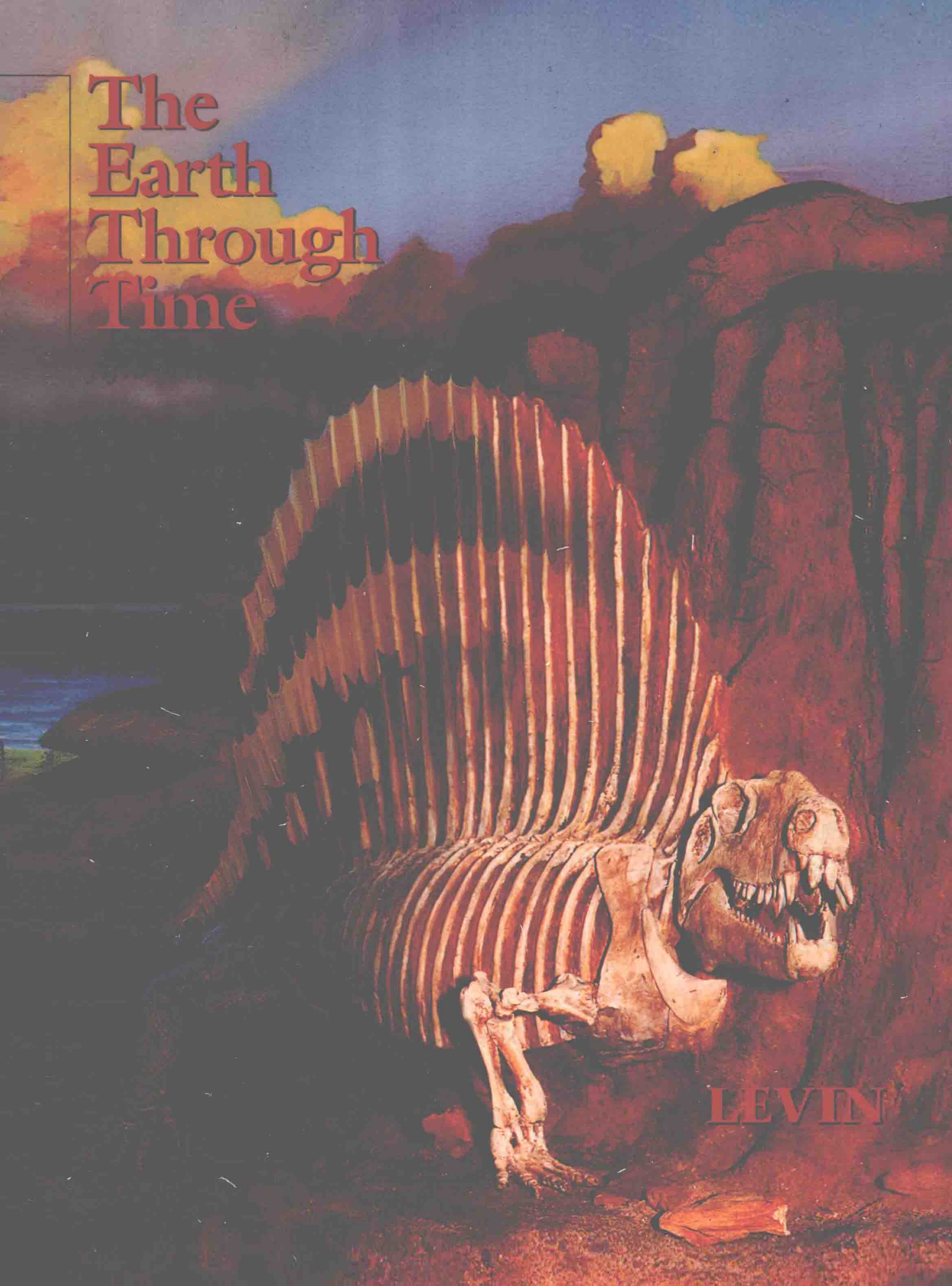
The Earth Through Time
LEVIN

Whenever it is possible to find the cause of what is happening, one should not have recourse to the gods.

