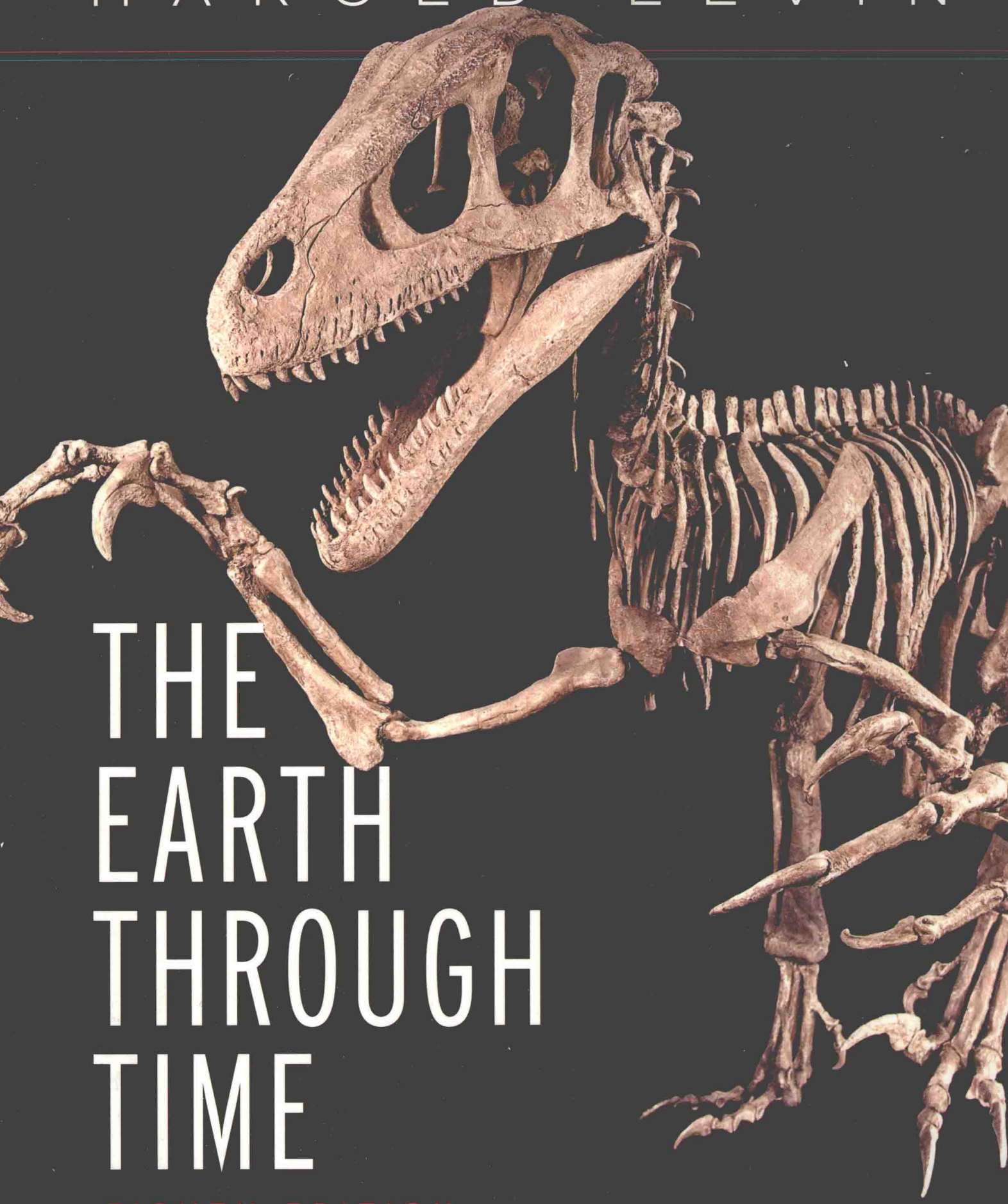
HAROLD LEVIN



THE EARTH THROUGH TIME

EIGHTH EDITION

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The Earth Through Time

HAROLD L. LEVIN

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To see where we might be going,
we must understand where we have been.

