

Table of Contents

Preface xvi

1 An Introduction to Geology 3

Geology: The Science of Earth 5

Physical and Historical Geology 5

Geology, People, and the Environment 5

GEOGRAPHICS **World Population Passes
7 BILLION 6**

The Development of Geology 9

Catastrophism 9

The Birth of Modern Geology 9

Geology Today 9

The Magnitude of Geologic Time 10

The Nature of Scientific Inquiry 13

Hypothesis 13

Theory 14

Scientific Methods 14

Plate Tectonics and Scientific Inquiry 14

Earth's Spheres 15

Hydrosphere 16

Atmosphere 16

Biosphere 17

Geosphere 18

Earth as a System 19

Earth System Science 19

The Earth System 19

Early Evolution of Earth 21

Origin of Planet Earth 21

GEOGRAPHICS **Solar System: Size
and Scale 23**

Formation of Earth's Layered Structure 24

Earth's Internal Structure 25

Earth's Crust 25

Earth's Mantle 26

Earth's Core 26

Rocks and the Rock Cycle 27

The Basic Cycle 27

Alternative Paths 28

The Face of Earth 30

Major Features of the Continents 32

Major Features of the Ocean Floor 33

2 Plate Tectonics: A Scientific Revolution Unfolds 41

From Continental Drift to Plate Tectonics 43

Continental Drift: An Idea Before Its Time 44

Evidence: The Continental Jigsaw Puzzle 44

Evidence: Fossils Match Across the Seas 44

Evidence: Rock Types and Geologic

Features 46

Evidence: Ancient Climates 46

The Great Debate 48

Rejection of the Drift Hypothesis 48



GEOGRAPHICS **The Breakup of
Pangaea 49**

The Theory of Plate Tectonics 50

Rigid Lithosphere Overlies Weak
Asthenosphere 50

Earth's Major Plates 50

Plate Boundaries 51

**Divergent Plate Boundaries and Seafloor
Spreading 53**

Oceanic Ridges and Seafloor Spreading 53

Continental Rifting 55

Convergent Plate Boundaries and Subduction 56

Oceanic–Continental Convergence 57

Oceanic–Oceanic Convergence 58

Continental–Continental Convergence 58

Transform Plate Boundaries 61

Testing the Plate Tectonics Model 63

Evidence: Ocean Drilling 63

Evidence: Mantle Plumes and Hot Spots 63

Evidence: Paleomagnetism 65

How Is Plate Motion Measured? 69

Geologic Evidence for Plate Motion 69

Measuring Plate Motion from Space 69

How Does Plate Motion Affect Plate
Boundaries? 70

What Drives Plate Motions? 71

Forces That Drive Plate Motion 71

Models of Plate–Mantle Convection 72

3 Matter and Minerals 81

Minerals: Building Blocks of Rocks 83

Defining a Mineral 83

What Is a Rock? 84

Atoms: Building Blocks of Minerals 85

Properties of Protons, Neutrons,
and Electrons 85

Elements: Defined by Their Number
of Protons 85

Why Atoms Bond 87

The Octet Rule and Chemical Bonds 87
Ionic Bonds: Electrons Transferred 87
Covalent Bonds: Electron Sharing 87
Metallic Bonds: Electrons Free to Move 88
Hybrid Bonds 88

How Do Minerals Form? 89

Precipitation of Mineral Matter 89
Crystallization of Molten Rock 89
Deposition as a Result of Biological Processes 90

Physical Properties of Minerals 91

Optical Properties 91
Crystal Shape, or Habit 92
Mineral Strength 92
Density and Specific Gravity 94
Other Properties of Minerals 95

GEOGRAPHICS Gold 96

Mineral Structures and Compositions 98

Mineral Structures 98
Compositional Variations in Minerals 99
Structural Variations in Minerals 100

How Minerals Are Classified 101

Classifying Minerals 101
Silicate Versus Nonsilicate Minerals 101

The Silicates 102

Silicate Structures 102
Joining Silicate Structures 103

Common Silicate Minerals 104

The Light Silicates 105
The Dark Silicates 106

Important Nonsilicate Minerals 108

GEOGRAPHICS Gemstones 110

4

Magma, Igneous Rocks, and Intrusive Activity 117

Magma: Parent Material of Igneous Rock 119

The Nature of Magma 119

From Magma to Crystalline Rock 120

Igneous Processes 120

Igneous Compositions 122

Granitic (Felsic) versus Basaltic (Mafic)
Compositions 122
Other Compositional Groups 123
Silica Content as an Indicator of
Composition 123

