EDWARD A. KELLER

INTRODUCTION TO ENVIRONMENTAL GEOLOGY

FOURTH EDITION

FOURTH EDITION

Introduction to Environmental Geology

Edward A. Keller

University of California, Santa Barbara

PEARSON Prentice Hall

Upper Saddle River, NJ 07458

Library of Congress Cataloging-in-Publication Data

Keller, Edward A., 1942-
Introduction to environmental geology/Edward A. Keller.–4th ed.
p. cm.
Includes bibliographical references and index.
ISBN 0-13-225150-7
1. Environmental geology. I. Title.

QE38.K46 2007
550–dc22 2006037684

Publisher: Daniel Kaveney
Editor-in-Chief, Science: Nicole Folchetti
Assistant Editor: Sean Hale
Executive Managing Editor: Kathleen Schiaparelli
Assistant Managing Editor: Beth Sweeten
Marketing Manager: Amy Porubsky
Media Editor: Andrew Sobel
Creative Director: Juan López
Art Director: Heather Scott
Interior and Cover Design: Michael Fruhbeis
Manufacturing Manager: Alexis Heydt-Long
Senior Managing Editor, Art Production and Management: Patricia Burns
Manager, Production Technologies: Matthew Haas
Managing Editor, Art Management: Abigail Bass
Illustrations: GEX, Inc.
Manufacturing Buyer: Ilene Kahn
Editorial Assistants: John DeSantis, Jessica Neumann
Director, Image Resource Center: Melinda Patelli
Manager, Rights and Permissions: Zina Arabia
Manager, Interior Research: Beth Brenzel
Manager, Visual Research and Permissions: Karen Sanatar
Image Permission Coordinator: Debbie Hewitson
Photo Researcher: Truitt and Marshall
Composition: ICC Macmillan Inc.
Cover Image: Dave Martin/AP Wide World Photos

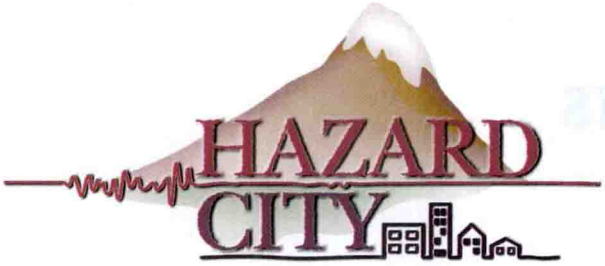
Pearson Prentice Hall
Pearson Education, Inc.
Upper Saddle River, NJ 07458

Printed in the United States of America
10 9 8 7 6 5 4 3 2 1

ISBN-13: 978-0-13-225150-1
ISBN-10: 0-13-225150-7

Pearson Education Ltd., *London*
Pearson Education Australia, PTY. Limited, *Sydney*
Pearson Education Singapore, Pte. Ltd
Pearson Education North Asia Ltd, *Hong Kong*
Pearson Education Canada, Ltd., *Toronto*
Pearson Educacion de Mexico, S.A. de C.V.
Pearson Education—Japan, *Tokyo*
Pearson Education Malaysia, Pte. Ltd

Introduction to **Environmental Geology**



Hazard City: Assignments in Applied Geology CD-ROM, Third Edition

This CD is included inside every new copy of this textbook. In these 11 assignments, students investigate the fictional town of Hazard City and play the role of a practicing geologist.

NEW Map Reading: Students learn basic map reading skills and apply them by planning a route to collect stream water specimens in a case of suspected contamination.

NEW Tsunami/Storm Surge: Students research the causes, controls, and impacts of tsunamis and storm surge. They then use maps and basic math to determine maximum warning time, number of residents needing evacuation, and the percentage of a town to be rebuilt after a tsunami/storm surge of known run up.

Ground Water Contamination: Students use field and laboratory data to prepare a countour map of the water table, determine the direction of ground water flow and map a contaminated area.

Volcanic Hazard Assessment: Researching volcanic hazards, collecting field information, and decision-making are all used to determine the potential impact of a volcanic eruption on different parts of Hazard City.

Landslide Hazard Assessment: Students research the factors that determine landslide hazard at five construction sites and make recommendations for development.

Earthquake Damage Assessment: Students research the effects of earthquakes on buildings, explore Hazard City, and determine the number of people needing emergency housing given an earthquake of specific intensity.

