

BRIEF CONTENTS



Chapter 1	Introducing Geology, the Essentials of Plate Tectonics, and Other Important Concepts	3
Chapter 2	Atoms, Elements, and Minerals	29
Chapter 3	Igneous Rocks, Intrusive Activity, and the Origin of Igneous Rocks	55
Chapter 4	Volcanism and Extrusive Rocks	83
Chapter 5	Weathering and Soil	113
Chapter 6	Sediment and Sedimentary Rocks	137
Chapter 7	Metamorphism, Metamorphic Rocks, and Hydrothermal Rocks	169
Chapter 8	Time and Geology	193
Chapter 9	Mass Wasting	221
Chapter 10	Streams and Floods	249
Chapter 11	Groundwater	285
Chapter 12	Glaciers and Glaciation	309
Chapter 13	Deserts and Wind Action	341
Chapter 14	Waves, Beaches, and Coasts	363
Chapter 15	Geologic Structures	385
Chapter 16	Earthquakes	407
Chapter 17	Earth's Interior and Geophysical Properties	439
Chapter 18	The Sea Floor	463
Chapter 19	Plate Tectonics – The Unifying Theory	485
Chapter 20	Mountain Belts and the Continental Crust	521
Chapter 21	Global Climate Change	545
Chapter 22	Resources	571
Chapter 23	The Earth's Companions	601

Preface xiv



1 Introducing Geology, the Essentials of Plate Tectonics, and Other Important Concepts 3

Who Needs Geology? 4

- Supplying Things We Need 4
- Protecting the Environment 5
- Avoiding Geologic Hazards 5
- Understanding Our Surroundings 10

Earth Systems 10

An Overview of Physical Geology—Important Concepts 12

- Internal Processes: How the Earth's Internal Heat Engine Works 12
- Earth's Interior 12
- The Theory of Plate Tectonics 13
- Divergent Boundaries 16
- Convergent Boundaries 17
- Transform Boundaries 20
- Surficial Processes: The Earth's External Heat Engine 20

Geologic Time 21

SUMMARY 25



2 Atoms, Elements, and Minerals 29

Relationships to Earth Systems 30

Minerals 30

- Introduction 30
- Minerals and Rocks 31

Atoms and Elements 32

- Ions and Bonding 33
- Crystalline Structures 36

The Silicon-Oxygen Tetrahedron 37

Nonsilicate Minerals 39

Variations in Mineral Structures and Compositions 41

The Physical Properties of Minerals 42

- Color 43
- Streak 43
- Luster 43
- Hardness 43
- External Crystal Form 44
- Cleavage 47
- Fracture 48
- Specific Gravity 48
- Special Properties 49
- Chemical Tests 50

The Many Conditions of Mineral Formation 50

SUMMARY 52



3 Igneous Rocks, Intrusive Activity, and the Origin of Igneous Rocks 55

Relationships to Earth Systems 56

The Rock Cycle 56

- A Plate Tectonic Example 57

Igneous Rocks 58

- Classification of Igneous Rocks 59
- Igneous Rock Textures 59
- Chemistry of Igneous Rocks 63
- Identifying Igneous Rocks 65

Intrusive Bodies 66

- Shallow Intrusive Structures 66
- Intrusives that Crystallize at Depth 68

Abundance and Distribution of Plutonic Rocks 69

How Magma Forms 70

- Heat for Melting Rock 70
- The Geothermal Gradient and Partial Melting 70
- Decompression Melting 70
- Addition of Water (Flux Melting) 71

How Magmas of Different Compositions Evolve 71

- Sequence of Crystallization and Melting 71
- Differentiation 72
- Partial Melting 73
- Assimilation 74
- Mixing of Magmas 74

Explaining Igneous Activity by Plate Tectonics	75
Igneous Processes at Divergent Boundaries	75
Intraplate Igneous Activity	76
Igneous Processes at Convergent Boundaries	76
SUMMARY	78



