

FOURTH EDITION

ESSENTIALS *of* GEOLOGY



FREDERICK LUTGENS
EDWARD TARBUCK

FOURTH EDITION

*Essentials of
Geology*

FREDERICK K. LUTGENS

EDWARD J. TARBUCK

Illinois Central College

*Macmillan Publishing Company
New York*

*Maxwell Macmillan Canada
Toronto*

*Maxwell Macmillan International
New York Oxford Singapore Sydney*

Cover photo by Pat O'Hara/ALLSTOCK. Mt. Assiniboine Provincial Park, British Columbia, Canada.

Editor: Robert A. McConnin

Production Editor: Rex Davidson

Art Coordinator: Raydelle M. Clement

Photo Editor: Chris Migdol

Text Designer: Anne Flanagan

Cover Designer: Robert Vega

Production Buyer: Bruce Johnson

Illustrations: Dennis Tasa

Library of Congress Cataloging-in-Publication Data

Lutgens, Frederick K.

Essentials of geology/Frederick K. Lutgens, Edward J. Tarbuck.—4th ed.

p. cm.

Includes index.

ISBN 0-02-372830-2

1. Geology. I. Tarbuck, Edward J. II. Title.

QE26.2.L87 1992

550—dc20

91-3064

CIP

This book was set in Garamond by York Graphic Services, Inc., and was printed and bound by R. R. Donnelley & Sons Company. The cover was printed by Philips Offset.

Copyright © 1992 by Macmillan Publishing Company, a division of Macmillan, Inc.

Printed in the United States of America

All rights reserved. No part of this book may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopy, recording, or any information storage and retrieval system, without permission in writing from the Publisher.

Earlier editions copyright © 1989, 1986, and 1982 by Merrill Publishing Company.

Macmillan Publishing Company
866 Third Avenue
New York, New York 10022

Macmillan Publishing Company is part of the
Maxwell Communication Group of Companies.

Maxwell Macmillan Canada, Inc.
1200 Eglinton Avenue East, Suite 200
Don Mills, Ontario M3C 3N1

Printing: 1 2 3 4 5 6 7 8 9 Year 2 3 4 5

PREFACE

*I*n recent years, media reports have made us increasingly aware of the geological forces at work in our physical environment. News stories graphically portray the violent force of a volcanic eruption, the devastation generated by a strong earthquake, and the large numbers left homeless by mudflows and flooding. Such events, and many others as well, are destructive to life and property, and we must be better able to understand and deal with them. However, our natural environment has an even greater importance, for the earth is our home. The earth provides the mineral resources so basic to modern society, as well as most of the ingredients necessary to support life. Therefore, as many members of society as possible should acquire an understanding of how the earth works.

With this in mind, we have written a text to help people increase their understanding of the physical environment. We hope this new knowledge will encourage some to actively participate in the preservation of the environment, while others may be sufficiently stimulated to pursue a career in the earth sciences. Equally important, however, is our belief that a basic understanding of earth will greatly enhance appreciation of our planet and thereby enrich the reader's life.

The fourth edition of *Essentials of Geology*, like its predecessors, is a nonquantitative text intended for students taking their first course in geology. We have attempted to write a text that is not only informative and timely, but one that is highly usable as well. The language is straightforward and written to be understood by a student with little or no college-level science experience. Although we have deliberately refrained from using excessive jargon, a number of

terms in each chapter will probably be unfamiliar to the reader. Therefore, when new terms are introduced, they are placed in boldface type and defined. To aid study and review, an alphabetical list of key terms with page references concludes each chapter, a new feature in this edition. As in prior editions, a glossary is also included at the end of the text for easy reference to important terms. Review questions are also found at the end of each chapter to help the reader prepare for exams and quizzes. Useful information on metric conversions, common minerals, and topographic maps can be found in the appendices.

In the earlier editions of this text special attention was given to the quality of photographs and artwork because geology is a highly visual science. This emphasis has been maintained in the fourth edition. More than 50 new color photographs appear in this revision. The photographs were carefully selected to add realism to the topics covered and to heighten the interest of the reader. Moreover, the already excellent art program of the previous editions has been strengthened. We believe that carefully planned and executed line art will significantly aid student understanding by making difficult concepts less abstract. To that purpose, more than 80 new and redrawn figures appear in the fourth edition. Once again, the text has benefited greatly from the talents and imaginative production of Dennis Tasa of Tasa Graphic Arts, Inc.

