

| | |
|-----------------|------|
| Preface | xi |
| Reviewers | xii |
| From the Author | xiii |
| To the Student | xiv |

PART I

INTRODUCTION

CHAPTER 1

ROCKS AND EARTH STRUCTURE 2

| | |
|---|---|
| Introduction | 2 |
| The Three Classes of Rocks | 2 |
| Rock Distribution in the Earth | 3 |
| Earth Structure and Petrotectonic Assemblages | 3 |

PART II

IGNEOUS ROCKS

CHAPTER 2

IGNEOUS ROCKS: THEIR STRUCTURES AND TEXTURES 8

| | |
|------------------------------|----|
| Introduction | 8 |
| Recognition of Igneous Rocks | 8 |
| Structures of Igneous Rocks | 9 |
| Extrusive Structures | 10 |
| Intrusive Structures | 13 |
| Textures of Igneous Rocks | 18 |
| Origins of Igneous Textures | 24 |

CHAPTER 3

CHEMISTRY, MINERALOGY, AND CLASSIFICATION OF IGNEOUS ROCKS 33

| | |
|---|----|
| Introduction | 33 |
| Chemistry of Igneous Rocks: An Overview | 34 |
| Igneous Minerals | 38 |

| | |
|--|----|
| Nesosilicates, Sorosilicates, and Cyclosilicates | 38 |
| Inosilicates | 38 |
| Phyllosilicates | 39 |
| Tectosilicates | 39 |
| Nonsilicates | 39 |

Textural-Mineralogical Classifications of Igneous Rocks 40

| | |
|--|----|
| Classifications of Phaneritic Feldspathic Rocks | 41 |
| Classification of Phaneritic Ferromagnesian Rocks | 44 |
| Mineralogical-Textural Classification of Fine-Grained to Glassy (Volcanic) Rocks | 45 |

Chemical Classifications 46

| | |
|---|----|
| Classification of Rocks and Rock Series Using Chemical Data | 46 |
| Classification Using Modified Chemical Data | 50 |

Classifications Using Multiple Criteria and Tectonic Setting 51

CHAPTER 4

THE PHASE RULE AND PHASE DIAGRAMS 57

Introduction 57

Systems and the Phase Rule 57

Unary Systems 59

Binary Systems 60

The System $\text{SiO}_2\text{-H}_2\text{O}$ 60

Solid-Solid Eutectic Binary Systems 61

Equilibrium Crystallization in the System

$\text{Si}_2\text{O-NaAlSi}_3\text{O}_8$ 63

The Lever Rule 65

Disequilibrium Crystallization in the System

$\text{CaMgSi}_2\text{O}_6\text{-CaAl}_2\text{Si}_2\text{O}_8$ 66

Melting in Binary Eutectic Systems 66

Binary Peritectic Systems 68

The System $\text{SiO}_2\text{-KAlSi}_2\text{O}_6$ 68

The System $\text{SiO}_2\text{-Mg}_2\text{SiO}_4$ 71

Binary Solid Solution Systems 71

Single-Loop Systems 71

More Complex Systems: The System $\text{NaAlSi}_3\text{O}_8\text{-KAlSi}_3\text{O}_8$ 73

Ternary and Other Multicomponent Systems 74

| | |
|---|----|
| A Basalt Analogue | 76 |
| Petrogeny's Residua System and the Granites | 78 |
| Bowen's Reaction Series | 79 |

CHAPTER 5

PETROGENESIS, MOVEMENT, AND MODIFICATION OF MAGMAS 83

| | |
|--|----|
| Introduction | 83 |
| Primitive, Primary, and Parental Magmas | 83 |
| Magma Genesis | 84 |
| Igneous Rocks and Parental Magmas | 84 |
| Source Rocks | 84 |
| <i>Seismic Indications of Magma Sources</i> | 84 |
| <i>Mantle Xenoliths</i> | 84 |
| <i>Chemical Constraints on Magma Sources and Magma Origins</i> | 85 |
| Magma Movements | 88 |
| Modification of Magmas | 91 |
| Differentiation of Magmas | 91 |
| Magma Mixing and Mingling | 92 |
| Assimilation | 92 |
| The Formation of Rocks | 93 |

