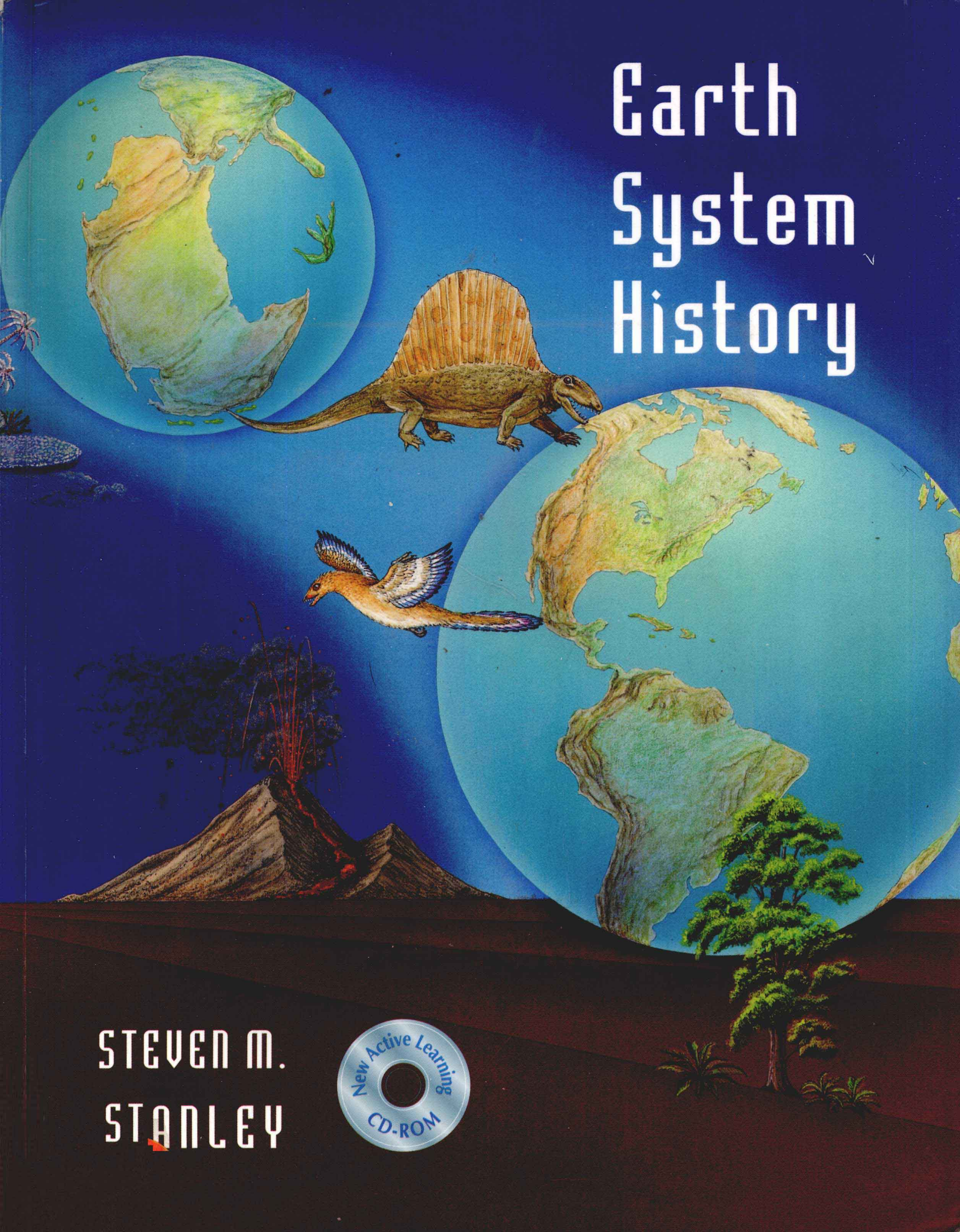
Earth System History

STEVEN M. STANLEY



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STEVEN M. STANLEY

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To Nell and Sveta

About the Cover: Early Earth was a glowing, liquid planet. After it cooled, the ocean, atmosphere, and continental crust formed, and as continents coalesced and fragmented, life appeared. Throughout its subsequent evolution, life has interacted with Earth's dynamic crust and enveloping fluids. The cover for this first edition of *Earth System History* depicts these geologic and biological events, showing four stages of Earth's development as a planet.

