FOURTH EDITION

ESSENTIALS of GEOLOGY

FREDERICK LUTGENS
EDWARD TARBUCK

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PREFACE

In recent years, media reports have made us increasingly aware of the geological forces at work in our physical environment. News stories graphically portray the violent force of a volcanic eruption, the devastation generated by a strong earthquake, and the large numbers left homeless by mudflows and flooding. Such events, and many others as well, are destructive to life and property, and we must be better able to understand and deal with them. However, our natural environment has an even greater importance, for the earth is our home. The earth provides the mineral resources so basic to modern society, as well as most of the ingredients necessary to support life. Therefore, as many members of society as possible should acquire an understanding of how the earth works.

With this in mind, we have written a text to help people increase their understanding of the physical environment. We hope this new knowledge will encourage some to actively participate in the preservation of the environment, while others may be sufficiently stimulated to pursue a career in the earth sciences. Equally important, however, is our belief that a basic understanding of earth will greatly enhance appreciation of our planet and thereby enrich the reader's life.

The fourth edition of *Essentials of Geology,* like its predecessors, is a nonquantitative text intended for students taking their first course in geology. We have attempted to write a text that is not only informative and timely, but one that is highly usable as well. The language is straightforward and written to be understood by a student with little or no college-level science experience. Although we have deliberately refrained from using excessive jargon, a number of terms in each chapter will probably be unfamiliar to the reader. Therefore, when new terms are introduced, they are placed in boldface type and defined. To aid study and review, an alphabetical list of key terms with page references concludes each chapter, a new feature in this edition. As in prior editions, a glossary is also included at the end of the text for easy reference to important terms. Review questions are also found at the end of each chapter to help the reader prepare for exams and quizzes. Useful information on metric conversions, common minerals, and topographic maps can be found in the appendices.

In the earlier editions of this text special attention was given to the quality of photographs and artwork because geology is a highly visual science. This emphasis has been maintained in the fourth edition. More than 50 new color photographs appear in this revision. The photographs were carefully selected to add realism to the topics covered and to heighten the interest of the reader. Moreover, the already excellent art program of the previous editions has been strengthened. We believe that carefully planned and executed line art will significantly aid student understanding by making difficult concepts less abstract. To that purpose, more than 80 new and redrawn figures appear in the fourth edition. Once again, the text has benefited greatly from the talents and imaginative production of Dennis Tasa of Tasa Graphic Arts, Inc.

The fourth edition of *Essentials of Geology* represents a thorough revision. Extensive rewriting has made many discussions more timely and more readable. We emphasize, however, that the main focus of the fourth edition remains the same as in the first three editions—to foster an understanding of basic geological principles. As much as possible, we have attempted to provide the reader with a sense of the observational techniques and reasoning processes that constitute the discipline of geology. As with other sciences, geology is much more than a mere collection of facts. At its heart are the various methods and skills used to uncover the secrets of the earth. Some of these methods are discussed in the section on the nature of scientific inquiry in Chapter 1. Moreover, an excellent example of the way geological "truths" are uncovered and reworked is found in Chapter 16. Here we trace the historical formation and subsequent rejection of the hypothesis that continents drift about the face of the earth. Then we examine the data that led to the "rebirth" of this idea as part of a more encompassing theory known as plate tectonics.

The organization of the text remains intentionally traditional. Following the overview of geology in Chapter 1, we turn to a discussion of earth materials and the related process of volcanism and weathering. Next, we explore the geological work of gravity, water, wind, and ice in modifying and sculpturing landscapes. After this look at external processes, we examine the earth's internal structure and the processes that deform rocks and give rise to mountains. Finally, the text concludes with chapters on geologic time and earth history. This particular organization accommodates the study of minerals and rocks in the laboratory, which usually comes early in the course. Realizing that some instructors may prefer to structure their courses somewhat differently, we made each of the chapters self-contained so that they may be taught in a different sequence. Thus, the instructor who wishes to discuss earthquakes, plate tectonics, and mountain building prior to dealing with erosional processes may do so without difficulty. We also chose to provide a brief overview of plate tectonics in Chapter 1 so that this important theory could be incorporated in appropriate places throughout the text.

