DAVIDSON ▲ REED ▲ DAVIS

EXPLORING EARTH

Second Edition

Exploring Earth

An Introduction to Physical Geology

Second Edition

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Preface

Preface

With this book, we hope to introduce readers to the world of physical geology and to share with them the excitement of exploring Earth and the processes that formed it. We hope that readers of this book will gain a better understanding of Earth and an increased awareness of our planet. When traveling by airplane, a reader will appreciate how mountains, rivers, and deserts were formed, and what governs their locations, shapes, and textures. A hiker will understand how multicolored pebbles in a stream formed and where they came from. Earthquakes, volcanic eruptions, tidal waves, and other geologic hazards will be viewed with a greater understanding of the processes that give rise to such events.

We have taught the introductory geology and geophysics courses at the University of California at Los Angeles and the University of Durham for a cumulative total of forty years. Students have traveled with us on field trips to every continent. Because our special areas of study include not only geology, but also geophysics and geochemistry, we seized the opportunity to present an interdisciplinary approach to physical geology. We felt the need for a book that presents geology in the framework of plate tectonics with a strong emphasis on geologic processes. We feel strongly that this approach presents the field of geology in its full richness while making the subject both more interesting and easier to learn.

We wrote this book for students with little or no scientific background. Toward this end, we have avoided unnecessary use of jargon, introducing geologic terms in context and only as needed. We describe geologic time using millions and billions of years rather than using the traditional geological time scale, which we have found can cause unnecessary difficulty for students taking their first geology course. We have limited the use of mathematical expressions, but those that we have included serve to introduce students to a few of the powerful and concise tools geologists use to quantify the processes and characteristics of Earth.

We think this book will give pleasure to students by increasing their awareness and understanding of their surroundings. Indeed, we hope that some will continue on to become geologists and share in the excitement that we have experienced working in this field. In any case, it has been our intention here to make the subject easy to learn and one of never-ending fascination.

Organization of the Book

After a brief introduction to the Earth as a system in Chapter 1, in which plate tectonics, climate, and time are all closely linked, the order of material presented in the book follows the evolution of Earth from its formation to the development of plate tectonics and present-day geology. Chapter 2 presents the formation of Earth and the elements and the partition of Earth into crust, mantle, and core. Throughout, we emphasize how scientists arrived at our present understanding of Earth's internal composition and processes. Students can then appreciate the origin of Earth's huge internal energy source and understand how that energy drives plate tectonics. In Chapters 3 and 4, we turn to the material of Earth itself and explore rocks and the minerals from which rocks are formed.

Chapter 5 introduces the approaches that gave rise to our present understanding of Earth's interior and internal processes. These include measurements of seismic waves, gravity, and magnetism of Earth. It also provides the background for the development of the plate-tectonic theory. Chapter 6 then takes a closer look at geologic time—how it is measured and how we can appreciate the operation of processes at various different rates—many imperceptible over human lifetimes. Chapter 7 explores plate tectonics from its early roots in the theory of continental drift to our present-day understanding—including some of the outstanding problems which are still being researched.

The subsequent chapters concentrate on processes that occur at plate margins, starting with earthquakes and deformation in Chapter 8. Chapters 9 and 10 explore the lithospheric plates, their relative movements, and how interaction of these plates gives rise to earthquakes, volcanoes, and mountain ranges. Many of Earth's features are most conveniently and logically discussed in the context of the three types of plate margins—divergent margins, convergent margins, and transform margins. We point out the context in which igneous, metamorphic, and sedimentary rocks form and how they differ from margin to margin.

Chapter 11 examines the role of water in determining many of the properties of our planet—including its accommodation of life. Water is a vital component of the hydrosphere and atmosphere, which feature prominently in the later chapters of the book. The following chapters deal with surficial processes, examining the processes of

weathering and erosion that occur at Earth's surface and the transport and deposition of the sedimentary material formed in this way (Chapters 12 and 13). A natural consequence of these processes is the modification of landscapes, and we next explore the characteristics of different landforms in the geomorphology chapter (Chapter 14). Students will discover that different combinations of climate, geology, and environment will produce distinct landform characteristics. Finally, we address some of the more practical aspects of the earth sciences. From an understanding of how Earth works, we take a look at the environment from a geologic perspective in Chapter 15 and at how natural resources are formed in Chapter 16.