POLYBIUS, Greek Historian, Second Century, BCE

The Earth Through Time

FIFTH EDITION

Harold L. Levin

Professor of Geology

Washington University

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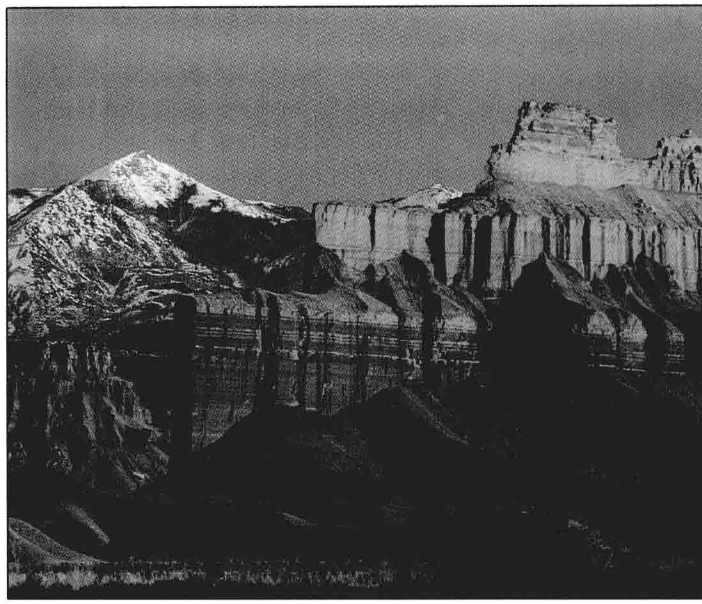
For Kay,
and for our grandchildren,
Eli, Mollie, Natalie, Emily, Caitlyn, and Candis.

May they have the wisdom to treat the Earth kindly.



Preface

A friend who knows little of science recently remarked, "at work on yet another textbook revision? Surely things have not changed that much since the last edition!" I explained that we live in a time when the frontiers of Earth science advance with exceptional speed. Rapid progress is catalyzed by technological advances that permit us to gather data that were beyond our capabilities only a few years ago. "The Earth has changed," I said, "but more to the point, our knowledge, and the way we test and interpret that knowledge, has changed. Students merit the most up-to-date information."

The Earth Through Time is for college students taking either their initial course in geology, or their second course in a physical geology–historical geology sequence. Many of these students will not major in a science, but have an understandable interest in the vibrant planet on which they live. The text will help these students understand the many physical, chemical, and biologic events that have shaped their environment, and will provide insight into how scientific questions are resolved. Few would disagree that such matters are important to a student's liberal education. For those planning to complete an academic major in the earth sciences, *The Earth Through Time* provides much of the background information needed for upper-level earth science courses.

We now possess an enormous body of facts about the Earth. Some of these facts must be learned, for one cannot understand processes that have shaped the Earth without them. It is not, however, the objective of *The Earth Through Time* to present Earth history as a compendium of facts. Rather, the text emphasizes how theories have been developed, how they are validated, and how inferences can be made from observations about fossil remains, from the physical and chemical characteristics of rocks, or from the isotopic composition of minerals.

To facilitate an approach that emphasizes understanding over memorization, the first chapter of the fifth edition presents the underlying principles used in deciphering Earth history as developed by such founders of the science as Nicolaus Steno, James Hutton, and Charles Lyell. Time provides the framework for any history, whether cultural or geologic. Therefore, methods used in dating rocks and the development of the geologic time scale are also introduced in this initial chapter.

The second chapter is a survey of common rocks and minerals—the raw materials from which inferences about Earth history are drawn. Some students may have been exposed to this information in an earlier physical geology course. For such students, the chapter will provide a helpful review. Having learned the basic prerequisite information, students can proceed to the core information of historical geology. They can explore the historical significance of sedimentary rocks and fossils, learn about the operation of plate tectonics and sea-floor spreading, and follow the chronologic sequence of topics dealing with the physical and biological events of each geologic era.

