Essentials of GEOLOGY

SEVENTH EDITION

Frederick K. Lutgens
Edward J. Tarbuck

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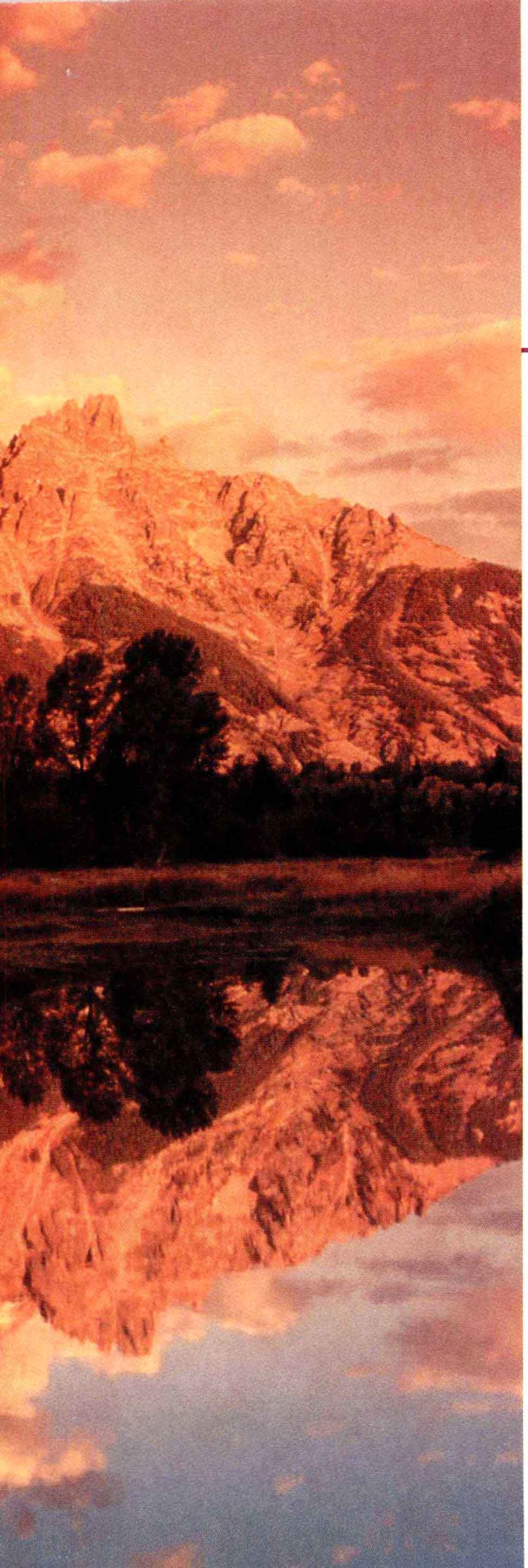

Seventh Edition

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C. Features of the Continents
D. Floor of the Ocean

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Unit Internal Processes

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D. Igneous Activity
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Unit Geologic Time

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B. Relative Dating
C. Radiometric Dating

Unit Landforms of the United States

A. Landform Regions
B. A Geologic Tour

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Preface

The Seventh Edition of *Essentials of Geology*, like its predecessors, is a college-level text intended for students taking their first and perhaps only course in geology. The book is intended to be a meaningful nontechnical survey for people with little background in science. Usually students are taking this class to meet a portion of their college's or university's general requirements.

In addition to being informative and up-to-date, a major goal of *Essentials of Geology* is to meet the need of beginning students for a readable and user-friendly text, a book that is a highly-usable "tool" for learning the basic principles and concepts of geology.

Distinguishing Features

Readability

The language of this book is straightforward and *written to be understood*. Clear, readable discussions with a minimum of technical language are the rule. The frequent headings and subheadings help students follow discussions and identify the important ideas presented in each chapter. In the Seventh Edition, improved readability was achieved by examining chapter organization and flow, and writing in a more personal style. Large portions of several chapters were substantially rewritten in an effort to make the material more understandable.

Illustrations and Photographs

Geology is highly visual. Therefore, photographs and artwork are a very important part of an introductory book. *Essentials of Geology*, Seventh Edition, contains dozens of new high-quality photographs that were carefully selected to aid understanding, add realism and heighten the interest of the reader.

The many new and revised pieces of art help illustrate ideas and concepts even more clearly and realistically than before. The art program was carried out by Dennis Tasa, a gifted artist and respected Earth science illustrator.

