

Essentials of  
**GEOLOGY** 13e



# Essentials of **GEOLOGY** <sup>13e</sup>

**Frederick K. Lutgens**

**Edward J. Tarbuck**

Illustrated by  
**Dennis Tasa**



330 Hudson Street, NY NY 10013

**Executive Editor, Geosciences Courseware:** Christian Botting  
**Director, Courseware Portfolio Management:** Beth Wilbur  
**Content Producer:** Lizette Faraji  
**Managing Producer:** Mike Early  
**Courseware Director, Content Development:** Ginnie Simione Jutson  
**Courseware Sr. Analyst:** Margot Otway  
**Geosciences Courseware Editorial Assistant:** Emily Bornhop  
**Rich Media Content Producer:** Mia Sullivan  
**Full Service Vendor:** SPi Global

**Full Service Project Manager:** Patty Donovan  
**Copyeditor:** Kitty Wilson  
**Design Manager:** Mark Ong  
**Cover and Interior Designer:** Jeff Puda  
**Photo and Illustration Support:** Kevin Lear, International Mapping  
**Rights and Permissions Project Manager:** Kathleen Zander  
**Rights and Permissions Management:** Ben Ferrini  
**Manufacturing Buyer:** Maura Zaldivar-Garcia  
**Marketing Managers:** Neena Bali/Mary Salzman  
**Cover Image Credit:** © Tim Kemple

Credits and acknowledgments borrowed from other sources and reproduced, with permission, in this textbook appear on the appropriate page within text or are listed below.

Page 6: Quote by Aristotle from *The Birth and Development of the Geological Sciences* by Frank Dawson Adams. Published by Dover Publications, © 1954; page 7: Excerpt from *Essentials of Earth History*, 3e by William Lee Stokes. Published by Pearson Education Inc., © 1973; page 7: Quote from *Transactions of the Royal Society of Edinburgh* by James Hutton. Published by The Royal Society of Edinburgh, © 1788; page 10: Quote from *The Common Sense of Science* by Jacob Bronowski. Published by Harvard University Press, © 1953; page 10: Quote from *Science for All Americans* by F. James Rutherford and Andrew Ahlgren. Published by Oxford University Press, © 1990; page 11: Quote by Louis Pasteur from *Pasteur Vallery-Radot*. Published by Masson et cie, © 1939; page 37: Quote from *The Origin of Continents and*

*Oceans* by Alfred Wegener. Published by Methuen Publishing, Ltd., © 1966; page 14: Quote by R. T. Chamberlain from *A Revolution in the Earth Sciences* by Anthony Hallam. Published by Oxford University Press, © 1973; page 356: Quote from *Exploration of the Colorado River of the West and Its Tributaries*. Published by U.S. Government Printing Office, © 1875; page 417: Excerpt from *Variations in the Earth's Orbit: Pacemaker of the Ice Ages* by J.D. Hays, John Imbrie and N.J. Shackleton in *Science*, Vol 194, Issue 4270, pp.1121–1132. Published by American Association for the Advancement of Science, © 1976; page 438: Quote from *The Physics of Blown Sand and Desert Dunes* by R.A. Bagnold. Published by Courier Corporation, © 2005; page 474: Quote from James Hutton, *Transactions of the Royal Society of Edinburgh*, 1805.

Copyright © 2018, 2015, 2012 by Pearson Education, Inc. All rights reserved. Manufactured in the United States of America. This publication is protected by Copyright, and permission should be obtained from the publisher prior to any prohibited reproduction, storage in a retrieval system, or transmission in any form or by any means: electronic, mechanical, photocopying, recording, or likewise. To obtain permission(s) to use material from this work, please submit a written request to Pearson Education, Inc., Permissions Department, One Lake Street, Upper Saddle River, New Jersey 07458.

Many of the designations by manufacturers and sellers to distinguish their products are claimed as trademarks. Where those designations appear in this book, and the publisher was aware of a trademark claim, the designations have been printed in initial caps or all caps.

### Library of Congress Cataloging-in-Publication Data

Names: Lutgens, Frederick K. | Tarbuck, Edward J. | Tasa, Dennis.  
Title: *Essentials of geology* / Frederick K. Lutgens, Edward J. Tarbuck; illustrated by Dennis Tasa.  
Description: 13e. [13th edition]. | Hoboken, New Jersey : Pearson Education, 2016.  
Identifiers: LCCN 2016042061 | ISBN 9780134446622 | ISBN 0134446623  
Subjects: LCSH: Geology—Textbooks.  
Classification: LCC QE26.3 .L87 2016 | DDC 551—dc23 LC record available at <https://lcn.loc.gov/2016042061>

ISBN-10: 0-13-466349-7 (HS Binding)  
ISBN-13: 978-0-13-466349-4 (HS Binding)



# BRIEF CONTENTS

- 1 An Introduction to Geology 2**
  - 2 Plate Tectonics: A Scientific Revolution Unfolds 32**
  - 3 Matter & Minerals 66**
  - 4 Igneous Rocks & Intrusive Activity 94**
  - 5 Volcanoes & Volcanic Hazards 126**
  - 6 Weathering & Soils 160**
  - 7 Sedimentary Rocks 184**
  - 8 Metamorphism & Metamorphic Rocks 216**
  - 9 Earthquakes & Earth's Interior 238**
  - 10 Origin & Evolution of the Ocean Floor 268**
  - 11 Crustal Deformation & Mountain Building 292**
  - 12 Mass Movement on Slopes: The Work of Gravity 320**
  - 13 Running Water 340**
  - 14 Groundwater 368**
  - 15 Glaciers & Glaciation 394**
  - 16 Deserts & Wind 422**
  - 17 Shorelines 440**
  - 18 Geologic Time 468**
  - 19 Earth's Evolution Through Geologic Time 492**
  - 20 Global Climate Change 526**
- Appendix**  
**Metric and English Units Compared 556**
- Glossary 557**
- Index 568**

# CONTENTS

PREFACE xviii

DIGITAL AND PRINT RESOURCES xviii

WALKTHROUGH xxi

## 1 An Introduction to Geology 2

- 1.1 **Geology: The Science of Earth 4**
    - Physical and Historical Geology 4
    - Geology, People, and the Environment 5
  - 1.2 **The Development of Geology 6**
    - Catastrophism 6
    - The Birth of Modern Geology 6
    - Geology Today 7
    - The Magnitude of Geologic Time 8
  - 1.3 **The Nature of Scientific Inquiry 9**
    - Hypothesis 10
    - Theory 10
    - Scientific Methods 10
    - Plate Tectonics and Scientific Inquiry 11
  - 1.4 **Earth as a System 11**
    - Earth's Spheres 11
    - Hydrosphere 12
    - Atmosphere 13
    - Biosphere 14
    - Geosphere 14
    - Earth System Science 14
    - The Earth System 15
  - 1.5 **Origin and Early Evolution of Earth 17**
    - Origin of Planet Earth 17
    - Formation of Earth's Layered Structure 18
  - 1.6 **Earth's Internal Structure 19**
    - Earth's Crust 19
    - Earth's Mantle 19
    - Earth's Core 20
  - 1.7 **Rocks and the Rock Cycle 21**
    - The Basic Cycle 21
    - Alternative Paths 21
  - 1.8 **The Face of Earth 24**
    - Major Features of the Ocean Floor 26
    - Major Features of the Continents 26
- Concepts in Review 28**  
**Give It Some Thought 30**

## 2 Plate Tectonics: A Scientific Revolution Unfolds 32

- 2.1 **From Continental Drift to Plate Tectonics 34**
  - 2.2 **Continental Drift: An Idea Before Its Time 35**
    - Evidence: The Continental Jigsaw Puzzle 35
    - Evidence: Fossils Matching Across the Seas 36
    - Evidence: Rock Types and Geologic Features 37
    - Evidence: Ancient Climates 37
    - The Great Debate 38
  - 2.3 **The Theory of Plate Tectonics 39**
    - Rigid Lithosphere Overlies Weak Asthenosphere 39
    - Earth's Major Plates 40
    - Plate Movement 40
  - 2.4 **Divergent Plate Boundaries and Seafloor Spreading 41**
    - Oceanic Ridges and Seafloor Spreading 42
    - Continental Rifting 43
  - 2.5 **Convergent Plate Boundaries and Subduction 44**
    - Oceanic–Continental Convergence 45
    - Oceanic–Oceanic Convergence 46
    - Continental–Continental Convergence 46
  - 2.6 **Transform Plate Boundaries 48**
  - 2.7 **How Do Plates and Plate Boundaries Change? 50**
    - The Breakup of Pangaea 50
    - Plate Tectonics in the Future 51
  - 2.8 **Testing the Plate Tectonics Model 52**
    - Evidence: Ocean Drilling 52
    - Evidence: Mantle Plumes and Hot Spots 53
    - Evidence: Paleomagnetism 54
  - 2.9 **How Is Plate Motion Measured? 57**
    - Geologic Measurement of Plate Motion 57
    - Measuring Plate Motion from Space 58
  - 2.10 **What Drives Plate Motions? 59**
    - Forces That Drive Plate Motion 59
    - Models of Plate–Mantle Convection 60
- Concepts in Review 61**  
**Give It Some Thought 63**

## 3 Matter & Minerals 66

- 3.1 **Minerals: Building Blocks of Rocks** 68
    - Defining a Mineral 68
    - What Is a Rock? 69
  - 3.2 **Atoms: Building Blocks of Minerals** 70
    - Properties of Protons, Neutrons, & Electrons 70
    - Elements: Defined by Their Number of Protons 71
  - 3.3 **Why Atoms Bond** 72
    - The Octet Rule & Chemical Bonds 72
    - Ionic Bonds: Electrons Transferred 72
    - Covalent Bonds: Electron Sharing 73
    - Metallic Bonds: Electrons Free to Move 74
  - 3.4 **Properties of Minerals** 74
    - Optical Properties 74
    - Crystal Shape, or Habit 75
    - Mineral Strength 76
    - Density & Specific Gravity 78
    - Other Properties of Minerals 78
  - 3.5 **Mineral Groups** 79
    - Classifying Minerals 79
    - Silicate Versus Nonsilicate Minerals 79
  - 3.6 **The Silicates** 80
    - Silicate Structures 80
    - Joining Silicate Structures 81
  - 3.7 **Common Silicate Minerals** 82
    - The Light Silicates 82
    - The Dark Silicates 85
  - 3.8 **Important Nonsilicate Minerals** 86
  - 3.9 **Minerals: A Nonrenewable Resource** 88
    - Renewable Versus Nonrenewable Resources 88
    - Mineral Resources & Ore Deposits 88
- Concepts in Review** 91
- Give It Some Thought** 92

## 4 Igneous Rocks & Intrusive Activity 94

- 4.1 **Magma: Parent Material of Igneous Rock** 96
  - The Nature of Magma 96
  - From Magma to Crystalline Rock 97
  - Igneous Processes 97

- 4.2 **Igneous Compositions** 98
    - Compositional Categories 98
    - Silica Content as an Indicator of Composition 100
  - 4.3 **Igneous Textures: What Can They Tell Us?** 100
    - Types of Igneous Textures 100
  - 4.4 **Naming Igneous Rocks** 103
    - Felsic Igneous Rocks 105
    - Intermediate Igneous Rocks 106
    - Mafic Igneous Rocks 106
    - Pyroclastic Rocks 106
  - 4.5 **Origin of Magma** 108
    - Generating Magma from Solid Rock 108
  - 4.6 **How Magmas Evolve** 110
    - Bowen's Reaction Series & the Composition of Igneous Rocks 110
    - Magmatic Differentiation & Crystal Settling 111
    - Assimilation & Magma Mixing 111
  - 4.7 **Partial Melting & Magma Composition** 112
    - Formation of Basaltic Magma 113
    - Formation of Andesitic & Granitic Magmas 113
  - 4.8 **Intrusive Igneous Activity** 114
    - Nature of Intrusive Bodies 114
    - Tabular Intrusive Bodies: Dikes & Sills 115
    - Massive Intrusive Bodies: Batholiths, Stocks, & Laccoliths 116
  - 4.9 **Mineral Resources & Igneous Processes** 117
    - Magmatic Differentiation & Ore Deposits 118
    - Hydrothermal Deposits 119
    - Origin of Diamonds 120
- Concepts in Review** 120
- Give It Some Thought** 124



## 5 Volcanoes & Volcanic Hazards 126

- 5.1 **Mount St. Helens Versus Kilauea** 128
  - 5.2 **The Nature of Volcanic Eruptions** 129
    - Magma: Source Material for Volcanic Eruptions 129
    - Effusive Versus Explosive Eruptions 130
    - Effusive Hawaiian-Type Eruptions 131
    - How Explosive Eruptions Are Triggered 131
  - 5.3 **Materials Extruded During an Eruption** 133
    - Lava Flows 133
    - Gases 135
    - Pyroclastic Materials 135
  - 5.4 **Anatomy of a Volcano** 136
  - 5.5 **Shield Volcanoes** 137
    - Mauna Loa: Earth's Largest Shield Volcano 137
    - Kilauea: Hawaii's Most Active Volcano 138
  - 5.6 **Cinder Cones** 139
    - Parícutin: Life of a Garden-Variety Cinder Cone 140
  - 5.7 **Composite Volcanoes** 141
  - 5.8 **Volcanic Hazards** 142
    - Pyroclastic Flow: A Deadly Force of Nature 142
    - Lahars: Mudflows on Active & Inactive Cones 144
    - Other Volcanic Hazards 144
  - 5.9 **Other Volcanic Landforms** 146
    - Calderas 146
    - Fissure Eruptions & Basalt Plateaus 147
    - Lava Domes 149
    - Volcanic Necks 149
  - 5.10 **Plate Tectonics & Volcanism** 150
    - Volcanism at Divergent Plate Boundaries 151
    - Volcanism at Convergent Plate Boundaries 151
    - Intraplate Volcanism 154
- Concepts in Review** 156  
**Give It Some Thought** 158

