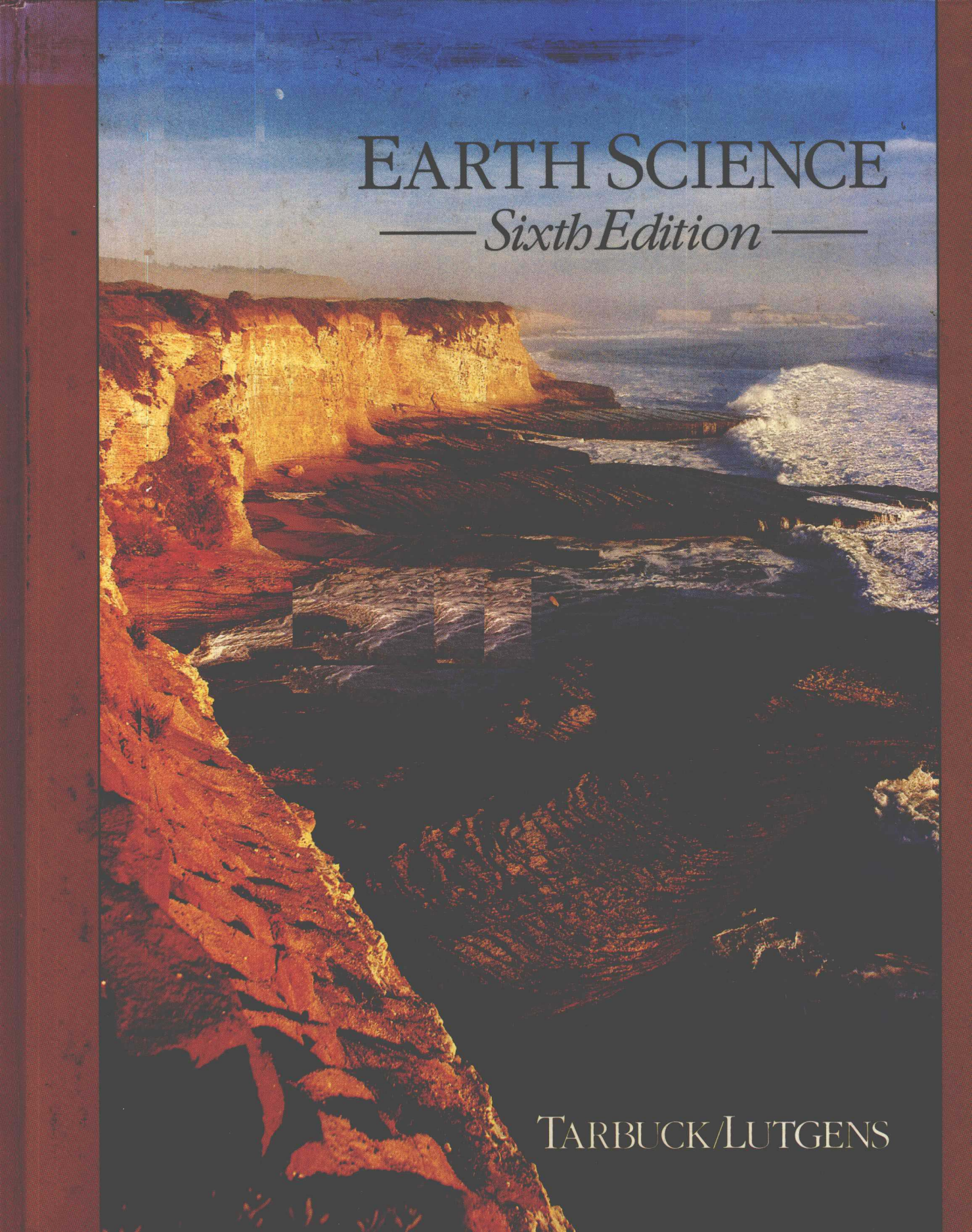
