

Preface xii Meet the Authors xix





Introducing Geology and an Overview of Important Concepts 3

Who Needs Geology? 4

Supplying Things We Need 4

Protecting the Environment 5

Avoiding Geologic Hazards 5

Understanding Our Surroundings 8

Earth Systems 9

An Overview of Physical Geology—Important Concepts 10

Internal Processes: How the Earth's Internal Heat Engine

Works 12

Earth's Interior 12

The Theory of Plate Tectonics 13

Surficial Processes: The Earth's External Heat Engine 16

Geologic Time 17

SUMMARY 21





Atoms, Elements, and Minerals 25

Introduction 26

Atoms and Elements 27

Chemical Activity 30

Ions 30

Chemical Composition of the Earth's Crust 30

Crystallinity 32

The Silicon-Oxygen Tetrahedron 33

Nonsilicate Minerals 35

Minerals 35

Crystalline Solid 37

Geologic Processes 37

Specific Chemical Composition 37

The Important Minerals 37

The Physical Properties of Minerals 40

Color 40

Streak 40

Luster 40

Hardness 40

External Crystal Form 41

Cleavage 43

Fracture 44

Specific Gravity 45

Special Properties 46

Other Properties 46 Chemical Tests 47

SUMMARY 47



Igneous Rocks, Intrusive Activity, and the Origin of Igneous Rocks 51

The Rock Cycle 52

A Plate-Tectonic Example 53

Igneous Rocks 53

Igneous Rock Textures 55

Identification of Igneous Rocks 57

Varieties of Granite 58

Chemistry of Igneous Rocks 58

Intrusive Bodies 60

Shallow Intrusive Structures 60

Intrusives That Crystallize at Depth 61

Abundance and Distribution of Plutonic Rocks 63

How Magma Forms 64

Heat for Melting Rock 64

Factors That Control Melting Temperatures 64

How Magmas of Different Compositions Evolve 66

Sequence of Crystallization and Melting 66

Differentiation 67

Partial Melting 68

Assimilation 68

Mixing of Magmas 69

CONTENTS

Explaining Igneous Activity by Plate Tectonics 69
Igneous Processes at Divergent Boundaries 69
Intraplate Igneous Activity 69
Igneous Processes at Convergent Boundaries 70