The fourth edition of *Essentials of Geology* represents a thorough revision. Extensive rewriting has made many discussions more timely and more readable. We emphasize, however, that the main focus of the fourth edition remains the same as in the first three editions—to foster an understanding of basic geological principles. As much as possible, we have attempted to provide the reader with a sense of the observational techniques and reasoning processes that constitute the discipline of geology. As with other sciences, geology is much more than a mere collection of facts. At its heart are the various methods and skills used to uncover the secrets of the earth. Some of these methods are discussed in the section on the nature of scientific inquiry in Chapter 1. Moreover, an excellent example of the way geological “truths” are uncovered and reworked is found in Chapter 16. Here we trace the historical formation and subsequent rejection of the hypothesis that continents drift about the face of the earth.

Then we examine the data that led to the “rebirth” of this idea as part of a more encompassing theory known as plate tectonics.

The organization of the text remains intentionally traditional. Following the overview of geology in Chapter 1, we turn to a discussion of earth materials and the related process of volcanism and weathering. Next, we explore the geological work of gravity, water, wind, and ice in modifying and sculpturing landscapes. After this look at external processes, we examine the earth’s internal structure and the processes that deform rocks and give rise to mountains. Finally, the text concludes with chapters on geologic time and earth history. This particular organization accommodates the study of minerals and rocks in the laboratory, which usually comes early in the course. Realizing that some instructors may prefer to structure their courses somewhat differently, we made each of the chapters self-contained so that they may be taught in a different sequence. Thus, the instructor who wishes to discuss earthquakes, plate tectonics, and mountain building prior to dealing with erosional processes may do so without difficulty. We also chose to provide a brief overview of plate tectonics in Chapter 1 so that this important theory could be incorporated in appropriate places throughout the text.

A comparison between this volume and earlier editions will reveal that the number of chapters in the fourth edition has been increased. This resulted from expanding the introduction into an introductory chapter and splitting two other chapters. Weathering and soils are now separate from sedimentary rocks and mass wasting appears as a chapter preceding the one on running water. Another change has been the reorganization of Chapter 18 on geologic time so that relative dating principles are treated prior to the discussion of radiometric dating. Discussions of many basic topics have also been strengthened in the fourth edition. The text contains expanded and updated coverage of sedimentary rocks, landslides, and glaciers, as well as broader coverage of deserts, shoreline processes, and continental margins.

As in earlier editions, topics related to resources and environmental issues remain an important focus and continue to be integrated at appropriate places throughout the text. Treatment of these areas has been strengthened by revising and updating existing discussions as well as adding new ones. Among the

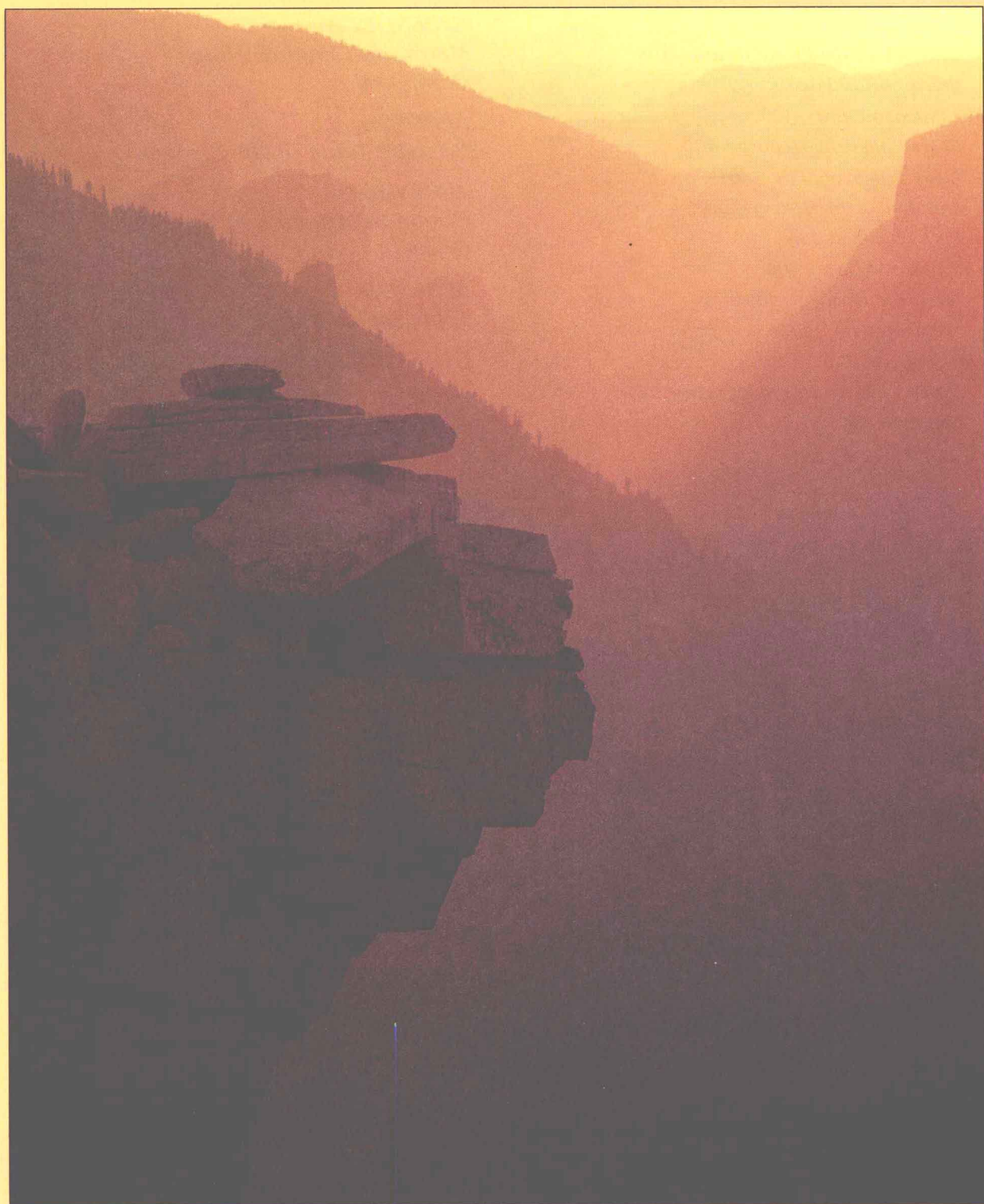
revised discussions are those on groundwater issues (Chapter 10) and earthquake prediction (Chapter 15). New sections include an overview of population, resources, and environmental issues (Chapter 1), soil erosion (Chapter 5), tar sands (Chapter 6), non-metallic mineral resources (Chapter 6), wind energy (Chapter 12), and earthquake destruction (Chapter 15).

