

REED WICANDER | JAMES S. MORRIS

# THE CHANGING Earth

Exploring Geology and Evolution | Fifth Edition





# The Changing Earth FIFTH EDITION

## Exploring Geology and Evolution

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**The Changing Earth: Exploring Geology and Evolution, Fifth Edition****James S. Monroe and Reed Wicander**

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Cover Image: Dr. Parvinder Sethi

Aerial view of Arctic glaciers belonging to the Canadian 'Queen Elizabeth Islands', near Northwestern Greenland. The dark lines represent a system of lateral and medial moraines caused by transportation of rock debris and merging of strands of glaciers as they move downslope.

Compositor: Pre-Press PMG

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Library of Congress Control Number: 2007940303

ISBN-13: 978-0-495-55480-6

ISBN-10: 0-495-55480-4

**Brooks/Cole**10 Davis Drive  
Belmont, CA 94002-3098  
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# BRIEF CONTENTS

1. Understanding Earth: A Dynamic and Evolving Planet 2
2. Plate Tectonics: A Unifying Theory 28
3. Minerals—The Building Blocks of Rocks 60
4. Igneous Rocks and Intrusive Igneous Activity 84
5. Volcanoes and Volcanism 106
6. Weathering, Soil, and Sedimentary Rocks 132
7. Metamorphism and Metamorphic Rocks 166
8. Earthquakes and Earth's Interior 188
9. The Seafloor 222
10. Deformation, Mountain Building, and the Continents 244
11. Mass Wasting 272
12. Running Water 300
13. Groundwater 328
14. Glaciers and Glaciation 356
15. The Work of Wind and Deserts 382
16. Shorelines and Shoreline Processes 406
17. Geologic Time: Concepts and Principles 434
18. Evolution—The Theory and Its Supporting Evidence 468
19. Precambrian Earth and Life History 492
20. Paleozoic Earth History 522
21. Paleozoic Life History 560
22. Mesozoic Earth and Life History 594
23. Cenozoic Earth and Life History 634
24. Physical and Historical Geology in Perspective 676

# CONTENTS

## 1 Understanding Earth: A Dynamic and Evolving Planet 2



- Introduction 4
- What Is Geology? 4
- Geology and the Formulation of Theories 6
- How Does Geology Relate to the Human Experience? 7
  - Natural Events 8
  - Economics and Politics 8
  - Our Role as Decision Makers 8
  - Consumers and Citizens 8
- Global Geologic and Environmental Issues Facing Humankind 9

### **GEO-FOCUS:** Global Warming and Climate Change, and How They Affect You 10

- Origin of the Universe and Solar System, and Earth's Place in Them 12
  - Origin of the Universe—Did it Begin with a Big Bang?* 12
  - Our Solar System—Its Origin and Evolution* 13

### **GEO-INSIGHT:** The Terrestrial and Jovian Planets 14

- Earth—Its Place in Our Solar System* 17
- Why Earth Is a Dynamic and Evolving Planet 17
  - Plate Tectonic Theory* 18
- The Rock Cycle 18
  - How Are the Rock Cycle and Plate Tectonics Related?* 20
- Organic Evolution and the History of Life 21
- Geologic Time and Uniformitarianism 23
- How Does the Study of Geology Benefit Us? 24

### **GEO-RECAP** 25

## 2 Plate Tectonics: A Unifying Theory 28



- Introduction 30
- Early Ideas About Continental Drift 30
  - Alfred Wegener and the Continental Drift Hypothesis* 31
- What Is the Evidence for Continental Drift? 31

- Continental Fit* 31
- Similarity of Rock Sequences and Mountain Ranges* 32
- Glacial Evidence* 33
- Fossil Evidence* 33
- Earth's Magnetic Field 35
- Paleomagnetism and Polar Wandering 36
- Magnetic Reversals and Seafloor Spreading 36
  - Deep-Sea Drilling and the Confirmation of Seafloor Spreading* 38
- Plate Tectonics: A Unifying Theory 39
  - The Three Types of Plate Boundaries 39
    - Divergent Boundaries* 40
    - Convergent Boundaries* 41

### **GEO-INSIGHT:** Tectonics of the Terrestrial Planets 42

- Transform Boundaries* 48
- Hot Spots and Mantle Plumes 48
- Plate Movement and Motion 50
- The Driving Mechanism of Plate Tectonics 51
  - The Supercontinent Cycle* 52
- Plate Tectonics and the Distribution of Natural Resources 53
  - Mineral Deposits* 53
- Plate Tectonics and the Distribution of Life 54

### **GEO-FOCUS:** Oil, Plate Tectonics, and Politics 55

### **GEO-RECAP** 57

## 3 Minerals—The Building Blocks of Rocks 60



- Introduction 62
- Matter—What Is It? 63
  - Atoms and Elements* 63
  - Bonding and Compounds* 64
- Explore the World of Minerals 66
  - Naturally Occurring Inorganic Substances* 66
  - Mineral Crystals* 66
  - Chemical Composition of Minerals* 68
  - Physical Properties of Minerals* 68
- Mineral Groups Recognized by Geologists 68
  - Silicate Minerals* 69
  - Carbonate Minerals* 71
  - Other Mineral Groups* 71



**GEO-INSIGHT:** The Precious Metals 72

- Physical Properties of Minerals 74
- Luster and Color 74
- Crystal Form 74
- Cleavage and Fracture 74
- Hardness 75
- Specific Gravity (Density) 75
- Other Useful Mineral Properties 75

**GEO-FOCUS:** Welcome to the Wonderful World of Micas 76

- Rock-Forming Minerals 76
- How Do Minerals Form? 76
- Natural Resources and Reserves 77

**GEO-RECAP** 82

## 4 Igneous Rocks and Intrusive Igneous Activity 84



- Introduction 86
- The Properties and Behavior of
  - Magma and Lava 86
  - Composition of Magma 87
  - How Hot Are Magma and Lava? 87
  - Viscosity—Resistance to Flow 88
- How Does Magma Originate and Change? 88
  - Bowen's Reaction Series 89
  - The Origin of Magma at Spreading Ridges 90
  - Subduction Zones and the Origin of Magma 90
  - Hot Spot and the Origin of Magma 91
  - Processes That Bring About Compositional Changes in Magma 91
- Igneous Rocks—Their Characteristics and Classification 92
  - Igneous Rock Textures 93
  - Composition of Igneous Rocks 94
  - Classifying Igneous Rocks 94
- Intrusive Igneous Bodies—Plutons 97
  - Dikes, Sills, and Laccoliths 98
  - Volcanic Pipes and Necks 99
  - Batholiths and Stocks 99
- How Are Batholiths Intruded into Earth's Crust? 99

**GEO-INSIGHT:** Plutons 100**GEO-FOCUS:** Some Remarkable Volcanic Necks 102**GEO-RECAP** 102

## 5 Volcanoes and Volcanism 106



- Introduction 108
- Volcanism and Volcanoes 108

- Volcanic Gases 109
- Lava Flows 110
- Pyroclastic Materials 112
- What Are the Types of Volcanoes? 114
  - Shield Volcanoes 115
  - Cinder Cones 116
  - Composite Volcanoes (Stratovolcanoes) 117
  - Lava Domes 117
  - Supervolcano Eruptions 118
- Other Volcanic Landforms 119
  - Fissure Eruptions and Basalt Plateaus 119

