Physical Geology

Across the American Landscape

John J. Renton

Third Edition

Edited by
Susan Wilcox
and
Curtis J. Williams

National Park Sidebars
written by Erica S. Gardiner

Coast
LEARNING SYSTEMS
A LEADER IN DISTANCE
EDUCATION SINCE 1973

Kendall Hunt
publishing company

Kendall Hunt Book Team
Chairman and Chief Executive Officer Mark C. Falb
President and Chief Operating Officer Chad M. Chandlee
Vice President, Higher Education David L. Tart
Director of Publishing Partnerships Paul B. Carty
Editorial Manager Georgia Botsford
Senior Editor Lynne Rogers
Vice President, Operations Timothy J. Beitzel
Assistant Vice President, Production Services Christine E. O’Brien
Senior Production Editor Mary Melloy
Senior Permissions Editors Colleen Zelinsky and Renae Horstman
Senior Cover Designer Janell Edwards

Coast Learning Systems Book Team
Ding-Jo H. Currie, Chancellor, Coast Community College District
Loretta P. Adrian, President, Coastline Community College
Dan C. Jones, Executive Dean, Office of Instructional Systems Development
Laurie R. Melby, Director of Production
Lynn M. Dahnke, Director of Marketing & Publisher Partnerships
Judy Garvey, Director, E-Media & Publishing
Robert D. Nash, Director, Instructional Design & Faculty Support
Sylvia Amito’elau, Instructional Designer
Wendy Sacket, E-Media & Publishing Project Coordinator
Marie Hulett, Production Coordinator
Linda Wojciechowski, Senior E-Media & Publishing Assistant
Thien Vu, E-Media & Publishing Assistant

Cover design by Don Vierstra; cover images © iStock, Inc., and Shutterstock, Inc.
All Shutterstock images used under license from Shutterstock, Inc.

Kendall Hunt
publishing company
www.kendalhunt.com
Send all inquires to:
4050 Westmark Drive
Dubuque, IA 52004-1840

ISBN 978-0-7575-5598-5 Student Edition

Printed in the United States of America
10 9 8 7 6 5 4 3 2 1

BRIEF CONTENTS

INTRODUCTION

Introduction: *Formation of Earth and Its Place in the Solar System* 2

UNIT 1

CHAPTER 1: *Interior of the Earth* 38

CHAPTER 2: *Plate Tectonics* 66

CHAPTER 3: *Rock Deformation and Mountain Building* 104

CHAPTER 4: *Earthquakes and Seismology* 148

UNIT 2

CHAPTER 5: *Minerals* 186

CHAPTER 6: *Igneous Rocks and Volcanism* 224

CHAPTER 7: *Weathering, Soils, and Sedimentary Rocks* 286

CHAPTER 8: *Metamorphism and Metamorphic Rocks* 346

UNIT 3

CHAPTER 9: *The Age of Earth and Geologic Time* 385

CHAPTER 10: *Mass Wasting* 428

CHAPTER 11: *Streams and Groundwater* 474

CHAPTER 12: *Oceans and Coastlines* 538

CHAPTER 13: *Glaciers and Deserts—Climatic Features* 594

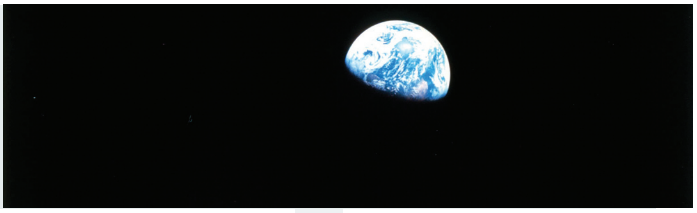
CHAPTER 14: *Economic Geology and Resources* 658

CONTENTS

PREFACE XVI
TEXTBOOK FEATURES XVIII
ABOUT THE AUTHOR AND INSTRUCTIONAL DESIGNER XX
ACKNOWLEDGMENTS XXI

INTRODUCTION

Formation of Earth and Its Place in the Solar System *2*



INTRO.1 EARTH AND ITS SYSTEMS 4
- Intro.1.1 The Atmosphere 5
- Intro.1.2 The Hydrosphere 6
- Intro.1.3 The Cryosphere 7
- Intro.1.4 The Lithosphere 8
- Intro.1.5 The Biosphere 10

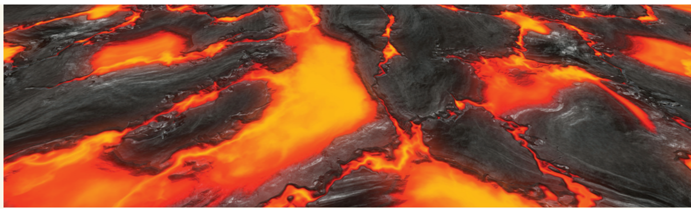
INTRO.2 EARTH'S FORMATION 11
- Intro.2.1 From Solar Nebula to Solar System 11
- Intro.2.2 The Organization of the Solar System 13

INTRO.3 THE TERRESTRIAL PLANETS 19
- Intro.3.1 Stages of Planetary Development 19
- Intro.3.2 Earth's Neighbors 23

SUMMARY 29
KEY TERMS 31
ANSWERS TO CONCEPT CHECKS 32
REVIEW EXERCISES 34

UNIT 1 EARTH'S INTERIOR AND TECTONIC PROCESSES

CHAPTER 1



Interior of the Earth 38

1.1 SEISMIC WAVES 40
- 1.1.1 Compression and Shear Waves 40
- 1.1.2 Body Waves 41
- 1.1.3 Surface Waves 42

1.2 THE SEISMOGRAPH 44

1.3 LOCATING EARTHQUAKES 47
- 1.3.1 Focus and Epicenter 47
- 1.3.2 Arrival Times of the Seismic Waves at Seismic Stations 48
- 1.3.3 Distance Calculations 48

1.4 THE DETERMINATION OF EARTH'S COMPOSITION USING SEISMIC WAVES 50
- 1.4.1 Density, Seismic Waves, and Refraction 51
- 1.4.2 Increased Density with Depth 52

1.5 SEISMIC DISCONTINUITIES AND EARTH'S STRUCTURE 53
- 1.5.1 Mohorovicic Discontinuity 53
- 1.5.2 Gutenberg Discontinuity 54
- 1.5.3 Evidence for a Solid Inner Core 55
- 1.5.4 Lithosphere-Asthenosphere 55

1.6 ISOSTASY 57
- 1.6.1 Gravitational Balance 57
- 1.6.2 Isostatic Balance 57

SUMMARY 60
KEY TERMS 61
ANSWERS TO CONCEPT CHECKS 61
REVIEW EXERCISES 64

CHAPTER 2

Plate Tectonics 66

2.1 HISTORICAL DEVELOPMENT OF THE THEORY 68
- 2.1.1 Conceptual Models of Earth 68
- 2.1.2 Continental Drift 69

2.2 MODERN DEVELOPMENTS 73
2.2.1 Marine Geology and Geophysics 74
2.2.2 Magnetism and Paleomagnetism 76
2.2.3 Seafloor Spreading 79
2.3 PLATE TECTONICS THEORY 81
2.3.1 Tectonic Plates 81
2.3.2 Plate Boundaries 81
2.3.3 Plate Movement 84
See It Sidebar: Joshua Tree National Park 86
See It Sidebar: Wrangell-St. Elias National Park and Preserve 92
2.3.4 The Supercontinent Cycle 96