Flood Insurance Rate Maps: Flood insurance premiums are estimated using a flood insurance rate map, insurance tables and site characteristics.

Snowpack Monitoring: Students utilize climatic data to estimate variables that are key to flood control and water supply management.

Coal Property Evaluation: The potential value of a mineral property is estimated by learning about mining and property evaluation, then applying that knowledge in a resource calculation.

Landfill Siting: Students use maps and geological data to determine if any of five proposed sites meet the requirements of the State Administrative Code for landfill siting.

Shoreline Property Assessment: Students visit four related waterfront building sites—some developed and some not—and analyze the risk each faces due to shoreline erosion processes.

PREFACE

The main objective of *Introduction to Environmental Geology,* Fourth Edition, is to help equip students—particularly those who intend to take only a single science course—with an understanding of the interactions between geologic processes, ecological processes, and society. During the first half of the twenty-first century, as the human population increases and the use of resources grows, many decisions concerning our use of those resources, such as water, soil, air, minerals, energy, and space to live, will determine our standard of living and the quality of our environment. Scientific knowledge combined with our values will dictate those decisions. Your charge, as a future leader or informed citizen, is to choose paths of development that are good for people and the environment, that larger community that includes plants, animals, water, and air—in other words, the environment consisting of ecosystems that we and all living things depend upon for our well-being.

Earth's dynamic and changing environment constitutes one of the most compelling and exciting areas of study. Environmental geology is the application of geologic information to the entire spectrum of interactions between people and the physical environment. During a course in environmental geology, you will develop an understanding of how geology interacts with major environmental problems facing people and society. This is the essence of *Introduction to Environmental Geology,* Fourth Edition. Our strategy with this text is to:

- Introduce you to the basic concepts and principles of physical and environmental geology, focusing on Earth materials and processes.
- Provide you with sufficient information concerning natural hazards and the geologic environment so that you will be a more informed citizen. You will be better prepared to make decisions concerning where you live and how society responds to natural hazards and catastrophes such as earthquakes, volcanic eruptions, and flooding.
- Help you develop an understanding of relationships between natural resources and pollution. We seek, find, and use resources and, as a result, may pollute our environment. Thus, it is important to know how we might minimize pollution problems.
- Help you understand the basic concepts of environmental management as they relate to the geologic environment in areas such as waste management, environmental health, global change, and environmental assessment.

After finishing your course in environmental geology, you will be better prepared to make decisions concerning where you build or buy a home, what resources you choose to utilize, and appropriate environmental actions relevant to society and Earth's ecosystems from a local to a global scale.

Five Fundamental Concepts

To this end, this book introduces a device we call the "Fundamental Concepts of Environmental Geology." These five concepts are designed to provide a memorable, transportable framework of understanding that you can carry away from the class and use throughout life to make informed choices about your interaction with and effect upon geologic processes:

- ***Human population growth:*** Population growth is the number one environmental problem. As population increases, so do our effects and demands on the environment.

- ***Sustainability:*** Sustainability is the long-term environmental objective of providing for the future of humans and other living things who share the planet.
- ***Earth as a system:*** The activities of human beings can have important effects on any or all of Earth's systems, often affecting the global environment.
- ***Hazardous Earth processes, risk assessment, and perception:*** Earth's hazardous processes have always occurred and will always occur. Human beings need to recognize the threat of hazards, assess the risk to life and property, and either avoid them or plan accordingly.
- ***Scientific knowledge and values:*** Scientific inquiries often provide a variety of potential solutions to environmental problems. The solution we choose is a direct reflection of our value system.

These concepts are introduced in the first chapter and then highlighted throughout the text (look for the "Revisiting the Fundamental Concepts" section at the end of every chapter). By tying the content to these five principles, the text provides a framework for understanding that will extend far beyond the confines of this course and into your everyday life.

Organization

Introduction to Environmental Geology, Fourth Edition, is well suited to your study of environmental geology, whether you are a geology major or are taking this class as a science elective. I have organized *Introduction to Environmental Geology*, Fourth Edition, to flow naturally from the introduction of fundamental principles of environmental science and geology, to more specific information concerning how Earth works, to natural processes and hazards, to understanding natural resources and their management, with the objective of minimizing environmental degradation. We end with a detailed discussion of global change, focusing on climate and some important interactions between society and the geologic environment.

