

Contents

Preface xv

CHAPTER 1

Natural Disasters and the Human Population 1

- Natural Disasters in 2004 and 2005 2
- Pakistan Earthquake, 8 October 2005 2
- Hurricane Katrina, 29 August 2005 2
- Great Natural Disasters 3
- Human Fatalities in Natural Disasters 4
 - Human Responses to Disaster 4
- Economic Losses from Natural Disasters 5
 - Insured Portion of Economic Losses 7
- Natural Hazards 7
 - Popocatepetl Volcano, Mexico 7 • Magnitude, Frequency, and Return Period 9 • Role of Population Growth 10
- Overview of Human Population History 10
- The Power of an Exponent on Growth 11
- The Last 10,000 Years of Human History 11
- The Human Population Today 12
- Side Note** Interest Paid on Money: An Example of Exponential Growth 13
- Future World Population 15
 - The Demographic Divide 15 • Urbanization and Earthquake Fatalities 17 • Carrying Capacity 17
- Summary 19; Terms to Remember 20; Questions for Review 20; Questions for Further Thought 20*

CHAPTER 2

Energy Flows in Earth History and Natural Disasters 21

- Energy Sources of Disasters 22
- Earth: An Energetic Planet 22

- Origin of the Sun and Planets 26
 - Impact Origin of the Moon 27

Earth History 27

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 30

Isostasy 32

Internal Sources of Energy 33

Impact Energy and Gravitational Energy 33 •
Radioactive Isotopes 33

In Greater Depth Radioactive Isotopes 35

In Greater Depth Radioactivity Disasters 36

Gravity 36

In Greater Depth Energy, Force, Work, Power, and Heat 37

External Sources of Energy 38

The Sun 38

In Greater Depth Water—The Most Peculiar Substance on Earth? 42

Processes of Construction Versus Destruction 45

Impacts with Asteroids and Comets 46

How We Understand the Earth 46

Uniformitarianism 47

Summary 47; Terms to Remember 48; Questions for Review 48; Questions for Further Thought 48

CHAPTER 3

Plate Tectonics and Earthquakes 49

Plate Tectonics 50

Development of the Plate Tectonics Concept 51

In Greater Depth Earth's Magnetic Field 53

Magnetization of Volcanic Rocks 54

Magnetization Patterns on the Seafloors 55

Other Evidence of Plate Tectonics 56

- Earthquake Epicenters Outline the Plates 56 • Deep Earthquakes 57 • Ages from the Ocean Basins 57 • Oceanic Mountain Ranges and Deep Trenches 58 • Systematic Increases in Seafloor Depth 58 • The Fit of the Continents 59

The Grand Unifying Theory 59

Plate Tectonics and Earthquakes 62

Spreading Centers and Earthquakes 63

- Iceland 63 • Red Sea and Gulf of Aden 64

Convergent Zones and Earthquakes 65

- Subduction Zones 65 • Continent-Continent Collisions 69

Transform Faults and Earthquakes 71

The Arabian Plate 73

Continent-Continent Collision Earthquakes 73 • Transform Fault Earthquakes 73

Side Note Historical Perspective 75

Summary 75; Terms to Remember 76; Questions for Review 76; Questions for Further Thought 76

CHAPTER 4

Earthquake Geology and Seismology 77

The Lisbon Earthquake of 1755 78

What Is an Earthquake? 79

Faults and Geologic Mapping 80

Types of Faults 82

- Dip-Slip Faults 82 • Strike-Slip Faults 84 • Transform Faults 85

Development of Seismology 86

- Waves 88

Seismic Waves 88

- Body Waves 88 • Seismic Waves and the Earth's Interior 90 • Surface Waves 90 • Sound Waves and Seismic Waves 91

Locating the Source of an Earthquake 91

Magnitude of Earthquakes 92

- Richter Scale 92 • Other Measures of Earthquake Size 93 • Foreshocks, Mainshock, and

- Aftershocks 95 • Magnitude, Fault-Rupture Length, and Seismic-Wave Frequencies 95

