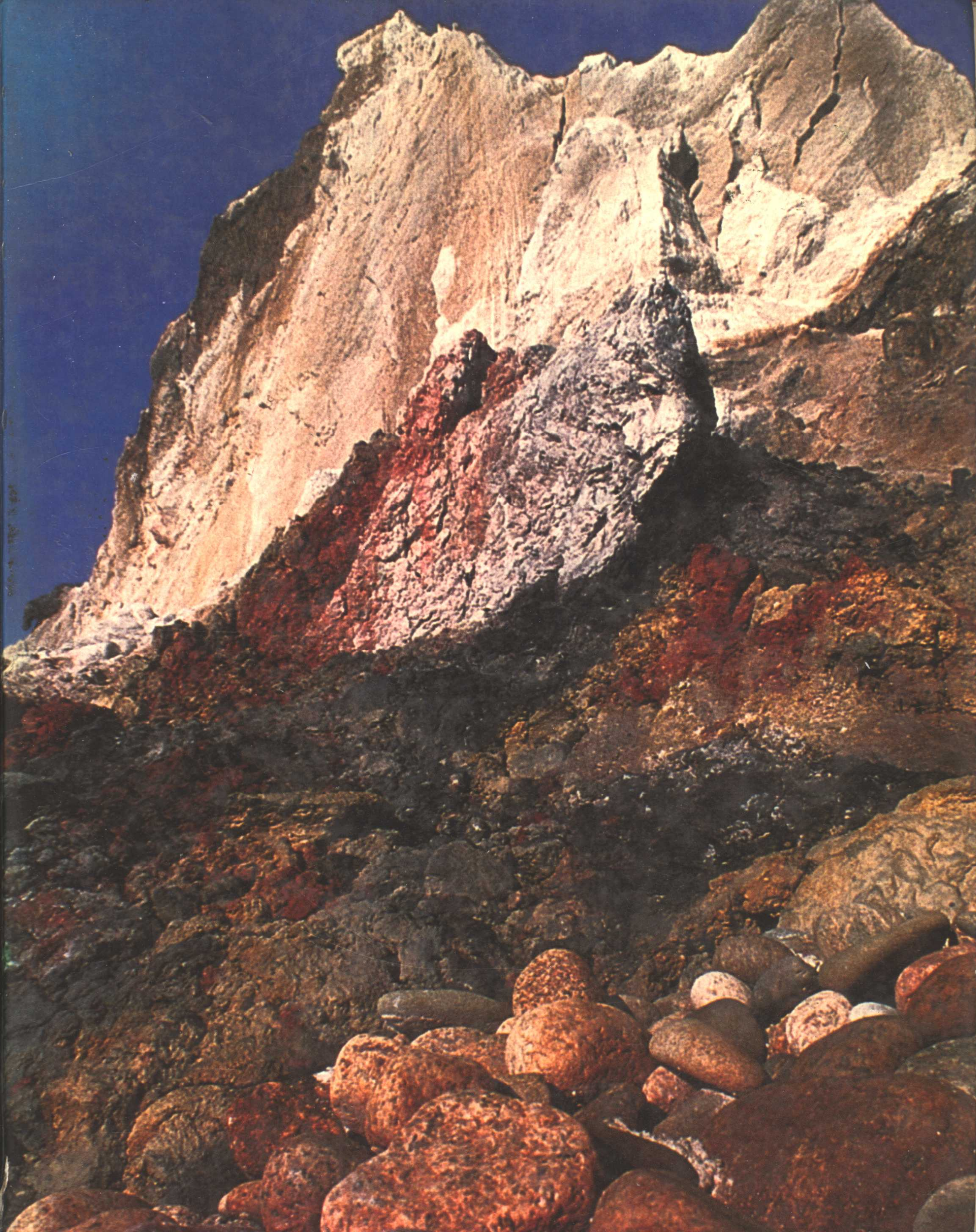

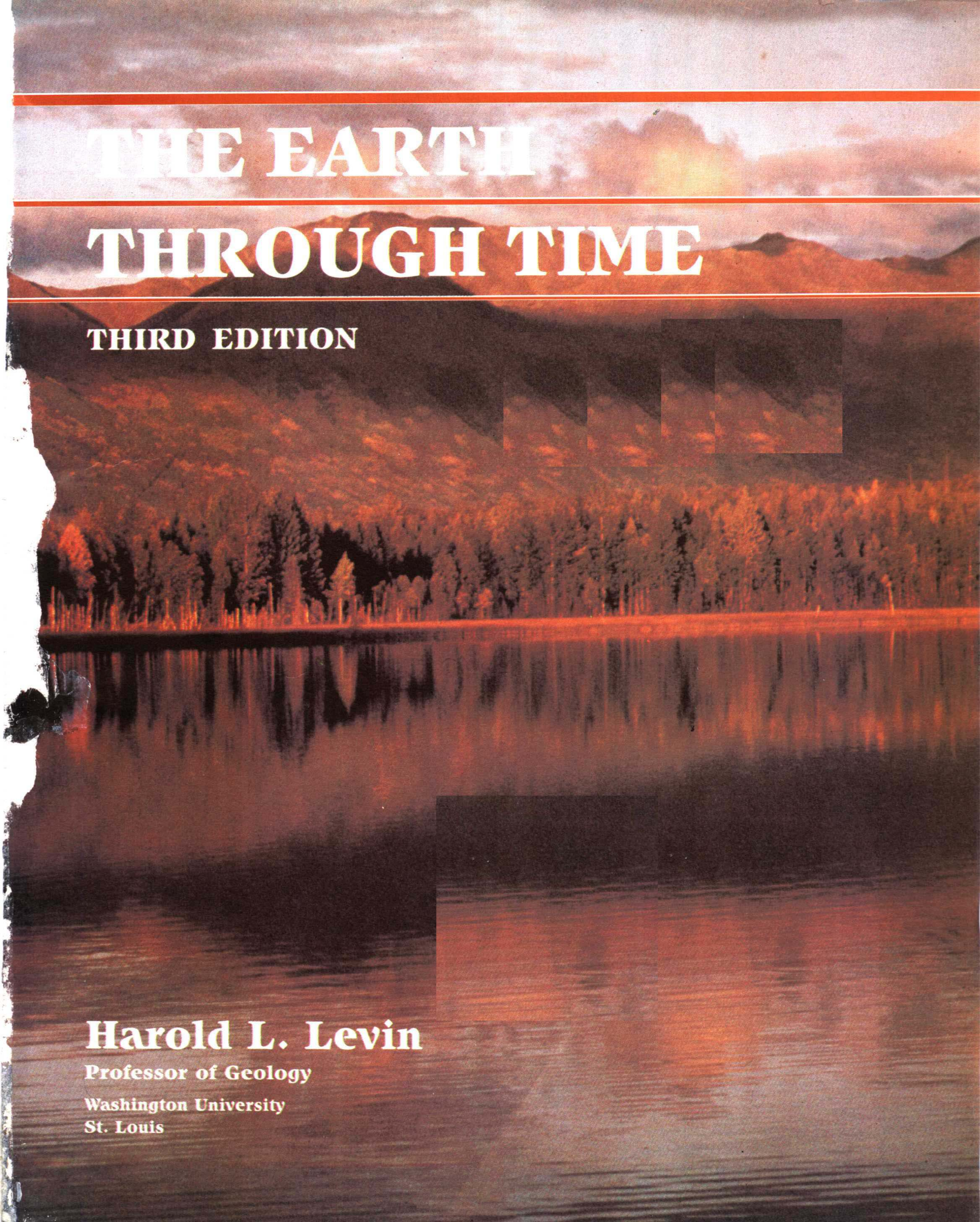

THE EARTH THROUGH TIME

THIRD EDITION

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St. Louis

To Kay Levin and our students Linda, Stephen, and Janet, this book is inscribed.

Text Typeface: New Baskerville
Compositor: York Graphic Services, Inc.
Acquisitions Editor: John Vondeling
Project Editor: Margaret Mary Kerrigan
Copy Editor: Joanne Fraser
Art Director: Carol Bleistine
Art Assistant: Doris Roessner
Text Designer: William Boehm
Cover Design: Lawrence R. Didona
Text Artwork: J & R Technical Services, Inc.
Production Manager: Jo Ann Melody

Cover credit: Gay Head Massachusetts by Nicholas Foster/
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Title Page credit: Lake George in Anchorage, Alaska by
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Printed in the United States of America

