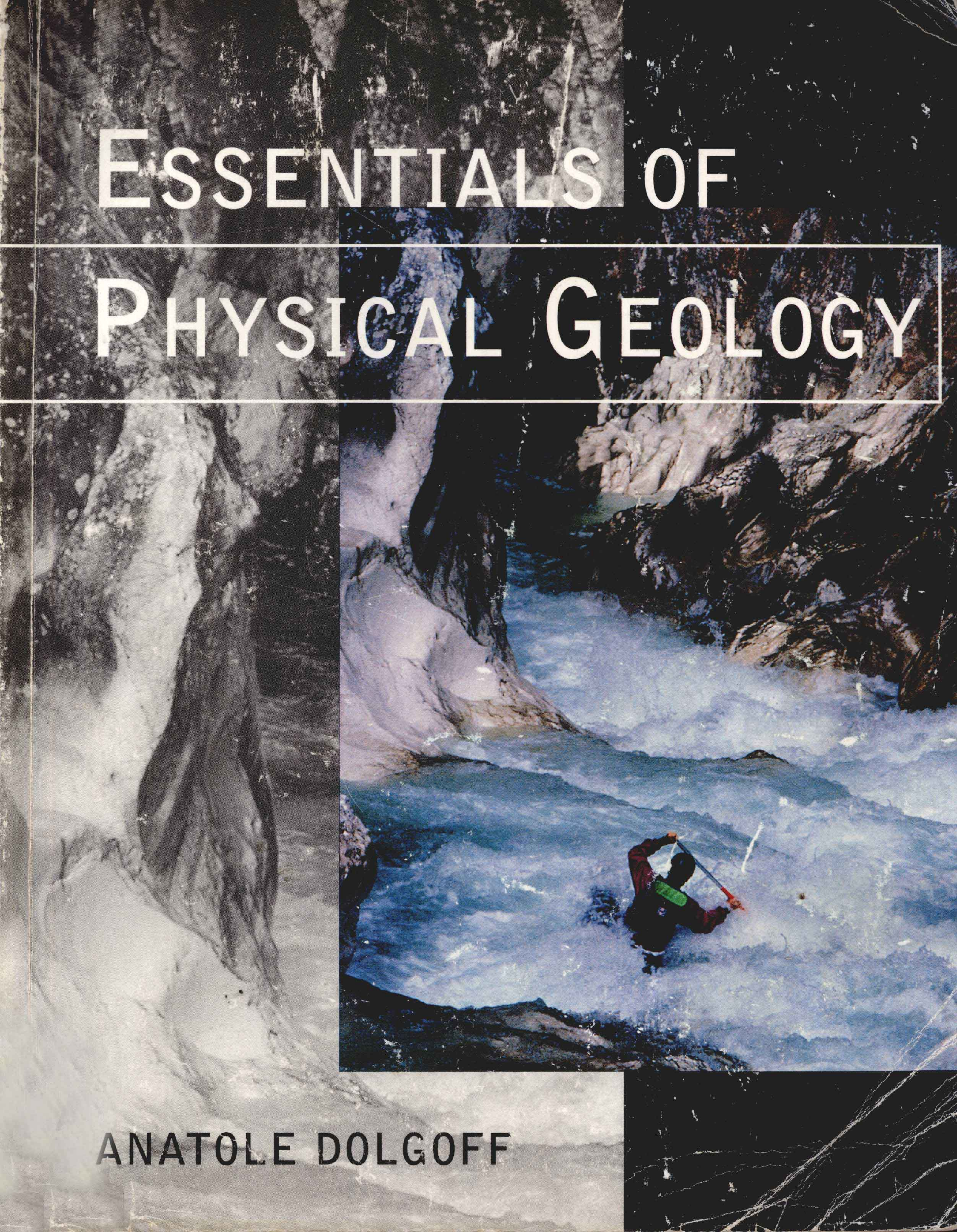
ESSENTIALS OF PHYSICAL GEOLOGY



ANATOLE DOLGOFF

GEOLOGY

ANATOLE DOLGOFF

City University of New York–New