CHAPTER 6

BASALTS AND ULTRAMAFIC VOLCANIC ROCKS 98

| | |
|--|-----|
| Introduction | 98 |
| Basalt Types and Derivatives | 98 |
| Occurrences of Basalts | 100 |
| Rift Volcanism | 100 |
| Volcanism in Subduction Zone Compressional Settings | 101 |
| Intraplate Volcanism | 101 |
| Basalt Chemistry, Mineralogy, Textures, and Structures | 102 |
| Specific Occurrences and Origins of Basalts | 103 |
| Intraplate Volcanism: Hot Spot—The Hawaiian Islands | 104 |
| <i>Observations</i> | 104 |
| <i>Interpretations and Petrogenesis</i> | 106 |
| Intraplate Volcanism: Flood Basalts—The Columbia River Plateau | 108 |
| <i>Observations</i> | 109 |
| <i>Interpretations and Petrogenesis</i> | 110 |
| Rift Basalts | 111 |
| <i>Observations</i> | 111 |
| <i>Magma Genesis</i> | 112 |
| <i>Formation of the Oceanic Crust</i> | 113 |
| Continental Rift Volcanism: The Rio Grande Rift | 114 |
| Arc Basalts | 114 |
| <i>Observations</i> | 114 |
| <i>Petrogenesis</i> | 115 |
| Ultramafic Volcanic Rocks | 118 |
| Komatiites | 118 |
| Kimberlites | 119 |

CHAPTER 7

RHYOLITES AND PYROCLASTIC ROCKS 125

| | |
|---|-----|
| Introduction | 125 |
| Mineralogy, Textures, and Structures of Rhyolites | 125 |
| Chemistry of Rhyolitic Rocks | 126 |
| Occurrences | 128 |
| Mantle-Plume (Hot Spot) Rhyolites | 128 |
| Rift, Transform, and Triple-Junction Rhyolites | 128 |
| Arc Rhyolites | 128 |
| Petrogenesis of Rhyolites | 129 |
| Rhyolite Volcanism: The Yellowstone Example | 131 |
| Observations | 131 |
| Interpretations | 134 |
| Other Pyroclastic and Volcaniclastic Rocks | 134 |

CHAPTER 8

ANDESITES AND RELATED ROCKS 138

| | |
|--|-----|
| Introduction | 138 |
| Mineralogy and Textures of Andesites | 138 |
| Types and Occurrences of Andesites and Related Rocks | 140 |
| Chemistry of Andesites | 140 |
| Major Element Chemistry | 140 |
| Trace Elements and Isotopes | 141 |
| Petrogenesis of Andesites | 142 |
| The Models and Subduction Effects | 143 |
| Models of Andesite Formation | 145 |
| <i>Anatexis of Subducted Sediment (C) ± Oceanic Crust (B) (Model 1)</i> | 145 |
| <i>Anatexis of Basal Crust (F, G) (Model 2)</i> | 145 |
| <i>Anatexis of Subducted Crust (B) ± Mantle (A) (Model 3)</i> | 146 |
| <i>Anatexis of Pyrolite and Pyroxenite with Fractional Crystallization (Model 4)</i> | 146 |
| <i>Anatexis of Mantle Rocks (Model 5)</i> | 146 |
| <i>Fractional Crystallization of Basaltic Magma (Model 6)</i> | 147 |
| <i>Mantle Anatexis plus Crustal Rock Assimilation (Model 7)</i> | 148 |
| <i>Mixing of Magmas (Model 8)</i> | 148 |
| Conclusions on Petrogenesis | 149 |
| Examples of Andesite Origins | 149 |
| The Aleutian Arc | 149 |
| The Cascade Range | 151 |