The changes in this fifth edition include new photographs and drawings, refashioned explanations, and additions of new information that has recently appeared in the primary literature. Descriptions of the geology of several national parks has been added. In Chapter 3, a broader discussion of Walther's Law, Vail cycles, and facies analysis is presented. The section on the evolution of plants in Chapter 4 is rewritten, and new concepts relating to evolutionary theory introduced. With reorganization of the text, material relating to the origin of the solar system and the beginning of life precede the chapters dealing with Archean and Proterozoic history. A discussion of organisms dependent upon deep sea hydrothermal vents has been added. Chapters 7 through 15 examine the sequential history of the Earth and its inhabitants. Mass extinctions during the Paleozoic and Mesozoic eras, causes of cyclicity in the stratigraphic succession, dinosaur habits, effects of Deccan volcanism, the Messinian event, and hominid evolution are among the many topics that have been revised in this edition.

Not all instructors will have time for the final chapter dealing with "Moons, Meteorites, and Planets." The chapter, however, is largely self-contained. It can be omitted, assigned as reading, or inserted wherever the instructor deems appropriate. The chapter reminds students that the Earth is one of a family of planets that are related in origin.

■ *Special Features*

Topics related to text discussions have been placed throughout the text as boxes labeled ***Commentary.*** Their purpose is to further illustrate concepts and spark student interest. Examples include *Sedimentary Way-up Structures; A Tale of Two Deltas; Amber, the Golden Preservative; Riches of Greenstone Belts; The Colossal Ordovician Ash Fall;* and *Is There a Bolide Impact in Our Future?*

Nearly everyone agrees that one of the best ways students can learn about geology is to visit rock and fossil localities in the field. Students usually get a taste of the importance of field observations in field trips taken as part of their geology course. One would hope that non-majors would have an opportunity to continue making such observations on their own. Often the opportunity to do so is provided during vacation trips. For this reason, as well as to provide further illustration of concepts examined in the text, seven special boxes about the geology of national parks are provided. Among these are brief descriptions of the geology of Grand Canyon, Hawaii Volcanoes, Voyageurs, Shenandoah, Acadia, Zion, and Badlands national parks.

■ *Help for the Student*

Many learning aids have been included to help the student master the content of their geology course. Each chapter begins with an outline that informs the reader about content and sequence. This is followed by introductory paragraphs that provide an overview of what follows and why it is important. A summary is provided at the end of each chapter for review and use in preparation for examinations. Throughout the text, key terms are in **boldface** type. Two kinds of questions are provided with each chapter. A list of **Review Questions** focuses on important themes and text knowledge. They can usually be answered directly from information given in the text. **Discussion Questions** test comprehension and challenge the student to expand on text information. **Supplemental Readings and References** provide more comprehensive information for the student wishing to pursue topics further, perhaps as a basis for term papers.

At the back of the text, students will find an extensive illustrated **Glossary.** All definitions in the glossary are in conformity with the *Glossary of Geologic Terms* published by the American Geological Institute. Should the need arise to check the age or correlation of a rock unit mentioned in the text, the student can refer to the **Formation Correlation Charts** in the Appendices. Also in the Appendices are **A Classification of Living Things, Physiographic Provinces of the United States, Periodic Table of Chemical Elements,** and English/Metric **Convenient Conversion Factors.**

■ *Ancillaries*

The Earth Through Time is amply supported with materials to facilitate and enhance teaching. These supplementary materials include an **Instructor's Manual** with **Test Bank** written by David T. King, Jr. of Auburn University. It includes detailed chapter outlines, multiple choice questions, and answers to all the end-of-chapter Discussion Questions. To enhance the students' understanding of the text, **A Study Guide** has been prepared by Vicki Harder. It includes Chapter Overviews, Learning Objectives, detailed Chapter Outlines, Summaries, Questions for Review, Terms to Remember, Completion Questions, and True/False Questions. Answers to all True/False Questions and Multiple Choice Questions are provided. **Computerized Test Banks** are available in Macintosh and IBM Windows 3.5 and 5.25 disks.

The **Saunders College Videodisc** includes over 2000 colorful, still images from 10 of Saunders' best-selling Geology, Earth Science, and Geography texts. The videodisc also includes almost an hour of live-action footage. Derived from the Encyclopedia Britannica archives, these moving images feature video clips of landscapes and geological phenomena, along with animated segments that bring geological processes to life.

