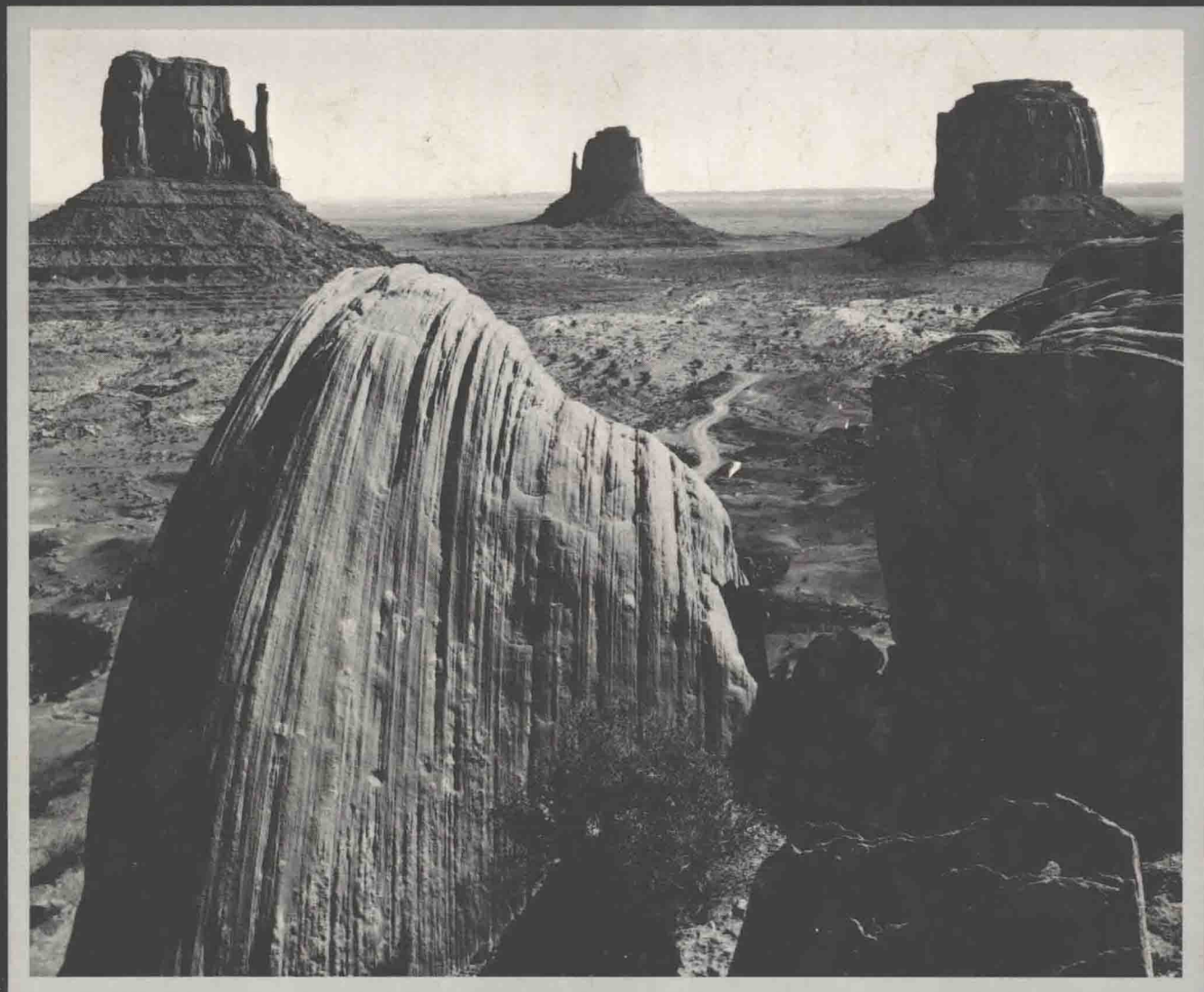


Fourth  
Edition

# EVOLUTION OF THE EARTH

Robert H. Dott, Jr.  
Roger L. Batten



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# EVOLUTION OF THE EARTH

## FOURTH EDITION

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COVER: Monument Valley, Arizona, 1958 by Ansel Adams. Courtesy of the Trustees of the Ansel Adams Publishing Rights Trust. All rights reserved. Photograph shows The Mittens buttes eroded from 270 million-year-old sandstone and shale of Permian age. The sandstone block in the foreground displays conspicuous stratification etched by time.

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**To our parents and all our other teachers.**

## **EVOLUTION OF THE EARTH**

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# PREFACE

Time present and time past  
Are both perhaps present in time future,  
And time future contained in time past.