Introduction to Environmental Geology, Fourth Edition, consists of 20 chapters arranged in four parts:

- Part 1 introduces philosophy and fundamental concepts, the structure of Earth and plate tectonics, and the origin and significance of minerals and rocks. Thus, Part 1 presents fundamentals of physical geology with important environmental information necessary to understand the remainder of the text. Chapter 1 introduces five fundamental concepts of environmental science, with an emphasis on the geologic environment. Chapter 2 discusses the structure of Earth and the important subject of plate tectonics and how our planet works from a geologic perspective. Chapter 3 presents geologic information concerning rocks and minerals necessary for understanding environmental geology problems and solutions to those problems. In Chapter 3, we also introduce some of the fundamental principles of geology, including the law of original horizontality, the law of cross-cutting relationships, the concept of the depositional environment, the concept of the rock cycle, and the principle of magmatic differentiation. Chapter 4 presents basics of ecology with links to geology. An ecosystem includes a community of life and it's non-living environment (rock, soil, etc.). The new emerging study of geology linked to ecology is exciting and offers many opportunities.
- Part 2 addresses natural hazards, including an introduction to natural hazards (Chapter 5), earthquakes (Chapter 6), volcanic activity (Chapter 7), rivers and flooding (Chapter 8), landslides (Chapter 9), coastal processes (Chapter 10), and impacts of extraterrestrial objects (Chapter 11). The intent is not to provide copious amounts of detailed information concerning these processes but to focus on the basics involved and the environmental concerns of Earth processes and natural hazards.

- Part 3 presents the major resources associated with the geologic environment and the subject of pollution. Important topics include water resources (Chapter 12), water pollution (Chapter 13), mineral resources (Chapter 14), energy resources (Chapter 15), soils (Chapter 16), waste management (Chapter 17), and air pollution (Chapter 18). The focus is to present the basic principles concerning natural resources and to identify potential environmental problems and solutions.
- Part 4 is concerned with the important topics of global change, environmental management, and relationships between environment and society. Chapter 19 discusses global change with a focus on global warming and stratospheric ozone depletion. Finally, in Chapter 20, which is a "capstone," we discuss relationships between environment and society with topics such as environmental health, land-use planning, environmental law, environmental impact analysis, how we may achieve the goal of obtaining environmental sustainability, and what that environment might entail.

Major New Material in the Fourth Edition

The fourth edition benefited greatly from feedback from instructors using the text—most of the changes reflect their thoughtful reviews. One new chapter—Ecology and Geology (Chapter 4) recognizes important links between physical and biological processes in the study of the environment. In addition to this new chapter, new or extensively revised discussions include:

- Why solving environmental problems is difficult (Chapter 1)
- Environmental policy and the precautionary principle (Chapter 1)
- Tsunamis (Chapter 6)
- Evaluation of flooding (Chapter 8)
- La Conchita landslide (Chapter 9)
- Hurricanes (Chapter 10)
- Water resources (Chapter 13)
- Peak oil (Chapter 15)
- E-waste (Chapter 17)
- Air toxics (Chapter 18)
- Global warming (Chapter 19)
- What a sustainable environment involves—a vision for the future (Chapter 20)

In addition to the above mentioned new chapter and new or revised discussions, the discussion of many topics has been updated. At the request of reviewers, many figures have been revised to more clearly illustrate the topics under discussion.

Features of the Text

This book is sensitive to the study needs of students. Each chapter is clearly structured to help you understand the material and effectively review the major concepts. To help you use the material from the book, each chapter is organized with the following study aids:

- Learning objectives that state clearly what you should be able to do upon completing the chapter.
- Selected features, called *Case History* or *A Closer Look*, are added where appropriate to help you relate topics in the text to the world around you.

- A chapter summary reinforces the major points of the chapter to help you refocus on the important subjects.
- The foundations of environmental geology are presented in Chapters 1 through 4, and Chapters 5 through 20 contain a discussion that revisits the five fundamental principles in terms of the material presented in the chapter.
- Detailed references are supplied at the end of the text to provide additional readings and to give credit to the scholars who did the research reported in the chapter.
- Key terms are presented at the end of the chapters. These will help you identify the important concepts and terminology necessary to better understand the chapter.
- Review questions help with your review of important subject matter.
- Critical thinking questions stimulate you to think about some of the important issues in the chapters and try to relate these to your life and society.