LectureActive Software accompanies the videodisc. This software allows the instructor to customize lectures by giving quick access to the video clip and still frame data on the videodisc.

A barcode manual is also part of the ancillary package. The manual contains descriptions, barcodes, and text references for each still image and video clip. This allows the professor to access the images on the videodisc by either using a light pen to scan the barcodes or using the remote control to enter the frame number.

Many aspects of geology are based on observations of exposed strata in the field. Although not as effective as an actual field excursion, an extensive set of 35-mm slides is one way to bring field observations into the classroom. The **Saunders 35-mm Slide Package** includes five hundred 35-mm slides, and is accompanied by **125 overhead transparencies.**

■ *Acknowledgments*

This edition of *The Earth Through Time* owes much to the guidance and wisdom of its reviewers. Their scrutiny of the manuscript and incisive comments have improved the text, and facilitated the endless endeavor to keep it up-to-date. I extend my thanks to all of these earth scientists, including:

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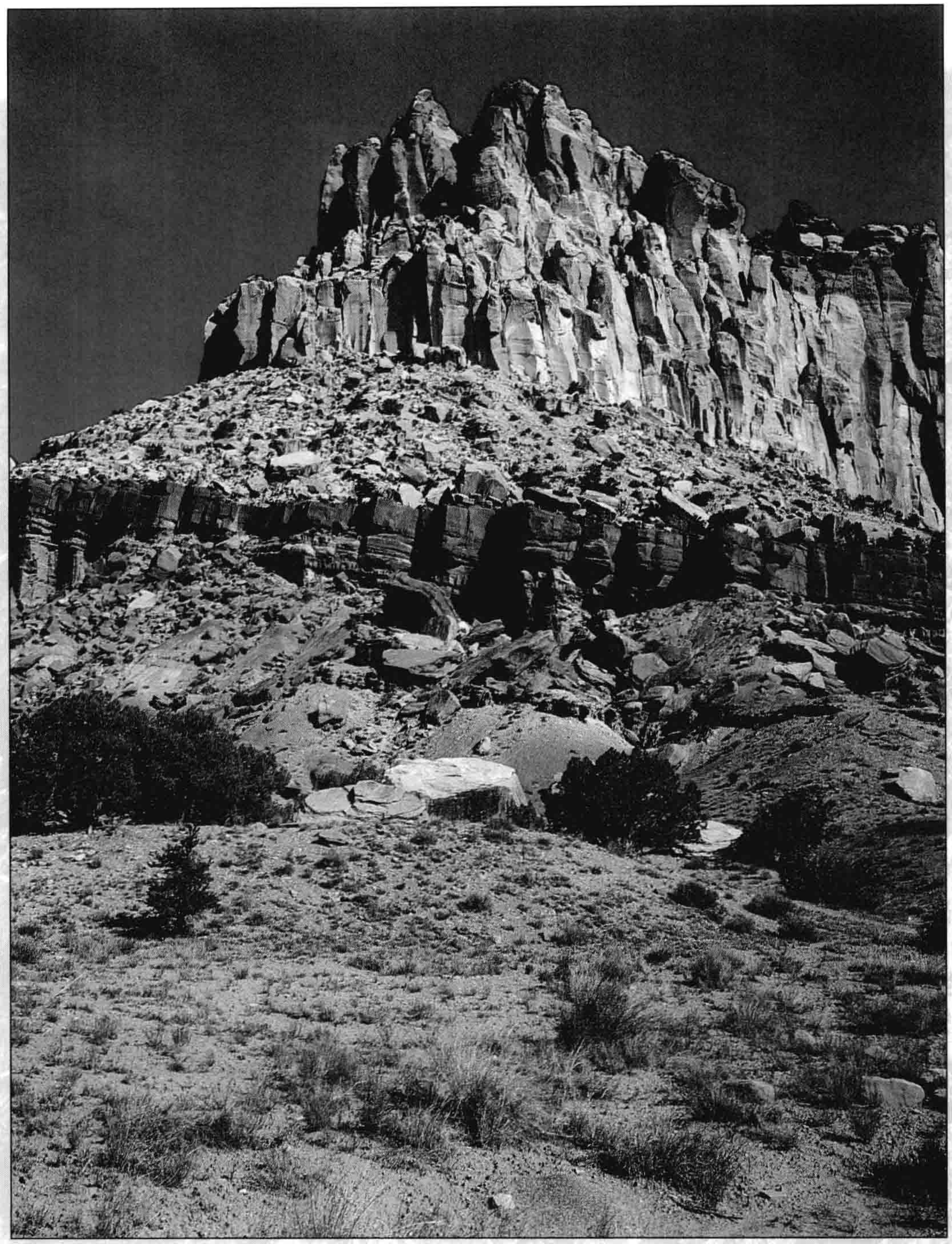
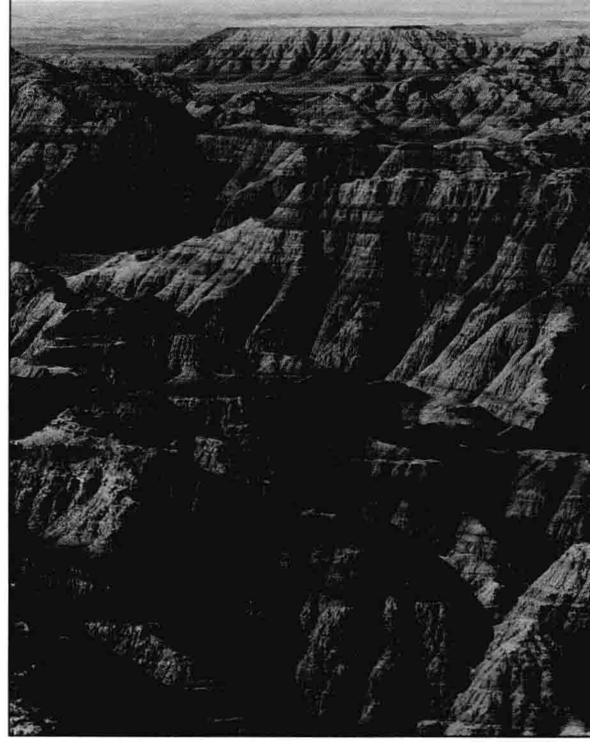
Harold L. Levin
St. Louis
July 1995

