

Contents

Boxes xi
Preface xiii

Introduction to Physical Geology 1

1

Purpose 1
The Earth: A Giant Machine 2
*Understanding Our Surroundings/Supplying Things
We Need/Protecting the Environment/Avoiding
Geologic Hazards*
An Overview of Physical Geology 9
*Internal Processes: How the Earth's Internal Heat
Engine Works/The Earth's Interior/The Theory of
Plate Tectonics/Surficial Processes: The Earth's
External Heat Engine and the Hydrologic Cycle/The
Rock Cycle and Equilibrium*
Geologic Time 18
Uniformitarianism
Summary 19
Terms to Remember 20
Questions for Review 20
Questions for Thought 20
Supplementary Readings 20

Atoms, Elements, and Minerals 21

2

Purpose 21
Atoms and Elements 22
Chemical Activity/Ions/Bonding
Chemical Composition of the Earth's Crust 25
The Silica Tetrahedron

Minerals 30
*Crystalline Solids/Natural and Inorganic Substances/
Definite Chemical Composition/Physical Properties/
The Important Minerals*
The Physical Properties of Minerals 32
Color/Streak/Luster/Hardness
*External Crystal Form/Cleavage/Fracture/Specific
Gravity/Other Properties/Simple Chemical Tests*
Summary 41
Terms to Remember 41
Questions for Review 41
Questions for Thought 42
Supplementary Readings 42

Volcanism and Extrusive Rocks 43

3

Purpose 43
Volcanism 48
*Effects on Humans/Eruptive Violence and Physical
Characteristics of Lava/Scientific Investigation of
Volcanism/Chemistry of Volcanic Rocks/Viscosity of
Lava*
Types of Volcanoes 52
*Shield Volcanoes/Cinder Cones/Composite
Volcanoes/Volcanic Domes*
Lava Floods 59
Submarine Eruptions 60
Pillow Basalts
Identification of Extrusive Rocks 63
Composition/Textures
The Source of Lava 65
*Plate Tectonics and the Origin of Basalt/Plate
Tectonics and the Origin of Andesite*
Summary 69
Terms to Remember 70

Questions for Review 70
Questions for Thought 70
Supplementary Readings 70

Sediments and Sedimentary Rocks 107

6

Intrusive Activity and the Origin of Igneous Rocks 71

4

Purpose 71
Intrusive Bodies 73
 *Shallow Intrusive Structures/Intrusions That
 Crystallize at Depth*
Identification of Intrusive Igneous Rocks 77
 Ultramafic Rocks/Varieties of Granite
Abundance and Distribution of Plutonic Rocks 80
How Magma Forms 81
 *Sources of Heat for Melting/Factors That Control
 Melting Temperatures*
Theories About the Origin of Magmas 82
 *Differentiation and Bowen's Reaction Theory/
 Assimilation/Mixing of Magmas/Partial Melting*
Explaining Igneous Activity by Plate Tectonics 87
 *The Origin of Basalt and Ultramafic Rocks/The Origin
 of Granite and Andesite*
Summary 89
Terms to Remember 90
Questions for Review 90
Questions for Thought 90
Supplementary Readings 90

Weathering and Soil 91

5

Purpose 91
How Weathering Alters Rocks 92
 Effects of Weathering
Mechanical Weathering 95
 Frost Action/Abrasion/Pressure Release
Chemical Weathering 98
 *Role of Oxygen/Role of Acid/Solution Weathering/
 Chemical Weathering of Feldspar/Chemical
 Weathering of Other Minerals*
Soil 101
 *Soil Horizons/Residual and Transported Soils/Soils,
 Parent Rock, and Time/Soils and Climate*
Summary 105
Terms to Remember 105
Questions for Review 105
Questions for Thought 106
Supplementary Readings 106