The appendixes in *Introduction to Environmental Geology,* Fourth Edition, are intended to add additional information useful in helping you understand some of the more applied aspects of environmental geology. This information may be most useful in supplementing laboratory exercises and field exercises in which you may participate. Specific topics include:

- Identification of rocks and minerals with accompanying tables and suggestions.
- Introduction to topographic and geologic maps with specific information concerning how to read topographic maps, construct topographic profiles, and understand geologic maps.
- Introduction to Digital Elevation Models (DEMs) and Global Positioning System instrumentation (GPS).
- Discussion of how geologists determine and interpret geologic time.
- Darcy's Law, with example of how we use it to solve groundwater problems.
- A glossary of terms used in the field of environmental geology.

The New Instructional Package

Prentice Hall has assembled a greatly improved resource package for *Introduction to Environmental Geology,* Fourth Edition.

For the Instructor

- ***Instructor Resource Center on CD-ROM, with PowerPoint Presentations and Animations*** **(0-13-225153-1):** Included on the Instructor Resource CD are three PowerPoint® presentations for each chapter: (1) **Lecture outline**—"plug-and-play" lecture presentations based on the outline of the text to get you up and running as quickly as possible; (2) **Art only**—every illustration and most of the photos in the text, in order, pre-loaded onto PowerPoint slides; (3) **Animations**—high-quality animations of key geologic processes (see below for more details). Also included are all illustrations and a selection of photos for the text in 16-bit, low-compression JPEG files. All images are manually adjusted for color, brightness, and contrast.
- ***PH Geoscience Animations*** **(0-13-600377-X):** The Prentice Hall Geoscience Animation Library resulted from a survey in which we asked instructors to identify the concepts most difficult to teach using traditional, static resources. Then we animated them. Created through a unique collaboration among five of Prentice Hall's leading geoscience authors, these animations represent a

significant leap forward in lecture presentation. Available on the Instructor Resource Center on CD, the animations are provided as Flash files and, for your convenience, pre-loaded into PowerPoint slides. The list of animations includes:

- Convergent Margins
- Seafloor Spreading
- Faults
- Transform Faults
- Foliation
- Folding
- P & S Waves
- Stream Processes
- Angular Unconformity and Nonconformity
- Global Warming
- Beach Drift
- Seismograph Operations
- Breakup of Pangaea
- Nebular Hypothesis
- Oxbow Lake Formation
- Crater Lake
- Igneous Features
- Hydrologic Cycle
- Tidal Cycle
- Glacial Processes—Ice Budget
- Relative Dating
- Tectonic Settings of Volcanic Activity
- Glacial Processes—Plucking and Moraines
- Water Phases
- Wave Motion
- Coastal Processes—Jetties, Groins, Breakwaters
- Ocean Circulation
- Accretion of Terranes
- Global Atmospheric Circulation
- Cyclones and Anticyclones

- ***Transparencies* (0-13-600575-6):** Full-color transparencies containing a carefully selected, vibrant assembly of figures, tables, and graphs taken from the text, manually adjusted for color, brightness, and contrast for optimal projection.
- ***Instructor's Manual with Test Item File* (0-13-255152-7):** Authored by Glenn D. Thackray of Idaho State University, the Instructor's Manual provides chapter outlines and objectives, classroom discussion topics, and answers to the end-of-chapter questions in the text. The test item file includes nearly 1,000 multiple choice, true/false, and short-answer test questions based on the text. The test item file is also available in both **WebCT** and **Blackboard formats** for easy import into your course management system.

For the Student

- MyGeologyPlace: **www.prenhall.com/keller** Organized by chapter for easy integration into the course, this website offers numerous review exercises from which students can get automatic feedback, updated Internet links for further exploration, and critical thinking questions. In addition, the Regional Updates section links students to USGS Fact Sheets applicable to their local area.
- ***Hazard City: Assignments in Applied Geology, 3e:*** Included inside every new copy of the text, *Hazard City* provides meaningful, easy-to-assign, and easy-to-grade assignments. Based on the idealized town of Hazard City, the

assignments put students in the role of a practicing geologist—gathering and analyzing real data, evaluating risk, and making assessments and recommendations. The third edition of this widely used CD-ROM contains two new modules: Map Reading and Tsunami/Storm Surge. In Map Reading, students apply basic map reading skills by planning a route to collect stream water specimens in a case of suspected contamination. In Tsunami/Storm Surge, students use maps and basic math to determine the potential impact of a tsunami or storm surge on a coastal community.