## 6 Weathering & Soils 160

- 6.1 **Weathering** 162
  - 6.2 **Mechanical Weathering** 163
    - Frost Wedging 163
    - Salt Crystal Growth 163
    - Sheeting 164
    - Biological Activity 165
  - 6.3 **Chemical Weathering** 166
    - The Importance of Water 166
    - How Granite Weathers 167
    - Weathering of Silicate Minerals 167
    - Spheroidal Weathering 168
  - 6.4 **Rates of Weathering** 168
    - Rock Characteristics 168
    - Climate 169
    - Differential Weathering 169
  - 6.5 **Soil: An Indispensable Resource** 170
    - What Is Soil? 171
    - Controls of Soil Formation 171
  - 6.6 **Describing & Classifying Soils** 173
    - The Soil Profile 173
    - Classifying Soils 175
  - 6.7 **The Impact of Human Activities on Soil** 176
    - Clearing the Tropical Rain Forest: A Case Study of Human Impact on Soil 176
    - Soil Erosion: Losing a Vital Resource 177
  - 6.8 **Weathering & Ore Deposits** 180
    - Bauxite 180
    - Other Deposits 180
- Concepts in Review** 181  
**Give It Some Thought** 183



## 7 Sedimentary Rocks 184

- 7.1 **An Introduction to Sedimentary Rocks** 186
  - Importance 186
  - Origins 187
- 7.2 **Detrital Sedimentary Rocks** 188
  - Shale 189
  - Sandstone 190
  - Conglomerate & Breccia 192
- 7.3 **Chemical Sedimentary Rocks** 192
  - Limestone 193
  - Dolostone 195
  - Chert 195
  - Evaporites 196
- 7.4 **Coal: An Organic Sedimentary Rock** 197
- 7.5 **Turning Sediment into Sedimentary Rock: Diagenesis & Lithification** 198
  - Diagenesis 198
  - Lithification 198
- 7.6 **Classification of Sedimentary Rocks** 199
- 7.7 **Sedimentary Rocks Represent Past Environments** 200
  - Importance of Sedimentary Environments 201
  - Sedimentary Facies 201
  - Sedimentary Structures 201
- 7.8 **Resources from Sedimentary Rocks** 206
  - Nonmetallic Mineral Resources 206
  - Energy Resources 207
- 7.9 **The Carbon Cycle & Sedimentary Rocks** 210
  - Concepts in Review 211
  - Give It Some Thought 214

## 8 Metamorphism & Metamorphic Rocks 216

- 8.1 **What Is Metamorphism?** 218
- 8.2 **What Drives Metamorphism?** 219
  - Heat as a Metamorphic Agent 219
  - Confining Pressure 220
  - Differential Stress 220
  - Chemically Active Fluids 221
  - The Importance of Parent Rock 222
- 8.3 **Metamorphic Textures** 222
  - Foliation 222
  - Foliated Textures 224
  - Other Metamorphic Textures 225

- 8.4 **Common Metamorphic Rocks** 225
  - Foliated Metamorphic Rocks 226
  - Nonfoliated Metamorphic Rocks 227
- 8.5 **Metamorphic Environments** 228
  - Contact, or Thermal, Metamorphism 229
  - Hydrothermal Metamorphism 229
  - Burial & Subduction Zone Metamorphism 231
  - Regional Metamorphism 231
  - Other Metamorphic Environments 231
- 8.6 **Metamorphic Zones** 232
  - Textural Variations 232
  - Index Minerals & Metamorphic Grade 233
- Concepts in Review** 234
- Give It Some Thought** 236

## 9 Earthquakes & Earth's Interior 238

- 9.1 **What Is an Earthquake?** 240
  - Discovering the Causes of Earthquakes 240
  - Aftershocks & Foreshocks 242
  - Faults & Large Earthquakes 242
  - Fault Rupture & Propagation 243
- 9.2 **Seismology: The Study of Earthquake Waves** 244
  - Instruments That Record Earthquakes 244
  - Seismic Waves 244
- 9.3 **Locating the Source of an Earthquake** 246
- 9.4 **Determining the Size of an Earthquake** 248
  - Intensity Scales 248
  - Magnitude Scales 248
- 9.5 **Earthquake Destruction** 250
  - Destruction from Seismic Vibrations 251
  - Landslides & Ground Subsidence 252
  - Fire 252
  - Tsunamis 253
- 9.6 **Where Do Most Earthquakes Occur?** 255
  - Earthquakes Associated with Plate Boundaries 255
  - Damaging Earthquakes East of the Rockies 256
- 9.7 **Can Earthquakes Be Predicted?** 257
  - Short-Range Predictions 258
  - Long-Range Forecasts 259
- 9.8 **Earth's Interior** 261
  - Probing Earth's Interior: "Seeing" Seismic Waves 261
  - Earth's Layered Structure 261
- Concepts in Review** 263
- Give It Some Thought** 266

## 10 Origin & Evolution of the Ocean Floor 268

- 10.1 **An Emerging Picture of the Ocean Floor** 270
  - Mapping the Seafloor 270
  - Provinces of the Ocean Floor 274
- 10.2 **Continental Margins** 274
  - Passive Continental Margins 274
  - Active Continental Margins 275
- 10.3 **Features of Deep-Ocean Basins** 276
  - Deep-Ocean Trenches 276
  - Abyssal Plains 277
  - Volcanic Structures on the Ocean Floor 277
  - Explaining Coral Atolls—Darwin’s Hypothesis 278
- 10.4 **Anatomy of the Oceanic Ridge** 279
- 10.5 **Oceanic Ridges & Seafloor Spreading** 280
  - Seafloor Spreading 281
  - Why Are Oceanic Ridges Elevated? 281
  - Spreading Rates & Ridge Topography 281
- 10.6 **The Nature of Oceanic Crust** 282
  - How Does Oceanic Crust Form? 282
  - Interactions Between Seawater & Oceanic Crust 283
- 10.7 **Continental Rifting: The Birth of a New Ocean Basin** 284
  - Evolution of an Ocean Basin 284
  - Failed Rifts 286
- 10.8 **Destruction of Oceanic Lithosphere** 286
  - Why Oceanic Lithosphere Subducts 286
  - Subducting Plates: The Demise of Ocean Basins 287
- Concepts in Review** 289
- Give It Some Thought** 290

## 11 Crustal Deformation & Mountain Building 292

- 11.1 **Crustal Deformation** 294
  - What Causes Rocks to Deform? 294
  - Types of Deformation 296
  - Factors That Affect How Rocks Deform 296
- 11.2 **Folds: Rock Structures Formed by Ductile Deformation** 297
  - Anticlines & Synclines 298
  - Domes & Basins 299
  - Monoclines 300
- 11.3 **Faults & Joints: Rock Structures Formed by Brittle Deformation** 301
  - Dip-Slip Faults 301
  - Strike-Slip Faults 303
  - Joints 304

- 11.4 **Mountain Building** 306
- 11.5 **Subduction & Mountain Building** 307
  - Island Arc–Type Mountain Building 307
  - Andean-Type Mountain Building 307
  - Sierra Nevada, Coast Ranges, & Great Valley 308
- 11.6 **Collisional Mountain Belts** 309
  - Cordilleran-Type Mountain Building 309
  - Alpine-Type Mountain Building: Continental Collisions 310
  - The Himalayas 311
  - The Appalachians 312
- 11.7 **Vertical Motions of the Crust** 314
  - The Principle of Isostasy 314
  - How High Is Too High? 315
- Concepts in Review** 316
- Give It Some Thought** 318

## 12 Mass Movement on Slopes: The Work of Gravity 320

- 12.1 **The Importance of Mass Movement** 322
  - Landslides as Geologic Hazards 323
  - The Role of Mass Movement in Landscape Development 323
  - Slopes Change Through Time 324
- 12.2 **Controls & Triggers of Mass Movement** 324
  - The Role of Water 324
  - Oversteepened Slopes 324
  - Removal of Vegetation 326
  - Earthquakes as Triggers 327
  - The Potential for Landslides 328
- 12.3 **Classification of Mass Movement Processes** 328
  - Type of Material 328
  - Type of Motion 329
  - Rate of Movement 329
- 12.4 **Common Forms of Mass Movement: Rapid to Slow** 330
  - Rockslide & Debris Avalanche 331
  - Debris Flow 332
  - Earthflow 334
- 12.5 **Very Slow Mass Movements** 334
  - Creep 334
  - Solifluction 335
  - The Sensitive Permafrost Landscape 335
- Concepts in Review** 336
- Give It Some Thought** 338

**13** Running Water 340**13.1** Earth as a System: The Hydrologic Cycle 342

Earth's Water 342

Water's Paths 342

Storage in Glaciers 343

Water Balance 343

**13.2** Running Water 343

Drainage Basins 344

River Systems 345

Drainage Patterns 346

**13.3** Streamflow Characteristics 347

Factors Affecting Flow Velocity 347

Changes Downstream 349

**13.4** The Work of Running Water 350

Stream Erosion 350

Transport of Sediment by Streams 351

Deposition of Sediment by Streams 353

**13.5** Stream Channels 353

Bedrock Channels 353

Alluvial Channels 353

**13.6** Shaping Stream Valleys 355

Base Level &amp; Graded Streams 356

Valley Deepening 356

Valley Widening 357

Incised Meanders &amp; Stream Terraces 357

**13.7** Depositional Landforms 359

Deltas 359

The Mississippi River Delta 359

Natural Levees 360

Alluvial Fans 361

**13.8** Floods & Flood Control 362

Types of Floods 362

Flood Control 363

**Concepts in Review 364****Give It Some Thought 366****14** Groundwater 368**14.1** The Importance of Groundwater 370

Groundwater &amp; the Hydrosphere 370

Geologic Importance of Groundwater 370

Groundwater: A Basic Resource 371

**14.2** Groundwater & the Water Table 372

Distribution of Groundwater 372

Variations in the Water Table 372

Interactions Between Groundwater &amp; Streams 374

**14.3** Storage & Movement of Groundwater 374

Influential Factors 374

How Groundwater Moves 375

**14.4** Wells & Artesian Systems 377

Wells 377

Artesian Systems 378

**14.5** Springs, Geysers, & Geothermal Energy 379

Springs 379

Hot Springs 380

Geysers 380

Geothermal Energy 381

**14.6** Environmental Problems 383

Treating Groundwater as a Nonrenewable Resource 383

Land Subsidence Caused by Groundwater Withdrawal 384

Saltwater Contamination 384

Groundwater Contamination 385

**14.7** The Geologic Work of Groundwater 386

Caverns 387

Karst Topography 388

**Concepts in Review 390****Give It Some Thought 392**

**15** **Glaciers & Glaciation** 394

- 15.1 **Glaciers: A Part of Two Basic Cycles** 396  
 Valley (Alpine) Glaciers 396  
 Ice Sheets 396  
 Other Types of Glaciers 398
- 15.2 **Formation & Movement of Glacial Ice** 399  
 Glacial Ice Formation 399  
 How Glaciers Move 399  
 Observing & Measuring Movement 400  
 Budget of a Glacier: Accumulation Versus Wastage 401
- 15.3 **Glacial Erosion** 402  
 How Glaciers Erode 403  
 Landforms Created by Glacial Erosion 404
- 15.4 **Glacial Deposits** 407  
 Glacial Drift 407  
 Moraines, Outwash Plains, & Kettles 408  
 Drumlins, Eskers, & Kames 410
- 15.5 **Other Effects of Ice Age Glaciers** 411  
 Crustal Subsidence & Rebound 411  
 Sea-Level Changes 411  
 Changes to Rivers & Valleys 412  
 Ice Dams Create Proglacial Lakes 412  
 Pluvial Lakes 413
- 15.6 **The Ice Age** 414  
 Historical Development of the Glacial Theory 414  
 Causes of Ice Ages 415  
**Concepts in Review** 418  
**Give It Some Thought** 420

**16** **Deserts & Wind** 422

- 16.1 **Distribution & Causes of Dry Lands** 424  
 What Is Meant by *Dry*? 424  
 Subtropical Deserts & Steppes 424  
 Middle-Latitude Deserts & Steppes 425
- 16.2 **Geologic Processes in Arid Climates** 426  
 Dry-Region Weathering 426  
 The Role of Water 427
- 16.3 **Basin & Range: The Evolution of a Desert Landscape** 428
- 16.4 **Wind Erosion** 430  
 Transportation of Sediment by Wind 430  
 Erosional Features 430
- 16.5 **Wind Deposits** 433  
 Sand Deposits 433  
 Types of Sand Dunes 434  
 Loess (Silt) Deposits 435  
**Concepts in Review** 436  
**Give It Some Thought** 438

