Contents

Preface xiii About the Authors xxv

Chapter

Introduction to Earth Science 3

- 1.1 Earth Science and the Earth System 4
 - The Scope of Earth Science5Your Study of Earth Science6
- 1.2 What Is Science? 7 Science in Full View: The Hutchinson Gas Explosions 8
- 1.3 Doing Science 10
 From Observation to Hypothesis 10
 Inductive and Deductive Reasoning 10
 From Hypothesis to Theory 11
 The Characteristics of Good Science 11
 An Example of Good Science: The Alvarez Hypothesis 13
 Limitations of Science 15
 The Characteristics of Bad Science 16
 An Example of Bad Science: Prediction of a Midcontinent
 Earthquake 16
- 1.4 Science and Society 16 The Role of Earth Science 17 Protecting Against Natural Hazards 17 Finding and Sustaining Earth's Resources 19 Protecting the Health of the Environment 20 Ensuring the Future of Human Life 21 The Anthropocene: A New Time on Earth? 21
- 1.5 THE BIG PICTURE 22

chapter 2 Earth in Space 25

- 2.1 Old Ideas, New Ideas 26
- 2.2 Origin of the Universe 28 Determining the Age and Size of the Universe 28 The Big Bang Theory 30
- 2.3 Stars and Planets 31 How Stars Formed 31 How Planets Formed 33

- 2.4 Our Solar System 34 Characteristics of the Sun 34 Eight, Nine, or Ten Planets? 37 Types of Planets 39
- Chapter Snapshot: The Solar System 40
- 2.5 Earth, the Sun, and the Seasons 42 Distribution of Solar Radiation 42
- 2.6 The Unique Composition of Earth 44 Core, Mantle, and Crust 45 Why Is There Life on Earth? 47
- 2.7 THE BIG PICTURE 51



- 3.1 Chevy Asteroid (Not Chevy Astro) 54 The Potential for NEO Impacts 54
- 3.2 Characteristics of Near-Earth Objects 55 Asteroids and Meteorites 55 Comets 56
- 3.3 Impact Features 61 Crater Characteristics 61
- 3.4 Impact Hazards 64 An Impact Event 65

Chapter Snapshot:

Neo Impact with Earth 66

- 3.5 Beware of Flying Rocks 69 Predicting and Preventing Impact Events 69
- 3.6 THE BIG PICTURE 72



- 4.1 Science and Santa Claus 76 Hey, Good Lookin' 76
- 4.2 Continental Drift 77 Wegener's Hypothesis 77
- 4.3 Evidence from the Seafloor 80 Seafloor Topography 80

Age of the Ocean Floor 82 Heat Flow, Volcanoes, and Earthquakes 82 Seafloor Spreading Hypothesis 83 Paleomagnetism 84

- 4.4 Plate Tectonics 87 Key Layers and Processes 88 The Process of Plate Tectonics 89
- Chapter Snapshot: Plates of the World 90 An Ongoing Process 95 Do Other Planets Have Plate Tectonics? 95
- 4.5 Plate Boundaries 95
 Divergent Plate Boundaries 95
 Convergent Plate Boundaries 96
 Transform Plate Boundaries 100
 Plate Tectonics and Climate 102
- 4.6 THE BIG PICTURE 103
- Chapter 5

Earthquakes 105

- 5.1 Experiencing an Earthquake Firsthand 106
- 5.2 The Science of Ghost Forests and Megathrust Earthquakes 107 Evidence from Trees 107 Evidence from Plate Tectonics 108 Linking the Evidence to the Orphan Tsunami 109 What These Findings Mean for the Future 109
- 5.3 Faults, Earthquakes, and Plate Tectonics 110 Common Features of Faults and Earthquakes 111 Directions of Fault Movement 111 Amounts of Fault Movement 112 Stress and Deformation 113 Where to Expect Earthquakes 114
- 5.4 Seismic Waves and Earthquake Detection 117 Types of Seismic Waves 118 Determining Earthquake Location and Magnitude 119 Seismic Waves and Earthquake Warning Systems 122
- 5.5 Measurement of Earthquakes 122 Earthquake Magnitude 122 Earthquake Intensity (Modified Mercalli Scale) 123
- 5.6 Earthquake Hazards 126 Ground Shaking 127 Aftershocks 128 Landslides 128