THE EARTH THROUGH TIME, 3rd edition

ISBN 0-03-008912-3

Library of Congress Catalog Card Number: 87-16512

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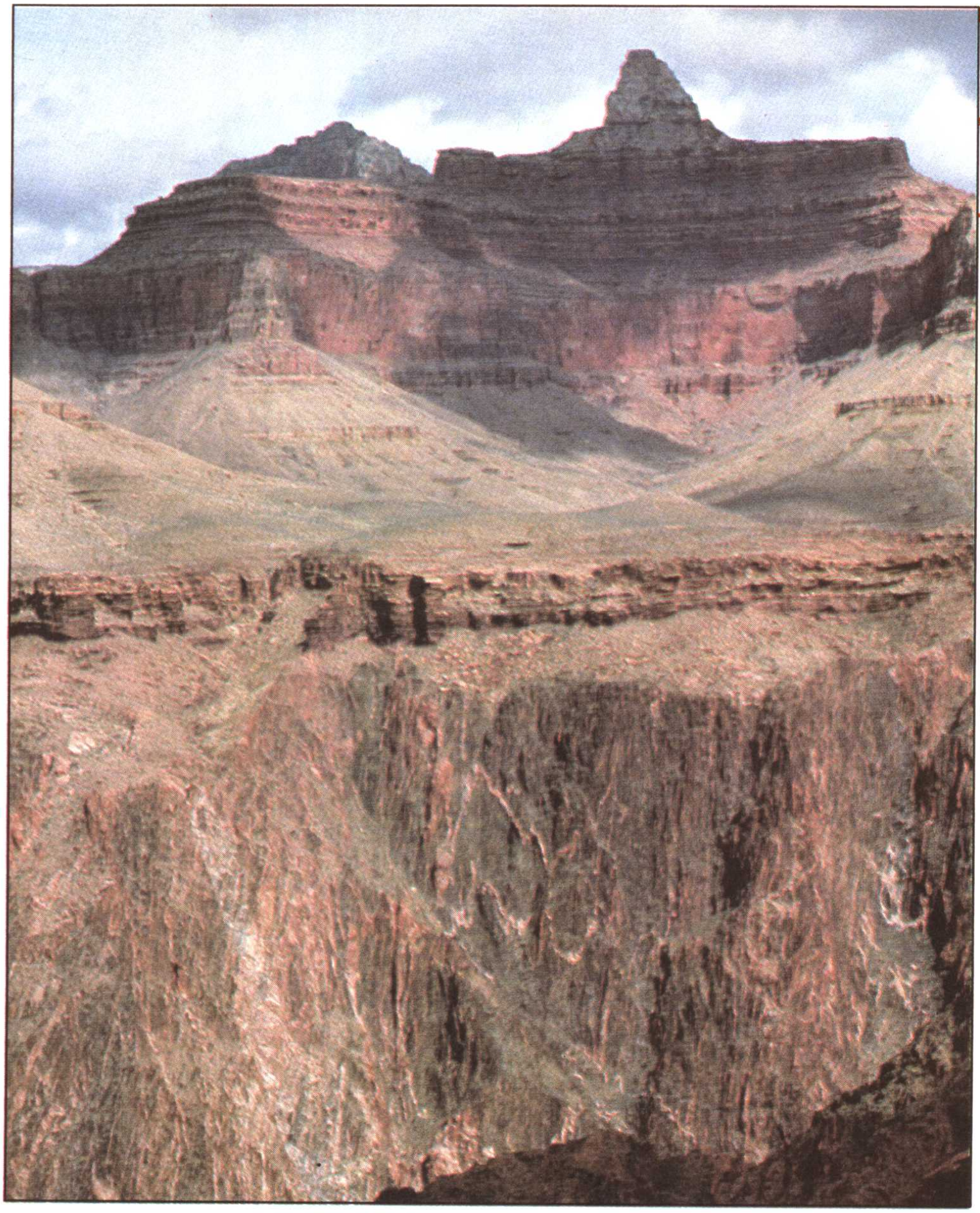
The gigantic armored skull and thoracic shield of the formidable Late Devonian placoderm fish known as *Dunkleosteus. Dunkleosteus* was over 10 meters (about 30 feet) long. The skull shown here is about a meter tall. It is equipped with large bony cutting plates that functioned as teeth. Each eye socket was protected by a ring of four plates, and a special joint at the rear of the skull permitted the head to be raised and thereby provided for an extra large bite. *Dunkleosteus* ruled the seas 350 million years ago. (Courtesy U.S. National Museum of Natural History, photograph by Chip Clark.)