Igneous Textures: What Can They Tell Us? 124

Types of Igneous Textures 125

GEOGRAPHICS Granite: An Intrusive Igneous Rock 128

Naming Igneous Rocks 130

Granitic (Felsic) Igneous Rocks 131
Andesitic (Intermediate) Igneous Rocks 132
Basaltic (Mafic) Igneous Rocks 132
Pyroclastic Rocks 132

Origin of Magma 134

Generating Magma from Solid Rock 134

How Magmas Evolve 137

Bowen's Reaction Series and the Composition
of Igneous Rocks 137
Magmatic Differentiation and Crystal
Settling 138
Assimilation and Magma Mixing 138

Partial Melting and Magma Composition 140

Formation of Basaltic Magma 140
Formation of Andesitic and Granitic
Magmas 140

Intrusive Igneous Activity 142

Nature of Intrusive Bodies 143
Tabular Intrusive Bodies: Dikes and Sills 143
Massive Intrusive Bodies: Batholiths, Stocks,
and Laccoliths 144

5

Volcanoes and Volcanic Hazards 153

The Nature of Volcanic Eruptions 155

Factors Affecting Viscosity 155
Quiescent versus Explosive Eruptions 156

GEOGRAPHICS Eruption of Mount St. Helens 158



Materials Extruded During an Eruption 160

Lava Flows 160
Gases 161
Pyroclastic Materials 163

Anatomy of a Volcano 164

GEOGRAPHICS Comparison of Three Types of Volcanic Cones 165

Shield Volcanoes 166

Mauna Loa: Earth's Largest Shield Volcano 166
Evolution of Volcanic Islands 167

GEOGRAPHICS Kilauea's East Rift Zone Eruption 168

Cinder Cones 170

Parícutin: Life of a Garden-Variety Cinder
Cone 171

Composite Volcanoes 172

Volcanic Hazards 173

Pyroclastic Flow: A Deadly Force of
Nature 173
Lahars: Mudflows on Active and Inactive
Cones 174
What Are Other Volcanic Hazards? 175

GEOGRAPHICS Eruption of Mount Vesuvius, AD 79 177

Other Volcanic Landforms 178

- Calderas 178
- Fissure Eruptions and Large Igneous Provinces 181
- Lava Domes 182
- Volcanic Necks and Pipes 183

Plate Tectonics and Volcanic Activity 185

- Volcanism at Convergent Plate Boundaries 185
- Volcanism at Divergent Plate Boundaries 188
- Intraplate Volcanism 188

Monitoring Volcanic Activity 190

6

Weathering and Soil 197

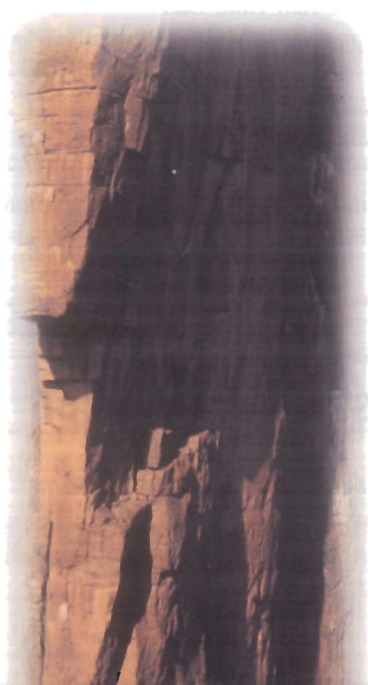
Weathering 199

GEOGRAPHICS Some Everyday Examples of Weathering 200

Mechanical Weathering 201

- Frost Wedging 201
- Salt Crystal Growth 202
- Sheeting 202
- Biological Activity 203

GEOGRAPHICS The Old Man of the Mountain 204



Chemical Weathering 205

- Dissolution 205
- Oxidation 206
- Hydrolysis 207
- Spheroidal Weathering 209

Rates of Weathering 210

- Rock Characteristics 210
- Climate 210
- Differential Weathering 210

GEOGRAPHICS Acid Precipitation: A Human Impact on the Earth System 212

Soil 213

- An Interface in the Earth System 213
- What Is Soil? 213

Controls of Soil Formation 214

- Parent Material 214
- Time 214
- Climate 215
- Plants and Animals 215
- Topography 216