Major Changes to the Second Edition

Based on feedback from instructors around the country, as well our own personal experience, we have extensively revised the second edition of *Exploring Earth.* The major changes include:

- **Specific treatment of Earth as a *system*** (Chapter 1). The connections among different aspects of earth science are pointed out explicitly. This serves as a better basis on which to discuss the influence of, for instance, climate on tectonics (and vice versa) or the way the hydrologic cycle links the atmosphere, biosphere, hydrosphere, and lithosphere.
- **A new, separate chapter on geologic time** (Chapter 6). In the first edition we had resisted an entire chapter on time, feeling that this was more the purview of historical geology. However, careful consideration of the importance of a basic understanding of time and the ways in which geologic histories can be understood is critical to the process theme of this text—particularly when it comes to the consideration of process *rates.* We have tried to give insights into the fundamental principles on which geologic dating is based, and to distinguish between relative and absolute dating. This is also an opportunity to introduce the geologic time scale used widely by geologists—although, given that this is a book for the nonspecialist, we have retained simple annotation of ages in millions of years throughout the book rather than using formal eras and epochs.
- **A new, separate chapter on water** (Chapter 11) detailing its role in the formation and behavior of the planet, its distribution, and its influence on many Earth processes. We felt that such a chapter serves as a critical link between the second and third parts of the book. The former deals largely with plate tectonic and lithospheric processes, while the latter focuses on surface processes—weathering, erosion, deposition, and landscape formation—that reflect the interaction of the hydrologic cycle with the lithosphere. This chapter also gives us an opportunity to examine the origin of water in and on Earth and to reemphasize its many important roles. Given that its most important direct relevance to humans is in the basic support of life, we have included a discussion of the distribution and recovery of water in the context of being our most important natural resource.
- **Consolidation of the specific chapters on plate tectonic environments** (formerly four) into two—Chapters 9 and 10. This change has enabled us to achieve a better balance and remove some of the detail that was included in the first edition principally to ensure broadly comparable chapter lengths. Chapter 9 examines rifting—from the initial breakup of continents to "steady state" mid-ocean ridge processes. Transform faults—both oceanic and continental—are included here by virtue of their close association with spreading centers. Chapter 10 explores the opposite phenomena of ocean basin closure and continental collision. Convergent margin processes, both continental and oceanic, are discussed, as are variations in convergence effects from collage tectonics to the ultimate death of oceans in continental collision.
- **Revised focus boxes.** A revised edition gives us an opportunity to remove focus boxes that were regarded as unnecessary and add some exciting new material. For example, we have added a graphical illustration of the effects of magma crystallization in a Hawaiian lava lake in Focus 4.2, added a new focus (11.2) with a simple numerical treatment of water movement at variable permeability, and consolidated several interesting aspects and consequences of continental collision into a case study of the Himalayas (Focus 10.2).
- **Inclusion of one or more numerical questions at the end of each chapter**. Reflecting our belief that a simple way to explain and understand many natural processes is through an expression in math, we have designed some simple numerical exercises, requiring no more than a familiarity with algebra, many of which allow worked examples to be revisited.
- **Appendix of common rock types, cross-referenced to discussion in the main text**. This serves as a useful reference analogous to the table of common minerals already included as an appendix.
- **Spectacular new photographs and figures**. From the earliest days of the first edition we have been of the strongest opinion that an understanding of geology leans heavily on illustration. We have taken this opportunity to replace less effective photographs and add new ones. We have also designed new illustrations—not just for the new chapters, but to improve revised versions of the other chapters. Central to this is an improved global map with digitally shaded relief that serves as a common base map for several illustrations throughout the book—for plate boundaries and the distributions of earthquakes, volcanoes, mountain ranges, and so on.