SUMMARY 55
KEY TERMS 56
ANSWERS TO CONCEPT CHECKS 57
REVIEW EXERCISES 58

CHAPTER 3

Rock Deformation and Mountain Building *104*

3.1 ROCK DEFORMATION 106
3.1.1 Stress 106
3.1.2 Strain or Deformation 107
3.2 STRIKE AND DIP AND GEOLOGIC STRUCTURES 111
3.2.1 Strike and Dip 111
3.2.2 Geologic Structures 112
3.3 DIRECTION OF ROCK MOVEMENT 120
3.3.1 Apparent Motion of Faults 120
See It Sidebar: Great Smoky Mountiains National Park 122
3.3.2 Apparent Motion of Folds 126
3.4 MOUNTAINS AND MOUNTAIN BUILDING 127
3.4.1 Volcanic Mountains 127
3.4.2 Fold Belt Mountains 130
3.4.3 Domal and Fault-Block Mountains 132
See It Sidebar: Grand Tetons National Park 134
3.5 TERRANES 136
3.5.1 Accreted Terranes 137

SUMMARY 139
KEY TERMS 141
ANSWERS TO CONCEPT CHECKS 142
REVIEW EXERCISES 144

CHAPTER 4

Earthquakes and Seismology 148

4.1 DISTRIBUTION OF EARTHQUAKES 151
- 4.1.1 How Earthquakes Occur 151
- 4.1.2 Determining Earthquake Location 151
- 4.1.3 Earthquake Depths 153
- 4.1.4 Plate Boundary Earthquakes 154
- 4.1.5 Intraplate Earthquakes 155
- *See It* Sidebar: Denali National Park and Preserve 156

4.2 MEASURING EARTHQUAKES 159
- 4.2.1 Intensity 159
- 4.2.2 Magnitude 159

4.3 EARTHQUAKE DAMAGE 163
- 4.3.1 Examples of Significant Earthquakes 164
- 4.3.2 Factors Contributing to Earthquake Destruction 169
- 4.3.3 Earthquake Damage Prevention 171

4.4 EARTHQUAKE PREDICTION 175
- 4.4.1 Worldwide Seismic Network 175
- 4.4.2 Paleoseismology 175
- 4.4.3 Long- and Short-Term Earthquake Prediction 177

SUMMARY 178
KEY TERMS 179
ANSWERS TO CONCEPT CHECKS 180
REVIEW EXERCISES 181

UNIT 2

EARTH'S MINERALS AND ROCKS

CHAPTER 5

Minerals 186

5.1 MINERALS AND ROCKS DEFINED 188
5.1.1 Elements and Compounds 189
5.1.2 Chemical Bonding 193
5.2 EARTH'S CRUST 196
5.2.1 Composition of Earth's Crust 196
5.2.2 The Silicate Minerals 196
5.2.3 Nonsilicate Minerals 201
See It Sidebar: White Sands National Monument 202
5.3 MINERAL IDENTIFICATION 208
5.3.1 Physical Properties Used in Mineral Identification 208
See It Sidebar: Petrified Forest National Park 210
5.3.2 Hand Mineral Identification 216
5.3.3 Instrumental Identification 217
SUMMARY 219
KEY TERMS 220
ANSWERS TO CONCEPT CHECKS 221
REVIEW EXERCISES 222

CHAPTER 6

Igneous Rocks and Volcanism *224*

6.1 IGNEOUS ROCKS 226
6.1.1 The Melting and Crystallization of Solids 227
6.1.2 Melting Mechanisms 227
6.1.3 Partial Melting of Rock 229
6.1.4 Crystallization of Rock 231
6.2 CLASSIFICATION OF IGNEOUS ROCKS 233
6.2.1 Texture 233
6.2.2 Composition 235
6.3 MAGMA FORMATION AND ASCENT 238
6.3.1 Types of Magma 238
6.3.2 Magma Formation 240
6.3.3 Magma Ascent 241
6.4 IGNEOUS ROCK BODIES 242
6.4.1 Classifying Plutons 242
6.4.2 Tabular Plutons 243
6.4.3 Massive Plutons 244

6.5 VOLCANOES 249
6.5.1 Anatomy of a Volcano 249
6.5.2 Shield Volcanoes 250
See It Sidebar: Hawaii Volcanoes National Park 252
6.5.3 Fissure Eruptions 258
6.5.4 Composite Volcanoes 259
6.5.5 Other Volcanic Features 264
See It Sidebar: Lassen Volcanic National Park 266

6.6 PREDICTING VOLCANIC ACTIVITY 272
6.6.1 Monitoring Systems 273
6.6.2 Past and Future Predictions 274

SUMMARY 276
KEY TERMS 278
ANSWERS TO CONCEPT CHECKS 279
REVIEW EXERCISES 282

CHAPTER 7
Weathering, Soils, and Sedimentary Rocks ***286***

7.1 WEATHERING AND ITS CONTROLS 288
7.1.1 Mechanical Weathering 288
7.1.2 Chemical Weathering 292
7.1.3 Rates of Weathering 294
See It Sidebar: Zion National Park 298
7.1.4 Products of Weathering 300
7.2 SOILS 302
7.2.1 Soil Horizons 302
7.2.2 Soil Formation 304
7.2.3 Types of Soils 307
7.3 SEDIMENTARY ROCKS 310
7.3.1 Importance of Sedimentary Rocks 310
7.3.2 Formation of Clastic Sedimentary Rocks 311
7.3.3 Classification of Clastic Sedimentary Rocks 313
7.3.4 Chemical Sedimentary Rocks 316
7.3.5 Biochemical Sedimentary Rocks 320
7.3.6 Depositional Environments 322
7.3.7 Sedimentary Features 323
See It Sidebar: Grand Canyon National Park 324
7.3.8 Interpreting Sedimentary Rocks 329

7.4 ENVIRONMENTAL CONCERNS 331
7.4.1 Environmental Concerns Related to Weathering 331
7.4.2 Environmental Concerns Related to Soils 331
7.4.3 Environmental Concerns Related to Sedimentary Rocks 335

SUMMARY 336
KEY TERMS 338
ANSWERS TO CONCEPT CHECKS 339
REVIEW EXERCISES 342

CHAPTER 8

Metamorphism and Metamorphic Rocks *346*

8.1 METAMORPHISM 348
8.1.1 Metamorphic Conditions 349
8.1.2 Metamorphic Grades 351
8.1.3 Metamorphic Processes 352
8.2 METAMORPHIC TYPES AND SETTINGS 356
8.2.1 Regional Metamorphism 356
See It Sidebar: Isle Royale National Park 358
8.2.2 Contact Metamorphism 360
8.2.3 Hydrothermal Metamorphism 361
8.2.4 Dynamic Metamorphism 362
8.3 METAMORPHIC ROCK CLASSIFICATION 363
8.3.1 Foliated Metamorphic Rocks 363
8.3.2 Nonfoliated Metamorphic Rocks 366
See It Sidebar: Acadia National Park 368
8.3.3 Metamorphic Rock Identification 372
8.3.4 Metamorphic Facies 373
8.4 ENVIRONMENTAL CONCERNS 375