York City Technical College

with

MARY FALCON

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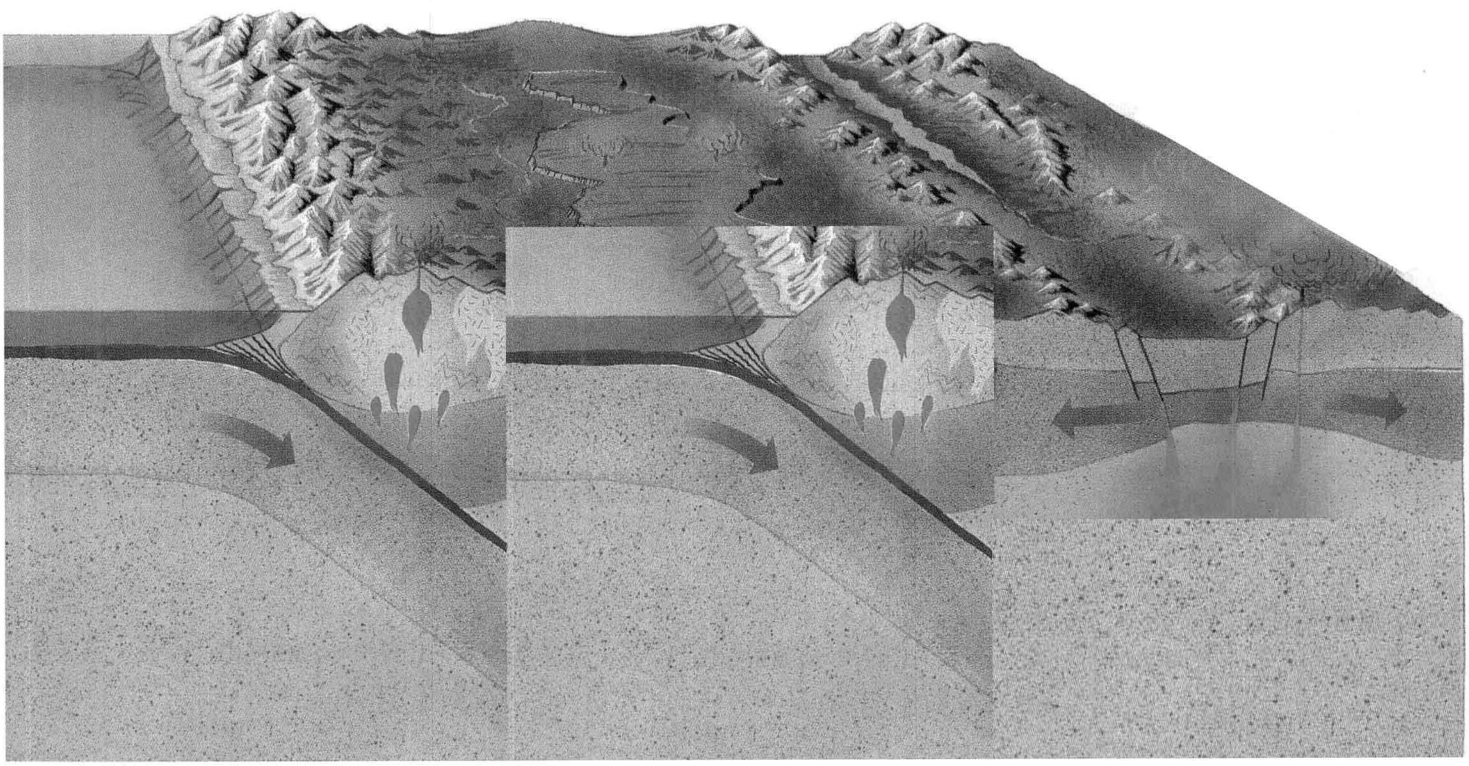

