Updated Version

Physical Geology

ANATOLE DOLGOFF

GEOLOGY

UPDATED VERSION

ANATOLE DOLGOFF

City University of New York–New York City Technical College

with

MARY FALCON

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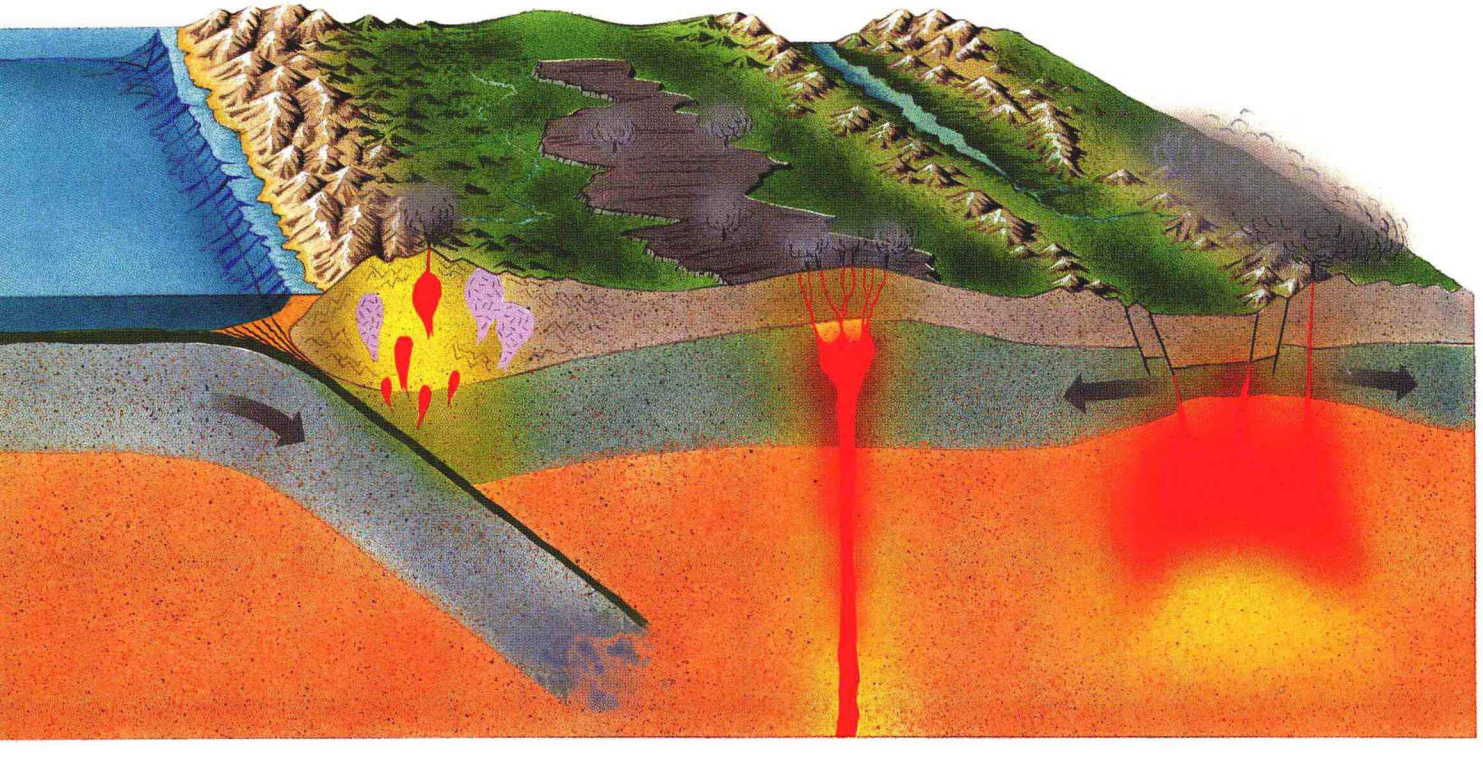