SUMMARY 378
KEY TERMS 379
ANSWERS TO CONCEPT CHECKS 380
REVIEW EXERCISES 382

UNIT 3 TIME, SURFACE FEATURES, AND RESOURCES

CHAPTER 9

The Age of Earth and Geologic Time *386*

9.1 RELATIVE DATING 388
    9.1.1 Relative Dating Principles 389
    9.2.2 Gaps in the Geologic Record 397
9.2 ABSOLUTE DATING 401
    9.2.1 Absolute Dating Based on Cyclical Processes 401
    9.2.2 Isotopes and Radioactive Decay 403
    9.2.3 Radiometric Dating 406
    9.2.4 Limitations of Radiometric Dating 407
    See It Sidebar: Canyonlands National Park 410
9.3 THE GEOLOGIC TIME SCALE 412
    9.3.1 Geologic Time 412
    9.3.2 Divisions and Subdivisions of the Geologic Time Scale 414
    9.3.3 The Geologic Record 415
SUMMARY 421
KEY TERMS 422
ANSWERS TO CONCEPT CHECKS 423
REVIEW EXERCISES 425

CHAPTER 10

Mass Wasting *428*

10.1 THE NATURE OF MASS WASTING 430
    10.1.1 The Driving Force: Gravity 430
    10.1.2 Resisting Factors 431
    10.1.3 Slope Stability 432
    10.1.4 Triggers 433
    See It Sidebar: Cuyahoga Valley National Park 440
10.2 TYPES OF MASS WASTING 444
    10.2.1 Falls 444

10.2.2 Landslides 447
10.2.3 Flows 449

10.3 ENVIRONMENTAL CONCERNS 455
10.3.1 Regional Hazards 455
See It Sidebar: Capitol Reef National Park 456
10.3.2 Local Indications of Slope Instability 460
10.3.3 Methods of Slope Stabilization 462

SUMMARY 468
KEY TERMS 469
ANSWERS TO CONCEPT CHECKS 470
REVIEW EXERCISES 471

CHAPTER 11

Streams and Groundwater *474*

11.2 STREAMS 478
11.2.1 River Systems 479
11.2.2 The Energy of Stream Flow 482
11.2.3 Dynamics of Water Flow 485
11.2.4 Sculpting the Landscape: Erosion 486
11.2.5 Sculpting the Landscape: Transportation 488
11.2.6 Sculpting the Landscape: Deposition 490
11.2.7 The Ages of a River 490
11.2.8 Floods 496
See It Sidebar: Mississippi National River and Recreation Area 498

11.3 GROUNDWATER 502
11.3.1 Definition of Groundwater 502
11.3.2 Porosity and Permeability 503
11.3.3 Aquifers and Aquitards 504
11.3.4 The Water Table 505
11.3.6 Water Wells 508
11.3.5 Aquifer Systems 509
11.3.6 Geologic Effects of Groundwater 512

11.4 KARST TOPOGRAPHY 514
11.4.1 Characteristics of Karst Topography 514
11.4.2 Cave Development and Construction 515
11.4.3 Collapse Sinkholes 517
See It Sidebar: Carlsbad Caverns National Park 518

11.5 ENVIRONMENTAL CONCERNS 523
- 11.5.1 Stream Pollution 523
- 11.5.2 Groundwater Pollution 524
- 11.5.3 Saltwater Intrusion 525
- 11.5.4 Overproduction 526

SUMMARY 527
KEY TERMS 530
ANSWERS TO CONCEPT CHECKS 531
REVIEW EXERCISES 535

CHAPTER 12

Oceans and Coastlines ***538***

12.1 ORIGIN OF THE OCEAN BASINS 540
- 12.1.1 A Cosmic Hypothesis 540
- 12.1.2 Plate Tectonics 540

12.2 LANDFORMS OF THE OCEAN BASINS 541
- 12.2.1 Oceanic Ridges 541
- 12.2.2 Abyssal Hills 544
- 12.2.3 Abyssal Plains 545
- 12.2.4 Seamounts 545
- 12.2.5 Deep-Sea Trenches 547

12.3 CONTINENTAL MARGINS 548
- 12.3.1 The Continental Shelf 548
- 12.3.2 The Continental Slope 549
- 12.3.3 The Continental Rise 550

12.4 MOVEMENT OF OCEAN WATER 552
- 12.4.1 Waves 552
- 12.4.2 Currents 558

12.5 COASTAL CURRENTS 566
- 12.5.1 Emergent or High-Energy Coastlines 566
- ***SEE IT*** SIDEBAR: CHANNEL ISLANDS NATIONAL PARK 568
- 12.5.2 Submergent or Low-Energy Coastlines 572

12.6 REEFS 577
- 12.6.1 Reef Building 577
- 12.6.2 Kinds of Reefs 577
- ***SEE IT*** SIDEBAR: VIRGIN ISLANDS NATIONAL PARK 578

12.7 MODIFICATION OF COASTAL PROCESSES 583

12.8 ENVIRONMENTAL PROBLEMS 585

SUMMARY 586
KEY TERMS 588
ANSWERS TO CONCEPT CHECKS 589
REVIEW EXERCISES 592

CHAPTER 13

Glaciers and Deserts—Climatic Features *594*

13.1 GLACIAL FORMATION, STRUCTURE, AND MOVEMENT 596
- 13.1.1 Formation of Glaciers 597
- 13.1.2 Glacial Ice Formation 599
- 13.1.3 Movement of Glacial Ice 600
- 13.1.4 The Glacial Budget 601

13.2 GLACIAL FEATURES 603
- 13.2.1 Erosional Processes and Features 603
- ***See It*** Sidebar: Glacier Bay National Park and Preserve 608
- 13.2.2 Depositional Processes and Features 615

13.3 CAUSES OF CONTINENTAL GLACIATION 623
- 13.3.1 Milankovitch Hypothesis 623
- 13.3.2 Volcanic Activity 624
- 13.3.3 Changes in the Concentration of Carbon Dioxide 624

13.4 GLACIAL ENVIRONMENTAL CONCERNS 625
- 13.4.1 Climate 625
- 13.4.2 Medical Concerns 627

13.5 DESERTS 627
- 13.5.1 Deserts and Relative Humidity 628
- 13.5.2 Types of Deserts 629

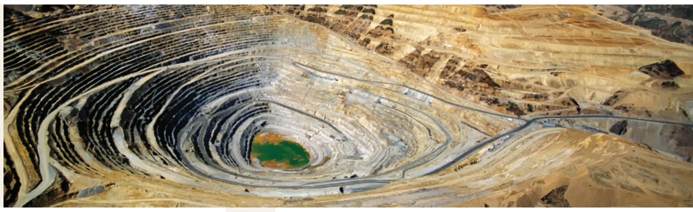
13.6 DESERT FEATURES 634
- 13.6.1 Weathering and Mass Wasting 634
- 13.6.2 Water Erosion and Deposition 634
- ***See It*** Sidebar: Death Valley National Park 638
- 13.6.3 Wind Erosion and Deposition 640