Acknowledgments

Successful completion of this book was greatly facilitated by the assistance of many individuals, companies, and agencies. In particular, I am indebted to the U.S. Geological Survey and their excellent environmental programs and publications. To the Internet as a tremendous tool to quickly contact people and organizations doing environmental work. To authors of papers cited in this book, I offer my thanks and appreciation for their contributions. Without their work, this book could not have been written. I must also thank the thoughtful people who dedicated valuable time completing reviews of chapters or the entire book. Their efforts have greatly contributed to this work. I wish to thank Scott Brame, Clemson University; John Bratton, Stonehill College; Eleanor J. Camann, Georgia Southern University; Elizabeth Catlos, Oklahoma State University; Raymond M. Coveney, Jr., University of Missouri; William M. Harris, University of St. Thomas; Michael Krol, Bridgewater State College; Dan Leavell, Ohio State University—Newark; J. Barry Maynard, University of Cincinnati; Stephen R. Newkirk, University of Memphis; Michael Phillips, Illinois Valley Community College; Hongbing Sun, Rider University; and Cynthia Venn, Bloomsburg University.

Special thanks go to Tanya Atwater, William Wise, and Frank Spera for their assistance in preparing the chapters on plate tectonics, minerals and rocks, and impacts, respectively. I greatly appreciate the review of the new chapter on geology and ecology by Carla D'Antonio, who provided important information and advice on basic principles of ecology and ecological restoration.

I am particularly indebted to my editors at Prentice Hall. Special thanks go to Geosciences Publisher Daniel Kaveney, whose enthusiasm, intelligence, encouragement, ideas, and creativity made this book possible. I greatly appreciate the assistance of Amy Porubsky, marketing manager. I also appreciate the efforts of Brittney Corrigan-McElroy, production editor, and Jerry Marshall, photo acquisitions. Art was rendered by MapQuest and Imagineering. Thanks to Heather Scott, art director, for her work in updating the interior and cover design for this new edition. I appreciate the encouragement and support from my wife, Valery, who assisted by pointing out ways to improve the content and presentation.

Edward A. Keller
Santa Barbara, California

For the people of the Gulf Coast and the City of New Orleans who lost so much. Hopefully, the Federal Emergency Management Administration, the U.S. Army Corps of Engineers, and local and national elected officials have learned from Hurricane Katrina to better plan for disasters and catastrophes. There will be more, even stronger hurricanes . . . how we choose to be prepared reflects our values and hopefully elevates our human spirit and compassion.

About the Author

Edward A. Keller

Ed Keller is a professor, researcher, writer, and, most importantly, mentor and teacher to undergraduate and graduate students. Currently, Dr. Keller's students are working on earthquake hazards, how waves of sediment move through a river system following disturbance, and geologic controls on habitat to endangered southern steelhead trout. Born and raised in California (Bachelor's degrees in Geology and Mathematics from California State University at Fresno, Master's degree in Geology from the University of California at Davis), it was while pursuing his Ph.D. in Geology from Purdue University in 1973 that Ed wrote the first edition of *Environmental Geology*. The text soon became a foundation of the environmental geology curriculum. Ed joined the faculty of the University of California at Santa Barbara in 1976 and has been there since, serving multiple times as the chair of both the Environmental Studies and Hydrologic Science programs. In that time he has been an author on more than 100 articles, including seminal works on fluvial processes and tectonic geomorphology. Ed's academic honors include the Don J. Easterbrook Distinguished Scientist Award, Geological Society of America (2004), the Quatercentenary Fellowship from Cambridge University, England (2000), two Outstanding Alumnus Awards from Purdue University (1994, 1996), a Distinguished Alumnus Award from California State University at Fresno (1998), and the Outstanding Outreach Award from the Southern California Earthquake Center (1999).

Ed and his wife Valery, who brings clarity to his writing, love walks on the beach at sunset and when the night herons guard moonlight sand at Arroyo Burro Beach in Santa Barbara.

BRIEF CONTENTS

CONTENTS