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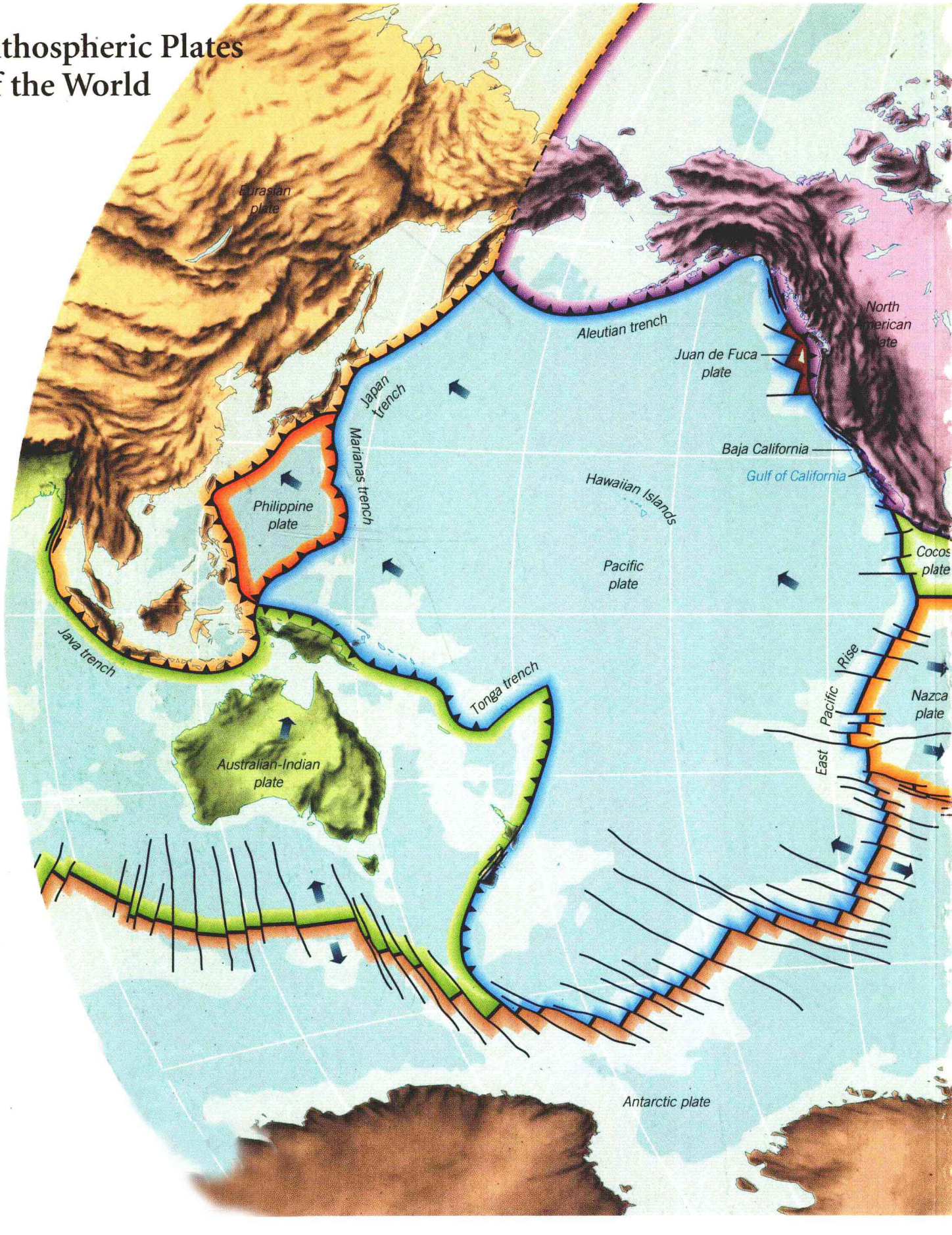