SUMMARY 73

vi



HAPTER



Volcanism and Extrusive Rocks 77

Introduction 78

Living with Volcanoes 81

Supernatural Beliefs 81

The Growth of an Island 81

Geothermal Energy 81

Effect on Climate 81

Volcanic Catastrophes 81

Eruptive Violence and Physical Characteristics of Lava 84

Extrusive Rocks and Gases 85

Scientific Investigation of Volcanism 85

Gases 85

Extrusive Rocks 86

Composition 86

Extrusive Textures 87

Types of Volcanoes 89

Shield Volcanoes 90

Cinder Cones 92

Composite Volcanoes 94

Volcanic Domes 96

Lava Floods 99

Submarine Eruptions 100

Pillow Basalts 100

SUMMARY 102



CHAPTER



Weathering and Soil 107

Weathering, Erosion, and Transportation 108 Weathering and Earth Systems 108

> Solar System 108 Atmosphere 109 Hydrosphere 109

Biosphere 109

How Weathering Alters Rock 109

Effects of Weathering 109

Mechanical Weathering 111

Frost Action 111

Pressure Release 111

Other Processes 111

Chemical Weathering 113

Role of Oxygen 114

Role of Acids 114

Solution Weathering 114

Chemical Weathering of Feldspar 116

Chemical Weathering of Other Minerals 116

Weathering Products 118

Weathering and Climate 118

Soil 118

Soil Horizons 119

Soil Classification 119

Residual and Transported Soils 120

Soils, Parent Material, Time, and Slope 120

Organic Activity 122

Soils and Climate 122

Buried Soils 124

SUMMARY 124



CHAPTER



Sediment and Sedimentary Rocks 127

Sediment 129

Transportation 129

Deposition 130

Preservation 131

Lithification 132

Types of Sedimentary Rocks 133

Clastic Rocks 133

Breccia and Conglomerate 133

Sandstone 135

The Fine-Grained Rocks 136

Chemical Sedimentary Rocks 137

Carbonate Rocks 137

Chert 141

Evaporites 141

Organic Sedimentary Rocks 142

Coal 142

The Origin of Oil and Gas 142

Sedimentary Structures 142

Formations 147

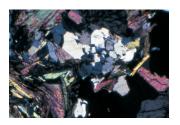
Interpretation of Sedimentary Rocks 148

Source Area 148

Environment of Deposition 150

Plate Tectonics and Sedimentary Rocks 152

SUMMARY 153



CHAPTER



Metamorphism, Metamorphic Rocks, and Hydrothermal Rocks 157

Introduction 158

Factors Controlling the Characteristics of Metamorphic

Rocks 159

Composition of the Parent Rock 160

Temperature 160

Pressure 160

Fluids 162

Time 162

Classification of Metamorphic Rocks 163

Types of Metamorphism 163

Contact Metamorphism 163

Regional Metamorphism 165

Plate Tectonics and Metamorphism 169

Hydrothermal Processes 172

Hydrothermal Activity at Divergent Plate Boundaries 172

Water at Convergent Boundaries 173

Metasomatism 173

Hydrothermal Rocks and Minerals 174

SUMMARY 176



CHAPTER



Time and Geology 179

The Key to the Past 180

Relative Time 181

Principles Used to Determine Relative Age 181

Unconformities 186

Correlation 187

The Standard Geologic Time Scale 191

Numerical Age 193

Isotopic Dating 193

Uses of Isotopic Dating 196

Combining Relative and Numerical Ages 198

Age of the Earth 199

Comprehending Geologic Time 201

SUMMARY 201



CHAPTER



Mass Wasting 205

Classification of Mass Wasting 206

Rate of Movement 206

Type of Material 206

Type of Movement 206

Controlling Factors in Mass Wasting 208

Gravity 210

Water 210

Triggering Mechanisms 211

Common Types of Mass Wasting 212

Creep 212

Debris Flow 213

Rockfalls and Rockslides 217

Underwater Slides 220

Preventing Landslides 221

Preventing Mass Wasting of Debris 221

Preventing Rockfalls and Rockslides on Highways 222

SUMMARY 224



CHAPTER

Streams and Floods 227

Earth Systems—The Hydrologic Cycle 229

Channel Flow and Sheet Flow 229

Drainage Basins 230

Drainage Patterns 231

Factors Affecting Stream Erosion and Deposition 231

Velocity 232

Gradient 233

Channel Shape and Roughness 233

Discharge 234

Stream Erosion 235

Stream Transportation of Sediment 236

Stream Deposition 237

Bars 237

Braided Streams 240

Meandering Streams and Point Bars 241

Flood Plains 243

Deltas 243

Alluvial Fans 246

CONTENTS viii

Flooding 246 Urban Flooding 247 Flash Floods 247 Controlling Floods 251

The Great Flood of 1993 251

Stream Valley Development 253

Downcutting and Base Level 253 The Concept of a Graded Stream 253 Lateral Erosion 255

Headward Erosion 255

Stream Terraces 256 Incised Meanders 257

Superposed Streams 257

SUMMARY 259





Ground Water 263

Introduction 264 Porosity and Permeability 264 The Water Table 265 The Movement of Ground Water 267 Aguifers 268 Wells 269 Springs and Streams 270 Contamination of Ground Water 272 Balancing Withdrawal and Recharge 277 Effects of Ground-Water Action 277 Caves, Sinkholes, and Karst Topography 277 Other Effects 280 Hot Water Underground 281 Geothermal Energy 282

SUMMARY 283





Glaciers and Glaciation 287

The Theory of Glacial Ages 288 Glaciers—What They Are, How They Form and Move 289 Distribution of Glaciers 289 Types of Glaciers 289