Purpose 107
Some Lengthy Definitions 108
 Sediment/Lithification/Sedimentary Rock
Sediment 108
 Transportation/Deposition
Types of Sedimentary Rocks 110
 *Clastic Sedimentary Rocks/Chemical and Organic
 Sedimentary Rocks*
Sedimentary Structures 117
Interpretation of Sedimentary Rocks 120
 *Source Area/Paleogeography/Environment of
 Deposition*
Sedimentary Facies 125
Summary 126
Terms to Remember 127
Questions for Review 127
Questions for Thought 127
Supplementary Readings 127

Metamorphism, Metamorphic Rocks, and Hydrothermal Rocks 129

7

Purpose 129
Factors Controlling the Characteristics of Metamorphic
Rocks 131
 *Composition of the Parent Rock/Temperature/
 Pressure/Foliation/Effects of Fluids/Time*
Classification of Metamorphic Rocks 135
Types of Metamorphism 136
 *Contact (Thermal) Metamorphism/Regional
 (Dynamothermal) Metamorphism/Intensity of
 Metamorphism*
Plate Tectonics and Metamorphism 140
Hydrothermal Processes 141
 *Metasomatism/Hydrothermal Rocks/Sources of
 Water*
Summary 143
Terms to Remember 145
Questions for Review 145
Questions for Thought 145
Supplementary Readings 146

Time and Geology 147

8

- Purpose 147
- The Key to the Past 148
- Relative Time 149
 - Principles Used to Determine Relative Age/Correlation/The Standard Geologic Time Scale*
- Absolute Age 158
 - Radioactive Dating*
- Combining Relative and Absolute Ages 161
- Summary 163
- Terms to Remember 164
- Questions for Review 164
- Questions for Thought 164
- Supplementary Readings 164

Mass Wasting 165

9

- Purpose 165
- Classification of Mass Wasting 167
 - Rate of Movement/Type of Material/Type of Movement*
- Controlling Factors in Mass Wasting 168
 - Water*
- Common Types of Mass Wasting 171
 - Creep/Earthflow/Mudflow/Rockfall/Rockslide/Debris Slides, Falls, and Avalanches*
- Summary 182
- Terms to Remember 182
- Questions for Review 182
- Questions for Thought 182
- Supplementary Readings 182

Streams, Stream Action, and Landscape Development 183

10

- Purpose 183
- Channel Flow and Sheet Flow 184
- Drainage Basins 185
- Drainage Patterns 187
- Longitudinal Profile 187
- Factors Affecting Stream Erosion and Deposition 187
 - Velocity/Gradient/Channel Shape and Roughness/Discharge*

- Stream Erosion 191
- Stream Transportation of Sediment 192
- Stream Deposition 193
 - Bars/Braided Streams/Meandering Streams and Point Bars/Meandering Versus Braiding/Flood Plains/Deltas/Alluvial Fans*
- Valley Development 202
 - Downcutting and Base Level/The Concept of a Graded Stream/Lateral Erosion/Headward Erosion*
- Slope Development and Regional Erosion 205
- Two Stream Features That Are Difficult to Interpret 209
 - Stream Terraces/Incised Meanders*
- Summary 211
- Terms to Remember 212
- Questions for Review 212
- Questions for Thought 212
- Supplementary Readings 212

Ground Water 213

11

- Purpose 213
- The Hydrologic Cycle 214
- Porosity and Permeability 214
- The Water Table 214
- The Movement of Ground Water 215
- Springs and Rivers 216
- Aquifers 217
- Wells 218
 - Artesian Aquifers and Wells*
- Pollution of Ground Water 220
- Balancing Withdrawal and Recharge 221
- Effects of Ground-Water Action 222
 - Caves, Sinkholes, and Karst Topography/Other Effects*
- Hot Water Underground 224
 - Geothermal Energy*
- Summary 229
- Terms to Remember 229
- Questions for Review 229
- Question for Thought 230
- Supplementary Readings 230

Glaciers and Glaciation 231

12

- Purpose 231
- The Theory of Glacial Ages 232
- Glaciers—Where They Are, How They Form and Move 233

Distribution of Glaciers/Types of Glaciers/Formation and Growth of Glaciers/Movement of Valley Glaciers/Movement of Ice Sheets

Glacial Erosion 238

Erosional Landscapes Associated with Alpine Glaciation/Erosional Landscapes Associated with Continental Glaciation