Robert Tamarkin, 1993

This book is dedicated to my wife Kay, who has cheerfully endured my preoccupation with preparing this new edition, and to Noah, Lillie, Eli, Mollie, Natalie, Emily, Caitlyn, Hannah, and Candis. May they have the wisdom to treat the Earth kindly.

ABOUT THE AUTHOR

Harold ("Hal") Levin began his career as a petroleum geologist in 1956 after receiving bachelor's and master's degrees from the University of Missouri and a doctorate from Washington University. His fondness for teaching brought him back to Washington University in 1962, where he is currently professor of geology and paleontology in the Department of Earth and Planetary Sciences. His writing efforts include authorship of seven editions of *The Earth Through Time*; four editions of *Contemporary Physical Geology*; *Essentials of Earth Science*; and co-authorship of *Earth: Past and Present*, as well as eight editions of *Laboratory Studies in Historical Geology*; *Life Through Time*; and, most recently, *Ancient Invertebrates and Their Living Relatives*.

For his courses in physical geology, historical geology, paleontology, sedimentology, and stratigraphy, Hal has received several awards for excellence in teaching. The accompanying photograph was taken during a lecture on life of the Cenozoic Era. The horse skull serves to illustrate changes in the teeth and jaws of grazing animals in response to the spread of prairies and savannahs during the Miocene and subsequent epochs.

The Earth Through Time is an excursion into the Earth's geologic past. The trip began about four and a half billion years ago, approaching the time when our planet had gathered most of its mass from a rotating cloud of dust, gases, and meteorites. From that time to the present, the Earth has undergone constant change. Ocean floors have expanded and moved, continents have broken apart, sea floors have been thrust skyward to form mountain ranges, and once peaceful landscapes have been disrupted by earthquakes and fiery floods of lava. Since about 3 billion years ago, life has existed on this dynamic planetary surface. Fossil remains of ancient life attest to their successes and failures in coping with perpetually changing conditions.

How the Earth and its inhabitants have changed provides a fascinating story. The story alone is sufficient reason for undertaking a study of the Earth's geologic past Historical geology, however, has value in many other ways as well. As a science, it informs us about the way science works, how discoveries are made, and how to tell the difference between valid and shoddy interpretations. Past events also relate to many problems we face today, including, global warming, environmental pollution, depletion of vital mineral resources, and the adverse effects of loss of animal and plant species. Understanding science, and realizing how each component of our past and present planet interacts with all other components will promote informed decisions about the many environmental issues now being debated in our governing bodies.

Determining the cause of past geologic events is a complex task. As an example, one might infer that the demise of a particular group of ancient animals resulted from cooling of the planet. This leads us to ask *why* cooling occurred. Was it the result of changes in the composition of the atmosphere, changes in the amount of radiation received from the sun, the upheaval of wind-diverting mountain ranges, changes in the Earth's axis of rotation, or shifts in the location of lands and seas? The answers come only after study of the reciprocal actions of all the Earth's systems: the solid Earth, the atmosphere, and the biosphere. This intergrated approach applies well both to the solution of contemporary problems and to an understanding of happenings in the remote geologic past. It is an approach embodied in this text.

As in earlier editions, this revision of *Earth Through Time* is designed to meet the requirements of the undergraduate student who has had little or no previous acquaintance with geology. However, for those exploring the possibility of an academic major in geology, the text will provide the initial background needed for advanced courses. Information about geologic materials and processes are included in *Earth Through Time* so that the book can be used either for a single, self-contained first course, or for the second course in a two semester sequence of Physical and Historical Geology.

THE EIGHTH EDITION

The preparation of a new edition provides many opportunities to refashion and improve explanations, to develop better illustrations, and to constructively expand, delete, and reorganize. The greatest effort in this revision has been to make the narrative more lively and engaging, to clearly convey the unique perspective and value of historical geology, and to improve the presentation so as to enhance the student's ability to retain essential concepts.

