ONTENTS



CHAPTER ••••••• NATURAL DISASTERS AND THE HUMAN POPULATION 3



Bam, Iran, Earthquake 4 Europe's Heat Wave 5 Human Fatalities in Natural Disasters 6 Indian Ocean Tsunami, 26 December 2004 7 Human Responses to Disaster 10

Economic Losses from Natural Disasters 10 Insured Portion of Economic Losses 10

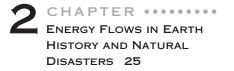
Natural Hazards 11 Popocatépetl Volcano, Mexico 13 • Magnitude, Frequency, and Return Period 14

The Twentieth Century was Unique 15 Overview of Human Population History 15 The Power of an Exponent on Growth 15 The Last 10,000 Years of Human History 16

• SIDE NOTE: Interest Paid on Money: An Example of Exponential Growth 17

The Human Population Today 18 Future World Population 18

Mathematical Extrapolation 20 • Carrying Capacity 20 Summary 22; Terms to Remember 23; Questions for Review 23; Questions for Further Thought 23



Energy Sources of Disasters 26 Origin of the Sun and Planets 26 Impact Origin of the Moon 27

Earth History 28 The Layered Earth 28

• SIDE NOTE: Mother Earth 29

• SIDE NOTE: Volcanoes and the Origin of the Ocean, Atmosphere, and Life 30 Behavior of Materials 31

Isostasy 32

Internal Sources of Energy 34

Impact Energy and Gravitational Energy 34 • Radioactive Elements 34

Gravity 35

- IN GREATER DEPTH: Radioactive Isotopes 36
- IN GREATER DEPTH: Radioactivity Disasters 37
- IN GREATER DEPTH: Energy, Force, Work, Power, and Heat 38

External Sources of Energy 39 The Sun 39

• IN GREATER DEPTH: Water—The Most Peculiar Substance on Earth? 42

Processes of Construction Versus Destruction 43 Impacts with Asteroids and Comets 44 How We Understand the Earth 44 Uniformitarianism 45

Summary 45; Terms to Remember 46; Questions for Review 46; **Ouestions for Further Thought** 46





Plate Tectonics 50 Development of the Plate Tectonics Concept 51 Magnetization of Volcanic Rocks 53

Magnetization Patterns on the Seafloors 53

• IN GREATER DEPTH: Earth's Magnetic Field 54

Other Evidence of Plate Tectonics 55

Earthquake Epicenters That Outline Plates 55 • Oceanic Mountain Ranges and Deep Trenches 55 • Deep Earthquakes 56 • Ages from the Ocean Basins 56 • Systematic Increases in Seafloor Depth 58 • The Fit of the Continents 58

The Grand Unifying Theory 60 Plate Tectonics and Earthquakes 61

Spreading Centers and Earthquakes 63 Iceland 63 • Red Sea and Gulf of Aden 64

Convergent Zones and Earthquakes 64 Subduction Zones 66 • Continent-Continent Collisions 68

Transform Faults and Earthquakes 70

The Arabian Plate 71

Continent-Continent Collision Earthquakes 71 • Transform Fault Earthquakes 72

• SIDE NOTE: Historical Perspective 73

Summary 74; Terms to Remember 74; Questions for Review 75; Questions for Further Thought 75





SEISMOLOGY, AND TSUNAMI 77

The Lisbon Earthquake of 1755 78 What Is an Earthquake? 79 Faults and Geologic Mapping 80 Types of Faults 83

Dip-Slip Faults 83 • Strike-Slip Faults 85 • Transform Faults 86 Development of Seismology 88

Waves 88

Seismic Waves 89 Body Waves 89 • Seismic Waves and the Earth's Interior 89 • Surface Waves 89 · Sound Waves and Seismic Waves 91

Locating the Source of an Earthquake 92

Magnitude of Earthquakes 92

Richter Scale 92 • Other Measures of Earthquake Size 95 • Foreshocks, Mainshock, and Aftershocks 96 • Magnitude, Fault-Rupture Length, and Seismic-Wave Frequencies 96

Ground Motion During Earthquakes 97 Acceleration 97 • Periods of Buildings and Responses of Foundations 97

Earthquake Intensity-What We Feel During an Earthquake 98 Mercalli Scale Variables 98

• IN GREATER DEPTH: What to Do Before and During an Earthquake 100

A Case History of Mercalli Variables 100 The San Fernando Valley, California, Earthquake of 1971 100