CHAPTER 9

ULTRAMAFIC-MAFIC COMPLEXES AND RELATED ROCKS 161

| | |
|--|-----|
| Introduction | 161 |
| Kinds of Ultramafic and Ultramafic-Mafic Rock Bodies | 161 |
| Occurrences of Igneous Complexes Containing Ultramafic Rocks | 162 |
| Layered Bodies | 162 |
| Zoned to Irregular Intrusions | 164 |
| Chemistry, Minerals, Textures, and Structures | 164 |

| | |
|--|-----|
| Chemistry and Minerals | 164 |
| Structures and Textures | 167 |
| The Nature and Origins of Ultramafic-Mafic Complexes | 172 |
| Dikes and Sills | 172 |
| <i>General Comments</i> | 172 |
| <i>Example: The Red Hill Dike</i> | 173 |
| Lopolithic Layered Intrusions | 174 |
| <i>General Comments</i> | 175 |
| <i>Example: The Stillwater Complex</i> | 175 |
| <i>The Origin of the Lopolithic Intrusions</i> | 176 |
| Ophiolites | 178 |
| <i>The Structure and Composition of Ophiolites</i> | 179 |
| <i>The Origin of Ophiolites</i> | 181 |
| <i>Example: The Del Puerto Ophiolite</i> | 183 |
| Alaska-Type Ultramafic-Mafic Complexes | 185 |
| <i>Descriptive Petrology and Chemistry</i> | 185 |
| <i>Example: The Duke Island Ultramafic Complex</i> | 185 |
| <i>The Origin of Alaska-Type Complexes</i> | 186 |
| Appinite-Type Ultramafic Rocks | 187 |
| Ultramafic Rocks in Alkaline Complexes | 187 |

CHAPTER 10

GRANITES, GRANODIORITES, AND RELATED ROCKS 193

| | |
|--|-----|
| Introduction | 193 |
| Chemistry, Mineralogy, and Textures of Granitoid Rocks | 194 |
| Chemistry | 194 |
| Minerals | 197 |
| Textures | 198 |
| Structure of Granitoid Plutons | 201 |
| Occurrences of Granitoid Rocks, Their Tectonic Significance, and Granitoid Rock Typing | 202 |
| The Origins of Granitoid Rocks | 205 |
| Granitization | 206 |
| Fractional Crystallization of Basaltic Magmas | 206 |
| Hybridization | 210 |
| Anatexis | 211 |
| Granitoid Rock Types: A Summary of Petrogenesis | 214 |
| Example: The Tuolumne Intrusive Series, Sierra Nevada Batholith | 214 |
| Example: The Rattlesnake Pluton, Massachusetts: A Case with Peralkaline Rocks | 220 |
| Petrogenesis of Pegmatitic Rocks | 222 |
| A Brief Review of Granite Origins | 222 |
| Pegmatitic Granites and Aplites | 222 |
| Aplite Petrogenesis | 222 |
| Pegmatite Petrogenesis | 223 |
| Example: The Tin Mountain Pegmatite, Black Hills, South Dakota | 225 |

CHAPTER 11

ALKALINE IGNEOUS ROCKS AND CARBONATITES 236

| | |
|---|-----|
| Introduction | 236 |
| Rock Types, Minerals, Textures, Structures, and Chemistries | 236 |

| | |
|---|-----|
| Rock Types and Their Essential Minerals | 236 |
| Textures and Structures | 237 |
| Chemistries | 237 |
| Occurrences | 239 |
| Petrogenesis of Alkaline and Other Odd Magmas and Rocks | 241 |
| Fractional Crystallization | 241 |
| Crystallization of Immiscible Melts | 244 |
| Mantle Melts | 244 |
| Examples of Alkaline and Related Rocks | 245 |
| Phonolite, Shonkinite, and Related Rocks of the Highwood Mountains, Montana | 245 |
| Alkaline and Related Rocks of Magnet Cove, Arkansas | 249 |
| Other Examples | 252 |
| <i>The Concord Gabbro-Syenite Complex</i> | 252 |
| <i>The Mount Monadnock Complex</i> | 253 |

