Temperatures 92

The Urban Heat Island 94

### Temperature Structure of the Atmosphere 95

Troposphere 96

Stratosphere and Upper Layers 96

High-Mountain Environments 97

Temperature Inversion 98

### The Annual Cycle of Air Temperature 99

Net Radiation and Temperature 99

Land and Water Contrasts 100

### World Patterns of Air Temperature 102

Factors Controlling Air Temperature Patterns 103

World Air Temperature Patterns for January and July 104

The Annual Range of Air Temperatures 104

### Global Warming and the Greenhouse Effect 108

Factors Influencing Climatic Warming and Cooling 108

The Temperature Record 109

Future Scenarios 110

*Eye on Global Change 3.1 • Carbon Dioxide—On the Increase* 110

### A Closer Look:

*Eye on Global Change 3.2 • The IPCC Report of 2001* 116

## 4 | Atmospheric Moisture and Precipitation 118

### Three States of Water 120

### The Hydrosphere and the Hydrologic Cycle 121

The Global Water Balance 122

### Humidity 123

Specific Humidity 123

Relative Humidity 124

### The Adiabatic Process 125

Dry Adiabatic Rate 126

Wet Adiabatic Rate 127

### Clouds 127



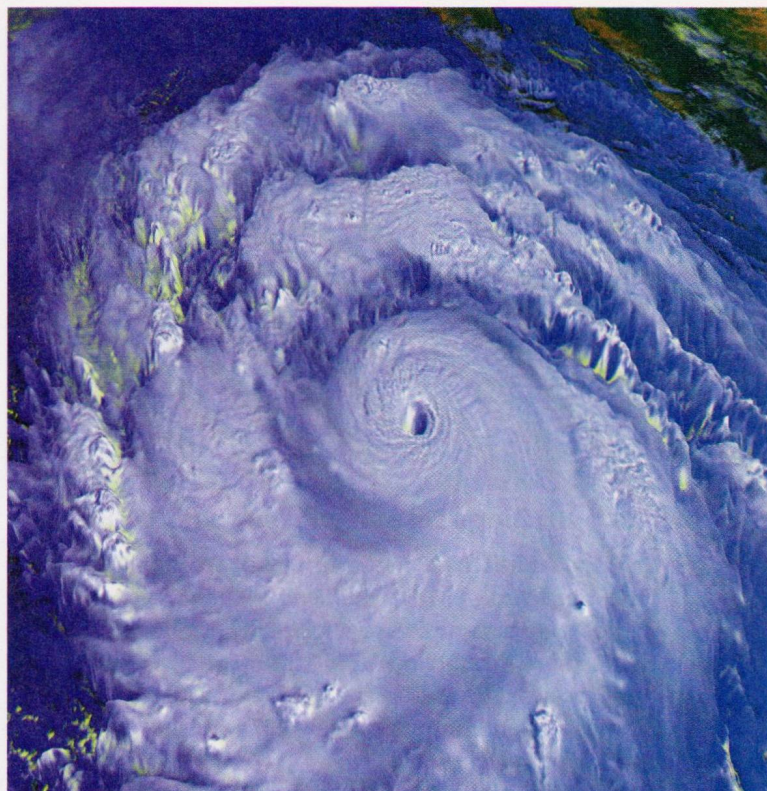
Cloud Forms	128
Fog	128
<b>Precipitation 129</b>	
<i>Focus on Remote Sensing 4.1 • Observing</i>	
Clouds from GOES	130
Precipitation Processes	133
Orographic Precipitation	133
Convective Precipitation	134
Thunderstorms	138
Microbursts	139
<b>Air Quality 140</b>	
<b>A Closer Look:</b>	
<i>Eye on the Environment 4.2 • Air Pollution</i>	143

## 5 | Winds and Global Circulation 150

<b>Atmospheric Pressure 152</b>	
Measuring Atmospheric Pressure	153
How Air Pressure Changes with Altitude	154
<b>Wind 154</b>	
Measurement of Wind	155
Winds and Pressure Gradients	155
A Simple Convective Wind System	156
Sea and Land Breezes	156
Local Winds	156
The Coriolis Effect and Winds	158
<i>Eye on the Environment 5.1 • Wind Power, Wave</i>	
Power, and Current Power	159
Cyclones and Anticyclones	161
Surface Winds on an Ideal Earth	162
<b>Global Wind and Pressure Patterns 163</b>	
Subtropical High-Pressure Belts	163
The ITCZ and the Monsoon Circulation	166
Wind and Pressure Features of Higher Latitudes	167
<b>Winds Aloft 167</b>	
The Geostrophic Wind	168
Global Circulation at Upper Levels	169
Rossby Waves, Jet Streams, and the Polar Front	170
<b>Oceanic Circulation 173</b>	
Temperature Layers of the Ocean	173
<b>Surface Currents 174</b>	
Deep Currents and Thermohaline Circulation	177
<i>Eye on Global Change 5.2 • El Niño</i>	178