Focus on Learning

To assist student learning, every chapter opens with a series of questions. Each question alerts the reader to an important idea or concept in the chapter. When a chapter has been completed, three useful devices help students review. First, a helpful summary—*The Chapter In Review*—recaps all of the major points. Next is a checklist of *Key Terms* with page references. Learning the language of geology helps students learn the material. This is followed by *Questions For Review* that help students examine their knowledge of significant facts and ideas.

Maintaining a Focus on Basic Principles and Instructor Flexibility

The main focus of the Seventh Edition remains the same as in the first six—to foster student 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.

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 processes of volcanism and weathering. Next, we explore the geological work of gravity, water, wind, and ice in modifying and sculpting landscapes. After this look at external processes, we examine 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 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.

The Seventh Edition

The Seventh Edition of *Essentials of Geology* represents a thorough revision. *Every* part of the book was examined carefully with the dual goals of keeping topics current and improving the clarity of text discussions. Based on feedback from reviewers and our students, we believe we have succeeded.

Supplements

To better meet the needs of beginning students, two outstanding supplements are new to the Seventh Edition.

GEODe II CD-ROM. A revision of the very successful *GEODe CD-ROM* by Dennis Tasa of Tasa Graphic Arts, Inc., Edward J. Tarbuck, and Frederick K. Lutgens. *GEODe II* is a dynamic interactive learning experience for beginning geology students. It provides tutorials, exercises, and activities that allow the user to examine and review important facts and concepts. Excellent animations, illustrations, and photographs accompany the clear explanations to make this an especially effective learning tool. This *GEODe II* icon  appears throughout the book wherever a text discussion has a corresponding *GEODe II* activity. Furthermore, a detailed table of contents for *GEODe II* can be found on page vi. The instructor's guide also contains helpful information about integrating *GEODe II* into your course and assignments. A copy of *GEODe II* is included with every text. This special offering gives students two valuable products (*GEODe II* and the textbook) for the price of one.

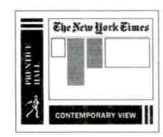
Essentials of Geology Companion Website. The Essentials of Geology Companion Website (http://www.prenhall.com/lutgens) provides students with material that allows them to review chapter materials independently, links them to up-to-the-minute data, and provides annotated Web links to help them get headed in the right direction when beginning to do research on the Web. Using the latest CW99 technology, professors can create customized syllabi on-line and link directly to activities on the *Essentials* Website.

Additional Supplements

Transparency Set: More than 100 full-color acetates of illustrations from the text are available free of charge to qualified adopters.

Slides: More than 150 slides of images taken from the text, many of which were taken by the authors, are also available to qualified adopters.

Presentation Manager: This user-friendly software enables professors to custom build multimedia presentations from a library of several hundred images from the text and animations from *GEODe II*. Prentice Hall Presentation Manager 3.0 allows professors to organize material in whatever order they choose; preview resources by chapter; search the digital library by keyword; integrate material from their hard drive, a network, or the Internet; or edit lecture notes and annotate images with an overlay tool. In addition, all images can be exported for use in Power Point. This powerful presentation tool is available at no cost to qualified adopters of the text.



The *New York Times* Themes of the Times—Changing Earth. This unique newspaper-format supplement features recent articles about the Earth sciences from the pages of the *New York Times*. This supplement, available at no extra charge from your local Prentice Hall representative, encourages students to make connections between the classroom and the world around them.

Instructor's Manual: Written by Kenneth Pinzke of Belleville Area College, the Instructor's Manual is intended as a resource for both new and experienced instructors. It includes a variety of lecture outlines, additional source materials, teaching tips, advice about how to integrate visual supplements (including the Web-based resources and *GEODe II*), and various other ideas for the classroom. Also included in every chapter are a wide variety of test questions.

PH Custom Test: Based on the powerful testing technology developed by Engineering Software Associates, Inc. (ESA), Prentice Hall Custom Test allows instructors to create and tailor exams to their own needs. With the on-line testing program, exams can also be administered on-line and data can then be automatically transferred for evaluation. The comprehensive desk reference guide is included along with on-line assistance.