**17** **Shorelines** 440

- 17.1 **The Shoreline & Ocean Waves** 442  
 A Dynamic Interface 442  
 Ocean Waves 442  
 Wave Characteristics 443  
 Circular Orbital Motion 443  
 Waves in the Surf Zone 444
- 17.2 **Beaches & Shoreline Processes** 445  
 Wave Erosion 446  
 Sand Movement on the Beach 446
- 17.3 **Shoreline Features** 449  
 Erosional Features 449  
 Depositional Features 449  
 The Evolving Shore 451
- 17.4 **Contrasting America's Coasts** 452  
 Coastal Classification 452  
 Atlantic & Gulf Coasts 453  
 Pacific Coast 454
- 17.5 **Hurricanes: The Ultimate Coastal Hazard** 455  
 Profile of a Hurricane 455  
 Hurricane Destruction 456
- 17.6 **Stabilizing the Shore** 459  
 Hard Stabilization 459  
 Alternatives to Hard Stabilization 461
- 17.7 **Tides** 462  
 Causes of Tides 462  
 Monthly Tidal Cycle 463  
 Tidal Currents 463  
**Concepts in Review** 464  
**Give It Some Thought** 466



**18 Geologic Time 468****18.1 Creating a Time Scale: Relative Dating Principles 470**

- The Importance of a Time Scale **470**
- Numerical & Relative Dates **471**
- Principle of Superposition **471**
- Principle of Original Horizontality **471**
- Principle of Lateral Continuity **472**
- Principle of Cross-Cutting Relationships **472**
- Principle of Inclusions **472**
- Unconformities **473**
- Applying Relative Dating Principles **475**

**18.2 Fossils: Evidence of Past Life 476**

- Types of Fossils **476**
- Conditions Favoring Preservation **478**

**18.3 Correlation of Rock Layers 478**

- Correlation Within Limited Areas **478**
- Fossils & Correlation **478**

**18.4 Numerical Dating with Nuclear Decay 481**

- Reviewing Basic Atomic Structure **481**
- Changes to Atomic Nuclei **481**
- Radiometric Dating **482**
- Half-Life **482**
- Using Unstable Isotopes **483**
- Dating with Carbon-14 **483**

**18.5 Determining Numerical Dates for Sedimentary Strata 484****18.6 The Geologic Time Scale 485**

- Structure of the Time Scale **485**
- Precambrian Time **486**
- Terminology & the Geologic Time Scale **487**

**Concepts in Review 488****Give It Some Thought 489****19 Earth's Evolution Through Geologic Time 492****19.1 Is Earth Unique? 494**

- The Right Planet **494**
- The Right Location **495**
- The Right Time **495**
- Viewing Earth's History **495**

**19.2 Birth of a Planet 497**

- From the Big Bang to Heavy Elements **497**
- From Planetesimals to Protoplanets **497**
- Earth's Early Evolution **497**

**19.3 Origin and Evolution of the Atmosphere and Oceans 499**

- Earth's Primitive Atmosphere **499**
- Oxygen in the Atmosphere **500**
- Evolution of the Oceans **500**

**19.4 Precambrian History: The Formation of Earth's Continents 502**

- Earth's First Continents **502**
- The Making of North America **504**
- Supercontinents of the Precambrian **505**

**19.5 Geologic History of the Phanerozoic: The Formation of Earth's Modern Continents 506**

- Paleozoic History **506**
- Mesozoic History **507**
- Cenozoic History **508**

**19.6 Earth's First Life 510**

- Origin of Life **510**
- Earth's First Life: Prokaryotes **510**

**19.7 Paleozoic Era: Life Explodes 513**

- Early Paleozoic Life-Forms **513**
- Vertebrates Move to Land **514**
- Reptiles: The First True Terrestrial Vertebrates **514**
- The Great Permian Extinction **516**

**19.8 Mesozoic Era: Dinosaurs Dominant 516**

- Gymnosperms: The Dominant Mesozoic Trees **516**
- Reptiles Take Over the Land, Sea, and Sky **516**
- Demise of the Dinosaurs **517**

**19.9 Cenozoic Era: Mammals Diversify 519**

- From Dinosaurs to Mammals **519**
- Marsupial and Placental Mammals **520**
- Humans: Mammals with Large Brains and Bipedal Locomotion **520**
- Large Mammals and Extinction **521**

**Concepts in Review 522****Give It Some Thought 524**

**20 Global Climate Change 526****20.1 Climate & Geology 528**The Climate System **528**Climate–Geology Connections **528****20.2 Detecting Climate Change 529**Climates Change **529**Proxy Data **530**Seafloor Sediment: A Storehouse of Climate Data **530**Oxygen Isotope Analysis **531**Climate Change Recorded in Glacial Ice **531**Tree Rings: Archives of Environmental History **532**Other Types of Proxy Data **532****20.3 Some Atmospheric Basics 533**Composition of the Atmosphere **533**Extent & Structure of the Atmosphere **534****20.4 Heating the Atmosphere 536**Energy from the Sun **536**The Paths of Incoming Solar Energy **537**Heating the Atmosphere: The Greenhouse Effect **538****20.5 Natural Causes of Climate Change 539**Plate Movements & Orbital Variations **539**Volcanic Activity & Climate Change **539**Solar Variability & Climate **541****20.6 Human Impact on Global Climate 542**Rising CO<sub>2</sub> Levels **542**The Atmosphere's Response **544**The Role of Trace Gases **544**How Aerosols Influence Climate **546****20.7 Climate Feedback Mechanisms 547**Types of Feedback Mechanisms **547**Computer Models of Climate: Important yet Imperfect Tools **547****20.8 Some Consequences of Global Warming 548**Sea-Level Rise **548**The Changing Arctic **550**Increasing Ocean Acidity **551**The Potential for Surprises **552****Concepts in Review 552****Give It Some Thought 555****APPENDIX**Metric and English Units Compared **556****GLOSSARY 557****INDEX 568**

Use your mobile device to scan a SmartFigure identified by a Quick Response (QR) code, and a video or animation illustrating the SmartFigure's concept launches immediately. No slow websites or hard-to-remember logins required. These mobile media transform textbooks into convenient digital platforms, breathe life into your learning experience, and help you grasp difficult geology concepts.

## CONDOR VIDEO

<https://goo.gl/dPwXf4>



## Chapter 1

- 1.5 **MOBILE FIELD TRIP:** A geologist's Grand Canyon (p. 7)
- 1.7 **TUTORIAL:** Magnitude of geologic time (p. 9)
- 1.10 **VIDEO:** Two classic views of Earth from space (p. 12)
- 1.18 **TUTORIAL:** Nebular theory (p. 17)
- 1.20 **TUTORIAL:** Earth's layers (p. 20)
- 1.23 **TUTORIAL:** The rock cycle (p. 23)
- 1.25 **TUTORIAL:** The continents (p. 27)

## Chapter 2

- 2.2 **TUTORIAL:** Reconstructions of Pangaea (p. 35)
- 2.9 **TUTORIAL:** The rigid lithosphere overlies the weak asthenosphere (p. 40)
- 2.12 **MOBILE FIELD TRIP:** Fire and ice land (p. 42)
- 2.13 **TUTORIAL:** Continental rifting: Formation of new ocean basins (p. 43)
- 2.14 **CONDOR VIDEO:** Continental rifting (p. 44)
- 2.15 **TUTORIAL:** Three types of convergent plate boundaries (p. 45)
- 2.18 **ANIMATION:** The collision of India and Eurasia formed the Himalayas (p. 47)
- 2.19 **TUTORIAL:** Transform plate boundaries (p. 48)
- 2.21 **MOBILE FIELD TRIP:** The San Andreas Fault (p. 50)
- 2.29 **TUTORIAL:** Time scale of magnetic reversals (p. 56)
- 2.31 **ANIMATION:** Magnetic reversals and seafloor spreading (p. 57)

## Chapter 3

- 3.3 **TUTORIAL:** Most rocks are aggregates of minerals (p. 69)
- 3.12 **TUTORIAL:** Color variations in minerals (p. 75)
- 3.13 **VIDEO:** Streak (p. 75)
- 3.15 **TUTORIAL:** Some common crystal habits (p. 76)
- 3.16 **TUTORIAL:** Hardness scales (p. 76)
- 3.17 **ANIMATION:** Micas exhibit perfect cleavage (p. 77)
- 3.18 **TUTORIAL:** Cleavage directions exhibited by minerals (p. 77)
- 3.21 **VIDEO:** Calcite reacting with a weak acid (p. 79)
- 3.24 **TUTORIAL:** Five basic silicate structures (p. 81)

## Chapter 4

- 4.3 **TUTORIAL:** Intrusive versus extrusive igneous rocks (p. 97)
- 4.5 **TUTORIAL:** Mineral makeup of common igneous rocks (p. 99)
- 4.7 **TUTORIAL:** Igneous rock textures (p. 101)
- 4.12 **TUTORIAL:** Classification of igneous rocks (p. 104)
- 4.13 **MOBILE FIELD TRIP:** Yosemite: Granite and glaciers (p. 105)
- 4.24 **TUTORIAL:** Partial melting (p. 113)
- 4.25 **ANIMATION:** Formation of granitic magma (p. 113)
- 4.26 **ANIMATION:** Intrusive igneous structures (p. 114)
- 4.27 **MOBILE FIELD TRIP:** Dikes and sills of the Sinbad country (p. 115)
- 4.28 **CONDOR VIDEO:** Intrusive igneous bodies (p. 115)
- 4.33 **TUTORIAL:** Pegmatites and hydrothermal deposits (p. 119)

## Chapter 5

- 5.5 **VIDEO:** Eruption column generated by viscous, silica-rich magma (p. 132)
- 5.11 **TUTORIAL:** Anatomy of a volcano (p. 137)
- 5.13 **ANIMATION:** Comparing scales of different volcanoes (p. 138)
- 5.14 **MOBILE FIELD TRIP:** Kilauea volcano (p. 139)
- 5.15 **MOBILE FIELD TRIP:** S. P. Crater (p. 139)
- 5.16 **CONDOR VIDEO:** Cinder cones and basaltic lava flows (p. 140)
- 5.23 **ANIMATION:** Formation of Crater Lake-type calderas (p. 146)
- 5.24 **TUTORIAL:** Super-eruptions at Yellowstone (p. 147)
- 5.28 **TUTORIAL:** Volcanic neck (p. 150)
- 5.30 **TUTORIAL:** Earth's zones of volcanism (p. 152)
- 5.31 **TUTORIAL:** Subduction-produced Cascade Range volcanoes (p. 154)
- 5.32 **TUTORIAL:** Global distribution of large basalt provinces. (p. 154)

## Chapter 6

- 6.1 **ANIMATION:** Arches National Park (p. 162)
- 6.2 **TUTORIAL:** Mechanical weathering increases surface area (p. 163)
- 6.4 **TUTORIAL:** Ice breaks rock (p. 164)
- 6.5 **TUTORIAL:** Unloading leads to sheeting (p. 164)
- 6.10 **TUTORIAL:** The formation of rounded boulders (p. 168)
- 6.11 **TUTORIAL:** Rock type influences weathering (p. 169)
- 6.13 **MOBILE FIELD TRIP:** Bisti Badlands (p. 170)
- 6.17 **TUTORIAL:** Soil horizons (p. 174)

## Chapter 7

- 7.2 **TUTORIAL:** The big picture (p. 187)
- 7.7 **TUTORIAL:** Sorting and particle shape (p. 191)
- 7.17 **TUTORIAL:** Bonneville salt flats (p. 196)
- 7.18 **TUTORIAL:** From plants to coal (p. 197)
- 7.22 **MOBILE FIELD TRIP:** The sedimentary rocks of Capitol Reef National Park (p. 200)
- 7.24 **TUTORIAL:** Lateral change (p. 204)
- 7.30 **TUTORIAL:** U.S. energy consumption, 2014 (p. 207)
- 7.32 **TUTORIAL:** Common oil traps (p. 209)

## Chapter 8

- 8.3 **TUTORIAL:** Sources of heat for metamorphism (p. 220)
- 8.4 **TUTORIAL:** Confining pressure and differential stress (p. 221)
- 8.7 **ANIMATION:** Mechanical rotation of platy mineral grains to produce foliation (p. 223)
- 8.10 **TUTORIAL:** Development of rock cleavage (p. 224)
- 8.19 **TUTORIAL:** Contact metamorphism (p. 229)
- 8.25 **TUTORIAL:** Metamorphism along a fault zone (p. 232)
- 8.26 **TUTORIAL:** Textural variations caused by regional metamorphism (p. 233)
- 8.29 **TUTORIAL:** Garnet, an index mineral, provides evidence of medium- to high-grade metamorphism (p. 234)