Elevation Changes 129 Liquefaction 129 Tsunami 129 Chapter Snapshot: 2004 Tsunami 130

5.7 THE BIG PICTURE 136

chapter 6 Volcanoes and Other Mountains 139

- 6.1 The Volcano Commandos 140 The Speedy Lavas of Nyiragongo 141
- 6.2 Magma Viscosity 142
- 6.3 Magma Sources and Magma Composition 144
- 6.4 The Mount St. Helens Eruption 147
 Prior Activity 147
 The May 18 Eruption 149
 How Does Mount St. Helens Compare to Other Eruptions? 150
- 6.5 Products of Volcanic Eruptions 152 Airborne Elements 152

Chapter Snapshot: Potential Products of Volcanic Eruption 154

Surface Effects 156 6.6 Volcanoes and Volcanic Landforms 160

- Three Classes of Volcanic Cones 161 Other Volcanic Landforms 163
- 6.7 Mountains: Why Are They There? 164 Mountains and Plate Tectonics 164
- 6.8 The Rise and Fall of Mountains and Temperatures 167 Mountains and Climate 169
- 6.9 THE BIG PICTURE 170

chapter 7 Rocks and Minerals 173

- 7.1 Earth Scientists: Nature Detectives 174 Where Do Bricks Come From? 175
- 7.2 Elements and Atoms: The Basic Building Blocks 176
- 7.3 Minerals 180 Mineral Characteristics 180

7.4 Igneous Rocks 184 The Classification of Igneous Rocks 185 Chapter Snapshot:

Origin of Rocks 188

- 7.5 Sedimentary Rocks 192 Clastic Sedimentary Rocks 192 Chemical Sedimentary Rocks 195 Biochemical Sedimentary Rocks 195 Sedimentary Rocks and Fossil Fuels 197
- 7.6Metamorphic Rocks198Contact Metamorphism199Regional Metamorphism200
- 7.7 The Rock Cycle and Mineral Resources 201 The Rock Cycle 203 Mineral Resources 203
- 7.8 THE BIG PICTURE 206



- 8.1 Thinking About Time 210
- 8.2 The History of (Relative) Time 211 Relative Time 211
- Chapter Snapshot:

Geological History of the Grand Canyon 218 Fossils and Chronology 220

- 8.3 Geologic Time 222 The Geologic Timescale 222 Mass Extinctions 226
- 8.4 Numerical Time 228 Radioactive Decay 228 Half-Lives 229 Applying Both Relative and Numerical Time 230
- 8.5 Rates of Change 232 Catastrophism 233 Uniformitarianism 233
- 8.6 THE BIG PICTURE 235



9.1 The Dirt on Weatherintg 238 Weathering of Cultural Sites 238 Where Does Dirt Come From? 239

- 9.2 Physical Weathering 240 Unloading 240 Wedging 241
- 9.3 Chemical Weathering 243 Dissolution 243
- Chapter Snapshot: Weathering 244 Hydrolysis 247 Oxidation 248 Linking Chemical and Physical Weathering Processes 249
- 9.4 Biological Weathering and Decay 249 Macroscopic Processes 250 Microscopic Processes 250
- 9.5 Weathering Rates 251 Rock Composition 251 Rock Properties 252 Climate 252 Weathering at World Heritage Sites 253
- 9.6 Soils: An Introduction 255 Soil-Forming Factors 256 Soil Types 257
- 9.7 Soil Erosion and Conservation 259 Erosion by Water and Wind 259 Effects of Land Use Practices on Erosion 260 Soil Conservation 262
- 9.8 THE BIG PICTURE 264



