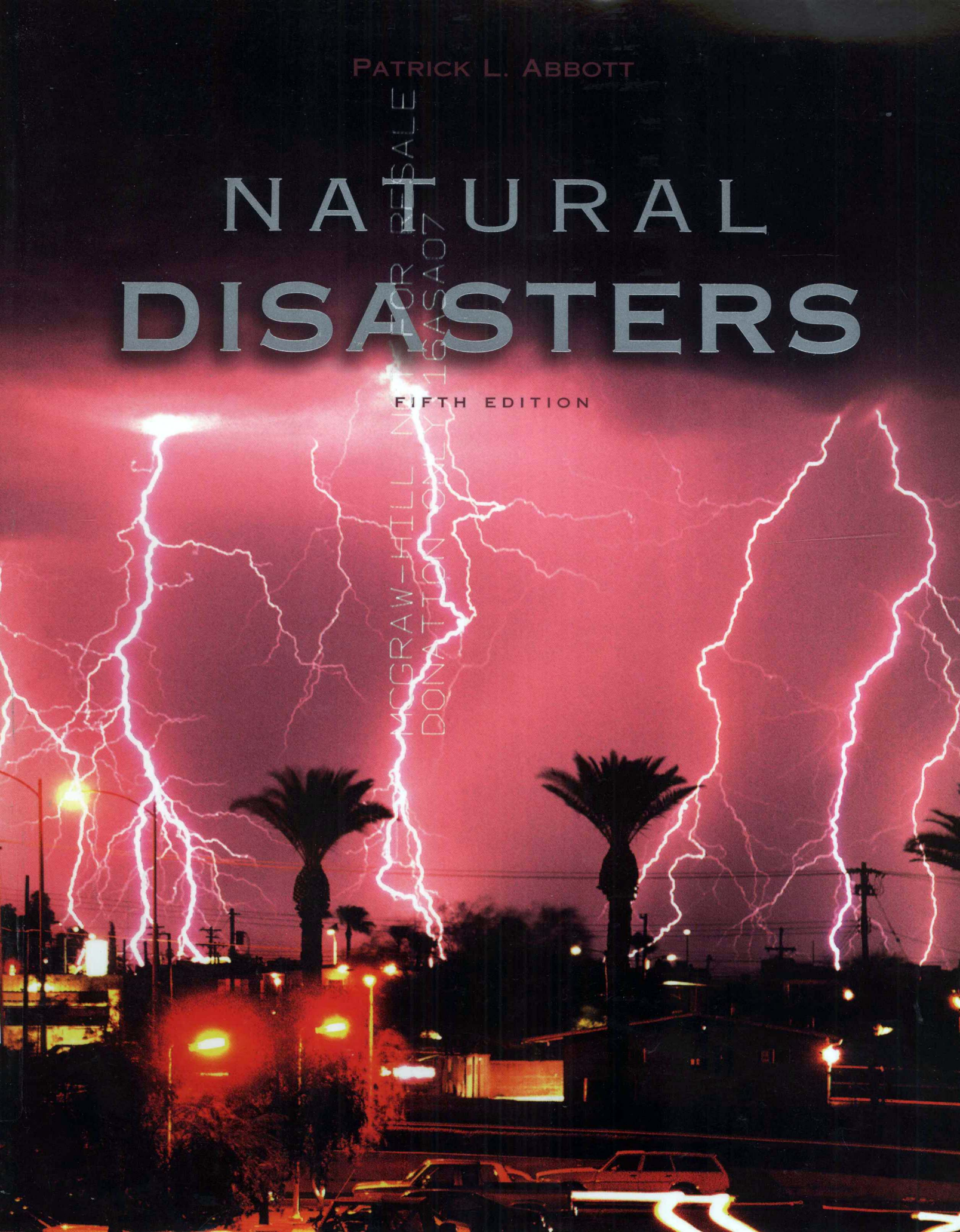


PATRICK L. ABBOTT

NATURAL DISASTERS

FIFTH EDITION

FOR RESALE
16SASAO7
MCGRAW-HILL
DONATION ONLY





Higher Education

NATURAL DISASTERS, FIFTH EDITION

Published by McGraw-Hill, a business unit of The McGraw-Hill Companies, Inc., 1221 Avenue of the Americas, New York, NY 10020. Copyright © 2006, 2004, 2002, 1999, 1996 by The McGraw-Hill Companies, Inc. All rights reserved. No part of this publication may be reproduced or distributed in any form or by any means, or stored in a database or retrieval system, without the prior written consent of The McGraw-Hill Companies, Inc., including, but not limited to, in any network or other electronic storage or transmission, or broadcast for distance learning.

