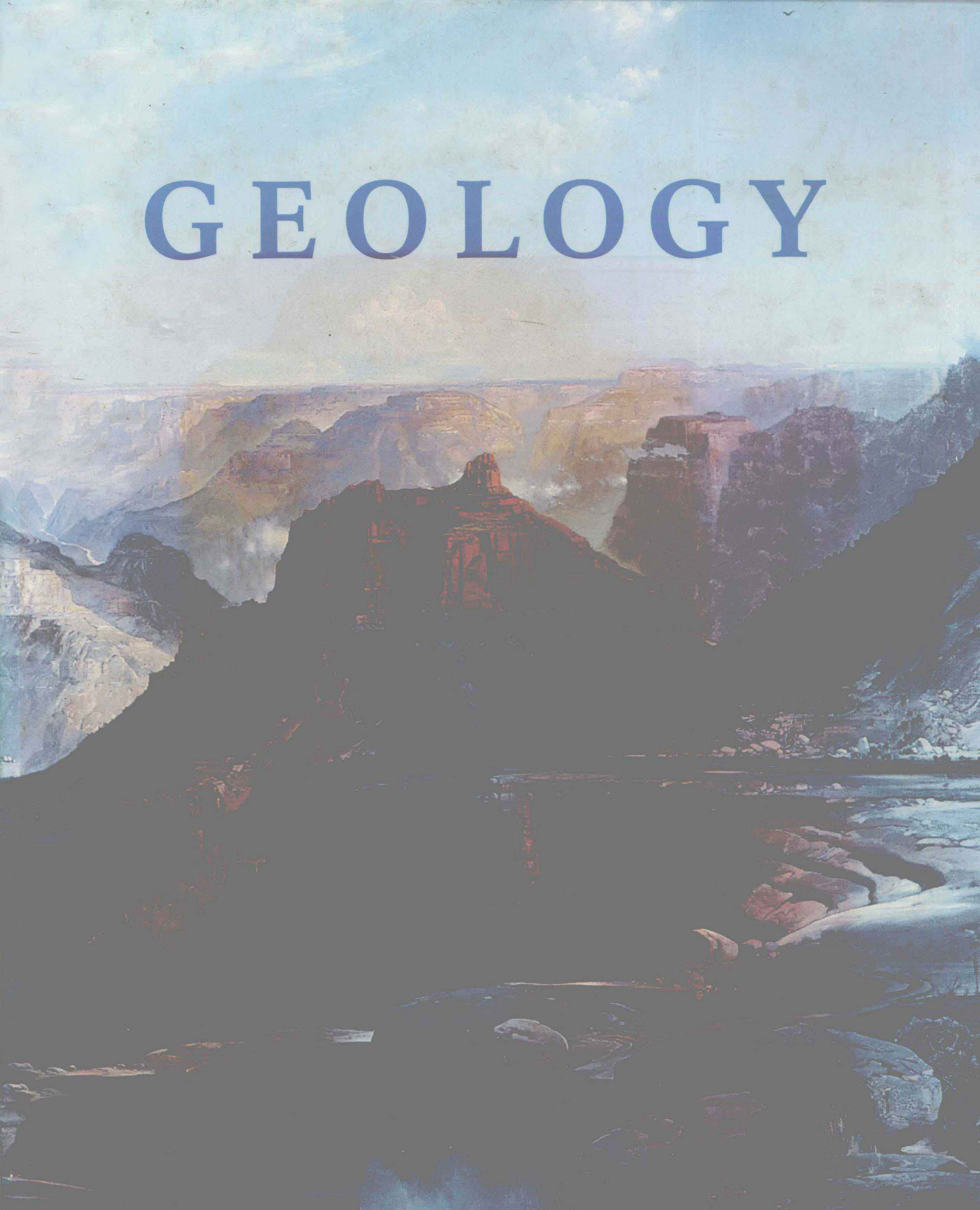
GEOLOGY



GEOLOGY

An Introduction to Physical Geology

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University of Washington, Seattle