PART

III

SEDIMENTARY ROCKS

CHAPTER 12

SEDIMENTARY ROCKS: THEIR STRUCTURES, TEXTURES, AND COMPOSITIONS 260

| | |
|--|-----|
| Introduction | 260 |
| Structures of Sedimentary Rocks | 261 |
| Bedding, Lamination, and Internal Structures | 261 |
| Surface Structures and Other Features | 266 |
| Textures in Sedimentary Rocks | 268 |
| Crystalline Textures and Their Origins | 268 |
| Clastic Textures and Their Origins | 269 |
| Mineralogy of Sedimentary Rocks | 272 |
| Chemistry of Sedimentary Rocks | 272 |

CHAPTER 13

CLASSIFICATION OF SEDIMENTARY ROCKS 279

| | |
|--|-----|
| Introduction | 279 |
| Classification of Group S Rocks | 279 |
| Siliciclastic Conglomerates, Breccias, and Diamictites | 279 |
| Sandstone Classification | 280 |
| Classification of Mudrocks | 283 |
| Classification of Group P Rocks | 285 |
| Carbonate Rock Classifications | 286 |
| Classification of Other Precipitates | 288 |
| Classification of Group A Rocks | 288 |

CHAPTER 14

SEDIMENTARY PROVENANCE, PROCESSES, AND DIAGENESIS 292

| | |
|---------------------------|-----|
| Introduction | 292 |
| Weathering and Provenance | 292 |
| Weathering | 292 |
| Provenance | 294 |

| | |
|--|-----|
| The Products of Weathering | 294 |
| Transportation of Sediments | 295 |
| Mechanical Transportation and Deposition | 296 |
| <i>Gravity Transportation and Deposition</i> | 296 |
| <i>Glacial Transportation and Deposition</i> | 298 |
| <i>Transportation in and Deposition from Air and Water</i> | 298 |
| Chemical Transportation and Deposition | 298 |
| Diagenesis | 299 |
| Types of Diagenetic Processes and Diagenetic Environments | 299 |
| The Fluid Phase | 301 |
| Diagenesis of Sediments and Rocks | 302 |
| <i>Carbonate Rocks</i> | 302 |
| <i>Cherts</i> | 306 |
| <i>Mudrocks</i> | 307 |
| <i>Sandstones and Conglomerates</i> | 307 |
| <i>Other Sedimentary Rocks</i> | 311 |

CHAPTER 15

SEDIMENTARY ENVIRONMENTS 316

| | |
|--|-----|
| Introduction | 316 |
| Types of Sedimentary Environments and Their Deposits | 316 |
| Continental Environments | 316 |
| Fluvial Environments | 316 |
| Desert Environments and Rocks | 319 |
| Glacial Environments and Deposits | 320 |
| Lacustrine and Other Continental Environments and Deposits | 321 |
| Transitional Environments | 322 |
| Coastal Deltaic Environments | 322 |
| Estuarine-Lagoonal Environments | 323 |
| Littoral and Related Environments | 323 |
| Marine Environments | 325 |
| Shelf-Shallow Sea Environments | 326 |
| Reefs | 326 |
| Slope-Rise Environments | 329 |
| Submarine Canyons and Trenches | 330 |
| <i>The Submarine Fan Model</i> | 330 |
| <i>Submarine Fan Facies</i> | 330 |
| <i>Trench Slope and Trench Floor Environments</i> | 332 |
| Seafloor Environments | 334 |
| Rift-Transform Environments | 334 |