**GEO-INSIGHT:** Types of Volcanoes 120

- Pyroclastic Sheet Deposits 122
- Distribution of Volcanoes 122
  - North America's Active Volcanoes 123
    - Alaska's Volcanoes 123
    - The Cascade Range 123
  - Plate Tectonics, Volcanoes, and Plutons 123

**GEO-FOCUS:** The Bronze Age Eruption of Santorini 124

- Igneous Activity at Divergent Plate Boundaries 124
- Igneous Activity at Convergent Plate Boundaries 125
  - Intraplate Volcanism 127
- Volcanic Hazards, Volcano Monitoring, and Forecasting Eruptions 127
  - How Large Is an Eruption, and How Long Do Eruptions Last? 128
  - Is it Possible to Forecast Eruptions? 128

**GEO-RECAP** 129

## 6 Weathering, Soil, and Sedimentary Rocks 132



- Introduction 134
- How Are Earth Materials Altered? 135
  - Mechanical Weathering 135
- GEO-INSIGHT:** Arches National Park, Utah 136
  - Chemical Weathering 138
  - How Does Soil Form and Deteriorate? 142
    - The Soil Profile 143
    - Factors That Control Soil Formation 143
    - Soil Degradation 146
  - Weathering and Resources 147
  - Sediment and Sedimentary Rocks 147

**GEO-FOCUS:** The Dust Bowl—An American Tragedy 148

- Sediment Transport and Deposition 148
  - How Does Sediment Become Sedimentary Rock? 149
- Types of Sedimentary Rocks 150

<i>Detrital Sedimentary Rocks</i>	151
<i>Chemical and Biochemical Sedimentary Rocks</i>	153
Sedimentary Facies	156
Reading the Story in Sedimentary Rocks	157
<i>Sedimentary Structures</i>	157
<i>Fossils—Remains and Traces of Ancient Life</i>	157
<i>Determining the Environment of Deposition</i>	160
Important Resources in Sedimentary Rocks	160
<i>Petroleum and Natural Gas</i>	161
<i>Uranium</i>	162
<i>Branded Iron Formation</i>	163

**GEO-RECAP** 163**7 Metamorphism and Metamorphic Rocks 166**

Introduction	168
The Agents of Metamorphism	168
<i>Heat</i>	169
<i>Pressure</i>	169
<i>Fluid Activity</i>	169
The Three Types of Metamorphism	170
<i>Contact Metamorphism</i>	170

**GEO-FOCUS: Asbestos: Good or Bad?** 172

<i>Dynamic Metamorphism</i>	174
<i>Regional Metamorphism</i>	174
<i>Index Minerals and Metamorphic Grade</i>	174
How Are Metamorphic Rocks Classified?	175
<i>Foliated Metamorphic Rocks</i>	175
<i>Nonfoliated Metamorphic Rocks</i>	178
Metamorphic Zones and Facies	179

**GEO-INSIGHT: The Many Uses of Marble** 180

Plate Tectonics and Metamorphism	183
Metamorphism and Natural Resources	184

**GEO-RECAP** 185**8 Earthquakes and Earth's Interior 188**

Introduction	190
Elastic Rebound Theory	190
Seismology	192
<i>The Focus and Epicenter of an Earthquake</i>	193
Where Do Earthquakes Occur, and How Often?	193
Seismic Waves	196
<i>Body Waves</i>	196
<i>Surface Waves</i>	196
Locating an Earthquake	197
Measuring the Strength of an Earthquake	197

<i>Intensity</i>	198
<i>Magnitude</i>	200
What Are the Destructive Effects of Earthquakes?	200
<i>Ground Shaking</i>	202

**GEO-INSIGHT: The San Andreas Fault** 204

<i>Fire</i>	206
<i>Tsunami: Killer Waves</i>	206
<i>Ground Failure</i>	207
Earthquake Prediction	209
<i>Earthquake Precursors</i>	209
<i>Earthquake Prediction Programs</i>	209
Earthquake Control	210
What Is Earth's Interior Like?	211

**GEO-FOCUS: Paleoseismology** 213

The Core	214
<i>Density and Composition of the Core</i>	215
Earth's Mantle	216
<i>The Mantle's Structure, Density, and Composition</i>	216
Seismic Tomography	217
Earth's Internal Heat	217
Earth's Crust	218

**GEO-RECAP** 218**9 The Seafloor 222**

Introduction	224
Exploring the Oceans	224
<i>Early Exploration</i>	224
<i>How Are Oceans Explored Today?</i>	225
Oceanic Crust—Its Structure and Composition	226
The Continental Margins	227
<i>The Continental Shelf</i>	227
<i>The Continental Slope and Rise</i>	228
<i>Submarine Canyons, Turbidity Currents, and Submarine Fans</i>	228
<i>Types of Continental Margins</i>	229
What Features Are Found in the Deep-Ocean Basins?	230
<i>Abyssal Plains</i>	230
<i>Oceanic Trenches</i>	232
<i>Oceanic Ridges</i>	232
<i>Submarine Hydrothermal Vents</i>	232
<i>Seafloor Fractures</i>	234
<i>Seamounts, Guyots, and Aseismic Ridges</i>	234
Sedimentation and Sediments on the Deep Seafloor	235
Reefs	235

**GEO-INSIGHT: Reefs: Rocks Made by Organisms** 236

Resources from the Oceans 239

**GEO-FOCUS:** Oceanic Circulation and Resources from the Sea 240

**GEO-RECAP** 241

## 10 Deformation, Mountain Building, and the Continents 244

Introduction 246

Rock Deformation—How Does It Occur? 246

*Stress and Strain* 246

*Types of Strain* 247

Strike and Dip—The Orientation of Deformed Rock Layers 248

Deformation and Geologic Structures 248

*Folded Rock Layers* 249

**GEO-FOCUS:** Engineering and Geology 252

*Joints* 252

*Faults* 253

Deformation and the Origin of Mountains 257

*Mountain Building* 258

*Plate Tectonics and Mountain Building* 258

**GEO-INSIGHT:** Types of Faults 262

*Terranes and the Origin of Mountains* 264

Earth's Continental Crust 265

*Floating Continents?* 265

*Principle of Isostasy* 265

*Isostatic Rebound* 269

**GEO-RECAP** 270

## 11 Mass Wasting 272

Introduction 274

Factors That Influence Mass Wasting 274

*Slope Angle* 275

*Weathering and Climate* 275

*Water Content* 275

*Vegetation* 276

*Overloading* 276

*Geology and Slope Stability* 276

*Triggering Mechanisms* 278

Types of Mass Wasting 278

*Falls* 278

*Slides* 279

**GEO-FOCUS:** Southern California Landslides 282

**GEO-INSIGHT:** Point Fermin—Slip Sliding Away 284

*Flows* 286

*Complex Movements* 290

Recognizing and Minimizing the Effects of Mass Wasting 291

**GEO-RECAP** 297

## 12 Running Water 300

Introduction 302

Water on Earth 302

*The Hydrologic Cycle* 303

*Fluid Flow* 304

Running Water 304

*Sheet Flow and Channel Flow* 304

*Gradient, Velocity, and Discharge* 305

How Does Running Water Erode and Transport Sediment? 306

**GEO-FOCUS:** The River Nile and the History of Egypt 307

Deposition by Running Water 309

*The Deposits of Braided and Meandering Channels* 310

*Floodplain Deposits* 310

*Deltas* 311

*Alluvial Fans* 313

Can Floods Be Predicted and Controlled? 314

Drainage Systems 315

**GEO-INSIGHT:** The Flood of '93 316

The Significance of Base Level 319

*What is a Graded Stream?* 320

The Evolution of Valleys 321

*Stream Terraces* 322

*Incised Meanders* 323

*Superposed Streams* 324

**GEO-RECAP** 325

## 13 Groundwater 328

Introduction 330

Groundwater and the Hydrologic Cycle 330

Porosity and Permeability 331

The Water Table 331

Groundwater Movement 332

Springs, Water Wells, and Artesian Systems 333

*Springs* 333

*Water Wells* 334

*Artesian Systems* 334

Groundwater Erosion and Deposition 335

*Sinkholes and Karst Topography* 335

**GEO-INSIGHT:** The Burren Area of Ireland 336





*Caves and Cave Deposits* 339  
 Modifications of the Groundwater System  
 and Its Effects 340  
*Lowering the Water Table* 340  
*Saltwater Incursion* 342  
*Subsidence* 343  
*Groundwater Contamination* 345  
*Groundwater Quality* 345

