THE EARTH THROUGH TIME

FOURTH EDITION

LEVIN

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Title Page Photo Credit: Sea stacks composed of Quaternary sediments, Crescent City, California, at sunset. (Photo by Stephen D. Levin)
Page vi Photo Credit: Pinnacle of Jurassic Wingate Formation underlain by the Chinle Formation (Triassic), central Utah. (Courtesy of Lehi Hintze)

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Preface

While reflecting on the progress of science in his time, Charles Lyell concluded that never before had geology revealed "so many novel and unexpected truths and overcome so many preconceived opinions." The great nineteenth century geologist had in mind the changing view of the earth from a static planet unaltered since its origin to a "theatre of reiterated change." Lyell believed that he lived during a time of revolution in the geologic sciences. Today, we are experiencing another such revolution, and Lyell's remarks about the progress of geology are even more appropriate now than they were when he wrote his monumental *Principles of Geology* nearly 160 years ago. As a result of bold new discoveries, geologists are now able to recognize the deeper and more fundamental causes for the many changes the earth has undergone. They have synthesized older interpretations of geologic events into a grand scenario of a dynamic planet in which ocean floors are in constant movement, continents break apart and reassemble, and great mountain systems rise from quiet seas. With some amazement, they have discovered pieces of Africa firmly anchored within the state of Georgia and splinters of China and Russia in the mountains of western North America. It is an exciting time to study the history of the earth.

The Earth Through Time is a college-level textbook for a course in historical geology. It is broad in scope so as to serve both the beginning geology major and the undergraduate seeking to learn about the earth while completing a college science course requirement. Few would disagree that the components of a course in the history of the earth and its life will enrich any student's liberal education.

Approach

The geologic history of the earth, like the planet's brief cultural history, includes information about the nature and time of occurrence of important events. Cultural history is largely dependent upon written documents, whereas geologic history must be inferred from the careful study of fossils and rocks. The historical geologist sees the results of past events and then searches for their causes. An important objective of this book is to provide the student with an understanding of how this is accomplished. The approach is first to provide the facts and then to examine the meaning of those facts. For example, the characteristics of rocks formed during a particular interval of time are described, not as self-important entities, but rather to demonstrate their value in revealing conditions at particular times and places. Although interesting in themselves, fossils are described so as to indicate their value in understanding evolution and interpreting past environments.

Organization

For the student to fully understand how geologists learn about the history of the earth, a considerable amount of background information is needed. The first chapter of the text provides an introduction to earth materials and an overview of plate tectonics. Readers who have already taken a course in physical geology may wish to use the section dealing with rocks and minerals as a review. In subsequent chapters, the text explores the historical significance of sedimentary rocks and fossils, the methods used by geologists in ascertaining the age of strata, and the operation of plate tectonics and sea floor spreading. After a thorough consideration of the essential background material in the first six chapters, the text proceeds to a traditional chronologic sequence of topics dealing with the events and life of the Archean and Proterozoic eons and the eras of the Phanerozoic. The final chapter, "Meteorites, Moons, and Planets," is written as an independent unit that can be inserted into a topic sequence of the instructor's choosing. This chapter reminds the reader that the earth is but one of nine planets and shares many aspects of its history with neighboring bodies in space.

Changes in the Fourth Edition

Preparation of a new edition of a textbook provides the opportunity to refashion explanations, find better illustrations, and provide information about new discoveries. Readers will find that all of the drawings and most of the photographs are in color. We have utilized the exceptional talents of Dennis Tasa in the art program. Also new in this edition are interviews with four geologists (Preston Cloud, Tanya Atwater, Samuel Bowring, and B. Clark Burchfiel), who have made significant contributions to our understanding of the earth's history. Students are often keenly interested in the people that have been influential in advancing science. For those undergraduates thinking about a career in geology, the interviews provide a glimpse of the intellectual rewards and challenges afforded by a career in geology.