CHAPTER 16

MUDROCKS 341

| | |
|---|-----|
| Introduction | 341 |
| Types and Occurrences of Mudrocks | 341 |
| Mineralogy, Chemistry, and Colors of Mudrocks | 342 |
| Mineralogy | 342 |
| Chemistry | 344 |
| <i>Inorganic Chemistry</i> | 345 |
| <i>Organic Chemistry</i> | 346 |
| Colors | 347 |

| | |
|---|-----|
| Structures and Textures of Mudrocks | 348 |
| Contemporary Settings of Mudrock Deposition | 348 |
| Deposition of Mudrock Precursors on the Nazca Plate | 349 |
| Shelf Muds Along the South Texas Gulf Coast | 351 |
| Muddy Sediments in Western Lake Superior | 352 |
| Ancient Mudrocks | 353 |
| Upper Ordovician Shales of the Cincinnati Arch Area | 353 |
| Devonian Shales of the Appalachian Basin and Adjacent Areas | 354 |
| The Green River Formation | 357 |

CHAPTER 17

SANDSTONES 364

| | |
|--|-----|
| Introduction | 364 |
| Sandstone Classifications and Textures | 364 |
| Classifications and the Nature of Matrix | 364 |
| Matrix | 365 |
| Textures | 366 |
| Sandstone Compositions | 366 |
| Sandstone Structures | 371 |
| Occurrences and Origins of Wackes | 371 |
| Turbidites and Related Rocks | 371 |
| Contourites and Shelf Wackes | 372 |
| Transitional Environment and Continental Wackes | 373 |
| <i>Example: Deep-Sea Sands</i> | 373 |
| <i>Example: Wackes of the Franciscan Complex, California</i> | 373 |
| Occurrences and Origins of Arenites | 375 |
| The Great Sand Sheets | 378 |
| Shoestring Sandstones | 380 |
| Examples of Arenite Sandstones | 380 |
| <i>The St. Peter Sandstone, North-Central North America</i> | 380 |
| <i>The Navajo Sandstone of the Rocky Mountains-COLORADO Plateau Region</i> | 380 |
| Sequences with Mixed Sandstone Lithologies | 382 |
| Environments and Occurrences | 382 |
| Example: The Great Valley Group, California | 382 |

CHAPTER 18

CONGLOMERATES, DIAMICTITES, AND BRECCIAS 391

| | |
|--|-----|
| Introduction | 391 |
| Distinctions between Major Types of Coarse Clastic Rocks | 391 |
| Textures, Structures, and Compositions of Coarse Clastic Sedimentary Rocks | 394 |
| Textures and Structures | 394 |
| Compositions | 397 |
| Origins of Coarse Clastic Sedimentary Rocks | 398 |
| Examples | 402 |
| Upper Miocene Conglomerates of the Carbona Quadrangle, California | 402 |
| Allochemical Dolostone-Chert Breccias of the Middle Ordovician Mosheim Limestone, Virginia | 403 |
| Conglomerates of the Cape Enragé Formation, Quebec | 405 |

CARBONATE ROCKS 408

- Introduction 408
- Characteristics of Carbonate Rocks 408
- Mineral Compositions and Chemistries of Carbonate Rocks 409
- Carbonate Minerals 409
- Other Minerals 409
- Chemistries of Carbonate Rocks 409
- Textures and Structures of Carbonate Rocks 410
- Textural Elements of Carbonate Rocks 410
- Textures and Classifications of Carbonate Rocks 410
- Structures in Carbonate Rocks 411
- Occurrences and Origins of Carbonate Rocks 414
- Marine Carbonate Rocks 415
- Basinal Rocks 415
- Slope Rocks 415
- Platform, Shoal, Shelf, and Ramp Rocks 417
- Rocks, Reefs, and Buildups on Bank, Shelf, and Platform Margins 418
- Carbonate Rocks Formed in Transitional Environments 419
- Tidal Flat, Bay, and Lagoonal Rocks 419
- Sabkha Rocks 419
- Beach Rocks and Beachrock 420
- Continental Carbonate Rocks 420
- Examples 422
- Shallow Marine Carbonate Sediments of the Andros Platform and Adjoining Areas, Great Bahama Bank 422
- The Ordovician Ramp-to-Basin Facies of Southwestern Virginia 425
- A Closer Look at a Buildup: Algal Mounds of the Permian Laborcita Formation, New Mexico 427