The Soil Profile 217

Classifying Soils 219

The Impact of Human Activities on Soil 221

- Clearing the Tropical Rain Forest—A Case Study of Human Impact on Soil 221
- Soil Erosion: Losing a Vital Resource 222

GEOGRAPHICS The 1930s Dust Bowl: An Environmental Disaster 225

7

Sedimentary Rocks 231

The Importance of Sedimentary Rocks 233

Origins of Sedimentary Rock 234

Detrital Sedimentary Rocks 236

- Shale 236
- Sandstone 238
- Conglomerate and Breccia 240

Chemical Sedimentary Rocks 241

- Limestone 241

Dolostone 243

Chert 243

Evaporites 244

GEOGRAPHICS Limestone: An Important and Versatile Commodity 246

Coal: An Organic Sedimentary Rock 247

GEOGRAPHICS Coal: A Major Energy Source 249

Turning Sediment into Sedimentary Rock: Diagenesis and Lithification 250

- Diagenesis 250
- Lithification 250

Classification of Sedimentary Rocks 251

Sedimentary Rocks Represent Past Environments 253

- Types of Sedimentary Environments 253
- Sedimentary Facies 257

Sedimentary Structures 258

The Carbon Cycle and Sedimentary Rocks 262



8

Metamorphism and Metamorphic Rocks 269

What Is Metamorphism? 271

What Drives Metamorphism? 273

Heat as a Metamorphic Agent 273

Confining Pressure 274

Differential Stress 274

Chemically Active Fluids 275

The Importance of Parent Rock 275

Metamorphic Textures 277

Foliation 277

Foliated Textures 278

Other Metamorphic Textures 279

Common Metamorphic Rocks 281

Foliated Rocks 281

Nonfoliated Rocks 282

GEOGRAPHICS

Marble 284

Metamorphic Environments 286

Contact or Thermal Metamorphism 286

Hydrothermal Metamorphism 287

Burial and Subduction Zone

Metamorphism 288

Regional Metamorphism 288

Other Metamorphic Environments 290

GEOGRAPHICS

Impact Metamorphism 291

Metamorphic Zones 292

Textural Variations 292

Index Minerals and Metamorphic Grade 293

Interpreting Metamorphic Environments 295

Common Metamorphic Facies 295

Metamorphic Facies and Plate Tectonics 295

Mineral Stability and Metamorphic Environments 296

9

Geologic Time 303

Creating a Time Scale—Relative Dating Principles 305

The Importance of a Time Scale 305

Numerical and Relative Dates 305

Principle of Superposition 306

Principle of Original Horizontality 307

Principle of Lateral Continuity 307

Principle of Cross-Cutting Relationships 308

Inclusions 308

Unconformities 309

Applying Relative Dating Principles 312

GEOGRAPHICS

Dating the Lunar Surface 313

Fossils: Evidence of Past Life 314

Types of Fossils 314

Conditions Favoring Preservation 315



Correlation of Rock Layers 316

Correlation Within Limited Areas 317

Fossils and Correlation 317

GEOGRAPHICS

How Is Paleontology Different from Archaeology? 319

Dating with Radioactivity 320

Reviewing Basic Atomic Structure 320

Radioactivity 320

Half-Life 321

Using Various Isotopes 321

Dating with Carbon-14 323

The Geologic Time Scale 324

Structure of the Time Scale 325

Precambrian Time 325

Terminology and the Geologic Time Scale 325

GEOGRAPHICS

Did Humans and Dinosaurs Ever Coexist? 327

Determining Numerical Dates for Sedimentary Strata 328

10

Crustal Deformation 335

What Causes Rock to Deform? 337

Stress: The Force That Deforms Rocks 337

Strain: A Change in Shape Caused by Stress 338



How Do Rocks Deform? 339

- Elastic, Brittle, and Ductile Deformation 339
- Factors That Affect Rock Strength 340
- Ductile Versus Brittle Deformation and the Resulting Rock Structures 340