Throughout the text, the reader will find discussions of interesting topics in new special boxes entitled **Commentaries.** Their purpose is to reinforce ideas, present applications of some of the concepts discussed in the text, illustrate methods used in geologic research, and, most of all, to spark student interest.

In this edition, the treatment of Precambrian history has been extensively revised and a new chapter added so that students can examine the Archean (Chapter 7) and Proterozoic (Chapter 8) separately. Discussion of such topics as Precambrian life, the Burgess Shale fauna, the origin of mountain ranges, important figures in the history of geology, plate tectonics, methods of stratigraphy, evolution in populations, and dinosaur paleoecology have all been augmented. The description of rocks and minerals in the third edition's Chapter 2 has been shortened and included in Chapter 1 ("The Science of Historical Geology"), and the discussion of planets and meteorites has been moved to the final chapter (Chapter 17) to be included in the course at the instructor's discretion.

Learning Aids

Many pedagogic aids have been included to help the student in mastering the diverse information of a historical geology course. New terms are set in **boldface** for emphasis. At the end of each chapter, there is a **Summary**, a set of **Questions for Review**, **Terms to Remember**, and **Supplemental Readings and References.** The boxes entitled **Commentaries** and **Interviews** provide additional insight and relevance. Color is used throughout the text, not as a cosmetic, but as an aid in understanding diagrams and photographs. A visit to an outcrop is the best way to teach geology, but when confined to the classroom, the student may find that a color photograph can be the next best thing.

At the back of the text is an illustrated **Glossary of Terms** containing over 400 entries, all defined in conformity with the *Dictionary of Geological Terms* published by the American Geological Institute. When the need arises to check the age of a rock unit mentioned in the text or to find its equivalents in other locations, the reader can refer to the **Formation Correlation Charts for Representative Sections** in the appendices. Also included in the appendices are a **Classification of Living Things**, a map depicting the **Physiographic Provinces of the United States**, a **Periodic Table of Chemical Elements**, and **Convenient Conversion Factors.**

Ancillaries

The Earth Through Time is accompanied by an extensive set of support materials. To enhance the students' understanding of the text, a **Study Guide** has been prepared by Vicki Harder of Texas A&M University. The Study Guide includes chapter overviews, learning objectives, detailed chapter outlines and study questions. An **Instructor's Manual with Test Bank** written by Michael S. Smith of Montana State University provides learning objectives, teaching aids, answers to the review questions in the text, and a variety of test questions for each chapter including true/false, multiple choice, and essay questions. For use in the classroom or laboratory, a set of 100 **overhead transparencies** in color are provided, as well as a set of 100 **35-mm slides** of text illustrations and photographs.

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Many of the modifications in this new edition were suggested by our reviewers, as well as colleagues who have used the previous edition in their historical geology courses. I extend my thanks to all of these earth scientists, including:

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My thanks conclude with a special note of gratitude to my wife Kay, who has cheerfully endured my preoccupation with the writing of textbooks for over fifteen years.

Photograph of the earth taken by the crew of Apollo 17 in 1972. The orange-red deserts of Africa and Saudi Arabia stand in contrast to white clouds and the deep blue of the ocean. Snow and ice covered Antarctica is clearly visible at the bottom. *(Courtesy of NASA).*

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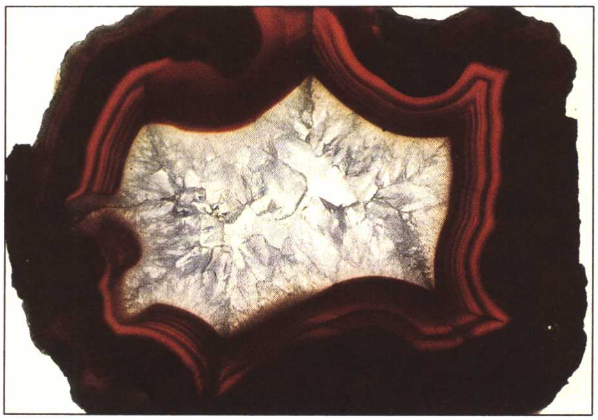