CHAPTER 20

CHERTS, EVAPORITES, AND OTHER PRECIPITATED ROCKS 436

- Introduction 436
- Cherts 437
- The Compositions, Textures, and Structures of Cherts 437
- Origins of Cherts 439
- Examples 442
- Chert of the Kaibab Formation, Grand Canyon, Arizona 442
- Chert of the Franciscan Complex, California 444
- Evaporites and Related Rocks 447
- Mineralogy, Petrography, and Structures of Evaporites 447
- Origins of Evaporites and Related Rocks 448
- Examples 449
- Evaporites of the Silurian Salina Group, Michigan Basin 449
- The Green River Formation of Colorado, Utah, and Wyoming 450
- Ironstones and Iron-Formations 455

Petrography and Structures of Ironstones and Iron-Formations 455

Origins of Ironstones and Iron-Formations 455

Phosphorites 458

The Petrography of Phosphatic Rocks 458

Origins of Phosphorites 458

PART IV

METAMORPHIC ROCKS

CHAPTER 21

METAMORPHISM AND METAMORPHIC ROCK TEXTURES AND STRUCTURES 466

- Introduction 466
- Definitions: Metamorphism and Metamorphic Rocks 466
- Agents and Types of Metamorphism 467
- Pressure 467
- Deviatoric Stress 467
- Temperature 467
- Chemically Active Fluids 469
- Types of Metamorphism 470
- Structures and Textures of Metamorphic Rocks 472
- Structures 472
- Cleavage 473
- Layers and Transposition of Bedding 474
- Other Structures 474
- Textures 476
- Texture Types 476
- Recrystallization, Neocrystallization, Nucleation, and Crystal Growth: An Overview 477
- Nucleation and Growth 477
- Diffusion 480
- Recrystallization 480
- Metamorphic Differentiation 484

CHAPTER 22

METAMORPHIC CONDITIONS, CLASSIFICATIONS, MINERALOGIES, PROTOLITHS, FACIES, AND FACIES SERIES 490

- Introduction 490
- Mineralogy, Protoliths, and Rock Chemistry 490
- Classifications of Metamorphic Rocks 491
- Textural Classifications 491
- Other Classifications 492
- Conditions of Metamorphism and Petrogenetic Grids 493
- Conditions of Metamorphism 494
- The Beginnings of Metamorphism 494
- The Upper Limit of Metamorphism 495
- Petrogenetic Grids, Geothermometry, and Geobarometry 495
- The Facies Concept 497
- Facies and the Petrogenetic Grid 497
- Critical Minerals 499
- Facies Series 500

METAMORPHIC PHASE DIAGRAMS 508

- Introduction 508
- The System $\text{SiO}_2\text{-CaO-MgO-H}_2\text{O-CO}_2$ as a Model 508
- Mineral Assemblages, Reactions, and Facies 510
 - Reactions and the Use of Triangular Phase Diagrams 510
 - Facies and Phase Diagrams 511
- The ACF Diagram 512
- The AFM Diagram 514
- The CFM Diagram 515
- Other Diagrams 515
- Mineral-Facies Charts 515

CHAPTER 24

CONTACT METAMORPHISM 520

- Introduction 520
- Facies and Facies Series 520
- Conditions of Contact Metamorphism 522
- Processes in Contact Metamorphism 523
- The Fluid Phase 523
 - Recrystallization and Neocrystallization 524
- Mineralogical Changes During Contact Metamorphism 525
- Aluminous Rocks (Pelitic Rocks) 525
 - Silicic and Siliceous-Alkalic-Calcic Rocks 528
 - Basic Rocks 529
- The Origin of Spilites 531
- Carbonate Rocks 531
- The Importance of the Fluid Phase* 532
 - Metamorphism of Dolomitic, Argillaceous, and Siliceous Carbonate Rocks* 533
- Ultramafic Rocks 536