## Chapter 9

- 9.4 **TUTORIAL:** Elastic rebound (p. 242)
- 9.8 **ANIMATION:** Principle of the seismograph (p. 244)
- 9.9 **TUTORIAL:** Body waves (P and S waves) versus surface waves (p. 245)
- 9.11 **ANIMATION:** Two types of surface waves (p. 246)
- 9.16 **TUTORIAL:** USGS Community Internet Intensity Map (p. 249)
- 9.25 **TUTORIAL:** Turnagain Heights slide caused by the 1964 Alaska earthquake (p. 253)
- 9.26 **TUTORIAL:** How a tsunami is generated by displacement of the ocean floor during an earthquake (p. 254)
- 9.27 **ANIMATION:** Tsunami generated off the coast of Sumatra, 2004 (p. 254)

## Chapter 10

- 10.1 **TUTORIAL:** HMS *Challenger* (p. 270)
- 10.8 **TUTORIAL:** Passive continental margins (p. 275)
- 10.16 **TUTORIAL:** Rift valleys (p. 280)
- 10.21 **TUTORIAL:** East African Rift Valley (p. 284)
- 10.22 **ANIMATION:** Formation of an ocean basin (p. 285)
- 10.25 **TUTORIAL:** The demise of the Farallon plate (p. 288)

## Chapter 11

- 11.1 **TUTORIAL:** Deformed sedimentary strata (p. 294)
- 11.6 **CONDOR VIDEO:** Anticlines and synclines (p. 298)
- 11.7 **TUTORIAL:** Common types of folds (p. 298)
- 11.8 **MOBILE FIELD TRIP:** Sheep Mountain anticline (p. 299)
- 11.9 **TUTORIAL:** Domes versus basins (p. 299)
- 11.12 **CONDOR VIDEO:** Monoclines of the Colorado Plateau (p. 301)
- 11.13 **CONDOR VIDEO:** Faults versus joints (p. 301)
- 11.14 **ANIMATION:** Hanging wall block and footwall block (p. 301)
- 11.16 **TUTORIAL:** Normal dip-slip fault (p. 302)
- 11.17 **MOBILE FIELD TRIP:** Death Valley (p. 303)
- 11.18 **ANIMATION:** Reverse faults (p. 303)
- 11.19 **ANIMATION:** Thrust fault (p. 304)
- 11.27 **TUTORIAL:** Collision and accretion of small crustal fragments to a continental margin (p. 310)
- 11.28 **ANIMATION:** Terranes that have been added to western North America during the past 200 million years (p. 310)
- 11.29 **ANIMATION:** Continental collision: The formation of the Himalayas (p. 311)
- 11.30 **TUTORIAL:** India's continued northward migration severely deformed much of China and Southeast Asia (p. 312)
- 11.31 **TUTORIAL:** Formation of the Appalachian Mountains (p. 313)
- 11.32 **MOBILE FIELD TRIP:** The folded rocks of Massanutten Mountain (p. 314)
- 11.33 **ANIMATION:** The principle of isostasy (p. 315)
- 11.34 **TUTORIAL:** The effects of isostatic adjustment and erosion on mountainous topography (p. 315)

## Chapter 12

- 12.1 **MOBILE FIELD TRIP:** Landslide! (p. 322)
- 12.2 **TUTORIAL:** Excavating the Grand Canyon (p. 323)
- 12.10 **ANIMATION:** Watch out for falling rock! (p. 329)
- 12.15 **TUTORIAL:** Gros Ventre rockslide (p. 332)
- 12.19 **TUTORIAL:** Creep (p. 335)
- 12.21 **TUTORIAL:** When permafrost thaws (p. 336)

## Chapter 13

- 13.2 **TUTORIAL:** The hydrologic cycle (p. 343)
- 13.4 **TUTORIAL:** Mississippi River drainage basin (p. 344)
- 13.5 **TUTORIAL:** Headward erosion (p. 345)

- 13.7 **MOBILE FIELD TRIP:** Drainage patterns (p. 346)
- 13.10 **MOBILE FIELD TRIP:** The Mississippi River (p. 348)
- 13.13 **TUTORIAL:** Channel changes from head to mouth (p. 350)
- 13.15 **ANIMATION:** Transport of sediment (p. 351)
- 13.18 **TUTORIAL:** Formation of cut banks and point bars (p. 354)
- 13.19 **ANIMATION:** Formation of an oxbow lake (p. 355)
- 13.24 **CONDOR VIDEO:** Meandering rivers (p. 357)
- 13.25 **TUTORIAL:** Incised meanders (p. 358)
- 13.26 **CONDOR VIDEO:** River terraces and base level (p. 358)
- 13.29 **MOBILE FIELD TRIP:** Mississippi River delta (p. 360)
- 13.30 **ANIMATION:** Formation of a natural levee (p. 361)
- 13.33 **TUTORIAL:** Dams have multiple functions (p. 364)

## Chapter 14

- 14.4 **TUTORIAL:** Water beneath Earth's surface (p. 372)
- 14.11 **TUTORIAL:** Hypothetical groundwater flow system (p. 376)
- 14.12 **ANIMATION:** Cone of depression (p. 377)
- 14.14 **TUTORIAL:** Artesian systems (p. 378)
- 14.19 **TUTORIAL:** How a geyser works (p. 381)
- 14.29 **MOBILE FIELD TRIP:** A Mammoth Cave (p. 387)

## Chapter 15

- 15.2 **VIDEO:** Ice sheets (p. 397)
- 15.4 **MOBILE FIELD TRIP:** Fire and ice land (p. 398)
- 15.6 **TUTORIAL:** Movement of a glacier (p. 400)
- 15.9 **TUTORIAL:** Zones of a glacier (p. 401)
- 15.14 **MOBILE FIELD TRIP:** Erosional glacial landforms (p. 404)
- 15.15 **ANIMATION:** A U-shaped glacial trough (p. 405)
- 15.21 **MOBILE FIELD TRIP:** The glaciers of Alaska (p. 408)
- 15.24 **TUTORIAL:** Common depositional landforms (p. 410)
- 15.25 **ANIMATION:** Changing sea level (p. 411)
- 15.33 **TUTORIAL:** Orbital variations (p. 417)

## Chapter 16

- 16.1 **TUTORIAL:** Dry climates (p. 425)
- 16.2 **ANIMATION:** Subtropical deserts (p. 425)
- 16.3 **ANIMATION:** Rainshadow deserts (p. 426)
- 16.7 **TUTORIAL:** Landscape evolution in the Basin and Range region (p. 429)
- 16.8 **CONDOR VIDEO:** Characteristics of alluvial fans (p. 429)
- 16.9 **ANIMATION:** Transporting sand (p. 430)
- 16.10 **VIDEO:** Wind's suspended load (p. 431)
- 16.13 **TUTORIAL:** Formation of desert pavement (p. 432)
- 16.15 **MOBILE FIELD TRIP:** The dunes of White Sands National Monument (p. 433)
- 16.16 **TUTORIAL:** Cross-bedding (p. 434)
- 16.17 **TUTORIAL:** Types of sand dunes (p. 435)

## Chapter 17

- 17.3 **ANIMATION:** Wave basics (p. 443)
- 17.4 **TUTORIAL:** Passage of a wave (p. 444)
- 17.5 **ANIMATION:** Waves approaching the shore (p. 444)
- 17.9 **TUTORIAL:** Wave refraction (p. 447)
- 17.10 **TUTORIAL:** The longshore transport system (p. 448)
- 17.14 **MOBILE FIELD TRIP:** A trip to Cape Cod (p. 450)
- 17.17 **TUTORIAL:** East coast estuaries (p. 452)
- 17.23 **TUTORIAL:** Hurricane source regions and paths (p. 456)
- 17.24 **VIDEO:** Cross section of a hurricane (p. 457)
- 17.34 **ANIMATION:** Spring and neap tides (p. 463)

## Chapter 18

- 18.5 **VIDEO:** Cross-cutting fault (p. 472)
- 18.7 **TUTORIAL:** Inclusions (p. 473)
- 18.8 **TUTORIAL:** Formation of an angular unconformity (p. 473)
- 18.13 **TUTORIAL:** Applying principles of relative dating (p. 476)
- 18.18 **TUTORIAL:** Fossil assemblage (p. 480)
- 18.21 **TUTORIAL:** Changing parent/daughter ratios (p. 482)

## Chapter 19

- 19.4 **TUTORIAL:** Major events that led to the formation of early Earth (p. 498)
- 19.10 **TUTORIAL:** The formation of continents (p. 503)
- 19.12 **TUTORIAL:** The major geologic provinces of North America (p. 504)
- 19.15 **TUTORIAL:** Connection between ocean circulation and the climate in Antarctica (p. 506)
- 19.17 **TUTORIAL:** Major provinces of the Appalachian Mountains (p. 508)
- 19.28 **TUTORIAL:** Relationships of vertebrate groups and their divergence from lobefin fish (p. 515)

## Chapter 20

- 20.1 **VIDEO:** Earth's climate system (p. 529)
- 20.5 **TUTORIAL:** Ice cores: Important sources of climate data (p. 531)
- 20.9 **TUTORIAL:** Composition of the atmosphere (p. 534)
- 20.10 **VIDEO:** Aerosols (p. 534)
- 20.14 **VIDEO:** The electromagnetic spectrum (p. 537)
- 20.15 **TUTORIAL:** Paths taken by solar radiation (p. 537)
- 20.17 **TUTORIAL:** The greenhouse effect (p. 538)
- 20.20 **VIDEO:** Sunspots (p. 541)
- 20.23 **TUTORIAL:** Monthly concentrations (p. 543)
- 20.26 **VIDEO:** Global temperatures (p. 544)
- 20.27 **VIDEO:** Temperature projections to 2100 (p. 545)
- 20.30 **VIDEO:** Sea ice as a feedback mechanism (p. 547)
- 20.32 **VIDEO:** Changing sea level (p. 549)
- 20.33 **TUTORIAL:** Slope of the shoreline (p. 550)
- 20.34 **VIDEO:** Climate change spurs plant growth beyond 45° north (p. 550)
- 20.35 **VIDEO:** Tracking sea ice changes (p. 551)

# PREFACE

The thirteenth edition of *Essentials of Geology*, like its predecessors, is a college-level text that is intended to be a meaningful, nontechnical survey for students taking their first course in geology. In addition to being informative and up-to-date, a major goal of this book is to meet the need of students for a readable and user-friendly text that is a valuable tool for learning the basic principles and concepts of geology.

Although many topical issues are treated in the 13th edition of *Essentials*, it should be emphasized that the main focus of this new edition remains the same as the focus of each of its predecessors: to promote student understanding of basic principles. As much as possible, we have attempted to provide the reader with a sense of the observational techniques and reasoning processes that constitute the science of geology.

## New & Important Features

This 13th edition is an extensive and thorough revision of *Essentials of Geology* that integrates improved textbook resources with new online features to enhance the learning experience:

- **Significant updating and revision of content.** A basic function of a college science textbook is to provide clear, understandable presentations that are accurate, engaging, and up-to-date. In the long history of this textbook, our number-one goal has always been to keep *Essentials of Geology* current, relevant, and highly readable for beginning students. With this goal as a priority, every part of this text has been examined carefully. The following are a few examples. In Chapter 9, the text and figures for Section 9.3, “Locating the Source of an Earthquake,” are substantially revised, and a discussion of the USGS Community Internet Intensity Map project is added. In Chapter 11, the treatment of stress, strain, and rock deformation are substantially revised, as is the final section on isostatic balance. In Chapter 12, the mechanism responsible for long-runout landslides is updated, with reference to the occurrence of such landslides on Mars, and the 2015 Nepal earthquake is used as a landslide-triggering event. In Chapter 13, a section on the loss of wetlands in coastal Louisiana is added, and the treatment of flood control is updated and tightened. Many discussions, case studies, examples, and illustrations have been updated and revised.
- **SmartFigures make this 13th edition much more than a traditional textbook.** Through its many editions, an important strength of *Essentials* has always been clear, logically organized, and well-illustrated explanations. Now complementing and reinforcing this strength are a series of SmartFigures. Simply by scanning the Quick Response (QR) code next to a SmartFigure with a mobile device, students can link to hundreds of unique and innovative digital learning opportunities that will increase their understanding of important ideas. Each SmartFigure also displays a short URL for students who may lack a smartphone. SmartFigures are truly media that teach! The more than 200 SmartFigures in the 13th edition of *Essentials of Geology* are of five types:

1. **SmartFigure Tutorials.** Each of these 2- to 4-minute tutorials, prepared and narrated by Professor Callan Bentley, is a mini-lesson that examines and explains the concepts illustrated by the figure.
  2. **SmartFigure Mobile Field Trips.** Scattered throughout this new edition are 24 video field trips that explore classic geologic sites from Iceland to Hawaii. On each trip you will accompany geologist/pilot/photographer Michael Collier in the air and on the ground to see and learn about landscapes that relate to discussions in the chapter.
  3. **SmartFigures Condor.** The 10 *Project Condor* videos take you to sites in the American Mountain West. By coupling videos acquired by a quadcopter aircraft with ground-level views, effective narrative, and helpful animations, these videos will engage you in real-life case studies.
  4. **SmartFigure Animations.** These animations bring the art to life, illustrating and explaining difficult-to-visualize topics more effectively than static art alone.
  5. **SmartFigure Videos.** Rather than providing a single image to illustrate an idea, these figures include short video clips that help illustrate such diverse subjects as mineral properties and the structure of ice sheets.
- **Objective-driven active learning path.** Each chapter in this 13th edition begins with *Focus on Concepts*: a set of learning objectives that correspond to the chapter's major sections. By identifying key knowledge and skills, these objectives help students prioritize the material. Each major section concludes with *Concept Checks* so that students can check their learning. Two end-of-chapter features complete the learning path. *Concepts in Review* is coordinated with the *Focus on Concepts* at the beginning of the chapter and with the numbered sections within the chapter. It is a readable and concise overview of key ideas, with photos, diagrams, and questions. Finally, the questions and problems in *Give It Some Thought* challenge learners by requiring higher-order thinking skills to analyze, synthesize, and apply the material.
  - **An unparalleled visual program.** In addition to more than 100 new high-quality photos and satellite images, dozens of figures are new or have been redrawn by the gifted and highly respected geoscience illustrator Dennis Tasa. Maps and diagrams are frequently paired with photographs for greater effectiveness. Further, many new and revised figures have additional labels that narrate the process being illustrated and guide students as they examine the figures, resulting in a visual program that is clear and easy to understand.