Some ancillaries, including electronic and print components, may not be available to customers outside the United States.

♻️ This book is printed on recycled, acid-free paper containing 10% postconsumer waste.

2 3 4 5 6 7 8 9 0 / 0 9 8 7 6

ISBN-13: 978-0-07-282681-4

ISBN-10: 0-07-282681-9

Publisher: *Margaret J. Kemp*

Senior Sponsoring Editor: *Daryl Bruflodt*

Senior Developmental Editor: *Lisa A. Bruflodt*

Executive Marketing Manager: *Lisa L. Gottschalk*

Project Manager: *Peggy S. Lucas*

Senior Production Supervisor: *Sherry L. Kane*

Senior Media Project Manager: *Jodi Banowetz*

Senior Media Technology Producer: *Jeffrey Schmitt*

Designer: *Rick D. Noel*

Cover/Interior Designer: *Jamie O'Neal*

(USE) Cover Image: ©Science Source, BA4713, Lightning Bolts by Kent Wood

Senior Photo Research Coordinator: *John Leland*

Photo Research: *Mary Reeg*

Compositor: *Carlisle Communications, Ltd.*

Typeface: *10/12 Times Roman*

Printer: *Quebecor World Dubuque, IA*

The credits section for this book begins on page 485 and is considered an extension of the copyright page.

Library of Congress Cataloging-in-Publication Data

Abbott, Patrick L.

Natural disasters / Patrick L. Abbott.—5th ed.

p. cm.

Includes bibliographical references and index.

ISBN 0-07-282681-9 (hard copy : alk. paper)

1. Natural disasters. I. Title.

GB5014.A24 2006

904'.5—dc22

2005003495

CIP

TO MY PARENTS

Clement L. and Constance V. Abbott
for their lifetime of interest and support
of my activities

• • •



PATRICK L. ABBOTT • • •

Patrick Abbott is a native San Diegan on the faculty of San Diego State University. Pat earned his MA and PhD degrees in geology at the University of Texas at Austin. He benefited greatly from the depth and breadth of the faculty in the Department of Geological Sciences at Austin; this was extended by their requirement to take five additional graduate courses outside the de-

partment. Developing interests in many topics helped lead to writing this textbook.

Pat's research has concentrated on the Mesozoic and Cenozoic sedimentary rocks of the southwestern United States and northwestern Mexico. Studies have focused on reading the history stored within the rocks—depositional environments, provenance, paleoclimate, palinspastic reconstructions, and high-energy processes.

Pat has long been involved in presenting earth knowledge to the public, primarily through local TV news. At present, he has embarked on producing videos for TV broadcast in a series called *Written in Stone*. The first video, *The Rise and Fall of San Diego*, won 2002 awards in the Videographers (Award of Distinction) and AXIEM (Silver Axiem) competitions. The second video, *Earthquake Country—Los Angeles*, was completed in 2004 and is now playing on some California TV stations. To add a little spice to life, Pat played the role of The Professor on season one of the “reality” TV series *The Real Gilligan's Island*, which aired on TBS in late 2004.

PREFACE



WHY THE BOOK WAS WRITTEN

In the early 1970s, Bill Ganus and I developed an environmental geology course at San Diego State University. The growing awareness of the environment and the availability of good textbooks made it natural to offer a general education course looking at geological hazards, resource utilization and disposal, and intelligent planning in concert with the environment. The course had moderately successful enrollments, chugging along at 25 to 35 students per semester for over a decade.

In 1987, Tom Rockwell and I were discussing the environmental geology course and speculating on why it never attracted large enrollments. We agreed that the natural disasters portions of the course were the most popular. So, I formally changed the name of the course to "Natural Disasters" but did not change the course description or textbook, or advertise the change in any way. Yet almost instantly, students reading through the fine print of semester course offerings saw the "Natural Disasters" listing and enrollments skyrocketed. Now we offer multiple sections filling more than 5,000 classroom seats per academic year and still do not satisfy demand.