Glacial Deposition 244

Moraines/Outwash/Glacial Lakes and Varves

Effects of Past Glaciation 248

The Glacial Ages/Direct Effects of Past Glaciation in North America/Indirect Effects of Past Glaciation/Evidence for Older Glaciation

Summary 254

Terms to Remember 255

Questions for Review 255

Questions for Thought 256

Supplementary Readings 256

Deserts and Wind Action 257

Purpose 257

Distribution of Deserts 258

Some Characteristics of Deserts 258

Desert Features in the Southwestern United States 261

Wind Action 265

Wind Erosion and Transportation/Wind Deposition

Summary 270

Terms to Remember 272

Questions for Review 272

Questions for Thought 272

Supplementary Readings 272

Waves, Beaches, and Coasts 273

Purpose 273

Water Waves 274

Surf

Nearshore Circulation 275

Wave Refraction/Longshore Currents

Beaches 277

Longshore Drift of Sediment 278

Human Interference with Sand Drift/Sources of Sand on Beaches

Coasts and Coastal Features 281

Classification of Coasts/Coastal Landforms

Summary 285

Terms to Remember 285

Questions for Review 285

Questions for Thought 285

Supplementary Readings 286

Geologic Structures 287

Purpose 287

Tectonic Forces at Work 288

Stress and Strain/Stress and Strain of Bed Rock

Structures as a Record of the Geologic Past 290

Implications of Horizontal and Inclined Layers of Rock/Geologic Maps and Field Methods

Folds 293

Geometry of Folds/Interpreting Folds

Fractures in Rock 299

Joints/Faults

Unconformities 307

Disconformities/Angular Unconformities/Nonconformities

Summary 308

Terms to Remember 310

Questions for Review 310

Questions for Thought 310

Supplementary Readings 310

Earthquakes 311

Purpose 311

Causes of Earthquakes 312

Seismic Waves 313

Locating and Measuring Earthquakes 313

Seismographs and Seismograms/Determining the Location of an Earthquake/Earthquake Strength/Earthquakes in the United States

Effects of Earthquakes 321

Tsunamis

Distribution of Earthquakes 324

First-Motion Studies of Earthquakes 326

Earthquakes and Plate Tectonics 327

Earthquakes at Plate Boundaries/Subduction Angle

Earthquake Prediction 331

Earthquake Control 332

Summary 333

Terms to Remember 334

Questions for Review 334

Questions for Thought 334

Supplementary Readings 334

The Earth's Interior 335

- Purpose 335
- Evidence from Seismic Waves 336
- The Earth's Internal Layers 337
 - The Earth's Crust/The Mantle/The Core*
- Isostasy 341
- Gravity Measurements 344
- The Earth's Magnetic Field 345
 - Magnetic Reversals/Magnetic Anomalies*
- Heat Within the Earth 348
 - Geothermal Gradient/Heat Flow*
- Summary 350
- Terms to Remember 350
- Questions for Review 351
- Questions for Thought 351
- Supplementary Readings 351

The Sea Floor 353

- Purpose 353
- Methods of Studying the Sea Floor 354
- Features of the Sea Floor 357
- Continental Shelves and Continental Slopes 357
- Submarine Canyons 358
 - Turbidity Currents*
- Passive Continental Margins 360
 - The Continental Rise/Abyssal Plains*
- Active Continental Margins 361
 - Oceanic Trenches*
- The Mid-Oceanic Ridge 362
 - Geologic Activity on the Ridge*
- Fracture Zones 363
- Seamounts, Guyots, and Aseismic Ridges 364
- Sediments of the Sea Floor 364
- Oceanic Crust and Ophiolites 366
- The Age of the Sea Floor 366
- Summary 368
- Terms to Remember 368
- Questions for Review 368
- Questions for Thought 369
- Supplementary Readings 369