Pedagogical Features

Table of Contents In contrast with many other popular introductory geology textbooks, this text integrates topics in context rather than isolating a topic in a given chapter; therefore, some topics are found in more than one location. For example, volcanoes are introduced in Chapter 4 during our discussion of rocks. Chapter 9 discusses the vast regions of volcanic activity along the mid-ocean ridges which, until thirty years ago, were largely unknown and unexplored. Chapter 10 presents volcanoes in the context of convergent margins where they are at their most explosive and spectacular. Finally, Chapter 15 examines volcanic hazards and the climatic effects of volcanoes.

Speedbumps Brief interim summaries are incorporated throughout each chapter, especially after discussion of an important concept, allowing students to pause, review, remember, and then continue on to the next concept.

Cross-references Cross-references are included to help students connect concepts. They are indicated by the icon ∞ and indicate where the referenced material was introduced or previously mentioned.

Focus Boxes Each chapter contains one or more boxed topics; this boxed text either applies a concept that is being raised in a given chapter or takes a closer, more in-depth look at a topic being presented.

Key Terms and Glossary Important vocabulary terms are boldfaced in the text and defined in the glossary at the back of the text.

Questions for Review and Further Thought can be found at the end of each chapter. Some are simply to aid review of important material; others are to encourage deeper reflection on the material in the chapter. At least one question for each chapter is designed to practice numerical calculations. These are indicated by a calculator icon.

Art Program The art program was carefully designed both to facilitate student understanding of difficult concepts and to present geologic processes and place these processes in context. Believing strongly in the adage that a picture is worth a thousand words, we have included a rich variety of photographs and illustrations. Examination of these illustrations will help students realize the naturalist, or observational, nature of geology as a science.

Appendices Appendices include a conversion table for metric units, a geologic time scale, a periodic table of the elements, a table of common minerals and their properties, a table of common rock types cross-referenced to their place in the text, and a list of Earth statistics.

Instructor and Student Resources

For the Instructor

Prentice Hall has crafted a greatly expanded set of instructor resources to accompany the second edition of *Exploring Earth.* These resources are designed to help you simplify your preparation for the lecture, efficiently integrate material from the text into your lecture and assessment activities, and assist you in administering your course.

- Digital Image Gallery CD-ROM. Includes digital versions of the illustrations and selected photos from the text, as well as the slide set, in high-resolution, minimum-compression, 16-bit jpeg files. The Digital Image Gallery makes it easy to integrate text-based resources into your electronic lecture presentation, such as PowerPoint® or Astound®. All these pieces are viewable via a thumbnail catalog, the Image Viewer, for easy searching and sorting. Also included on the CD-ROM is a collection of data visualizations created by Paul Morin (University of Minnesota) and selected for their applicability to the topics in *Exploring Earth,* 2/e. These data visualizations are a powerful way to illustrate to your students the connection between the topics they are studying and the actual data being gathered by geologists working in the field and in laboratories throughout the world.
- Transparency Set. Includes full-color acetates of *every diagram and table* in the text. The images and labels are enlarged and the colors modified for the best quality projection. The transparencies can also be found in digital form on the Digital Image Gallery CD-ROM.
- Slides. 150 full-color slides including both photos drawn from the text and an independent set of photographs from Martin Miller (University of Oregon), himself a geologist, instructor, and professional photographer. The slides can also be found in digital form on the Digital Image Gallery CD-ROM.
- Instructor's Manual with Test Item File. Includes lecture outlines, teaching tips, and advice on how to integrate visual resources. The Instructor's Manual is meant to be both a guide for less experienced instructors and a resource and source of new ideas for experienced instructors. Also included is the Test Item File, a collection of over 1,000 questions keyed directly to the text.
- Prentice Hall Custom Test Manager. This newly updated testing software includes all the questions from the Test Item File and permits easy creation and editing of tests. The software also allows easy porting of quizzes into MS Word® format and supports administration of quizzes over a LAN. Available in both Windows and Macintosh formats.
- On-Line Course Management Solutions. Prentice Hall offers content specific to *Exploring Earth,* 2/e, preloaded in the WebCT, BlackBoard, and CourseCompass course management system platforms. Each of these platforms lets you easily post your syllabus, communicate with students on-line or off-line, administer quizzes, and record student results and track their progress. Please call your local Prentice Hall representative for details on how to adopt and implement any of these options.