A comparison between this volume and earlier editions will reveal that the number of chapters in the fourth edition has been increased. This resulted from expanding the introduction into an introductory chapter and splitting two other chapters. Weathering and soils are now separate from sedimentary rocks and mass wasting appears as a chapter preceding the one on running water. Another change has been the reorganization of Chapter 18 on geologic time so that relative dating principles are treated prior to the discussion of radiometric dating. Discussions of many basic topics have also been strengthened in the fourth edition. The text contains expanded and updated coverage of sedimentary rocks, landslides, and glaciers, as well as broader coverage of deserts, shoreline processes, and continental margins.

As in earlier editions, topics related to resources and environmental issues remain an important focus and continue to be integrated at appropriate places throughout the text. Treatment of these areas has been strengthened by revising and updating existing discussions as well as adding new ones. Among the revised discussions are those on groundwater issues (Chapter 10) and earthquake prediction (Chapter 15). New sections include an overview of population, resources, and environmental issues (Chapter 1), soil erosion (Chapter 5), tar sands (Chapter 6), nonmetallic mineral resources (Chapter 6), wind energy (Chapter 12), and earthquake destruction (Chapter 15).

As with any project of this scope, the contributions of others were very important. We wish to express our thanks to the many individuals, institutions, and government agencies that provided information, photographs, and illustrations for use in this text. A special debt of gratitude goes to those colleagues who prepared in-depth prerevision reviews of the third edition of *Essentials of Geology*. Their critical comments and thoughtful input helped guide our revision and strengthen the fourth edition. We wish to thank David S. Ziegler, Hocking College; John B. Droste, Indiana University; Douglas L. Smith, University of Florida; William R. Shirk, Shippensburg University; Bryan Gregor, Wright State University; Fred Goldstein, Trenton State College; and Monte D. Wilson, Boise State University.