**GEO-FOCUS:** Arsenic and Old Lace 346

Hydrothermal Activity 348  
*Hot Springs* 348  
*Geysers* 351  
*Geothermal Energy* 352

**GEO-RECAP** 353

## 14 Glaciers and Glaciation 356



Introduction 358  
 The Kinds of Glaciers 359  
*Valley Glaciers* 359  
*Continental Glaciers* 360  
 Glaciers—Moving Bodies of Ice on Land 360  
*Glaciers—Part of the Hydrologic Cycle* 361  
*How Do Glaciers Originate and Move?* 361  
*Distribution of Glaciers* 362  
 The Glacial Budget—Accumulation and Wastage 362  
*How Fast Do Glaciers Move?* 363

**GEO-FOCUS:** Glaciers and Global Warming 364

*Glacial Surges* 364  
 Erosion and Transport by Glaciers 367  
*Erosion by Valley Glaciers* 367

**GEO-INSIGHT:** Valley Glaciers and Erosion 370

*Continental Glaciers and Erosional Landforms* 372  
 Deposits of Glaciers 372  
*Glacial Drift* 372  
*Landforms Composed of Till* 373  
*Landforms Composed of Stratified Drift* 374  
*Deposits in Glacial Lakes* 375  
 What Causes Ice Ages? 376  
*The Milankovitch Theory* 377  
*Short-Term Climactic Events* 379

**GEO-RECAP** 379

## 15 The Work of Wind and Deserts 382

Introduction 384  
 Sediment Transport by Wind 384



*Bed Load* 384  
*Suspended Load* 385  
 Wind Erosion 385  
*Abrasion* 385  
*Deflation* 386  
 Wind Deposits 386  
*The Formation and Migration of Dunes* 387  
*Dune Types* 388  
*Loess* 389

Air-Pressure Belts and Global Wind  
 Patterns 390

The Distribution of Deserts 392

**GEO-INSIGHT:** Rock Art for the Ages 394

Characteristics of Deserts 396  
*Temperature, Precipitation, and Vegetation* 396  
*Weathering and Soils* 397  
*Mass Wasting, Streams, and Groundwater* 397

**GEO-FOCUS:** Windmills and Wind Power 398

*Wind* 399  
 Desert Landforms 400

**GEO-RECAP** 404

## 16 Shorelines and Shoreline Processes 406



Introduction 408  
 Tides, Waves, and Nearshore  
 Currents 409

*Tides* 409  
*Waves* 409  
*Nearshore Currents* 413  
 Shoreline Erosion 414  
*Wave-Cut Platforms* 414  
*Sea Caves, Arches, and Stacks* 415  
 Deposition Along Shorelines 415

**GEO-FOCUS:** Energy from the Oceans 416

*Beaches* 416  
*Seasonal Changes in Beaches* 417  
*Spits, Baymouth Bars, and Tombolos* 418  
*Barrier Islands* 420

The Nearshore Sediment Budget 422

Types of Coasts 422  
*Depositional and Erosional Coasts* 422  
*Submergent and Emergent Coasts* 423

**GEO-INSIGHT:** Shoreline Processes and Beaches 424

Storm Waves and Coastal Flooding 426  
 How Are Coastal Areas Managed as Sea Level  
 Rises? 427

**GEO-RECAP** 431

## 17 Geologic Time: Concepts and Principles 434



- Introduction 436
- How Is Geologic Time Measured? 436
- Early Concepts of Geologic Time and the Age of Earth 436
- James Hutton and the Recognition of Geologic Time 437
- Relative Dating Methods 438
  - Fundamental Principles of Relative Dating* 438
  - Unconformities* 441
  - Applying the Principles of Relative Dating* 443
- Correlating Rock Units 446
  - Subsurface Correlation* 448
- Absolute Dating Methods 449
  - Atoms, Elements, and Isotopes* 449
  - Radioactive Decay and Half-Lives* 451
  - Sources of Uncertainty* 452
  - Long-Lived Radioactive Isotope Pairs* 454
  - Fission Track Dating* 455
  - Radiocarbon and Tree-Ring Dating Methods* 455

**GEO-INSIGHT:** Uluru and Kata Tjuta 456

- Development of the Geologic Time Scale 458
- Stratigraphy and Stratigraphic Terminology 459

**GEO-FOCUS:** Denver's Weather—280 Million Years Ago! 460

- Geologic Time and Climate Change 463

**GEO-RECAP** 465

## 18 Evolution—The Theory and Its Supporting Evidence 468



- Introduction 470
- Evolution: What Does It Mean? 470
  - Jean-Baptiste de Lamarck and his Ideas on Evolution* 470
  - The Contributions of Charles Robert Darwin and Alfred Russel Wallace* 472
  - Natural Selection—What is Its Significance?* 472

**GEO-FOCUS:** The Tragic Lysenko Affair 474

- Mendel and the Birth of Genetics 474
  - Mendel's Experiments* 474
  - Genes and Chromosomes* 475
- The Modern View of Evolution 476
  - What Brings About Variation?* 476
  - Speciation and the Rate of Evolution* 477
  - Divergent, Convergent, and Parallel Evolution* 478
  - Microevolution and Macroevolution* 479

- Cladistics and Cladograms* 480
- Evolutionary Trends and Mosaic Evolution* 480
- Extinctions* 481
- What Kinds of Evidence Support Evolutionary Theory? 482
  - Classification—A Nested Pattern of Similarities* 483
  - How Does Biological Evidence Support Evolution?* 484
  - Fossils: What Do We Learn From Them?* 485
  - The Evidence—A Summary* 487

**GEO-INSIGHT:** Fossilization 488

**GEO-RECAP** 490

## 19 Precambrian Earth and Life History 492



- Introduction 494
- What Happened During the Eoarchean? 494
- Continental Foundations—Shields, Platforms, and Cratons 496
- Archean Earth History 496
  - Archean Rocks* 496
  - Archean Plate Tectonics and the Origin of Cratons* 499
- Proterozoic Earth History 500
  - Paleoproterozoic History of Laurentia* 500
  - Paleo- and Mesoproterozoic Igneous Activity* 503
  - Mesoproterozoic Orogeny and Rifting* 503
  - Meso- and Neoproterozoic Sedimentation* 503
  - Proterozoic Supercontinents* 504
  - Proterozoic Rocks* 504
- Origin and Evolution of the Atmosphere and Hydrosphere 507
  - The Atmosphere* 507