Inner Gorge, Grand Canyon of the Colorado River. Precambrian metamorphic rocks intruded by veins of pink granite are unconformably overlain by flat-lying Lower Paleozoic rocks.

Preface

This book about the history of the earth is written for all who have an interest in the planet on which they live. Over the past three decades, our understanding of the earth has expanded at a phenomenal rate. The old views of static global geography have been revolutionized by the recognition that continents and ocean floors are in endless migration, that these movements have controlled geologic events and climates of long ago, and that the ceaseless shift of land and water has placed constraints even on the development of life on earth. With some amazement, we have learned that pieces of Africa may lie anchored in Georgia, and that our western mountains may contain slivers of Russia and China. It is indeed an exciting time to study the history of our dynamic planet.

The Earth Through Time is an introductory textbook for a course in historical geology. The text 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 in a highly interesting area of science. In some colleges, students will already have taken a previous course in physical geology and may therefore use the text's discussion of earth materials as a review. For the student with no previous acquaintance with geology, the chapters on minerals and rocks provide the background needed to proceed with the study of the earth's history.

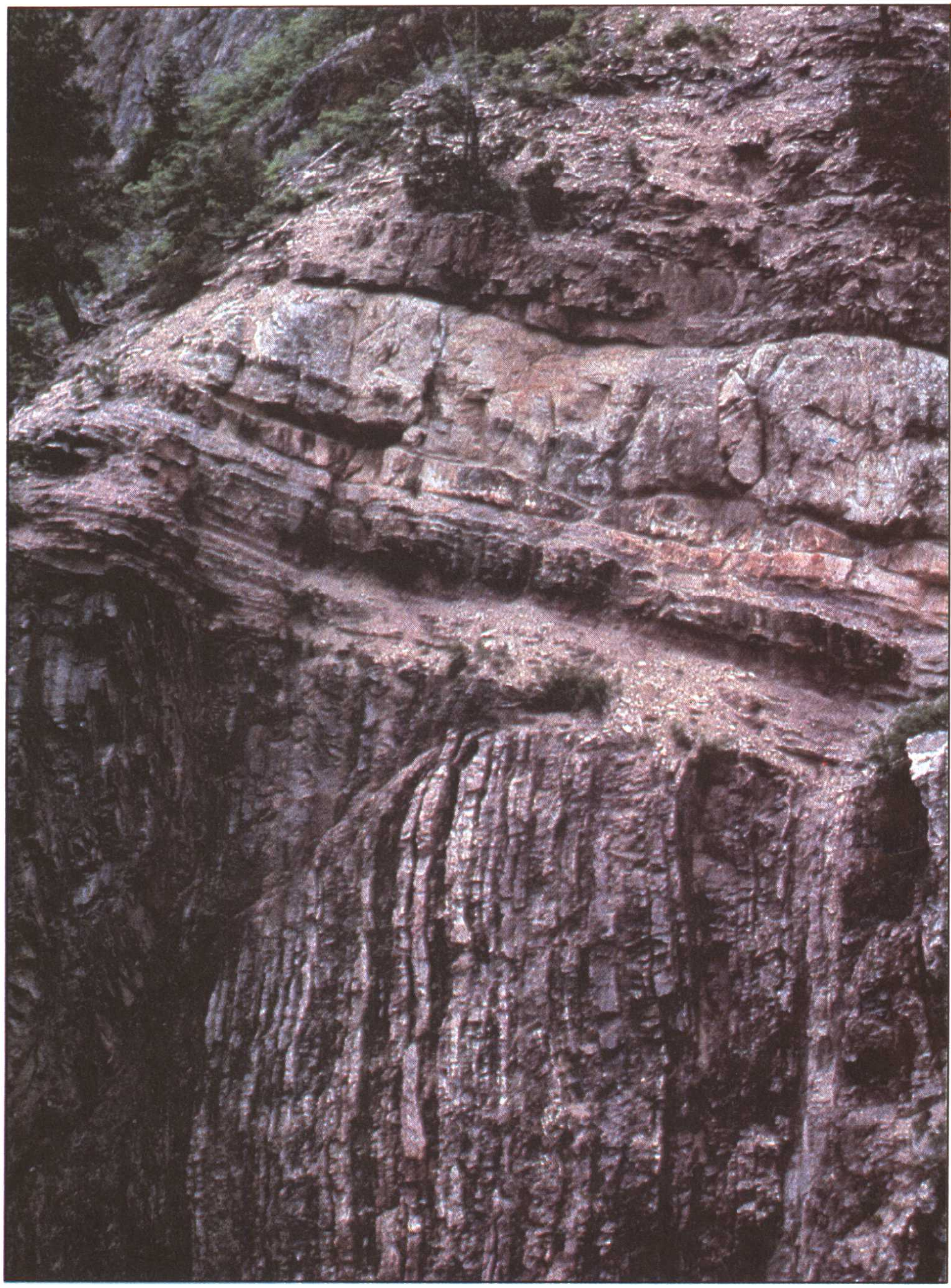
Any history, whether geologic or cultural, necessarily includes information about the nature and the time of occurrence of important events. Cultural history is largely dependent upon written documents; geologic history must be inferred from the careful study of fossils and rocks. It is important that the student of earth history understand the scientific reasoning by which events and conditions of the past are interpreted. Therefore, cause-and-effect relationships and evidence for interpretations of past events on earth will be frequent topics in these chapters.