4 Volcanism and Extrusive Rocks 83

Relationships to Earth Systems	84
What are volcanoes and why should we study them?	85
Creation of New Land	87
Geothermal Energy	87
Effect on Climate	87
Eruptive Violence and Physical Characteristics of Lava	87
The Eruptive Products of Volcanoes	90
Effusive Eruptions	90
Explosive Eruptions	94
Types of Volcanoes	98
Shield Volcanoes	98
Cinder Cones	99
Composite Volcanoes	99
Lava Domes	101
Calderas	102
Living With Volcanoes	104
Volcanic Hazards	104
Monitoring Volcanoes	107
Plate Tectonics and Volcanism	108
Volcanic Activity at Divergent Boundaries	108
Volcanic Activity at Convergent Boundaries	108
Within-Plate Volcanic Activity	108
SUMMARY	108



5 Weathering and Soil 113

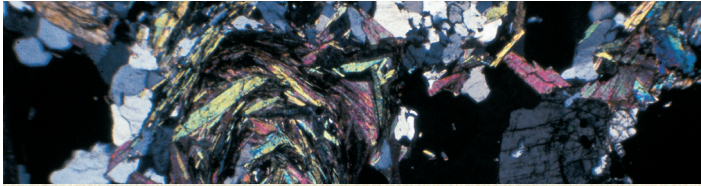
Weathering, Erosion, and Transportation	114
Weathering and Earth Systems	114
Atmosphere	114
Hydrosphere	114
Biosphere	115
How Weathering changes Rocks	115

Effects of Weathering	116
Mechanical Weathering	116
Pressure Release	117
Frost Action	117
Other Processes	118
Chemical Weathering	118
Role of Oxygen	119
Role of Acids	120
Solution Weathering	121
Chemical Weathering of Feldspar	122
Chemical Weathering of Other Minerals	123
Weathering Products	123
Factors Affecting Weathering	124
Soil	124
Soil Horizons	125
Factors Affecting Soil Formation	127
Soil Erosion	130
Soil Classification	131
SUMMARY	133



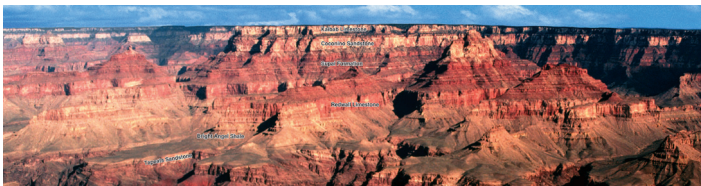
6 Sediment and Sedimentary Rocks 137

Relationship to Earth Systems	138
Sediment	138
Transportation	139
Deposition	140
Preservation	141
Lithification	141
Types of Sedimentary Rocks	142
Detrital Rocks	142
Breccia and Conglomerate	142
Sandstone	143
The Fine-Grained Rocks	143
Chemical Sedimentary Rocks	146
Carbonate Rocks	146
Chert	150
Evaporites	152
Organic Sedimentary Rocks	152
Coal	152
The Origin of Oil and Gas	152
Sedimentary Structures	153
Fossils	157
Formations	159
Interpretation of Sedimentary Rocks	160
Source Area	160
Environment of Deposition	160
Transgression and Regression	162
Plate Tectonics and Sedimentary Rocks	162
SUMMARY	165



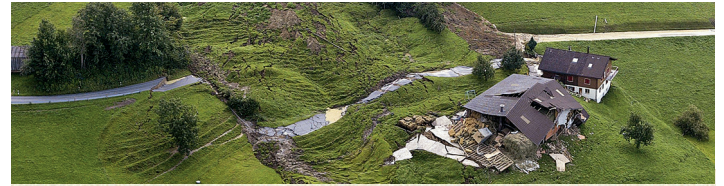
7 Metamorphism, Metamorphic Rocks, and Hydrothermal Rocks 169

- Relationships to Earth Systems 170
- Introduction 170
- Factors Controlling the Characteristics of Metamorphic Rocks 171
 - Composition of the Parent Rock 172
 - Temperature 172
 - Pressure 173
 - Fluids 174
 - Time 175
- Classification of Metamorphic Rocks 175
 - Nonfoliated Rocks 175
 - Foliated Rocks 177
- Types of Metamorphism 179
 - Contact Metamorphism 179
 - Regional Metamorphism 179
- Plate Tectonics and Metamorphism 183
 - Foliation and Plate Tectonics 183
 - Pressure-Temperature Regimes 183
- Hydrothermal Processes 185
 - Hydrothermal Activity at Divergent Plate Boundaries 186
 - Water at Convergent Boundaries 187
 - Metasomatism 187
 - Hydrothermal Rocks and Minerals 188
- SUMMARY 190