## 6 | Weather Systems 184

<b>Air Masses 186</b>	
North American Air Masses	188
Cold, Warm, and Occluded Fronts	188
<b>Traveling Cyclones and Anticyclones 190</b>	
Wave Cyclones	192
Weather Changes within a Wave Cyclone	193
Cyclone Tracks and Cyclone Families	194
The Tornado	195
<b>Tropical and Equatorial Weather Systems 196</b>	
Easterly Waves and Weak Equatorial Lows	197
Polar Outbreaks	197



<i>Focus on Remote Sensing 6.1 • TRMM—The Tropical</i>	
Rainfall Monitoring Mission	198
Tropical Cyclones	200
Impacts of Tropical Cyclones	201
<b>Poleward Transport of Heat and Moisture 204</b>	
Atmospheric Heat and Moisture Transport	205
Oceanic Heat Transport	205
<i>Eye on the Environment 6.2 • Hurricane Andrew—Killer</i>	
Cyclone	206
<b>Cloud Cover, Precipitation, and Global</b>	
<b>  Warming 208</b>	

## 7 | Global Climates 212

<b>Keys to Climate 214</b>	
Temperature Regimes	215
Global Precipitation	215
Seasonality of Precipitation	219
<b>Climate Classification 221</b>	
<i>Special Supplement 7.1 • The Köppen Climate</i>	
System	222
Overview of the Climates	227
Dry and Moist Climates	228
<b>Low-Latitude Climates 230</b>	
The Wet Equatorial Climate ①	230
The Monsoon and Trade-Wind Coastal Climate ②	231
The Wet-Dry Tropical Climate ③	235
The Dry Tropical Climate ④	236
<i>Eye on Global Change 7.2 • Drought and Land</i>	
Degradation in the African Sahel	238
<b>Midlatitude Climates 241</b>	
The Dry Subtropical Climate ⑤	245

- The Moist Subtropical Climate ⑥ 246
- The Mediterranean Climate ⑦ 249
- The Marine West-Coast Climate ⑧ 251
- The Dry Midlatitude Climate ⑨ 254
- The Moist Continental Climate ⑩ 255

**High-Latitude Climates 258**

- The Boreal Forest Climate ⑪ 258
- The Tundra Climate ⑫ 260
- The Ice Sheet Climate ⑬ 262

**Highland Climates 263**

**Our Changing Climate 263**

**A Closer Look:**

*Eye on Global Change 7.3 • Regional Impacts of Climate Change on North America 270*

**8 | Biogeographic Processes 278**

**Energy and Matter Flow in Ecosystems 280**

- The Food Web 281
- Photosynthesis and Respiration 281
- Net Primary Production 285
- Net Production and Climate 287
- Biomass as an Energy Source 287
- The Carbon Cycle 288
- Eye on Global Change 8.1 • Human Impact on the Carbon Cycle 290*

The Nitrogen Cycle 292

**Ecological Biogeography 293**

- Water Need 294
- Temperature 295

- Other Climatic Factors 296
- Bioclimatic Frontiers 297
- Geomorphic Factors 298
- Edaphic Factors 299
- Disturbance 300
- Interactions among Species 300
- Focus on Remote Sensing 8.2 • Remote Sensing of Fires 302*

**Ecological Succession 304**

Succession, Change, and Equilibrium 306

**Historical Biogeography 307**

- Evolution 307
- Eye on the Environment 8.3 • The Great Yellowstone Fire 310*
- Speciation 311
- Extinction 313
- Dispersal 313
- Distribution Patterns 316
- Biogeographic Regions 316

**Biodiversity 317**

**A Closer Look:**

*Eye on Global Change 8.4 • Monitoring Global Productivity from Space 324*

**9 | Global Biogeography 330**

**Natural Vegetation 332**

**Structure and Life-Form of Plants 333**

**Terrestrial Ecosystems—The Biomes 333**

- Forest Biome 335
- Focus on Remote Sensing 9.1 • Mapping Global Land Cover by Satellite 336*
- Eye on Global Change 9.2 • Exploitation of the Low-Latitude Rainforest Ecosystem 342*
- Savanna Biome 350
- Grassland Biome 351
- Desert Biome 353
- Tundra Biome 355
- Altitude Zones of Vegetation 357
- Climatic Gradients and Vegetation Types 357