T. S. ELIOT,  
*Four Quartets*

**W**hen our first edition appeared in 1971, there was a vacuum in historical geology instruction. The long-standing approach was to present a very detailed, dry descriptive relation of lists of formation names for many areas, but with little or no unifying theme and little emphasis upon interpretation and hypothesis testing. That approach was aptly characterized by our friend L. L. Sloss as “The Roll Call of the Ages.” We selected, instead, an overall chemical-physical as well as organic evolution of the earth as a central theme, and it was fortunate that the unifying plate tectonic theory appeared in time to provide more coherence to physical history. We also pioneered with the first use of color for figures in a historical geology book. Looking back, we take considerable satisfaction that our hoped-for renaissance in the treatment of earth history has been successful as evidenced both by the popularity of *Evolution of the Earth* and by the obvious influence of many of our innovations upon several other fine books that have appeared subsequently. The general response of our own and others’ students has been most pleasing of all! *Evolution of the Earth* has not escaped the notice of combatants in the continuing controversy between evolutionists and creationists, either. We receive both praise and condemnation, for besides being criticized for endorsing evolution, we also have been

scolded for being too soft-spoken on the issue. A worse fate is to be ignored.

## WHAT IS NEW?

### Content

The fourth edition of *Evolution of the Earth* is organized in much the same way as the third edition, but there are several innovations. The *World Map Supplement* introduced in the third edition is presented in this edition together with reproductions of several ancient-life reconstructions in full color. Chapter 9, *Early Life and Its Patterns*, has been modified in several ways. First, the discussion of the origin of life has been moved to this chapter, where it seems to fit more logically. Second, a fuller discussion of different kinds of metabolisms has been introduced. The treatment of Precambrian and Cambrian life are kept together in Chapter 9 as before, but the discussion of Ordovician life and the establishment of modern ecosystems has been moved to Chapter 12.

### Pedagogy

The new edition features several changes intended to make it easier for the reader to use the book



both as a reference and for reviewing purposes. All chapter introductions have been rewritten to provide a clear and succinct “map” of the chapter. These spell out in a straightforward way what will be emphasized. Chapter summaries have also been revised to provide a very clear listing of the essential points of each chapter. Several humorous anecdotal items and some supplemental details have been set apart in Boxes so as not to interrupt the flow of the main theme of a chapter. The Glossary has been expanded to provide many new entries. For quick reference, the endpapers provide a new diagram summarizing the history of major groups of animals and plants. They also retain the detailed geologic time scale and the Phanerozoic global sea-level curve.

Many other changes in the new edition are less obvious, but are at least as important as those mentioned above. These include updating of the text in countless ways and the addition of many new illustrations. We have expanded the treatment of the history of life—both in text and illustrations. Included are the latest concepts of evolution and extinction, and forthright discussions of the creationism issue. Also significant are numerous revisions of, or additions to, the treatments of global tectonics, planetology, Precambrian history, paleoclimate, and cratonic sequences and structures.

## APPROACH

Our basic philosophy remains unchanged in this new edition. As we stated in the Preface to all previous editions of *Evolution of the Earth*, we are committed to the proposition that introductions to the sciences should be primarily conceptual rather than informational. Our book reveals the logical framework of geology, shows relations of the science to the totality of human knowledge, and gives some idea of what it is like to be a participant in the discipline. Our experience indicates that students are stimulated by constant exposure to scientific controversies, occasional spicy personal feuds, or an amusing faux pas. In this fourth edition, these are mostly presented in Boxes. The

student also needs to become a partner in the endless process of hypothesis testing. In this book, we have tried to use all of these approaches.

In keeping with our preference for a “How do we know?” rather than “What do we know?” approach, we stress what assumptions are made by earth historians, what kinds of evidence (and tools for gathering that evidence), and what processes of reasoning and limitations of hypotheses are involved in reconstructing and interpreting the past. At the same time, we have again in this edition tried to emphasize that which is more or less unique about geology as an intellectual discipline. Its historical nature sets geology apart from the more familiar nonhistorical sciences; therefore, we have deliberately tried to draw out and to illustrate this uniqueness. As readers use the book, we hope that they will keep in mind the following three maxims, which seem to us to be of transcendent importance for all educated people: (1) new concepts of time, (2) the universality of irreversible evolutionary changes, and (3) the importance throughout time of ecological interactions—feedbacks—between life and the physical world.

## USING THE BOOK

Initial encounters with the sciences generally involve major shifts of scales—both spatial and temporal. We have had success by beginning with discussions of familiar geologic processes that have affected humans directly in historic times. We then shift into truly geologic frames of reference. For the more science-oriented student, we recommend also simple homework problems that deal with geologic time and the rates of a wide variety of geologic processes. Suggested examples are contained in a supplementary *Instructor's Manual*.