San Diego State University students do not have to take Natural Disasters. They can select from over 30 courses among 10 departments with offerings such as Biology of Sex, Evolution, Origin of Life, The Oceans, Dinosaurs, and Confronting AIDS. But more students opt for Natural Disasters than any other course. If your department could benefit from higher enrollments of nonmajor students, I strongly recommend offering a Natural Disasters course. Earthquakes, hurricanes, tornadoes, and other high-energy processes of our active Earth affect children's lives. As students, they want to understand why these natural disasters happen. The students' high level of interest can be channeled by the instructor into some significant understanding about how the Earth works.



ABOUT THE BOOK

This book focuses on natural disasters: how the normal processes of the Earth concentrate their energies and deal heavy blows to humans and their structures. It largely ignores the numerous case histories describing human actions and resultant environmental responses; these topics are left to the excellent textbooks on environmental geology. Nor does this book address resource extraction, utilization, and disposal; these subjects are covered by fine textbooks on earth resources, minerals, energy, soils, and water. This book is concerned with how the natural world operates and, in so doing, kills and maims humans and destroys their works.

Throughout the book, certain themes are maintained:

- Energy sources underlying disasters
- Plate tectonics and climate change
- Earth processes operating in rock, water, and atmosphere
- Significance of geologic time
- Complexities of multiple variables operating simultaneously
- Detailed and readable case histories

The text aims to explain important principles about the Earth and then develop further understanding through numerous case histories. I hope that students will actually enjoy reading most of this book.

The primary organization of the book is based on an energy theme. Chapter 1 leads off with data describing natural disasters and the human population. Chapter 2 examines the energy sources underlying disasters: (1) Earth's internal energy from

its formative impacts and continuing decay of radioactive elements; (2) gravity; (3) external energy from the Sun; and (4) impacts with asteroids and comets.

Disasters fueled by Earth's internal energy are addressed in chapters 3 through 8 and are organized on a plate-tectonics theme. Chapter 3 provides the basic description of plate tectonics and its relationship to earthquakes. Chapter 4 covers the basic principles of earthquake geology, seismology and tsunami. Chapter 5 uses plate tectonics and historic and prehistoric records to explain earthquakes along western North America. Chapter 6 examines the history and potential for earthquakes throughout the rest of North America. The intent is to cover every geographic area and major historic earthquake. Chapters 7 and 8 discuss volcanoes; their characteristic magmas are organized around the three Vs—viscosity, volatiles, and volume. Eruptive behaviors are related to plate-tectonic setting. As throughout, case histories are employed to enliven the text.

Disasters powered primarily by gravity are covered in chapter 9 on mass movements. Many types are discussed and illustrated, from falls to flows and slides to subsidence.

Disasters fueled by the external energy of the Sun are examined in chapters 10 through 14. Chapter 10 begins with principles of atmosphere and ocean underlying weather and climate, and then moves on to long-term climate change over timescales of millions, thousands, and hundreds of years. The time focus shrinks through the chapter, leading into chapter 11 on short-term climate change and severe weather phenomena, such as thunderstorms, lightning, and tornadoes. Chapter 12 examines hurricanes and the coastline. The emphasis on water continues in chapter 13 on floods and how human activities increase flood damage. Chapter 14 on fire examines the liberation of ancient sunlight captured by photosynthesis and stored in organic material.

Before moving to the fourth energy source (impacts), chapter 15 examines the great dyings encased in the fossil record. The intent is to document the greatest of all natural disasters and to use multiple variables in analyzing their causes. Specific mass extinctions are examined using causative factors, such as continental unification and separation, climate change, flood-basalt volcanism, sea-level rise and fall, impacts, biologic processes, and the role of humans in the latest mass dying. Chapter 16 examines impact mechanisms in greater detail and includes plans to protect Earth from future impacts.

There is a lot of material in this book, probably too much to cover in one semester. But the broad range of natural disasters topics allows each instructor to select those chapters that cover their interests and local hazards. The goal is to involve the students for a lifetime in understanding the Earth, atmosphere, oceans, and skies—to observe, think, explain, and discuss.