• IN GREATER DEPTH: Design of Buildings in Earthquake-Prone Areas 101

Tsunami 106

Tsunami Versus Wind-Caused Waves 107

Tsunami Case Histories 108 Alaska, 1 April 1946 108 • Chile, 22 May 1960 109 • Alaska, 27 March 1964 110 • Nicaragua, 1 September 1992 111 • Papua New Guinea, 17 July 1998 111

Summary 112; Terms to Remember 113; Questions for Review 113; Questions for Further Thought 113

CHAPTER •••••

SOME EARTHQUAKES IN WESTERN NORTH AMERICA 115

Subduction Zone Earthquakes 116 The Good Friday Earthquake, Alaska, 1964 116 Mexico City, 1985 118 • Pacific Northwest, The Upcoming Earthquake 120

Spreading-Center Earthquakes 122 Transform Fault Earthquakes in California 123 San Francisco, 1906 123 • San Andreas Fault Earthquakes 125

• IN GREATER DEPTH: Neotectonics and Paleoseismology 128

World Series (Loma Prieta) Earthquake, 1989 130 • Bay Area Earthquakes—Past and Future 134 • Kobe, Japan, 1995 vs. Oakland, California, 20?? 135

How Faults Work 136 Old View 136 • Newer View 137 • Southern San Andreas Fault 140

• IN GREATER DEPTH: Earthquake Prediction—Short Term 141

Thrust Fault Earthquakes in Southern California 142 Northridge, California, 1994 142

The "Big One" 143

The Biggest One 143 • Annualized Earthquake Losses 143 Summary 144; Terms to Remember 145; Questions for Review 145; Questions for Further Thought 145



MORE U.S. AND CANADIAN EARTHQUAKES 147

Western North America: Plate Tectonic-Related Earthquakes 148

• IN GREATER DEPTH: Human-Triggered Earthquakes 150

Pacific Northwest: Oregon, Washington, and British Columbia 150

Western Great Basin: Eastern California, Western Nevada 151 • The Intermountain Seismic Belt 154 • Intermountain Belt: Utah, Idaho, Wyoming, Montana 154 • Rio Grande Rift: New Mexico, Colorado, Westernmost Texas, Mexico 156

- Intraplate Earthquakes: "Stable" Central United States 157 New Madrid, Missouri, 1811-1812 157 • Reelfoot Rift: Missouri, Arkansas, Tennessee, Kentucky, Illinois 161 • Ancient Rifts in the Central United States 162
- Intraplate Earthquakes: Eastern North America 163 New England Earthquakes 163 • St. Lawrence River Valley Earthquakes 164
- Fracture-Zone Hypothesis of Major Earthquakes 164 Charleston, South Carolina, 1886 166
- Earthquakes and Volcanism in Hawaii 167
 - Summary 169; Terms to Remember 169; Questions for Review 169; **Ouestions for Further Thought** 169

CHAPTER •• **VOLCANIC ERUPTIONS:** PLATE TECTONICS AND MAGMAS 171



The Hazards of Studying Volcanoes 172 • How We Understand Volcanic Eruptions 174

Plate-Tectonic Setting of Volcanoes 175

Chemical and Mineral Composition of Magmas 176 Viscosity, Temperature, and Water Content of Magmas 178

Plate-Tectonic Setting of Volcanoes Revisited 179

How a Volcano Erupts 180 Some Volcanic Materials 181

SIDE NOTE: How a Geyser Erupts 182

Eruption Styles 184

- The Three Vs of Volcanology: Viscosity, Volatiles, Volume 185 Shield Volcanoes: Low Viscosity, Low Volatiles, Large Volume 185
- IN GREATER DEPTH: Volcanic Explosivity Index (VEI) 187

Flood Basalts: Low Viscosity, Low Volatiles, Very Large Volume 188 • Scoria Cones: Medium Viscosity, Medium Volatiles, Small Volume 188 • Stratovolcanoes: High Viscosity, High Volatiles, Large Volume 188

- SIDE NOTE: British Airways Flight 9 191
 - Lava Domes: High Viscosity, Low Volatiles, Small Volume 192 Calderas: High Viscosity, High Volatiles, Very Large Volume 192
- IN GREATER DEPTH: Hot Spots 197

Summary 200; Terms to Remember 201; Questions for Review 201; Questions for Further Thought 201

Х







KILLER EVENTS 203 Volcanism at Spreading Centers 204

Iceland 204

Volcanism at Subduction Zones 206 Cascade Range, Pacific Coast United States and Canada 206

Killer Events and Processes 215 The Historic Record of Volcano Fatalities 215 • Pyroclastic Flows 216 • Tsunami 219 • Lahars 220