*Evolution of the Earth* developed first in the late 1960s from a second-semester course at the University of Wisconsin, Madison, taken mostly by first- and second-year college students representing a broad spectrum of science and nonscience backgrounds. The modifications incorporated in

this new edition reflect our own experience together with the constructive criticisms of many other teachers at a variety of different colleges having widely differing requirements. We have also adapted to changing times and rapid advances in the science. We believe that this new edition of *Evolution of the Earth* lends itself to great flexibility of usage. The book assumes only a prior knowledge of general geology comparable to a high-school earth science or first-semester college physical geology course. We have retained the classical foundations of earth and life history, but certain material, especially of a chemical and physical nature that seems necessary to us for an adequate understanding of modern geology, may prove difficult for some readers. We are confident that the skillful teacher can help students through such material by drawing out the essential highlights without intimidating them. The Glossary should aid all readers, but especially those with limited backgrounds.

### Historical Approach

The historical elaboration of the development of basic principles for interpreting earth and life history invoked in the early chapters is continued in streamlined form in later ones. First, it provides a kind of proxy for the reader's actually recapitulating discoveries and interpretations accomplished by past generations that make up the fabric of geologic principles. Second, it helps to make clear that the science is a human activity, and that the quest for the understanding of nature is an ongoing, open-ended process in which readers themselves could participate if they should so choose. Finally, the historical approach reveals the cultural relationships of the science, which are unusually rich in the case of geology. Historical geology provides both a great opportunity and an obligation to present a broad integration of diverse material and to clarify the relevance of science. The first three chapters in which the historical approach is most prominently incorporated can be read rather quickly and understood by most students with a

minimum of classroom elaboration if the instructor so chooses; nonscience students especially like this material.

### Relationships to Physical Geology

Chapters 4 through 7 present some of the more complex principles and concepts basic to interpreting earth and life history. These are very important to the remainder of the book, and experience shows that they require classroom supplementation. We realize that these chapters overlap with books on physical geology, which are used as texts for the first course in geology. Nonetheless, because they provide the *raison d'être for the remainder of the book*, we feel that it is important to have them here as essential introductions to earth history. They also help to show the tie between physical and historical geology.

### Topical Approach to Chronology

After these background chapters, which themselves contain abundant earth history, we prefer to bring up new important concepts (and to expand upon some already-introduced ones) within the context of the actual historical record as each becomes important to the discussion. This is our rationale for taking up organic evolution after reviewing the record of Precambrian and early Paleozoic life. In this way, evolution is discussed after the need becomes apparent for a general explanation of the actual fossil record. Similarly, the principal discussion of mountain building is reserved until the first major orogeny of the Paleozoic is treated under Ordovician history; mountain building is further elaborated several times later, too. And reefs are not discussed in detail until the middle Paleozoic, when large fossil reefs built by animals first became widespread.

In developing new emphases in historical geology, we have minimized the encyclopedic "Roll Call of the Ages" so prevalent in the past. Chapter 8 and 11 through 18 treat the historic record for the earth with North American data integrated more closely with that for other continents than in



prior editions. But whether a given discussion concerns North America or some other part of the world, the purpose always is to illustrate how geologists unravel and interpret the historical record more than to burden the reader with a formidable mass of factual detail and terminology. Instead, while a broad chronologic framework is provided throughout, chief emphasis is placed upon interpretation of physical and biological environments, reconstruction of paleogeography, and evolution. Our unifying theme throughout is that of *overall chemical evolution of the earth!* Interaction or feedback between the living and the nonliving are emphasized, as are major stratigraphic and tectonic patterns that recur in both time and space. In this way, each of the North American chapters, as noted above, tends to be topical as well as chronological, with only one or a few rather unique circumstances (such as evaporite deposition and organic reefs in Chapter 13) developed fully in each at the expense of more mundane, nonunique stratigraphic detail. Factual detail that is presented is for documentation only; students should not be expected to memorize much of it but rather to understand the principles and logic of the historical arguments for which the facts provide essential evidence.

The concluding chapter reminds the reader of the three fundamental maxims that follow from a study of earth history, which were stated above. Brief illustrations of each are discussed, and then the extrapolation of some implications of these maxims into humanity's future are developed briefly in order to suggest some conclusions following from a study of earth history that have relevance to all members of the human race.

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And I have written books on the soul,  
Proving absurd all written hitherto,  
And putting us to ignorance again.  
(So said Robert Browning's  
skeptical philosopher Cleon.)

Robert H. Dott, Jr.  
Roger L. Batten







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