Earth

Then and Now

Carla W. Montgomery and David Dathe

Third Edition

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Carla W. Montgomery
Northern Illinois University

David Dathe
Alverno College

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PREFACE

Geology, more so than most other sciences, is much concerned with the passage of time. Many geologic processes are so slow or occur in such minute stages that their effects become significant only over long time periods. Over the course of the earth's history, certain irreversible changes have altered the nature of geologic processes. For example, the earth is slowly cooling, which means that the extent and nature of modern volcanic processes and other temperature-related phenomena are somewhat different from their ancient counterparts; in addition, biological evolution has fundamentally altered the composition of the atmosphere and, consequently, the nature of many surface processes. Therefore, a general introduction to geology appropriately includes both physical geology and historical geology.

Physical geology comprises the study of the various geologic features and materials of the earth, as well as the nature of the processes by which they are formed and modified. It therefore gives us a greater understanding of the planet upon which we live. As humans have come increasingly to depend on geologic resources, knowledge of geology has been important in realizing the origins and the limitations of those resources. We have also come to recognize that we can anticipate—and therefore avoid—some of the disasters that are a natural consequence of certain geologic processes; in a few cases, we may even be able to modify those processes for our benefit.

Historical geology, as the name suggests, is concerned mainly with the history of the earth. Beyond the inherent interest we might naturally have in the development of our home planet and the life-forms on it, historical geology adds to our understanding of the processes that have shaped our world and gives us a particular appreciation for the role of time in geology.

In practice, most students who study geology fall into one of two groups. Some are prospective geology majors, for whom the broad perspectives of physical and historical geology are the foundation on which more advanced coursework builds. A much larger number are nonmajors, and indeed not prospective scientists of any kind, who are prompted to take the course by some mixture of interest in the subject and the need to satisfy a science distribution requirement. Although the needs of these two groups are not identical, every effort has been made to devise a text with sufficient versatility and appropriate learning aids to serve both kinds of students.

About the Book

This book is intended for an introductory-level college course or course sequence in physical and historical geology. It assumes no prior exposure to college-level mathematics or science. For the most part, metric units are used throughout, except where other units are conventional within a discipline. For the convenience of students not yet comfortable with the metric system, a unit-conversion table is given in appendix A, and English-unit equivalents are frequently given within the text also.

In the early chapters, the student is introduced to the nature of geology as a science; to a brief outline of the history of the earth by way of historical perspective; and to minerals and rocks, the building blocks of geologic features, and the processes by which they form. Included in this section are the closely related topics of volcanic activity, soils, and weathering. This group of chapters concludes with the chapter on geologic time, concepts from which are fundamental to understanding many aspects of geologic process rates.

Once this groundwork has been laid, the next several chapters explore the major features and processes of the earth's interior. This exploration begins with plate tectonics, which provides the conceptual framework for understanding much about seismicity and volcanism. The data of seismology are also the major source of information about the earth's interior. Moving from the interior toward the surface, the next two chapters focus, respectively, on the continental crust, including crustal structures and mountain building, and on the ocean basins and oceanic crust.

Superimposed on these large-scale features are the effects of various surface processes, the subjects of the next several chapters. These processes include the various ways in which water, ice, wind, and gravity act to modify the earth's surface features and forms. It is at the surface that we see the interaction between the internal heat that drives the internal processes of volcanism, seismicity, and tectonics, and solar energy, which drives the winds and the water cycle.

Explaining the geologic and biologic history of the world in chronologic order for the last 4.5 billion years is difficult, if not impossible, for two reasons. First, the amount of information is immense. To circumvent this problem, the historical-geology chapters concentrate exclusively on North America, the United States in particular. Not only is the intended reader already somewhat familiar with the geology—or at least the geography—of this part of the world, but that reader is also most likely to travel within this area in the future. A second potential difficulty is the tedium of presenting geologic history by listing events and saying "this happened here at this time" over and over again. To address this problem, details have been kept to a minimum. Major rock types, styles and patterns of sedimentation, and deformational and mountain-building events for each period are summarized. The goal is to describe the rocks we see for a given period and show what their character and distribution allow us to infer about the earth of that time.

The last chapter, in a sense, looks ahead to the future. As populations grow and technology advances, there is growing dependence upon the availability of the supporting resources. Mineral and many energy sources are formed or concentrated by geologic processes, and issues of resource occurrence and availability are explored in chapter 27.

Appendix A shows the common unit conversions. Appendix B provides an identification chart for common minerals and some guidelines and a key for recognizing different rock types. Appendix C offers a brief introduction to topographic and geologic maps and satellite imagery, which should be particularly helpful to students whose courses do not include a laboratory. Appendix D is a guide to the major characteristics of important fossil groups. Appendix E is a listing of state, province, and territory geological surveys. Appendix F describes and illustrates localities in which certain rock units are particularly well represented.