Formation and Growth of Glaciers 291 Movement of Valley Glaciers 292 Movement of Ice Sheets 296

Glacial Erosion 298

Erosional Landscapes Associated with Alpine Glaciation 298 Erosional Landscapes Associated with Continental Glaciation 301

Glacial Deposition 302

Moraines 303

Outwash 305

Glacial Lakes and Varves 306

Effects of Past Glaciation 308

The Glacial Ages 308

Direct Effects of Past Glaciation in North America 309 Indirect Effects of Past Glaciation 310

Evidence for Older Glaciation 311

SUMMARY 313





Deserts and Wind Action 317

Distribution of Deserts 318 Some Characteristics of Deserts 319 Desert Features in the Southwestern United States 322 Wind Action 326 Wind Erosion and Transportation 326 Wind Deposition 328

SUMMARY 330





Waves, Beaches, and Coasts 339

Introduction 340 Water Waves 340 Surf 341

Near-shore Circulation 342 Wave Refraction 342 Longshore Currents 342 Rip Currents 342

Beaches 344

Longshore Drift of Sediment 345 Human Interference with Sand Drift 346 Sources of Sand on Beaches 348

CONTENTS

ix

Coasts and Coastal Features 348
Erosional Coasts 349
Depositional Coasts 350
Drowned Coasts 351
Uplifted Coasts 352
The Biosphere and Coasts 353

SUMMARY 356



CHAPTER

15

Geologic Structures 359

Introduction 360

Tectonic Forces at Work 360

Stress and Strain in the Earth's Crust 360 Behavior of Rocks to Stress and Strain 361

Present Deformation of the Crust 362

Structures as a Record of the Geologic Past 362 Geologic Maps and Field Methods 362

Folds 365

Geometry of Folds 365

Interpreting Folds 368

Fractures in Rock 369

Joints 369 Faults 370

SUMMARY 379



CHAPTER

16

Earthquakes 383

Introduction 384

Causes of Earthquakes 386

Seismic Waves 387

Body Waves 388

Surface Waves 389

Locating and Measuring Earthquakes 389

Determining the Location of an Earthquake 389

Measuring the Size of an Earthquake 392

Location and Size of Earthquakes in the United States 395

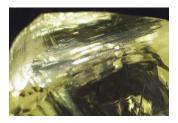
Effects of Earthquakes 395

Tsunami 399

World Distribution of Earthquakes 403

First-Motion Studies of Earthquakes 403
Earthquakes and Plate Tectonics 405
Earthquakes at Plate Boundaries 405
Subduction Angle 407
Earthquake Prediction and Seismic Risk 407

SUMMARY 412



CHAPTER

Earth's Interior and Geophysical Properties 417

Introduction 418

Evidence from Seismic Waves 418

Earth's Internal Structure 421

The Crust 421

The Mantle 422

The Core 424

Isostasy 428

Gravity Measurements 429

Earth's Magnetic Field 432

Magnetic Reversals 433

Magnetic Anomalies 434

Heat Within the Earth 437 Geothermal Gradient 437 Heat Flow 438

SUMMARY 439



HAPTFR

18

The Sea Floor 443

Origin of the Ocean 444
Methods of Studying the Ocean Floor 444
Features of the Sea Floor 446
Continental Shelves and Continental Slopes 446
Submarine Canyons 448
Turbidity Currents 449
Passive Continental Margins 450
The Continental Rise 451
Abyssal Plains 451

X

CONTENTS

Active Continental Margins 452
Oceanic Trenches 452

The Mid-Oceanic Ridge 453
Geologic Activity on the Ridge 453
Biologic Activity on the Ridge 455

Fracture Zones 455

Seamounts, Guyots, and Aseismic Ridges 456
Reefs 457

Sediments of the Sea Floor 459
Oceanic Crust and Ophiolites 459

The Age of the Sea Floor 462

The Sea Floor and Plate Tectonics 462

SUMMARY 462





Plate Tectonics 467

The Early Case for Continental Drift 469
Skepticism About Continental Drift 472
Paleomagnetism and the Revival of Continental Drift 472
Recent Evidence for Continental Drift 473
History of Continental Positions 474
Seafloor Spreading 474