**GEO-INSIGHT:** North America's Precambrian Rocks 508

- The Hydrosphere* 511
- Life—Its Origin and Early History 512
  - The Origin of Life* 512
  - Archean Organisms* 513
  - Life of the Proterozoic* 514
- Resources in Precambrian Rocks 517
  - Archean Resources* 517
  - Proterozoic Resources* 518

**GEO-FOCUS:** Banded Iron Formation—From Mine to Steel Mill 519

**GEO-RECAP** 520

## 20 Paleozoic Earth History 522



- Introduction 524
- Continental Architecture: Cratons and Mobile Belts 524

- Paleozoic Paleogeography 525
- Early-Middle Paleozoic Global History* 526
- Late Paleozoic Global History* 529
- Paleozoic Evolution of North America 529
- The Sauk Sequence 531

**GEO-FOCUS:** Pictured Rocks National Lakeshore 532

- The Tippecanoe Sequence 533

**GEO-INSIGHT:** The Grand Canyon—A Geologist’s Paradise 534

- Tippecanoe Reefs and Evaporites* 537
- The End of the Tippecanoe Sequence* 539
- The Kaskaskia Sequence 539
- Reef Development in Western Canada* 540
- Black Shales* 540
- The Late Kaskaskia—A Return to Extensive Carbonate Deposition* 542
- The Absaroka Sequence 542
- What Are Cyclothems, and Why Are They Important?* 542
- Cratonic Uplift—The Ancestral Rockies* 544
- The Late Absaroka—More Evaporite Deposits and Reefs* 545
- History of the Paleozoic Mobile Belts 546
- Appalachian Mobile Belt* 546
- Cordilleran Mobile Belt* 552
- Ouachita Mobile Belt* 553
- What Role Did Microplates and Terranes Play in the Formation of Pangaea? 553
- Paleozoic Mineral Resources 554

**GEO-RECAP** 556

**21 Paleozoic Life History 560**

- Introduction 562
- What Was the Cambrian Explosion? 562
- The Emergence of a Shelly Fauna 563
- Paleozoic Invertebrate Marine-Life 564
- The Present Marine Ecosystem* 564
- Cambrian Marine Community* 565
- The Burgess Shale Biota* 566
- Ordovician Marine Community* 568
- Silurian and Devonian Marine Communities* 568
- Carboniferous and Permian Marine Communities* 569
- The Permian Marine Invertebrate Mass Extinction* 570



- Vertebrate Evolution 571
- GEO-INSIGHT:** Trilobites—Paleozoic Arthropods 572
- Fish 574
- Amphibians—Vertebrates Invade the Land 578

- Evolution of the Reptiles—The Land Is Conquered 580
- Plant Evolution 581
- Silurian and Devonian Floras* 585

**GEO-FOCUS:** Palynology: A Link Between Geology and Biology 586

- Late Carboniferous and Permian Floras* 587

**GEO-RECAP** 590

**22 Mesozoic Earth and Life History 594**

- Introduction 596
- The Breakup of Pangaea 596
- The Effects of the Breakup of Pangaea on Global Climates and Ocean Circulation Patterns* 598
- Mesozoic History of North America 599
- Continental Interior* 599
- Eastern Coastal Region* 599
- Gulf Coastal Region* 600
- Western Region* 601
- What Role Did Accretion of Terranes Play in the Growth of Western North America? 606
- Mesozoic Mineral Resources 607
- Life of the Mesozoic Era 611
- Marine Invertebrates and Phytoplankton* 611
- Plants—Primary Producers on Land* 613
- The Diversification of Reptiles* 613



**GEO-INSIGHT:** Dinosaurs 618

- From Reptiles to Birds* 621

**GEO-FOCUS:** Mary Anning’s Contributions to Paleontology 622

- Origin and Evolution of Mammals* 624
- Mesozoic Climates and Paleogeography 626
- Mass Extinctions—A Crisis in the History of Life 627

**GEO-RECAP** 628

**23 Cenozoic Earth and Life History 634**

- Introduction 636
- Cenozoic Plate Tectonics—An Overview 637
- Cenozoic Orogenic Belts 637
- The Alpine-Himalayan Orogenic Belt* 637
- The Circum-Pacific Orogenic Belt* 639



Paleogene and Neogene Evolution of North America	639
<i>The North American Cordillera</i>	639
<i>Cordilleran Igneous Activity</i>	642
<i>Basin and Range Province</i>	643
<i>Colorado Plateau</i>	643
<i>Pacific Coast</i>	644
<i>The Continental Interior</i>	645
<i>Cenozoic History of the Appalachian Mountains</i>	646
<i>North America's Southern and Eastern Continental Margins</i>	647
<i>The Gulf Coastal Plain</i>	647
<i>The Atlantic Continental Margin</i>	648
The Pleistocene and Holocene Epochs	648
<i>Pleistocene and Holocene Tectonism and Volcanism</i>	648
<i>Pleistocene Glaciation</i>	648
<b>GEO-INSIGHT:</b> Cascade Range Volcanoes	650
Cenozoic Mineral Resources	653
<b>GEO-FOCUS:</b> A Miocene Catastrophe in Nebraska	654
Paleogene and Neogene Life History	654
<i>Marine Invertebrates and Phytoplankton</i>	654
<i>Cenozoic Vegetation and Climate</i>	655
<i>Paleogene and Neogene Birds</i>	656
<i>Diversification of Mammals</i>	658
<i>Cenozoic Mammals</i>	660
Pleistocene Faunas	662
<i>Mammals and Birds</i>	662
<i>Primate Evolution</i>	663
<i>Hominids</i>	664
<i>Pleistocene Extinctions</i>	672
<b>GEO-RECAP</b>	673

## 24 Physical and Historical Geology in Perspective 676



Introduction	678
Geology Is All Around Us	678
Geology, History, and the Agricultural Revolution	679
Geologic Hazards	680
Geology and the Environment	680
<i>Acid Rain</i>	680
<i>Do Volcanic Gases Cause Ozone Depletion?</i>	681
<i>Radon: The Silent Killer</i>	682
Humans as Geologic Agents	683

### GEO-RECAP 685

## Appendices

A: English-Metric Conversion Chart	686
B: Topographic Maps	687
<i>Contours</i>	687
<i>Map Scales</i>	687
<i>Map Locations</i>	688
<i>Where to Obtain Topographic Maps</i>	689

## Answers

Multiple-Choice Questions	691
Selected Short-Answer Questions	692

## Glossary 697

## Index 713

# PREFACE

Earth is a dynamic planet that has changed continuously during its 4.6 billion years of existence. The size, shape, and geographic distribution of the continents and ocean basins have changed through time, as have the atmosphere and biota. As scientists and concerned citizens, we have become increasingly aware of how fragile our planet is and, more importantly, how interdependent all of its various systems and subsystems are.

We have also learned that we cannot continually pollute our environment and that our natural resources are limited and, in most cases, nonrenewable. Furthermore, we are coming to realize how central geology is to our everyday lives. For example, a 9.0-magnitude earthquake in the Indian Ocean on December 26, 2004, generated a tsunami that killed more than 220,000 people in Indonesia, Sri Lanka, India, Thailand, Somalia, Myanmar, Malaysia, and the Maldives, and caused billions of dollars in damage. Two hurricanes in 2005, Katrina and Rita, damaged many offshore oil platforms and oil refineries in Texas and Louisiana, demonstrating how fragile our energy network, from production to the finished refined product, is and how dependent we are on petroleum to run our economy. For these and other reasons, geology is one of the most important college or university courses that a student can take.