To the Instructor

The text organization just described places internal processes ahead of surface processes, with the latter followed by historical-geology chapters. This organization puts discussion of the large-scale processes ahead of that of the more localized surface processes that act on the resulting features, and it aims to help the reader achieve some understanding of current processes before reaching back in time to review the historical development of the planet and its organisms. However, the various chapters are relatively independent overall, so an instructor who prefers to do so can cover surface processes first with minimal difficulty. In addition, individual chapters are as self-contained as possible (without undue repetition), so that the order can be adjusted by the instructor if desired. The glossary should help to bridge any gaps arising from reordering of blocks of the text.

The historical-geology chapters follow a consistent organization, both for the convenience of the reader and to facilitate comparisons between different portions of the earth's history. Each chapter begins with a few general comments: What was the regional setting of North America during this interval? Were there any events going on in the world that particularly affected North America? What was the tectonic situation? Included in this section is a paleogeographic map showing the inferred distribution of land and sea for the periods under consideration. Next, each part of the continent is considered—the craton, the eastern margin, and the western margin. Major rock types found and inferred tectonics are reviewed. Cross sections of the regions are included, and some of the more significant geologic formations are identified. Finally, the life of that interval of time is discussed. Index fossils are listed, and important evolutionary and extinction events are noted.

A discussion of environmental geology has been added to some texts as a separate chapter. However, there are environmental aspects to many of the topics in the text, from volcanoes to streams to resources. Therefore, in this book, environmental and human-impact considerations are woven into many physical-geology chapters as appropriate. This helps students to appreciate the current relevance of the subject matter while mastering the corresponding facts, theories, and vocabulary.

A variety of pedagogical aids and features are included. Each chapter begins with an outline of the subject headings to follow, by way of overview. Key terms are printed in boldface and defined at first encounter; these boldfaced terms are collected as "Terms to Remember" at the end of each chapter and are defined in the glossary for quick reference. At the end of each chapter are "Questions for Review" to assist students' study efforts, and a small number of questions or problems "For Further Thought" that go beyond basic review of text material. Certain of the latter might serve as starting points for class discussions or for short outside-of-class research projects. There are also "Suggestions for Further Reading" that include several kinds of material: up-to-date (but sometimes relatively sophisticated) references in the subject area of the chapter; materials that may be more readable for the nonspecialist (including some older but fundamentally accurate works); and, occasionally, "classic" works by prominent geologists.

All of the chapters contain one or more boxed inserts. These are of several types. Some describe tools of the geologic trade (for example, thin sections, mass spectrometry). Some present case studies or regional close-ups related to chapter material (flood recurrence-interval projection for a particular stream, groundwater depletion in the Ogallala aquifer system, geologic highlights of particular national parks). A few present somewhat more advanced concepts that might be appreciated most by better-prepared students (for example, an introduction to simple binary phase diagrams). In all cases, the material is included for enrichment or information without disrupting the flow of the main body of the text and the presentation of fundamental concepts. Individual boxes may be included or omitted at the instructor's discretion. Occasional "miniboxes" also appear within the text. These could be viewed somewhat as long parenthetical remarks, minor digressions not lengthy enough to justify a major boxed insert and usually lacking associated figures.

Appendices B, D, and F will probably be of most use to those students whose geology course does not include a required laboratory. They may also be helpful in cases in which lecture and laboratory sections proceed independently, so that the lecture may get ahead of the corresponding subject in the lab.

Users of the second edition will be interested in changes made in the third. The increase in number of chapters from twenty-three to twenty-seven does not reflect a major increase in the relative emphasis placed on physical geology, but rather the splitting of several chapters into more manageable and, perhaps, more logically constructed shorter chapters, as suggested by reviewers and adopters. Certain of the physical-geology chapters have significant new additions—for example, earthquake-cycle theory in chapter 10, and expanded discussion of global climate change in chapter 18. Data in the resources chapter (27) have been brought more up-to-date, and a number of figures and photos throughout the text have been improved or replaced. The map appendix (C), dropped in the second edition, has been returned by popular demand. And, of course, numerous smaller corrections and improvements have been made.

Acknowledgments

A great many individuals have contributed to this project. The first edition of this text owes its existence particularly to the persistence and energy of Jeff Hahn, who instigated it, and Lynne Meyers, who has perfected the gentle art of nudging busy authors into producing their manuscripts more or less on time, without exhausting her seemingly infinite supply of patience. The second edition was thoughtfully shepherded to completion through the very supportive guidance of Bob Fenchel; Jeff Hahn elected to reentangle himself in the third edition.