• SIDE NOTE: Death at Ashfall, Nebraska 223

Indirect—Famine 223 • Gas 224 • Lava Flows 226

VEIs of Some Killer Eruptions 226

Volcano Monitoring and Warning 226

Signs of Impending Eruption 229

Summary 230; Terms to Remember 230; Questions for Review 230; Questions for Further Thought 230



The Role of Gravity 234 Creep 235 External Causes of Slope Failures 236

Internal Causes of Slope Failures 238 Inherently Weak Materials 238 • Canadian Quick-

Clay Slope Failures 239 • Water in Its Different Roles 240

• IN GREATER DEPTH: Analysis of Slope Stability 241

Decreases in Cohesion 242 • Adverse Geologic Structures 242 • Triggers of Mass Movements 243

Classification of Mass Movements 243 Falls 244

Slides 244

Rotational Slides 244 • Translational Slides 246

Flows 252

Gansu Province, China, Loess Flow 253 • Portuguese Bend, California, Earthflow 253 • Long-Runout Debris Flows 255 • Snow Avalanches 260 • Submarine Mass Movements 260

Subsidence 261

Slow Subsidence 261

• SIDE NOTE: How to Create a Cave 265

Catastrophic Subsidence 265

Summary 266; Terms to Remember 267; Questions for Review 267; Questions for Further Thought 267

O CHAPTER ••••• Atmosphere, Oceans, and Long-Term Climate Change 269



Solar Radiation Received by Earth 270

• SIDE NOTE: The Maya Civilization 271

Water and Heat 271

• SIDE NOTE: Temperature Scales 272

Vertical Movement of Air 274 General Circulation of the Atmosphere 274

Low Latitudes 274 • Middle and High Latitudes 275

• IN GREATER DEPTH: Coriolis Effect 278

General Circulation of the Oceans 281 Surface Circulation 281 • Deep-Ocean Circulation 282

Early Earth Climate—A Runaway Greenhouse 283 Climate History of the Earth: Timescale in Millions of Years 284

Late Paleozoic Ice Age 287 • Late Paleocene Torrid Age 288

• IN GREATER DEPTH: Oxygen Isotopes and Temperature 289

Late Cenozoic Ice Age 290

Glacial Advance and Retreat: Timescale in Thousands of Years 290

Climate Variations: Timescale in Hundreds of Years 294 Summary 296; Terms to Remember 297; Questions for Review 297; Questions for Further Thought 297

CHAPTER •••••• SHORT-TERM CLIMATE CHANGE AND SEVERE WEATHER 299



Shorter-Term Climatic Changes: Timescale in Multiyears 300

El Niño 300 • La Niña 302 • Pacific Decadal Oscillation 303

Volcanism and Climate 303 Volcanic Climate Effects 306

Drought and Famine 306 U.S. Dust Bowl, 1930s 307 • Sub-Sahelian Africa, 1968–75 307 • The Last Thousand Years 308

• IN GREATER DEPTH: When Did Humans Begin Adding to Greenhouse Warming? 310

The Twentieth and Twenty-First Centuries 309 The Greenhouse Effect Today 309

• **SIDE NOTE:** Stradivari Violins 309

The Twenty-First Century 312

Severe Weather 313

Midlatitude Cyclones 313

The Eastern U.S. "White Hurricane" of 1993 314 • Blizzards 315 • Ice Storms 315

How a Thunderstorm Works 316 Microbursts: An Airplane's Enemy 316

Thunderstorms in the Conterminous United States 318 Heavy Rains and Flash Floods 319 • Hail 320 • Lightning 321 • Winds 324

Tornadoes 324

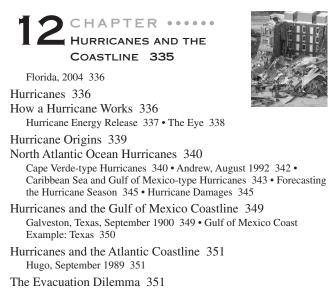
Tri-State Tornado, 18 March 1925 324 • How a Tornado Works 325 • Tornadoes in the United States and Canada 327 • The Super Outbreak, 3–4 April 1974 330 • Tornadoes and Cities 330

Extreme Heat 331

Heat Wave 331

Summary 333; Terms to Remember 333; Questions for Review 333; Questions for Further Thought 333





Reduction of Hurricane Damages 351 Building Codes 351 • Land-Use Planning 353 • Coastal Development Restrictions 353