Folds: Rock Structures Formed by Ductile Deformation 342

- Anticlines and Synclines 342
- Domes and Basins 344
- Monoclines 345

Faults and Joints: Rock Structures Formed by Brittle Deformation 347

- Dip-Slip Faults 347
- Strike-Slip Faults 349
- Oblique-Slip Faults 351
- Joints 352

GEOGRAPHICS The San Andreas Fault System 354

Mapping Geologic Structures 356

- Strike and Dip 356

11

Earthquakes and Earthquake Hazards 361

What Is an Earthquake? 363

- Discovering the Causes of Earthquakes 363
- Aftershocks and Foreshocks 364

Faults and Earthquakes 366

- Types of Faults 366
- Fault Rupture and Propagation 367

Seismology: The Study of Earthquake Waves 368

- Instruments That Record Earthquakes 368
- Seismic Waves 368

GEOGRAPHICS Finding the Epicenter of an Earthquake 371

Determining the Size of Earthquakes 372

- Intensity Scales 372
- Magnitude Scales 373

GEOGRAPHICS Historic Earthquakes East of the Rockies 376

Earthquake Destruction 378

- Destruction from Seismic Vibrations 378
- Landslides and Ground Subsidence 380
- Fire 380
- What Is a Tsunami? 380

Earthquake Belts and Plate Boundaries 383

Can Earthquakes Be Predicted? 384

- Short-Range Predictions 384
- Long-Range Forecasts 385

GEOGRAPHICS Seismic Risks on the San Andreas Fault System 388

12

Earth's Interior 395

Earth's Internal Structure 397

- Gravity and Layered Planets 397
- Mineral Phase Changes 397

Probing Earth's Interior 399

- "Seeing" Seismic Waves 399

GEOGRAPHICS Recreating the Deep Earth 401

Earth's Layers 402

- Earth's Crust 402
- Earth's Mantle 403
- Earth's Core 405

Earth's Temperature 407

- How Did Earth Get So Hot? 407
- Heat Flow 408
- Earth's Temperature Profile 410

Earth's Three-Dimensional Structure 412

- Earth's Gravity 412
- Seismic Tomography 413
- Earth's Magnetic Field 414

13

Divergent Boundaries: Origin and Evolution of the Ocean Floor 423

An Emerging Picture of the Ocean Floor 425

- Mapping the Seafloor 425
- Provinces of the Ocean Floor 428

Continental Margins 430

- Passive Continental Margins 430
- Active Continental Margins 431

Features of Deep-Ocean Basins 433

- Deep-Ocean Trenches 433
- Abyssal Plains 433
- Volcanic Structures on the Ocean Floor 434

Anatomy of the Oceanic Ridge 436

GEOGRAPHICS Explaining Coral Atolls: Darwin's Hypothesis 438

Oceanic Ridges and Seafloor Spreading 440

- Seafloor Spreading 440
- Why Are Oceanic Ridges Elevated? 440
- Spreading Rates and Ridge Topography 440

The Nature of Oceanic Crust 442

- How Does Oceanic Crust Form? 442
- Interactions Between Seawater and Oceanic Crust 443

GEOGRAPHICS Deep-Sea Hydrothermal Vents 444

Continental Rifting: The Birth of a New Ocean Basin 446

- Evolution of an Ocean Basin 446
- Mechanisms for Continental Rifting 448

Destruction of Oceanic Lithosphere 451

- Why Oceanic Lithosphere Subducts 451
- Subducting Plates: The Demise of Ocean Basins 452

14

Convergent Boundaries: Origin of Mountains 459

Mountain Building 461

Convergence and Subducting Plates 463

- Major Features of Subduction Zones 463
- Extension and Back-Arc Spreading 464

Subduction and Mountain Building 465

- Island Arc-Type Mountain Building 465
- Andean-Type Mountain Building 465
- Sierra Nevada, Coast Ranges, and Great Valley 466

Collisional Mountain Belts 468

- Cordilleran-Type Mountain Building 468
- Alpine-Type Mountain Building: Continental Collisions 469
- The Himalayas 470
- The Appalachians 471

Fault-Block Mountains 475

- The Basin and Range Province 475

What Causes Earth's Varied Topography? 477

- The Principle of Isostasy 477
- Mantle Convection: A Cause of Vertical Crustal Movement 478