As with any project of this scope, the contributions of others were very important. We wish to express our thanks to the many individuals, institutions, and government agencies that provided information, photographs, and illustrations for use in this text. A special debt of gratitude goes to those colleagues who prepared in-depth prerevision reviews of the third edition of *Essentials of Geology*. Their critical comments and thoughtful input helped guide our revision and strengthen the fourth edition. We wish to thank David S. Ziegler, Hocking College; John B. Droste, Indiana University; Douglas L. Smith, University of Florida; William R. Shirk, Shippensburg Uni-

versity; Bryan Gregor, Wright State University; Fred Goldstein, Trenton State College; and Monte D. Wilson, Boise State University.

We also thank the reviewers of previous editions: Genevieve Cook, Valencia Community College; Bryan Gregor, Wright State University; Karl J. Koenig, Texas A & M University; Douglas L. Smith, University of Florida; Monte D. Wilson, Boise State University; David S. Ziegler, Hocking College; Harold E. Featherman, Monroe Community College; Louis J. Pineo, Monroe Community College; Stuart J. Inglis, Chabot College; Stanley E. Karp, Bakersfield College; and Sr. Michael Ann Durrer, St. Francis College.

Finally, we must express our appreciation to our efficient senior editor, Bob McConnin, and to the outstanding production team at Macmillan Publishing Company. As always, they skillfully transformed our manuscript into a finished product. They are true professionals with whom we are very fortunate to be associated.



CONTENTS

CHAPTER ONE

An Introduction to Geology 1

Some Historical Notes about Geology 1

Catastrophism 2

The Birth of Modern Geology 3

Geologic Time and the Geologic Time Scale 5

The Nature of Scientific Inquiry 7

Population, Resources, and Environmental Issues 9

A View of the Earth 11

The Dynamic Earth 12

The Rock Cycle 18

CHAPTER TWO

Matter and Minerals 23

Rocks versus Minerals 23

The Composition of Matter 24

Atomic Structure 24

Bonding 25

Atomic Mass 28

Physical Properties of Minerals 28

Crystal Form 28

Luster 28

Color 28

Streak 29

Hardness 29

<i>Cleavage</i>	30
<i>Fracture</i>	30
<i>Specific Gravity</i>	30
<i>Mineral Groups</i>	31
<i>Silicate Structures</i>	31
<i>Silicate Minerals</i>	33
<i>Ferromagnesian Silicates</i>	35
<i>Nonferromagnesian Silicates</i>	36
<i>Nonsilicate Minerals</i>	37
<i>Mineral Resources</i>	37