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Preface

This textbook is designed for students enrolled in a one-semester geology course. This course typically attracts a variety of students fulfilling a science requirement. My purpose in writing this book has been to present geological principles in a manner that conveys the delight that geologists take in their subject. I have been guided by several major goals:

- *To provide basic information about geology in a way that is inviting for students who have probably taken little interest in the subject before this course.* Many students have grown up in an environment in which the indoor shopping mall has almost completely supplanted the natural world. The sense of connection they should feel with the Earth has largely been stifled, and a good geology textbook must work toward motivating students to reestablish this link. To this end, I have woven the dramatic interactions between geological processes and human activities into the very fabric of the book. I have highlighted such timely issues as successful and failed efforts to design earthquake-resistant buildings; the advantages and disadvantages of flood-control measures on the Mississippi River; the impact of human activity on fragile beaches and hillsides; and the threat of human-induced global warming. I have explored such serious environmental problems as famine and land degradation in the Sahel; the undesirable effects of water diversion in arid climates; and groundwater pollution and overuse. Throughout the book I have discussed geologists' practical contributions toward solving these problems.

  I have not hesitated to stress that many problems geologists, engineers, and regional planners thought they had overcome or were on the verge of overcoming have turned out to be thornier than they originally believed—for example, predicting earthquakes in light of such recent events as the Northridge and Kobe disasters or constructing artificial levee systems strong enough to withstand the likes of the Mississippi floods. Probing these matters emphasizes the challenge of geology and reinforces the concept that science is largely about unfinished business. Indeed, there is much that we leave for the next generation of geologists to accomplish.
- *To maintain the traditional core of the subject while giving proper weight to the advances of recent years.* The list of recent geological advances is virtually endless, and for the author of an introductory textbook, the main problem that arises is determining what to include and what to leave out. The material I have chosen to include strikes a reasonable balance between the theoretical and the practical, between classical ideas and topics now of wide interest. For example, the chapter on earthquakes treats plate

tectonics and elastic-rebound theory on the one hand, and engineers' new findings as a result of the Mexico City, Northridge, and Kobe disasters on the other.

- *To involve students actively in the scientific process.* For most of the students taking the one-semester geology course it may be the only science studied in college. For this reason, an introductory textbook must demonstrate how scientists look at problems and attempt to solve them.

  I have set the tone of science as inquiry in Chapter 1, where I discuss Hutton's uniformitarianism not simply as an axiom but as a case study of a basic principle derived through direct observation of the physical world. The emphasis in this book is not so much on the answers to scientific questions but on how geologists go about *seeking* the answers.

  I have maintained the same inquiry-based approach throughout the book. No topic, no matter how familiar, is presented as a finished piece of business. Rather, I have described explanations and theories as working hypotheses, some more firmly established than others.

- *To demonstrate geology's core role in advancing human knowledge.* Finally, I have tried to convey the pivotal knowledge that geology has contributed to human intellectual development. This knowledge includes the concepts of the Earth's vast age and of slow evolutionary change; geologists' explanations of the natural causes of catastrophic events such as earthquakes and volcanoes; and the application of rational methods in evaluating competing ideas.

Organization

I believe that the introductory physical geology course is most solid when it is built upon a foundation of plate tectonics. In this book I have laid the cornerstone of plate tectonics early. Chapter 1 takes readers from the basics of classical geology—uniformitarianism, the age of the Earth, and the rock cycle—to continental drift, the precursor of plate tectonics, to the process of scientific inquiry. In Chapter 2, I have employed an inductive, quasi-historical approach in developing the case for plate tectonics, describing the features of the ocean floor and explaining the significance of the supporting evidence as I go along. The chapter concludes with a preview of the impact of plate tectonics on continental evolution. Thus Chapters 1 and 2 give students the solid foundation and context needed to understand subsequent concepts.

Chapter 3 focuses on earthquakes and the Earth's interior. I then discuss minerals, rocks, volcanism, and rock deformation (Chapters 4–9). Students are now in a position to appreciate the surficial processes (Chapters 10–15) that act upon the continental crust.