Plate Tectonics 371

- Purpose 371
- The Early Case for Continental Drift 372

The Ideas of Alfred Wegener/Skepticism about Continental Drift

- Paleomagnetism and the Revival of Continental Drift 376
 - Additional Evidence for Continental Drift/History of Continental Positions*
- Sea-Floor Spreading 379
 - The Driving Force/Explanations*
- Plates and Plate Motion 381
- How Do We Know That Plates Move? 382
 - Marine Magnetic Anomalies/Another Test: Fracture Zones and Transform Faults*
- Diverging Plate Boundaries 386
 - Oceanic Divergence/Continental Divergence*
- Converging Plate Boundaries 391
 - Ocean-Ocean Convergence/Ocean-Continent Convergence/Continent-Continent Convergence*
- Transform Boundaries 398
- Plate Size 398
- The Attractiveness of Plate Tectonics 400
- What Causes Plate Motions? 401
 - Mantle Convection/Plumes and Hot Spots*
- A Cautionary Note 405
- Summary 406
- Terms to Remember 407
- Questions for Review 407
- Question for Thought 408
- Supplementary Readings 408

Mountain Belts and the Continental Crust 409

- Purpose 409
- Characteristics of Major Mountain Belts 411
 - Size and Alignment/Ages of Mountain Belts and Continents/Thickness of Rock Layers/Patterns of Folding and Faulting/Metamorphism and Plutonism/Episode of Normal Faulting/Thickness and Density of Rocks/Features of Active Mountain Ranges*
- The Evolution of a Mountain Belt 417
 - The Accretion Stage/The Orogenic Stage/Uplift and Block-faulting Stage*
- The Growth of Continents 426
- Summary 427
- Terms to Remember 429
- Questions for Review 429
- Questions for Thought 429
- Supplementary Readings 429

Geologic Resources 431

21

- Purpose 431
- Types of Resources 432
- Energy Use 433
- Petroleum and Natural Gas 433
 - The Origin of Oil and Gas/The Occurrence of Oil and Gas/Recovering the Oil/How Much Oil Do We Have Left?*
- Heavy Crude and Tar Sands 439
- Oil Shale 439
- Coal 440
 - Origin of Coal/Occurrence of Coal/Environmental Effects/Reserves and Resources*
- Uranium 443
- Metals and Ores 444
- Origin of Metallic Ore Deposits 444
 - Ores Associated with Igneous Rocks/Ores Formed by Surface Processes*
- Metal Ores and Plate Tectonics 447
- Mining 450
 - Environmental Effects*
- Some Important Metals 451
 - Iron/Copper/Aluminum/Lead/Zinc/Silver/Gold/Other Metals*
- Nonmetallic Resources 453
 - Construction Materials/Fertilizers and Evaporites/Other Nonmetallics*
- Substitutes, Recycling, and Conservation 455
- Some Future Trends 455
- Summary 455
- Terms to Remember 456
- Questions for Review 456
- Question for Thought 456
- Supplementary Readings 456

- Mercury 464
- Venus 465
 - Surface Features/The Atmosphere of Venus/Venusian Rocks*
- Mars 466
 - Surface Features/The Martian Atmosphere and Wind Activity/Polar Regions/Martian Rocks/The Martian Interior/Life on Mars?/Mars's Moons*
- The Jovian Planets 470
- The Satellites of Jupiter and Saturn 471
- The Origin of the Solar System 473
- A Short History of the Terrestrial Planets 473
- Summary 474
- Terms to Remember 475
- Questions for Review 475
- Questions for Thought 475
- Supplementary Readings 475

- Appendix A Identification of Minerals 477
- Appendix B Identification of Rocks 481
- Appendix C The Elements Most Significant to Geology 486
- Appendix D Periodic Table of Elements 488
- Appendix E Selected Conversion Factors 489
- Appendix F Rock Symbols 490
- Glossary 491
- Index 509

Astrogeology 457

22

- Purpose 457
- The Sun 458
 - The Sun's Structure*
- The Planets 459
- The Asteroids 459
- Comets 459
- Satellites and Rings 460
- Meteors and Meteorites 460
 - Effects of Impact/Classification*
- The Moon 461
 - Surface Features/Lunar Minerals/Lunar Rocks/The Moon's Interior*