CHAPTER THREE	
<i>Igneous Rocks</i>	43
<i>Crystallization of Magma</i>	43
<i>Igneous Textures</i>	45
<i>Mineral Composition</i>	48
<i>Naming Igneous Rocks</i>	49
<i>Granitic Rocks</i>	52
<i>Andesitic Rocks</i>	54
<i>Basaltic Rocks</i>	54
<i>Pyroclastic Rocks</i>	55
<i>Mineral Resources and Igneous Processes</i>	55

CHAPTER FOUR	
<i>Igneous Activity</i>	63
<i>The Nature of Volcanic Activity</i>	65
<i>Materials Extruded During an Eruption</i>	67
<i>Lava Flows</i>	68
<i>Gases</i>	68
<i>Pyroclastic Materials</i>	68
<i>Volcanoes and Volcanic Eruptions</i>	69
<i>Shield Volcanoes</i>	70
<i>Cinder Cones</i>	71
<i>Composite Cones</i>	73
<i>Volcanic Pipes and Necks</i>	74
<i>Formation of Calderas</i>	76

<i>Fissure Eruptions</i>	77
<i>Volcanoes and Climate</i>	78
<i>Intrusive Igneous Activity</i>	80
<i>Igneous Activity and Plate Tectonics</i>	82
<i>Origin of Magma</i>	82
<i>Distribution of Igneous Activity</i>	82

CHAPTER FIVE	
<i>Weathering and Soils</i>	89
<i>Weathering</i>	89
<i>Mechanical Weathering</i>	90
<i>Chemical Weathering</i>	92
<i>Rates of Weathering</i>	94
<i>Soil</i>	96
<i>Controls of Soil Formation</i>	97
<i>The Soil Profile</i>	99
<i>Soil Types</i>	100
<i>Soil Erosion</i>	102
<i>Weathering and Ore Deposits</i>	103

CHAPTER SIX	
<i>Sedimentary Rocks</i>	107
<i>Types of Sedimentary Rocks</i>	108
<i>Detrital Sedimentary Rocks</i>	109
<i>Chemical Sedimentary Rocks</i>	112
<i>Turning Sediment into Sedimentary Rock</i>	116
<i>Classification of Sedimentary Rocks</i>	117
<i>Features of Sedimentary Rocks</i>	117
<i>Nonmetallic Mineral Resources</i>	121
<i>Energy Resources from Sedimentary Rocks</i>	122
<i>Coal</i>	122
<i>Oil and Natural Gas</i>	124
<i>Tar Sands and Oil Shale</i>	127

CHAPTER SEVEN**Metamorphic Rocks 131***Metamorphism 131**Agents of Metamorphism 132**Heat as a Metamorphic Agent 133**Pressure as a Metamorphic Agent 133**Chemical Activity and Metamorphism 133**Textural and Mineralogical Changes 134**Common Metamorphic Rocks 137**Foliated Rocks 137**Nonfoliated Rocks 139**Occurrences of Metamorphic Rocks 140**Metamorphism Along Fault Zones 140**Contact Metamorphism 141**Regional Metamorphism 142**Mineral Resources and Metamorphic Processes 144*

CHAPTER EIGHT**Mass Wasting 147***Controls of Mass Wasting 148**Classification of Mass Wasting Processes 149**Slump 151**Rockslide 151**Mudflow 154**Earthflow 155**Creep 156**Permafrost and Solifluction 157*

CHAPTER NINE**Running Water 161***The Hydrologic Cycle 161**Running Water 163**Streamflow 163**Changes Downstream 164**The Effect of Urbanization on Discharge 165**Base Level and Graded Streams 166**Work of Streams 167**Erosion 168**Transportation 168**Deposition 170**Placer Deposits 173**Stream Valleys 175**Drainage Systems and Patterns 178**Stages of Valley Development 179**Cycle of Landscape Evolution 182*

CHAPTER TEN**Groundwater 187***Importance of Underground Water 187**Distribution of Underground Water 188**The Water Table 188**Movement of Groundwater 189**Springs 191**Wells 192**Artesian Wells 192**Problems Associated with Groundwater Withdrawal 194**Groundwater as a Nonrenewable Resource 194**Subsidence 194**Saltwater Contamination 195**Groundwater Pollution 196**Hot Springs and Geysers 197**Geothermal Energy 198**The Geologic Work of Groundwater 200**Caverns 200**Karst Topography 203*