Preparation of the third edition of a textbook provides many benefits. There is an opportunity to refashion explanations, find better illustrations, constructively augment discussions, and most important, provide information about new discoveries. In this edition, the section on organic evolution has been expanded to include discussions of speciation, evolution in populations, and the lively debate about punctuated equilibria and phyletic gradualism. A series of easily understandable paleogeographic maps of North America have been added, and information about the founders of geology has been augmented. This edition contains new information on sea level changes, the significance of greenstone belts, the evolution of the atmosphere, alien terranes and accretionary tectonics, and the history of Precambrian Shields. New information about the tectonic history of the Catskill Delta is included, and a review of recent theories about both terrestrial and extraterrestrial causes for extinctions has been added to the chapter on Mesozoic life. For visual enhancement of the concepts discussed, the third edition contains 32 plates of color photographs and full-color treatment of hundreds of illustrations. In addition, the text contains many internal learning aids, including chapter summaries, review questions, suggested readings, an illustrated glossary, and stratigraphic correlation charts. Important terms are listed at the end of each chapter and emphasized in boldface type within the body of the text.

Many of the above modifications result from the comments provided by reviewers of the third edition manuscript, as well as colleagues who have used the second edition in their historical geology courses. I extend my thanks to all of these

earth scientists, including David R. Berry (California State Polytechnic Univ.), Donald W. Groff (Western Connecticut State Univ.), John A. Howe (Bowling Green State Univ.), William M. Jordan (Millersville Univ. of Pennsylvania), William H. Matthews III (Lamar University), Thomas W. Small (Frostburg Univ.), Leonard W. Soroka (St. Cloud State Univ.), and Kenneth Van Dellen (Macomb Community College).

The support and prudent advice I received from the staff and editors of Saunders College Publishing were indispensible. In particular, the book has benefited from the enthusiastic guidance of John J. Vondeling and his able assistant Kate Pachuta. The project editor for this third edition was Margaret Mary Kerrigan, who accomplished a mind-boggling multitude of tasks with precision and extraordinary efficiency.



An angular unconformity separates vertical beds of the Precambrian (Proterozoic) Uncompahgre Sandstone from overlying, nearly horizontal Devonian strata of the Elbert Formation at Box Canyon Falls, Ouray, Colorado. (Photograph by Thomas E. Williams, with permission.)

Contents Overview

Contents

A Science Named Historical Geology

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). It was born nearly 5 billion years ago and since that time has circled continuously around the sun like a small spaceship in heavy traffic. 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 500,000 years ago, primates called humans appeared on earth. Unlike earlier animals, these creatures of oversized brains and clever fingers asked questions about themselves and their surroundings. Their questioning has continued to this very hour. How was the earth formed? Why does the earth sometimes tremble? What lies beneath the seas and beyond the stars? Timidly, ancient people probed the limits of their world, fearing that they might tumble from its edge. Their descendants came to know the planet as an imperfect sphere and began an examination of every obscure corner 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. The new frontiers for exploration lie beneath the oceans and outward into space.

The earth. This computer-simulated image depicts our planet as it would appear if photographed from space by a camera capable of "seeing" through the ocean and atmosphere. The topography of the continents and ocean basins is based on actual elevation and depth measurements and shown by color and shaded relief. The view is centered on Lat. 45° N., Long. 270° E. (Courtesy of M. Edwards and R. A. Arvidson, Dept. Earth and Planetary Sciences, Washington University.)