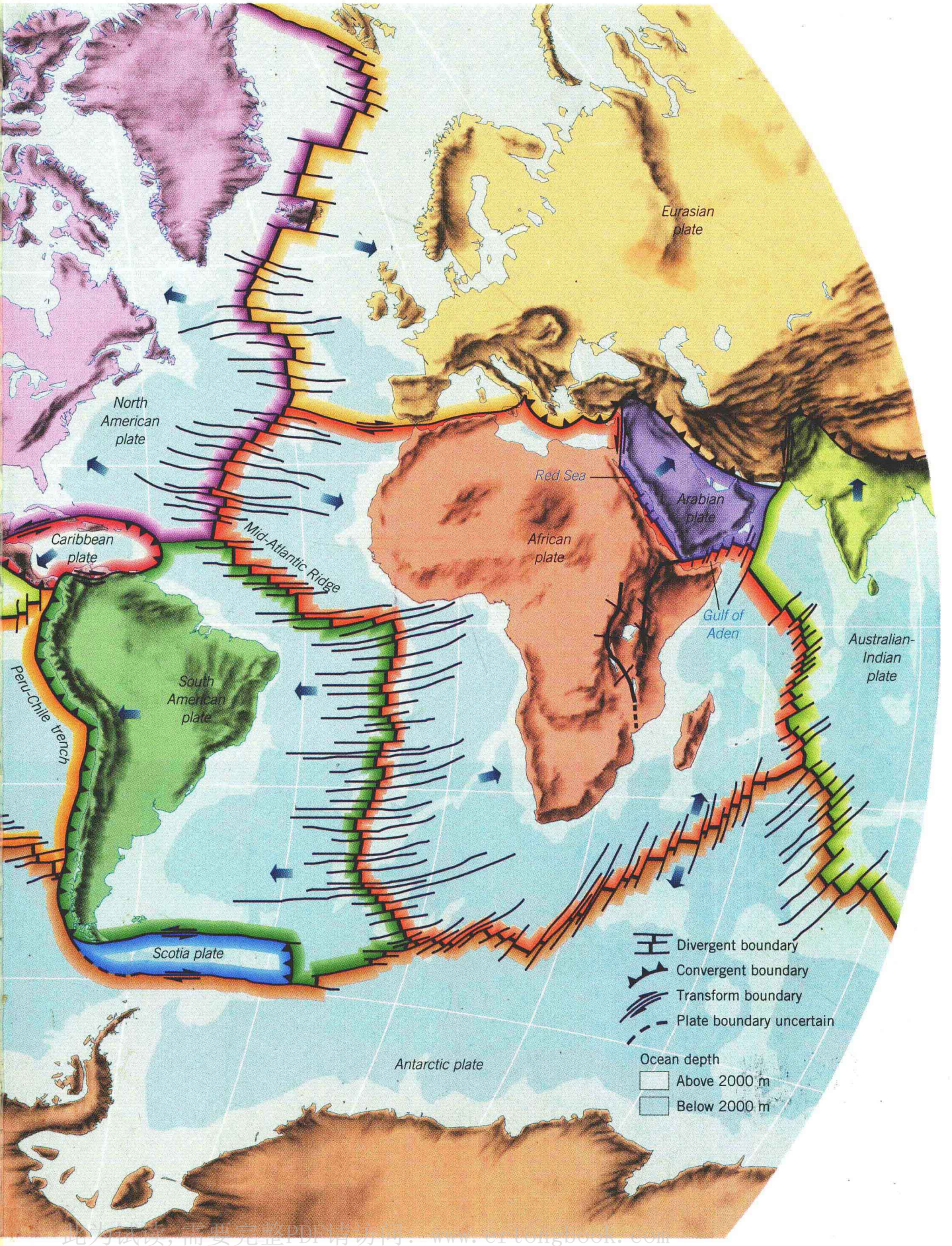

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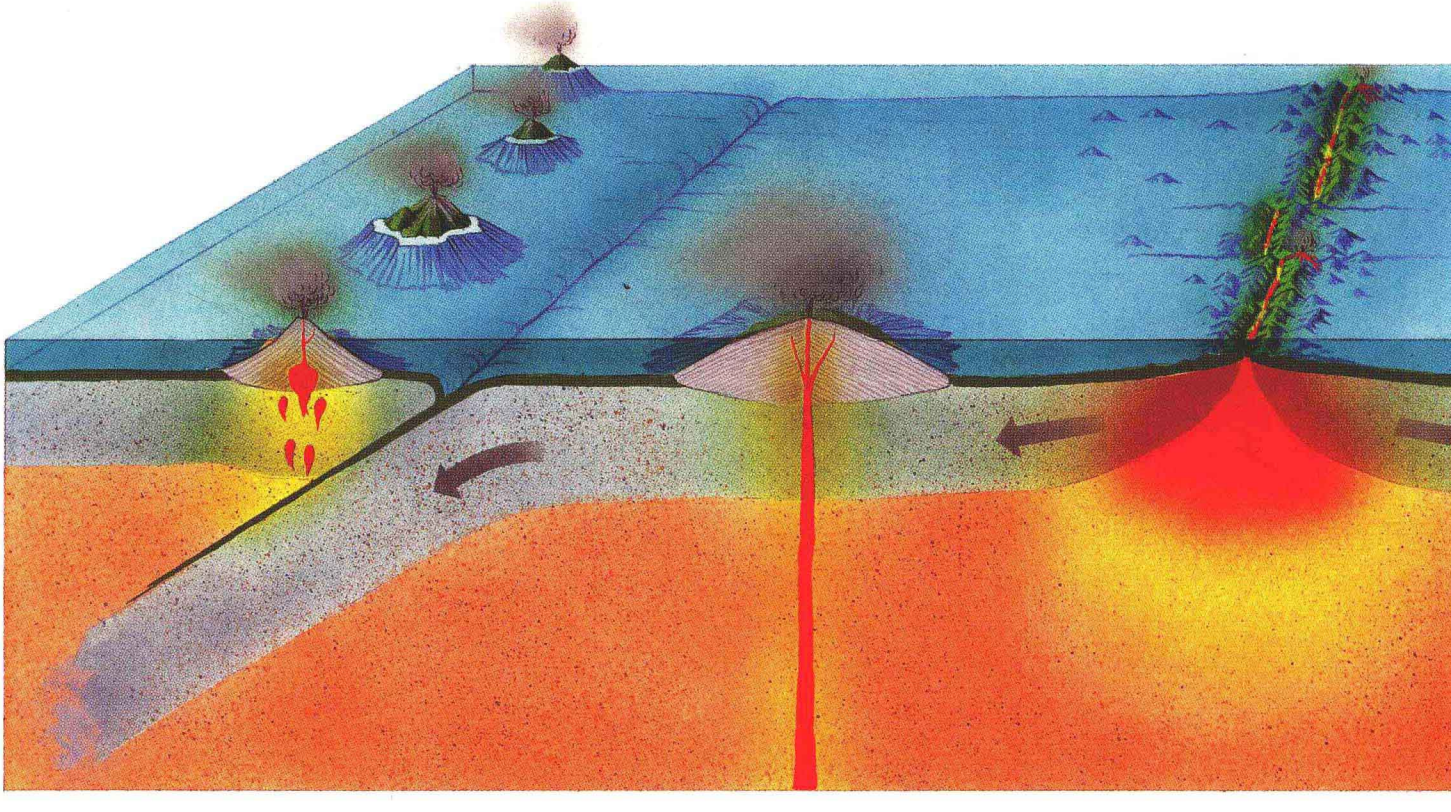

This book is dedicated to the memory
of my parents,
Esther and Samuel Dolgoff.

Preface

This textbook is designed for students enrolled in the introductory physical geology course offered at most two- and four-year colleges. This first course typically attracts a variety of students, from geology and other science majors to business, education, and humanities majors 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; groundwater pollution and overuse; and subsurface nuclear- and toxic-waste disposal. 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; constructing artificial levee systems strong enough to withstand the likes of the Mississippi and Sacramento floods; and finding a safe place to bury nuclear waste in view of recent discoveries about the long-term explosive potential of plutonium. 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 some students, physical geology is only the first of numerous science courses they will take as undergraduates, but for many, 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 the introductory chapter, where I have posed the intriguing geological question, What is the meaning of the thick salt deposits beneath the floor of the Mediterranean Sea? For more than twenty years, the dominant view has been that 6 million years ago, the Mediterranean dried up and left behind a huge sunken desert. But the emphasis of the discussion is not so much on the answer—which, in any case, is in dispute—but on how geologists have gone about *seeking* the answer.