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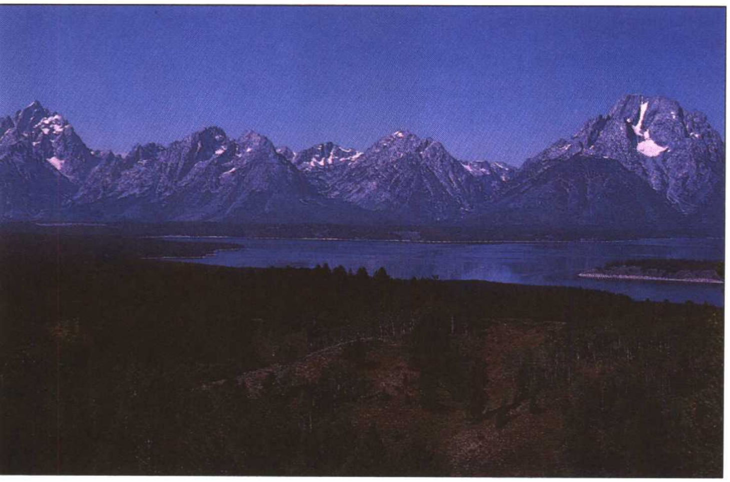

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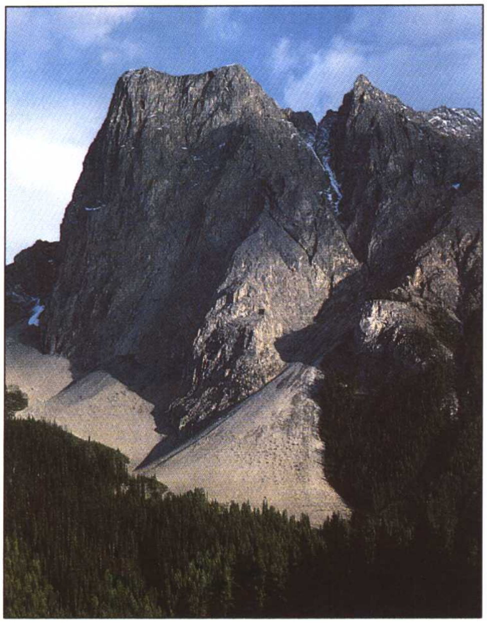

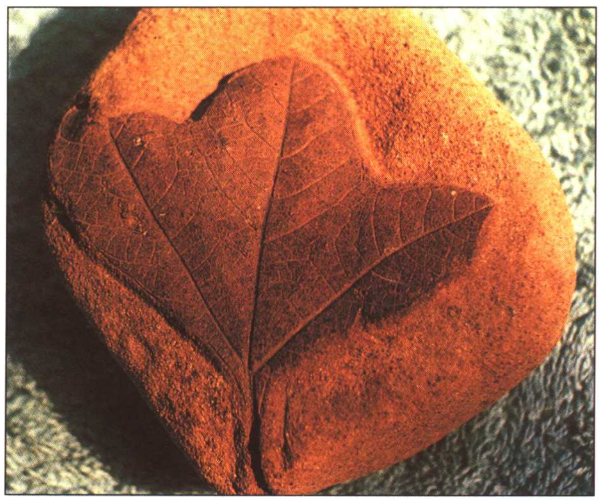

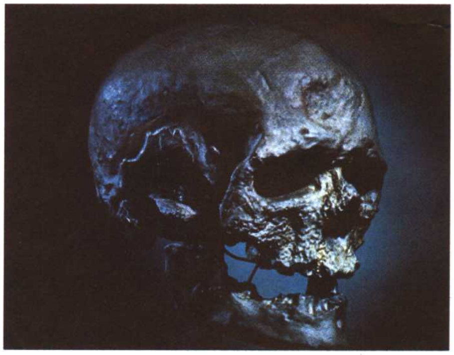

The Science of Historical Geology

1

The face of places and their forms decay;
And that is solid earth that once was sea;
Seas, in their turn, retreating from the shore,
Make solid land, what ocean was before.