Ramesh Venkatakrishnan
Consulting Geologist/Illustrator

WORTH PUBLISHERS

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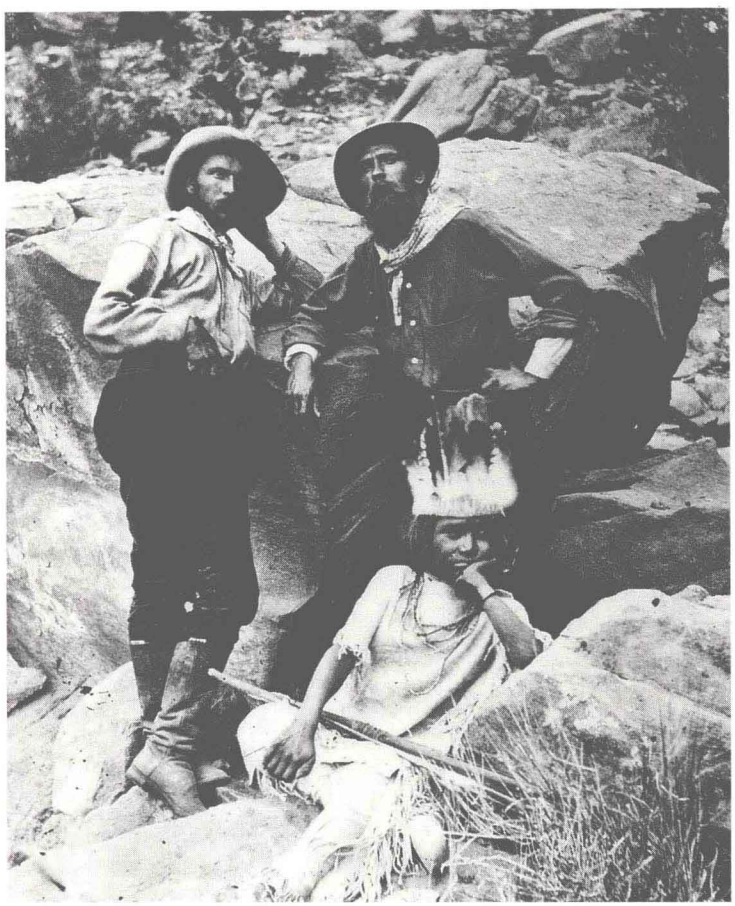
Thomas **Moran's** *The Chasm of the Colorado,* 1873–74, oil on canvas, 84 3/8″ × 144 3/4″ (214.3 × 267.6 cm). Lent by the U.S. Department of the Interior, Office of the Secretary. National Museum of American Art, Washington, D.C./Art Resource, N.Y.



Moran (center), with journalist J.E. Colburn and a Kaibab Paiute boy, photographed by Jack Hillers, 1873. National Anthropological Archives, Smithsonian Institution (photo #1592-B).

Cover Artist

You cannot see the Grand Canyon in one view, as if it were a changeless spectacle from which a curtain might be lifted, but to see it you have to toil from month to month through its labyrinths.

John Wesley Powell

Thomas Moran (1837-1926), who was already well known for an impressive painting of the cliffs along the Yellowstone River, was a guest artist accompanying John Wesley Powell's 1873 expedition to the Grand Canyon. Powell, who in 1869 had led the first expedition ever to explore the entire Grand Canyon, returned there from 1870 to 1874 with larger and better prepared explorers, the Congressionally chartered Geographical and Geological Survey of the Rocky Mountains (also known as the Powell Survey and the Colorado Exploration Expedition). Powell would be a founder of the United States Geological Survey in 1879, and its second director. He would also be a founder and director of the Smithsonian Institution's Bureau of American Ethnology.

