

2750-6365

E N V I R O N M E N T A L G E O L O G Y
Eighth Edition

EDWARD A. KELLER

University of California, Santa Barbara



PRENTICE HALL, UPPER SADDLE RIVER, NEW JERSEY 07458

BRIEF CONTENTS

PART 1

Foundations of Environmental Geology 1

CHAPTER 1
Philosophy and Fundamental Concepts 2

CHAPTER 2
Earth Materials and Processes 24

CHAPTER 3
Soils and Environment 56

PART 2

Hazardous Earth Processes 85

CHAPTER 4
Natural Hazards: An Overview 86

CHAPTER 5
Rivers and Flooding 98

CHAPTER 6
Landslides and Related Phenomena 132

CHAPTER 7
Earthquakes and Related Phenomena 161

CHAPTER 8
Volcanic Activity 205

CHAPTER 9
Coastal Hazards 232

PART 3

Human Interaction with the Environment 259

CHAPTER 10
Water: Process, Supply, and Use 260

CHAPTER 11
Water Pollution and Treatment 291

CHAPTER 12
Waste Management 317

CHAPTER 13
The Geologic Aspects of Environmental Health 342

PART 4

Minerals, Energy, and Environment 373

CHAPTER 14
Mineral Resources and Environment 374

CHAPTER 15
Energy and Environment 400

PART 5

Global Change, Land Use, and Decision Making 445

CHAPTER 16
Global Change and Earth System Science 446

CHAPTER 17
Air Pollution 472

CHAPTER 18
Landscape Evaluation and Land Use 493

C O N T E N T S

Preface xiii

PART I

Foundations of Environmental Geology 1



CHAPTER 1

Philosophy and Fundamental Concepts 2

Introduction to Environmental Geology 3

How Geologists Work: The Scientific Method 4

Culture and Environmental Awareness 4

Environmental Ethics 5

The Environmental Crisis 5

▶ *A Closer Look* The Land Ethic and the American Experience 6

Fundamental Concepts of Environmental Science 7

Concept One: Population Growth 7

▶ *Case History* Aral Sea 8

Concept Two: Sustainability 9 / Concept Three: Systems 11

▶ *Putting Some Numbers On* Exponential Growth 16

Concept Four: Limitation of Resources 16 / Concept Five: Uniformitarianism 17

▶ *A Closer Look* The Gaia Hypothesis 17

Concept Six: Hazardous Earth Processes 18 / Concept Seven: Geology as a Basic Environmental Science 19

Concept Eight: Our Obligation to the Future 19

▶ *A Closer Look* Geology and Ecosystems 20

CHAPTER 2

Earth Materials and Processes 24

The Geologic Cycle 24

The Tectonic Cycle 24 / The Rock Cycle 30 / The Hydrologic Cycle 31 / Biogeochemical Cycles 31

Rocks 35

▶ *A Closer Look* Minerals 36

The Strength of Rocks 36

▶ *A Closer Look* Stress and Strain 38

Types of Rocks 38

▶ *Case History* Baldwin Hills Dam 40

Surficial Processes: Ice and Wind 45

Ice 45

▶ *Case History* St. Francis Dam 46

▶ *Case History* Hubbard Glacier 48

Wind 50



CHAPTER 3

Soils and Environment 56

Introduction to Soils 56

Soil Profiles 57

Soil Horizons 57 / Soil Color 59 / Soil Texture 59

Soil Structure 59 / Relative Profile Development 60

Soil Chronosequences 60

Soil Fertility 61

Water in Soil 61

Soil Classification 62

Soil Taxonomy 62 / Engineering Classification of Soils 63

Engineering Properties of Soils 63

▶ *Putting Some Numbers On* Properties of Soil 64

Rates of Soil Erosion 69

Sediment Pollution 69

▶ *A Closer Look* Universal Soil Loss Equation 71

▶ *Case History* Reduction of Sediment Pollution, Maryland 72

Land Use and Environmental Problems of Soils 73

Urbanization 75 / Off-Road Vehicles 75

Soil Pollution 77

Desertification 78

Soil Surveys and Land-Use Planning 79

▶ *Case History* Desertification of the San Joaquin Valley 80

PART 2**Hazardous Earth Processes 85****CHAPTER 4****Natural Hazards: An Overview 86****Hazards as Natural Processes 86**