*The Changing Earth: Exploring Geology and Evolution*, Fifth Edition, is designed for an introductory course in geology that can serve both majors and nonmajors in geology and the earth sciences. One of the problems with any introductory science course is that students are overwhelmed by the amount of material that must be learned. Furthermore, most of the material does not seem to be linked by any unifying theme and does not always appear to be relevant to their lives. This book, however, is written to address that problem in that it shows, in its easy-to-read style, that geology is an exciting and ever-changing science, and one in which new discoveries and insights are continually being made.

The goals of this book are to provide students with a basic understanding of geology and its processes and, most importantly, an understanding of how geology relates to the human experience—that is, how geology affects not only individuals, but society in general. It is also our intent to present the geologic and biologic history of Earth, not as a set of encyclopedic facts to memorize, but rather as a continuum of interrelated events that reflect the underlying geologic and biologic principles and processes that have shaped our planet and life upon it. Instead of emphasizing individual, and seemingly unrelated, events, we seek to understand the underlying causes of why things happened the way they did and how all of Earth's systems and subsystems are interrelated.

Using this approach, students will gain a better understanding of how everything fits together.

With these goals in mind, we introduce the major themes of the book in the first chapter to provide students with an overview of the subject and to enable them to see how the various systems and subsystems of Earth are interrelated. We then cover the unifying theme of geology—plate tectonics, in the second chapter. Plate tectonic theory is central to the study of geology because it links many aspects of geology together. It is a theme that is woven throughout this edition. We also discuss the economic and environmental aspects of geology throughout the book rather than treating these topics in separate chapters. In this way, students can see, through relevant and interesting examples, how geology impacts our lives.

## NEW AND RETAINED FEATURES IN THE FIFTH EDITION

Just as Earth is dynamic and evolving, so too is *The Changing Earth: Exploring Geology and Evolution*. The fifth edition has undergone considerable rewriting and updating, resulting in a volume that is still easy to read and has a high level of current information. Drawing on the comments and suggestions of reviewers, we have retained and incorporated a number of new features into this edition.

- The *Chapter Objectives* outline at the beginning of each chapter has been retained to alert students to the key points that the chapter will address.
- Chapter content has been rewritten to help clarify concepts and make the material more exploratory.
- Current events have been incorporated throughout the text.
- Additional content can be found throughout the book, particularly in the historical section.
- Many of the popular *Geo-Focus* features contain either new topics or have been updated.
- The successful *What Would You Do?* boxes in each chapter continue to encourage students to think critically about what they're learning by asking open-ended questions related to the chapter material. Many of these boxes are either new or have been rewritten to reflect current topics in the news.
- The two-page concept art spreads have been renamed *Geo-inSight* and redesigned to enhance students' interest in the chapter material. Furthermore, there is now a *Geo-inSight* feature in every chapter (except for Chapter 24).



- The art program has undergone revision to better illustrate the material covered in the text. In addition, the figure captions have been expanded and improved to help explain what students are seeing.
- The format of 10 multiple-choice questions and 10 short-answer questions has been retained in the *Review Questions* section at the end of each chapter. Answers to all of the multiple-choice questions, as well as two of the short-answer questions per chapter are provided at the back of the book.

It is our strong belief that the rewriting and updating done in the text, as well as the addition of new photographs and newly rendered art greatly improve the fifth edition of *The Changing Earth: Exploring Geology and Evolution*. We think that these changes and enhancements make this textbook easier to read and comprehend, as well as a more effective teaching tool.

## TEXT ORGANIZATION

Plate tectonic theory is the unifying theme of geology and this book. This theory has revolutionized geology because it provides a global perspective of Earth and allows geologists to treat many seemingly unrelated geologic phenomena as part of a total planetary system.

Another theme of this book is that Earth is a complex, dynamic planet that has changed continuously since its origins some 4.6 billion years ago. We can better understand this complexity by using a systems approach to the study of Earth and emphasizing this approach throughout the book.

We have organized *The Changing Earth: Exploring Geology and Evolution*, Fifth Edition, into the following informal categories:

- Chapter 1 is an introduction to geology and Earth systems, geology's relevance to the human experience, and the origin of the solar system and Earth's place in it.
- Chapter 2 deals with plate tectonics in detail and sets the stage for its integration throughout the rest of the book.
- Chapters 3–7 examine Earth's materials (minerals and igneous, sedimentary, and metamorphic rocks) and the geologic processes associated with them, including the role of plate tectonics in their origin and distribution.
- Chapters 8–10 deal with the related topics of Earth's interior, the seafloor, earthquakes, and deformation and mountain building.
- Chapters 11–16 cover Earth's surface processes such as running water and mass wasting.
- Chapter 17 discusses geologic time and Chapter 18 explores fossils and evolution.
- Chapters 19–23 constitute our chronological treatment of the geologic and biologic history of Earth.
- Chapter 24 summarizes and synthesizes the concepts, themes, and major topics covered in this book.

Of particular assistance to students are the end-of-chapter summary tables found in Chapters 20–22. These tables are

designed to give an overall perspective of the geologic and biologic events that occurred during the particular time interval covered in that chapter and to show how the events are interrelated.

We have found that presenting the material in the order discussed above works well for most students. We know, however, that many instructors prefer an entirely different order of topics, depending on the emphasis in their course. We have therefore written this book so that instructors can present the chapters in any order that suits the needs of a particular course.

## CHAPTER ORGANIZATION

All chapters have the same organizational format as follows:

- Each chapter opens with a photograph related to the chapter material, an Outline of the topics covered, and an Objectives list that alerts students to the learning outcome objectives of the chapter.
- An *Introduction* follows that is intended to stimulate interest in the chapter and show how the chapter material fits into the larger geologic perspective.
- The text is written in a clear, informal style, making it easy for students to comprehend.
- Numerous newly rendered color diagrams and photographs complement the text and provide a visual representation of the concepts and information presented.
- Each chapter contains one *Geo-Focus* feature that presents a brief discussion of an interesting aspect of geology or geologic research.
- A *Geo-inSight* art spread is now in every chapter (except Chapter 24). These two-page features are designed to enhance students' interest in the chapter material through visual learning.
- Two *What Would You Do?* boxes per chapter encourage students to engage in critical thinking by solving hypothetical problems or issues that are related to the chapter material.
- Topics related to environmental and economic geology are discussed throughout the text. Integrating economic and environmental geology with the chapter material helps students relate the importance and relevance of geology to their lives.
- The end-of-chapter *Geo-Recap* begins with a concise review of important concepts and ideas presented in the chapter.
- The *Important Terms*, which are printed in boldface type in the chapter text, are listed at the end of each chapter for easy review, along with the page numbers on which they are first defined. A full *Glossary* of important terms appears at the end of the text.
- The *Review Questions* are another important feature of this book and include multiple-choice questions with answers, as well as short-answer questions, two of which per chapter have the answers provided at the end of the book. Many new questions have been added to each chapter of the fifth edition.

## ANCILLARY MATERIALS

### FOR INSTRUCTORS

We are pleased to offer a full suite of text and multimedia products to accompany *The Changing Earth: Exploring Geology and Evolution*, Fifth Edition.

*Geology Resource Center* [academic.cengage.com/earthscience](http://academic.cengage.com/earthscience)

*Book Companion Website* [academic.cengage.com/earthscience](http://academic.cengage.com/earthscience)

The Geology Resource Center and the Book Companion Website feature a rich array of learning resources for your students. The text-specific companion website includes quizzing and other web-based activities that will help students explore the concepts presented in the text.