For the Student:

The student supplements are engineered to multiply the instructor's efforts by providing extensive review, moderated feedback, and guidance for further exploration outside of the classroom.

- *Exploring Earth* Companion Web Site. www.prenhall.com/davidson This innovative on-line study guide is tied chapter-by-chapter to the text and includes: automatically graded, reportable review quizzes; short answer and critical thinking questions; and annotated links to the best geology sites on the Web.
- Study Guide. Guides students through the text's coverage with an extensive selection of study questions for each chapter.
- New York Times Themes of the Times—The Changing Earth. A unique newspaper-format supplement that brings together a collection of recent geology-related articles from the pages of *The New York Times.* This free supplement, updated twice a year, encourages students to make connections between the geology they are learning in the classroom and the world around them. Available free with a new book; please call your local Prentice Hall representative for more details.

Acknowledgments

We are deeply indebted to the thorough reviews solicited by Prentice Hall from Spencer Cotkin (University of Illinois), Michael Heaney (Texas A&M University), Alan Kafka (Boston College), David Lageson (Montana State University), George McCormick (University of Iowa), Joe Meert (Indiana State University), Otto Muller (Alfred University), Claudia Owen (Florida International University), Carl Renshaw (Dartmouth College), Kevin Stewart (UNC—Chapel Hill), Skip Stoddard (North Carolina State University), and Douglas Thompson (Connecticut College). We are especially indebted to J. K. Osmond (Florida State University) and Donna Jurdy (Northwestern University) who read the entire manuscript of the revision and provided invaluable feedback in helping to ensure the text's accuracy. We also received helpful suggestions from James E. Court (City College, San Francisco) and UCLA colleagues, Ray Ingersoll, Mark Harrison, Wayne Dollase, and Gary Axen. We have tried very hard to address all concerns but cannot simultaneously satisfy all suggestions. For this we are sorry, but your efforts did not go unheeded.

We are particularly grateful to the many colleagues who have commented on the first edition. We are encouraged to find a great deal of support for the process-orientated approach and for the way we have tried to restructure the delivery of introductory geology.

We would like to again thank the reviewers involved in the first edition of this text, who provided extremely valuable input and many helpful suggestions: E. Calvin Alexander, Jr. (University of Minnesota), Don L. Anderson (California Institute of Technology), Duwayne M. Anderson (Texas A&M University), Thomas W. Broadhead (University of Tennessee), George H. Davis (University of Arizona), Wakefield Dort (University of Kansas), Karen Goodman (Broome Community College), Barbara E. Grandstaff (New Jersey State Museum), Bryce M. Hand (Syracuse University), Vicki Hansen (Southern Methodist University), W. Burleigh Harris (University of North Carolina—Wilmington), Richard B. Hathaway (State University of New York—College at Geneseo), John R. Huntsman (University of North Carolina at Wilmington), Karl E. Karlstrom (University of New Mexico), David King, Jr. (Auburn University), Ronald Krauth (Middlesex County College), Lawrence Krissek (The Ohio State University), Albert M. Kudo (University of New Mexico), Ralph L. Langenheim, Jr. (University of Illinois at Urbana-Champaign), Douglas Levin (Bryant College), Lawrence Lundgren (University of Rochester), Greg Mack (New Mexico State University), John A. Madsen (University of Delaware), Bart S. Martin (Ohio Wesleyan), Richard L. Mauger, William S. McLoda (Mountain View College), James M. McWhorter (Miami-Dade Community College), Donald S. Miller (Rensselaer Polytechnic Institute), Kula C. Misra (University of Tennessee), Paul Morgan (Northern Arizona University), David B. Nash (University of Cincinnati), David A. Nellis (University of Massachusetts at Boston), Hallan C. Noltimier (Ohio State University), Nilgun Okay (Hunter College of the City University of New York), Bruce C. Panuska (Mississippi State University), Richard Pardi (William Paterson College), Robert W. Pinker (Johnson County Community College), Nicholas Rast (University of Kentucky), Gregory J. Retallack (University of Oregon), Justin Revenaugh (University of California—Santa Cruz), Richard Robinson (Santa Monica College), Barbara L. Ruff (University of Georgia), Douglas L. Smith (University of Florida), William A. Smith (Western Michigan University), Bryan Tapp (University of Tulsa), Paul Tayler (Utah Valley State College), Jack W. Travis (University of Wisconsin—Whitewater), Kenneth L. White (Texas A&M University), Monte D. Wilson (Boise State University), William H. Wright (Sonoma State University), Michael Wysession (Washington University).