- ▶ *A Closer Look* The Magnitude-Frequency Concept 88

Benefits of Natural Hazards 88 / Death and Damage Caused by Natural Hazards 88

Evaluating Hazards: Disaster Prediction and Risk Assessment 89

Disaster Prediction and Warning 90

- ▶ *A Closer Look* Scientists, Hazards, and the Media 91

Risk Assessment 92

The Human Response to Hazards 92

Reactive Response: Impact of and Recovery from Disasters 92 / Anticipatory Response: Avoiding and Adjusting to Hazards 93

Global Climate and Hazards 94**Population Increase, Land-Use Change, and Natural Hazards 94**

Population Increase and Hazardous Events 94

Land-Use Change and Hazardous Events 95

CHAPTER 5**Rivers and Flooding 98****River Processes 98**

Streams and Rivers 99 / Sediments in Rivers 99
River Velocity, Erosion, and Sediment Deposits 100
Effect of Land-Use Changes 101 / Channel Patterns and Floodplain Formation 102

Flooding 105

Upstream and Downstream Floods 105

Development and Flooding 107

- ▶ *A Closer Look* Magnitude and Frequency of Floods 108

The Nature and Extent of Flood Hazards 109

- ▶ *Case History* Las Vegas, Nevada 110

The Response to Flood Hazards 111

Prevention: Physical Barriers 111

- ▶ *Case History* Flash Floods in Eastern Ohio 112

Adjustment: Floodplain Regulation 116

- ▶ *Case History* Tucson, Arizona 115

The Channelization Controversy 117

- ▶ *A Closer Look* History of a River 118

Perception of Flooding 122

Mississippi River Flooding, 1973 and 1993 122

- ▶ *Putting Some Numbers On* Flood Hazard Analysis 124

**CHAPTER 6****Landslides and Related Phenomena 132****Introduction to Landslides 132****Slope Processes and Slope Stability 133**

Slope Stability 134

- ▶ *Putting Some Numbers On* Landslides 136

Causes of Landslides 143

Human Use and Landslides 144

Timber Harvesting and Landslides 145

Urbanization and Landslides 145

- ▶ *Case History* Vaiont Dam 146

- ▶ *A Closer Look* Determining Landslide Hazard and Risk 148

Minimizing the Landslide Hazard 149

Identification of Potential Landslides 149

Prevention of Landslides 150

- ▶ *Case History* Portuguese Bend Landslide 151

Landslide Warning Systems 152 / Landslide

Correction 152

Snow Avalanche 152**Subsidence 154**

Sinkholes 154 / Salt Deposits and Subsidence 156

Coal Mining and Subsidence 156

- ▶ *Case History* Lehigh Valley, Pennsylvania 157

Perception of the Landslide Hazard 157

- ▶ *Case History* Lake Peigneur, Louisiana 158

CHAPTER 7**Earthquakes and Related Phenomena 161****Introduction to Earthquakes 161****Earthquake Processes 162**

Faults and Fault Movement 162

- ▶ *A Closer Look* Intraplate Earthquakes at New Madrid 163
- ▶ *A Closer Look* The Northridge Earthquake and Buried Faults 166

Seismic Waves and Ground Shaking 168
 Comparing Earthquakes 172 / The Earthquake Cycle 175

- ▶ *A Closer Look* Moment Magnitude 176

Earthquakes Caused by Human Activity 179

Effects of Earthquakes 180

- Shaking and Ground Rupture 182 / Liquefaction 182
- Landslides 183 / Fires 183 / Tsunamis 183
- Regional Changes in Land Elevation 184

Earthquake Risk and Earthquake Prediction 184

- Estimation of Seismic Risk 184 / Conditional Probabilities for Future Earthquakes 185
- Short-Term Prediction 187 / Toward Earthquake Prediction 189
- ▶ *A Closer Look* Twelve Centuries of Earthquakes on the San Andreas Fault in Southern California 190

The Response to Earthquake Hazards 190

- Earthquake Hazard-Reduction Programs 190
- Earthquakes and Critical Facilities 191
- Adjustments to Earthquake Activity 192
- Earthquake Warning Systems 193 / Perception of the Earthquake Hazard 195
- ▶ *Putting Some Numbers On* Earthquake Hazard Evaluation 196