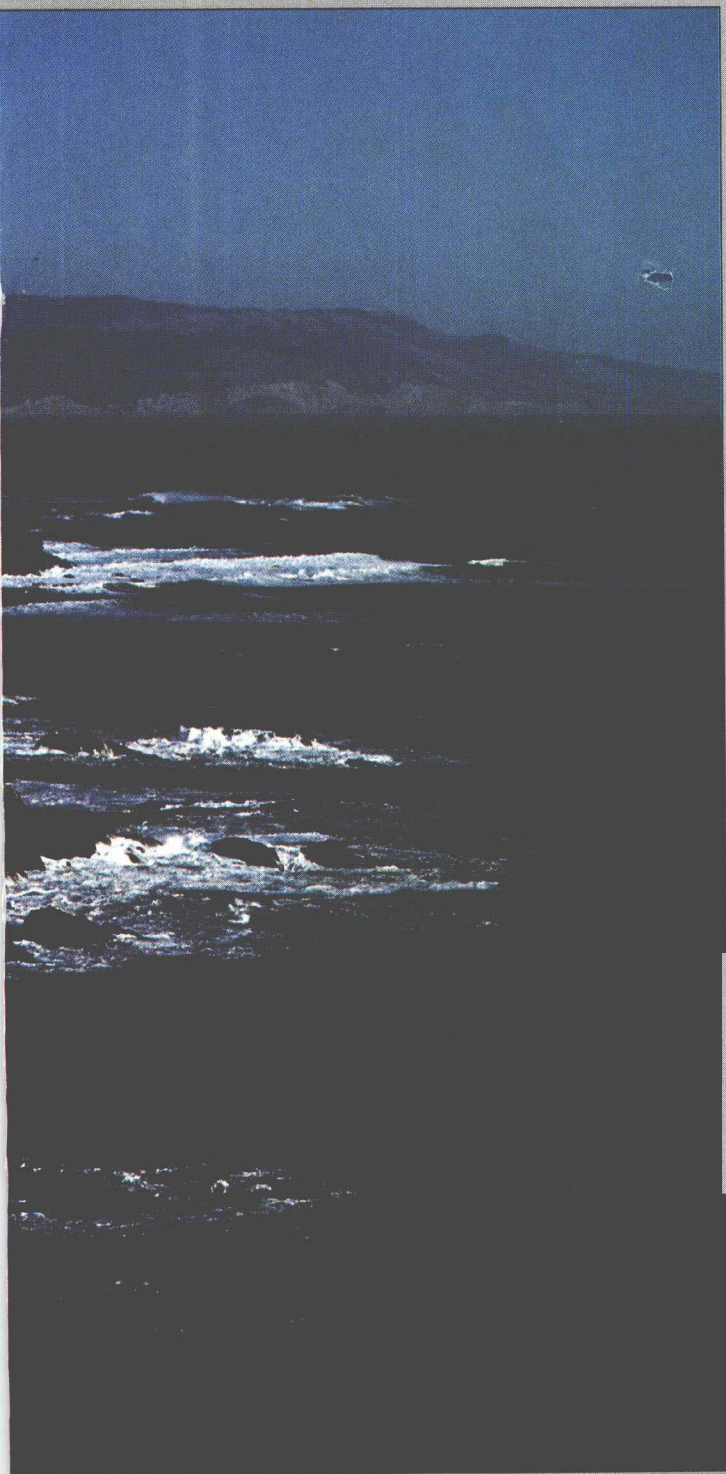