13.7 DESERT ENVIRONMENTAL CONCERNS 645

SUMMARY 648
KEY TERMS 650
ANSWERS TO CONCEPT CHECKS 651
REVIEW EXERCISES 655

CHAPTER 14

Economic Geology and Resources *658*



14.1 NATURAL RESOURCES 660
  14.1.1 Historical Use of Resources 660
  14.1.2 Renewable and Nonrenewable Resources 662
  14.1.3 Resources versus Reserves 664
14.2 ENERGY RESOURCES 665
  14.2.1 Fossil Fuels 665
  14.2.2 Nuclear Power 672
14.3 MINERAL RESOURCES 675
  14.3.1 Metallic Resources 675
  14.3.2 Nonmetallic Resources 678
14.4 WATER RESOURCES 680
  14.4.1 Surface and Groundwater Supplies 681
  14.4.2 The Pressure on Water Supplies 682
14.5 THE FUTURE OF GEOLOGIC RESOURCES 685
  14.5.1 Population and Resources 685
  14.5.2 Environmental Issues 686
  14.5.3 Alternative Energy Resources 689
  See It SIDEBAR: YELLOWSTONE NATIONAL PARK 696

SUMMARY 703
KEY TERMS 705
ANSWERS TO CONCEPT CHECKS 706
REVIEW EXERCISES 710

APPENDIX 713
GLOSSARY 716
INDEX 739

Preface

It seems almost every child goes through a rock phase, a time when every outing results in bags and pockets stuffed with rocks that must be brought home to be studied or merely possessed. Rocks seem to bring out an innate curiosity in all of us about the world in which we live, how it formed, and how it works.

Some people never leave that rock phase; those people become geologists. Others may leave the rocks behind as they pursue new interests, but that childhood curiosity, we are convinced, continues to operate within us. *Physical Geology Across the American Landscape* is a textbook designed not only to impart scientific data about the landforms of the North American continent but also to take students on an exploration that stimulates and satisfies the desire to know more about their home planet.

During that exploration, students will discover that geology is more than identifying the rocks that found their way into childhood pockets. It is the study of features and processes that are often either too distant or too ordinary to occupy daily attention, but that have a dramatic impact on their daily lives. While reading this textbook, the student will discover that the local backdrops so taken for granted—the rolling hills, streams and rivers, shorelines, and mountains—are more than just scenery. Every geological feature has a story to tell.

Some of the stories are short and dramatic, such as a single earthquake, volcanic eruption, or landslide. Others unfold over millions of years and involve incomprehensibly large forces. Still others are unfolding as the result of our own actions. *Physical Geology Across the American Landscape* ties together all of this information to create a comprehensive understanding of Earth's features, events, and processes. In reaching this understanding, students not only will be able to identify some of those pocket rocks but also will be prepared to make new assessments of the state of our planet, to make smart decisions, and to find solutions to some of humanity's most pressing issues. At the same time, they'll discover what every geologist already knows: not only is the study of Earth useful, it's also captivating—not to mention, a lot of fun.

Textbook Objectives

Physical Geology Across the American Landscape was designed to be used as a guide and core source of content for a college introductory geology lecture course or as an integral part of *Physical Geology Across the American Landscape Online Course*. This textbook was written to accomplish three overall objectives with the general purpose of creating a greater understanding of the planet on which we live, with a focus on the North American continent. After reading this textbook and completing the activities assigned by their instructor, students will be able to:

- **Explain common geological features and processes, using the major concepts and theories of geology.**

Why do earthquakes happen in California and rarely in Florida? Why are there volcanoes in Alaska but not in Texas? Why are some states flat and others hilly or mountainous? Why do we care about glaciers that existed 10,000 years ago? Why are there so many landslides after a big rain? How do geologists know where to look for oil or gold? Why are some rocks colorful, some banded, and some a boring gray? How do scientists know how old a fossil is? Throughout this textbook, students will learn the answers to all of these questions and more. They'll not only be able to identify key geological features, but will also be able to explain the processes that formed them.

- **Effectively write and verbally communicate, using solid research, observations, reasoning, and the scientific method, to support opinions and ideas.**

Students will not only learn about features and processes, they will take a look at how geologists have gathered and analyzed information to discover how Earth works. In doing so, students will gain a new appreciation of the ways in which geologists have objectively observed the environment, noted and mapped details, obtained data, and then used logic and inference to draw the conclusions that are the foundation for our understanding of our planet.

- **Critically analyze and evaluate information to make informed decisions about environmental issues and/or current events using the principles and methods of geology.**

Earth may be at its most critical period in human history. Climate change, dwindling resources, and toxins in our environment present simultaneous challenges to the generations alive today. The choices that must be made over the next few years and decades require a thorough understanding of the factors and processes involved. Each chapter in this book contains a section on environmental concerns that brings these issues into focus. After reading this textbook, students not only will comprehend individual issues but also should have a grasp of the big picture that will allow them to make informed decisions.

Unifying Theme

Earth is a dynamic planet with processes that produce constant change, some of it fast and some of it slow. These changes have formed the landscapes around us, which will continue to be altered over time. This is the underlying theme and message of *Physical Geology Across the American Landscape*. Once students complete reading this book, nothing in the American landscape will look quite the same to them.

Textbook Organization

Physical Geology Across the American Landscape contains 14 chapters plus an introductory chapter. The chapters are presented in distinct units within the textbook, allowing instructors to customize the course to suit their individual teaching preferences.

The Introduction chapter places Earth within context. It first describes the various Earth systems—atmosphere, hydrosphere, cryosphere, lithosphere, and biosphere—and how these systems interact to produce both short-term and long-term changes familiar to the student. The chapter then goes on to reveal how Earth formed and how Earth compares to other planets in our Solar System.

Unit 1: Earth's Interior and Tectonic Processes

Chapters 1 through 4 discuss how seismologists use data, logic, and inference to determine the composition of Earth's interior and figure out the workings of plate tectonics. Chapter 1 reveals how the refraction of seismic waves provided evidence for what lies beneath Earth's surface. Chapter 2 tells the story of how the theory of plate tectonics slowly evolved through the gradual accumulation of evidence. Chapter 3 focuses on two of the consequences of plate tectonics, rock deformation and mountain-building. Chapter 4 completes the sequence with an in-depth look at earthquakes.

Unit 2: Earth's Minerals and Rocks

Chapters 5 through 8 zoom in on the actual substances that compose Earth. Chapter 5 provides a brief introduction to minerals, their chemistry, their properties, and their identification. Chapter 6 focuses on igneous rocks, how they form, and how they are identified, and then goes on to discuss volcanoes and volcanic activity. Chapter 7 explores weathering, soils, and sedimentary rocks. Chapter 8 discusses metamorphic rocks and explains and describes what happens when rocks are exposed to extreme conditions.