*PowerLecture with JoinIn™ on Turning Point®* A complete all in one reference for instructors, the PowerLecture CD contains PowerPoint slides of images from the text, stepped art from the text, zoomable art figures from the text, Active Figures that interactively demonstrate concepts, and lectures that outline the main points of each chapter. In addition to providing you with fantastic course presentation material, the PowerLecture CD also contains electronic files of the Test Bank and Instructor's Manual as well as JoinIn, the easiest Audience Response System to use, featuring instant classroom assessment and learning. ISBN-10: 0495555029 | ISBN-13: 978-0495555025

*Online Instructor's Manual with Test Bank* This invaluable guide contains resources designed to streamline and maximize the effectiveness of your course preparation, including a complete test item file in Microsoft Word™ format, ideal for homework, group work or laboratory exercises. ISBN-10: 0495555010 | ISBN-13: 978-0495555018

*ExamView* Create, deliver, and customize tests and study guides (both print and online) in minutes with this easy-to-use assessment and tutorial system. ExamView offers both a Quick Test Wizard and an Online Test Wizard that guide you step by step through the process of creating tests, whereas its “what you see is what you get” interface allows you to see the test you are creating on the screen exactly as it will print or display online. You can build tests of up to 250 questions using up to 12 question types. Using ExamView's complete word processing capabilities, you can enter an unlimited number of new questions or edit existing questions. ISBN-10: 0495555045 | ISBN-13: 978-0495555049

*Active Earth Collection CD* The Active Earth Collection allows you to pick and choose from more than 120 earth science animations and active figures, ABC natural hazards video clips, and in-depth Google Earth lecture activities. Grab your students' attention by creating your lectures using these dynamic tools. ISBN-10: 0495555320 | ISBN-13: 978-0495555322

### FOR STUDENTS

*Geology Resource Center* [academic.cengage.com/earthscience](http://academic.cengage.com/earthscience)

*Book Companion Website* [academic.cengage.com/earthscience](http://academic.cengage.com/earthscience)

This website features a rich array of learning resources, including quizzing and other web-based activities that will help you explore the concepts that are presented in the text.

## ACKNOWLEDGMENTS

As the authors, we are, of course, responsible for the organization, style, and accuracy of the text, and any mistakes, omissions, or errors are our responsibility. The finished product is the culmination of many years of work during which we received numerous comments and advice from many geologists who reviewed all or parts of the text for the first three editions. They are: Kenneth Beem, Montgomery College; Patricia J. Bush, Dèlgado Community College; Paul J. Bybee, Utah Valley State College; Deborah Caskey, El Paso Community College; Renee M. Clary, University of Louisiana at Lafayette; Michael Conway, Arizona Western College; William C. Cornell, University of Texas at El Paso; Kathleen Devaney, El Paso Community College; Richard Diecchio, George Mason University; Robert Ewing, Portland Community College; David J. Fitzgerald, St. Mary's University; Dann M. Halverson, University of Southwestern Louisiana; Kristi Higginbotham, San Jacinto College; Ray Kenny, New Mexico Highlands University; Gary L. Kinsland, University of Louisiana at Lafayette; Bob Mims, Richland College; Michelle Stoklosa, Boise State University; Glenn B. Stracher, East Georgia College; Azam M. Tabrizi, Tide Water Community College; Monte D. Wilson, Boise State University; and Guy Worthey, St. Ambrose University.

We wish to express our sincere appreciation to the reviewers who reviewed the Fourth Edition and made many helpful and useful comments that led to the many improvements seen in this Fifth Edition. They are: David Berry, California State Polytechnic University, Pomona; Wesley A. Brown, Stephen F. Austin State University; David Cordero, Lower Columbia College; Kathleen Devaney, El Paso Community College; Yongli Gao, East Tennessee State University; Jorg Maletz, University at Buffalo-SUNY; Kevin McCartney, University of Maine - Presque Isle; Roger Steinberg, Del Mar College; and Thomas J. Weiland, Georgia Southwestern State University.

We also wish to thank Kathy Benison, Richard V. Dietrich (Professor Emeritus), David J. Matty, Jane M. Matty, Wayne E. Moore (Professor Emeritus), and Sven Morgan of the Geology Department, and Bruce M. C. Pape (Emeritus) of the Geography Department of Central Michigan University, as well as Eric Johnson (Hartwick College, New York), and Stephen D. Stahl (St. Bonaventure, New York) for providing us with photographs and answering our questions concerning various topics. We are also grateful for the generosity of the various agencies and individuals from many countries who provided photographs.

Special thanks must go to Peter Adams, Executive Editor Health/Nutrition/Earth Sciences at Cengage Learning – Brooks/Cole, who initiated this fifth edition, and to our Development Editor, Amy Collins of WriteWorks, who

edited and managed the content for this edition. We are indebted to our production manager, Belinda Krohmer, for her attention to detail and consistency. We would also like to thank Vernon Boes for the fresh design, and Patricia A. Onufrak for her copyediting skills. We thank Parvinder Sethi for his help in locating appropriate photographs. We would also like to recognize Hal Humphrey, Cengage Learning Production Project Manager; Melinda Newfarmer and Alexandria Brady, Technology Project Managers, for developing the media program; Joe Rogove, Executive Marketing Manager; Talia Wise and Belinda Krohmer, Marketing Communications Managers; and Liana Monari, Assistant Editor, who managed the accompanying ancillary package. We also extend thanks to the artists at Precision

Graphics, who are responsible for updating much of the art program.

As always, our families were very patient and encouraging when much of our spare time and energy were devoted to this book. We again thank them for their continued support and understanding.

*James S. Monroe*  
*Reed Wicander*

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# The Changing Earth





## CHAPTER 1

# Understanding Earth: A Dynamic and Evolving Planet



USGS/NASA

## OUTLINE

Introduction

What Is Geology?

Geology and the Formulation of Theories

How Does Geology Relate to the Human Experience?

How Does Geology Affect Our Everyday Lives?

Global Geologic and Environmental Issues Facing Humankind

**GEO-FOCUS:** Global Warming and Climate Change, and How They Affect You

Origin of the Universe and Solar System, and Earth's Place in Them

**GEO-INSIGHT:** The Terrestrial and Jovian Planets

Why Earth is a Dynamic and Evolving Planet

The Rock Cycle

Organic Evolution and the History of Life

Geologic Time and Uniformitarianism

How Does the Study of Geology Benefit Us?

Geo-Recap

## OBJECTIVES

*At the end of this chapter, you will have learned that*

- Geology is the study of Earth.
- Earth is a complex, integrated system of interconnected components that interact and affect one another in various ways.
- Theories are based on the scientific method and can be tested by observation and/or experiment.
- Geology plays an important role in the human experience and affects us as individuals and members of society and nation-states.
- The universe is thought to have originated approximately 14 billion years ago with a big bang. The solar system and

Satellite-based image of Earth. North America is visible in the center of this view, as well as Central America and South America. The present locations of continents and ocean basins are the result of plate movements. The interaction of plates through time has affected the physical and biological history of Earth.

planets evolved from a turbulent, rotating cloud of material surrounding the embryonic Sun.

- Earth consists of three concentric layers—core, mantle, and crust—and this orderly division formed during Earth’s early history.
- Plate tectonics is the unifying theory of geology and this theory revolutionized the science.
- The rock cycle illustrates the interrelationships between Earth’s internal and external processes and shows how and why the three major rock groups are related.
- The theory of organic evolution provides the conceptual framework for understanding the history of life.
- An appreciation of geologic time and the principle of uniformitarianism is central to understanding the evolution of Earth and its biota.
- Geology is an integral part of our lives.