CHAPTER ELEVEN**Glaciers and Glaciation 207***Types of Glaciers 207**Glaciers and the Hydrologic Cycle 209**Glacial Movement 209**Glacial Erosion 212**Glacial Deposits 216**Moraines, Outwash Plains, and Kettle
Holes 218**Medial Moraines and Mineral
Exploration 221**Other Depositional Features 222**Glaciers in the Geologic Past 223**Some Indirect Effects of Ice Age**Glaciers 224**Causes of Glaciation 225*

CHAPTER TWELVE**Deserts and Wind 231***Distribution and Causes of Dry
Lands 231**Geologic Processes in Arid
Climates 234**Transportation of Sediment by
Wind 234**Bed Load 235**Suspended Load 236**Wind Erosion 237**Wind Deposits 238**Sand Deposits 238**Types of Sand Dunes 239**Loess 242**Wind Energy 243**The Evolution of a Desert
Landscape 244*

CHAPTER THIRTEEN**Shorelines 249***Waves 249**Wave Erosion 251**Wave Refraction and Longshore
Transport 252**Shoreline Features 254**Shoreline Erosion Problems 256**Gulf and Atlantic Coasts 257**Sea Level Is Rising 261**Pacific Coast 262**Emergent and Submergent Coasts 262**Tides 263**Tidal Power 265*

CHAPTER FOURTEEN**The Ocean Floor 269***The Earth Beneath the Sea 269**Continental Margins 271**Submarine Canyons and Turbidity
Currents 276**Features of the Ocean Basin Floor 278**Deep-Ocean Trenches 278**Abyssal Plains 278**Seamounts 278**Mid-Ocean Ridges 279**A Close-Up View of the Ocean
Floor 280**Coral Reefs and Atolls 281**Sea-Floor Sediments 282**Types of Sea-Floor Sediments 283**Sea-Floor Sediments and Climatic
Change 285*

CHAPTER FIFTEEN**Earthquakes and the
Earth's Interior 289***What Is an Earthquake? 291**Earthquake Waves 294**Location of Earthquakes 295**Earthquake Intensity and
Magnitude 297*

<i>Earthquake Destruction</i>	300
<i>Destruction Caused by Seismic Vibrations</i>	300
<i>Tsunami</i>	303
<i>Fire</i>	304
<i>Landslides and Ground Subsidence</i>	305
<i>Earthquake Prediction</i>	305
<i>The Earth's Interior</i>	308
<i>Composition of the Earth</i>	312

CHAPTER SIXTEEN

Plate Tectonics 315

<i>Continental Drift: An Idea Before Its Time</i>	315
<i>Fit of the Continents</i>	316
<i>Fossil Evidence</i>	317
<i>Rock Type and Structural Similarities</i>	318
<i>Paleoclimatic Evidence</i>	319
<i>The Great Debate</i>	320
<i>Plate Tectonics: A Modern Version of an Old Idea</i>	321
<i>Plate Boundaries</i>	322
<i>Divergent Boundaries</i>	322
<i>Convergent Boundaries</i>	327
<i>Transform Boundaries</i>	331
<i>Testing the Model</i>	331
<i>Plate Tectonics and Paleomagnetism</i>	332
<i>Plate Tectonics and Earthquakes</i>	334
<i>Evidence from Ocean Drilling</i>	336
<i>Hot Spots</i>	337
<i>A New Test of Plate Tectonics</i>	339
<i>Pangaea: Before and After</i>	340
<i>Breakup of Pangaea</i>	340
<i>Before Pangaea</i>	340
<i>A Look into the Future</i>	343
<i>The Driving Mechanism</i>	343

CHAPTER SEVENTEEN

Mountain Building 347

<i>Crustal Uplift</i>	347
<i>Rock Deformation</i>	349
<i>Folds</i>	350
<i>Faults</i>	352
<i>Mountain Types</i>	354
<i>Fault-Block Mountains</i>	355
<i>Upwarped Mountains</i>	355
<i>Folded Mountains</i>	358
<i>Mountain Building</i>	358
<i>Mountain Building at Subduction Zones</i>	358
<i>Continental Collisions</i>	361
<i>Orogenesis and Continental Accretion</i>	364

CHAPTER EIGHTEEN

Geologic Time 369

<i>Relative Dating</i>	369
<i>Correlation</i>	374
<i>Fossils</i>	377
<i>Conditions Favoring Preservation</i>	379
<i>Fossils and Correlation</i>	380
<i>Radioactivity and Radiometric Dating</i>	381
<i>The Magnitude of Geologic Time</i>	386
<i>The Geologic Time Scale</i>	386
<i>Difficulties in Dating the Geologic Time Scale</i>	389