## Digital & Print Resources

### MasteringGeology™

MasteringGeology® is the most effective and powerful online tutorial, homework, and assessment system available, proven to improve results by helping students master concepts quickly. Interactive,

self-paced coaching activities provide individualized coaching to help students stay on track. With a wide range of activities available, students learn actively and master challenging course concepts. See the MasteringGeology visual walkthrough section for more in-depth details.

Upon textbook purchase, students and teachers are granted access to MasteringGeology. High school teachers can obtain preview or adoption access to MasteringGeology in one of the following ways:

- **Preview Access:** Teachers can request preview access online by visiting [www.PearsonSchool.com/Access\\_Request](http://www.PearsonSchool.com/Access_Request). Select Science, choose Initial Access, and complete the form under Option 2. Preview Access information will be sent to the teacher via e-mail.
- **Adoption Access:** With the purchase of this program, a Pearson Adoption Access Card with Instructor Manual will be delivered with your textbook purchase. (ISBN: 978-0-13-353986-8)
- Ask your sales representative for a Pearson Adoption Access Card with Instructor Manual. (ISBN: 978-0-13-353986-8)  
OR
- Visit [PearsonSchool.com/Access\\_Request](http://PearsonSchool.com/Access_Request), select Science, choose initial Access, and complete the form under Option 3—MyLab/Mastering Class Adoption Access. Adoption access information will be sent to the teacher via e-mail.

#### Students, ask your teacher for access.

Pearson reserves the right to change and/or update technology platforms, including possible edition updates to customers during the term of access. This will allow Pearson to continue to deliver the most up-to-date content and technology to customers. Customer will be notified of any change prior to the beginning of the new school year.

## For Instructors

*Essentials of Geology, 13th Edition*, provides an integrated teaching and learning package of support material for students and instructors.

Most of the teacher supplements and resources for this text are available electronically to qualified adopters within Mastering and on the Instructor Resource Center (IRC). Upon adoption or to preview, please go to [www.pearsonschool.com/access\\_request](http://www.pearsonschool.com/access_request) and select Instructor Resource Center. You will be required to complete a brief one-time registration subject to verification of educator status. Upon verification, access information and instructions will be sent to you via email. Once logged into the IRC, enter ISBN 0-13-466349-7 in the “Search our Catalog” box to locate resources. Electronic teacher supplements are also available within the Instructor’s tab of MasteringGeology.

#### Instructor Resource Center (Download Only)

The IRC puts all of your lecture resources in one easy-to-reach place:

- The IRC provides all the line art, tables, and photos from the text in JPEG files.
- PowerPoint™ Presentations: Found in the IRC are three PowerPoint files for each chapter. Cut down on your preparation time, no matter

what your lecture needs, by taking advantage of these components of the PowerPoint files:

- **Exclusive art.** All the photos, art, and tables from the text, in order, have been loaded into PowerPoint slides.
- **Lecture outline.** This set averages 50 slides per chapter and includes customizable lecture outlines with supporting art.
- **Classroom Response System (CRS) questions.** Authored for use in conjunction with classroom response systems, these PowerPoint files allow you to electronically poll your class for responses to questions, pop quizzes, attendance, and more.
- The IRC provides Word and PDF versions of the *Instructor Resource Manual*.

#### Instructor Resource Manual (Download Only)

The *Instructor Resource Manual* has been designed to help seasoned and new instructors alike, offering the following sections in each chapter: an introduction to the chapter, outline, learning objectives/focus on concepts; teaching strategies; teacher resources; and answers to *Concept Checks* and *Give It Some Thought* questions from the textbook. [www.pearsonhighered.com/irc](http://www.pearsonhighered.com/irc)

#### TestGen Computerized Test Bank (Download Only)

TestGen is a computerized test generator that lets instructors view and edit Test Bank questions, transfer questions to tests, and print the test in a variety of customized formats. This Test Bank includes more than 2,000 multiple-choice, matching, and essay questions. Questions are correlated to Bloom's Taxonomy, each chapter's learning objectives, the Earth Science Learning Objectives, and the Pearson Science Global Outcomes to help instructors better map the assessments against both broad and specific teaching and learning objectives. The Test Bank is also available in Microsoft Word and can be imported into Blackboard, [www.pearsonhighered.com/irc](http://www.pearsonhighered.com/irc)

## For Students

*The following resources are available for purchase.*

**Laboratory Manual in Physical Geology, 11th Edition** by the American Geological Institute and the National Association of Geoscience Teachers, edited by Vincent Cronin, illustrated by Dennis G. Tasa (0134446607)

This user-friendly, best-selling lab manual examines the basic processes of geology and their applications to everyday life. Featuring contributions from more than 170 highly regarded geologists and geoscience educators, along with an exceptional illustration program by Dennis Tasa, *Laboratory Manual in Physical Geology*, 11th edition, offers an inquiry- and activities-based approach that builds skills and gives students a more complete learning experience in the lab. Pre-lab videos linked from the print labs introduce students to the content, materials, and techniques they will use each lab. These teaching videos help TAs prepare for lab setup and learn new teaching skills. The lab manual is available in MasteringGeology with Pearson eText, allowing teachers to use activity-based exercises to build students’ lab skills.

**Dire Predictions: Understanding Global Climate Change, 2nd Edition** by Michael Mann, Lee R. Kump (0133909778)

Periodic reports from the Intergovernmental Panel on Climate Change (IPCC) evaluate the risk of climate change brought on by humans. But the sheer volume of scientific data remains inscrutable to the general public, particularly to those who may still question the validity of climate change. In just over 200 pages, this practical text presents and expands upon the latest climate change data and scientific consensus of the IPCC's *Fifth Assessment Report* in a visually stunning and undeniably powerful way to the lay reader. Scientific findings that provide validity to the implications of climate change are presented in clear-cut graphic elements, striking images, and understandable analogies. The second edition integrates mobile media links to online media. The text is also available in various eText formats, including an eText upgrade option from MasteringGeology courses.

## Acknowledgments

Writing a college textbook requires the talents and cooperation of many people. It is truly a team effort, and the authors are fortunate to be part of an extraordinary team at Pearson Education. In addition to being great people to work with, all of them are committed to producing the best textbooks possible. Special thanks to our geology editor, Christian Botting. We appreciate his enthusiasm, hard work, and quest for excellence. We also appreciate our conscientious project manager, Lizette Faraji, whose job it was to keep track of all that was going on—and a lot was going on. As always, our marketing managers, Neena Bali and Mary Salzman, who talk with faculty daily, provide us with helpful advice and many good ideas. The 13th edition of *Essentials of Geology* was certainly improved by the talents of our developmental editor, Margot Otway. Our sincere thanks to Margot for her fine work. It was the job of the production team, led by Patty Donovan at SPi Global, to turn our manuscript into a finished product. The team also included copyeditor Kitty Wilson, proofreader Erika Jordan, and photo researcher Kristin Piljay. We think these talented people did great work. All are true professionals, with whom we are very fortunate to be associated.

The authors owe special thanks to four people who were very important contributors to this project:

- **Dennis Tasa.** Working with Dennis Tasa, who is responsible for all of the text's outstanding illustrations and several of its animations, is always special for us. He has been part of our team for more than 30 years. We value not only his artistic talents, hard work, patience, and imagination but his friendship as well.
- **Michael Collier.** As you read this text, you will see dozens of extraordinary photographs by Michael Collier. Most are aerial shots taken from his nearly 60-year-old Cessna 180. Michael was also responsible for preparing the remarkable Mobile Field Trips that are scattered through the text. Among his many awards is the American

Geological Institute Award for Outstanding Contribution to the Public Understanding of Geosciences. We think that Michael's photographs and field trips are the next best thing to being there. We were very fortunate to have had Michael's assistance on *Essentials of Geology*, 13th edition. Thanks, Michael.

- **Callan Bentley.** Callan Bentley made many contributions to the new edition of *Essentials*. Callan is a professor of geology at Northern Virginia Community College in Annandale, where he has been honored many times as an outstanding teacher. He is a frequent contributor to *EARTH* magazine and is author of the popular geology blog *Mountain Beltway*. Callan assisted with the revision of Chapter 11, "Crustal Deformation & Mountain Building," and was responsible for preparing the SmartFigure Tutorials that appear throughout the text. As you take advantage of these outstanding learning aids, you will hear his voice explaining the ideas.
- **Scott Linneman.** We were fortunate to have Scott Linneman join the *Essentials of Geology* team as we prepared the 13th edition. Scott provided many thoughtful suggestions and ideas and was responsible for revising Chapter 12, "Mass Movement on Slopes: The Work of Gravity." Scott is an award-winning professor of geology and science education and director of the Honors Program at Western Washington University in Bellingham.

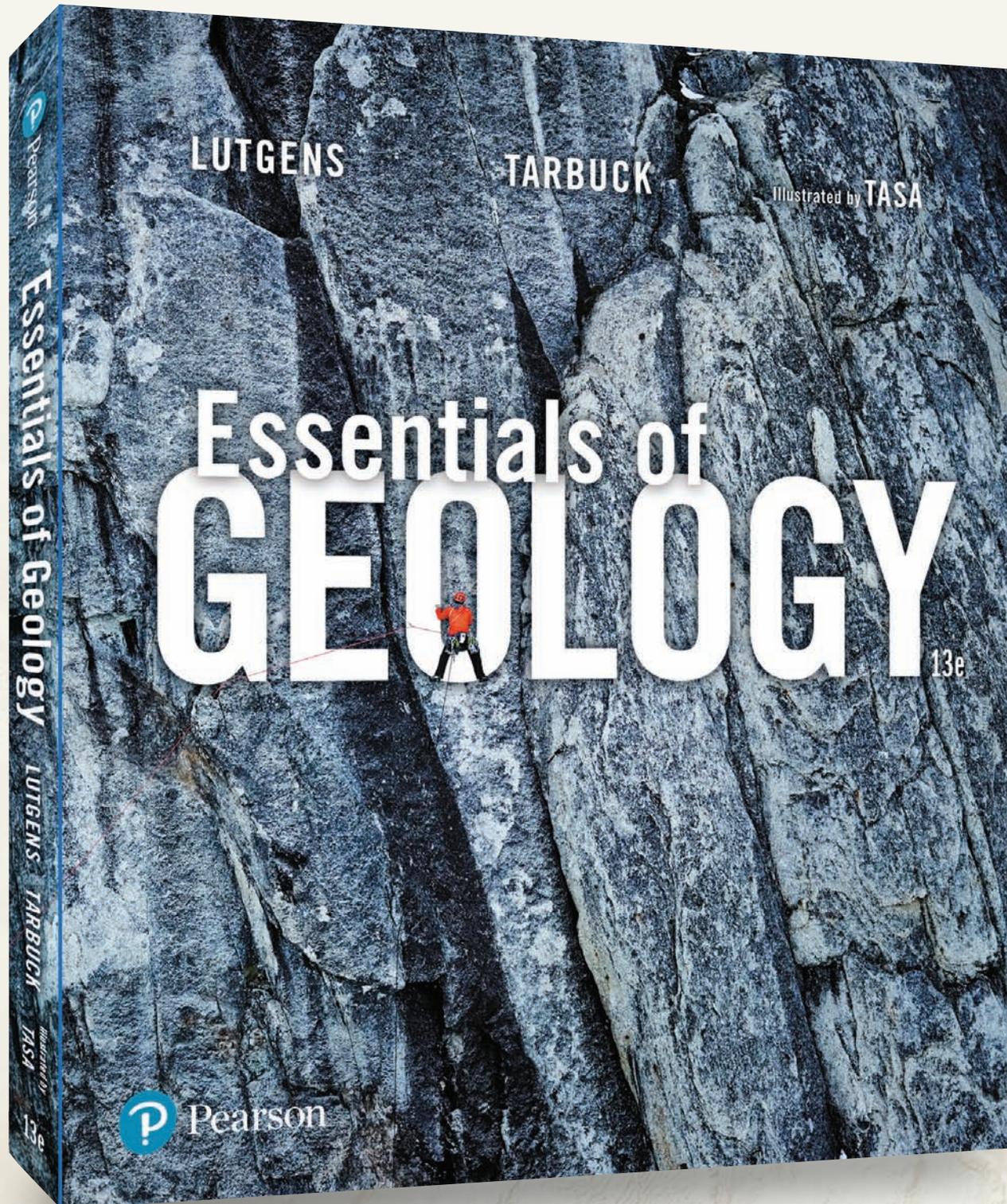
Great thanks also go to our colleagues who prepared in-depth reviews. Their critical comments and thoughtful input helped guide our work and clearly strengthened the text. Special thanks to:

Jessica Barone, Monroe Community College  
 Paul Belasky, Ohlone College  
 Larry Braile, Purdue University  
 Alan Coulson, Clemson University  
 Nels Forsman, University of North Dakota  
 Edward Garnero, Arizona State University  
 Maria Mercedes Gonzales, Central Michigan University  
 Callum Hetherington, Texas Tech University  
 Uwe Richard Kackstaetter, Metropolitan State University  
 of Denver  
 Haraldur Karlsson, Texas Tech University  
 Johnny MacLean, Southern Utah University  
 Jennifer Nelson, Indiana University–Purdue University  
 Indianapolis  
 Cassiopeia Paslick, Rock Valley College  
 Jeff Richardson, Columbus State Community College  
 Jennifer Stempien, University of Colorado–Boulder  
 Donald Thieme, Valdosta State University

Last but certainly not least, we gratefully acknowledge the support and encouragement of our wives, Nancy Lutgens and Joanne Bannon. Preparation of this edition of *Essentials* would have been far more difficult without their patience and understanding.