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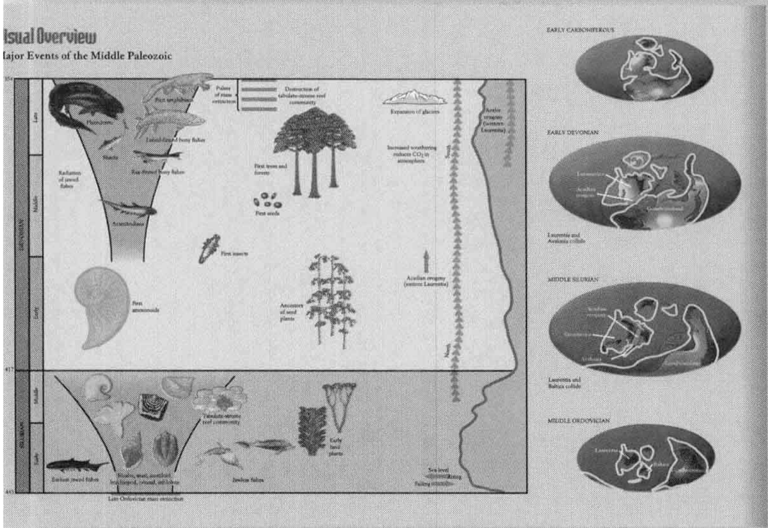
Preface

The curriculum in the Earth sciences has been evolving rapidly in the last few years, after many decades of relative stability. Appropriately, the new approach to teaching reflects a shift in research toward integrative study of the entire Earth system and its many subsystems. This Earth system approach demands a rethinking of the field traditionally called historical geology: the only way to reconstruct and interpret Earth's history effectively is by treating the lithosphere, biosphere, hydrosphere, and atmosphere as parts of a single system. *Earth System History* reforges its successful predecessor, *Exploring Earth and Life Through Time*, to reflect this powerful new way of studying Earth's history. The traditional topics of historical geology still remain at the core of *Earth System History* but are enriched by placement in the broader framework of the planet as a whole.

Now more than ever, Earth's history deserves a central place in a balanced undergraduate curriculum. The rock record of Earth's deep history is what sets geology apart from all other sciences, and in an era of heightened concern about the environment it is imprudent to ignore this unique archive and to focus strictly on present-day geologic processes. The full geologic record of life and environments is more broadly relevant: it documents the myriad unique natural experiments that show how the Earth system functions. We will never duplicate these experiments in the laboratory or in the field. We must study them in rocks. Understanding changes of the past will help us—and our students—confront future environmental changes.

The history of life and the history of the physico-chemical environment are inextricably intertwined. This is not a unidirectional relationship: environmental changes affect life, but biologic changes in turn alter the environment. For example, my colleague Lawrie Hardie and I have found that simple changes in ocean chemistry, governed by global spreading rates along mid-ocean ridges, have determined what kinds of organisms have been the dominant reef formers and sediment producers during particular intervals of the Phanerozoic Eon. Thus, "For The Record 10-1: Seawater Chemistry and Chalk" presents strong evidence that the massive chalk deposits that gave the Cretaceous System its name accumulated because of the presence of "calcite seas," which resulted from unusually high rates of seafloor spreading. As another example, Chapters 10 and 14 describe how the advent of forests in Devonian time must have reduced carbon dioxide levels in the



atmosphere and set the stage for the late Paleozoic ice age.

A survey of instructors revealed a strong consensus that courses covering Earth's history should explain how studies of stable isotopes shed light on events of the geologic past. Accordingly, Chapter 10 introduces the use of stable isotopes to study the history of key chemical cycles and other aspects of the Earth system including the greenhouse effect and the effects of plate tectonic activity on seawater. This new chapter is central to the Earth system approach, introducing concepts and techniques that later emerge in discussions of particular events in Earth's history. The Earth system approach culminates in the new final chapter on the Holocene, which ushers students into the modern ice age and raises issues about future global change.

How This Book Is Organized

This edition has been substantially revised to provide teachers and students with a comprehensive guide to Earth system history. It has been updated in accordance with the latest scientific knowledge.

Chapter 1 introduces the Earth system approach, emphasizing the rock cycle and the hydrological cycle as well as plate tectonic cycling of materials. It also contrasts the gradual and catastrophic processes that shape Earth.

New to this book, Chapter 2 introduces important groups of rocks and rock-forming minerals and explains how they relate to one another within the rock cycle. This chapter includes information on how chemical bonds and structures affect the properties of minerals. It can serve as a review for students who have completed a course in physical geology or as a primer for those with no background in physical geology.