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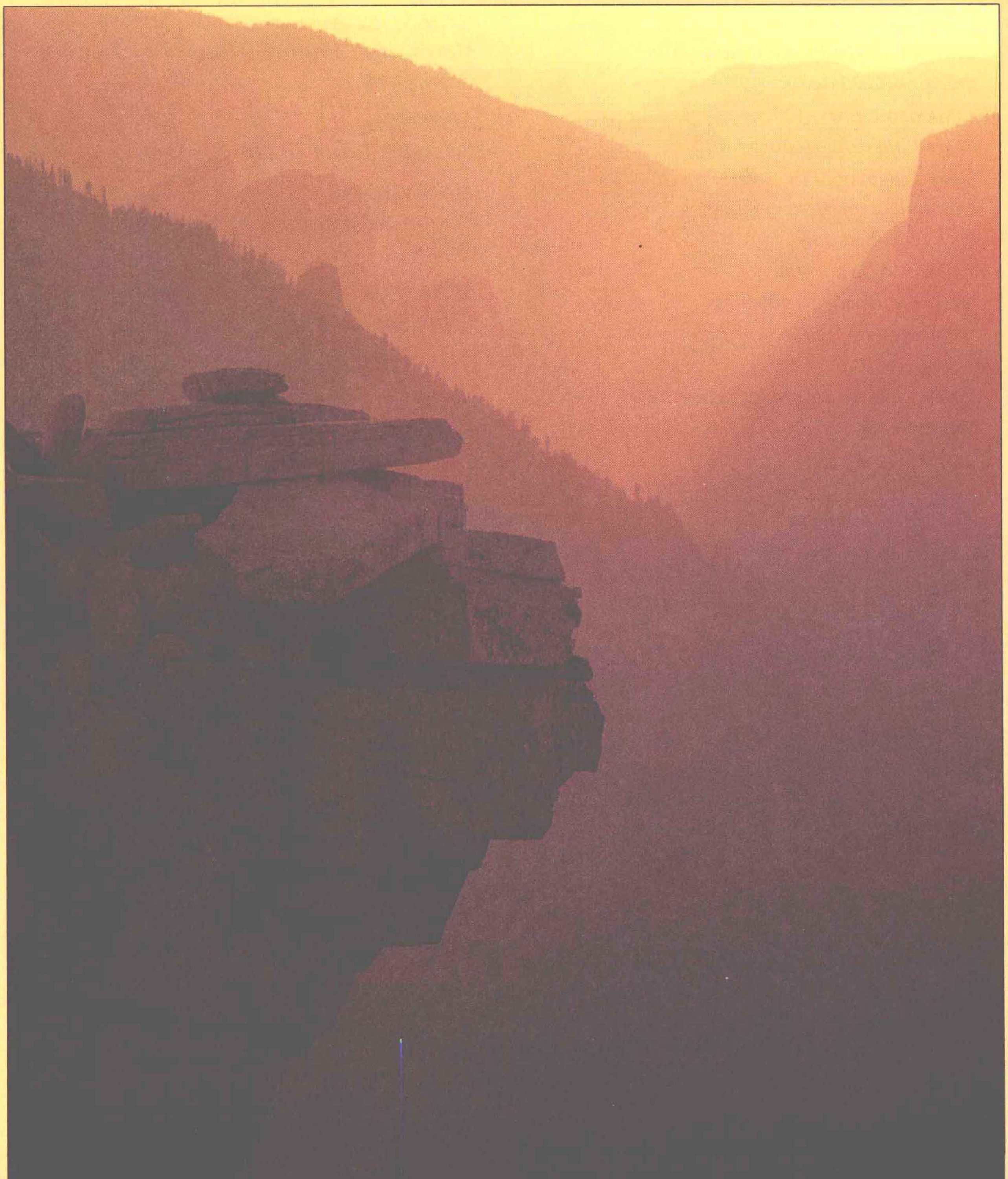
Finally, we must express our appreciation to our efficient senior editor, Bob McConnin, and to the outstanding production team at Macmillan Publishing Company. As always, they skillfully transformed our manuscript into a finished product. They are true professionals with whom we are very fortunate to be associated.



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CHAPTER ONE

An Introduction to Geology

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The Birth of Modern Geology

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THE NATURE OF SCIENTIFIC INQUIRY

POPULATION, RESOURCES, AND ENVIRONMENTAL ISSUES

A VIEW OF THE EARTH

THE DYNAMIC EARTH

THE ROCK CYCLE

Sunset over Half Dome in Yosemite National Park, California. (Photo by Galen Rowell)

The spectacular eruption of a volcano, the terror brought by an earthquake, the magnificent scenery of a mountain valley, the destruction created by a landslide—all are subjects for the geologist (Figure 1.1). The study of geology deals with many fascinating and practical questions about our physical environment. What forces produce mountains? What was the Ice Age like? Will there be another? What created this cave and the stone icicles hanging from its ceiling? Should we look for water here? Is strip mining practical in this area? Will oil be found if a well is drilled at this location? What will result if the landfill is located in the old quarry?

The subject of this text is **geology**, a word that literally means "the study of the earth." To understand the earth is not an easy task because our planet is not an unchanging mass of rock, but rather a dynamic body possessing a long and complex history.

The science of geology is traditionally divided into two broad areas—physical and historical. **Physical geology**, which is the primary focus of this book, examines the materials composing the earth and seeks to understand the many processes that operate beneath and upon its surface. The aim of **historical geology**, on the other hand, is to understand the origin of the earth and its development through time. Thus, it strives to establish an orderly chronological arrangement of the multitude of physical and biological changes that have occurred in the geologic past. The study of physical geology logically precedes the study of earth history, because we must first understand how the earth works before we attempt to unravel its past.