GEOGRAPHICS **The Laramide Rockies** 480

15

Mass Wasting: The Work of Gravity 487

The Importance of Mass Wasting 489

- Landslides as Geologic Hazards 489
- The Role of Mass Wasting in Landform Development 489
- Slopes Change Through Time 490

GEOGRAPHICS **Landslides as Natural Disasters** 492

Controls and Triggers of Mass Wasting 493

- The Role of Water 493
- Oversteepened Slopes 494
- Removal of Vegetation 494
- Earthquakes as Triggers 496
- Landslides Without Triggers? 497

Classification of Mass-Wasting Processes 498

- Type of Material 498
- Type of Motion 498
- Rate of Movement 499

Rapid Forms of Mass Wasting 501

- Slump 501
- Rockslide 501
- Debris Flow 502
- Earthflow 504

Slow Movements 506

- Creep 506
- Solifluction 506
- The Sensitive Permafrost Landscape 507

GEOGRAPHICS **Landslide Risks: United States and Worldwide** 509

16

Running Water 515

Earth as a System: The Hydrologic Cycle 517

Running Water 519

- Drainage Basins 519
- River Systems 519

Streamflow 521

- Factors Affecting Flow Velocity 521
- Changes Downstream 522

GEOGRAPHICS **What Are the Largest Rivers?** 525

The Work of Running Water 526

- Stream Erosion 526
- Transport of Sediment by Streams 526
- Deposition of Sediment by Streams 529

Stream Channels 530

- Bedrock Channels 530
- Alluvial Channels 530

Shaping Stream Valleys 532

- Base Level and Graded Streams 532
- Valley Deepening 533
- Valley Widening 534
- Incised Meanders and Stream Terraces 534

Depositional Landforms 537

- Deltas 537
- The Mississippi River Delta 537
- Natural Levees 539
- Alluvial Fans 540

Drainage Patterns 541

- Formation of a Water Gap 541
- Headward Erosion and Stream Piracy 542

GEOGRAPHICS **Flash Floods** 544

Floods and Flood Control 545

- Types of Floods 545
- Flood Recurrence Intervals 546
- Flood Control 547



17

Groundwater 555

- The Importance of Groundwater** 557
 - Groundwater and the Hydrosphere 557
 - Geologic Importance of Groundwater 557

GEOGRAPHICS Our Water Supply 558

- The Distribution of Groundwater** 560

- The Water Table** 561
 - Variations in the Water Table 561
 - Interaction Between Groundwater and Streams 561

Factors Influencing the Storage and Movement of Groundwater 563

- Porosity 563
- Permeability, Aquitards, and Aquifers 563

How Groundwater Moves 565

- A Simple Groundwater Flow System 565
- Measuring Groundwater Movement 565
- Different Scales of Movement 566

Wells 568

GEOGRAPHICS Drought Impacts the Hydrologic System 570

Artesian Systems 571

- Springs, Hot Springs, and Geysers** 573
 - Springs 573
 - Hot Springs 573
 - Geysers 574

- Environmental Problems** 576
 - Mining Groundwater 576

- Subsidence 576
- Saltwater Contamination 577
- Groundwater Contamination 578

The Geologic Work of Groundwater 582

- Caverns 582
- Karst Topography 583

18

Glaciers and Glaciation 591

Glaciers: A Part of Two Basic Cycles 593

- Valley (Alpine) Glaciers 593
- Ice Sheets 594
- Other Types of Glaciers 595

Formation and Movement of Glacial Ice 597

- Glacial Ice Formation 597
- Movement of a Glacier 597
- Rates of Glacial Movement 598
- Budget of a Glacier 599

GEOGRAPHICS Antarctica Fact File 602

Glacial Erosion 604

Landforms Created by Glacial Erosion 607

- Glaciated Valleys 608
- Arêtes and Horns 609
- Roches Moutonnées 609

Glacial Deposits 611

- Glacial Till 611
- Stratified Drift 612

Landforms Made of Till 613

- Lateral and Medial Moraines 613
- End and Ground Moraines 613
- Drumlins 616

Landforms Made of Stratified Drift 617

- Outwash Plains and Valley Trains 617
- Ice-Contact Deposits 617

Other Effects of Ice Age Glaciers 618

- Crustal Subsidence and Rebound 618
- Sea-Level Changes 618
- Changes to Rivers and Valleys 618
- Ice Dams Create Proglacial Lakes 619
- Pluvial Lakes 620