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Internet Resources

Organizations

AGI American Geological Institute
http://agi.umd.edu/agi/agi.html

GSA Geological Society of America
http://www.aescon.com/geosociety/index.htm

NASA National Aeronautics and Space Administration
http://hypatia.gsfc.nasa.gov/NASA_homepage.html

The Paleontological Society
http://www.uic.edu/orgs/paleo/homepage.html

SEPM Society for Sedimentary Geology
http://www.ngdc.noaa.gov/mgg/sepm/sepm.html

DOE U.S. Department of Energy
http://www.em.doe.gov

USGS United States Geological Survey
http://www.usgs.gov/

Mineralogy

Mineralogical Society of America teaching resource site
http://geology.smith.edu/msa/Teaching.html

USGS Minerals Page
http://minerals.er.usgs.gov

Earthquakes and Volcanoes

The National Earthquake Information Center
http://wwwneic.cr.usgs.gov/

The National Geophysical Data Center
http://www.ngdc.noaa.gov/whatsnew.html

Paleontology

The Burgess Shale
http://www.geo.ucalgary.ca/~macrae/Burgess_Shale

Paleo Net Pages
http://www.nhm.ac.uk/paleonet/

The Trilobite Page
http://www.ualberta.ca/~kbrett/Trilobites.html

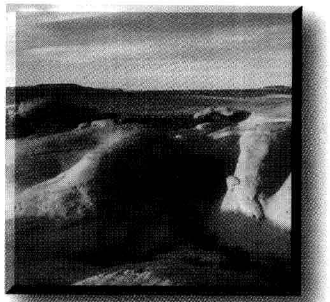
Museums

The Museum of Paleontology—University of California, Berkeley
http://ucmpl.berkeley.edu/

The Royal Tyrrell Museum
http://www.tyrrell.com/

The Smithsonian Institution gem and mineral collection
http://galaxy.einet.net/images/gems/gems-icons/html

Internet addresses for geological surveys can be found in appendix E.



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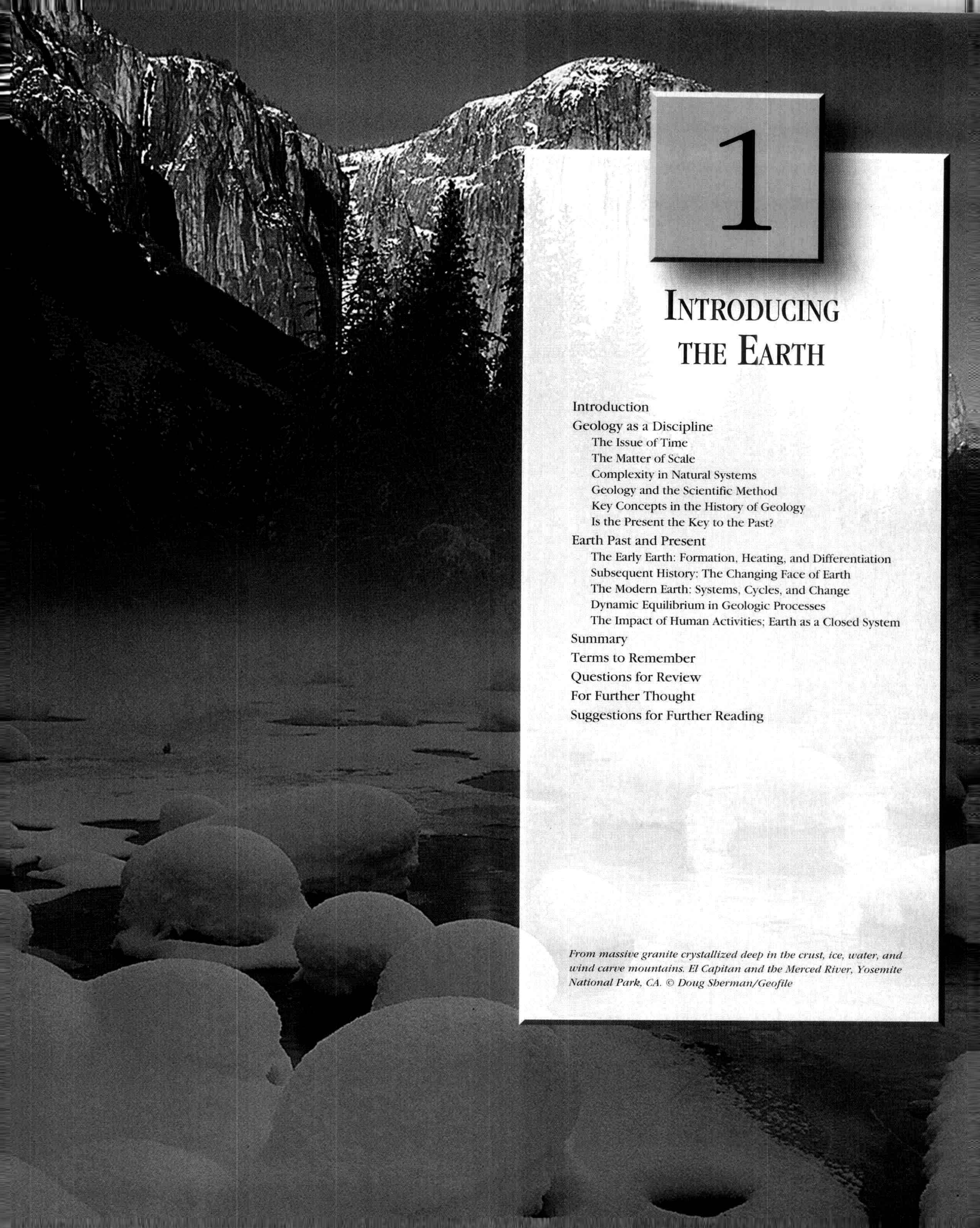