CHAPTER NINETEEN

<i>Earth History:</i>	
<i>A Brief Summary</i>	393
<i>Origin of the Earth</i>	393
<i>Origin of the Atmosphere</i>	395

<i>The Precambrian</i>	395	<i>APPENDIX A</i>	
<i>Unraveling the Precambrian</i>	395	<i>Metric and English Units</i>	
<i>Precambrian Fossils</i>	397	<i>Compared</i>	417
<i>The Paleozoic Era</i>	399	<i>APPENDIX B</i>	
<i>Early Paleozoic History</i>	400	<i>Periodic Table of the Elements</i>	419
<i>Early Paleozoic Life</i>	401	<i>APPENDIX C</i>	
<i>Late Paleozoic History</i>	402	<i>Common Minerals of the Earth's</i>	
<i>Late Paleozoic Life</i>	402	<i>Crust</i>	420
<i>The Mesozoic Era</i>	405	<i>APPENDIX D</i>	
<i>Mesozoic History</i>	405	<i>Topographic Maps</i>	424
<i>Mesozoic Life</i>	406	<i>GLOSSARY</i>	429
<i>The Cenozoic Era</i>	409	<i>INDEX</i>	443
<i>North America in the Cenozoic</i>	410		
<i>Cenozoic Life</i>	411		

CHAPTER ONE

An Introduction to Geology

SOME HISTORICAL NOTES ABOUT GEOLOGY

Catastrophism

The Birth of Modern Geology

GEOLOGIC TIME AND THE GEOLOGIC TIME SCALE

THE NATURE OF SCIENTIFIC INQUIRY

POPULATION, RESOURCES, AND ENVIRONMENTAL ISSUES

A VIEW OF THE EARTH

THE DYNAMIC EARTH

THE ROCK CYCLE

The spectacular eruption of a volcano, the terror brought by an earthquake, the magnificent scenery of a mountain valley, the destruction created by a landslide—all are subjects for the geologist (Figure 1.1). The study of geology deals with many fascinating and practical questions about our physical environment. What forces produce mountains? What was the Ice Age like? Will there be another? What created this cave and the stone icicles hanging from its ceiling? Should we look for water here? Is strip mining practical in this area? Will oil be found if a well is drilled at this location? What will result if the landfill is located in the old quarry?

The subject of this text is **geology**, a word that literally means “the study of the earth.” To understand the earth is not an easy task because our planet is not an unchanging mass of rock, but rather a dynamic body possessing a long and complex history.

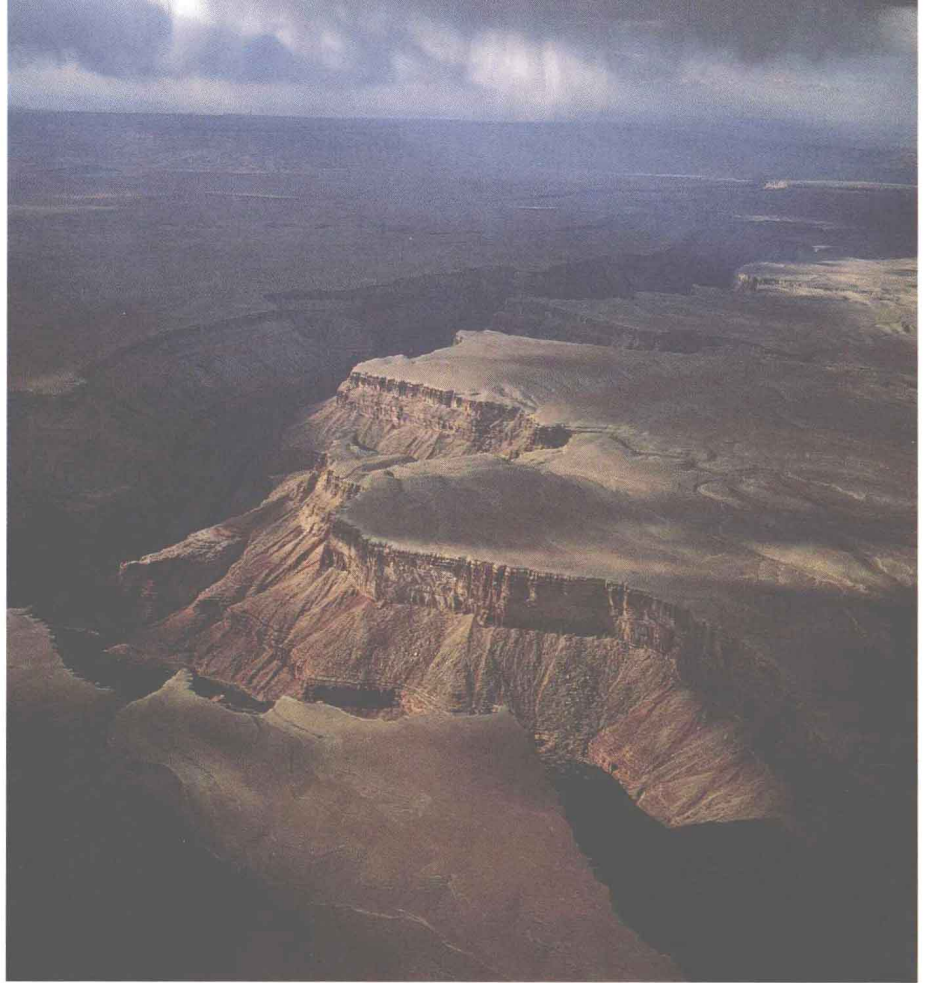
The science of geology is traditionally divided into two broad areas—physical and historical. **Physical geology**, which is the primary focus of this book, examines the materials composing the earth and seeks to understand the many processes that operate beneath and upon its surface. The aim of **historical geology**, on the other hand, is to understand the origin of the earth and its development through time. Thus, it strives to establish an orderly chronological arrangement of the multitude of physical and biological changes that have occurred in the geologic past. The study of physical geology logically precedes the study of earth history, because we must first understand how the earth works before we attempt to unravel its past.