Additional CD-ROMs from Tasa Graphic Arts:

Other interactive, Earth science CD-ROM products are available from Tasa Graphic Arts, the creators of GEODe II:

- *Illustrated Dictionary of Earth Science* by the American Geological Institute.
- *The Theory of Plate Tectonics* by Edward J. Tarbuck, Illinois Central College.
- *Introduction to Topographic Maps* by Kenneth Pinzke, Belleville Area College.
- *Explore the Planets* by G. Jeffrey Taylor, Hawaii Institute of Geophysics and Planetology.
- *The Wonders of Rocks and Minerals* by Edward J. Tarbuck and Frederick K. Lutgens, Illinois Central College, and Edward Greaney, Hunterdon Central Regional High School.
- *The Study of Minerals* by M. Darby Dyar, Mount Holyoke College, and Richard M. Busch and C. Gil Wiswall, West Chester University.
- *Plate Tectonics and How the Earth Works* by Kent C. Condie, New Mexico Institute of Technology.

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Special thanks goes to those colleagues who prepared in-depth reviews. Their critical comments and thoughtful input helped guide our work and clearly strengthened the text.

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In addition we would like to acknowledge the aid of our students. Their comments and suggestions continue to help us to maintain our focus on readability and understanding.

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Frederick K. Lutgens
Edward J. Tarbuck

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An Introduction to Geology

Chapter 1

Focus on Learning

To assist you in learning the important concepts in this chapter, you will find it helpful to focus on the following questions:

- What is the fundamental difference between the doctrine of uniformitarianism and the doctrine of catastrophism?
- What is relative dating? What are some principles of relative dating?
- How does a scientific hypothesis differ from a scientific theory?
- What are the principal divisions of Earth's interior?
- What is the theory of plate tectonics? How do the three types of plate boundaries differ?
- What is the rock cycle? Which geologic interrelationships are illustrated by the cycle?

Mount Ritter and Banner Peak, in Ansel Adams Wilderness, Sierra Nevada, California. Photo © by Carr Clifton Photography.

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? Will there soon be another great earthquake in California? 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 appropriate in this area? Will oil be found if a well is drilled at this location? What if the landfill is located in the old quarry?

The Science of Geology

This book introduces you to the science of **geology**, a word that literally means "the study of Earth." Unraveling Earth's secrets is not an easy task because our planet is not a static, unchanging mass of rock. It is a dynamic body possessing a long and complex history.

The science of geology is divided into two broad areas—physical and historical. **Physical geology** examines Earth's rocks and minerals and seeks to understand the hundreds of processes that operate beneath or upon its surface.

The aim of **historical geology**, in contrast, is to understand Earth's origin and how it changed through time. Historical geology strives to establish the chronology of physical and biological changes of the past 4.5 billion years.

The study of physical geology logically precedes the study of Earth history because we must first understand how Earth works before attempting to unravel its past. Thus, the first seventeen chapters of this book introduce physical geology, whereas the last two chapters present Earth's remarkable history.

Historical Notes About Geology

The nature of our Earth—its materials and processes—has been a focus of study since early times. Writings about fossils, gems, earthquakes, and volcanoes date back to the Greeks, more than 2300 years ago. The most influential Greek philosopher was Aristotle, but unfortunately his explanations of the natural world were not derived from keen observations and experiments, as modern science is. Instead, they were his opinions, based on the limited knowledge of his day. Aristotle believed that rocks were created under the "influence" of the stars and that earthquakes occurred when air in the ground was heated by central fires and escaped explosively! When confronted with a fos-

FIGURE 1.1 The August 20, 1997, eruption of Soufriere Hills volcano on the Caribbean island of Montserrat. Geologists seek to understand the processes that create such events. (Photo by Kevin West/Gamma Liaison)

sil 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 believed for many centuries, thus thwarting the acceptance of better ideas that were based on observations.

Catastrophism

During the 1600s and 1700s, the doctrine of **catastrophism** strongly influenced explanations of Earth dynamics. Catastrophists believed that Earth's landscapes had been shaped primarily by great catastrophes. They felt that mountains and canyons resulted from sudden, often worldwide disasters produced by unknowable causes that no longer operate. Catastrophism tried to fit the *rate* of Earth processes to then-current ideas of Earth's age.

In the mid-seventeenth century, James Ussher, an Anglican Archbishop in Ireland and a respected Bible scholar, constructed a chronology of human and Earth history. He calculated that Earth was only a few thousand 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 Earth has been summarized nicely:

> *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

Against this backdrop of Aristotle's views and an Earth created in 4004 B.C., a Scottish physician and gentleman farmer named James Hutton published *Theory of the Earth* in 1795 (Figure 1.2). In it he put forth the doctrine of **uniformitarianism**. Today, uniformitarianism is a fundamental principle of modern geology. It states that the *physical, chemical, and biological laws that operate today also operated in the geologic past*. In other words, the forces and processes that we observe shaping our planet today 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*.