Ground Motion During Earthquakes 95

- Acceleration 96 • Periods of Buildings and Responses of Foundations 97

Earthquake Intensity—What We Feel During an Earthquake 97

In Greater Depth What to Do Before and During an Earthquake 99

- Mercalli Scale Variables 99

A Case History of Mercalli Variables 100

- The San Fernando Valley, California, Earthquake of 1971 100

Building in Earthquake Country 102

- Shear Walls 102 • Braced Frames 103 • Retrofit Buildings 103 • Base Isolation 103 • Retrofit Bridges 105 • Houses 105

Summary 106; Terms to Remember 107; Questions for Review 107; Questions for Further Thought 107

CHAPTER 5

Tsunami 109

Indian Ocean Tsunami, 26 December 2004 110

Tsunami 111

Tsunami Versus Wind-Caused Waves 112

- Tsunami at the Shoreline 113

Causes of Tsunami 116

Earthquake-Caused Tsunami 117

- Tsunami Warnings 117 • Alaska, 1 April 1946 117 • Chile, 22 May 1960 117 • Alaska, 27 March 1964 118 • British Columbia, Washington, and Oregon—Upcoming 119

Volcano-Caused Tsunami 120

- Krakatau, Indonesia, 26–27 August 1883 120

Landslide-Caused Tsunami 121

- Volcano Collapses 121 • Earthquake-Triggered Movements 122 • In Bays and Lakes 124

Seiches 125

Tsunami and You 126

- If You Feel the Earthquake 126 • Tsunami Warnings 127

Summary 129; Terms to Remember 129; Questions for Review 129; Questions for Further Thought 129

CHAPTER 6

Some Earthquakes in Western North America 131

Subduction Zone Earthquakes 133

The Good Friday Earthquake, Alaska, 1964 133 • Mexico City, 1985 134 • Pacific Northwest, the Upcoming Earthquake 135

Spreading-Center Earthquakes 137

Transform Fault Earthquakes in California 138

San Francisco, 1906 138 • San Andreas Fault Earthquakes 139

In Greater Depth Neotectonics and Paleoseismology 142

World Series (Loma Prieta) Earthquake, 1989 144 • Bay Area Earthquakes—Past and Future 148 • Kobe, Japan, 1995 Versus Oakland, California, 20?? 150

How Faults Work 152

Old View 152 • Newer View 152 • Southern San Andreas Fault 154

In Greater Depth Earthquake Prediction—Short Term 155

Thrust Fault Earthquakes in Southern California 155

Northridge, California, 1994 156

The “Big One” 158

The Biggest One 158 • Annualized Earthquake Losses 158

Summary 159; Terms to Remember 160; Questions for Review 160; Questions for Further Thought 160

CHAPTER 7

Earthquakes in Continental US and Canada plus Hawaii 161

Western North America: Plate Boundary-Zone Earthquakes 163

Pacific Northwest: Oregon, Washington, and British Columbia 163

In Greater Depth Human-Triggered Earthquakes 165

Western Great Basin: Eastern California, Western Nevada 166 • The Intermountain Seismic Belt 168 • Intermountain Belt: Utah, Idaho, Wyoming, Montana 169 • Rio Grande Rift: New Mexico, Colorado, Westernmost Texas, Mexico 170

Intraplate Earthquakes: “Stable” Central United States 171

New Madrid, Missouri, 1811–1812 171 • Reelfoot Rift: Missouri, Arkansas, Tennessee, Kentucky, Illinois 175 • Ancient Rifts in the Central United States 176

Intraplate Earthquakes: Eastern North America 177

New England Earthquakes 177 • St. Lawrence River Valley Earthquakes 178 • Chareleston, South Carolina, 1886 178

Earthquakes and Volcanism in Hawaii 179

Earthquake in 1975 181 • Earthquakes in 2006 182

Summary 182; Terms to Remember 182; Questions for Review 182; Questions for Further Thought 183