Global Rise in Sea Level 353 Hurricanes and the Pacific Coastline 354 Pauline, October 1997 355 • Iniki, September 1992 355

Cyclones and Bangladesh 355

Coastline 356

Waves in Water 356 Rogue Waves 357

Waves on the Coastline 358 Why a Wave Breaks 358 • Summer Versus Winter Beaches 358

• IN GREATER DEPTH: Deep-Water Wave Velocity, Length, Period, and Energy 359 Wave Refraction 360 • Longshore Drift 360 • Submarine Canyons 360

Human Effects on the Coast 360

Dams 362 • Cliff Protection 362 • Groins 364 • Jetties 364 • Breakwaters 364

• SIDE NOTE: You Can Never Do Just One Thing 366

Summary 367; Terms to Remember 367; Questions for Review 368; Questions for Further Thought 368

CHAPTER FLOODS 371

• SIDE NOTE: A Different Kind of Killer Flood 373

How Rivers and Streams Work 374 Longitudinal Cross Section of a Stream 374 • The Equilibrium Stream 374

• SIDE NOTE: Feedback Mechanisms 377

The Floodplain 377 Flood Frequency 377

• **IN GREATER DEPTH:** Constructing Flood-Frequency Curves 378

Flood Styles 380 Flash Floods 380 Regional Floods 384

XII

Red River of the North 384 • Mississippi River System 385 • China 387

Societal Responses to Flood Hazards 389 Dams 389 • Levees 390 • Sandbagging 390 • Forecasting 390 •

Zoning and Land Use 390 •Insurance 390 • Presidential Disaster Declarations 390

Urbanization and Floods 391

Hydrographs 391 • Flood Frequencies 392 • Channelization 393 The Biggest Floods 396

Ancient Tales of Deluge 396 • Ice-Dam Failure Floods 397 Summary 399; Terms to Remember 400; Questions for Review 400; **Ouestions for Further Thought 400**



What Is Fire? 404 The Need for Fire 405

• **SIDE NOTE:** The Burning of Rome, 64 c.e. 406

The Fire Triangle 406

• SIDE NOTE: An Ancient View of Fire 407

The Stages of Fire 408 The Spread of Fire 409 Fire Weather 411 Winds of Fire 411

Great Lakes Region 412 • California 413 Home Design and Fire 418

• SIDE NOTE: The Winds of Madness 419

How Well Have Californians Learned? 419

Fire Suppression 422

Fossils 430

Geologic Time 431 Brief History of Life 432

Yellowstone National Park 422 • California Versus Baja California: Pay Now or Pay Later 423 • The Western and Southern United States in 2000 425 • Prescribed Fires 425 • Australia 426

The Similarities of Fire and Flood 426

Summary 427; Terms to Remember 427; Questions for Review 427; **Ouestions for Further Thought** 427





Early Understanding of Extinctions and

Species and the Fossil Record 434 The Tropical Reef Example 435

Mass Extinctions During Phanerozoic Time 435

Possible Causes of Mass Extinctions 437 Plate-Tectonic Causes 437 • Volcanic Causes 439 • Climate Change Causes 439 • Ocean Composition Causes 440 • Extraterrestrial Causes 440 • Biologic Causes 440 • Multiple Causes of Mass Extinction 442

Examples of Mass Extinctions 442 Closing of Permian Time (Ended 251 Million Years Ago) 442 • Close of Cretaceous Time (Ended 65 Million Years Ago) 443

Living Fossils 446

Quaternary Extinctions 447

• IN GREATER DEPTH: La Brea Tar Pits, Metropolitan Los Angeles 449

Summary 450; Terms to Remember 451; Questions for Review 451; Questions for Further Thought 451





Impact Scars 454 Sources of Extraterrestrial Debris 455 Asteroids 455 • Comets 457

Rates of Meteoroid Influx 458 Cosmic Dust 459 • Shooting Stars 459 • Meteorites 459

• IN GREATER DEPTH: Shoemaker-Levy 9 Comet Impacts on Jupiter 460

The Crater-Forming Process 461 Crater-Forming Impacts 463 Meteor Crater, Arizona 463 Impact Origin of Chesapeake Bay 465
The Cretaceous/Tertiary Boundary Event 465
Problems for Life from Impacts 467
Biggest Event of the Twentieth Century 467
Tunguska, Siberia, 1908 467
Biggest "Near Events" of the Twentieth Century 469
Frequency of Large Impacts 470
A Defense Plan 470
Summary 472; Terms to Remember 472; Questions for Review 473; Questions for Further Thought 473

GLOSSARY 475 CREDITS 485