  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. I have discussed some theories as much for where they can lead the student as for the facts they explain. For example, I have presented the probable Cretaceous meteoroid impact as much for its influence on the traditional concept of uniformitarianism as for its role in the extinction of the dinosaurs.

- *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

Some authors offer a skeletal description of plate tectonics in the first chapter and reserve major discussion of the theory for the end of the book. Others treat it somewhere in the middle. While these traditional approaches have merit, I believe that the introductory physical geology course is most solid when it is built upon a foundation of plate tectonics. Traditional organizations force an author to play catch-up, dragging in various aspects of plate tectonics theory by the hair. Not only does the student get a disjointed view, but by the time the theory is presented, it has lost much of its impact.

In this book I have laid the cornerstone of plate tectonics early. After a brief introductory chapter on the process of scientific inquiry and career opportunities in the geosciences, 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. 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.

Chapters 3 and 4 focus on earthquakes and the Earth's interior. I have included such generally neglected subjects as paleoseismology, mantle convection, and the relationship between theories of the Earth's interior and theories of the Earth's origin. Then,

after discussing minerals, rocks, volcanism, geologic time, and rock deformation (Chapters 5–11), I have concluded this section—which is mainly concerned with internal processes—with plate tectonics and continental structure (Chapter 12). I have treated Chapter 12 as a synthesis of Chapters 1 through 11. Students are then in a position to appreciate the surficial processes (Chapters 13–19) that act upon the continental crust.