NEW TO THIS EDITION

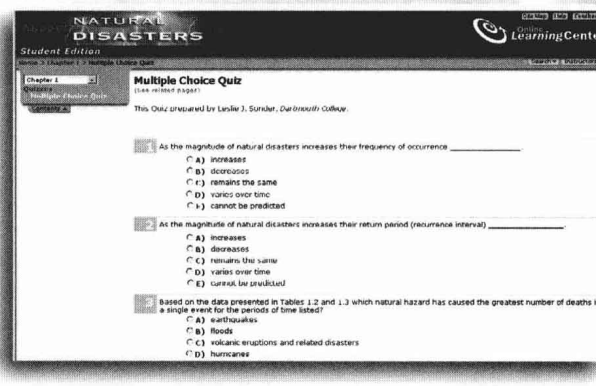
For the fifth edition, *all* chapters have been revised and updated, and many new pieces of line art have been created, and lots of new photos, and new tables have been added. Changes include major reorganizations and expansions. Chapter 1 has more physical and economic data on disasters and hazards and now covers human population, the condensed remains of the former chapter 16. Chapter 2 examines energy flows in Earth history and natural disasters. Chapters 6 and 7 on volcanism have been significantly revised while retaining the continuous sequence based on plate tectonics and magma characteristics, with eruptions explained using the three Vs—viscosity, volatiles, and volume. Chapters 10 and 11 have been radically reorganized. They begin with expanded principles to increase the basis for understanding climate change and severe weather. Chapter 14 on fire has again added several new figures and new tables on wildland fire data and how fires work. Chapter 15 on mass extinctions has added new sections on fossils plus new photos.

SUPPLEMENTS

FOR THE STUDENT

ONLINE LEARNING CENTER at www.mhhe.com/abbott5e

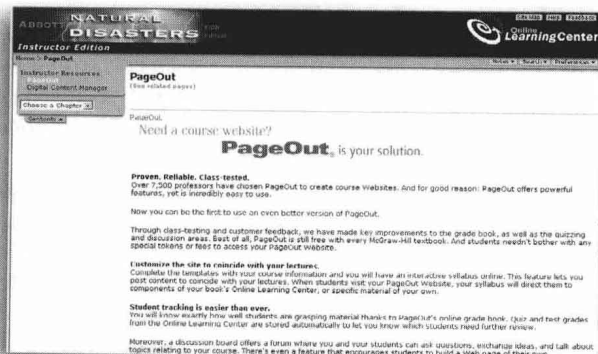
This site gives you the opportunity to further explore topics presented in the book using the Internet. The site contains interactive quizzing with immediate feedback, web links, a career center, and more.



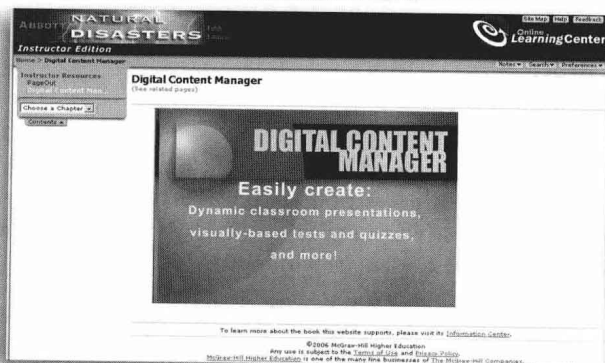
FOR THE INSTRUCTOR

ONLINE LEARNING CENTER at www.mhhe.com/abbott5e

Take advantage of the instructor's manual, PowerPoint lecture outlines, and access to PageOut—McGraw-Hill's course management tool.



DIGITAL CONTENT MANAGER CD-ROM This CD-ROM contains **all of the line art, photographs, and tables** from the book to make customizing your multimedia presentation easy. You can organize figures in any order you want; add labels, lines, and your own artwork; integrate materials from other sources; edit and annotate lecture notes; and then have the option of placing your media lecture into a presentation program, such as PowerPoint.



INSTRUCTOR'S TESTING AND RESOURCE CD-ROM This cross-platform CD-ROM provides a wealth of resources for the instructor. Supplements featured on this CD-ROM include computerized testing software that allows instructors to quickly create customized exams. This user-friendly program allows instructors to sort questions by format, edit existing questions or add new ones; and scramble questions for multiple versions of the same test.

Other assets on this CD are grouped within easy-to-use folders. The Instructor's Manual and Test Item File are available in both Word and PDF formats. Word files of the test bank are included for those instructors who prefer to work outside of the test-generator software.



ACKNOWLEDGMENTS

I am deeply appreciative of the help given by others to make this book a reality. The photograph collection in the book is immeasurably improved by the aerial photographs generously given by John S. Shelton, the greatest geologist photographer of them all. The collection of John Shelton photographs in this book is second in number only to his classic book *Geology Illustrated*. Many of the older figures were drafted by Rene Wagemakers of San Diego State University.