After viewing the Canyon from a mountain overlook, Moran wrote:

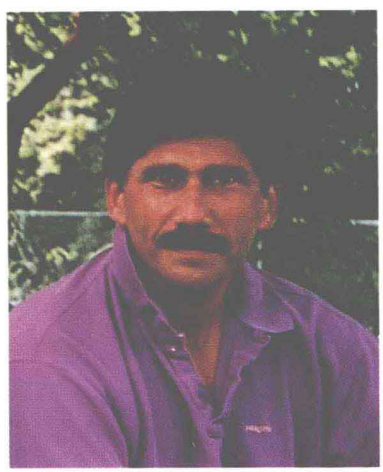
> The whole gorge for miles lay beneath us and it was by far the most awfully grand and impressive scene that I have ever yet seen. . . . Above and around us rose a wall of 2000 feet and below us a vast chasm 2500 feet in perpendicular depth and 1/2 mile wide. . . . The color of the Grand Canyon itself is red, a light Indian Red, and the material sandstone and red marble and is in terraces all the way down. All above the canyon is variously colored sandstone mainly a light flesh or cream color and worn into very fine forms. . . .

Powell described Moran's painting:

> Mr. Moran has represented depths and magnitudes and distances and forms and color and clouds with the greatest fidelity. But his picture not only tells the truth, it displays the beauty of the truth. The painting is called "The Chasm of the Colorado," and rightly. The Grand Canyon of the Colorado is yet to be painted. The view selected is from a point many miles away from the canyon itself and at a place where the side of the plateau had been deeply eroded by a cataract stream. . . .

Moran returned to and painted views of the Grand Canyon numerous times. His paintings were widely exhibited in cities back east. He also made prints of Grand Canyon scenes, which were published in various magazines and journals, thus making the grandeur of the continent's western scenery accessible everywhere.

About the Author

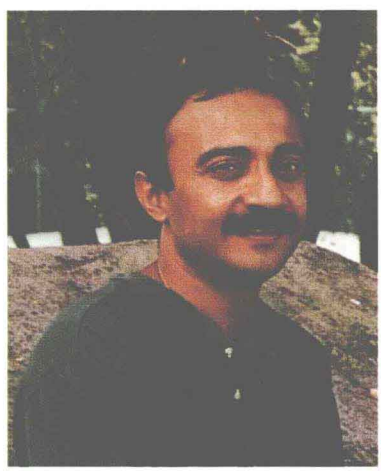


Born in Brooklyn, New York, **Stan Chernicoff** began his academic career as a political science major at Brooklyn College of the City University of New York. Upon graduation, he intended to enter law school and pursue a career in constitutional law. He had, however, the good fortune to take geology as his last requirement for graduation in the spring of his senior year, and he was so thoroughly captivated by it that his plans were immediately changed.

After an intensive post-baccalaureate program of physics, calculus, chemistry, and geology, Stan entered the University of Minnesota-Twin Cities, where he received his doctorate in Glacial and Quaternary Geology under the guidance of one of North America's preeminent glacial geologists, Dr. H. E. Wright. Stan launched his career as a purveyor of geological knowledge as a senior graduate student teaching physical geology to hundreds of bright Minnesotans.

Stan has been a member of the faculty of the Department of Geological Sciences at the University of Washington in Seattle since 1981, where he has won several teaching awards. At Washington, he has taught Physical Geology, the Great Ice Ages, and the Geology of the Pacific Northwest to more than 20,000 students, and he has trained hundreds of graduate teaching assistants in the art of bringing geology alive for non-science majors. Stan studies the glacial history of the Puget Sound region and pursues his true passion, coaching Little League baseball. He lives in Seattle with his wife, Dr. Julie Stein, a professor of archaeology, and their two sons, Matthew (the shortstop) and David (the left fielder).

About the Illustrator



Born in New Delhi, India, **Ramesh Venkatakrishnan** came to the United States after receiving his M.S. in Applied Geology from the University of Delhi in 1975. Ramesh first met Stan Chernicoff at the University of Minnesota-Twin Cities, where he became a laboratory teaching assistant for Physical Geology and in collaboration with Stan developed a series of charts and drawings for the laboratories. In 1979, Ramesh moved to the University of Idaho in Moscow, where he received his doctorate in Geology in 1982.