Also new to this edition, Chapter 3 reviews the biology and classification of the six kingdoms of organisms and introduces methods of phylogenetic reconstruction. This chapter assumes no background in biology on the student's part, but provides a context for subsequent discussions of the history of life.

Chapter 4 includes an expanded discussion of the influence of topography on climate and a new treatment of thermal regimes of shallow seas.

Chapter 5 includes a new discussion of the use of fossils to delineate sedimentary environments.

Chapter 6 now introduces the field of stratigraphy by showing how it arose as a branch of geology. This chapter also integrates the definition of formal stratigraphic units with discussions of stratigraphic concepts.

Chapter 7 invokes the origin of whales to exemplify the origins of higher taxa. It also contains a new introduction to major mass extinctions.

Chapter 8 integrates an introduction to the basic kinds of faults with a discussion of plate tectonics, and Chapter 9 integrates folding with mountain building in a similar way.

Chapter 10 is an entirely new chapter that uses an approach never before seen in an introductory textbook. This chapter examines the oxygen and carbon cycles and describes the factors that govern levels of atmospheric oxygen and carbon dioxide. To comprehend Earth system history it is necessary to understand the impact of major chemical cycles on Earth, and Chapter 10 uses simple diagrams and real-world examples to clearly explain the effects of chemical cycles in the past and their possible consequences for the future.

Chapter 11 presents the widely favored explanation of the origin of the moon as the result of an asteroid impact and the likely origin of life in the heated zone along a mid-ocean ridge.

Chapter 12 presents new evidence about major events near the end of the Proterozoic Eon, including the assembly of a supercontinent, profound glaciation, the possible buildup of atmospheric oxygen, and the explosive diversification of multicellular organisms.

In response to instructors' comments, I have rewritten Chapters 13, 14, and 15 to place mountain-building episodes in the Appalachian region in the context of Earth's Paleozoic history. These chapters also provide up-to-date reviews of the great Paleozoic mass extinctions and show how the origin of forests and coal swamps probably led to late Paleozoic glaciation by reducing greenhouse warming.

Chapters 16 and 17 are highlighted by new discoveries that change our view of dinosaurs and Mesozoic land plants. Chapter 16 also focuses on new evidence that the arrival of a meteorite brought the Mesozoic Era to an end.

Chapters 18 and 19 present new evidence of climatic, biotic, and oceanographic changes during the Cenozoic, new chronologies of mountain building in the American West, and recent discoveries that place human origins in a new light.

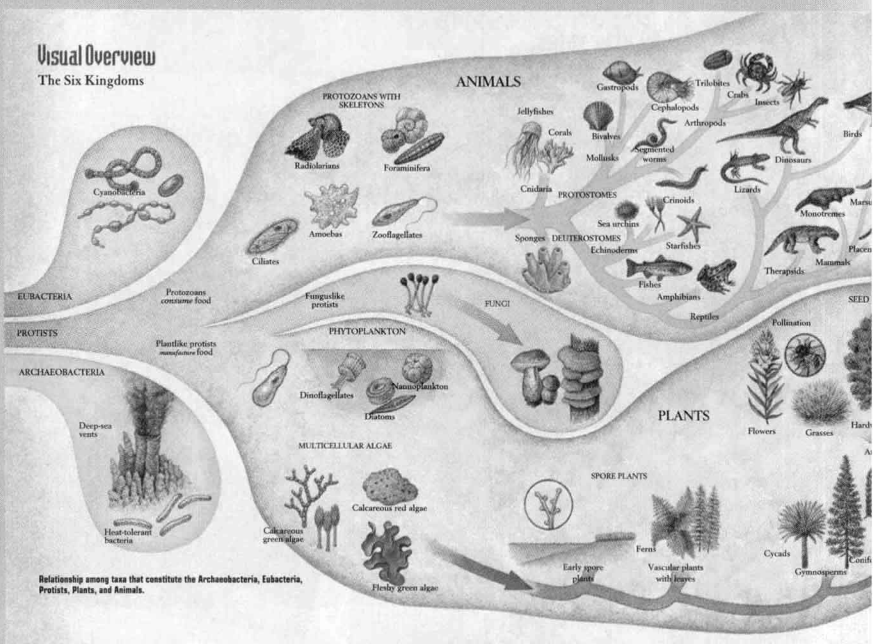
Chapter 20, an entirely new review of the Holocene, describes Earth's complicated emergence from the most recent glacial maximum. This chapter emphasizes changes in climate and sea level in recent history, and their consequences for the environment. The present world emerges in this chapter: having gained a broad knowledge of Earth's past, the student becomes oriented toward its future.