I am indebted to other geologists who provided photographs: Alan Mayo of GeoPhoto Publishing Company on the Winter Park sinkhole and Tucson flooding; Gerald G. Kuhn of San Diego from his space shuttle image collection; Michael W. Hart of San Diego on mass movements; Al Boost of Caltrans on the San Fernando earthquake; Peter Weigand of California State University Northridge, Greg Davis of University of Southern California, and Kerry Sieh of Caltech on the Northridge earthquake; Anne Jennings of the University of Colorado on climate; José Aguirre on the Berkeley fire; and the photo libraries of the USGS, NOAA, and NASA.

For the first edition several chapters benefited from helpful reviews by San Diego State University colleagues: Michael J. Walawender on volcanism, J. David Archibald and Richard H. Miller on great dyings, and David L. Kimbrough on impacts.

The quality of the book was significantly improved by the insights provided by comments from the following reviewers of the fourth and earlier editions:

Judson Ahern, *University of Oklahoma*
Sandra Allen, *Lindenwood University*
Cathy Busby, *University of California—Santa Barbara*
Victor E. Camp, *San Diego State University*
Wang-Ping Chen, *University of Illinois at Urbana-Champaign*

Patrick Colgan, *Northeastern University*
Michael Conway, *Arizona Western University*
Stanley Dart, *University of Nebraska—Kearney*
John Dooley, *North Hennepin Community College*
John Dunbar, *Baylor University*
Michael Forrest, *Rio Hondo Junior College*
Kevin P. Furlong, *Pennsylvania State University*
David Gonzales, *Fort Lewis College*
Paul K. Grogger, *University of Colorado—Colorado Springs*
John Hidore, *University of North Carolina—Greensboro*
George Hupper, *University of Wisconsin—LaCrosse*
Ernest L. Kern, *Southeast Missouri State University*
Alan Lester, *University of Colorado*
Sue Morgan, *Utah State University—Logan*
Jon Nourse, *California State Polytechnic University—Pomona*

Peter Sadler, *University of California–Riverside*
Bingming Shen-Tu, *Indiana University*
Leslie Sonder, *Dartmouth College*
Don Steeples, *University of Kansas*
Donald J. Stierman, *University of Toledo*
Philip Suckling, *University of Northern Iowa*

The fifth edition benefited greatly from detailed reviews by:

Cathy Busby, *University of California–Santa Barbara*
Edward Catanzaro, *Fairleigh Dickinson University*
John Dassinger, *Chandler–Gilbert Community College*
John F. Dewey, *University of California–Davis*
Kevin Furlong, *Pennsylvania State University*
Oswaldo Garcia, *San Francisco State University*
Sue Morgan, *Utah State University–Logan*
Robert S. Nelson, *Illinois State University*
Jim Rickard, *San Diego State University*
Peter M. Sadler, *University of California–Riverside*
Leslie Sonder, *Dartmouth College*
Don Steeples, *University of Kansas–Lawrence*
Christiane Stidham, *SUNY–Stony Brook*

Roland Stull, *University of British Columbia*
Stephen I. Wareham, *California State University–Fullerton*
John P. Wilson, *University of Southern California*
Terry Wright, *Sonoma State University*
Youxue Zhang, *University of Michigan*

I am grateful for the help of others at San Diego State University: Jacobe Washburn for his original line drawings, Tony Carrasco for invaluable aid on the computer with photos and line drawings, and Marie Grace for forming many of the tables.

I sincerely appreciate the talents and accomplishments of the McGraw-Hill professionals in Dubuque who took my manuscript and produced it into this book. For the shortcomings that remain in the book, I alone am responsible. I welcome all comments, pro and con, as well as suggested revisions.

Pat Abbott
pabbott@geology.sdsu.edu



BRIEF CONTENTS

PREFACE XIV

- 1 NATURAL DISASTERS AND THE HUMAN POPULATION 3
- 2 ENERGY FLOWS IN EARTH HISTORY AND NATURAL DISASTERS 25
- 3 PLATE TECTONICS AND EARTHQUAKES 49
- 4 BASIC PRINCIPLES OF EARTHQUAKE GEOLOGY, SEISMOLOGY, AND TSUNAMI 77
- 5 SOME EARTHQUAKES IN WESTERN NORTH AMERICA 115
- 6 MORE U.S. AND CANADIAN EARTHQUAKES 147
- 7 VOLCANIC ERUPTIONS: PLATE TECTONICS AND MAGMAS 171
- 8 VOLCANO CASE HISTORIES: KILLER EVENTS 203
- 9 MASS MOVEMENTS 233
- 10 ATMOSPHERE, OCEANS, AND LONG-TERM CLIMATE CHANGE 269
- 11 SHORT-TERM CLIMATE CHANGE AND SEVERE WEATHER 299
- 12 HURRICANES AND THE COASTLINE 335
- 13 FLOODS 371
- 14 FIRE 403
- 15 THE GREAT DYINGS 429
- 16 IMPACTS WITH SPACE OBJECTS 453