**Fred Lutgens  
 Ed Tarbuck**

# Use Dynamic Media to Bring Geology to Life



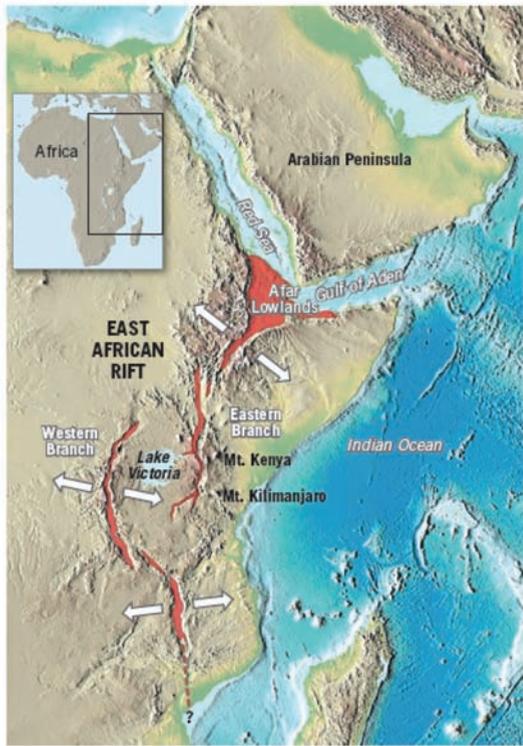
# Bring Field Experience to Students' Fingertips...

## ▶ SmartFigure 2.14

**East African Rift valley**  
The East African Rift valley represents the early stage in the breakup of a continent. Areas shown in red consist of lithosphere that has been stretched and thinned, allowing magma to well up from the mantle.

### CONDOR VIDEO

<https://goo.gl/FKv9qH>



## ◀ SmartFigure 2.13

**Continental rifting:  
Formation of new  
ocean basins**

### TUTORIAL

<https://goo.gl/9CokZD>

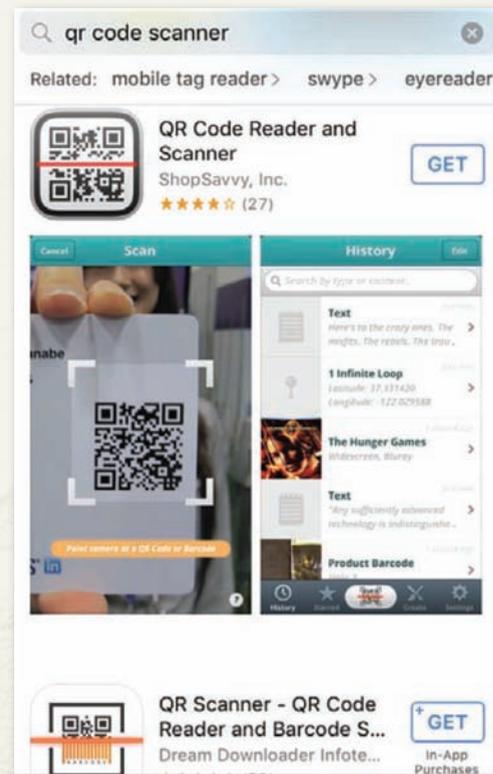


## NEW! QR Codes link out to SmartFigures

Quick Response (QR) codes link out to over 200 videos and animations, giving readers immediate access to five types of dynamic media: Project Condor Quadcopter Videos, Mobile Field Trips, Tutorials, Animations, and Videos to help visualize physical processes and concepts. SmartFigures extend the print book to bring geology to life.

## How to download a QR Code Reader

Using a smartphone, students are encouraged to download a QR Code reader app from Google Play or the Apple App Store. Many are available for free. Once downloaded, students open the app and point the camera to a QR Code. Once scanned, they're prompted to open the url to immediately be connected to the digital world and deepen their learning experience with the printed text.



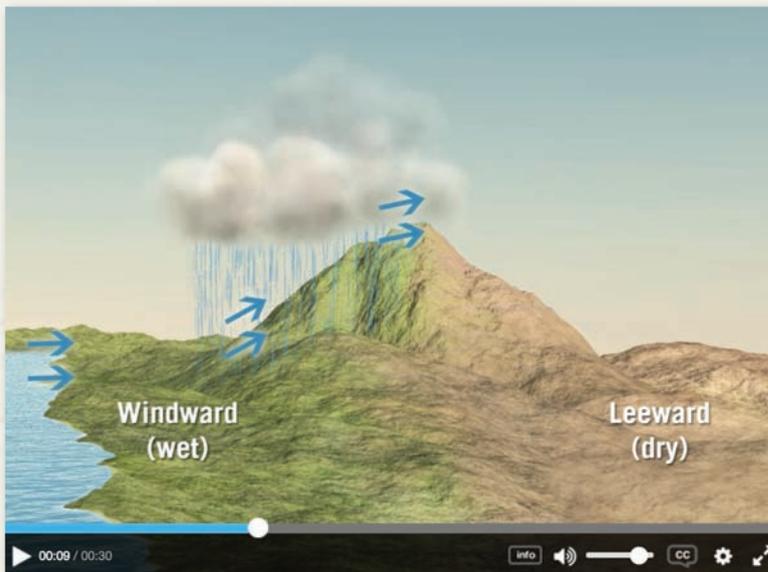
## NEW! SmartFigure: Project Condor Quadcopter Videos

Bringing Physical Geology to life for geology students, three geologists, using a quadcopter-mounted GoPro camera, have ventured into the field to film 10 key geologic locations and processes. These process-oriented videos, accessed through QR codes, are designed to bring the field to the classroom and improve the learning experience within the text.

# ...with SmartFigures

## NEW! SmartFigure: Mobile Field Trips

On each trip, students will accompany geologist-pilot-photographer Michael Collier in the air and on the ground to see and learn about iconic landscapes that relate to discussions in the chapter. These extraordinary field trips are accessed by using QR codes throughout the text. New Mobile Field Trips for the 13th edition include *Formation of a Water Gap*, *Ice Sculpts Yosemite*, *Fire and Ice Land*, *Dendrochronology*, and *Desert Geomorphology*.

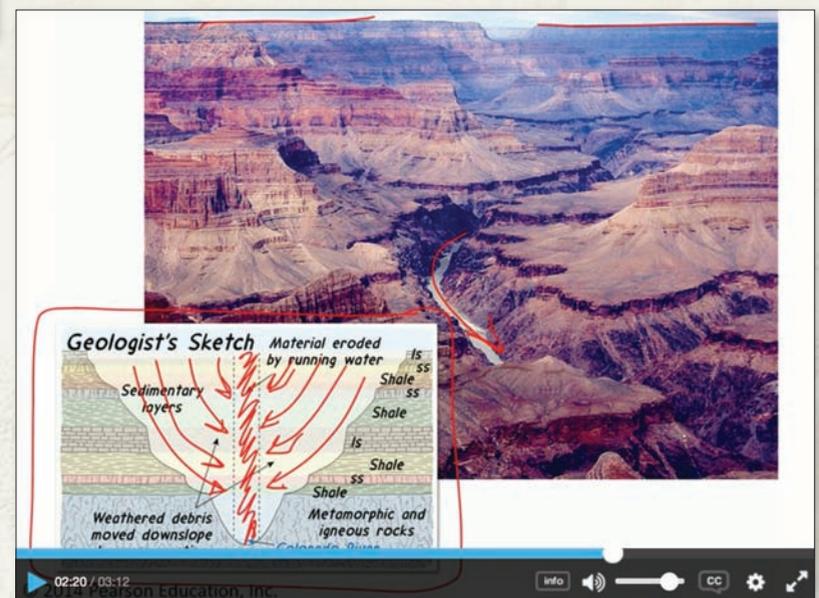


## NEW! SmartFigure: Animations

Brief animations created by text illustrator Dennis Tasa animate a process or concept depicted in the textbook's figures. With QR codes, students are given a view of moving figures rather than static art to depict how geologic processes move throughout time.

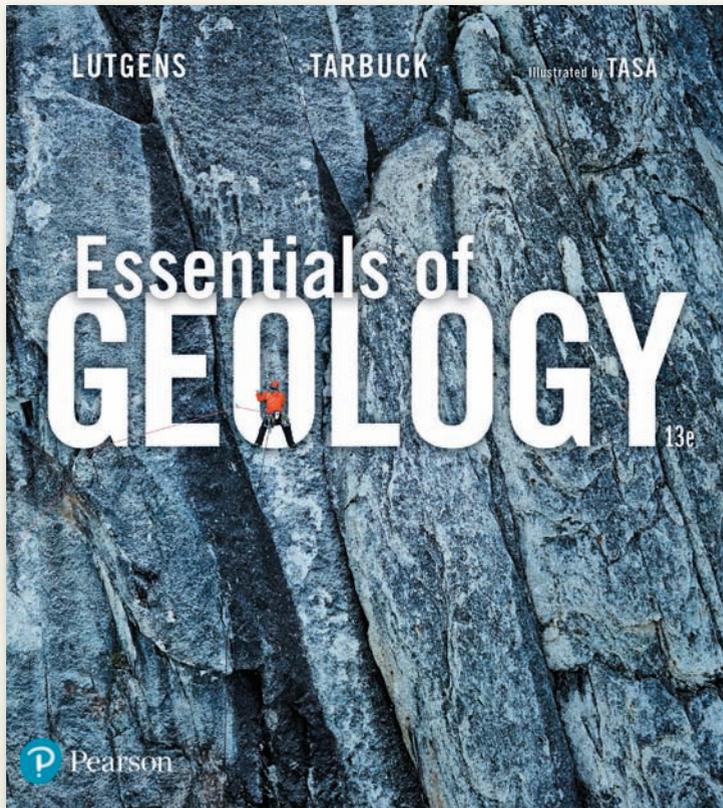
## HALLMARK! SmartFigure: Tutorials

These brief tutorial videos present the student with a 3- to 4-minute feature (mini-lesson) narrated and annotated by Professor Callan Bentley. Each lesson examines and explains the concepts illustrated by the figure. With over 100 SmartFigure Tutorials inside the text, students have a multitude of ways to enjoy art that teaches.



# Award-Winning Contributing Authors

The language of this text is straightforward and written to be understood. Clear, readable discussions with a minimum of technical language is the rule. In the 13th edition, we have continued to improve readability with the addition of two new contributing authors, Scott Linnenman and Callan Bentley.



**Scott Linnenman** provided many thoughtful suggestions and idea throughout the text and was responsible for **revising Chapter 12: Mass Movement on Slopes: The Work of Gravity**. Linnenman is an award-winning Professor of Geology and Science Education and director of the Honors Program at Western Washington University in Bellingham.



**Callan Bentley** is Professor of Geology at Northern Virginia Community College in Annandale, where he has been honored many times as an outstanding teacher. He is a frequent contributor to EARTH magazine and is author of the popular geology blog Mountain Beltway. Bentley assisted with the **revision of Chapter 11: Crustal Deformation and Mountain Building** and created the SmartFigure Tutorials that appear throughout the text. As students take advantage of these outstanding learning aids, they will hear his voice explaining the ideas.

# Objective-Driven Active Learning

Most chapters have been designed to be self-contained so that materials may be taught in a different sequence, according to the preference of the instructor or the needs of the laboratory. Thus, an instructor who wishes to discuss erosional processes prior to earthquakes, plate tectonics, and mountain building may do so without difficulty.

The chapter-opening **Focus on Concepts** lists the learning objectives for each chapter. Each section of the chapter is tied to a specific learning objective, providing students with a clear learning path to the chapter content.