A New Vision, a New Book

Several features highlight the new approach of *Earth System History*.

Visual Overviews

Visual Overviews provide students with vivid illustrations of the key themes and concepts of Chapters 2 through 20. Expanded from the Major Events diagrams in the previous edition, *Visual Overviews* concisely portray major geologic events and cycles.



Relationship among taxa that constitute the Archaeobacteria, Eubacteria, Protists, Plants, and Animals.

Furthermore, a *Review Question* at the end of each chapter challenges the student to use the chapter's *Visual Overview* to synthesize key points. Each special *Review Question* is identified by a System Icon: ◉.

Review Questions

◉ 11 Suppose that you were to encounter a well-trained geologist who was unfairly imprisoned in 1955 and was deprived of reading materials until he was released last week. He entered prison firmly opposed to the idea that continents have moved large distances across Earth's surface. Given an hour of time, how would you convince this unfortunate geologist that continents have actually moved thousands of kilometers? Use the Visual Overview on p. 208 as a guide to develop your argument.

For the Record

Chapters 2 through 20 feature *For the Record*, an in-depth look at an environmental, evolutionary, or resource-oriented example in Earth system history. Ranging from the extinction of the dinosaurs to drilling for oil off the shore of New Jersey, *For the Record* boxes offer real-world examples of Earth system history in action.

Seawater Chemistry and Chalk

Chalk is a soft, white, fine-grained limestone that we use to write on blackboards, but it is also the formal name for a large Upper Cretaceous body in western Europe. Along the coast of France the Chalk forms cliffs that Allied troops scaled during the invasion of Normandy in 1944, and it rises up as the famous White Cliffs of Dover on the British side of the English Channel. The Cretaceous contains a vastly larger volume of chalk than any other geologic system. As it turns out, this un-usual abundance probably reflects the chemical composition of Cretaceous seas.

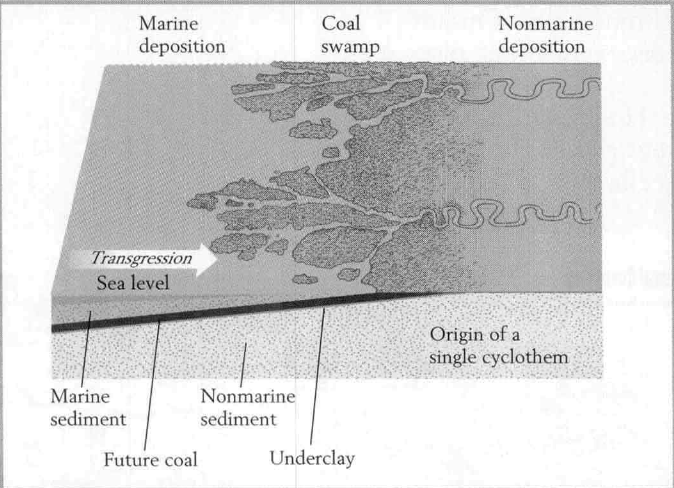
The most massive deposits of Cretaceous chalk are those of western Europe, which are typically about 200 meters (~660 feet) thick, but substantial bodies of chalk also accumulated in an epicontinental sea in North America. Between Alabama and Kansas, Upper Cretaceous chalks have yielded spectacularly well preserved fossils, including skeletons of huge marine reptiles that might be described as sea monsters. Fossils are exceptionally well preserved in chalk for the same reason that the chalk is soft: it is formed of minute grains of calcite. The small size of these grains makes