8 Time and Geology 193

- The Key to the Past 194
- Relative Time 195
 - Principles Used to Determine Relative Age 195
 - Unconformities 200
 - Correlation 202
 - The Standard Geologic Time Scale 205
- Numerical Age 205
 - Isotopic Dating 207
 - Uses of Isotopic Dating 211
- Combining Relative and Numerical Ages 212
- Age of the Earth 213
 - Comprehending Geologic Time 214
- SUMMARY 216



9 Mass Wasting 221

- Surficial Processes 221
- Relationships to Earth Systems 222
- Introduction to Mass Wasting 222
- Classification of Mass Wasting 225
 - Rate of Movement 225
 - Type of Material 225
 - Type of Movement 225
- Controlling Factors in Mass Wasting 226
 - Gravity 226
 - Water 227
 - Triggers 228
- Common Types of Mass Wasting 229
 - Creep 229
 - Flow 230
 - Rockfalls and Rockslides 236
- Underwater Landslides 241
- Preventing Landslides 243
 - Preventing Mass Wasting of Soil 243
 - Preventing Rockfalls and Rockslides on Highways 244
- SUMMARY 245



10 Streams and Floods 249

- Earth Systems—The Hydrologic Cycle 250
- Running Water 251
- Drainage Basins 252
- Drainage Patterns 252
- Factors Affecting Stream Erosion and Deposition 254
 - Velocity 254
 - Gradient 254
 - Channel Shape and Roughness 255
 - Discharge 256
- Stream Erosion 256
- Stream Transportation of Sediment 257
- Stream Deposition 258
 - Bars 258
 - Braided Streams 259
 - Meandering Streams and Point Bars 262
 - Flood Plains 264
 - Deltas 264
 - Alluvial Fans 269

Stream Valley Development	269
Downcutting and Base Level	269
The Concept of a Graded Stream	271
Lateral Erosion	272
Headward Erosion	272
Stream Terraces	272
Incised Meanders	272
Flooding	274
Urban Flooding	276
Flash Floods	276
Controlling Floods	277
Flooding in the Mississippi River Basin	277
SUMMARY	282



11 Groundwater 285

Introduction	286
Porosity and Permeability	286
The Water Table	286
The Movement of Groundwater	289
Aquifers	290
Wells	290
Springs and Streams	292
Contamination of Groundwater	294
Balancing Withdrawal and Recharge	298
Effects of Groundwater Action	299
Caves, Sinkholes, and Karst Topography	299
Other Effects	301
Hot Water Underground	302
Geothermal Energy	304
SUMMARY	305



12 Glaciers and Glaciation 309

Relationships to Earth Systems	310
Introduction	310
Glaciers—Where They Are, How They Form and Move	311
Distribution of Glaciers	311
Types of Glaciers	311
Formation and Growth of Glaciers	311

Movement of Valley Glaciers	314
Movement of Ice Sheets	316
Glacial Erosion	320
Erosional Landscapes Associated with Alpine Glaciation	322
Erosional Landscapes Associated with Continental Glaciation	326
Glacial Deposition	326
Moraines	326
Outwash	330
Glacial Lakes and Varves	331
PAST GLACIATION	331
Direct Effects of Past Glaciation in North America	334
Indirect Effects of Past Glaciation	335
Evidence for Older Glaciation	337
SUMMARY	338



13 Deserts and Wind Action 341

Distribution of Deserts	342
Some Characteristics of Deserts	343
Desert Features in the Southwestern United States	346
Wind Action	350
Wind Erosion and Transportation	351
Wind Deposition	354
SUMMARY	360



14 Waves, Beaches, and Coasts 363

Introduction	364
How Do Waves Form?	364
Surf	365
What happens when waves reach the Shore?	366
Wave Refraction	366
Longshore Currents	366
Rip Currents	366
How Do Beaches Develop?	368
Why Does Sand Move Along a Shoreline?	369
Human Interference with Sand Drift	370
Sources of Sand on Beaches	372
Why Are there Different Types of Coasts?	372
Erosional Coasts	372
Depositional Coasts	374