The Earth Through Time



The Castle, an erosional feature formed by erosion in the Wingate Sandstone, Capitol Reef National Park, Utah. *(Photograph by James Cowlin).*



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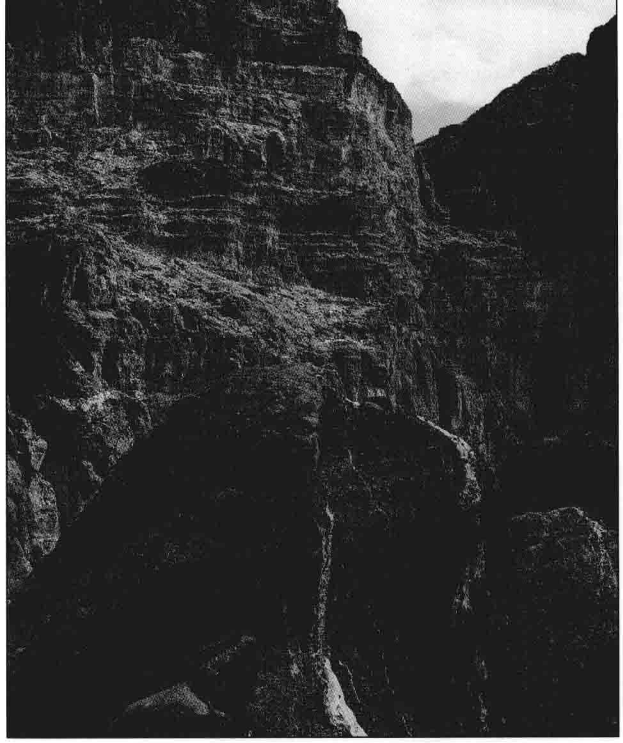