Ramesh began teaching at Old Dominion University in Norfolk, Virginia, in 1981, teaching physical geology, structural geology, tectonics, remote sensing, and field geology. During the summers he taught the Geology Field Camp for Virginia Tech. In 1986 he and Stan began developing the basic ideas for the illustration program for this textbook. Ramesh left academia in 1990 to pursue a career in consulting with Golder Associates, Inc., where he was a Senior Geologist. Ramesh became an independent consulting geologist in 1993. He has authored or coauthored more than 30 papers on a variety of topics, ranging from mineral exploration to tectonics, and remote sensing to site assessments. The illustrations in GEOLOGY are a natural outgrowth of Ramesh's passion for geologic field investigations and for representing geology in all its color, texture, and three-dimensionality. In addition to geology, his interests include watercolor painting, bicycling, and growing indoor plants. Ramesh works from his home in Mt. Laurel, New Jersey, where he lives with his wife, Kalpana, and daughter, Priya.

Preface

The introductory course in physical geology, taken predominantly by non-science majors, may be the only science course some students will take in their college years. What a wonderful opportunity this provides us to introduce students to the field we love and show them how fascinating and useful it is. Indeed, much of what students will learn in the course will be recalled throughout their lives, as they travel across this and other continents, dig in backyards, walk along a beach, or sit by a mountain stream. For this reason, Ramesh Venkatakrishnan, the book's illustrator, and I have expended the best of our abilities to craft an exciting, stimulating, and enduring introduction to the field.

The Book's Goal

The goal is basic—to teach "what everyone should know about geology" in a way that will engage and stimulate. The book embodies the view that this is the most useful college-level science class a non-science student can take, and one that all students should take. Physical geology can show students the essence of how science and scientists work at the same time as it nurtures their interest in understanding, appreciating, and protecting their surroundings. In this course they can learn to prepare for any number of geologic and environmental threats, and see how our Earth can continue providing all of our needs for food, shelter, and material well-being as long as we don't squander these resources.

Content and Organization

The unifying themes of plate tectonics, environmental geology and natural resources, and planetary geology are introduced in Chapter 1 and discussed in their proper context within nearly every chapter. Chapter 1 also presents the important groups of rocks, the rock cycle, and geological

time—building a foundation for the succeeding chapters. Chapters 1 through 8 introduce the "basics"—minerals, rocks, and time—to prepare the reader for the in-depth discussions of structural geology, geophysics, and tectonics that follow in Chapters 9 through 12. After the Earth's first-order features—ocean basins, continents, mountain systems—have been discussed, the processes that sculpt these large-scale features are addressed. Chapters 13 through 19 present the principal geomorphic processes of mass movement, streams, groundwater, glacial flow, arid region and eolian processes, and coastal evolution. Chapter 16, Caves and Karst, is a brief separate chapter covering material that is usually embedded in or appended to groundwater chapters. Because caves are among the natural settings that many students visit, and because karst environments are particularly sensitive to environmental damage, we have expanded the discussion as a separate chapter. The final chapter, Human Use of the Earth's Resources, ties together earlier discussions from throughout the book. It reinforces principles that relate to the origins of resources, especially energy-producing ones, and stresses our responsibility to manage them wisely.

Pedagogy

To help readers learn and retain the important principles, key terms are in boldface type and listed at the chapter's end. They also appear in boldface in the end-of-chapter Summary, a narrative discussion that recalls all the key chapter concepts. Also at the end of every chapter are two question sets: Questions for Review to help students retain the facts presented and those For Further Thought to challenge readers to think more deeply about the implications of the material studied.