- Drowned Coasts 375
- Uplifted Coasts 376
- The Biosphere and Coasts 377

SUMMARY 382



15 Geologic Structures 385

- Tectonic Forces at Work 386
 - Stress and Strain in the Earth's Lithosphere 386
 - How Do Rocks Behave When Stressed? 387
- How Do We Record and Measure Geologic Structures? 388
 - Geologic Maps and Field Methods 388
- Folds 390
 - Geometry of Folds 391
 - Interpreting Folds 393
- Fractures In Rock 395
 - Joints 395
 - Faults 395

SUMMARY 404

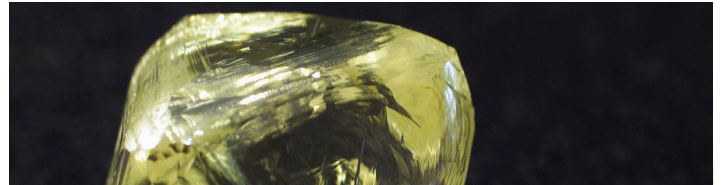


16 Earthquakes 407

- Causes of Earthquakes 408
- Seismic Waves 409
 - Body Waves 409
 - Surface Waves 410
- Locating and Measuring Earthquakes 411
 - Determining the Location of an Earthquake 412
 - Measuring the Size of an Earthquake 413
 - Location and Size of Earthquakes in the United States 415
- Earthquake-RELATED Hazards 416
 - Ground Motion 418
 - Ground Failure 419
 - Aftershocks 421
 - Tsunami 421
- World Distribution of Earthquakes 425
- First-Motion Studies of Earthquakes 427
- Earthquakes and Plate Tectonics 427
 - Earthquakes at Plate Boundaries 428
 - Subduction Angle 429

- Earthquake Prediction and Forecasting 429
 - Earthquake Precursors and Prediction 429
 - Earthquake Forecasting 432
 - Reducing Earthquake Damage and Risk 434

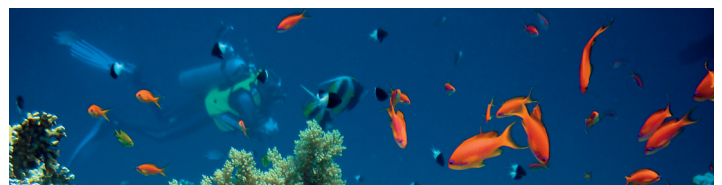
SUMMARY 434



17 Earth's Interior and Geophysical Properties 439

- Introduction 440
- Evidence from Seismic Waves 440
- Earth's Internal Structure 442
 - The Crust 442
 - The Mantle 443
 - The Core 445
- Isostasy 448
- Gravity Measurements 451
- Earth's Magnetic Field 452
 - Magnetic Reversals 452
 - Magnetic Anomalies 454
- Heat within the Earth 457
 - Geothermal Gradient 457
 - Heat Flow 458

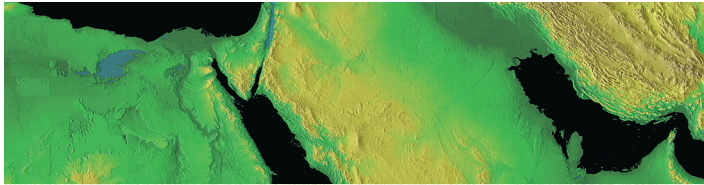
SUMMARY 459



18 The Sea Floor 463

- Origin of the Ocean 464
- Methods of Studying the Sea Floor 464
- Features of the Sea Floor 467
- Continental Shelves and Continental Slopes 467
- Submarine Canyons 468
 - Turbidity Currents 469
- Passive Continental Margins 470
 - The Continental Rise 470
 - Abyssal Plains 471
- Active Continental Margins 471
 - Oceanic Trenches 472

Mid-Oceanic Ridge	473
Geologic Activity at the Ridges	473
Biologic Activity at the Ridges	474
Fracture Zones	474
Seamounts, Guyots, and Aseismic Ridges	474
Reefs	476
Sediments of the Sea Floor	476
Oceanic Crust and Ophiolites	478
The Age of the Sea Floor	479
The Sea Floor and Plate Tectonics	481
SUMMARY	481