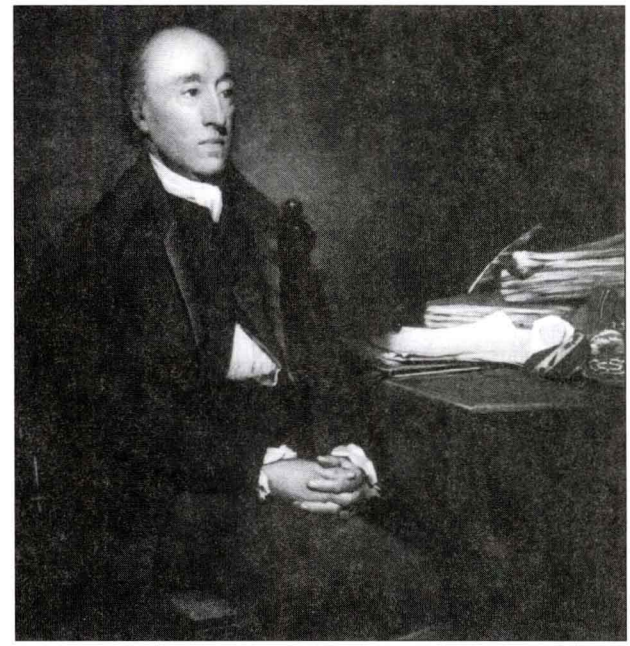

FIGURE 1.2 James Hutton, Scottish geologist of the 1700s, who is often called the "father of modern geology." (Photo courtesy of the Natural History Museum, London)

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

For example, when he argued that mountains are sculpted and ultimately destroyed by weathering and the work of running water, and that their wastes are carried to the oceans by processes that can be observed, Hutton said, "We have a chain of facts which clearly demonstrates ... that the materials of the wasted mountains have traveled through the rivers"; and further, "There is not one step in all this progress ... that is not to be actually perceived." He then went on to summarize this thought by asking a question and immediately providing the answer: "What more can we require? Nothing but time."

Hutton's literary style was cumbersome and difficult, so his work was not widely read nor easily understood. Fortunately, a more readable English geologist, Charles Lyell, advanced the basic principles of modern geology. Between 1830 and 1872, Lyell produced 11 editions of his great work, *Principles of*

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

Geology. As was customary in those days, Lyell's book had a long subtitle that outlined the main theme of the book: *Being an Attempt to Explain the Former Changes of the Earth's Surface, by Reference to Causes Now in Operation*. He painstakingly illustrated the concept of the uniformity of nature through time and was able to show more convincingly than Hutton that those geologic processes observed today most likely operated in the past. Although uniformitarianism did not originate with Lyell, he was most successful in interpreting and publicizing it for society at large.

Today uniformitarianism is just as viable as in Lyell's day. 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* or operated at the *same rate*. Although these processes have prevailed through time, their rates have undoubtedly varied.

The acceptance of uniformitarianism meant the acceptance of a very lengthy history for Earth. Although processes vary in their intensity, they still take a very long time to create or destroy major landscape features (Figure 1.3).

For example, geologists have established that mountains once existed in portions of present-day Minnesota, Wisconsin, and Michigan. Today the region consists of low hills and plains. Erosion (processes that wear land away) gradually destroyed these peaks. Estimates indicate that the North American continent is being lowered at a rate of about 3 centimeters per 1000 years. At this rate, it would take 100 million years for water, wind, and ice to lower mountains that were 3000 meters (10,000 feet) high.

But even this time span is relatively short on the time scale of Earth history, for the rock record contains evidence that shows Earth has experienced many cycles of mountain building and erosion.

It is important to remember that although many features of our physical landscape may seem to be unchanging in terms of the decades over which we observe them, they are nevertheless changing, but on time scales of hundreds, thousands, or even many millions of years. Concerning the ever-changing nature of Earth through great expanses of geologic time, James Hutton made a statement that was to become his most

FIGURE 1.3 Geologic processes usually act so slowly that changes may not be visible during an entire human lifetime. Today, Washington's Liberty Bell Mountain looks much the same as it did when first encountered by explorers. (Photo by Larry Ulrich/Tony Stone Images)