Chapter 20, on mineral resources, and Chapter 21, on planetary geology, reprise the major themes of the textbook from markedly different perspectives. Chapter 20 describes how natural processes directly affect our material well-being. Although I have examined problems of overconsumption and pollution, I have avoided apocalyptic statements, which I believe have hindered public appreciation of very real environmental issues. Chapter 21 seeks to place the Earth in the context of the geological evolution of the terrestrial planets, emphasizing the reasons why the Earth, the Moon, Mars, and Venus differ from one another.

Students like this sequence of topics—which I have used with minor variations 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. Furthermore, three decades have passed since the plate tectonics revolution transformed geology. Scientists almost universally accept the theory, and although they have modified it, no one has seriously challenged its basic premises. The time has come to put plate tectonics up front where it belongs.

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, there are two traditional ways of presenting surficial processes. One is to place the chapter on weathering before sedimentary rocks; the other is to present it later in the book, as the first chapter in a series presenting gradational processes. I have taken the latter approach because there is more to weathering and soils than simply supplying the raw materials for sediments, and I feel that it is important for students to see the entire gradational sequence. The concepts that students need to know about weathering and sediments are summarized at the beginning of the sedimentary chapter, but they are covered in depth in the weathering chapter. Yet instructors who would prefer to assign the weathering chapter before sedimentary rocks can do so easily and without redundancy.

For those who prefer a traditional approach, Chapter 5, on minerals, can be assigned either immediately before or after Chapter 2, on plate tectonics; and Chapters 3 and 4, on earthquakes and the Earth's interior, can be taught after the mineral and rock chapters (Chapters 5–9) without any loss of coherence. Instructors who opt to cover planetary geology as the introductory topic in the course can assign Chapter 21 early, either before Chapter 1 or after Chapter 2.

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 8, 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.

Two 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 introduced.

Also, to help students master material and study for exams, the textbook includes the following pedagogical devices:

- **Chapter Outline**. Each chapter begins with a preview outline of the headings within the chapter.
- **Study Terms.** This end-of-chapter list of key terms features references to the page where each term is first used and defined.
- **Critical Thinking Questions.** Five to ten questions at the end of each chapter test 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 terms and identifies the text pages where they are introduced.
- **Selected Bibliography.** This brief supplementary reading list, organized by chapter, includes both classic books and current articles.

New to this Update

The major changes in this Updated Version of the book may be divided into two categories: (1) an expanded and more accessible treatment of issues stemming from human interaction with the natural environment and (2) a significant recasting of certain key topics in light of recent discoveries.

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.

As in the earlier version of this book, environmental discussions appear throughout the text where relevant. However, in this Update, 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.

An innovation I personally am excited about is the Apply and Decide feature interspersed throughout the text. Each Apply and Decide describes how geological information in the chapter can be applied to a better understanding of—and possibly the solution to—an important environmental problem. The purpose is to encourage students to think critically about connections between scientific and social issues by asking: What inferences or conclusions can be drawn from the geological data? What options exist toward solving or ameliorating the problem? What are the social, economic, and political consequences of choosing a given course of action?

For example, Apply and Decide 8.1 describes studies of Guatemalan lake sediments suggesting that severe environmental degradation was a major contributing factor in the sudden collapse of the Mayan civilization. Students are then asked: Are there any parallels concerning our own civilization that can be drawn from the Guatemalan lake studies? How students arrive at the answer to this question is more important than their conclusions, which are always open to debate. At the very least, students will have explored an interesting linkage between sedimentology, human ecology, anthropology, and population dynamics.

Similarly, Apply and Decide 3.1 discusses how seismologists work with engineers to design seismically "safe" buildings. Students are then asked to consider such questions as: How much weight should be given to "expert" opinion? Who decides what is "acceptable" risk? In Apply and Decide 15.1 on the impact of large dams, students are asked to consider such issues as: Who pays? Who benefits? What are the tradeoffs? In 21.1 they are asked whether taxpayers' money should be spent to identify potential meteoroid hazards, and so on.