In this eighth edition, seventeen chapters have been organized under three major divisions. Part I. *Discovering Time and Deciphering Earth's Amazing History*, explains the methods used in reconstructing the Earth's geologic history, introduces contributions made by early geologists to the science, and describes how rocks are dated and then used to construct the geologic time scale. Part II, *Rocks and What They tell Us About Earth History* describes the nature and origin of Earth materials, and how rocks and fossils can reveal events of the geologic past. In Part III, *History of Planet Earth and Its Inhabitants* we explore the actual history of our planet from its fiery birth to the unfolding of the modern world.

WHAT KINDS OF PEDAGOGY DOES *EARTH THROUGH TIME* PROVIDE?

Earth Through Time has a variety of features to engage the student and promote learning.

- Technical terms are printed in **boldface** type the first time they are used, and clearly defined, both in the text and in the glossary.
- So that students will know what lies ahead, each chapter begins with a concise list of **Key Chapter Concepts**.

- Each chapter ends with a **Summary** of essential concepts. These provide students with a reality check. If the summary statement is not understood, it is a cue for the student to visit that topic in the chapter again.
- A list of **Key Terms** is provided. If the student does not remember the meaning of a term, it provides another opportunity to check their understanding of concepts developed in the chapter.
- **Questions for Review** allows students to test their understanding of material in a chapter and to further "process" what they have learned.

Caption questions occur beneath many photographs. These questions draw attention to geologic features depicted in the images, and clarify explanations in the text.

- Appendices in *Earth Through Time* include a **Classification of Living Things** that helps students place fossils described in the text in their correct taxonomic position, a **Glossary** containing a list of important terms and their definitions, Physiographic, political and bedrock geology **maps**, the **Periodic Table and Symbols for Chemical Elements, Convenient Conversion Factors**, an explanation of **Exponential or Scientific Notation**, a **Table of Rock Symbols**, and a table providing the composition and physical properties of **Common Rock-Forming Silicate Minerals**.
- Most chapters feature one or more boxes. The **Enrichment** boxes discuss some topics of general interest that relate to material in the chapter, and the **National Parks and Monuments** boxes provide an example of a location where the geology discussed can be directly seen.
- To help students correlate events they are reading about in the text to their actual time of occurrence, small time scales containing an age indicator accompany many photographs of rock formations and fossils.

SUPPLEMENTS

The eighth edition of *The Earth Through Time* is accompanied by an extensive set of supporting materials. These include:

A **Student Study Guide** prepared by Harry Wagner of Victoria College. Designed to enhance students' understanding of the text, the guide includes Chapter Overviews, Learning Objectives for each chapter, Questions for Review, Key Terms, illustrations and maps.

An **Instructor's Manual and Test Bank** has been prepared by David T. King Jr., of Auburn University. To facilitate use of the text by instructors, the manual includes chapter outlines, questions that can be incorporated into examinations, and answers to questions in the textbook.

Computerized Test Banks are available in three disk versions: Windows, IBM, and Macintosh.

A set of 100 full-color **Overhead Transparencies** is provided for use in the laboratory or lecture hall, as well as a set of one-hundred 25-mm slides of illustrations and photographs.

Earth Sciences Instructor's Resource CD-ROM provides numerous images from this and other John Wiley & Sons geology texts.

John Wiley and Sons, Inc. may provide complementary instructional aids and supplementary packages to those adopters qualified under our adoption policy. Please contact your sales representative for more information.

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BRIEF CONTENTS

CHAPTER 1

The Science of Historical Geology

To see where we might be going,
we must understand where we have been.
—Robert Tamarkin, 1993

Key Chapter Concepts

- The study of events in the Earth's past can often be used to predict future events.
- The Earth and its inhabitants have undergone continuous change during the past 4.6 billion (4,600,000,000) years.
- Physical geology examines the structure, composition, and processes that affect the Earth today. Historical geology considers all past events on Earth.
- The scientific method is a way to find answers to questions and solve problems. It involves collection of information through observation and experimentation, formulation of tentative answers, and validation by testing.
- The three most pervasive themes in the history of Earth are the immensity of geologic time, plate tectonics, and organic evolution.