CHAPTER 8

Volcanic Activity 205

Introduction to Volcanic Hazards 205

Volcanism and Volcanoes 206

- Volcano Types 206 / Volcano Origins 210
- Volcanic Features 211 / Caldera Eruptions 211

Volcanic Hazards 213

- Lava Flows 213
- ▶ *A Closer Look* The Long Valley Caldera 214
- Pyroclastic Hazards 216 / Poisonous Gases 216
- ▶ *Case History* Controlling a Lava Flow in Iceland 217
- Debris Flows and Mudflows 218

Some Case Histories 219

- Mt. Unzen, Japan 219 / Nevado del Ruiz 219
- Mt. Pinatubo 220 / Mount St. Helens 221
- ▶ *Case History* Surviving to Tell the Tale 224

Prediction of Volcanic Activity 225

- Seismic Activity 226 / Geophysical Monitoring 226

- Topographic Monitoring 226 / Monitoring of Volcanic Gases 226 / Geologic History 227
- Progress in Prediction of Eruptions 227 / Volcanic Alert or Warning 228

Adjustment to and Perception of the Volcanic Hazard 224



CHAPTER 9

Coastal Hazards 232

Introduction to Coastal Hazards 232

Tropical Cyclones 233

Tidal Floods 236

Coastal Processes 236

- Waves 236
- ▶ *Case History* The Thames Barrier 237
- Beach Form and Beach Processes 238
- Littoral Cells, Beach Budget, and Wave Climate 240

Coastal Erosion 241

- Erosion Factors 241 / Seacliff Erosion 242
- ▶ *Putting Some Numbers On* A Beach Budget 244

Coastal Hazards and Engineering Structures 246

- Seawalls 246 / Groins 246 / Breakwaters and Jetties 246 / Beach Nourishment 247
- ▶ *Case History* Galveston and Seabright 249

Human Activity and Coastal Erosion: Some Examples 250

- The Atlantic Coast 250 / The Gulf Coast 252
- The Great Lakes 252

Perception of and Adjustment to Coastal Hazards 248

- Perception of Coastal Erosion 253 / Adjustment to Coastal Hazards 253
- ▶ *A Closer Look* E-Lines and E-Zones 255
- The Cape Hatteras Lighthouse Controversy 256

PART 3

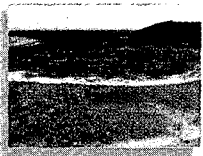

Human Interaction with the Environment 259

CHAPTER 10

Water: Process, Supply, and Use 260

Water: A Brief Global Perspective 261

Water as a Unique Liquid 262

Surface Runoff and Sediment Yield	263		
Factors Affecting Runoff 264 / Runoff Paths 266 Sediment Yield 266			
Groundwater	267		
Aquifers 269 / Groundwater Movement 270 Interactions Between Surface Water and Groundwater 270			
▶ <i>Putting Some Numbers On</i> Groundwater Flow 272			
Perceptions About Groundwater 272			
Water Supply	273		
The Water Budget 273 / The Groundwater Supply 274 / Desalination 275			
Water Use	275		
Movement of Water to People 277 / Trends in Water Use 279 / Water Conservation 280			
Water Management	281		
The Future of Water Management 281 / A Managed River: The Colorado 281			
Dams, Reservoirs, and Canals	284		
Dams and Reservoirs 284 / Canals 285			
Water and Ecosystems	285		
▶ <i>Case History</i> The Grand Canyon 286			
▶ <i>A Closer Look</i> Wetlands 288			
			