## INTRODUCTION

A major benefit of the space age has been the ability to look back from space and view our planet in its entirety. Every astronaut has remarked in one way or another on how Earth stands out as an inviting oasis in the otherwise black void of space (see this chapter’s opening photograph). We are able to see not only the beauty of our planet, but also its fragility. We can also decipher Earth’s long and frequently turbulent history by reading the clues preserved in the geologic record.

A major theme of this book is that Earth is a complex, dynamic planet that has changed continuously since its origin some 4.6 billion years ago. These changes and the present-day features we observe result from the interactions among Earth’s internal and external systems, subsystems, and cycles. Earth is unique among the planets of our solar system in that it supports life and has oceans of water, a hospitable atmosphere, and a variety of climates. It is ideally suited for life as we know it because of a combination of factors, including its distance from the Sun and the evolution of its interior, crust, oceans, and atmosphere. Life processes have, over time, influenced the evolution of Earth’s atmosphere, oceans, and, to some extent, its crust. In turn, these physical changes have affected the evolution of life.

By viewing Earth as a whole—that is, thinking of it as a system—we not only see how its various components are interconnected, but also better appreciate its complex and dynamic nature. The system concept makes it easier for us to study a complex subject such as Earth because it divides the whole into smaller components that we can easily understand, without losing sight of how the components fit together as a whole.

A **system** is a combination of related parts that interact in an organized manner. An automobile is a good example of a system. Its various components or subsystems, such as the engine, transmission, steering, and brakes, are

all interconnected in such a way that a change in any one of them affects the others.

We can examine Earth in the same way we view an automobile—that is, as a system of interconnected components that interact and affect each other in many ways. The principal subsystems of Earth are the *atmosphere*, *biosphere*, *hydrosphere*, *lithosphere*, *mantle*, and *core* (Figure 1.1). The complex interactions among these subsystems result in a dynamically changing planet in which matter and energy is continuously recycled into different forms (Table 1.1). For example, the movement of plates has profoundly affected the formation of landscapes, the distribution of mineral resources, and atmospheric and oceanic circulation patterns, which, in turn, have affected global climate changes.

We must also not forget that humans are part of the Earth system, and our activities can produce changes with potentially wide-ranging consequences. When people discuss and debate such environmental issues as acid rain, the greenhouse effect and global warming, and the depleted ozone layer, it is important to remember that these are not isolated issues, but are part of the larger Earth system. Furthermore, remember that Earth goes through time cycles that are much longer than humans are used to. Although they may have disastrous short-term effects on the human species, global warming and cooling are also part of a longer-term cycle that has resulted in many glacial advances and retreats during the past 1.8 million years.

Accordingly, we must understand that actions we take can produce changes with wide-ranging consequences that we might not initially be aware of. For this reason, an understanding of geology, and science in general, is of paramount importance. If the human species is to survive, we must understand how the various Earth systems work and interact and, more importantly, how our actions affect the delicate balance between these systems.

As you study the various topics covered in this book, keep in mind the themes discussed in this chapter and how, like the parts of a system, they are interrelated. By relating each chapter’s topic to its place in the entire Earth system, you will gain a greater appreciation of why geology is so integral to our lives.

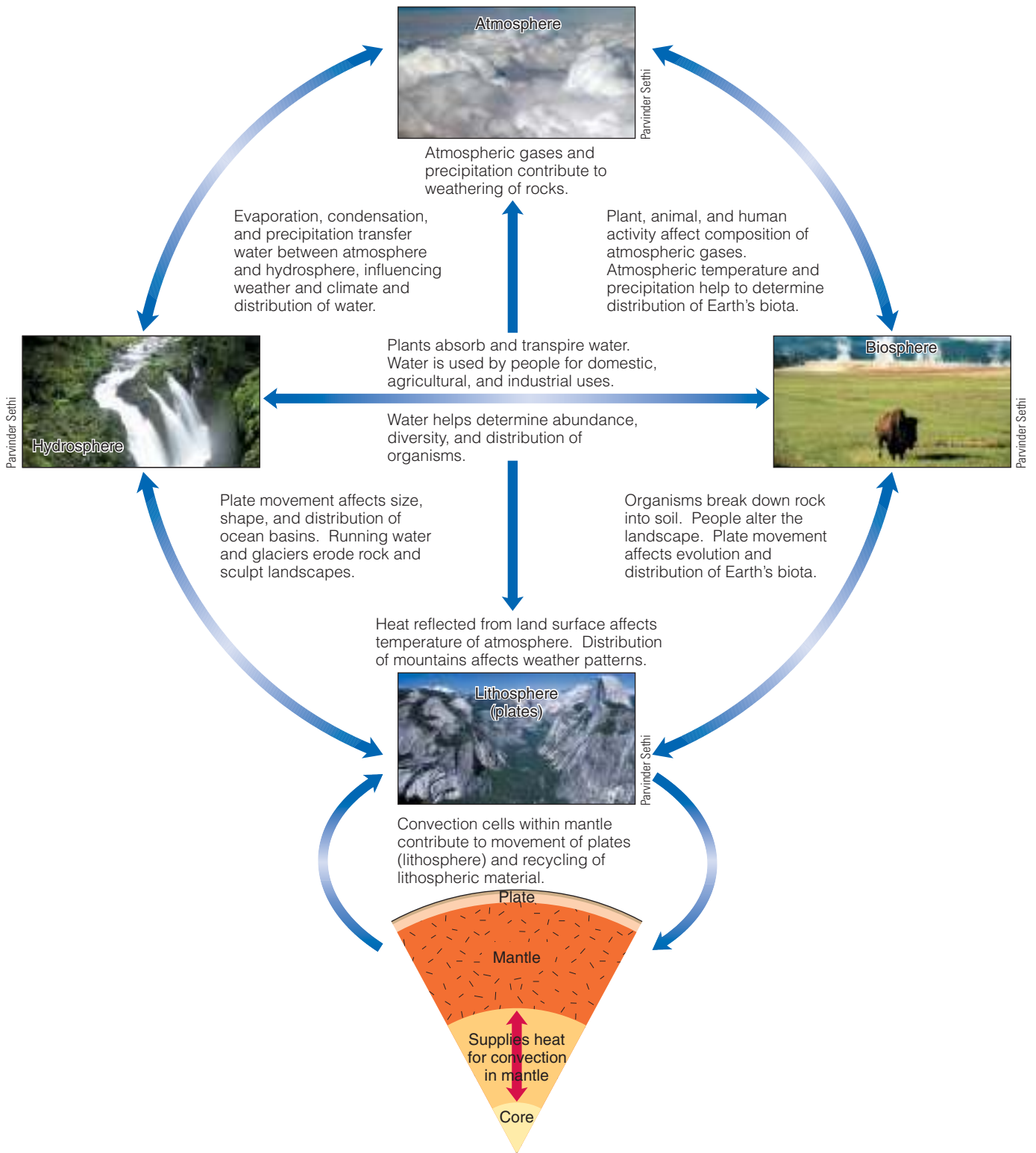
## WHAT IS GEOLOGY?

**Geology**, from the Greek *geo* and *logos*, is defined as the study of Earth, but now must also include the study of the planets and moons in our solar system. It is generally divided into two broad areas—physical geology and historical geology. *Physical geology* is the study of Earth materials, such as minerals and rocks, as well as the processes operating within Earth and on its surface. *Historical geology* examines the origin and evolution of Earth, its continents, oceans, atmosphere, and life.