At Prentice Hall this time around the unlucky victims of the editorial process were: Patrick Lynch, geology editor; Trish Nealon, our development editor; Martha Beyerlein, our production editor; and Karen Pugliano, photo researcher.

We wish to thank our colleagues at UCLA for supporting the project and providing keen insights and advice. A

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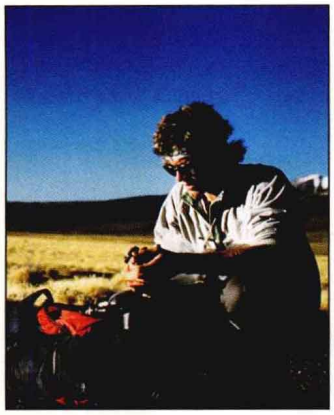
Again, a final and heartfelt thank you to our long-suffering wives who have supported us through a lot of hard work.

JON P. DAVIDSON
WALTER E. REED
PAUL M. DAVIS

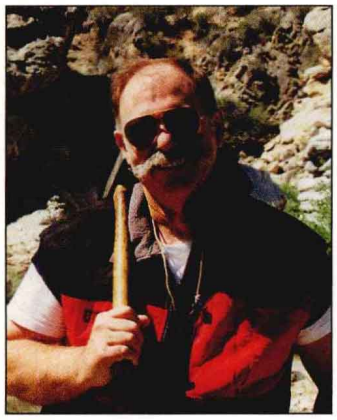
About the Authors



JON P. DAVIDSON

Jon Davidson received his undergraduate degree in Geology from the University of Durham and a Ph.D. in Geology from the University of Leeds. He has held a Visiting Assistant Professorship at both Southern Methodist University in Texas and the University of Michigan. He joined the University of California, Los Angeles, in 1988 and taught courses in Earth Science, Historical Geology, Igneous Petrology, Isotope Geochemistry, Volcanology, and the Regional Geology of Britain and New Zealand. In 2000 he was appointed Chair of Earth Sciences at the University of Durham, U.K. Professor Davidson has led field trips to the Cascades, the southwestern United States, Hawaii, New Zealand, and Britain.

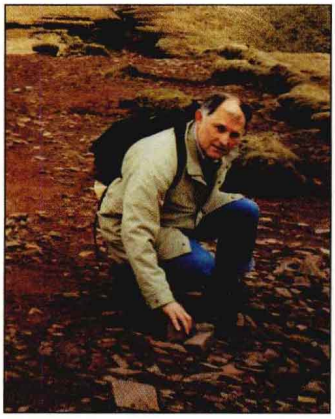
In 1994 Professor Davidson received the UCLA Harriet and Charles Luckman Outstanding Teaching award, and in 1998 he received the Wager Medal of the International Association of Volcanology and Chemistry of the Earth's Interior. Davidson is an igneous petrologist and geochemist, with a keen interest in volcanology. His work focuses primarily on volcanoes in the Caribbean, the Andes, Ascension Island in the south Atlantic, Iran, and Kamchatka in Russia. In his spare time, he enjoys travel, photography, cricket, football (both types), and music.



WALTER E. REED

Walter Reed received his Ph.D. in 1972 from the University of California, Berkeley and joined the faculty of the Department of Earth and Space Sciences at the University of California, Los Angeles, in 1973. Prior to his arrival at UCLA, he worked in an oil company research laboratory for four years and worked for two years for the Department of Defense on the Nuclear Test Site and at the National Reactor Test Range. He has won two "best paper" awards, one in organic geochemistry and one (with his graduate student) in structural geology. Professor Reed has taught continuously since arriving at UCLA, and his courses include Introductory Geology, Sedimentology and Sedimentary Petrology, and Field Geology, spending six to eight weeks each summer with students in the Sierra Nevadas with the latter course.