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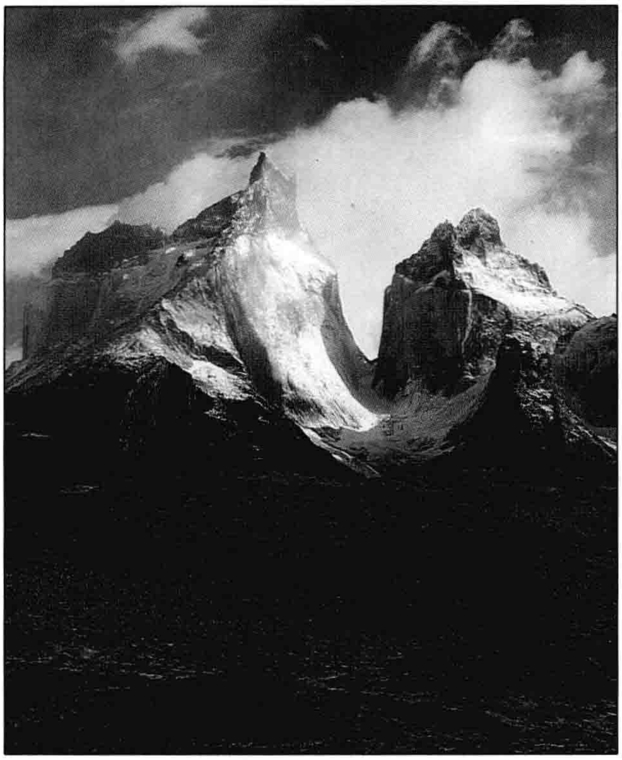

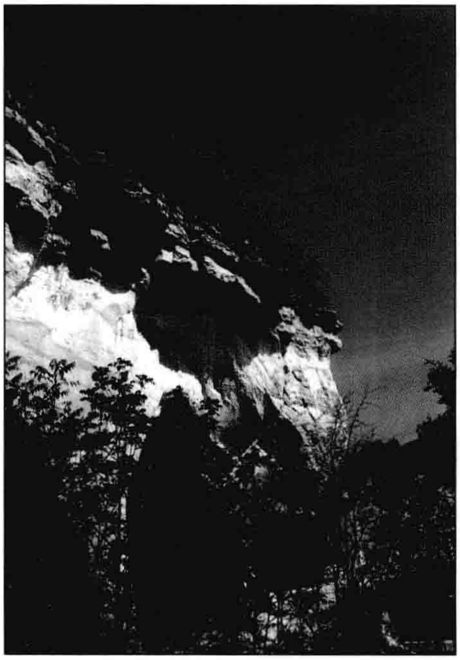

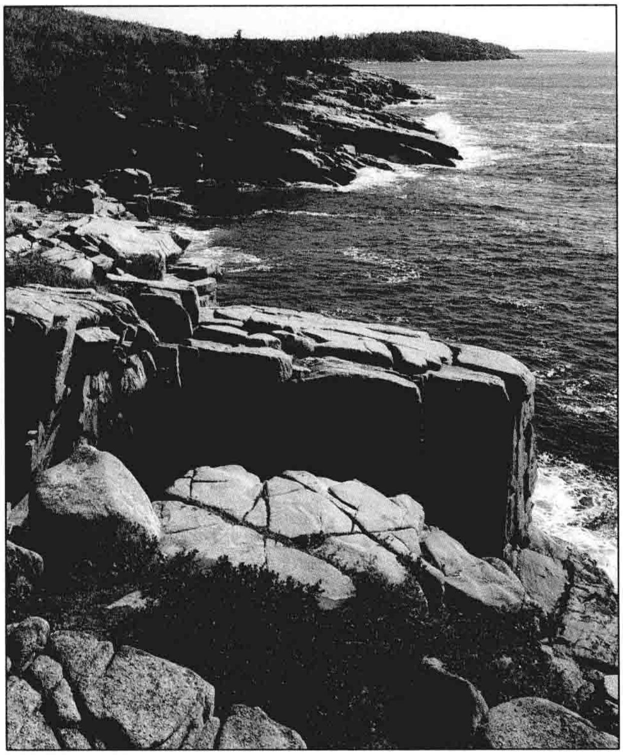

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ago. The seamounts continue the age sequence toward the end of the chain, where the peaks are about 80 million years old. Thus, 40 million years ago the Pacific plate changed course and put a kink in the Hawaiian chain.