EARTH SCIENCE

— *Sixth Edition* —

TARBUCK/LUTGENS



EARTH SCIENCE

Sixth Edition

Edward J. Tarbuck
Frederick K. Lutgens

Illinois Central College

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Photo Editor: Gail Meese
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PREFACE

In recent years, media reports have made us increasingly aware of the natural forces at work in our physical environment. News stories graphically portray the violent force of a hurricane, the devastation created 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 not only the mineral resources so basic to modern society, but it is also the source of most of the ingredients necessary to support life. Therefore, as many members of society as possible should acquire a basic understanding of how the earth works.

With this in mind, we have written a text to help people increase their understanding of our physical environment. We hope this 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.

Earth Science is a broad and nonquantitative survey at the introductory level of topics in geology,

oceanography, meteorology, and astronomy. 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. We have deliberately refrained from using excessive jargon and when new terms are introduced, they are placed in boldface and defined. A list of key terms with page references is found at the end of each chapter, and a glossary is included at the conclusion of the text for easy reference to important terms. Further, review questions conclude each chapter to help the student prepare for exams and quizzes.

In previous editions of this text special attention was given to the quality of photographs and artwork because the earth sciences are highly visual. This emphasis has been maintained in the Sixth Edition. More than 75 new color photographs appear in this revision. The photographs and images were carefully selected to add realism to the subject and to heighten the interest of the reader. Moreover, the already excellent art program of the earlier editions has been strengthened in the Sixth Edition. Because we believe that carefully planned and executed line art will significantly aid student understanding by making difficult concepts less abstract, more than 100 new and redrawn figures appear in the Sixth Edition.

Once again, the text has benefited greatly from the talents and imaginative production of Dennis Tasa of Tasa Graphic Arts, Inc.

The Sixth Edition of *Earth Science* represents a thorough revision. Extensive rewriting has made many discussions more timely and more readable. Examples include the sections on rock deformation and mountain building in Chapter 8 and the section on Neptune and Uranus in Chapter 19. Chapter 9 on earth history and geologic time has been reorganized so that relative dating principles are treated prior to the discussion of radiometric dating. The geology unit includes new discussions of types of glaciers, causes of deserts, and the extinction of dinosaurs. Sections on meteorological seasons, precipitation measurement, and global precipitation distribution have been added to the atmospheric unit.

The treatment of environmental and resource topics has always been an important part of *Earth Science*. In the Sixth Edition this focus has been given even greater emphasis. Beginning with a new section on population, resources, and environmental issues in the introduction, new material relating to this theme appears in Chapters 1, 2, 3, 5, 12, 14, and 16. Additions related to environmental concerns include a new section on soil erosion (Chapter 2) and a look at land subsidence caused by the withdrawal of groundwater (Chapter 3). Topical discussions about geologic hazards, including the Loma Prieta earthquake in the San Francisco Bay region, and the issue of earthquake prediction are also treated (Chapter 5). Updated looks at ozone depletion (Chapter 12), sources and types of air pollution (Chapter 16), and global warming (Chapter 16) also appear. New material on metallic and nonmetallic rock and mineral resources is now included in Chapters 1, 2, and 3. Additional information on alternative energy options, including hydroelectric power (Chapter 3), solar power (Chapter 12), and wind energy (Chapter 14) now complement the discussions of geothermal power and tidal energy that were already part of the text.

Although many new topical issues are treated in *Earth Science*, Sixth Edition, it should be emphasized that the main focus of this new edition remains the same as its predecessors—to foster student under-

standing of basic earth science principles. Whereas student use of the text is a primary concern, the book's adaptability to the needs and desires of the instructor is equally important. Realizing the broad diversity of earth science courses in both content and approach, we have continued to use a relatively non-integrated format to allow maximum flexibility for the instructor. Each of the four major units stands alone; hence, they can be taught in any order. A unit can be omitted entirely without appreciable loss of continuity, and portions of some chapters may be interchanged or excluded at the instructor's discretion. For example, some instructors may wish to include the section on the sun, which appears as a portion of Chapter 18, with the discussion of stars in Chapter 20.