CHAPTER 8

Volcanic Eruptions: Plate Tectonics and Magmas 185

The Hazards of Studying Volcanoes 188 • How We Understand Volcanic Eruptions 188

Plate-Tectonic Setting of Volcanoes 188

Chemical Composition of Magmas 190

In Greater Depth Minerals and Volcanic Rocks 191

Viscosity, Temperature, and Water Content of Magmas 192

Plate-Tectonic Setting of Volcanoes Revisited 193

How a Volcano Erupts 194

Eruption Styles and the Role of Water Content 194 • Some Volcanic Materials 196

Side Note How a Geyser Erupts 198

The Three Vs of Volcanology: Viscosity, Volatiles, Volume 199

Shield Volcanoes: Low Viscosity, Low Volatiles, Large Volume 199

In Greater Depth Volcanic Explosivity Index (VEI) 201

Flood Basalts: Low Viscosity, Low Volatiles, Very Large Volume 201 • Scoria Cones: Medium Viscosity, Medium Volatiles, Small Volume 202 • Stratovolcanoes: High Viscosity, High Volatiles, Large Volume 203

Side Note British Airways Flight 9 205

Lava Domes: High Viscosity, Low Volatiles, Small Volume 205 • Calderas: High Viscosity, High Volatiles, Very Large Volume 206

In Greater Depth Hot Spots 211

Summary 214; Terms to Remember 215; Questions for Review 215; Questions for Further Thought 215

CHAPTER 9

Volcano Case Histories: Killer Events 217

Volcanism at Spreading Centers 218

Iceland 218

Volcanism at Subduction Zones 219

Cascade Range, Pacific Coast of United States and Canada 220

Killer Events and Processes 229

The Historic Record of Volcano Fatalities 229 • Pyroclastic Flows 229 • Tsunami 234 • Lahars 234 • Indirect—Famine 236

Side Note Death at Ashfall, Nebraska 237

Gas 238 • Lava Flows 240

VEIs of Some Killer Eruptions 240

Volcano Monitoring and Warning 240

Signs of Impending Eruption 243 • Volcano Observatories 243

Summary 244; Terms to Remember 244; Questions for Review 244; Questions for Further Thought 244

CHAPTER 10

Mass Movements 245

The Role of Gravity 246

Creep 247

External Causes of Slope Failures 248

Water in Its External Roles 249

Internal Causes of Slope Failures 249

Inherently Weak Materials 249 • Canadian Quick-Clay Slope Failures 250 • Water in Its Internal Roles 250

In Greater Depth Analysis of Slope

Stability 251

Decreases in Cohesion 254 • Adverse Geologic Structures 254 • Triggers of Mass Movements 255

Classification of Mass Movements 255

Falls 256

Yosemite National Park, California 256

Slides 257

Rotational Slides 257 • Translational Slides 260

Flows 261

Portuguese Bend, California, Earthflow 262 • La Conchita, California Slump and Debris Flows, 1995 and 2005 263 • Long-Runout Debris Flows 265 • Snow Avalanches 269

Mitigation 270

Submarine Mass Movements 271

Subsidence 272

Slow Subsidence 272

Side Note How to Create a Cave 275

Catastrophic Subsidence 275

Summary 277; Terms to Remember 277; Questions for Review 278; Questions for Further Thought 278

CHAPTER 11

Weather Principles and Tornadoes 279

Weather Versus Climate 280

Solar Radiation Received by Earth 281

Albedo 281 • Greenhouse Effect 281

Side Note Temperature Scales 282

Water and Heat 282

Vertical Movement of Air 283

Adiabatic Processes 284 • Lapse Rates 284 • Differential Heating of Land and Water 284

Layering of the Lower Atmosphere 285

General Circulation of the Atmosphere 285

Low Latitudes 286 • Middle and High Latitudes 287

In Greater Depth Coriolis Effect 290

Observed Circulation of the Atmosphere 292

General Circulation of the Oceans 292

Surface Circulation 292 • Deep-Ocean Circulation 293

Severe Weather 294

Midlatitude Cyclones 294

The Eastern US “Storm of the Century” 12–15 March 1993 295

In Greater Depth Doppler Radar 297

Blizzards 297 • Ice Storms 298

How a Thunderstorm Works 298
Downbursts: An Airplane's Enemy 300
Thunderstorms in North America 302
Heavy Rains and Flash Floods 304 • Hail 305 •
Lightning 306 • Destructive Winds 310
Tornadoes 311
Tri-State Tornado, 18 March 1925 311 • What Makes
Tornadoes? 312 • Tornadoes in the United States and
Canada 313 • The Super Outbreak, 3–4 April 1974
317 • Tornadoes and Cities 319
Summary 320; *Terms to Remember* 320;
Questions for Review 320; *Questions for Further
Thought* 321