The book closes with four chapters on geologic time and Earth history. Chapter 16, Geologic Time, describes the principles of relative and radiometric dating, and how they are used to construct the geologic time scale. Chapter 17, Formation of the Continental Crust, describes the processes involved in mountain building and the assembly of continents as an amalgamation of plates. Recounted, in outline form, are several key events, such as the Appalachian orogeny and the assembly of western North America. These chapters prepare the student for a two-chapter summary of the chronological history of the Earth.

The challenge in writing a brief, two-chapter version of Earth history is to present coherent themes without losing the student in a thicket of terminology and subplots. Furthermore, while it is easier for academics to study the geologic, climatic, and biological history of the Earth separately, I believe it is more valuable to expose students—especially nonscience majors—to an integrative treatment of these factors over time. Chapters 18 and 19 were developed with this goal in mind.

The framework of Chapter 18, Earth History: From the Origin of the Planet Through the Proterozoic Eon, is based on four simple ideas:

1. The Archean and Proterozoic crust, as well as modern plate tectonics, are continuations of the same evolutionary processes that formed the planets.
2. The Earth's modern atmosphere and oceans have developed as consequences of the complex interplay of physical, chemical, and biological processes.
3. The basic cellular structure of organisms evolved during the Archean and Proterozoic eons.
4. The proliferation of life on Earth is a result of biological evolution by genetic alteration and natural selection.

You may notice that I devote more attention to organic evolution and natural selection than is usual for a chapter of this type. My quick tour through the vast store of evidence that proves evolution correct was purposefully designed to counteract the tenacity of creationist beliefs among today's college students. I believe that the concept of evolution is one of the most important components of a liberal arts education, yet most nonscience majors take only one science course. If they don't get it here, then where will they get it?

Chapter 19, Earth History: From the Paleozoic to the Present, is organized around three themes:

1. The breakup of the late Proterozoic supercontinent and its reassembly into Pangaea and the breakup of Pangaea and its reassembly into the modern world.
2. The impact of the organization and reorganization of the Earth's land masses on the Earth's climate.
3. The influence of these climatic and physical changes on the course of biological evolution.

Students like the sequence of topics in this book—which I have used with minor variations in my own classes for many years—because it presents the evidence in context. Moreover, earthquakes, continental drift, and plate tectonics intrigue them, so introducing these topics early in the book affords the opportunity to exploit a keen interest. As I have learned in the classroom, the earlier you capture students' interest, the more likely they will engage actively with the rest of the course.

I am sensitive, however, to the fact that instructors have personal preferences and practical needs that determine the sequence of topics in their courses. I have therefore made the chapters as self-contained as possible, so as to ensure maximum flexibility of use. For example, for those who prefer a traditional approach, Chapter 4, on minerals, can be assigned either immediately before or after Chapter 2, on plate tectonics; and Chapter 3, on earthquakes and the Earth's interior, can be taught after the mineral and rock chapters (Chapters 4–8) without any loss of coherence.

Humans and the Natural Environment

For purposes of this book, an environmental "issue" or "problem" is defined as *any human intervention in the natural environment that may cause actual or potential harm to either humans or the natural environment.* The criterion is broad enough to include the material most of us want to teach, but places limits on what is characterized as "environmental." Thus hurricanes and earthquakes themselves are not environmental issues, but groins and retaining walls that strip beaches of their ability to withstand hurricanes—and dangerous construction and zoning practices in earthquake-prone regions—are.

Topics relating to the environment are bracketed with icons. For those instructors who wish to emphasize the practical application of geology to environmental issues, the icons point to where such topics begin and where they end.