CHAPTER II			
Water Pollution and Treatment	291		
<hr/>			
An Overview of Water Pollution	292		
Selected Water Pollutants	293		
Oxygen-Demanding Waste 293 / Pathogenic Organisms 293 / Nutrients 294 / Oil 294			
▶ <i>Case History</i> Exxon Valdez 296			
Toxic Substances 296 / Sediments 297 Thermal Pollution 297			
Surface-Water Pollution and Treatment	297		
Point Sources of Surface-Water Pollution 298 Nonpoint Sources of Surface-Water Pollution 298 Reduction of Surface-Water Pollution 298			
▶ <i>A Closer Look</i> Acid Mine Drainage 299			
Groundwater Pollution and Treatment	299		
▶ <i>Case History</i> Cleaning Up the Hudson 300			
Comparison of Groundwater and Surface-Water Pollution 300 / Exchanges Between Groundwater and Its Surroundings 301 / Salt Water Intrusion 301			
▶ <i>Case History</i> The Threatened Groundwater of Long Island 302			
Groundwater Treatment 302			
Water Quality Standards	305		
Wastewater Treatment	305		
Septic-Tank Sewage Disposal 306 / Wastewater Treatment Plants 308 / Wastewater Renovation 309 Wastewater Treatment as Resource Recovery 309			
Water Law and Federal Legislation	310		
Surface Water Law 311 / Groundwater Law 311			
▶ <i>Case History</i> Mono Lake and the Public Trust Doctrine 312			
Federal Water Legislation 314			
CHAPTER 12			
Waste Management	317		
<hr/>			
Concepts of Waste Management: An Overview	317		
Earlier Views 318			
▶ <i>Case History</i> The Fresh Kills Landfill 319			
Modern Trends: Integrated Waste Management 320			
Materials Management	320		
Solid-Waste Disposal	320		
On-site Disposal 321 / Composting 321 Incineration 321 / Open Dumps 322 Sanitary Landfills 322			
Hazardous Waste Management	325		
▶ <i>Case History</i> Love Canal 326			
Responsible Management 327 / Secure Landfill 328 Land Application 330 / Surface Impoundment 330 Deep-well Disposal 330 / Incineration of Hazardous Chemical Waste 332 / Alternatives to Land Disposal 333			
Radioactive Waste Management	334		
Disposal of Low-level Radioactive Wastes 334 Disposal of High-level Radioactive Wastes 336			
Ocean Dumping	338		
Ocean Dumping and Pollution 338 / Ocean Dumping: The Conflict 339			
			
CHAPTER 13			
The Geologic Aspects of Environmental Health	342		
<hr/>			
Introduction to Environmental Health	343		
Environmentally Transmitted Infectious Diseases 343 Cultural Factors 343 / Climatic Factors 344			

Some Geologic Factors of Environmental Health	344
Natural Abundances of Elements	345
Concentration and Dispersion of Chemical Substances	345
▶ <i>A Closer Look</i> Nitrogen and People	349
Trace Elements and Health	349
Dose Dependency and Effective Dose	349
Imbalances of Selected Trace Elements	351
Human Use and Imbalances of Trace Elements	354
Chronic Disease and Geologic Environment	354
Heart Disease and the Geochemical Environment	354
▶ <i>Case History</i> Mining and Toxic Trace Elements	355
Cancer and the Geochemical Environment	356
▶ <i>Case History</i> Heart Disease in Georgia	357
▶ <i>A Closer Look</i> Asbestos	358
Radioactivity and Radon Gas	359
The Nature of Radioactivity	359 / Radiation Units 360 / The Health Danger from Radioactive Radiation 361 / Radon Gas 362
Risk Assessment in Toxicology	368



CHAPTER 15

Energy and Environment	400
Energy Supply and Energy Demand	400
Fossil Fuels	402
Coal 402 / Hydrocarbons: Oil and Gas 407	
▶ <i>Case History</i> A Tale of Two Mines	408
Fossil Fuels and Acid Rain	414
Environmental Effects of Acid Rain	415
A Solution to the Acid Rain Problem	416
Oil in the Twenty-first Century	417
Nuclear Energy: Fission and Fusion	417
Energy from Fission 417 / Energy from Fusion	421
Geothermal Energy	422
Geology of Geothermal Energy	422
▶ <i>Case History</i> Two Reactor Accidents	424
Environmental Impact of Geothermal Energy Development	427 / The Future of Geothermal Energy 427
Renewable Energy Sources	428
Direct Solar Energy 429 / Water Power 433	
Wind Power 435 / Energy from Biomass 436	
Conservation, Efficiency, and Cogeneration	437
Energy Policy for the Future	437
Hard Path Versus Soft Path 437 / A Sustainable Energy Policy 438	
▶ <i>A Closer Look</i> Fuel Cells	439

PART 4

Minerals, Energy, and Environment	373
------------------------------------------	------------