SOME HISTORICAL NOTES ABOUT GEOLOGY

The nature of our earth—its materials and processes—has been a focus of study for centuries. Writings about such topics as fossils, gems, earthquakes, and volcanoes date back to the Greeks, more than 2300 years ago. Certainly the most influential Greek philosopher was Aristotle. Unfortunately, Aristotle’s explanations about the natural world were not based on keen observations and experiments. Instead they were arbitrary pronouncements. He believed that rocks were created under the “influence” of the stars and that earthquakes occurred when air crowded into the ground was heated by central fires and es-

Figure 1.1

Marble Canyon, Arizona. Erosional processes create many of the earth's varied landscapes. (Photo by Michael Collier)



caped explosively. When confronted with a fossil fish, he explained that, “a great many fishes live in the earth motionless and are found when excavations are made.” Although Aristotle’s explanations may have been adequate for his day, they unfortunately continued to be expounded for many centuries, thus thwarting the acceptance of ideas that were more closely in accord with observations. Frank D. Adams states in *The Birth and Development of the Geological Sciences* (New York: Dover, 1938) that, “throughout the Middle Ages Aristotle was regarded as the head and chief of all philosophers; one whose opinion on any subject was authoritative and final.”

Catastrophism

During the seventeenth and eighteenth centuries the doctrine of **catastrophism** strongly influenced the formulation of explanations about the dynamics of the earth. Briefly stated, catastrophists believed that the earth’s landscape had been shaped primarily by great catastrophes. Features such as mountains and canyons, which today we know take great periods of

time to form, were explained as having been produced by sudden and often world-wide disasters produced by unknowable causes that no longer operate. This philosophy was an attempt to fit the rate of earth processes to the then-current ideas on the age of the earth. In the mid-seventeenth century, James Ussher, Anglican Archbishop of Armagh, Primate of all Ireland, published a major work that had immediate and profound influence. A respected scholar of the Bible, Ussher constructed a chronology of human and earth history in which he determined that the earth was only a few thousands of years old, having been created in 4004 B.C. Ussher’s treatise earned widespread acceptance among scientific and religious leaders alike, and his chronology was soon printed in the margins of the Bible itself.

The relationship between catastrophism and the age of the earth has been summarized nicely as follows:

That the earth had been through tremendous adventures and had seen mighty changes during its obscure past was plainly evident to every inquiring eye; but to

concentrate these changes into a few brief millennia required a tailor-made philosophy, a philosophy whose basis was sudden and violent change.*

The Birth of Modern Geology

The late eighteenth century is generally regarded as the beginning of modern geology, for it was during this time that James Hutton, a Scottish physician and gentleman farmer, published his *Theory of the Earth* in which he put forth a principle that came to be known as the doctrine of **uniformitarianism** (Figure 1.2). Uniformitarianism is a fundamental concept in modern geology. It simply states that the physical, chemical, and biological laws that operate today have also operated in the geologic past. That is to say that the forces and processes that we observe presently shaping our planet have been at work for a very long time. Thus, to understand ancient rocks, we must first understand present-day processes and their results. This idea is commonly stated as “the present is the key to the past.”