The advance of science along the oceanic frontiers began less than four decades ago. Crisscrossing the seas, ships equipped with precision depth recorders that employed the principle of echo sounding (Fig. 1–2) plotted continuous topographic profiles of the sea floors. Related methods utilizing stronger energy sources provided an image of the layers of rock and sediment beneath the ocean bottom. A panoramic view of undersea geology emerged that was more magnificent and complex than anyone had imagined (Fig. 1–3). 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.

In order to further study the effects of these phenomena on earth history, a unique deep-sea drilling ship, the *Glomar Challenger* was constructed. With the help of the National Science Foundation, it was quickly put into operation. With this splendid 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

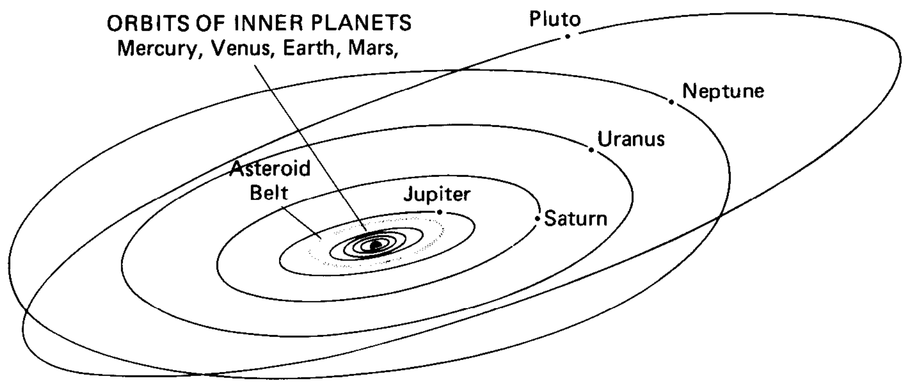


Figure 1–1 Orbits of the nine planets in the solar system.

beneath the sea as well as long strips of graph paper imprinted with jagged lines (Fig. 1–4) nourished exciting new hypotheses of drifting crustal segments, splitting continents, and changing world geography.

Between 1968 and 1983, the *Glomar Challenger* logged more than 600,000 km during 96 voyages across every ocean. The success of the *Glomar Challenger* led to the outfitting of a new drill ship, the *JOIDES Resolution* (Fig. 1–5), which began operation in 1985. This new vessel has twice the laboratory space of its predecessor, can accommodate 50 scientists, and provides them with state-of-the-art instrumentation and research facilities.

Exploration of the cosmic "ocean" has also contributed to our new view of the earth. Intricately engineered spacecraft circled the earth and set down on the moon. Two members of our inquisitive species reached down and held lunar pebbles in their gloved hands. Analysis of those pebbles yielded an astonishing number of clues to the early history of both the moon and the earth. Within the past decade, space vehicles have briefly experienced the hellish atmosphere of Venus, sampled the soil of Mars, and fixed electronic eyes on Mercury and Jupiter. Small satellites continue to circle the earth, transmitting repeating images of the planet. An unprecedented, synoptic view of a dynamic, delicately adjusted planet has emerged from these transmissions. On a day-to-day basis, data supplied by satellites have been used to find mineral deposits, to assess worldwide agricultural productivity, and to provide unexcelled meteorologic information. Perhaps more important, however, these data have helped to make all the residents on the third planet more aware of the beauty and fragility of their home.

An Eclectic Science

Geologists concern themselves with an exceptional variety of scientific tasks and must employ knowledge from diverse fields. Some examine the composition and texture of meteorites and moon rocks. With magnifiers and computers, others scrutinize photographs of planets to understand the features that characterize their surfaces. Still other geologists are busily unraveling the structure of mountain ranges or attempting to better understand the behavior of glaciers, underground water, volcanoes, and streams. Large numbers of geologists search for the fossil fuels and ores we require. They worry, as do you and I, about the fate of humans in a world of diminishing resources. To help in their work, geologists draw upon the knowledge of astronomy, physics, chemistry, mathematics, and biology. For example, petroleum geologists must understand the physics of moving fluids, the chemistry of hydrocarbons, and the biology of the invertebrate fossils they use to reconstruct the subsurface geology. Because geology incorporates the information of so many other scientific disciplines, it can be termed an **eclectic science.** "Eclectic" is a word useful in describing a body of