Pedagogy

Some introductory physical geology textbooks divide information into short, easily digestible bits, presumably to make the material accessible to students. Without the context that supports the facts, however, students have no choice but to memorize the material; moreover, educational studies have shown that they retain very little of such information after the final exam. In contrast, the chapters in this book are narratives built around themes and concepts; the details and definitions evolve naturally from the flow of the discussion. For example, in Chapter 7, on sedimentary rocks, the characteristics of coarse detrital sediments emerge logically from a description of their weathering, transport, and depositional history as we travel hypothetically from mountaintop to sea basin. Of course, geology is a very visual science, and I have illustrated and reinforced the major themes of this textbook with a rich and varied program of photographs, diagrams, graphs, and maps.

Three special features in each chapter allow students the freedom to read the material for understanding, without the need for underlining (or highlighting) passages and without the annoyance of breaking their train of thought to look up a word elsewhere.

- **Study Outline.** This detailed outline at the end of each chapter covers all the important concepts and uses every key term. The outline provides a more functional cognitive map than the ordinary paragraph-style summary because it visually conveys the relationships between topics and subtopics. Furthermore, in the paragraph format, many extra words are needed to complete full sentences and provide transitions from one sentence to the next. Because the outline format is economical, more information can be packed into the same number of words.
- **Marginal Definitions.** Each study term is defined in the margin next to the place in the text where it is first discussed.
- **Bold-faced and Italicized Terms.** An important contribution of geologists to the natural sciences has been to name the features and processes we have observed. As a consequence, over the years geologists have coined enough terms to fill an entire dictionary. (I am referring, of course, to the AGI's *Dictionary of Geological Terms.*) As I see it, my job as an introductory textbook author is to use those terms selectively in a way most beneficial to students. Thus I have divided geological terms into three groups:

  1. Study terms. These are words that I believe students should commit to memory and learn to employ as part of their speaking vocabulary. I have tried to make the study terms as accessible as possible by boldfacing them when they are first discussed in the body of the text and by placing their working definitions in the margin directly next to their first discussion. The list of study terms at the end of each chapter tells the student on which page each term is first discussed and defined in the margin, and the study terms and their definitions appear again in the alphabetized glossary at the end of the book.
  2. Terms to remember. These words are important enough that nonmajors ought to get the gist of them by seeing them employed in context. Hopefully, they will recall the general meaning of these words when they come across them again in other contexts, such as magazine articles or TV documentaries. Terms that I feel students ought to remember appear italicized the first time they are discussed, and a number of them are defined in the end-of-book glossary.
  3. Terms that I have found in my own teaching experience to be of little use to undergraduates. Accordingly, in this text written primarily for nonscience majors, I have made every effort to avoid jargon and have painstakingly replaced such terms with common everyday language.

I understand that my choices regarding appropriate vocabulary cannot possibly mirror the preferences of all instructors, but I think textbook authors who include every term so as not to "offend" anyone make the greater mistake in terms of students' needs.

Also, to help students master material and study for exams, the following pedagogical devices are employed in each chapter:

- **Chapter Outline.** Each chapter begins with a preview outline of the headings within the chapter.
- **Study Terms.** This end-of-chapter list of study terms features references to the page where each term is first used and defined.
- **Thought Questions.** A brief set of questions at the end of each chapter tests students' recall *and understanding* of the chapter material.

And in the back of the book:

- **Appendixes.** The appendixes feature a conversion table of metric and English units of measurement, the periodic table of the elements, mineral identification tables, and a basic guide to geologic maps.
- **Glossary.** The glossary provides complete definitions of all boldfaced study terms and useful working definitions of many italicized terms. Each entry is followed by a reference to the text page where the term was first discussed.
- **Selected Bibliography.** This brief supplementary reading list, organized by chapter, includes both classic books and current articles.

A Mixed Majors and Nonmajors Alternative

There may be instructors who are interested in the organization and approach of this book but prefer to use a text designed for science majors as well as nonmajors. To better meet the needs of these instructors, I have prepared an Updated Version of my full-length text *Physical Geology.*

For those instructors who prefer the full-length Updated Version of this book but also want to include more historical geology in their course, the two Earth history chapters may be packaged with the Updated Version. Contact your local Houghton Mifflin sales representative for further information.