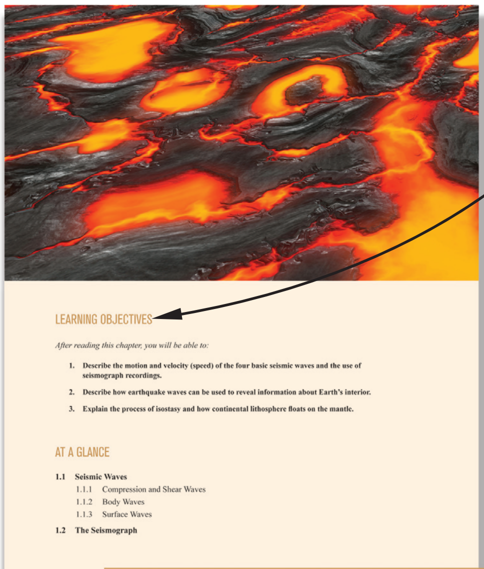
Unit 3: Time, Surface Features, and Resources

Chapter 9 on Geologic Time is a stand-alone chapter that explains relative and absolute dating in the context of geologic time and its divisions. Chapters 10 through 13 focus on the processes that form and alter the American landscape. Chapter 10 is a discussion of mass wasting processes. Chapter 11 discusses streams and rivers, the groundwater system, and karst topography. Chapter 12 takes the student offshore to explore the ocean floor, winds, waves, and currents, as well as shoreline erosional and depositional processes. Chapter 13 focuses on climatic features, first visiting the cryosphere with a discussion of glaciers and glacial features, and then moving to the desert environment. Chapter 14 on Geological Resources is another stand-alone chapter. It discusses the identification, classification and extraction of energy, mineral and water resources in the context of an exponential growth in population.

Textbook Features

Physical Geology Across the American Landscape includes a number of features designed to make learning easier and more productive.

Each chapter begins with clearly defined learning objectives so that students are aware of what they are expected to learn over the succeeding pages. The objectives are phrased in terms of not just what students will understand, but what they will be able to do to demonstrate their understanding.



LEARNING OBJECTIVES

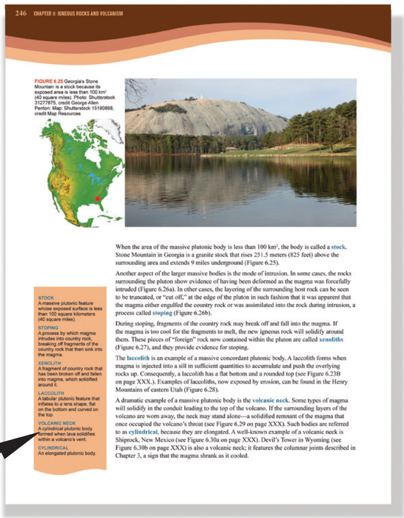
After reading this chapter, you will be able to:

1. **Describe the motion and velocity (speed) of the four basic seismic waves and the use of seismograph recordings.**
2. **Describe how earthquake waves can be used to reveal information about Earth's interior.**
3. **Explain the process of isostasy and how continental lithosphere floats on the mantle.**

AT A GLANCE

1.1 Seismic Waves
  1.1.1 Compression and Shear Waves
  1.1.2 Body Waves
  1.1.3 Surface Waves
1.2 The Seismograph

Key terms are highlighted, with formal definitions appearing in the margins for easy reference.



246 CHAPTER 6: IGNEOUS ROCKS AND VOLCANISM

FIGURE 6.25 Georgia's Stone Mountain is a stock because its exposed area is less than 100 km² (40 square miles). Photo: Shutterstock 31277875, credit George Allen Penton; Map: Shutterstock 15180868, credit Map Resources

When the area of the massive plutonic body is less than 100 km², the body is called a **stock**. Stone Mountain in Georgia is a granite stock that rises 251.5 meters (825 feet) above the surrounding area and extends 9 miles underground (Figure 6.25).

Another aspect of the larger massive bodies is the mode of intrusion. In some cases, the rocks surrounding the pluton show evidence of having been deformed as the magma was forcefully intruded (Figure 6.26a). In other cases, the layering of the surrounding host rock can be seen to be truncated, or "cut off," at the edge of the pluton in such fashion that it was apparent that the magma either engulfed the country rock or was assimilated into the rock during intrusion, a process called **stoping** (Figure 6.26b).

During stoping, fragments of the country rock may break off and fall into the magma. If the magma is too cool for the fragments to melt, the new igneous rock will solidify around them. These pieces of "foreign" rock now contained within the pluton are called **xenoliths** (Figure 6.27), and they provide evidence for stoping.

The **laccolith** is an example of a massive concordant plutonic body. A laccolith forms when magma is injected into a sill in sufficient quantities to accumulate and push the overlying rocks up. Consequently, a laccolith has a flat bottom and a rounded top (see Figure 6.23B on page XXX.). Examples of laccoliths, now exposed by erosion, can be found in the Henry Mountains of eastern Utah (Figure 6.28).

A dramatic example of a massive plutonic body is the **volcanic neck**. Some types of magma will solidify in the conduit leading to the top of the volcano. If the surrounding layers of the volcano are worn away, the neck may stand alone—a solidified remnant of the magma that once occupied the volcano's throat (see Figure 6.29 on page XXX). Such bodies are referred to as **cylindrical**, because they are elongated. A well-known example of a volcanic neck is Shiprock, New Mexico (see Figure 6.30a on page XXX). Devil's Tower in Wyoming (see Figure 6.30b on page XXX) is also a volcanic neck; it features the columnar joints described in Chapter 3, a sign that the magma shrank as it cooled.

STOCK
A massive plutonic feature whose exposed surface is less than 100 square kilometers (40 square miles).

STOPING
A process by which magma intrudes into country rock, breaking off fragments of the country rock that then sink into the magma.

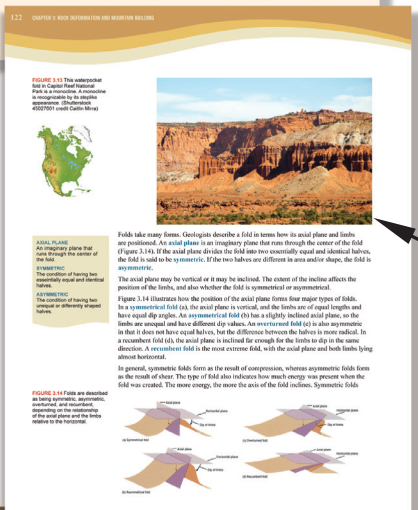
XENOLITH
A fragment of country rock that has been broken off and fallen into magma, which solidified around it.

LACCOLITH
A tabular plutonic feature that inflates to a lens shape, flat on the bottom and curved on the top.

VOLCANIC NECK
A cylindrical plutonic body formed when lava solidifies within a volcano's vent.

CYLINDRICAL
An elongated plutonic body.

High-quality photographs illustrate these concepts across the American landscape, supplemented with location maps placing each photograph within a geographic context.



122 CHAPTER 3: ROCK DEFORMATION AND MOUNTAIN BUILDING

FIGURE 3.13 This waterpocket fold in Capitol Reef National Park is a monocline. A monocline is recognizable by its steplike appearance. (Shutterstock 45027601 credit Caitlin Mirra)

Folds take many forms. Geologists describe a fold in terms how its axial plane and limbs are positioned. An **axial plane** is an imaginary plane that runs through the center of the fold (Figure 3.14). If the axial plane divides the fold into two essentially equal and identical halves, the fold is said to be **symmetric**. If the two halves are different in area and/or shape, the fold is **asymmetric**.

The axial plane may be vertical or it may be inclined. The extent of the incline affects the position of the limbs, and also whether the fold is symmetrical or asymmetrical.