GEOGRAPHICS Earth's Shrinking Glaciers 622

The Glacial Theory and the Ice Age 624

Causes of Ice Ages 626

- Plate Tectonics 626
- Variations in Earth's Orbit 626
- Other Factors 628

19

Deserts and Winds 635

Distribution and Causes of Dry Lands 637

- What Is Meant by *Dry*? 637
- Subtropical Deserts and Steppes 638
- Middle-Latitude Deserts and Steppes 638

Geologic Processes in Arid Climates 640

- Weathering 640
- The Role of Water 640

Basin and Range: The Evolution of a Desert Landscape 643

GEOGRAPHICS Common Misconceptions About Deserts 646

Transportation of Sediment by Wind 648

- Bed Load 648
- Suspended Load 649



Wind Erosion 650

- Deflation and Blowouts 650
- Desert Pavement 650
- Ventifacts and Yardangs 651

Wind Deposits 653

- Sand Deposits 653
- Types of Sand Dunes 654
- Loess (Silt) Deposits 656

20

Shorelines 663

The Shoreline: A Dynamic Interface 665

- The Coastal Zone 665
- Basic Features 665
- Beaches 667

GEOGRAPHICS A Brief Tour of America's Coasts 668

Waves 670

- Wave Characteristics 670
- Circular Orbital Motion 670
- Waves in the Surf Zone 671

The Work of Waves 673

- Wave Erosion 673
- Sand Movement on the Beach 673

Shoreline Features 677

- Erosional Features 677
- Depositional Features 677
- The Evolving Shore 680

Stabilizing the Shore 681

- Hard Stabilization 681
- Alternatives to Hard Stabilization 682

Erosion Problems Along U.S. Coasts 685

- Atlantic and Gulf Coasts 685
- Pacific Coast 686

Hurricanes: The Ultimate Coastal Hazard 687

- Profile of a Hurricane 687
- Hurricane Destruction 688
- Detecting and Tracking Hurricanes 690

Coastal Classification 692

- Emergent Coasts 692
- Submergent Coasts 692

GEOGRAPHICS Hurricane Katrina from Space 693

Tides 694

- Causes of Tides 694
- Monthly Tidal Cycle 695
- Tidal Patterns 695
- Tidal Currents 695
- Tides and Earth's Rotation 696

21

Global Climate Change 703

Climate and Geology 705

- The Climate System 705
- Climate–Geology Connections 705

How Is Climate Change Detected? 707

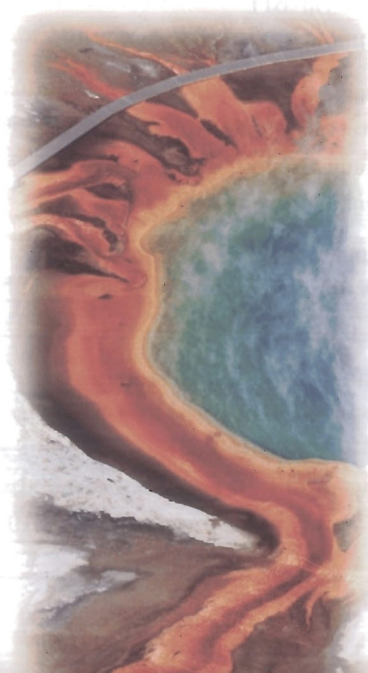
- Seafloor Sediment—A Storehouse of Climate Data 707
- Oxygen Isotope Analysis 708
- Climate Change Recorded in Glacial Ice 708
- Tree Rings—Archives of Environmental History 709
- Other Types of Proxy Data 709

Some Atmospheric Basics 711

- Composition of the Atmosphere 711
- Extent and Structure of the Atmosphere 712

Heating the Atmosphere 714

- Energy from the Sun 714
- The Paths of Incoming Solar Energy 714
- Heating the Atmosphere: The Greenhouse Effect 716



Natural Causes of Climate Change 717

- Plate Movements and Orbital Variations 717
- Volcanic Activity and Climate Change 717
- Solar Variability and Climate 719

Human Impact on Global Climate 721

- Rising CO₂ Levels 721
- The Atmosphere's Response 722
- The Role of Trace Gases 723