Hot spots may not sit still. In the past, they have been assumed to remain fixed in one location as plates slide over them. Recent investigations, however, suggest that hot spots may drift somewhat under the influence of moving currents of mantle material. The analogy would be smoke drifting from a smokestack under the influence of a breeze. Research by geologists Bernard Steinberger and Rick O'Connell indicates that the Hawaiian hot spot is drifting in a direction opposite to that of the Pacific plate, but at only one-tenth of its speed.

The ocean around Hawaii is not the only part of the globe that has hot spots. As indicated in Figure 5–62, hot spots are widely dispersed and occur beneath both continental and oceanic crust. Yellowstone National Park (Fig. 5–63) is over a hot spot that, like the Hawaiian Islands, is in the interior of a continent.

Lost Continents and Alien Terranes

We are accustomed to thinking of continental crust in terms of large land masses such as North America or Eurasia. There are, however, many relatively small patches of continental crust scattered about on the lithosphere. As long ago as 1915, Alfred Wegener described the Seychelles Bank (Fig. 5–64) in the Indian Ocean as a small continental fragment that had broken away from Africa. The higher parts of the Seychelles Bank project above sea level as islands, but many other such small patches of continental crust are totally submerged. Geologists use the term **microcontinents** for these bits of continental crust that are surrounded by oceanic crust. They are recognized by their granitic composition, by the velocity with which compressional seismic waves traverse them (6.0 to 6.4 km/second), by their general elevation above the oceanic crust, and by their comparatively quiet seismic nature.

It is apparent that microcontinents are small pieces of larger continents that have experienced fragmentation. As these smaller pieces of continental