Ovid, *Metamorphoses, XV*

Changing Views of the Third Planet

We live on the third planet from the sun (Fig. 1–1). Our planet was formed 4.6 billion years ago, and since that time it has circled around the sun like a small spacecraft observing a rather average star. The sun, in turn, carries the earth and its companion planets around the center of our galaxy, while the great galactic spiral that contains the solar system moves silently through the universe.

Scarcely 100,000 years ago, primates called humans evolved on earth. Unlike earlier animals, these creatures with oversized brains and nimble fingers asked questions about themselves and their surroundings. Their questioning has continued to the present day. How was the earth formed? Why do earthquakes occur? What lies beneath the lands we live on and beneath the floor of the ocean? Even ancient people sought answers for these questions. In frail wooden ships they probed the limits of the known world, fearing that they might tumble from its edge. Their descendants came to know the planet as an imperfect sphere, and they began an examination of every obscure recess of its surface. In harsher regions, exploration proceeded slowly. It has been only within the last 100 years that humans have penetrated the deep interior of Antarctica. Today, except for a few areas of great cold or dense forest, the continents are well charted. New frontiers for exploration now lie beneath the oceans and outward into space.

A major step in the advance of science in the oceanic frontier occurred in the late 1800s with the scientific expeditions of British oceanographic vessels. Prominent among these was the naval ship *H.M.S. Challenger* (Fig. 1–2). Although limited by the relatively primitive technology of their time, the *Challenger* scientists obtained an extraordinary amount of information about water depths, movement of ocean currents, marine life, and the nature of sediments on the ocean floor. The advancement of technology since that time has allowed that base of knowledge to be enormously expanded. Criss-crossing the seas, ships equipped with precision depth recorders that employed the principle of echo sounding (Fig. 1–3) plotted continuous topographic profiles of the sea floors. Related methods using stronger energy sources provided images of layers of rock and sediment beneath the ocean floor. Such cross-sections of the earth's crust are called seismic profiles (Fig. 1–4). A panoramic view of undersea geology emerged that was more magnificent and complex than anyone had imagined (Fig. 1–5). The magnetic characteristics of the ocean floors were also examined, and the scientific community was startled to learn that the earth's magnetic polarity had occasionally reversed itself during the past.