The authors wish to express their thanks to the many individuals, institutions, government agencies, and businesses that provided photographs and illustrations for use in the text. Further, we would like to acknowledge the aid of our students. Their comments continue to help us maintain our focus on readability and understanding. A special debt of gratitude goes to those colleagues who prepared in-depth prerevision reviews of the Fifth Edition of *Earth Science*. Their critical comments and thoughtful input helped guide our revision and strengthen the text. We wish to thank Prof. John Ernissee, Clarion University, Pennsylvania; Prof. Joseph C. Gould, St. Petersburg Junior College, Florida; Prof. Miriam Helen Hill, Indiana University Southwest, Indiana; Prof. William Kneller, University of Toledo, Ohio; Prof. Michael E. Lewis, University of North Carolina, North Carolina; Prof. Paul Nelson, St. Louis Community College at Forest Park, Missouri; Prof. Carl Ojala, Eastern Michigan University, Michigan; Prof. James R. Smith, Augustana College, South Dakota; and Prof. Dean G. Wilder, University of Wisconsin-LaCrosse, Wisconsin. Our thanks also go to Diane Weber for her help in preparing the manuscript and to the fine production team at Macmillan Publishing who skillfully transformed our manuscript into a finished product. The expertise of Rex Davidson, Raydelle Clement, Cynthia Brunk, and Jean Brown is gratefully acknowledged and sincerely appreciated.



CONTENTS

Introduction 1

THE EARTH'S STRUCTURE 3

THE EARTH SCIENCES 3

POPULATION, RESOURCES, AND ENVIRONMENTAL
ISSUES 4

THE NATURE OF SCIENTIFIC INQUIRY 6

PART ONE

THE SOLID EARTH 11

Chapter One

Minerals and Rocks 12

MINERALS 14

Structure of Minerals | Physical Properties of
Minerals | The Silicates | Nonsilicate Minerals

THE ROCK CYCLE 22

IGNEOUS ROCKS 23

Crystallization of Magma | Texture and Mineral
Composition | Naming Igneous Rocks

SEDIMENTARY ROCKS 29

Classification | Lithification | Features of
Sedimentary Rocks

METAMORPHIC ROCKS 36

Agents of Metamorphism | Textural and
Mineralogical Changes

RESOURCES FROM ROCKS AND MINERALS 40

Metallic Mineral Resources | Nonmetallic Mineral
Resources

Chapter Two

Weathering, Soil, and Mass Wasting 46

WEATHERING 48

Mechanical Weathering | Chemical Weathering |
Rates of Weathering

SOIL 54

Soil Texture and Structure | Controls of Soil
Formation | The Soil Profile | Soil Types | Soil
Erosion | Weathering and Ore Deposits

MASS WASTING 63

Controls of Mass Wasting | Classification of Mass
Wasting Processes | Slump | Rockslide | Mudflow |
Earthflow | Creep | Solifluction

Chapter Three

Running Water and Groundwater 74

THE HYDROLOGIC CYCLE 76

RUNNING WATER 77

Streamflow | Changes Downstream | The Effect of
Urbanization on Discharge

BASE LEVEL AND GRADED STREAMS	80
WORK OF STREAMS	82
Erosion Transportation Deposition	
STREAM VALLEYS	86
PLACER DEPOSITS	89
DRAINAGE SYSTEMS AND PATTERNS	90
STAGES OF VALLEY DEVELOPMENT	91
CYCLE OF LANDSCAPE EVOLUTION	93
HYDROELECTRIC POWER	93
WATER BENEATH THE SURFACE	95
DISTRIBUTION AND MOVEMENT OF GROUNDWATER	96
SPRINGS	97
WELLS	97
ARTESIAN WELLS	98
ENVIRONMENTAL PROBLEMS ASSOCIATED WITH GROUNDWATER	99
HOT SPRINGS AND GEYSERS	101
GEOTHERMAL ENERGY	102
THE GEOLOGIC WORK OF GROUNDWATER	104

Chapter Four Glaciers, Deserts, and Wind 110

TYPES OF GLACIERS	112
GLACIERS AND THE HYDROLOGIC CYCLE	113
GLACIAL MOVEMENT	113
GLACIAL EROSION	116
GLACIAL DEPOSITS	121
Moraines, Outwash Plains, and Kettle Holes Other Depositional Features	
GLACIERS IN THE GEOLOGIC PAST	125
SOME INDIRECT EFFECTS OF ICE AGE GLACIERS	127
CAUSES OF GLACIATION	127
DESERTS	130
DISTRIBUTION AND CAUSES OF DRY LANDS	131