The author and illustrator have tried to introduce readers to world geology. This book emphasizes, however, the geology of North America (including the "offshore" state, Hawaii), while acknowledging that geological processes do not stop at national boundaries or at the continent's coasts. Wherever data are available—from the distribution of coal to the survey of seismic hazards—we have tried to show our readers as much of this continent, and beyond, as feasible. Photos and examples have been selected from throughout the United States and Canada and from many other regions of the world.

The metric system is used for all numerical units, with their English equivalents in parentheses, so that U.S. students can become more familiar with the units of measurement used by every other country in the world.

The Artwork

The drawings in this book are unique. Ramesh Venkatakrishnan is an experienced and respected geology professor and consultant. He is also a gifted artist. His drawings evolved along with the earliest drafts of the manuscript, sometimes leading the way for the text discussions. We have worked together since we were graduate teaching assistants at the University of Minnesota-Twin Cities. The compulsion for "illuminating" what we want introductory students to know is shared by both of us.

As you will see when you leaf through this book, the art explains, describes, stimulates, and teaches. It is not schematic; it shows how the Earth and its geological features actually look. It is also not static; it shows geological processes in action, allowing students to see how geological features evolve through time. Every effort has been made to illustrate accurately a wide range of geologic and geomorphic settings, including vegetation and wildlife, weathering patterns, even the shadows cast by the Sun at various latitudes. The artistic style is consistent throughout, so that students may become familiar with the appearance of some features even before reading about them in subsequent chapters. For example, the stream drainage patterns appearing on volcanoes in Chapter 4, Volcanoes and Volcanism, set the stage for the discussion of drainage patterns in Chapter 14, Streams and Floods. The colors used and the map symbols keyed to various rock types follow international conventions and are consistent throughout.

The Supplements Package

GEOLOGY is accompanied by an array of materials to enhance teaching and learning.

For students who wish additional help mastering the text, there is the Study Guide by W. Carl Shellenberger (Montana State University—Northern). For each chapter, the Guided Study section helps students to focus on and review in writing the key ideas of each section of the chapter as they read. The Chapter Review, arranged by section and composed of fill-in statements, enables them to see if they have retained the ideas and terminology introduced in the chapter. The Practice Tests and the Challenge Test, which consist of multiple-choice, true/false, and brief essay questions test their mastery of the material. All answers are accompanied by page references for easy review.

The Instructor's Resources by Chip Fox (Clemson University) features chapter objectives, an outline lecture guide with teaching suggestions embedded in it, student activities and classroom demonstrations, and suggestions for further reading and for films, software, slide sets, and model kits. Answers to the end-of-chapter questions in the textbook are also provided.

The comprehensive Test Bank, also by Chip Fox, contains over a thousand questions. There are at least 40 multiple-choice questions per chapter, classified as either factual or conceptual/analytical. There are also 10 short essay questions, complete with answers, for each chapter. A

Computerized Version of the Test Bank is available in both IBM and Macintosh formats.

More than 130 of the text's diagrams and photographs are available for classroom use as full-color slides or transparencies.

Acknowledgments

Some remarkably talented, dedicated people have helped us to accomplish far more than we could have done alone. Worth Publishers assembled a "committee" of top-flight geologists who clarified definitions and explanations, eliminated ambiguities, corrected factual errors, and, in general, helped the author hone the manuscript in countless ways and helped the illustrator to select what to show and how best to do it. Special thanks must go to Jim McClurg at University of Wyoming, Howard Mooers at University of Minnesota-Duluth, and Carl Shellenberger at Montana State University—Northern for their thoughtful advice throughout the development of this book. In addition, for their constructive criticism at various stages along the way, we wish to thank these excellent reviewers:

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At Worth Publishers, developmental editor Marjorie Weiser performed the herculean task of reining in the author's long-windedness with extraordinary grace and intelligence and brought organization wherever she found disorder. Project editor Elizabeth Geller polished each chapter of prose and every rough sketch, working with all the elements of the book until they formed a coherent whole. Photo research was handled masterfully by picture editor Inge King and photo research assistants Siva Bonatti and Silvia Dinale. The book's pleasing appearance was created under the supervision of George Touloumes and his gifted staff, including Demetrios Zangos and Matthew Dvorozniak. Production supervisor Stacey Alexander oversaw all scheduling and quality control throughout the production process.