Welcome to the amazing history of our planet! Here you will discover many astonishing events of the past and learn how we came to understand them. You will learn the intriguing story of how life developed on Earth and how an extraordinary species evolved that is the only one capable of reading books like this: *us*.

Our planet formed about 4.6 billion years ago. Since that time, it has circled the sun like a small spacecraft observing a rather average star. Between about 300,000 and 150,000 years ago, a species of primate we call *Homo sapiens* (Latin: *wise human*) 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 did Earth form? Why do earthquakes occur? What lies beneath the land and below the ocean floor?*

Even ancient people sought answers to these questions. In frail wooden ships, they probed the limits of the known world, fearing that they might tumble from its edge or be consumed by dragons. Their descendants came to know the planet as an imperfect sphere, and they began to examine every obscure recess of its

OUTLINE

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 tropical forest, the continents are well charted. New frontiers for exploration now lie beneath the ocean and outward into space.

WHY STUDY EARTH HISTORY?

Earth's spectacular history deserves to be closely examined, for it permits us to see the future. Events of the past will happen again. We owe it to ourselves and to our home planet to look carefully at those events and attempt to understand them.

From the time of its origin to the present day, Earth has undergone continuous modification. Continents have been flooded by vast inland seas. They also have ponderously drifted across the face of the globe and slowly collided with other landmasses to form lofty mountain ranges (Fig. 1-1). Massive glaciers have buried vast tracts of forest and prairie. Earth has witnessed recurrent earthquakes, rampant volcanism, catastrophic impacts of meteorites and asteroids, and major changes in the chemistry of the ocean and atmosphere. Along with these physical changes, life on Earth has also undergone change—sometimes slow, but occasionally swift and deadly.

All of these events of the geologic past have relevance to our lives today. By discovering why they occur, we can better predict the future. For example, we are carefully examining climatic trends of the past so we can better understand today's climatic changes. With knowledge of Earth's history, we can plan ahead. We can avoid further damage to this planetary haven in space that is our home. Aside from these concerns, an important reason to study Earth history is simply to better understand our favorite and unique planet and its amazing forms of life.

GEOLOGY LIVES IN THE PRESENT AND THE PAST

For convenience, we divide the body of knowledge called geology into physical geology and historical geology. **Physical geology** studies Earth's materials (rocks and minerals) and the varied processes that occur both on the surface and deep in the interior. **Historical geology** addresses Earth's origin and evolution, changes in the distribution of lands and seas, the growth and reduction of mountains, and the succession of animals and plants through time. Historical geologists examine planetary materials and structures to discover how they came to exist. They observe the tangible *results* of past events and work backward in time to discover the *causes* of those events.

Geology primarily studies Earth, but its view has broadened to include other planets. This increase in scope is appropriate, because geologic knowledge is employed in interpreting the images of the surfaces of other planets and their moons, in estimating the power of volcanoes on Venus, and in identifying rocks and minerals from Earth's moon.

Geologists identify the minerals in meteorites (Fig. 1-2) to discover how Earth formed. With sophisticated instruments, they scrutinize images of planets or interpret data transmitted by space probes and planetary exploration rovers (Fig. 1-3). Still others busily unravel the structure of mountain ranges, attempt to predict hazards like earthquakes and volcanic eruptions (Fig. 1-4), or study the behavior of glaciers, streams, or underground water.

FIGURE 1-1 The magnificent Canadian Rocky Mountains viewed from Malign Lake, British Columbia. These mountains were initially raised over 80 million years ago. Their present appearance results from further uplift and erosional sculpting during subsequent geologic periods down to the present day.