Professor Reed is a field geologist with experience throughout the western United States, the Aleutian Islands, Spitsbergen, Norway, and Israel. His recent work focuses on California's western Transverse Ranges and on a tectonically emplaced metamorphic-plutonic complex in the Sierra Nevada Mountains. Professor Reed's hobbies include trout fishing, skiing, ice climbing, and building and riding Harley Davidson motorcycles.



PAUL M. DAVIS

Paul Davis is a Professor of Geophysics at the University of California, Los Angeles. He received his Ph.D. in Physics at the University of Queensland, followed by postdoctoral studies at both the Institute of Geophysics and Planetary Physics, University of Alberta and the Department of Geodesy and Geophysics at the University of Cambridge. He joined the faculty at UCLA in 1980 and has recently served as the Vice-Chair and Chair of the Department of Earth and Space Sciences. He teaches Seismology and Applied Geophysics.

Professor Davis received a Guggenheim Fellowship in 1995 to conduct research in the Department of Earth Sciences at the University of Oxford. Upon his return to UCLA, he assumed the position of senior editor of the American Geophysical Union *Journal of Geophysical Research (Solid Earth).* His research uses geophysical experiments to study lithospheric dynamics. He has installed magnetometer arrays on volcanoes on Kilauea, Hawaii and Washington's Mount St. Helens and has carried out seismic array studies of the Mount Etna volcano and the Rio Grande, East African, and Baikal rifts. Professor Davis' interests include racquetball, sailing, hiking, and backpacking with his family.

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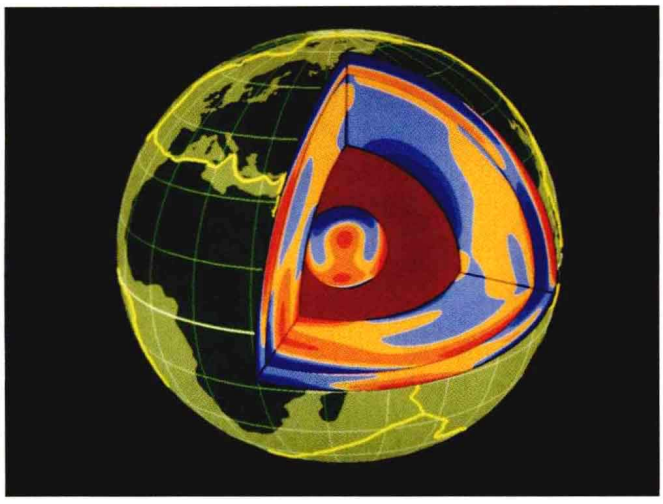

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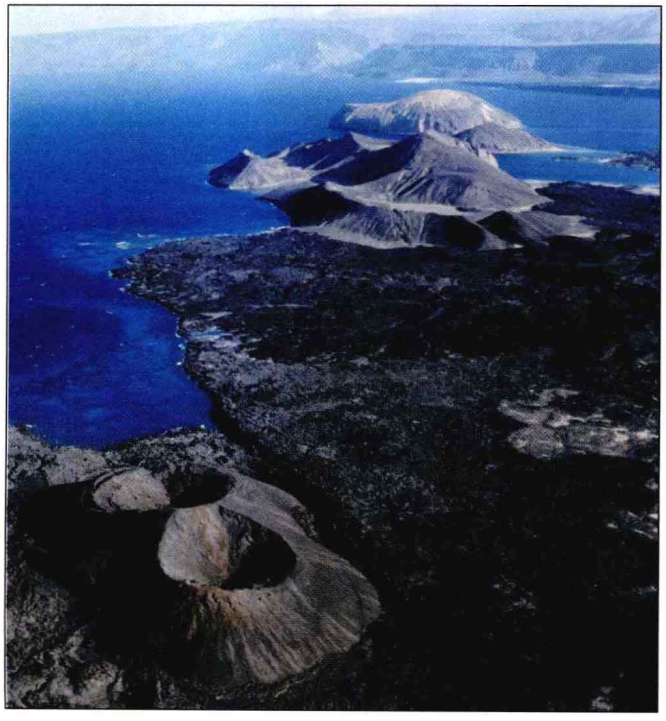

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