SOME HISTORICAL NOTES ABOUT GEOLOGY

The nature of our earth—its materials and processes—has been a focus of study for centuries. Writings about such topics as fossils, gems, earthquakes, and volcanoes date back to the Greeks, more than 2300 years ago. Certainly the most influential Greek philosopher was Aristotle. Unfortunately, Aristotle's explanations about the natural world were not based on keen observations and experiments. Instead they were arbitrary pronouncements. He believed that rocks were created under the "influence" of the stars and that earthquakes occurred when air crowded into the ground was heated by central fires and es-

Figure 1.1
Marble Canyon, Arizona. Erosional processes create many of the earth's varied landscapes. (Photo by Michael Collier)

caped explosively. When confronted with a fossil fish, he explained that, "a great many fishes live in the earth motionless and are found when excavations are made." Although Aristotle's explanations may have been adequate for his day, they unfortunately continued to be expounded for many centuries, thus thwarting the acceptance of ideas that were more closely in accord with observations. Frank D. Adams states in *The Birth and Development of the Geological Sciences* (New York: Dover, 1938) that, "throughout the Middle Ages Aristotle was regarded as the head and chief of all philosophers; one whose opinion on any subject was authoritative and final."

Catastrophism

During the seventeenth and eighteenth centuries the doctrine of **catastrophism** strongly influenced the formulation of explanations about the dynamics of the earth. Briefly stated, catastrophists believed that the earth's landscape had been shaped primarily by great catastrophes. Features such as mountains and canyons, which today we know take great periods of time to form, were explained as having been produced by sudden and often world-wide disasters produced by unknowable causes that no longer operate. This philosophy was an attempt to fit the rate of earth processes to the then-current ideas on the age of the earth. In the mid-seventeenth century, James Ussher, Anglican Archbishop of Armagh, Primate of all Ireland, published a major work that had immediate and profound influence. A respected scholar of the Bible, Ussher constructed a chronology of human and earth history in which he determined that the earth was only a few thousands of years old, having been created in 4004 B.C. Ussher's treatise earned widespread acceptance among scientific and religious leaders alike, and his chronology was soon printed in the margins of the Bible itself.

The relationship between catastrophism and the age of the earth has been summarized nicely as follows:

> That the earth had been through tremendous adventures and had seen mighty changes during its obscure past was plainly evident to every inquiring eye; but to

concentrate these changes into a few brief millenniums required a tailor-made philosophy, a philosophy whose basis was sudden and violent change.*

The Birth of Modern Geology

The late eighteenth century is generally regarded as the beginning of modern geology, for it was during this time that James Hutton, a Scottish physician and gentleman farmer, published his *Theory of the Earth* in which he put forth a principle that came to be known as the doctrine of **uniformitarianism** (Figure 1.2). Uniformitarianism is a fundamental concept in modern geology. It simply states that the physical, chemical, and biological laws that operate today have also operated in the geologic past. That is to say that the forces and processes that we observe presently shaping our planet have been at work for a very long time. Thus, to understand ancient rocks, we must first understand present-day processes and their results. This idea is commonly stated as "the present is the key to the past."

Prior to Hutton's *Theory of the Earth,* no one had effectively demonstrated that geological processes occur over extremely long periods of time. However, Hutton persuasively argued that processes which appear weak and slow-acting could, over long spans of time, produce effects that were just as great as those resulting from sudden catastrophic events. Unlike his predecessors, Hutton cited verifiable observations to support his ideas.