CHAPTER 12

Climate Change 323

Early Earth Climate—An Intense Greenhouse 324
Climate History of the Earth: Timescale in
Millions of Years 325
Late Paleozoic Ice Age 326 • Late Paleocene
Torrid Age 327

In Greater Depth Oxygen Isotopes
and Temperature 329

Late Cenozoic Ice Age 329

Glacial Advance and Retreat: Timescale in
Thousands of Years 329

Climate Variations: Timescale in Hundreds of
Years 333

Shorter-Term Climate Changes: Timescale in
Multiple Years 334

El Niño 334 • La Niña 337 • Pacific Decadal
Oscillation 338

Volcanism and Climate 338
Volcanic Climate Effects 340

In Greater Depth The Mayan Civilization
and Climate Change 341

The Last Thousand Years 341

The 20th Century 342

Side Note Stradivari Violins 343

Solar Energy Variation 343

The Greenhouse Effect Today 343

In Greater Depth When Did Humans Begin
Adding to Greenhouse Warming? 344

Carbon Dioxide (CO₂) 344 • Methane (CH₄) 345
• Nitrous Oxide (N₂O) 345 • Ozone (O₃) 345 •

Chlorofluorocarbons (CFCs) 345 • 20th-Century
Greenhouse Gas Increases 345

The 21st Century 346

Warmest Years 346

Heat Waves 346

Heat Wave in Chicago, July 1995 346 • Europe's
Heat Wave, 2003 347

Global Climate Models 348

Temperature 348 • Precipitation 348

Drought and Famine 349

US Dust Bowl, 1930s 350

Ice Melting 351

Arctic Sea Ice 351

In Greater Depth Tipping Points 352

Greenland 352 • Antarctica 352

In Greater Depth Lag Times 353

Sea-Level Rise 353

Ocean Circulation 353

Signs of Change 353

Mitigation Options 353

Cap-and-Trade 353 • Drastic Engineering 355

Summary 355; *Terms to Remember* 356;

Questions for Review 356; *Questions for Further
Thought* 357

CHAPTER 13

Hurricanes and the Coastline 359

Hurricanes 360

How a Hurricane Works 361

Hurricane Energy Release 362 • The Eye 362 •
Rain Bands 363

Hurricane Origins 363

North Atlantic Ocean Hurricanes 364

Cape Verde-Type Hurricanes 365 • Caribbean
Sea- and Gulf of Mexico-Type Hurricanes 369 •
Forecasting the Hurricane Season 370 • Hurricane
Damages 372

In Greater Depth The Role of Global Warming
in Hurricane Frequency and Intensity 374

Hurricanes and the Gulf of Mexico
Coastline 374

Galveston, Texas, September 1900 374 •
Hurricane Katrina 376

Hurricanes and the Atlantic Coastline 378

Hugo, September 1989 378

The Evacuation Dilemma 378
 Reduction of Hurricane Damages 379
 Building Codes 379 • Land-Use Planning 380 •
 Coastal Development Restrictions 380
 Global Rise in Sea Level 380
 Hurricanes and the Pacific Coastline 381
 Iniki, September 1992 381
 Cyclones and Bangladesh 382
 Coastline 383
 Waves in Water 383
 Rogue Waves 384
 Waves on the Coastline 386
 Why a Wave Breaks 386 • Summer Versus Winter
 Beaches 386 • Wave Refraction 387

In Greater Depth Deep-Water Wave
 Velocity, Length, Period, and Energy 388
 Longshore Drift 389

Human Effects on the Coast 389
 Dams 389 • Cliff Armoring 390 • Groins 390

Side Note You Can Never Do Just One
 Thing 391

Breakwaters 391 • Jetties 391

*Summary 392; Terms to Remember 393; Questions
 for Review 393; Questions for Further Thought 393*