Updating of Key Topics

This Updated Version also reflects the need to keep pace with fast-breaking developments that have occurred in a number of fields since initial publication in 1995. To this end, for example, I have:

- added a discussion of recent discoveries that the inner core is anisotropic and rotates at a faster rate than the Earth as a whole (Chapter 4, Interior of the Earth).
- extended and revised the treatment of meteoroid impacts. The main innovation is that impacts are treated as a normal geologic process and are referred to as necessary throughout the text. Thus you will find a new Aside feature devoted to impact craters as landforms in Chapter 11, Rock Deformation, and an Apply and Decide discussion of their potential future menace in Chapter 21, Planetary Geology. This is in addition to previous discussions of the role of impacts in mass extinctions (Chapter 10, Geologic Time) and of the role of impact cratering in dating planetary surfaces.
- extensively revised the section describing the geology of Venus (Chapter 21, Planetary Geology). The surface of the planet everywhere bears the imprint of volcanism, but impact cratering data tell us that, unlike the Earth, the entire surface of Venus is 500 million years old. The gradualistic uniformitarian model no longer seems to apply to Venus.

An Essential Alternative

There may be instructors who are interested in the organization and approach of this book but prefer to use an "essentials" text. To better meet their needs, I have prepared a new text entitled *Essentials of Physical Geology.* It is a condensed version of this Updated

edition that has been recast for use by nonscience majors in a one-semester or one-quarter course. Designed as well for instructors who include a unit on historical geology in their course, *Essentials of Physical Geology* closes with a four-chapter sequence, which includes Chapters 16 (Geologic Time) and 17 (Formation of the Continental Crust) plus two entirely new chapters: 18 (Earth History: From the Origin of the Planet Through the Proterozoic Eon) and 19 (Earth History: From the Paleozoic Era to the Present).

For those instructors who prefer the Updated Version of this book but also want to include historical geology in their course, the two new Earth history chapters may be packaged with the Updated Version. Contact your local Houghton Mifflin sales representative for further information. To create an expanded unit on historical geology, the instructor can assign Update chapters 10 (Geologic Time) and 12 (Plate Tectonics and the Continental Crust) and then assign the two supplementary historical chapters. Note, however, that because the historical geology chapters begin with a complete discussion of the origin of the solar system, you may want to delete the equivalent portion of Chapter 21 (Planetary Geology)—or the entire chapter for that matter—from your reading assignments.

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.* 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 1200 multiple-choice questions and approximately 200 additional essay and illustration-based questions, is conveniently organized by chapter. Also featured are 40 questions, covering the material in the first eleven chapters, that are suitable for use in a midterm exam, plus 40 questions, covering the material in the last eleven 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 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.

Acknowledgments

Writing 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.

I am very grateful to Luigia and Herbert Miller, my oldest and dearest friends, who encouraged me every step of the way and kept me focused on my writing. Isolda, my wife, put up with my long, work-related absences and occasional ill humor with a good grace I did not deserve. Maria Chen, my colleague at New York City Technical College, logged hour upon hour helping me with manuscript preparation and research for no other reasons than friendship and belief in the book. My brother, Abraham Dolgoff, an engineering geologist, was a patient and expert consultant. Jinny Joyner, a skilled editor, became involved in the book during the early stages of development. She sharpened my prose and made many astute suggestions for fine-tuning the chapter organization. My special thanks go to her, as well as to Kent Porter Hamann, the editor who launched this project at D. C. Heath, and to Jim Porter Hamann, my first marketing manager at Heath. Their hard work and enthusiastic support will not be forgotten.

Sylvia Mallory, geology editor at Heath, joined the team midstream but quickly proved her ability to sponsor the book with editorial acuity and market savvy. Behind the scenes, production editor Anne Starr guided the manuscript, photos, and illustrations through every phase of the production process, keeping me organized and holding me to a tight schedule, all with gracious (albeit relentless) persistence. Billie Porter and Judy Mason worked together to acquire the text's many beautiful photographs, and Robert E. Morency, Jr., assisted me in reviewing these photos for content. The elegant look of the book reflects the talents of our designer, Alwyn Velásquez, and the artistry of the page make-up was Irene Cinelli's contribution. Art editor Jim Roberts creatively and capably coordinated the rendering of the line illustrations. Many of the more complex line illustrations were the work of a wonderful artist, Elizabeth Morales, an anthropologist by training, but with a good deal of formal background in geology. The Heath staff calls her work reflective art, but I call it suitable for framing.

There follows a long list of geologists who reviewed the manuscript 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 Bridgeport; Pamela Martin at the University of California, Santa Barbara; and John Geissman at the University of New Mexico also devoted many tedious hours to checking the illustrations for accuracy. I thank them and all of the other excellent reviewers for their time and wise counsel:

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A. D.

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