Since Hutton's literary style was cumbersome and difficult, his work was not widely read nor easily understood. It is the English geologist Charles Lyell who is given the most credit for advancing the basic principles of modern geology. Between 1830 and 1872 Lyell produced eleven editions of his great work, *Principles of Geology.* As was customary, Lyell's book had a rather lengthy subtitle that outlined the main theme of the work: *Being an Attempt to Explain the Former Changes of the Earth's Surface, by Reference to Causes Now in Operation.* In the text, he painstakingly illustrated the concept of the uniformity of nature through time. He was able to show more convincingly than his predecessors that those geologic processes observed today can be assumed to have operated in the past. Although the doctrine of uniformitarianism did not originate with Lyell, he is the person who was most successful in interpreting and publicizing it for society at large.

Today the basic tenets of uniformitarianism are just as viable as in Lyell's day. Indeed, we realize more strongly than ever that the present gives us insight into the past and that the physical, chemical, and biological laws that govern geological processes remain unchanging through time. However, we also understand that the doctrine should not be taken too literally. To say that geological processes in the past were the same as those occurring today is not to suggest that they always had the same relative importance and operated at precisely the same rate. Although the same processes have prevailed through time, their rates have undoubtedly varied.

The acceptance of uniformitarianism, however, meant the acceptance of a very long history for the earth, for although processes vary in their intensity, they still take a very long time to create or destroy major landscape features.

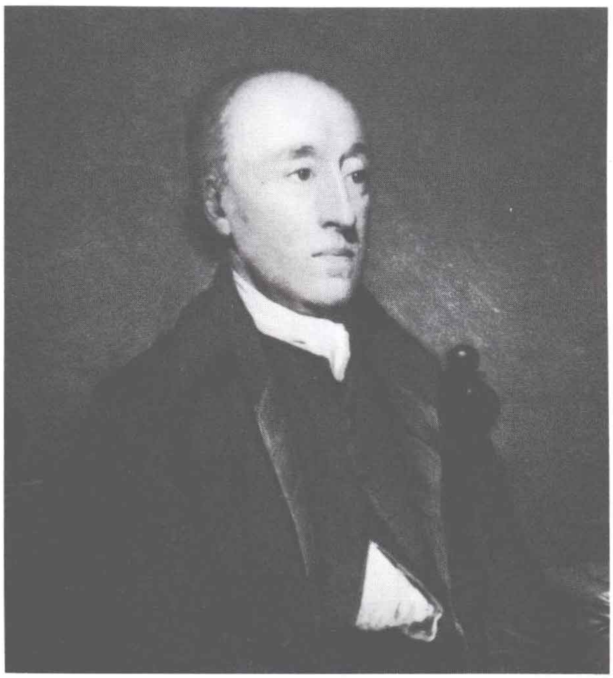

Figure 1.2
James Hutton, the 18th century Scottish geologist who is often called the "father of modern geology." (Photo courtesy of the British Museum)

*H. E. Brown, V. E. Monnett, and J. W. Stovall. *Introduction to Geology* (New York: Blaisdell, 1958).

For example, rocks containing fossils of organisms that lived in the sea more than 15 million years ago are now part of mountains that stand 3000 meters (9800 feet) above sea level. This means that the mountains were uplifted 3000 meters in about 15 million years—a rate of only 0.2 millimeter per year! Rates of erosion are equally slow (Figure 1.3). Estimates indicate that the North American continent is being lowered at a rate of just 3 centimeters per 1000 years. Thus, as you can see, it takes tens of millions of years for nature to build mountains and wear them down again. But even these time spans are relatively short on the time scale of earth history, for the rock record contains evidence that shows the earth has experienced many cycles of mountain building and erosion. Concerning the everchanging nature of the earth through great expanses of geologic time, Hutton stated: "We find no vestige of a beginning, no prospect of an end." A quote from William L. Stokes sums up the significance of Hutton's basic concept:

> In the sense that uniformitarianism implies the operation of timeless, changeless laws or principles, we can

Figure 1.3
Geologic processes often act so slowly that changes may not be visible during an entire human lifetime. Today, Monument Valley looks much the same as it did when first encountered by explorers. (Photo by Michael Collier)