**1**

## An Introduction to Geology

**FOCUS ON CONCEPTS**  
Each statement represents the primary learning objective for the corresponding major heading within the chapter. After you complete the chapter, you should be able to:

- 1.1 Distinguish between physical and historical geology and describe the connections between people and geology.
- 1.2 Summarize early and modern views on how change occurs on Earth and relate them to the prevailing ideas about the age of Earth.
- 1.3 Discuss the nature of scientific inquiry, including the construction of hypotheses and the development of theories.
- 1.4 List and describe Earth's four major spheres. Define system and explain why Earth is considered to be a system.
- 1.5 Outline the stages in the formation of our solar system.
- 1.6 Describe Earth's internal structure.
- 1.7 Sketch, label, and explain the rock cycle.
- 1.8 List and describe the major features of the continents and ocean basins.

All four of Earth's spheres are represented in this image in the Canadian Rockies of British Columbia. (Photo by ©Globebook.com)

**CONCEPT CHECKS 1.8**

1. Compare and contrast continents and ocean basins.
2. Name the three major regions of the ocean floor. What are some features associated with each?
3. Describe the general distribution of Earth's youngest mountains.
4. What is the difference between shields and stable platforms?

Each chapter section concludes with **Concept Checks**, a set of questions that is tied to the section's learning objective and allows students to monitor their grasp of significant facts and ideas.

**Give It Some Thought** activities challenge learners by requiring higher-order thinking skills to analyze, synthesize, and apply the material.

**GIVE IT SOME THOUGHT**

- 1 The length of recorded history for humankind is about 5000 years. Clearly, most people view this span as being very long. How does it compare to the length of geologic time? Calculate the percentage or fraction of geologic time that is represented by recorded history. To make calculations easier, round the age of Earth to the nearest billion.
- 2 After entering a dark room, you turn on a wall switch, but the light does not come on. Suggest at least three hypotheses that might explain this observation. Once you have formulated your hypotheses, what is the next logical step?

b. If you are flying in a commercial jet at an altitude of 12 kilometers (about 39,000 feet), about what percentage of the atmosphere's mass is below you?

**CONCEPTS IN REVIEW**

## Plate Tectonics: A Scientific Revolution Unfolds

### 2.1 From Continental Drift to Plate Tectonics

Summarize the view that most geologists held prior to the 1960s regarding the geographic positions of the ocean basins and continents.

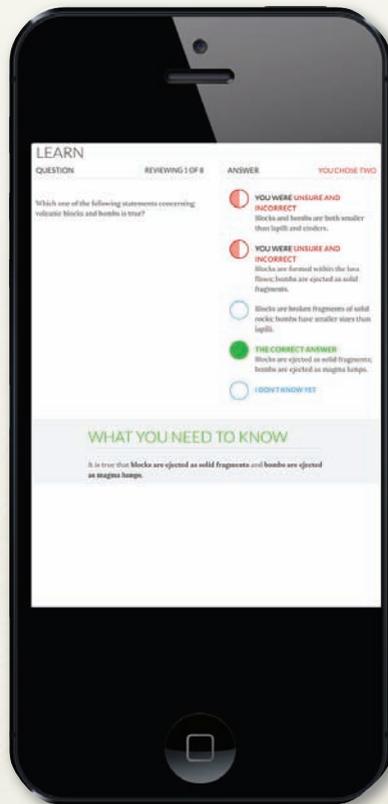
- Fifty years ago, most geologists thought that ocean basins were very old and that continents were fixed in place. Those ideas were discarded with a scientific revolution that revitalized geology: the theory of plate tectonics. Supported by multiple kinds of evidence, plate tectonics is the foundation of modern Earth science.

**Concepts in Review** provides students with a structured review of the chapter. Consistent with the Focus on Concepts and Concept Checks, the **Concepts in Review** is structured around the learning objective for each section.

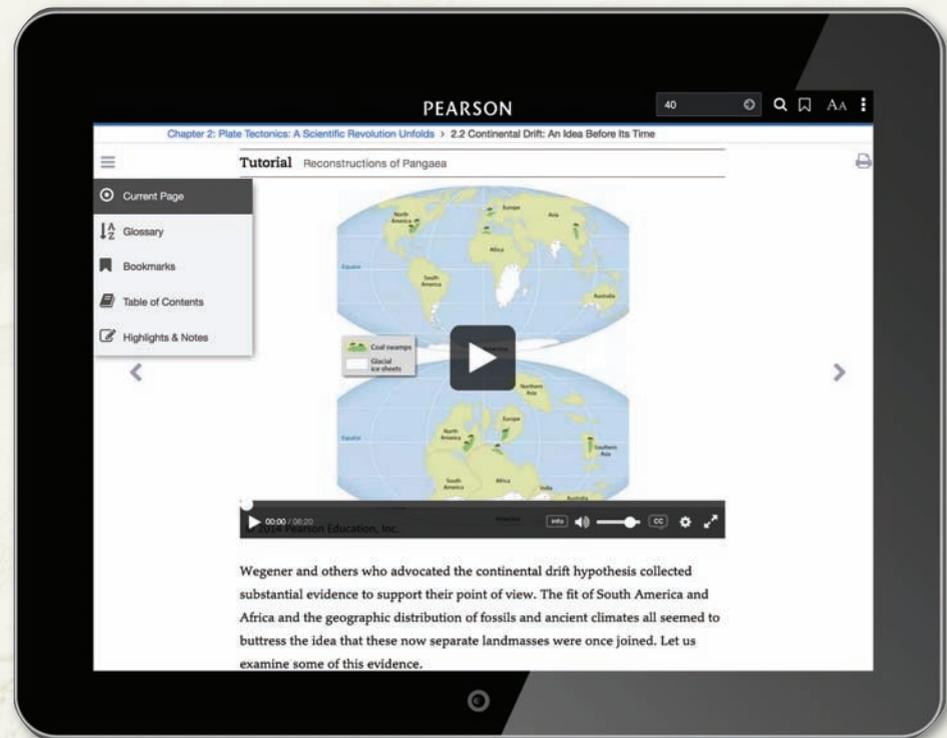
# Continuous Learning Before, During, and After Class

## BEFORE CLASS

Mobile Media and Reading Assignments Ensure Students Come to Class Prepared



**Updated!** **Dynamic Study Modules** help students study effectively by continuously assessing student performance and providing practice in areas where students struggle the most. Each Dynamic Study Module, accessed by computer, smartphone, or tablet, promotes fast learning and long-term retention.



**NEW!** **Interactive eText 2.0** gives students access to the text whenever they can access the internet. eText features include:

- Now available on smartphones and tablets.
- Seamlessly integrated videos and other rich media.
- Accessible (screen-reader ready).
- Configurable reading settings, including resizable type and night reading mode.
- Instructor and student note-taking, highlighting, bookmarking, and search.

## Pre-Lecture Reading Quizzes are easy to customize and assign

Reading Questions ensure that students complete the assigned reading before class and stay on track with reading assignments. Reading Questions are 100% mobile ready and can be completed by students on mobile devices.

# with MasteringGeology™

## DURING CLASS

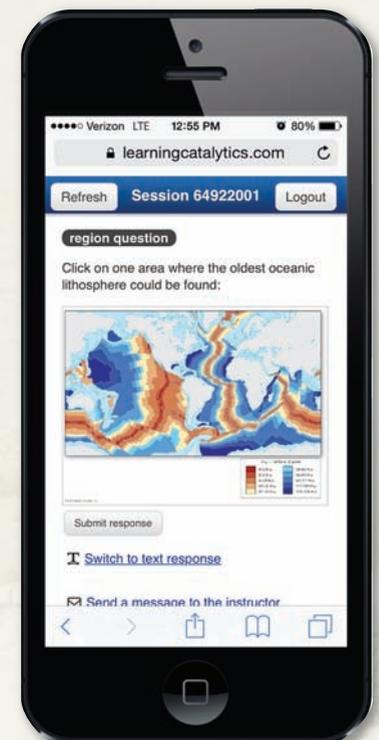
### Engage students with Learning Catalytics

What has teachers and students excited? Learning Catalytics, a 'bring your own device' student engagement, assessment, and classroom intelligence system, allows students to use their smartphone, tablet, or laptop to respond to questions in class. With Learning Catalytics, you can:

- Assess students in real time using open-ended question formats to uncover student misconceptions and adjust lecture accordingly.
- Automatically create groups for peer instruction based on student response patterns, to optimize discussion productivity.

*"My students are so busy and engaged answering Learning Catalytics questions during lecture that they don't have time for Facebook."*

Declan De Paor, Old Dominion University



# MasteringGeology™

## AFTER CLASS

Easy to Assign, Customizable, Media-Rich, and Automatically Graded Assignments

**Part B - A Direction of Crustal Extension in Continental Rifts**

The three Google Earth images below highlight segments of major continental rifts from around the world. The edge of the rift valley is shown in images B and C. Using what you learned from the video, determine the correct direction of extension for each rift shown.

Remember that the direction of spreading is perpendicular to the axis of the rift. Make sure you are not only focusing on the direction, its location perpendicular to the rift axis.

When you place the arrow on the target (images) both arrows should be outside of the rift edges (outlines).

Arrows that are aligned either perfectly horizontally or vertically should belong to a rift that has the same perfect alignment.

Drag the appropriate arrows to their respective targets. Not all arrows will be used.

### NEW! Project Condor Quadcopter Videos

A series of quadcopter videos with annotations, sketching, and narration help improve the way students learn about monoclines, streams and terraces, and so much more. In MasteringGeology™, these videos are accompanied by assessments to test student understanding.

**NEW! 24 Mobile Field Trips** take students to iconic geological locations with Michael Collier in the air and on the ground to see and learn about geologic locations that relate to concepts in the chapter. In Mastering, these videos are accompanied by auto-gradable assessments that will track what students have learned.

**Mobile Field Trip Video Quiz: Fire and Ice Land**

[Launch the Mobile Field Trip Video](#)

**Part A**

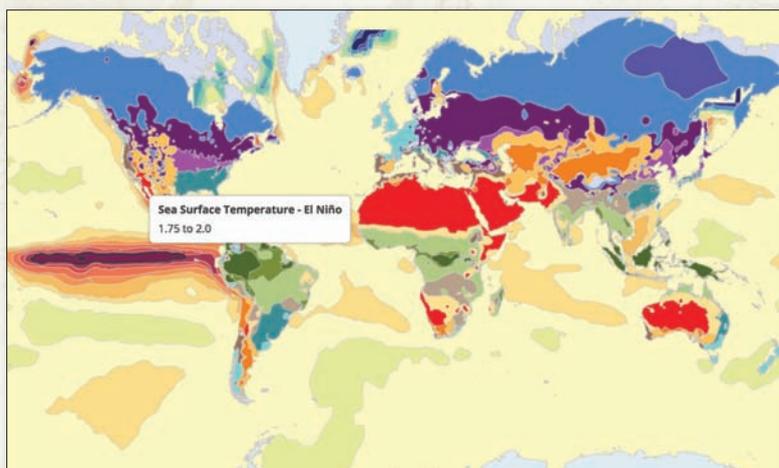
Which of the following scenarios best describes the activity present along the Mid-Atlantic Ridge?

- Magma wells up at the center of the ridge, which pushes the old seafloor apart as new seafloor is created.
- Magma is created by partial melting of crustal material as it sinks.
- A plume of hot mantle material is pushing up against the crust, adding material to the crust to thicken it.
- Segments of seafloor slide past each other without creating or destroying crustal material.
- Old seafloor is consumed as it is forced beneath another segment of seafloor.

**Part B**

The Mid-Atlantic Ridge crosses through Iceland. Physical features such as tensional fractures and cinder cone volcanoes are all aligned NE-SW. What does this indicate about the directions the tectonic plates are moving?

- The tectonic plates are separating to the NW and SE.
- The tectonic plates are separating to the N and S.
- The tectonic plates are separating to the S and E.
- The tectonic plates are separating to the NE and SW.
- The tectonic plates are separating to the N and E.



### NEW! MapMaster 2.0

GIS-inspired interactive map activities help to enhance students' data analysis and spatial reasoning skills, and overall geologic literacy.

**Part A - Types of convergent plate boundaries**  
Identify each type of convergent plate boundary.  
Drag the appropriate convergence labels to their respective targets.

Continental-continental convergence    Oceanic-oceanic convergence    Oceanic-continental convergence

Submit    Hints    My Answers    Give Up    Review Part

## GeoTutors

These coaching activities help students master important physical geoscience concepts with highly visual, kinesthetic activities focused on critical thinking and application of core geoscience concepts.

**GigaPan Activities** allow students to take advantage of a virtual field experience with high-resolution imaging technology developed by Carnegie Mellon University in conjunction with NASA.



**Part D - Making Observations**  
After exploring the Giganpan field site, arrange the following observations/inferences by their respective rock unit. These observations/inferences describe the material, appearance and weathering pattern of the respective rock units.  
Drag the appropriate items into their respective bins. Each item may be used only once.