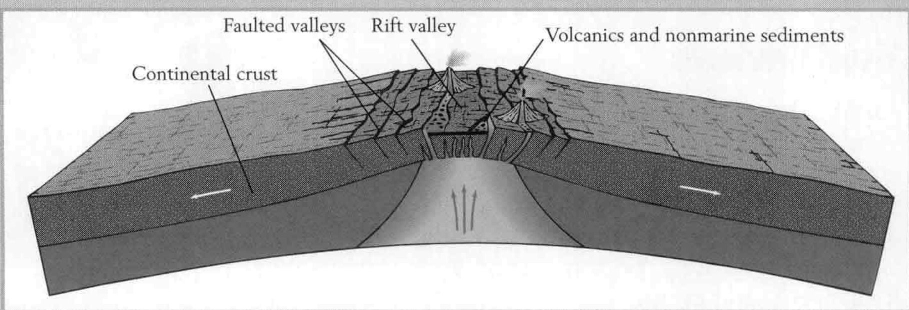
Illustration Program

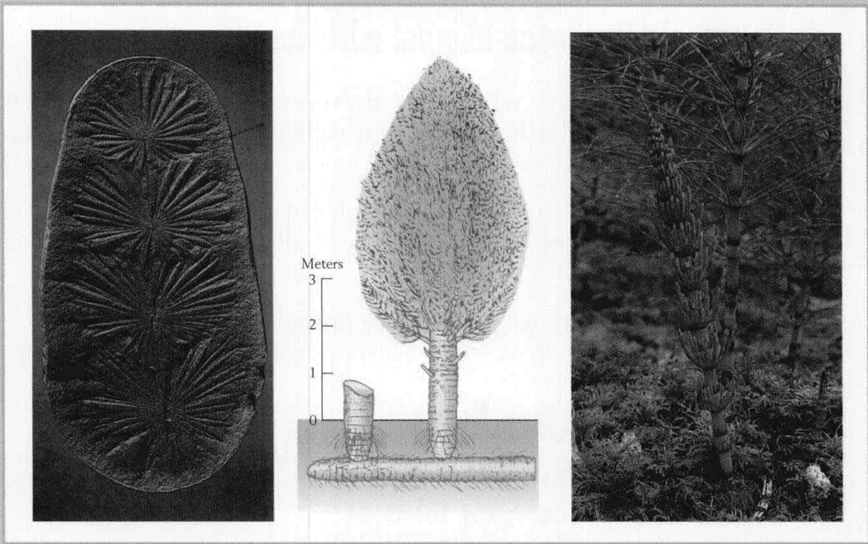
A full-color illustration program enhances *Earth System History*'s new approach. Line illustrations have been clarified and recreated in full-color, and many black-and-white photographs have been replaced by striking new color photographs.

New three-dimensional block diagrams illustrate processes, cycles, and events in Earth system history.

For effective presentation of key subjects, line art and photographs have been paired frequently: line diagrams illustrate important patterns and accompanying photographs provide actual examples.







Chapter Summaries, Review Questions, and Additional Readings

End-of-chapter material aids students in identifying and retaining key themes of each chapter. *Chapter Summaries* reiterate integral concepts and facts, *Review Questions* help students understand and remember important ideas, and *Additional Readings* offer interested students resources for learning more about Earth system history.

Appendix and Glossary

The *Appendix* covers the major stratigraphic stages of Earth's history in one compact, comprehensive source. The *Glossary* includes concise definitions of important scientific and geologic terms that may be unfamiliar to the student. Scientific and geologic terms are printed in **boldface** when they first appear in the text and then are gathered with their definitions in the comprehensive *Glossary.*

Supplements

Earth System History provides a complete historical geology program for instructors and students.

Student CD-ROM

- Selected exercise modules and activities on key areas such as the evolution of the continents and sedimentary environments.
- Student study features include multiple-choice quizzes with built-in feedback and mnemonic exercises for learning the intervals of the geologic time scale.
- Original geological animations convey challenging but essential concepts of atmospheric chemistry, mountain building, stratigraphy, sedimentology, and paleoclimatology.

Instructor's Resource Manual with Test Questions

- Recommendations, written by Steven Stanley, explain how to emphasize the Earth system approach in covering the material in each chapter.
- Many of the test questions for each chapter, in a variety of formats, contain geologic diagrams, and all test questions provide page references.
- Original transparency masters are provided.

Slide Set with Lecture Notes

- A selection of 60 top-quality historical geology slides picked specifically to accompany the text.
- An accompanying booklet of lecture notes puts each slide in the context of the course material. The slide set was curated by renowned geology photographer Peter Kresan of the University of Arizona.

Overhead Transparency Set

- 50 full-color overheads, including key diagrams from the text as well as original illustrations.

Computerized Test Banks

- Amenable to editing and the addition of questions.
- Available for both Windows and Macintosh operating systems.

Freeman Geology Web Site

http://www.whfreeman.com/geology/

- Provides links to hundreds of Web sites related to geology.
- Includes expansion modules with additional information on historical and physical geology.
- Presents a complete list of geology newsgroups.

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Contents in Brief

Contents