Supplements

This textbook is supplemented by a number of useful learning and teaching aids:

- **Student Study Guide.** For students who benefit from pencil-and-paper exercises, drills, and practice tests, the study guide offers an additional avenue of review. Dozens of interactive drills, along with practice multiple-choice exams with answers and self-evaluation charts, allow students to identify areas of weakness and pinpoint the text pages that they should review again.
- **Laboratory Manual for Students.** This manual offers lab studies and activities on topics closely tied to *Physical Geology* as well as *Essentials of Physical Geology.* Included are labs on plate tectonics, mineral identification, rock deformation, streams, groundwater, and glacial landscapes. Other units help to develop and hone students' skills in working with and interpreting geologic and topographic maps. *Physical Geology Interactive* is a CD-ROM version of the lab manual that extends all activities, using web resources for information and data to be used in the exercises.

- **Test Item File and Computerized Testing.** The printed test bank, offering over 1000 multiple-choice questions and approximately 160 additional essay and illustration-based questions, is conveniently organized by chapter. Also featured are 40 questions, covering the material in the first 9 chapters, that are suitable for use in a midterm exam, plus 90 questions, covering the material in the entire 19 chapters, that are designed for use in a final exam. The computerized testing program offers the same questions that appear in the printed test bank but in handy electronic format for IBM-compatible and Macintosh computers.
- **Instructor's Manual.** An invaluable aid for the instructor, this comprehensive manual, written by Michael Scanlin of Elizabethtown College, PA, includes brief chapter summaries, detailed chapter outlines, lecture suggestions, ideas for student activities, teaching tips, and up-to-date information on media resources.
- **Overhead Transparencies.** This set of some 100 color acetates of useful illustrations is grouped by topic for ease of presentation. Most illustrations are taken from the textbook, but some supplementary visuals are included to expand the range of options for the instructor.
- **The Earth Sciences Videodisc Set.** This state-of-the-art videodisc set features full-motion video with narration and numerous animations, as well as more than 3000 still images. All the core course topics are covered, including plate tectonics, minerals, volcanoes, faulting and folding, and the rock cycle, among many others.
- **The Earth Sciences Geology Slide Set.** This generous collection of full-color images features original photographs of rocks, minerals, landforms, and important geologic sites and phenomena from around the world.

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Writing both versions of this book was a major undertaking, and its completion would have been impossible without the unselfish contributions of numerous individuals. Their interest, support, and advice have sustained me throughout the process. It is only proper that I acknowledge them here, with deep thanks.

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There follows a long list of geologists who reviewed the manuscripts for one or both versions of this book and offered detailed suggestions and criticisms, often line by line; most were points well taken. Several of these reviewers deserve special mention. Craig Manning at the University of California, Los Angeles, urged me to trust my judgment concerning the decision to place plate tectonics at the beginning of the book and supplied expert advice on a number of chapters. Wang-Ping Chen at the University of Illinois, Urbana-Champaign, reviewed every manuscript chapter and most of the illustrations for accuracy. No concept or detail was too insignificant to escape his scrutiny, and the book is infinitely better for his careful attention. John Nicholas at the University of

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Craig Chesner, *Eastern Illinois University*
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David Dockstader, *Jefferson Community College*
Peter Harries, *University of South Florida*
Simon Peacock, *Arizona State University*
Donal Ragan, *Arizona State University*
L. Don Ringe, *Central Washington University*
Vernon Scott, *Oklahoma State University*
Laura Serpa, *University of New Orleans*
Anne Sturz, *University of San Diego*
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Reviewers of First Edition and Update of *Physical Geology*

Charles Alpers, *United States Geological Survey*
Robert Behling, *West Virginia University*
Mary Lou Bevier, *University of British Columbia*
Marcia Bjornerud, *Miami University*
Thomas Broadhead, *University of Tennessee, Knoxville*
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David Mogk, *Montana State University*
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