**10 | Global Soils 362**

**The Nature of the Soil 365**

- Soil Color and Texture 365
- Soil Colloids 366
- Soil Acidity and Alkalinity 367
- Soil Structure 367
- Minerals of the Soil 368
- Soil Moisture 368

**The Soil Water Balance 369**

A Simple Soil Water Budget 370

**Soil Development 371**

- Soil Horizons 371
- Soil-Forming Processes 372
- Soil Temperature and Other Factors 373
- Eye on the Environment 10.1 • Death of a Civilization 374*



**The Global Scope of Soils 376**

Soil Orders 377

Desert and Tundra Soils 387

A Midcontinental Transect from Aridisols to Alfisols  
389**Global Climate Change and Agriculture 389****A Closer Look:***Eye on Global Change 10.2 • Global Climate Change  
and Agriculture 393***11 | Earth Materials 396****The Crust and Its Composition 398**

Rocks and Minerals 399

**Igneous Rocks 400**

Common Igneous Rocks 400

Intrusive and Extrusive Igneous Rocks 402

Chemical Alteration of Igneous Rocks 404

**Sediments and Sedimentary Rocks 405***Eye on the Environment 11.1 • Battling Iceland's  
Heimaey Volcano 406*

Clastic Sedimentary Rocks 408

Chemically Precipitated Sedimentary Rocks 410

Hydrocarbon Compounds in Sedimentary Rocks 410

**Metamorphic Rocks 412****The Cycle of Rock Change 413***Focus on Remote Sensing 11.2 • Geologic Mapping  
with ASTER 414***12 | The Lithosphere and Plate  
Tectonics 420****The Structure of the Earth 423**

The Earth's Interior 423

The Lithosphere and Asthenosphere 424

**The Geologic Time Scale 425****Major Relief Features of the Earth's Surface 426**

Relief Features of the Continents 426

Relief Features of the Ocean Basins 428

**Plate Tectonics 432**

Tectonic Processes 432

Plate Motions and Interactions 433

*Eye on the Environment 12.1 • The Wilson Cycle  
and Supercontinents 436*

The Global System of Lithospheric Plates 440

Subduction Tectonics 441

Orogens and Collisions 442

Continental Rupture and New Ocean Basins 442

The Power Source for Plate Movements 444

**Continents of the Past 445****13 | Volcanic and Tectonic  
Landforms 450****Landforms 452****Volcanic Activity 453**

Stratovolcanoes 456



Shield Volcanoes 456

Volcanic Activity over the Globe 461

Volcanic Eruptions as Environmental Hazards 461

**Landforms of Tectonic Activity 461***Eye on the Environment 13.1 • Geothermal Energy  
Sources 462*

Fold Belts 463

Faults and Fault Landforms 463

*Focus on Remote Sensing 13.2 • Remote Sensing  
of Volcanoes 464*

The Rift Valley System of East Africa 468

**Earthquakes 469**

Earthquakes and Plate Tectonics 471

Seismic Sea Waves 472

Earthquakes along the San Andreas Fault 473

*Eye on Environment 13.3 • The Indian Ocean Tsunami  
of 2004 476***14 | Weathering and Mass  
Wasting 480****Physical Weathering 483**

Frost Action 483

Salt-Crystal Growth 484

Unloading 486

Other Physical Weathering Processes 486

**Chemical Weathering and Its Landforms 487**

Hydrolysis and Oxidation 487

Acid Action 487

**Mass Wasting 488**

Slopes 490

Soil Creep 491

Earthflow 491

Environmental Impact of Earthflows 492

Mudflow and Debris Flood 493

Landslide 494

**Induced Mass Wasting 494**

Induced Earthflows 495

Scarification of the Land 496

*Eye on the Environment 14.1 • The Great Hebgen  
Lake Disaster 497*

**Processes and Landforms of Arctic and Alpine Tundra 498**

- Permafrost 499
- The Active Layer 501
- Forms of Ground Ice 501
- Patterned Ground and Solifluction 502
- Alpine Tundra 504
- Environmental Problems of Permafrost 506
- Climate Change in the Arctic 506

**15 | Fresh Water of the Continents 510**

**Ground Water 514**

- The Water Table Surface 514
- Aquifers 515

**Limestone Solution by Ground Water 516**

- Limestone Caverns 516
- Karst Landscapes 517

**Problems of Ground Water Management 518**

- Water Table Depletion 519
- Contamination of Ground Water 520

**Surface Water 520**

- Overland Flow and Stream Flow 521
- Eye on Global Change 15.1 • Sinking Cities* 522
- Stream Discharge 522
- Drainage Systems 525