CHAPTER 14

Mineral Resources and Environment	374
Minerals and Human Use	374
Resources and Reserves 375 / Availability and Use of Mineral Resources	376
Geology of Mineral Resources	379
Local Concentrations of Metals	379
Igneous Processes	381
▶ <i>A Closer Look</i> Plate Tectonics and Minerals	382
Metamorphic Processes 385 / Sedimentary Processes 386 / Biological Processes 388	
Weathering Processes 389 / Minerals from the Sea 390	
Environmental Impact of Mineral Development	392
Impact of Mineral Exploration and Testing	392
Impact of Mineral Extraction and Processing	392
Minimizing the Impact of Mineral Development	394
The Impact of Mineral Development: Summary and Conclusions	395
Recycling of Mineral Resources	395
▶ <i>Case History</i> Homestake Mine, South Dakota	395
Recycling Scrap Metal 396 / Urban Ore 396	

PART 5

Global Change, Land Use, and Decision Making	445
-----------------------------------------------------	------------

CHAPTER 16

Global Change and Earth System Science	446
Global Change and Earth System Science: An Overview	446
Tools for Studying Global Change	448
The Geologic Record 448 / Real-Time Monitoring 449 / Mathematical Models 449	
Earth's Atmosphere and Energy Balance	450
The Atmosphere 450 / Solar Radiation and Earth's Energy Balance 451	

Atmospheric Carbon Dioxide and Global Warming 453
 The Greenhouse Effect 453 / Changes in Greenhouse Gases 454

Global Temperature Change: Evidence for a Warming Trend 456
 Role of Particulates in the Atmosphere 457
 ► *A Closer Look* Causes of Climatic Change 460
 Potential Effects of Global Warming 463 / Strategies for Reducing the Impact of Global Warming 464

Ozone Depletion 465
 Ozone Formation and the Ozone Layer 465
 Removal of Stratospheric Ozone 466
 Environmental Effects of Ozone Depletion 467
 Management Issues Related to Ozone Depletion 467

Coupling of Global-Change Processes 467
 ► *A Closer Look* Role of Stratospheric Clouds in Antarctic Ozone Depletion 468



CHAPTER 17

Air Pollution 472

Introduction to Air Pollution 472

Pollution of the Atmosphere 473
 General Effects of Air Pollution 473
 ► *Case History* The London Smog Crisis of 1952 474
 Sources of Air Pollution 475 / Air Pollutants 475

Urban Air Pollution 479
 Influence of Meteorology and Topography 479
 Potential for Urban Air Pollution 480 / The Urban Microclimate 480 / Smog Production 482
 The Future of Air Pollution in Urban Areas 483

Indoor Air Pollution 484

Control of Air Pollution 484
 Control of Particulates 486 / Control of Automobile Pollution 486 / Control of Sulfur Dioxide 486
 Air Quality Standards 488 / The Cost of Controls 490

CHAPTER 18

Landscape Evaluation and Land Use 493

Landscape Evaluation, Land Use, and the Earth Scientist 493

Environmental Geology Mapping 494
 Interpretive Environmental Geology Maps 494
 Environmental Resource Units (ERUs) 495
 The Geographic Information System 495

Site Selection 499
 Role of the Earth Scientist in Site Selection 499
 Methods of Site Selection 499 / Site Evaluation for Engineering Purposes 500

Environmental Impact Analysis 502
 Environmental Impact Statements 502 / State Environmental Impact Legislation 503 / Negative and Mitigated Negative Declarations 503
 Methodology and Achievements of Environmental Impact Analysis 504

Case Histories: Uses of Environmental Impact Analysis 504
 Cape Hatteras National Seashore 504 / The San Joaquin Valley 506

Land Use and Planning 511
 Scenic Resources 511 / Sequential Land Use 511
 Land-Use Planning 512 / Comprehensive Planning 512
 ► *Case History* Butchart Gardens 514
 Land Management 514 / Emergency Planning 515

Environmental Law 515
 The Process of Law 515 / Some Legal Case Histories 516 / Environmental Legislation 518
 Land-Use Planning and Law 519

Appendix A: World Wide Web: An Introductory Statement 523

Appendix B: Maps and Related Topics 527

Glossary 535

Index 551