GLOSSARY 475

CONTENTS

PREFACE XIV

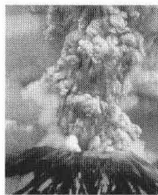
1 CHAPTER NATURAL DISASTERS AND THE HUMAN POPULATION 3

- 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
 Popocatepetl 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



2 CHAPTER ENERGY FLOWS IN EARTH HISTORY AND NATURAL DISASTERS 25

- 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;
 Questions for Further Thought 46

3 CHAPTER PLATE TECTONICS AND EARTHQUAKES 49

- 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



4 CHAPTER BASIC PRINCIPLES OF EARTHQUAKE GEOLOGY, 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*

5 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

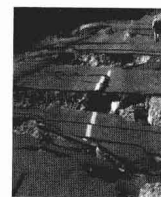
Northridge, California, 1994 142

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*

6 CHAPTER 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;
Questions for Further Thought 169*

7 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*

8 CHAPTER VOLCANO CASE HISTORIES: 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*



9 CHAPTER MASS MOVEMENTS 233

- 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*



10 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*

11 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-Saharan Africa, 1968–75 307 •
The Last Thousand Years 308
- **SIDE NOTE:** Stradivari Violins 309
- The Twentieth and Twenty-First Centuries 309
The Greenhouse Effect Today 309
- **IN GREATER DEPTH:** When Did Humans Begin Adding to Greenhouse Warming? 310
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*



12 CHAPTER HURRICANES AND THE COASTLINE 335



- Florida, 2004 336
- Hurricanes 336
- How a Hurricane Works 336
 - Hurricane Energy Release 337 • The Eye 338
- Hurricane Origins 339
- North Atlantic Ocean Hurricanes 340
 - Cape Verde-type Hurricanes 340 • Andrew, August 1992 342 • Caribbean Sea and Gulf of Mexico-type Hurricanes 343 • Forecasting the Hurricane Season 345 • Hurricane Damages 345
- Hurricanes and the Gulf of Mexico Coastline 349
 - Galveston, Texas, September 1900 349 • Gulf of Mexico Coast Example: Texas 350
- Hurricanes and the Atlantic Coastline 351
 - Hugo, September 1989 351
- The Evacuation Dilemma 351
- 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

13 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
 - 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; Questions for Further Thought 400

14 CHAPTER FIRE 403



- 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
 - 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; Questions for Further Thought 427

15 CHAPTER THE GREAT DYINGS 429



- Fossils 430
- Early Understanding of Extinctions and Geologic Time 431
 - Brief History of Life 432
- 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

16 CHAPTER IMPACTS WITH SPACE OBJECTS 453



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

PATRICK L. ABBOTT

San Diego State University

NATURAL DISASTERS



Higher Education

Boston · Burr Ridge, IL · Dubuque, IA · Madison, WI · New York · San Francisco · St. Louis
Bangkok · Bogotá · Caracas · Kuala Lumpur · Lisbon · London · Madrid · Mexico City
Milan · Montreal · New Delhi · Santiago · Seoul · Singapore · Sydney · Taipei · Toronto



Survivors had to bury many of the 41,000 dead people in mass graves following the 26 December 2003 earthquake in Bam, Iran.

© WOLFGANG RATTAY / Reuters / Corbis

NATURAL DISASTERS AND THE HUMAN POPULATION

"Mankind was destined to live on the edge of perpetual disaster. We are mankind because we survive."

James A. Michener, 1978, Chesapeake

O U T L I N E

- Bam, Iran, Earthquake
- Europe's Heat Wave
- Human Fatalities in Natural Disasters
- Indian Ocean Tsunami, 26 December 2004
- Economic Losses from Natural Disasters
- Natural Hazards
- The Twentieth Century was Unique
- Overview of Human Population History
- The Power of an Exponent on Growth
- The Last 10,000 Years of Human History
- The Human Population Today
- Future World Population