Prior to Hutton's *Theory of the Earth*, no one had effectively demonstrated that geological processes occur over extremely long periods of time. However, Hutton persuasively argued that processes which appear weak and slow-acting could, over long spans of time, produce effects that were just as great as those resulting from sudden catastrophic events. Unlike his predecessors, Hutton cited verifiable observations to support his ideas.

Since Hutton's literary style was cumbersome and difficult, his work was not widely read nor easily understood. It is the English geologist Charles Lyell who is given the most credit for advancing the basic principles of modern geology. Between 1830 and 1872 Lyell produced eleven editions of his great work, *Principles of Geology*. As was customary, Lyell's book had a rather lengthy subtitle that outlined the main theme of the work: *Being an Attempt to Explain the Former Changes of the Earth's Surface, by Reference to Causes Now in Operation*. In the text, he painstakingly illustrated the concept of the uniformity of nature through time. He was able to show more convincingly than his predecessors that those geologic processes observed today can be assumed

to have operated in the past. Although the doctrine of uniformitarianism did not originate with Lyell, he is the person who was most successful in interpreting and publicizing it for society at large.

Today the basic tenets of uniformitarianism are just as viable as in Lyell's day. Indeed, we realize more strongly than ever that the present gives us insight into the past and that the physical, chemical, and biological laws that govern geological processes remain unchanging through time. However, we also understand that the doctrine should not be taken too literally. To say that geological processes in the past were the same as those occurring today is not to suggest that they always had the same relative importance and operated at precisely the same rate. Although the same processes have prevailed through time, their rates have undoubtedly varied.

The acceptance of uniformitarianism, however, meant the acceptance of a very long history for the earth, for although processes vary in their intensity, they still take a very long time to create or destroy major landscape features.

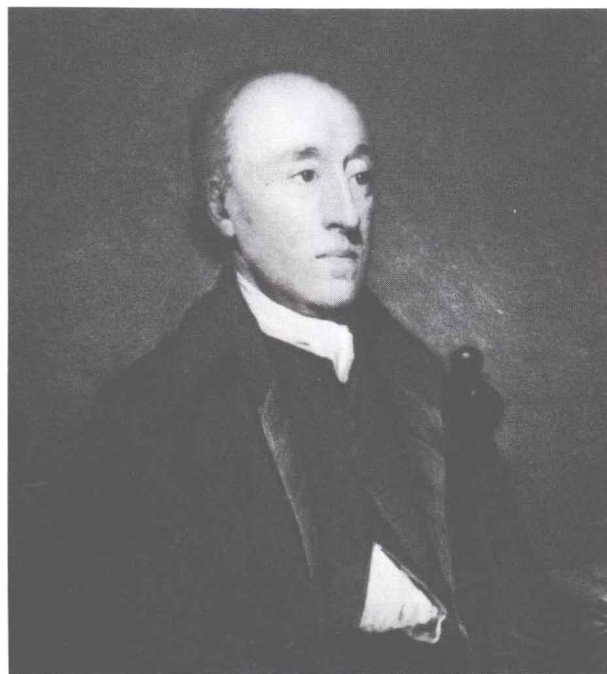


Figure 1.2
James Hutton, the 18th century Scottish geologist who is often called the “father of modern geology.” (Photo courtesy of the British Museum)

*H. E. Brown, V. E. Monnett, and J. W. Stovall. *Introduction to Geology* (New York: Blaisdell, 1958).

For example, rocks containing fossils of organisms that lived in the sea more than 15 million years ago are now part of mountains that stand 3000 meters (9800 feet) above sea level. This means that the mountains were uplifted 3000 meters in about 15 million years—a rate of only 0.2 millimeter per year! Rates of erosion are equally slow (Figure 1.3). Estimates indicate that the North American continent is being lowered at a rate of just 3 centimeters per 1000 years. Thus, as you can see, it takes tens of millions of years for nature to build mountains and wear them

down again. But even these time spans are relatively short on the time scale of earth history, for the rock record contains evidence that shows the earth has experienced many cycles of mountain building and erosion. Concerning the everchanging nature of the earth through great expanses of geologic time, Hutton stated: “We find no vestige of a beginning, no prospect of an end.” A quote from William L. Stokes sums up the significance of Hutton’s basic concept:

In the sense that uniformitarianism implies the operation of timeless, changeless laws or principles, we can

Figure 1.3

Geologic processes often act so slowly that changes may not be visible during an entire human lifetime. Today, Monument Valley looks much the same as it did when first encountered by explorers. (Photo by Michael Collier)