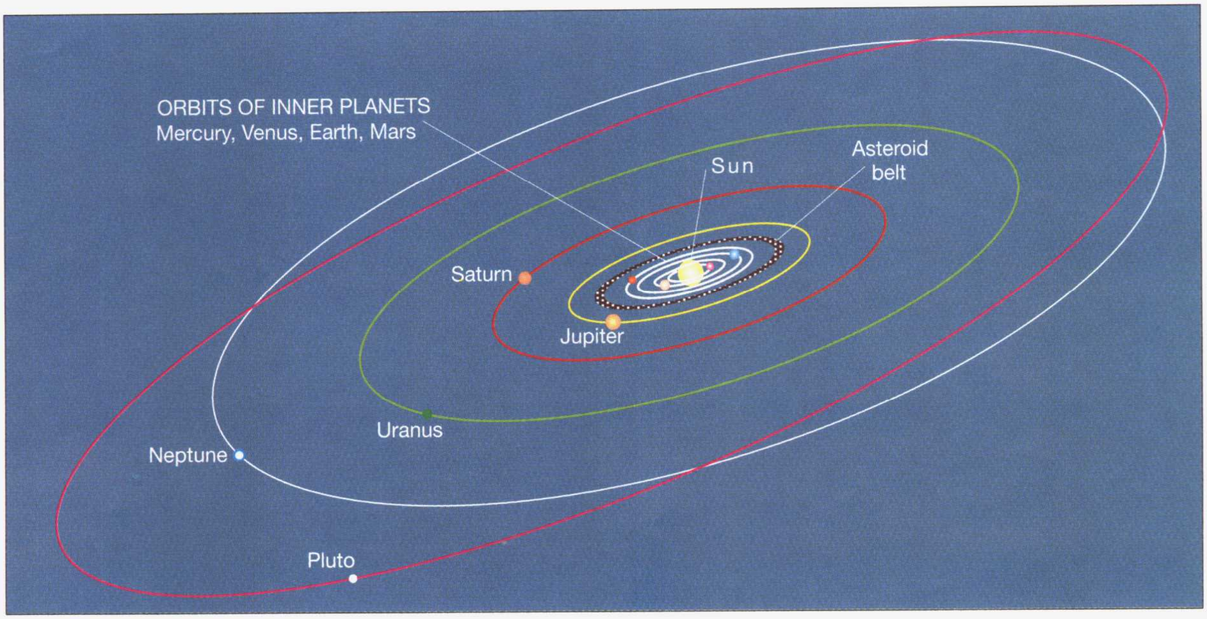

Figure 1–1 Orbits of the nine planets in the solar system.

To further study the effects of these phenomena on earth history, a unique deep-sea drilling ship, the *Glomar Challenger,* was constructed and quickly put into operation. With this research vessel, geologists were able to penetrate deeply into the sea floor and bring on deck the sediment and rock needed to decipher the history of the ocean basins. Samples from beneath the sea were combined with interpretations of seismic profiles and magnetic data, stimulating the development of exciting new hypotheses of drifting crustal segments, splitting continents, and continuously changing global geography. The success of the *Glomar Challenger* led to the outfitting of a new drilling ship, the *JOIDES Resolution* (Fig. 1–6), which began operation in 1985.

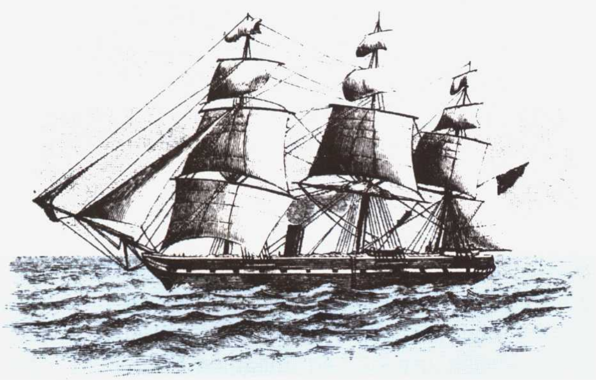

Figure 1–2 *H.M.S. Challenger (From the* Report of the Scientific Results of the Exploring Voyage of H.M.S. Challenger during the years 1873–1876, *Narrative, Part II, 1885.)*

Exploration of space has also contributed to our new view of the earth. Intricately engineered spacecraft circled the earth and set down on the moon. Members of our inquisitive species reached down and held lunar rocks in their gloved hands. Analysis of those rocks has yielded important clues to the early history of the earth. Satellites and spacecraft continue to circle the earth, transmitting thousands of images of our planet to scientists below. These images have given us an unprecedented synoptic view of a dynamic, vibrant planet, and on a day-to-day basis, they have provided information useful in finding mineral deposits, assessing worldwide agricultural productivity, and ascertaining global changes in environmental conditions. Perhaps most important, however, these data have made all of us aware of the stunning beauty and fragility of our planetary home.