Hess's Driving Force 474
Explanations 475

Plates and Plate Motion 476

How Do We Know That Plates Move? 477
Marine Magnetic Anomalies 477
Another Test: Fracture Zones and Transform Faults 480
Measuring Plate Motion Directly 480

Divergent Plate Boundaries 481

Transform Boundaries 484

Convergent Plate Boundaries 485

Ocean-Ocean Convergence 486 Ocean-Continent Convergence 487

Continent-Continent Convergence 489

Backarc Spreading 490

The Motion of Plate Boundaries 490

Plate Size 491

The Attractiveness of Plate Tectonics 491

What Causes Plate Motions? 492

Mantle Plumes and Hot Spots 494

The Relationship Between Plate Tectonics and Ore Deposits 497 A Final Note 498

SUMMARY 499



CHAPTER

Mountain Belts and the Continental Crust 503

Characteristics of Major Mountain Belts 506
Size and Alignment 506
Ages of Mountain Belts and Continents 506
Thickness and Characteristics of Rock Layers 508
Patterns of Folding and Faulting 508
Metamorphism and Plutonism 510
Normal Faulting 510
Thickness and Density of Rocks 510

Features of Active Mountain Ranges 511

The Evolution of a Mountain Belt 511
The Accumulation Stage 511

The Orogenic Stage 512
The Uplift and Block-Faulting Stage 515

The Growth of Continents 520 Displaced Terranes 520

SUMMARY 522



HAPTER

21

Geologic Resources 525

Types of Resources 526
Resources and Reserves 527

Energy Use 527

Oil and Natural Gas 528
The Occurrence of Oil and Gas 528
Recovering the Oil 529
How Much Petroleum Do We Have Left? 530

Heavy Crude and Oil Sands 530

Heavy Crude and Oil Sands 530

Oil Shale 532

Coal 532

Varieties of Coal 532 Occurrence of Coal 533 Environmental Effects 535 Reserves and Resources 535

CONTENTS

хi

| Uranium 535 |
|---------------------------------------|
| Alternative Sources of Energy 536 |
| Metals and Ores 536 |
| Origin of Metallic Ore Deposits 536 |
| Ores Associated with Igneous Rocks 53 |
| Ores Formed by Surface Processes 538 |
| Mining 539 |
| Environmental Effects 539 |
| Some Important Minerals 540 |
| Iron 540 |
| Copper 541 |
| Aluminum 541 |
| Lead 541 |
| Zinc 542 |
| Silver 542 |
| Gold 542 |
| Other Metals 543 |
| Nonmetallic Resources 543 |
| Construction Materials 543 |
| Fertilizers and Evaporites 544 |
| Other Nonmetallics 544 |
| Some Future Trends 544 |
| The Human Perspective 544 |
| SUMMARY 545 |



CHAPTER

The Earth's Companions 549

The Earth in Space 550
The Sun 550
The Solar System 550
The Milky Way and the Universe 554

Origin of the Planets 554 The Solar Nebula 554 Formation of the Planets 556 Formation of Moons 557 Final Stages of Planet Formation 557 Formation of Atmospheres 557 Other Planetary Systems 557 Portraits of the Planets 558 Our Moon 558 Description of the Moon 559 Structure of the Moon 562 Origin and History of the Moon 562 Mercury 564 Venus 565 Mars 566 Why Are the Terrestrial Planets So Different? 570 Jupiter 571 Saturn 573 Uranus 574 Neptune 574 Pluto 575 Minor Objects of the Solar System 575 Meteors and Meteorites 575 Asteroids 576 Comets 576 Giant Impacts 578

SUMMARY 579

Giant Meteor Impacts 578

Appendixes A—G A-1 Glossary G-1 Index I-1