GEOGRAPHICS Greenhouse Gas (GHG) Emissions 726

Climate-Feedback Mechanisms 728

- Types of Feedback Mechanisms 728
- Computer Models of Climate: Important Yet Imperfect Tools 728

How Aerosols Influence Climate 730

Some Possible Consequences of Global Warming 732

- Sea-Level Rise 732
- The Changing Arctic 733
- Increasing Ocean Acidity 734
- The Potential for “Surprises” 735

22

Earth's Evolution Through Geologic Time 741

Is Earth Unique? 743

- The Right Planet 743
- The Right Location 743
- The Right Time 744
- Viewing Earth's History 744

Birth of a Planet 746

- From the Big Bang to Heavy Elements 746
- From Planetesimals to Protoplanets 746
- Earth's Early Evolution 746

Origin and Evolution of the Atmosphere and Oceans 749

- Earth's Primitive Atmosphere 749
- Oxygen in the Atmosphere 749
- Evolution of the Oceans 750

Precambrian History: The Formation of Earth's Continents 751

- Earth's First Continents 751
- The Making of North America 753
- Supercontinents of the Precambrian 753



Geologic History of the Phanerozoic: The Formation of Earth's Modern Continents 756

- Paleozoic History 756
- Mesozoic History 757
- Cenozoic History 758

Earth's First Life 760

- Origin of Life 760
- Earth's First Life: Prokaryotes 760

GEOGRAPHICS Evolution of Life Through Geologic Time 762

Paleozoic Era: Life Explodes 763

- Early Paleozoic Life-Forms 763
- Vertebrates Move to Land 764
- Reptiles: The First True Terrestrial Vertebrates 764
- The Great Permian Extinction 766

Mesozoic Era: Age of the Dinosaurs 767

- Gymnosperms: The Dominant Mesozoic Trees 767
- Reptiles: Dominating the Land, Sea, and Sky 767

Cenozoic Era: Age of Mammals 769

- From Reptiles to Mammals 769
- Marsupial and Placental Mammals 769
- Humans: Mammals with Large Brains and Bipedal Locomotion 770

Large Mammals and Extinction 771

GEOGRAPHICS Demise of the Dinosaur 772

23

Energy and Mineral Resources 779

Renewable and Nonrenewable Resources 781

Energy Resources: Traditional Fossil Fuels 782

- Coal 782
- Oil and Natural Gas 783

Oil Sands, Oil Shale, and Gas Hydrates 787

- Oil Sands 787
- Oil Shale 787
- Gas Hydrates: A Fuel from Ocean-Floor Sediments 788

Nuclear Energy 789

- Uranium 789
- Obstacles to Development 789

Renewable Energy 791

- Solar Energy 791
- Wind Energy 792
- Hydroelectric Power 794
- Geothermal Energy 795
- Biomass: Renewable Energy from Plants and Animals 796
- Tidal Power 796

Mineral Resources 798

GEOGRAPHICS Alberta's Oil Sands 800

Igneous and Metamorphic Processes 802

- Magmatic Segregation 802
- Diamonds 802
- Hydrothermal Solutions 802
- Metamorphic Processes 804

Mineral Resources Related to Surface Processes 805

- Weathering and Ore Deposits 805
- Placer Deposits 805

Nonmetallic Mineral Resources 807

- Building Materials 807
- Industrial Minerals 808

24

Touring Our Solar System 815

Our Solar System: An Overview 817

- Nebular Theory: Formation of the Solar System 818
- The Planets: Internal Structures and Atmospheres 819
- Planetary Impacts 821

Earth's Moon: A Chip Off the Old Block 823

- How Did the Moon Form? 823

GEOGRAPHICS Is Earth on a Collision Course? 826

Terrestrial Planets 828

- Mercury: The Innermost Planet 828
- Venus: The Veiled Planet 829
- Mars: The Red Planet 830

GEOGRAPHICS Mars Exploration 834

Jovian Planets 836

- Jupiter: Lord of the Heavens 836
- Saturn: The Elegant Planet 838
- Uranus and Neptune: Twins 840

Small Solar System Bodies 843

- Asteroids: Leftover Planetesimals 843
- Comets: Dirty Snowballs 844
- Meteoroids: Visitors to Earth 845
- Dwarf Planets 847

Appendix A

Metric and English Units Compared 853

Glossary 855

Index 867