(text continued on page 6)

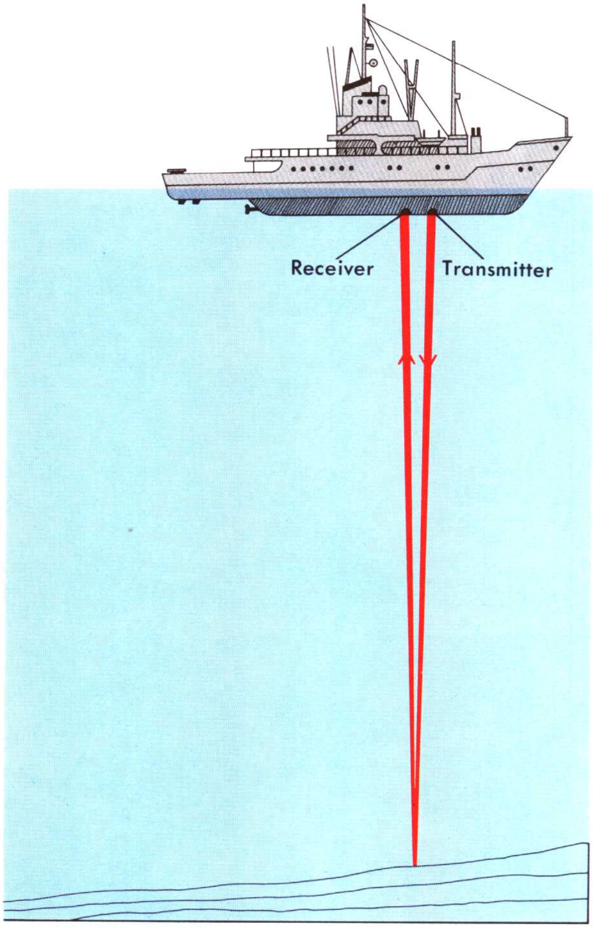

Figure 1–3 The principle of echo sounding. A transmitter sends a sound wave, which is reflected back to the surface by the ocean bottom and is picked up by a receiver. By knowing the total time involved and the speed of sound in the ocean (1500 meters per second), water depth can be determined. *(From J. M. McCormick and J. V. Thiruvathukal.* Elements of Oceanography, *2nd ed. Philadelphia, Saunders College Publishing, 1981.)*

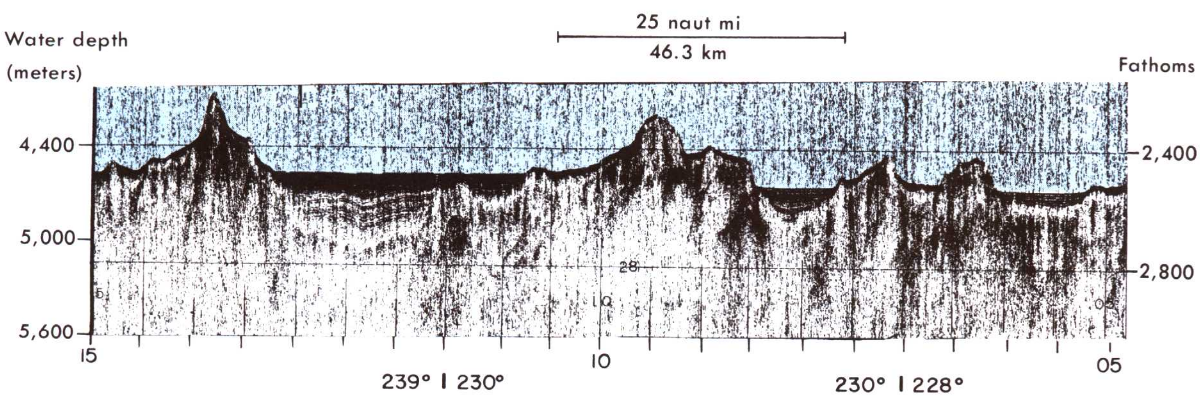

Figure 1–4 Continuous seismic profiles showing abyssal hills and abyssal plains along the edge of the Mid-Atlantic Ridge. *(From Hayes, D. E., and Pimm, A. C.,* Initial Reports of Deep Sea Drilling Project, *1972. National Science Foundation publication, vol. 14, pp. 341–376.)*

Figure 1–5 The physical features of the ocean floors and the continents. *(Copyright © Marie Tharp.)*