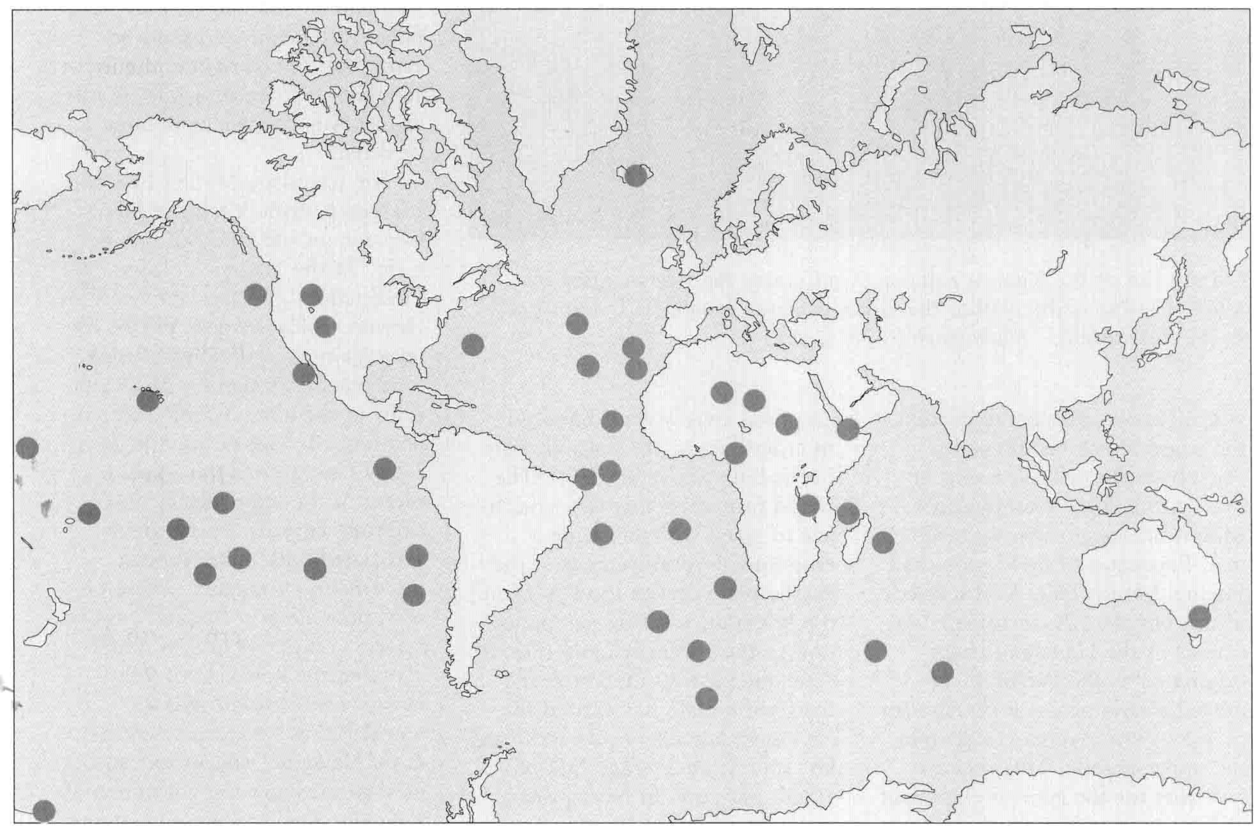

FIGURE 5–62 Locations of some of the major hot spots around the Earth. *(Courtesy of Tom Crough, Department of Geologic and Geophysical Sciences, Princeton University.)*

FIGURE 5–63 Mammoth Geyser, Yellowstone Park, Wyoming. Yellowstone is over a hot spot. Surface waters percolating through a system of deep fractures reach the hot rocks below and erupt in columns of hot water and steam.

crust are moved along by sea-floor spreading, they may ultimately converge on the subduction zone at the margin of a large continent. Because they are composed of relatively low-density rock and hence are buoyant, they are a difficult bite for the subduction zone to swallow. Their buoyancy prevents their being carried down into the mantle and assimilated. Indeed, the small patch of crust may become incorporated into the crumpled margin of the larger continent as an exotic block, or so-called **suspect terrane.**

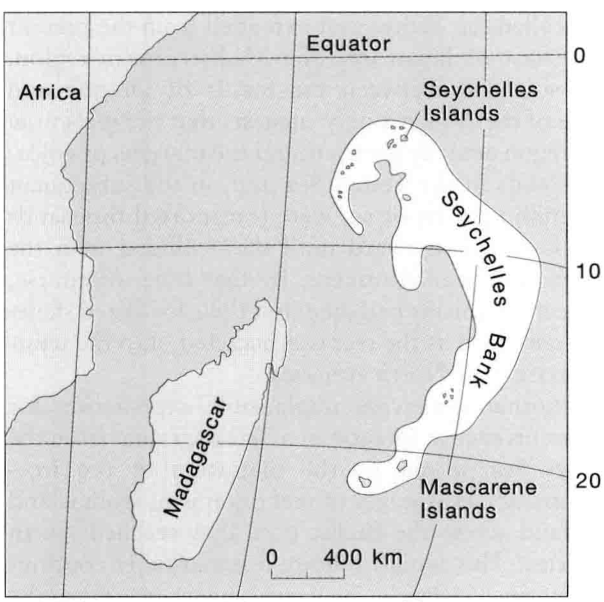

FIGURE 5–64 Location map of the Seychelles Bank.

It is interesting that geologists found evidence of microcontinents long before the present theory for their origin was formulated. While mapping Precambrian rocks, they came across areas that were incongruous in structure, age, fossil content, lithology, and paleomagnetic orientation when compared to the surrounding geology. It was as if these areas were small, self-contained, isolated geologic provinces. Often their boundaries were marked by major faults. Geologists designated these areas as **alien** or **allochthonous terranes** to indicate that they had not originated in the places where they now rested. Allochthonous terranes have been recognized on every major land mass, with well-studied examples in the northeastern former Soviet Union, in the Appalachians, and in many parts of western North America (Fig. 5–65). In particular, Alaska appears to be largely constructed of allochthonous terranes.

If splinters of continents can be transported on the spreading sea floor, so can pieces of oceanic crust. Particularly in the Cordilleran mountain belt of North America, one finds allochthonous terranes that were apparently microplates of ocean crust containing volcanoes, seamounts, segments of island arcs, and other features of the ocean floor. All of