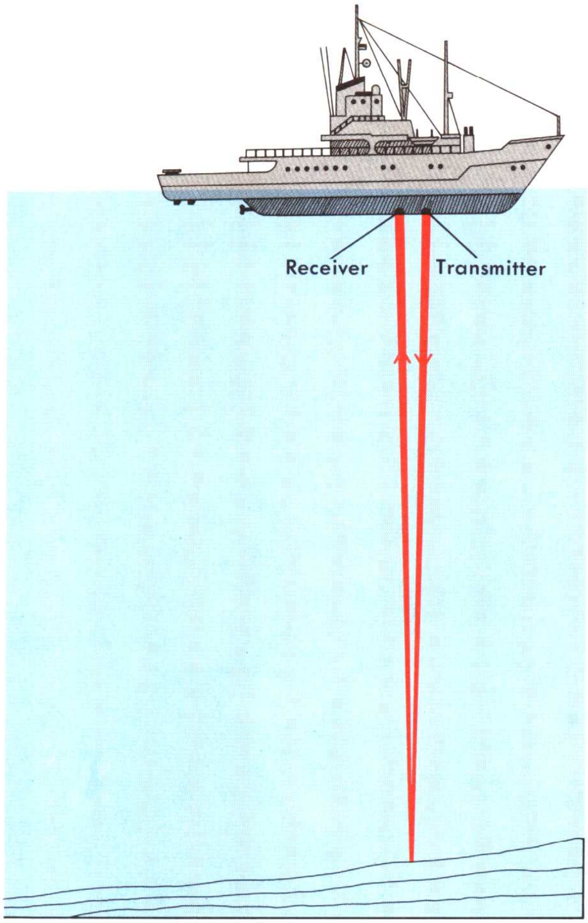


Figure 1–2 The principle of echo sounding. A transmitter sends a sound wave, which is reflected back to the surface by the ocean bottom and is picked up by a receiver. By knowing the total time involved and the speed of sound in the ocean (1500 meters per second), water depth can be determined. (From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

selected information drawn from a variety of sources. All sciences are eclectic to some degree, and geology is decidedly so.

For convenience of study, the body of knowledge called "geology" can be divided into **physical geology** and **historical geology.** The origin, classification, and composition of earth materials, as well as the varied processes that occur on the surface and in the deep interior of the earth, are the usual subjects of physical geology. Historical geology addresses itself to the earth's evolution, changes in the distribution of lands and seas, growth and destruction of mountains, succession of animals and plants through time, and chronologic changes in other planets in our solar system. Clearly, the division between physical and historical geology is somewhat arbitrary, and it is necessary to understand the physical aspects of our planet if we are to fully know its history.