Figure 3.14 illustrates how the position of the axial plane forms four major types of folds. In a **symmetrical fold** (a), the axial plane is vertical, and the limbs are of equal lengths and have equal dip angles. An **asymmetrical fold** (b) has a slightly inclined axial plane, so the limbs are unequal and have different dip values. An **overturned fold** (c) is also asymmetric in that it does not have equal halves, but the difference between the halves is more radical. In a recumbent fold (d), the axial plane is inclined far enough for the limbs to dip in the same direction. A **recumbent fold** is the most extreme fold, with the axial plane and both limbs lying almost horizontal.

In general, symmetric folds form as the result of compression, whereas asymmetric folds form as the result of shear. The type of fold also indicates how much energy was present when the fold was created. The more energy, the more the axis of the fold inclines. Symmetric folds

AXIAL PLANE
An imaginary plane that runs through the center of the fold.

SYMMETRIC
The condition of having two esseintially equal and identical halves.

ASYMMETRIC
The condition of having two unequal or differently shaped halves.

FIGURE 3.14 Folds are described as being symmetric, asymmetric, overturned, and recumbent, depending on the relationship of the axial plane and the limbs relative to the horizontal.

Vibrant illustrations bring to life key concepts in ways that help students visualize how geological processes work.

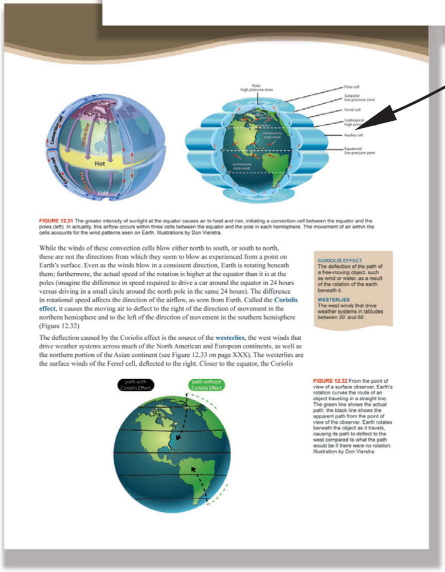


FIGURE 12.31 The greater intensity of sunlight at the equator causes air to heat and rise, initiating a convection cell between the equator and the poles (left). In actuality, this airflow occurs within three cells between the equator and the pole in each hemisphere. The movement of air within the cells accounts for the wind patterns seen on Earth. Illustrations by Don Vierstra.

While the winds of these convection cells blow either north to south, or south to north, these are not the directions from which they seem to blow as experienced from a point on Earth's surface. Even as the winds blow in a consistent direction, Earth is rotating beneath them; furthermore, the actual speed of the rotation is higher at the equator than it is at the poles (imagine the difference in speed required to drive a car around the equator in 24 hours versus driving in a small circle around the north pole in the same 24 hours). The difference in rotational speed affects the direction of the airflow, as seen from Earth. Called the **Coriolis effect**, it causes the moving air to deflect to the right of the direction of movement in the northern hemisphere and to the left of the direction of movement in the southern hemisphere (Figure 12.32)

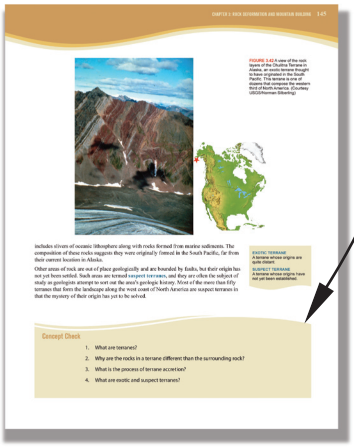
The deflection caused by the Coriolis effect is the source of the **westerlies**, the west winds that drive weather systems across much of the North American and European continents, as well as the northern portion of the Asian continent (see Figure 12.33 on page XXX). The westerlies are the surface winds of the Ferrel cell, deflected to the right. Closer to the equator, the Coriolis

CORIOLIS EFFECT
The deflection of the path of a free-moving object, such as wind or water, as a result of the rotation of the earth beneath it.

WESTERLIES
The west winds that drive weather systems in latitudes between 30° and 60°.

FIGURE 12.32 From the point of view of a surface observer, Earth's rotation curves the route of an object traveling in a straight line. The green line shows the actual path; the black line shows the apparent path from the point of view of the observer. Earth rotates beneath the object as it travels, causing its path to deflect to the west compared to what the path would be if there were no rotation. Illustration by Don Vierstra

At the end of each chapter section, concept checks test student comprehension, helping to ensure they have mastered key concepts before moving on to build upon them in the next section.



CHAPTER 3: ROCK DEFORMATION AND MOUNTAIN BUILDING 145

FIGURE 3.42 A view of the rock layers of the Chulitna Terrane in Alaska, an exotic terrane thought to have originated in the South Pacific. This terrane is one of dozens that compose the western third of North America. (Courtesy USGS/Norman Silberling)

includes slivers of oceanic lithosphere along with rocks formed from marine sediments. The composition of these rocks suggests they were originally formed in the South Pacific, far from their current location in Alaska.

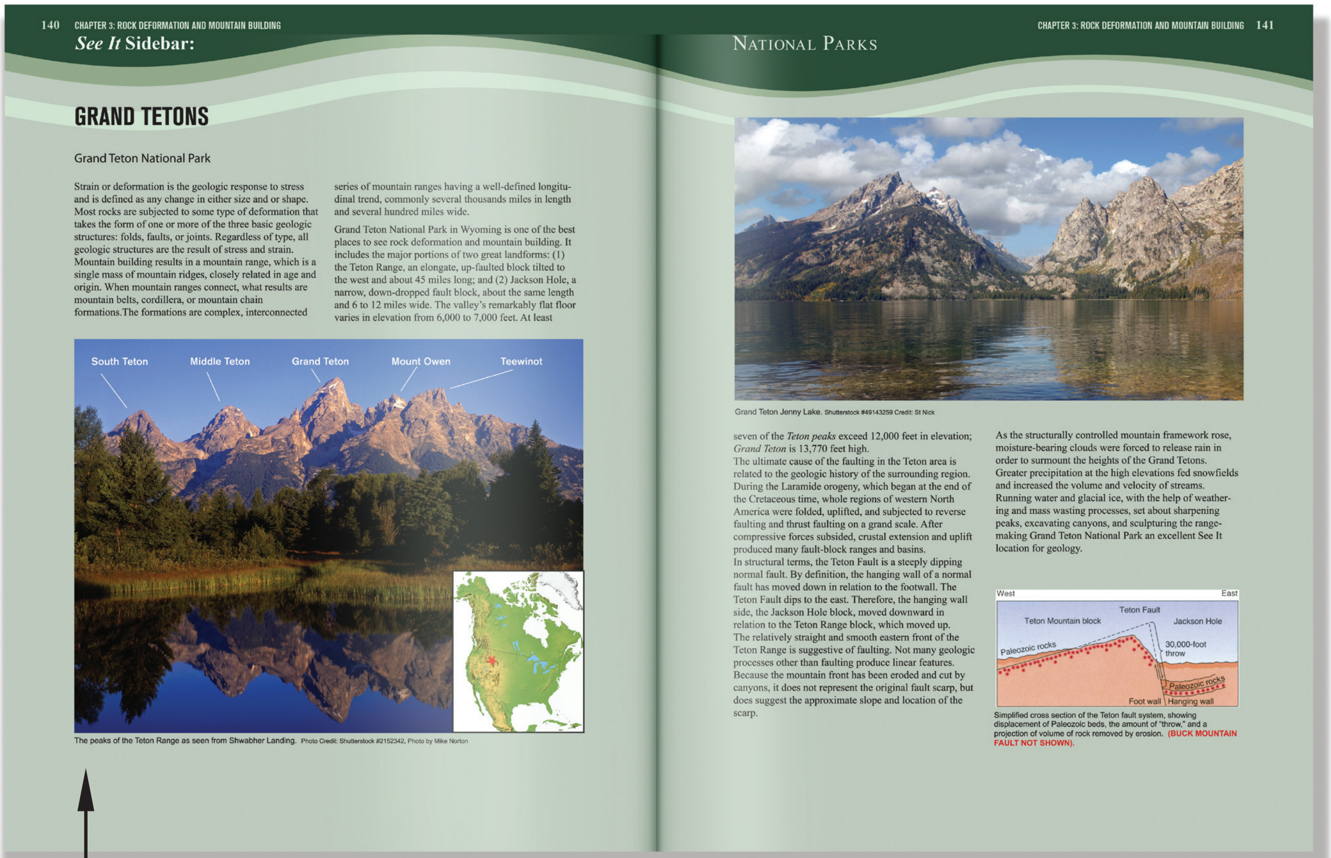
Other areas of rock are out of place geologically and are bounded by faults, but their origin has not yet been settled. Such areas are termed **suspect terranes**, and they are often the subject of study as geologists attempt to sort out the area's geologic history. Most of the more than fifty terranes that form the landscape along the west coast of North America are suspect terranes in that the mystery of their origin has yet to be solved.