I very much appreciate Managing Editor Anne Vinnicombe's support and behind-the-scenes hard work. Thanks are due also to Carol Bullock, who coordinated and edited the supplements; editorial assistants Paul Hamilton, Jeannie Jhun, and Marian Turk who coordinated communications and numerous other tasks efficiently; and Maja Lorkovic, who provided invaluable editing and production assistance at all stages of the project.

Finally, I also wish to acknowledge with deep appreciation the role of Ron Pullins (formerly of Little, Brown and now of West Educational Publishing) and Worth Publishers' Kerry Baruth who championed the cause of GEOLOGY with their respective companies.

After they leave our classrooms, students may well forget specific facts and terminology of geology, but they will still retain the general impressions and attitudes they formed during the course. We hope that our words and illustrations will help to advance the goals of those teaching this course and contribute to their classes. We have used our teaching experiences to craft a textbook that we think our own students will learn from and enjoy. We hope your students will too. We invite your comments; please send them to the author, whose e-mail address is: sechern@u.washington.edu.

Stan Chernicoff

To The Student

Geology is the scientific study of the structure and origin of the Earth, and the processes that have formed it over time. This book was created to bring you some of the excitement of that study through words and illustrations. We, the author and illustrator, are geologists who love the discipline and have derived much pleasure from introducing it to thousands of our own students. We have also been students and understand that some topics will be more interesting to you than others. We have worked to make every aspect of the book as fascinating and useful to you as possible.

Unlike some subjects you might study, geology is not over when your course is completed. Wherever you live or may travel, geology is far more than "the scenery"—although your appreciation for the landscape will be much enhanced by a basic knowledge of geology. When you drink from a kitchen tap, dig in garden soil, see a forest—or see it being cut down for some construction project—geology has a role. If you gaze at a waterfall, swim in coastal currents, endure an earthquake—or read about those who did—you will understand more about the experience after taking this course. As you will learn, geology is everywhere—in the products you buy, the food you eat, the quality of your environment. The materials and processes encountered in the study of geology supply all of our needs for shelter, food, and warmth. This course will help you to understand why earthquakes occur in some places and not in others, where we can live to avoid floods and landslides, where we can find safe drinking water, and more. Knowledge of geology can also help to make us better citizens as we learn how to prevent further damage to our environment.

You will also learn about more distant matters: the age of the Earth, how the planet has changed over its long lifetime, and how some of its creatures have changed along with it. You will explore some geological ideas about our moon and the planets with which we share our solar system. Highlighted discussions provide additional information about some particularly interesting topics.

The language geologists use helps us to describe natural phenomena with precision and accuracy. We have minimized the new terminology you will need to learn, but to do well in the course you will need to master some technical terms. The key terms are in bold type when introduced. They are also listed at the end of each chapter and defined in the glossary at the end of the book.

The drawings in this book are unique, showing you how the Earth really looks both on and below the surface. As you read and examine each illustration, you will find that the words, the photographs, and the drawings are all important in giving you a full picture of geology. The text and illustrations, the key terms, and even the chapter summaries work together to help you learn the concepts and terms. When you read the summary, ask yourself if you know these key points; can you cite examples beyond those given in the brief summary?

Each chapter also includes two sets of questions, one testing your retention of the facts and one challenging you to think more deeply about some of their implications. Test yourself, and then go back and reread any material you are not sure you understand.

As the author of this book, I hope you will enjoy it and gain an appreciation for geology that will enrich your life. If you have any comments, complaints, or compliments, please send them to me or to Worth Publishers. My e-mail address is: sechern@u.washington.edu.

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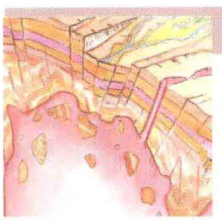

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