The discipline of geology is so broad that it is subdivided into numerous fields or specialties. Table 1.2 shows many of the diverse fields of geology and their relationship to the sciences of astronomy, biology, chemistry, and physics.

Nearly every aspect of geology has some economic or environmental relevance. Many geologists are involved in





**Figure 1.1 Subsystems of Earth** The atmosphere, hydrosphere, biosphere, lithosphere, mantle, and core are all subsystems of Earth. This simplified diagram shows how these subsystems interact, with some examples of how materials and energy are cycled throughout the Earth system. The interactions between these subsystems make Earth a dynamic planet that has evolved and changed since its origin 4.6 billion years ago.

TABLE 1.1 Interactions Among Earth's Principal Subsystems

	Atmosphere	Hydrosphere	Biosphere	Lithosphere
Atmosphere	Interaction among various air masses	Surface currents driven by wind; evaporation	Gases for respiration; dispersal of spores, pollen, and seeds by wind	Weathering by wind erosion; transport of water vapor for precipitation of rain and snow
Hydrosphere	Input of water vapor and stored solar heat	Hydrologic cycle	Water for life	Precipitation; weathering and erosion
Biosphere	Gases from respiration	Removal of dissolved materials by organisms	Global ecosystems; food cycles	Modification of weathering and erosion processes; formation of soil
Lithosphere	Input of stored solar heat; landscapes affect air movements	Source of solid and dissolved materials	Source of mineral nutrients; modification of ecosystems by plate movements	Plate tectonics

exploration for mineral and energy resources, using their specialized knowledge to locate the natural resources on which our industrialized society is based. As the demand for these nonrenewable resources increases, geologists apply the basic principles of geology in increasingly sophisticated ways to focus their attention on areas that have a high potential for economic success.

Whereas some geologists work on locating mineral and energy resources, other geologists use their expertise to help solve environmental problems. Finding adequate sources of groundwater for the ever-burgeoning needs of communities and industries is becoming increasingly important, as is the monitoring of surface and underground water pollution and its cleanup. Geologic engineers help find safe locations for dams, waste-disposal sites, and power plants, as well as designing earthquake-resistant buildings.

Geologists are also engaged in making short- and long-range predictions about earthquakes and volcanic eruptions, and the potential destruction that may result. Following the tragic events in Indonesia in 2004, geologists are now more involved than ever in working with various governmental

agencies and civil defense planners to ensure that timely warnings are given to potentially affected regions when natural disasters such as tsunami occur, and that contingency plans are in place.

## GEOLOGY AND THE FORMULATION OF THEORIES

The term **theory** has various meanings. In colloquial usage, it means a speculative or conjectural view of something—hence, the widespread belief that scientific theories are little more than unsubstantiated wild guesses. In scientific usage, however, a theory is a coherent explanation for one or several related natural phenomena supported by a large body of objective evidence. From a theory, scientists derive predictive statements that can be tested by observations and/or experiments so that their validity can be assessed. The law of universal gravitation is an example of a theory that describes the attraction between masses (an apple and Earth in the popularized account of Newton and his discovery).

TABLE 1.2 Specialties of Geology and Their Broad Relationship to the Other Sciences

Specialty	Area of Study	Related Science
Geochronology	Time and history of Earth	Astronomy
Planetary geology	Geology of the planets	
Paleontology	Fossils	Biology
Economic geology	Mineral and energy resources	
Environmental geology	Environment	
Geochemistry	Chemistry of Earth	Chemistry
Hydrogeology	Water resources	
Mineralogy	Minerals	
Petrology	Rocks	
Geophysics	Earth's interior	Physics
Structural geology	Rock deformation	
Seismology	Earthquakes	
Geomorphology	Landforms	
Oceanography	Oceans	
Paleogeography	Ancient geographic features and locations	
Stratigraphy/sedimentology	Layered rocks and sediments	



Theories are formulated through the process known as the **scientific method**. This method is an orderly, logical approach that involves gathering and analyzing facts or data about the problem under consideration. Tentative explanations, or **hypotheses**, are then formulated to explain the observed phenomena. Next, the hypotheses are tested to see whether what was predicted actually occurs in a given situation. Finally, if one of the hypotheses is found, after repeated tests, to explain the phenomena, then the hypothesis is proposed as a theory. Remember, however, that in science, even a theory is still subject to further testing and refinement as new data become available.

The fact that a scientific theory can be tested and is subject to such testing separates it from other forms of human inquiry. Because scientific theories can be tested, they have the potential for being supported or even proven wrong. Accordingly, science must proceed without any appeal to beliefs or supernatural explanations, not because such beliefs or explanations are necessarily untrue, but because we have no way to investigate them. For this reason, science makes no claim about the existence or nonexistence of a supernatural or spiritual realm.

Each scientific discipline has certain theories that are of particular importance. In geology, the formulation of plate tectonic theory has changed the way geologists view Earth. Geologists now view Earth from a global perspective in which all of its subsystems and cycles are interconnected, and Earth history is seen to be a continuum of interrelated events that are part of a global pattern of change.

## HOW DOES GEOLOGY RELATE TO THE HUMAN EXPERIENCE?

You would probably be surprised at the extent to which geology pervades our everyday lives and the numerous references to geology in the arts, music, and literature. Many sketches and paintings depict rocks and landscapes realistically. Leonardo da Vinci's *Virgin of the Rocks* and *Virgin and Child with Saint Anne*, Giovanni Bellini's *Saint Francis in Ecstasy* and *Saint Jerome*, and Asher Brown Durand's *Kindred Spirits* (Figure 1.2) are just a few examples by famous painters.

In the field of music, Ferde Grofé's *Grand Canyon Suite* was no doubt inspired by the grandeur and timelessness of Arizona's Grand Canyon and its vast rock exposures. The rocks on the Island of Staffa in the Inner Hebrides provided the inspiration for Felix Mendelssohn's famous *Hebrides Overture*.

References to geology abound in *The German Legends of the Brothers Grimm*. Jules Verne's *Journey to the Center of the Earth* describes an expedition into Earth's interior. There is even a series of mystery books by Sarah Andrews that features the fictional geologist Em Hansen, who uses her knowledge of geology to solve crimes. On one level, the poem "Ozymandias" by Percy B. Shelley deals with the fact that nothing lasts forever and even solid rock eventually disintegrates under the ravages of time and weathering. Even comics contain references to geology. One of the best known is *The Far Side* by Gary Larson, which, over the years, has had many cartoons with a geological theme.

Image not available due to copyright restrictions

Geology has also played an important role in the history and culture of humankind. Empires throughout history have risen and fallen on the distribution and exploitation of natural resources. Wars have been fought for the control of such natural resources as oil and gas, and valuable minerals such as gold, silver, and diamonds. The configuration of Earth's surface, or its topography, which is shaped by geologic agents, played a critical role in military tactics. For example, Napoleon included two geologists in his expeditionary forces when he invaded Egypt in 1798, and the Russians used geologists as advisors in selecting fortification sites during the Russo-Japanese war of 1904–1905. Natural barriers such as mountain ranges and rivers have frequently served as political boundaries, and the shifting of river channels has sparked numerous border disputes. Deserts, which most people think of as inhospitable areas, have been the home to many people, such as the Bedouin, throughout history.

## HOW DOES GEOLOGY AFFECT OUR EVERYDAY LIVES?

The most obvious connection between geology and our everyday lives is when natural disasters strike. Less apparent,

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