EXOTIC TERRANE
A terrane whose origins are quite distant.

SUSPECT TERRANE
A terrane whose origins have not yet been established.

Concept Check

1. What are terranes?
2. Why are the rocks in a terrane different than the surrounding rock?
3. What is the process of terrane accretion?
4. What are exotic and suspect terranes?



140 CHAPTER 3: ROCK DEFORMATION AND MOUNTAIN BUILDING

See It Sidebar:

NATIONAL PARKS

CHAPTER 3: ROCK DEFORMATION AND MOUNTAIN BUILDING 141

GRAND TETONS

Grand Teton National Park

Strain or deformation is the geologic response to stress and is defined as any change in either size and or shape. Most rocks are subjected to some type of deformation that takes the form of one or more of the three basic geologic structures: folds, faults, or joints. Regardless of type, all geologic structures are the result of stress and strain. Mountain building results in a mountain range, which is a single mass of mountain ridges, closely related in age and origin. When mountain ranges connect, what results are mountain belts, cordillera, or mountain chain formations.The formations are complex, interconnected series of mountain ranges having a well-defined longitudinal trend, commonly several thousands miles in length and several hundred miles wide.

Grand Teton National Park in Wyoming is one of the best places to see rock deformation and mountain building. It includes the major portions of two great landforms: (1) the Teton Range, an elongate, up-faulted block tilted to the west and about 45 miles long; and (2) Jackson Hole, a narrow, down-dropped fault block, about the same length and 6 to 12 miles wide. The valley's remarkably flat floor varies in elevation from 6,000 to 7,000 feet. At least seven of the *Teton peaks* exceed 12,000 feet in elevation; *Grand Teton* is 13,770 feet high.

The ultimate cause of the faulting in the Teton area is related to the geologic history of the surrounding region. During the Laramide orogeny, which began at the end of the Cretaceous time, whole regions of western North America were folded, uplifted, and subjected to reverse faulting and thrust faulting on a grand scale. After compressive forces subsided, crustal extension and uplift produced many fault-block ranges and basins.

In structural terms, the Teton Fault is a steeply dipping normal fault. By definition, the hanging wall of a normal fault has moved down in relation to the footwall. The Teton Fault dips to the east. Therefore, the hanging wall side, the Jackson Hole block, moved downward in relation to the Teton Range block, which moved up.

The relatively straight and smooth eastern front of the Teton Range is suggestive of faulting. Not many geologic processes other than faulting produce linear features. Because the mountain front has been eroded and cut by canyons, it does not represent the original fault scarp, but does suggest the approximate slope and location of the scarp.

As the structurally controlled mountain framework rose, moisture-bearing clouds were forced to release rain in order to surmount the heights of the Grand Tetons. Greater precipitation at the high elevations fed snowfields and increased the volume and velocity of streams. Running water and glacial ice, with the help of weathering and mass wasting processes, set about sharpening peaks, excavating canyons, and sculpturing the range-making Grand Teton National Park an excellent See It location for geology.

The peaks of the Teton Range as seen from Shwabher Landing. Photo Credit: Shutterstock #2152342, Photo by Mike Norton

Grand Teton Jenny Lake. Shutterstock #49143259 Credit: St Nick

Simplified cross section of the Teton fault system, showing displacement of Paleozoic beds, the amount of "throw," and a projection of volume of rock removed by erosion. **(BUCK MOUNTAIN FAULT NOT SHOWN).**

A highlight of *Physical Geology Across the American Landscape* is the collection of ***See It*** Sidebars that describe the most dramatic and pristine landscapes on our continent, our National Parks. Chapters feature various National Parks as examples illustrating the chapter material. The sidebars explore the geology of each park with regard to the chapter topic, accompanied by superb photographs from North America's most impressive scenery.

Finally, at the end of each chapter, a succinct summary capsulizes the material presented in the chapter, followed by a list of review questions to test student understanding of the material and flag any areas in which further study might be needed.

144 CHAPTER 3: ROCK DEFORMATION AND MOUNTAIN BUILDING

SUMMARY

When rocks are under sufficient stress, they deform. There are three types of stress: tension (stretching), compression (pushing), and shear (rotational or tearing). The response of rocks to stress is called strain. Strain varies depending on whether the rock is elastic, brittle or ductile (plastic). Elastic rocks temporarily deform and resume their shape when the stress is removed. If a rock's elastic limit is exceeded, its type of strain depends upon whether it is brittle or ductile. Brittle rocks break as a response to stress; plastic rocks become thinner and longer under tensional stress, and fold under compression.

The deformation of rocks under stress creates geologic structures. Geologists describe the orientation of geologic structures in terms of strike and dip. Strike describes the orientation of a structure's axis, and is the compass direction, relative to magnetic north, of an intersection between a horizontal plane and the surface of the structure. Dip describes the angle between the horizontal plane and the surface of a limb, or slope, of the structure, and is expressed in degrees.

Geologic structures formed by rocks under stress are folds, faults, and joints. Folds are described by the direction in which they bend. An anticline bulges upward and a syncline bulges downward. Anticlines and synclines often appear together. A monocline has a single limb, or slope, and is described as a local steepening in an otherwise gentle incline. Monoclines often have the appearance of steps. Symmetric folds have limbs of equal length and similar dips on either side of the axis; asymmetric folds have limbs of different lengths with different dip values.

Anticlines are further described by the inclination of the axis of the fold and the resulting orientation of the limbs. A symmetrical fold has a near vertical access and limbs of equal length and dip values; an asymmetrical fold has a slightly inclined axis and limbs of unequal length and dip values; an overturned fold has a very inclined axis with limbs that dip in the same direction; and a recumbent fold has an axis and limbs that lie almost horizontal. Plunging folds have an axis that tilts toward one of its ends, penetrating into the ground. Plunging folds can be recognized by the distinctive V or U shape they assume where the axis intersects with the ground.