Rock Unit 1  
Red and white in color    Appears to be made up of many thin layers  
Weathers in small irregular shapes    Weathers in large blocks  
Appears to be massive (no layers)    Sediments too small to see

Rock Unit 2  
Black and dark gray in color    Crystals too small to see

Submit    Hints    My Answers    Give Up    Review Part

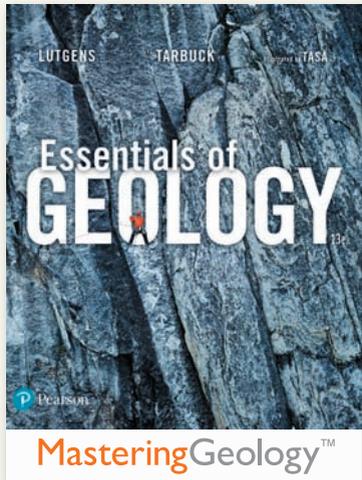
Which rock unit produces



## Encounter Activities

Using Google Earth™ to visualize and explore Earth's physical landscape, Encounter activities provide rich, interactive explorations of geology and earth science concepts. Dynamic assessments include questions related to core geology concepts. All explorations include corresponding Google Earth KMZ media files, and questions include hints and specific wrong-answer feedback to help coach students toward mastery of the concepts.

# Resources for YOU, the Instructor



**MasteringGeology™** provides you with everything you need to prep for your course and deliver a dynamic lecture, all in one convenient place. Resources include:

## LECTURE PRESENTATION ASSETS FOR EACH CHAPTER

- PowerPoint Lecture Outlines
- PowerPoint clicker questions and Jeopardy-style quiz show questions
- All book images and tables in JPEG and PowerPoint formats

## TEST BANK

- The Test Bank in Microsoft Word formats
- Computerized Test Bank, which includes all the questions from the printed test bank in a format that allows you to easily and intuitively build exams and quizzes.

## TEACHING RESOURCES

- Instructor Resource Manual in Microsoft Word and PDF formats
- Pearson Community Website (<https://communities.pearson.com/northamerica/s/>)

Upon textbook purchase, students and teachers are granted access to MasteringGeology. See page xviii for details.

## Measuring Student Learning Outcomes?

All MasteringGeology assignable content is tagged to learning outcomes from the book and Bloom's Taxonomy. You also have the ability to add your own learning outcomes, helping you track student performance against your learning outcomes. You can view class performance against the specified learning outcomes and share those results quickly and easily by exporting to a spreadsheet.

## Global

- QR codes for additional SmartFigures added, including Mobile Field Trips; SmartFigure types indicated in figure captions

## Chapter 1

- Subsection “Origin of Planet Earth” substantially revised
- New *Did You Know* feature added (Section 1.5)
- Two *Give It Some Thought* questions modified
- Substantively revised figures: 1.13, 1.17, 1.18, 1.20, 1.23, 1.24
- Eleven new photographs

## Chapter 2

- *Concept Check* questions for Section 2.6 revised
- Treatment of whole-mantle convection and plumes substantially rewritten for clarity and currency (Section 2.10)
- One *Give It Some Thought* question added and one modified
- Substantively revised figures: 2.9, 2.11, 2.17–2.19, 2.29, 2.30, 2.31, 2.35
- Two new photographs

## Chapter 3

- Introduction to mineral properties revised (Section 3.4)
- One new *Give It Some Thought* question added; one modified
- Figure 3.33 now combines illustration and tabular data
- New figures: 3.26, 3.28, 3.33. Figures that have been revised substantively: 3.5 (atomic weight changed to atomic mass), 3.8, 3.9, 3.11, 3.12
- Three new photographs

## Chapter 4

- Treatment of magmatic volatiles revised for clarity (Section 4.1)
- Subsection “Compositional Categories” rewritten for clarity; replaces former subsection “Granitic (Felsic) versus Basaltic (Mafic) Compositions” (Section 4.2)
- Terminology “felsic/intermediate/mafic” given priority over “granitic/andesitic/basaltic” (Section 4.4)
- Subsection “Temperature Increase: Melting Crustal Rocks” substantially rewritten for clarity (Section 4.5)
- Improved description of how mineral grains interact with a melt of changing composition
- Footnote added noting complex formation history of Palisades Sill (under “Magmatic Differentiation and Crystal Settling” in Section 4.6)
- Stocks now treated in the section on batholiths (paragraph 4 under “Batholiths” in Section 4.8)
- One *Give It Some Thought* question modified
- Substantively revised figures: 4.5, 4.12, 4.16, 4.17, 4.33
- Eight new photographs

## Chapter 5

- Section 5.2, “The Nature of Volcanic Eruptions,” largely rewritten
- Paragraph added to cover silica-rich pyroclastic intraplate volcanism
- In Section 5.10, volcanism at divergent boundaries now treated before volcanism at convergent boundaries
- Two new *Give It Some Thought* questions added; one modified
- New figures: 5.3 (replaces 12e Table 5.1), 5.8 (replaces 12e Figure 5.7). Figures that have been revised substantively: 5.5, 5.12, 5.16, 5.19, 5.21, 5.32
- Twelve new photographs

## Chapter 6

- New discussion of oxidation as an agent of weathering (“Oxidation” in Section 6.3)
- In the subsection “Controls of Soil Formation,” order of topics changed to put “Time” later (Section 6.5)

- Two new *Give It Some Thought* questions added
- Substantively revised figures: 6.11, 6.24
- Five new photographs

## Chapter 7

- Updated treatment of energy resources, including expanded discussion of emissions from coal combustion and changes in oil and gas production due to fracking (Section 7.8)
- Revised treatment of the slowest limb of the carbon cycle (Section 7.9, including Figure 7.34)
- One new *Give It Some Thought* question added
- New figure, 7.33. Figure 7.30 substantively expanded
- Five new photographs

## Chapter 8

- New contextual paragraph added at start of Section 8.1
- Improved introduction of temperature and pressure as agents of metamorphism at the end of Section 8.1
- Description and figure of a stretched pebble conglomerate added to help students understand the concept of differential stress (subsection “Differential Stress” in Section 8.2)
- In subsection “Other Metamorphic Textures,” improved treatment of nonfoliated metamorphic rocks, including coverage of hornfels (Section 8.3)
- One new *Give It Some Thought* question
- Four figures added: 8.5, 8.23, 8.27, 8.29. Figures that have been modified substantively: 8.4, 8.6, 8.10, 8.11, 8.24, 8.26
- Eight new photographs

## Chapter 9

- Subsection “Faults & Large Earthquakes” substantially rewritten for clarity and conciseness (Section 9.1)
- Section 9.3, “Locating the Source of an Earthquake,” substantially revised, including three figures
- Discussion added for the U.S.G.S. Community Internet Intensity Map project, including a figure (within “Intensity Scales” in Section 9.4)
- Section 9.8 reorganized to put the subsection “Probing Earth’s Interior: “Seeing” Seismic Waves” first; treatment of Earth’s layered structure substantially revised
- Two new *Give It Some Thought* questions added;
- Two figures added: 9.16, 9.23. Figures that have been modified substantively: 9.10, 9.13–9.15, 9.27 (completely redrawn)
- Two new photographs

## Chapter 10

- One *Give It Some Thought* question replaced with a new one
- One new figure added: 10.4 (two-page global sea-floor map). Figures that have been modified substantively: 10.12, 10.16, 10.21
- Two new photographs

## Chapter 11

- Treatment of deformation, stress, and strain in Section 11.1 significantly clarified
- Discussion of the factors that affect how rocks deform significantly clarified (Section 11.1)
- Distinction between faults and joints now covered at the start of Section 11.3
- Description of thrust faulting in the formation of the Himalayas improved (paragraph 4 under “The Himalayas” in Section 11.6)
- Description of isostatic balance and its effects rewritten (Section 11.7)
- One new *Give It Some Thought* question added

- Three figures added: 11.4, 11.5, 11.21. Figures that have been modified substantively: 11.3, 11.6–11.8, 11.10, 11.12, 11.14–11.16, 11.18, 11.19, 11.23, 11.27, 11.29, 11.30
- Six new photographs

## Chapter 12

- “Mass movement” introduced in place of older term “mass wasting.”
- Landslides introduced more thoroughly at the start of Section 12.1
- Treatment of mass movements that lack an obvious trigger clarified and moved to the start of section 12.2
- Treatment of mechanism for long-runout landslides updated (subsection “Rate of Movement” in Section 12.3)
- Definition and description of normal faults made clearer (first paragraph of section “Normal Faults” in Section 11.3)
- 2015 Nepal earthquake added as example of a landslide-triggering event (subsection “Examples from Plate Boundaries: California and Nepal” in Section 12.2)
- New *Did You Know* about 2013 Bingham Canyon Copper Mine landslide added (Section 12.2)
- One new *Give It Some Thought* question added
- Figure 12.11 modified substantively
- Six new photographs

## Chapter 13

- Section 13.1 largely rewritten
- Selected paragraphs of Section 13.2 tightened; headward erosion added as final paragraph in section “Drainage Basins; formation of a water gap added at the end of “Drainage Patterns.”
- Section on the loss of wetlands from the Mississippi delta and coastal Louisiana added (subsection “Vanishing Wetlands” in Section 13.7)
- Treatment of flood control updated and tightened (Section 13.8)
- One new *Give It Some Thought* question added
- Figure 13.29 added; “Floods & Flood Control” now supported by four new figures 13.31–13.33; Figure 13.24 substantively changed
- Three new photographs

## Chapter 14

- Section added on Geothermal Energy (p. 385 in Section 14.5)
- Section added on the impact of prolonged drought on groundwater resources (p. 387 of Section 14.5)
- Three figures added: 14.21, 14.23, 14.29. Figures that have been modified substantively: 14.1, 14.3, 14.22
- Three new photographs

## Chapter 15

- Information on Larsen B ice shelf updated (p. 402 in Section 15.1)
- New *Give It Some Thought* question
- Figures that have been replaced or modified substantively: 15.3, 15.4, 15.6, 15.9, 15.11, 15.22
- Five new photographs

## Chapter 16

- New *Give It Some Thought* question
- Figures that have been modified substantively: 16.2, 16.3, 16.9
- Three new photographs

## Chapter 17

- Section 17.1 (“The Shoreline & Ocean Waves”) has been revised to cover both the basic features of shorelines and the behavior of ocean waves. Beaches are now covered along with shoreline processes in Section 17.2 (“Beaches & Shoreline Processes”). Both sections have been tightened to focus more on processes and less on terminology
- Explanation of wave refraction reworded for greater clarity

- Section 17.6 (“Stabilizing the Shore”) moved to later in the chapter than in the preceding edition; it now follows Sections 17.4 (“Contrasting America’s Coasts”) and 17.5 (“Hurricanes: The Ultimate Hazard”)
- Section 17.4 (“Contrasting America’s Coasts”) reorganized to start with the basic classification of coasts as emergent or submergent. This section also now uses cliff retreat at Pacifica, CA as a topical example of erosion on an emergent coast
- Section 17.5 (“Hurricanes: The Ultimate Hazard”) now uses Superstorm Sandy as an example and covers the effect of sea-level rise on vulnerability
- The response of Staten Island to Superstorm Sandy added as an example of a decision to change how coastal land is used (“Changing Land Use” in Section 17.6)
- Four new photographs

## Chapter 18

- Section “Correlation within Limited Areas” tightened (in Section 18.3)
- Text and figures for Section 18.4, “Numerical Dating with Nuclear Decay,” substantially revised for better clarity and effectiveness
- Section 18.5, “Determining Numerical Dates for Sedimentary Strata,” moved so that it now immediately follows Section 18.4
- Two *Give It Some Thought* questions added
- Figures that have been modified substantively: 18.19–18.22, 18.24
- Two new photographs

## Chapter 19

- In the section “Oxygen in the Atmosphere,” updated treatment of the effects on land organisms of the apparent high levels of oxygen in the Pennsylvanian (in Section 19.3)
- Acasta Gneiss added to discussion of Earth’s oldest dated rocks (in Section 19.4)
- Section “Supercontinents and Climate” substantially revised (in Section 19.4)
- Figure 19.17 added, illustrating the major provinces of the Appalachian Mountains (in Section 19.5)
- Paragraphs on the origin of prokaryotes, eukaryotes, and photosynthesis substantively revised (“Earth’s First Life: Prokaryotes” in Section 19.6)
- Updated discussion of the origin of tetrapods (“Vertebrates Move to Land” in Section 19.7)
- Updated treatment of the extinction of nonavian dinosaurs (“Demise of the Dinosaurs” in Section 19.7)
- Updated treatment of hominin evolution (“Humans: Mammals with Large Brains & Bipedal Locomotion” in Section 19.9)
- New *Give It Some Thought* question
- Five new photographs

## Chapter 20

- Within Section 20.2 (“Detecting Climate Change,”) section “Climates Change” added, including Figures 20.2 and 20.3
- In Section 20.5, context-setting second paragraph added
- Section “Rising CO<sub>2</sub> Levels” updated to include current data, including updated discussion of tropical deforestation
- Section “The Atmosphere’s Response” updated to reflect the 2013–2014 IPCC 5th Assessment Report
- Section “The Role of Trace Gases” updated to reflect current science, and section “How Aerosols Influence Climate” moved into this section
- Section 20.7, “Climate Feedback Mechanisms,” updated to reflect current science
- Table 20.1, “IPCC Projections for the Late Twenty-First Century,” added to Section 20.8, and section updated to reflect current science
- Section “The Changing Arctic” largely revised
- Section “The Potential for Surprises” updated
- Three new *Give it Some Thought* questions added
- New figures added: 20.2, 20.3, 20.8, 20.34. Figures modified or updated substantively: 20.21, 20.23, 20.25, 20.26, 20.31, 20.25. Several new photographs.

Essentials of  
**GEOLOGY** 13e