19 Plate Tectonics—The Unifying Theory 485

The Early Case for Continental Drift	487
Skepticism about Continental Drift	489
Paleomagnetism and the Revival of Continental Drift	490
Recent Evidence for Continental Drift	492
History of Continental Positions	492
Seafloor Spreading	492
Hess's Driving Force	492
Explanations	493
Plates and Plate Motion	494
How Do We Know that Plates Move?	495
Marine Magnetic Anomalies	495
Another Test: Fracture Zones and Transform Faults	498
Measuring Plate Motion Directly	498
Divergent Plate Boundaries	498
Transform Boundaries	502
Convergent Plate Boundaries	503
Ocean-Ocean Convergence	504
Ocean-Continent Convergence	505
Continent-Continent Convergence	506
Do Plate Boundaries Move?	507
Can Plates Change in Size?	507
The Attractiveness of Plate Tectonics	507
What Causes Plate Motions?	509
Mantle Convection	509
Ridge Push	510
Slab Pull	510
Trench Suction	510
Mantle Plumes and Hot Spots	511
A Final Note	514
SUMMARY	516



20 Mountain Belts and the Continental Crust 521

Introduction	522
Characteristics of Major Mountain Belts	525
Size and Alignment	525
Ages of Mountain Belts and Continents	525
Thickness and Characteristics of Rock Layers	526
Patterns of Folding and Faulting	527
Metamorphism and Plutonism	527
Normal Faulting	528
Thickness and Density of Rocks	529
Features of Active Mountain Ranges	530
Evolution of Mountain Belts	530
Orogenies and Plate Convergence	530
Post-Orogenic Uplift and Block-Faulting	536
The Growth of Continents	539
Displaced Terranes	540
SUMMARY	541



21 Global Climate Change 545

WEATHER, CLIMATE, AND CLIMATE CHANGE	546
UNDERSTANDING THE ATMOSPHERE	546
Composition	546
Structure	547
Energy from the Sun	547
Blackbody Radiation	548
The Greenhouse Effect	548
CAUSES OF CLIMATE CHANGE	551
Solar Variability and the Orbital Theory of Climate	551
Variations in the Earth's Albedo	552
Greenhouse Gases	552
Clouds and Particles	556
Volcanoes	556
Plate Tectonics	557
A BRIEF HISTORY OF EARTH'S CLIMATE	557
Climate Millions of Years Ago	557
Climate Over the Last Million Years	558
Climate Over the Last Few Thousand Years to Present	558

CLIMATE CHANGE IN THE MODERN AGE	560
Temperature	560
Precipitation	560
Sea Ice and Glacier Melt	561
Sea-Level Rise	562
THE IPCC and CLIMATE MODELS	563
IMPACTS AND CONSEQUENCES OF GLOBAL CLIMATE CHANGE	564
Biodiversity and Agriculture	564
Ocean Acidification	565
Coastal Regions and Sea-Level Rise	565
GEOENGINEERING	565
Solar Radiation Management	565
Carbon Management	566
DECREASING EMISSIONS OF GREENHOUSE GASES	567
SUMMARY	567



Resources 571

Relationships to Earth Systems	572
INTRODUCTION	572
RESERVES AND RESOURCES	572
ENERGY RESOURCES	574
Nonrenewable Energy Resources	574
Renewable Energy Sources	586
METALLIC RESOURCES	589
Ores Formed by Igneous Processes	590
Ores Formed by Surface Processes	592
MINING	593
NONMETALLIC RESOURCES	595
Construction Materials	595
Fertilizers and Evaporites	595
Other Nonmetallics	596
Resources, The Environment, and Sustainability	596
SUMMARY	597



The Earth's Companions 601

The Earth in Space	602
The Sun	602
The Solar System	603
The Milky Way and the Universe	604
Origin of the Planets	606
The Solar Nebula	606
Formation of the Planets	608
Formation of Moons	608
Final Stages of Planet Formation	608
Formation of Atmospheres	608
Other Planetary Systems	608
Portraits of the Planets	609
Our Moon	609
Mercury	615
Venus	616
Mars	618
Why Are the Terrestrial Planets So Different?	624
Jupiter	625
Saturn	626
Uranus	628
Neptune	628
Pluto and the Ice Dwarves	628
Minor Objects of the Solar System	630
Meteors and Meteorites	630
Meteorites	630
Asteroids	631
Comets	631
Giant Impacts	633
Giant Meteor Impacts	633
SUMMARY	634
Appendices A–G	608
Glossary	620
Index	632