CHAPTER 14

Floods 395

How Rivers and Streams Work 396
 Longitudinal Cross Section of a Stream 396

Side Note A Different Kind of Killer
 Flood 397

The Equilibrium Stream 398

The Floodplain 400
 Flood Frequency 400

Side Note Feedback Mechanisms 401

In Greater Depth Constructing Flood-
 Frequency Curves 402

Flood Styles 403

Flash Floods 403

Antelope Canyon, Arizona, 1997 404 • Big
 Thompson Canyon, Colorado, 1976 404 • Rapid
 Creek, Black Hills, South Dakota, 1972 407

Regional Floods 407

Red River of the North 408 • Mississippi River
 System 409 • China 412

Societal Responses to Flood Hazards 413

Dams 413 • Levees 414 • Sandbagging 415 •
 Forecasting 415 • Zoning and Land Use 415 •
 Insurance 415 • Presidential Disaster
 Declarations 415

Urbanization and Floods 416

Hydrographs 416 • Flood Frequencies 416 •
 Channelization 416

The Biggest Floods 420

Ancient Tales of Deluge 420 • Ice-Dam Failure
 Floods 421

*Summary 423; Terms to Remember 424; Questions
 for Review 424; Questions for Further Thought 424*

CHAPTER 15

Fire 425

What Is Fire? 427

The Need for Fire 427

Side Note The Burning of Rome, 64 CE 428

The Fire Triangle 428

Side Note An Ancient View of Fire 429

The Stages of Fire 430

The Spread of Fire 431

Fuel 431 • Wind 433 • Topography 433 • Fire
 Behavior 433

The Fuels of Fire 433

Grasses 433 • Shrubs 434 • Forests 434

Fire Weather 435

Winds of Fire 436

Cold-Front Winds 436 • Foehn Winds 436 •
 Local Winds 437 • Great Lakes Region 437 •
 California 438

Home Design and Fire 442

Side Note The Winds of Madness 443

How Well Have We Learned? 445

Fire Suppression 446

Yellowstone National Park 446 • California Versus
 Baja California: Pay Now or Pay Later 448 • The
 Western and Southern United States in 2000 450 •
 Prescribed Fires 451 • Australia 452

The Similarities of Fire and Flood 452

*Summary 453; Terms to Remember 454; Questions
 for Review 454; Questions for Further Thought 454*

CHAPTER 16

The Great Dyings 455

- Fossils 456
- Early Understanding of Extinctions and Geologic Time 457
 - Brief History of Life 459
- Species and the Fossil Record 461
- The Tropical Reef Example 462
- Mass Extinctions During Phanerozoic Time 462
- Possible Causes of Mass Extinctions 464
 - Plate-Tectonic Causes 464 • Volcanic Causes 467 • Climate Change Causes 467 • Ocean Composition Causes 467 • Extraterrestrial Causes 467 • Biologic Causes 468 • Multiple Causes of Mass Extinction 469
- Examples of Mass Extinctions 469
 - Closing of Permian Time (Ended 253 Million Years Ago) 470 • Close of Cretaceous Time (Ended 65 Million Years Ago) 471
- Living Fossils 474
 - Quaternary Extinctions 475

In Greater Depth La Brea Tar Pits, Metropolitan Los Angeles 477

Side Note The Rewilding of North America 479

Summary 479; Terms to Remember 480; Questions for Review 480; Questions for Further Thought 480

CHAPTER 17

Impacts with Space Objects 481

- Impact Scars 482
- Sources of Extraterrestrial Debris 483
 - Asteroids 483 • Comets 486

- Rates of Meteoroid Influx 488
 - Cosmic Dust 488

In Greater Depth Shoemaker-Levy 9 Comet Impacts on Jupiter 489

- Shooting Stars 490 • Meteorites 490
- The Crater-Forming Process 491
- Crater-Forming Impacts 492
 - Meteor Crater, Arizona 493
- Impact Origin of Chesapeake Bay 495
- The Cretaceous/Tertiary Boundary Event 496
 - Evidence of the K/T Impact 496 • Site of the K/T Impact 497 • Angle of Impact 497
- Problems for Life from Impacts 497
- Biggest Event of the 20th Century 498
 - Tunguska, Siberia, 1908 498
- Biggest “Near Events” of the 20th Century 500
- Frequency of Large Impacts 500
 - A Defense Plan 501
- Summary 503; Terms to Remember 504; Questions for Review 504; Questions for Further Thought 504*

Glossary 505

Credits 514

Index 515