Faults are fractures that occur when brittle rocks are stressed and where there has been displacement after the fracture. Tension produces a normal fault in which the hanging wall moves down relative to the footwall. Compression produces reverse faults in which the hanging wall moves up relative to the footwall. A special type of reverse fault is known as a thrust fault which has a dip angle less than 30°, but the motion is still along the dip, so all reverse faults are referred to as dip slip faults. Shear produces strike-slip faults in which the fault plane is nearly vertical. Left-lateral strike-slip faults are those in which the opposite side of the fault appears to have moved to the left; in a right-lateral strike-slip fault, the opposite side of the fault appears to have moved to the right. Transform faults at plate boundaries are strike-slip faults.

Joints are fractures without any displacement, and often occur in sets as the result of stress. Most rock beds have joints. In addition, the shrinking of igneous rock as it cools can cause columnar jointing, and the expansion of igneous rock after overlying pressure is released can create exfoliation joints.

The apparent motion of rocks that have faulted can be determined by the presence of slickensides or drag folds. The apparent motion of rocks that have folded is determined by the direction in which asymmetric folds incline.

About the Author

John J. Renton, Ph.D., holds the Eberly Family Chair for Distinguished Teaching at West Virginia University, where he has been teaching for more than 40 years. He received his bachelor's degree in Chemistry from Waynesburg College and went on to earn his master's and Ph.D. in Geology from West Virginia University.

Renton is the author of the textbook, *Planet Earth*, second edition, which is the preceding edition of this textbook. He has also authored and coauthored nearly 50 geological academic papers and has worked on more than four million dollars of coal-related research grants.

Professor Renton is the recipient of several awards for his success in teaching, including the Outstanding Educator Award from the Eastern Section of the American Association of Petroleum Geologists, the Outstanding Teacher Award from the Eberly College of Arts and Sciences, the university-wide Outstanding Teacher Award and most recently, Professor of the Year Award from the West Virginia University Foundation.

About the Instructional Designer

Sylvia E. Amito'elau. M.S., served as the instructional designer of this textbook, as well as its accompanying laboratory manual, online laboratory, and online course, from concept to completion. She is an instructional designer for **Coast Learning Systems**, a division of Coastline Community College in Fountain Valley, California. Sylvia has assisted in design and development on several educational projects, including online courses in accounting, Arabic, chemistry, Chinese, education, math, and student success for more than 8 years. At Coastline Community College, Sylvia is responsible for providing instructional design, training, and support for all faculty, particularly in areas related to distance learning. As a member of the Senate Academic Standards Committee, she participated in the development of the Coastline Academic Quality Rubric. She is also a part-time faculty member teaching computer application courses and has experience teaching courses in various delivery modalities such as classroom, hybrid, and online. In addition, Sylvia has worked on the California Virtual Campus project, training and assisting Southern California community college faculty in the design, development, and delivery of online instruction. Sylvia holds a Master of Science degree in Instructional Technology and a Bachelor of Arts degree in Mathematics.

Acknowledgments

Many thanks and appreciation are expressed for the contributions of the following key individuals, who, without their input and dedication, this book would have not been possible.

Editors and Lead Advisors

Robert Altamura, Ph.D., Florida Community College at Jacksonville Open Campus, Urban Resources Center

James McClinton, M.S., Eastern New Mexico University—Roswell

Joseph Mraz, M.S., Santa Fe Community College

Kelly Ruppert, M.S., California State University, Fullerton, and Coastline Community College

Susan Wilcox, M.A., Writer and Media Producer

Curtis Williams, M.S., California State University, Fullerton

Jan (Jay) Yett, M.S., Orange Coast College

Members of the National Academic Advisory Team

The following scholars, teachers, and practitioners helped focus the approach and content of each chapter to ensure accuracy, academic validity, significance, and instructional integrity.

Robert Altamura, Ph.D., Florida Community College at Jacksonville Open Campus, Urban Resources Center

Edward (Erik) Bender, M.S., Orange Coast College

Theodore Erski, M.A., McHenry County College

Roberto Falero, M.S., DPRA, Inc.

Gail Gibson, Ph.D., Florida Community College at Jacksonville—Kent Campus

Jonathan Kuespert, M.S., M.B.A., BreitBurn Energy Management Company

Michael Leach, M.S., M.A., New Mexico State University

James McClinton, M.S., Eastern New Mexico University—Roswell

Joseph Mraz, M.S., Santa Fe Community College

Jay P. Muza, Ph.D., Broward College

Douglas Neves, Ph.D., Cypress College

Kathy Ann Randall, M.S., Lincoln County Campus of the Flathead Valley Community College

Kelly Ruppert, M.S., California State University, Fullerton, and Coastline Community College

Richard Schultz, Ph.D., C.P.G., Elmhurst College

Debbie Secord, M.S., Coastline Community College

William H. Walker, Ph.D., Thomas Edison State College

Curtis Williams, M.S., California State University, Fullerton

Jan (Jay) Yett, M.S., Orange Coast College

Special thanks go to our editors, Susan Wilcox and Curtis Williams, who spent countless hours editing the magnificent content of the chapters in this outstanding book, taking great pains to make sure concepts are explained thoroughly, yet clearly.

John Renton also deserves a huge amount of recognition and gratitude for the creation of and original work on *Planet Earth*, without which we would not have this book about this extremely interesting discipline called geology. Also, we are very grateful for the many illustrations that John created that appear throughout the book.

Many thanks go to Sylvia Amito'elau of Coast Learning Systems for instructional design and quality assurance.

Special thanks are extended to our editors and lead academic advisors for their diligent contribution, review, and scrutiny of content over each chapter, and for reviewing and creating the Review Exercises. Additional thanks are extended to Erica Gardiner, who wrote the ***See It*** Sidebars featured throughout the textbook on selected National Parks in the United States and Canada.

This textbook would not be as rich and beautiful without the many gorgeous photographs and vibrant illustrations that are great examples to help students visualize key concepts and how geological processes work. We thank John Renton for his many illustrations, as well as Don Vierstra, who produced most of the other artwork and illustrations in this book.

We especially thank the many individuals who so graciously supplied us with and allowed us to use many interesting photographs in this textbook.

Very special thanks goes to the dedicated members of the Coast Learning Systems eMedia & Publishing team headed by Judy Garvey, who worked on the coordination, design, and production of this textbook: Wendy Sacket, Thien Vu, Don Vierstra, and Linda Wojciechowski.

Many thanks go to Marie Hulett of Coast Learning Systems and Colleen Zelinsky of Kendall Hunt, who spent tireless hours researching and acquiring images and permissions for hundreds of photographs and images that appear in this textbook.

We also thank all staff members of Kendall Hunt Publishing, Higher Education Division, for their hard work and dedication and help in making this textbook happen, especially David Tart, Paul Carty, Lynne Rogers, Mary Melloy, Colleen Zelinsky, Renae Horstman, Angela Willenbring, and Georgia Botsford.

Last, but certainly not least, we wish to thank members of the Coast Community College District and Coast Learning Systems, especially our Board of Trustees, Chancellor, President, and our Executive Dean of Instructional Systems Development, for their support.