CHAPTER 25

REGIONAL METAMORPHISM UNDER LOW TO MEDIUM P/T CONDITIONS: BUCHAN AND BARROVIAN FACIES SERIES 542

- Introduction 542
- Buchan Facies Series 542
- Buchan Phase Assemblages and Reactions 543
 - Example: Buchan Metamorphism, Northern New England, U.S.A. 546
 - Differences and Similarities Between Contact and Buchan Facies Series 550
- Triple-Point Rocks 550
- Barrovian Facies Series 551
- Occurrences 551
 - The Barrovian Facies Series Revisited 551
 - Phase Assemblages and Reactions in Barrovian Facies Series 551
 - Assemblages and Reactions in Pelitic Rocks* 552
 - Siliceous-Alkali-Calcic (SAC) Rocks* 556
 - Assemblages and Reactions in Mafic Rocks* 557

Example: Barrovian Metamorphism in the Southern Appalachian Orogen 561

Migmatites 564

CHAPTER 26

HIGH P/T METAMORPHISM: FRANCISCAN AND SANBAGAWA FACIES SERIES AND THE ORIGIN OF BLUESCHISTS 577

- Introduction 577
- Occurrences 577
- Mineral Assemblages, Facies, and Textures 578
- Textures in Franciscan and Sanbagawa Facies Series Rocks 578
 - Characteristic Minerals, Mineral Assemblages, and Facies 580
 - Experimental Investigations and Mineral Stabilities 587
- Petrogenetic Models 589
- Metasomatic and Metastable Recrystallization Hypotheses 589
 - The Tectonic Overpressure Model 589
 - The Burial Metamorphism Hypothesis 590
- Example: Regional High P/T Metamorphism of the Franciscan Complex, California 595

CHAPTER 27

ECLOGITES AND ULTRAHIGH-PRESSURE METAMORPHISM 609

- Introduction 609
- Occurrences and Mineralogy of Eclogites 609
- P-T Conditions, Natural High-Pressure Phase Assemblages, and Associated Phase Topologies 613
- Examples of Eclogite Occurrences 618
- Eclogite of the East Pond Metamorphic Suite, Newfoundland 618
 - Eclogites of the Franciscan Complex, California and Oregon 619
- Petrogenesis of Eclogites 619
- Ultrahigh-Pressure (UHP) Rocks 623

CHAPTER 28

DYNAMIC METAMORPHISM 629

- Introduction 629
- Occurrences of Dynamoblastic Rocks 629
- Rock Types, Textures, and Structures 630
- Minerals and Facies of Dynamoblastic Rocks 634
- Processes During Dynamoblastic Rock Formation 635
- Cataclasis 635
 - Mylonitization 635
- Example: The Brevard Zone, Southern Appalachian Orogen 637

CHAPTER 29

ALPINE ULTRAMAFIC ROCKS AND THE MANTLE 642

Introduction 642

Occurrences of Alpine Ultramafic Rocks 642

Distinguishing Features of Alpine Ultramafic Rocks and Rock
Bodies 643

Minerals and Textures 643

Magmatic Differentiates 643

Shallow Mantle Slabs 644

Deeper Mantle Slabs/Mantle Diapirs (?) 645

The Nature of the Upper Mantle: A Brief Survey 646

Serpentinization 647

Examples of Alpine-Type Ultramafic Rocks 648

The Bay of Islands Ophiolite 648

Alpine Ultramafic Mantle Slabs in the North Carolina Blue
Ridge Belt 649

PART

V

EPILOGUE

CHAPTER 30

PETROTECTONIC ASSEMBLAGES 662

Introduction 662

Rocks and Plate Boundaries 663

Conclusion 665

Appendices 666

Glossary 685

Credits 708

Index 711