The Task of the Historical Geologist

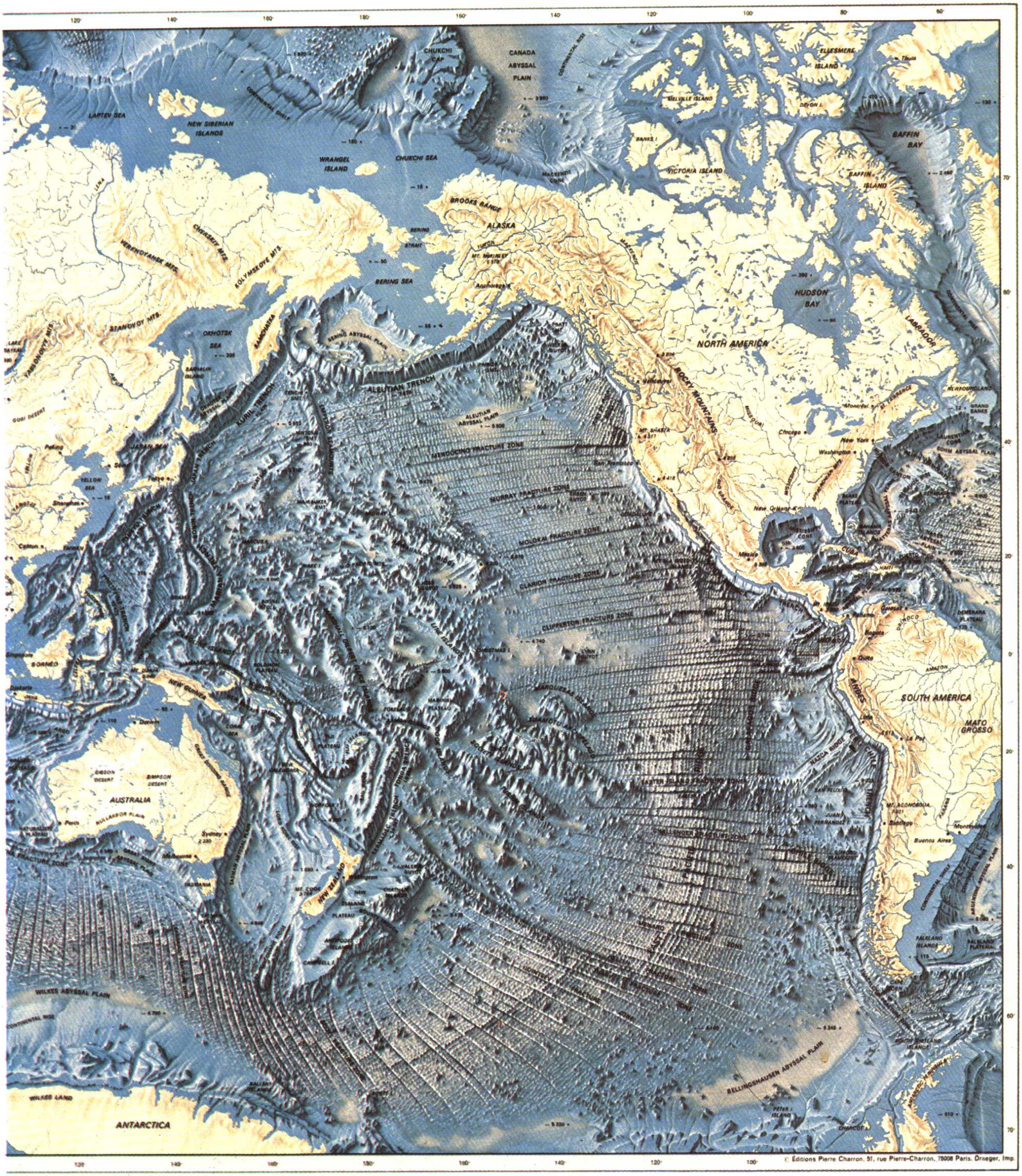
Simply stated, the task of historical geologists is to examine planetary materials and structures and to discover how they came into existence. Geologists have in the world about them the tangible *result* of past events, and they must work backward in time to discover the causes of those events. In their work, they use the usual procedures of science—namely, the collection of observations, the formulation of hypotheses to explain those observations, and the validation of the hypotheses by means of further observations. Thus, observed facts serve both as the basis for building hypotheses and as the ultimate check on their accuracy.

One way to better understand how geologists think and work is to describe a couple of interesting geologic research projects. One such project confirmed astronomic calculations indicating the number of days in the year have been decreasing throughout geologic time. Another resulted in a description of the Mediterranean region as it looked 6 million years ago.

Growth Lines and Time

In the early 1960s, Professor John Wells of Cornell University was musing over the fact that although paleontology (the study of fossils and ancient life forms; from the Greek *palaios,* meaning "ancient") provided a way to determine *relative* geologic age, fossils could not be used in determining absolute geologic time. His thoughts led him to consider the astronomic basis for time and to search for some detectable effect of movement in the sun-earth-moon system on the fossil re-

Figure 1–3 The physical features of the ocean floors and continents. (Copyright © Marie Tharp.)


CHUKCHI CAP
CANADA ABYSSAL PLAIN
ELLESMERE ISLAND
MELVILLE ISLAND
BAFFIN BAY
BAFFIN ISLAND
VICTORIA ISLAND
LAPTEV SEA
NEW SIBERIAN ISLANDS
WRANGEL ISLAND
CHUKCHI SEA
BROOKS RANGE
ALASKA
BERING STRAIT
BERING SEA
HUDSON BAY
NORTH AMERICA
LABRADOR
ROCKY MOUNTAINS
STANOVOY MTS.
OKHOTSK SEA
ALEUTIAN TRENCH
ALEUTIAN ABYSSAL PLAIN
MENDOCINO FRACTURE ZONE
MURRAY FRACTURE ZONE
MOLOKAI FRACTURE ZONE
CLARION FRACTURE ZONE
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