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INTRODUCING THE EARTH

From massive granite crystallized deep in the crust, ice, water, and wind carve mountains. El Capitan and the Merced River, Yosemite National Park, CA. © Doug Sherman/Geofile

INTRODUCTION

Geology is the study of the earth and the processes that shape it. **Physical geology,** in particular, is concerned with the materials and physical features of the earth, changes in those features, and the processes that bring them about. **Historical geology,** as the term suggests, examines the development of the earth and the organisms on it over time. Physical and historical geology together, then, provide a basis for understanding much about the earth and its evolution.

Intellectual curiosity about the way the earth works is one reason for the study of geology. Piecing together the history of a mountain range or even a single rock can be exciting. The nonspecialist can better appreciate the physical environment—from distinctive features like the granite domes of Yosemite or the geysers of Yellowstone (figure 1.1) to the rocks exposed in a roadcut or found in one's own backyard.

There are also practical aspects to the study of geology. Certain geologic processes and events can be hazardous (figure 1.2), and a better understanding of such phenomena may help us to minimize their risks. We have also come to depend heavily on certain earth materials for energy or as raw materials for manufacturing (figure 1.3), and knowing how, where, and when those resources formed can be very useful to modern society.

FIGURE 1.2 Fourth Avenue, Anchorage, Alaska, after the 1964 earthquake. Note how far the shops and street on the right have dropped relative to the left side of the street.
Photograph courtesy of USGS Photo Library, Denver, CO.

FIGURE 1.1 Geyser eruption. Riverside Geyser, Yellowstone National Park.

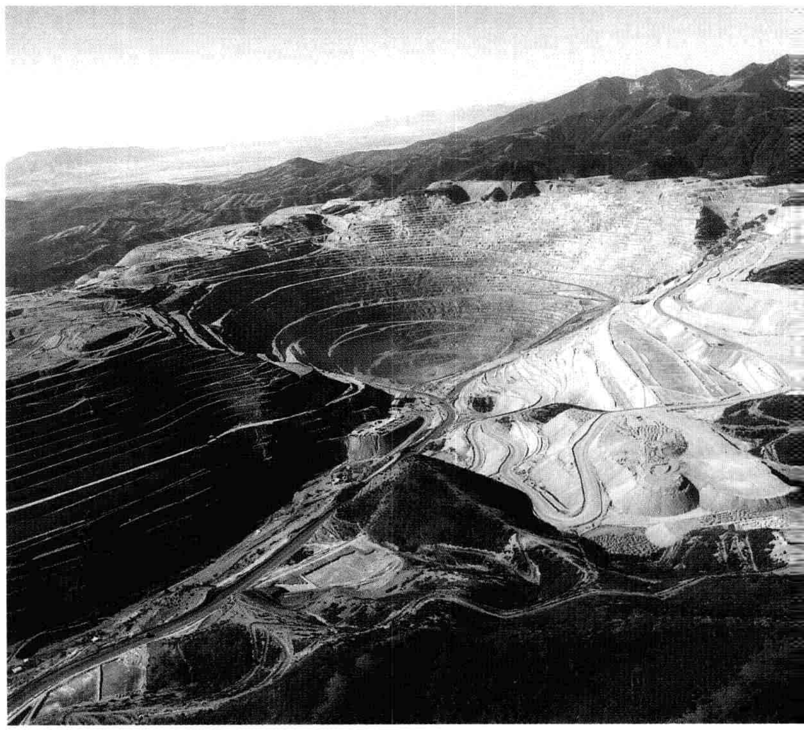

FIGURE 1.3 Bingham Canyon copper mine, the world's largest open-pit mine, from which over $6 billion worth of minerals has been extracted.
Photograph courtesy of Kennecott.