**Stream Flow 525**

- How Urbanization Affects Stream Flow 526
- The Annual Flow Cycle of a Large River 526
- River Floods 527
- Flood Prediction 528
- The Mississippi Flood of 1993 528

**Lakes 529**

- Saline Lakes and Salt Flats 533
- Desert Irrigation 533
- Eye on the Environment 15.2 • The Great Lakes* 534
- Pollution of Surface Water 536

**Surface Water as a Natural Resource 537**

**A Closer Look:**

- Eye on Global Change 15.3 • The Aral Sea—A Dying Saline Lake* 541

**16 | Landforms Made by Running Water 544**

**Fluvial Processes and Landforms 546**

- Erosional and Depositional Landforms 547

**Slope Erosion 547**

- Accelerated Erosion 547
- Sheet Erosion and Rilling 548
- Colluvium and Alluvium 549
- Slope Erosion in Semiarid and Arid Environments 549

**The Work of Streams 550**

- Stream Erosion 550
- Stream Transportation 551
- Capacity of a Stream to Transport Load 552

**Stream Gradation 552**

- Landscape Evolution of a Graded Stream 553
- Great Waterfalls 555
- Dams and Resources 557
- Aggradation and Alluvial Terraces 558
- Focus on Remote Sensing 16.1 • A Canyon Gallery* 560
- Alluvial Rivers and Their Floodplains 562
- Entrenched Meanders 563
- The Geographic Cycle 565
- Equilibrium Approach to Landforms 565
- Fluvial Processes in an Arid Climate 567**
- Alluvial Fans 568
- The Landscape of Mountainous Deserts 568

**17 | Landforms and Rock Structure 574**

**Rock Structure as a Landform Control 576**

- Strike and Dip 578

**Landforms of Horizontal Strata and Coastal Plains 578**

- Arid Regions 578
- Drainage Patterns on Horizontal Strata 579
- Coastal Plains 579
- Focus on Remote Sensing 17.1 • Landsat Views Rock Structures* 580

**Landforms of Warped Rock Layers 583**

- Sedimentary Domes 583



Fold Belts 585

### **Landforms Developed on Other Land-Mass Types 586**

Erosion Forms on Fault Structures 586

Metamorphic Belts 586

Exposed Batholiths and Monadnocks 587

Deeply Eroded Volcanoes 588

*Eye on the Environment 17.2 • Marvelous, Majestic, Monolithic Domes 590*

## **18 | Landforms Made by Waves and Wind 596**

### **The Work of Waves 598**

Wave Characteristics 599

Marine Scarps and Cliffs 600

Beaches 604

Littoral Drift 604

Littoral Drift and Shore Protection 605

### **Tidal Currents 606**

Tidal Current Deposits 606

### **Types of Coastlines 607**

Shorelines of Submergence 607

Barrier-Island Coasts 607

Delta and Volcano Coasts 608

Coral-Reef Coasts 611

Raised Shorelines and Marine Terraces 612

Rising Sea Level 612

### **Wind Action 613**

Erosion by Wind 613

Dust Storms 613

### **Sand Dunes 614**

Types of Sand Dunes 615

Coastal Foredunes 618

### **Loess 619**

Induced Deflation 620

### **A Closer Look:**

*Eye on Global Change 18.1 • Global Change and Coastal Environments 624*

## **19 | Glacial Landforms and the Ice Age 628**

### **Glaciers 630**

#### **Alpine Glaciers 632**

Landforms Made by Alpine Glaciers 633

Glacial Troughs and Fjords 633

*Focus on Remote Sensing 19.1 • Remote Sensing of Glaciers 636*

#### **Ice Sheets of the Present 638**

#### **Sea Ice and Icebergs 639**

#### **The Ice Age 639**

Glaciation During the Ice Age 640



### **Landforms Made by Ice Sheets 641**

Erosion by Ice Sheets 641

Deposits Left by Ice Sheets 642

Environmental Aspects of Glacial Deposits 644

### **Investigating the Ice Age 645**

Possible Causes of the Late-Cenozoic Ice Age 645

Possible Causes of Glaciation Cycles 648

Holocene Environments 649

*Eye on Global Change 19.2 • Ice Sheets and Global Warming 650*

## **Epilogue | News from the Future 654**

### **Appendix 1 | The Canadian System of Soil Classification 661**

### **Appendix 2 | Climate Definitions and Boundaries 668**

### **Appendix 3 | Topographic Map Symbols 670**

### **Appendix 4 | Conversion Factors 672**

### **Glossary 673**

### **Photo Credits 702**

### **Index 704**