- 10.1 Mass Wasting: The Human Impact 268 The Phenomenon of Mass Wasting 268
- 10.2 Factors Influencing Slope Failure 270 Slope Angle 270 The Influence of Gravity 270 The Effects of Water 271 Case Study: Slope Failure in Venezuela 272 Methods of Stabilizing Slopes 274
- 10.3 Slope Failure Processes 276 Rockfalls 276 Rockslides 277
- Chapter Snapshot: Landslides 278 Slumps 281 Debris Flows and Mudflows 281 Creep 281
- 10.4 THE BIG PICTURE 283



- 11.1 Humans and Rivers 286 The Nile River: An Example of Stream Impact 286 Stream Management 287
- 11.2 The Hydrologic Cycle 287 The Origin of Streams 289
- 11.3 Drainage Networks and Patterns 290
 The Drainage Basin 290
 Evolution of Stream Systems 291
 Drainage Patterns 292
- 11.4 Factors Affecting Stream Flow 293 Stream Gradient 293 Stream Velocity 294 Stream Discharge 294
- 11.5 The Work of Streams 296 Erosion 296 Transport 297 Deposition 298
- Chapter Snapshot:

Channel Migration in the Mamoré River 300

- 11.6 Floods 303
 - Causes of Floods 303 Estimating Floods: Measuring Stream Discharge and Stream Stage 305 Determining Recurrence Interval 306
- 11.7 Flood Control 308 Approaches to Flood Control 309
- 11.8 THE BIG PICTURE 312

Chapter

Groundwater and Wetlands 315

- 12.1 Meet Your Drinking Water 316
 Where Drinking Water Comes From 316
 A Case of Groundwater Contamination: Woburn, Massachusetts 316
- 12.2 Holes in Earth Materials 318 Porosity 319 Permeability 320
- 12.3 Groundwater Systems 321 Aquifers 323 Natural Groundwater Budget: Inflow Versus Outflow 325 Consequences of Human Actions 327

Chapter Snapshot:

Groundwater 330

- 12.4 A Case Study: The High Plains Aquifer 332
- 12.5 Groundwater Quality 334 Drinking Yourself to Death, Naturally 334 Do-It-Yourself Groundwater Contamination 335
- 12.6 Introduction to Wetlands 338 Characteristics of Wetlands 338 Case Study: The Florida Everglades 339
- 12.7 THE BIG PICTURE 341

chapter **13** Oceans and Coastlines 343

- 13.1 Our Changing Oceans 344 The Dynamic Nature of Oceans and Coastlines 344
- 13.2 Ocean Basins 346
 Sea Level 346
 Bathymetry of the Ocean Floor 346
 A Walk Across the Ocean Floor: The Four Major Depth Zones 347
- 13.3 Ocean Waters 350
 Water Chemistry 350
 Water Temperature 352
 Water's Density, Temperature, and Depth 352
- 13.4 Oceanic Circulation 354
 Ocean Currents 354
 Coriolis Effect 356
 Contents and Oceanic Circulation 357
- Chapter Snapshot: Global Circulation and Topography 358 Thermohaline Circulation 360
- 13.5 Ticles 361 Why Tides Occur 362 Tidal Patterns 363
- 13.6 Wave Action and Coastal Processes 364
 Wave Motion in the Open Ocean 364
 Effect of the Wind on Ocean Waves 365
 Wave Motion Close to Shore 366
 Wave Energy 368
- 13.7 Shoreline Features 369The Changing of Coastal Landforms 370The Sediment Budget 372
- 13.8 Shoreline Protection 373
 Erosion Prevention Strategies 374
 Erosion Adjustment Strategies 375
- 13.9 THE BIG PICTURE 376



- 14.1 Science and Skydiving 380
- 14.2 Air Evolves 381 An Atmosphere Evolves 381
- 14.3 Structure and Processes of the Atmosphere 383 Heat Versus Temperature 383 The Four Layers of the Atmosphere 384
- 14.4 Solar Radiation and the Atmosphere 385 Solar Radiation and the Electromagnetic Spectrum 385 Earth's Energy Budget 386

Chapter Snapshot:

The Earth's Albedo 388

- 14.5 The Role of Water in the Atmosphere 390 Three States of Water 390 Changing States of Water 391 Humidity 392
- 14.6 Air Pressure, Condensation, and Precipitation 394 Air Pressure and Air Density 394 Effects of Air Pressure on Temperature 395 Adiabatic Lapse Rates 396 Condensation and Cloud Formation 396 Precipitation 397
- 14.7 Clouds and Frontal Systems 397 Cloud Classification 398 Cloud Formation Mechanisms 399
- 14.8 Winds 401
 The Relationship Between Air Pressure and Wind 401
 Regional Pressure Gradient 402
 Coriolis Effect 402
 Friction 403
 Cyclones and Anticyclones 404
 Wind Energy 405
- 14.9 THE BIG PICTURE 406

Chapter

Weather Systems 409

- 15.1 The Weather Around Us 410 Facts About Severe Weather 410
- 15.2 The Science of Weather: From Folklore to Forecasting 411 The First Meteorologists 412 Communications Developments 412 Weather Technology Today 413

- 15.3 Air Masses 413 Source Areas 414 Types of Air Masses 414 Modification of Air Masses 415
- 15.4 Midlatitude Cyclones and Frontal Systems 416
 Cold Fronts 416
 Warm Fronts 419
 Occluded Fronts 419
- 15.5 Severe Weather: Thunderstorms and Tornadoes 420 Thunderstorms 421 Tornadoes 423
- 15.6 Severe Weather: Hurricanes 426 Building a Hurricane 428
- Chapter Snapshot: Hurricane Anatomy 430 Looking to the Future 434
- 15.7 THE BIG PICTURE 436



Earth's Climate System 439

- 16.1 Want Ice with That? 440 Climate Change and the Polar Bear Diet 440 The Consequences of Arctic Warming 442
- 16.2 Global Air Circulation 443
- Chapter Snapshot: Climate Data 444 The Nonrotating Earth Model 446 The Rotating Earth Reality 446
- 16.3 Global Climate Regions 448 Köppen-Geiger Classification System 448 Climate and the Biosphere 449 Energy and the Biosphere 450
- 16.4 Extreme Climate Environments 453
 Cold Climates 453
 Hot Deserts 458
- 16.5 Records of Climate Change 461
 Weather Records from Instruments 461
 Cultural Records 462
 Short-Term Climate Trends: Annual Cycles 463
 Long-Term Climate Trends: Abrupt Change and Millennial Cycles 466
 Interpreting the Climate Record 468
 Intervals and Rates of Climate Change 468
- 16.6 Natural Causes of Climate Change 470
 Distribution of the Continents 470
 Oceanic Circulation Patterns 470
 Variations in Earth's Orbit 471

16.7 THE BIG PICTURE 473



- 17.1 Alternative Climates, Alternative Choices 476
- 17.2. Ozone and the Stratosphere 477 The Nature of Ozone 478 Natural Variations in Ozone Concentrations 478
- 17.3 CFCs and Ozone Depletion 480 The Nature of CFCs 480 Reductions in Ozone Concentrations 480 Why Does Ozone Become Depleted over the South Pole? 481
 Our Ozone Future 481
- 17.4 Greenhouse Gases and Global Change 482 The Global Carbon Cycle 483 Carbon Produced by Human Activity 485 Greenhouse Gas Emissions 485

Chapter Snapshot: Carbon Cycle 486

- 17.5 Modeling Global Climate Change 490 Forcings and Feedbacks 490 Climate Models 492
- 17.6 A Warmer World 493 Effects of Warmer Temperatures 494
- 17.7 What Can Be Done? 497
 International Agreements to Improve the Environment 497
 Reducing Greenhouse Gas Emissions 498
 What Else Can Be Done? 500
- 17.8 THE BIG PICTURE 502
- Appendix A Conversion Factors 504 Appendix B The Periodic Table of Elements 505 Appendix C Answers to Selected Checkpoint Questions 506 Glossary 509 Credits 517 Index 520