GEOLOGIC PROCESSES IN ARID CLIMATES	133
THE EVOLUTION OF A DESERT LANDSCAPE	134
WIND EROSION	136
WIND DEPOSITS	137
Loess Sand Deposits Types of Sand Dunes	

Chapter Five Earthquakes and the Earth's Interior 144

WHAT IS AN EARTHQUAKE?	148
EARTHQUAKE WAVES	150
LOCATION OF EARTHQUAKES	153
EARTHQUAKE INTENSITY AND MAGNITUDE	154
EARTHQUAKE DESTRUCTION	157
Destruction Caused by Seismic Vibrations Tsunami Fire Landslides and Ground Subsidence	
EARTHQUAKE PREDICTION	163
THE EARTH'S INTERIOR	167
COMPOSITION OF THE EARTH	169

Chapter Six Plate Tectonics 172

CONTINENTAL DRIFT: AN IDEA BEFORE ITS TIME	174
Fit of the Continents Fossil Evidence Rock Type and Structural Similarities Paleoclimatic Evidence	
THE GREAT DEBATE	178
PLATE TECTONICS: A MODERN VERSION OF AN OLD IDEA	180
PLATE BOUNDARIES	183
Divergent Boundaries Convergent Boundaries Transform Boundaries	
TESTING THE MODEL	190
Plate Tectonics and Paleomagnetism Plate Tectonics and Earthquakes Evidence from Ocean Drilling Hot Spots A New Test of Plate Tectonics	

PANGAEA: BEFORE AND AFTER	199
Breakup of Pangaea Before Pangaea A Look into the Future	
THE DRIVING MECHANISM	202

Chapter Seven Igneous Activity 206

THE NATURE OF VOLCANIC ACTIVITY	211
MATERIALS EXTRUDED DURING AN ERUPTION	212
Lava Flows Gases Pyroclastic Materials	
VOLCANOES AND VOLCANIC ERUPTIONS	215
Shield Volcanoes Cinder Cones Composite Cones Volcanic Pipes and Necks Formation of Calderas	
FISSURE ERUPTIONS	222
VOLCANOES AND CLIMATE	223
INTRUSIVE IGNEOUS ACTIVITY	225
IGNEOUS ACTIVITY AND PLATE TECTONICS	227
Origin of Magma Distribution of Igneous Activity	

Chapter Eight Mountain Building 234

CRUSTAL UPLIFT	236
ROCK DEFORMATION	238
Folds Faults	
MOUNTAIN TYPES	244
Fault-Block Mountains Upwarped Mountains Folded Mountains	
MOUNTAIN BUILDING	247
Mountain Building at Subduction Zones Continental Collisions Orogenesis and Continental Accretion	

Chapter Nine Geologic Time and Earth History 258

SOME HISTORICAL NOTES ABOUT GEOLOGY	260
Catastrophism The Birth of Modern Geology	

RELATIVE DATING	263
CORRELATION	268
FOSSILS	269
Conditions Favoring Preservation Fossils and Correlation	
RADIOACTIVITY AND RADIOMETRIC DATING	272
THE MAGNITUDE OF GEOLOGIC TIME	277
THE GEOLOGIC TIME SCALE	278
DIFFICULTIES IN DATING THE GEOLOGIC TIME SCALE	280
LIFE OF THE GEOLOGIC PAST	280
Paleozoic Life Mesozoic Life Cenozoic Life	

PART TWO THE OCEANS 293

Chapter Ten Ocean Waters and the Ocean Floor 294

THE SEVEN SEAS?	296
EXTENT OF THE OCEANS	297
COMPOSITION OF SEAWATER	298
RESOURCES FROM SEAWATER	300
THE OCEAN'S LAYERED STRUCTURE	301
A BRIEF HISTORY OF OCEANOGRAPHY	302
THE EARTH BENEATH THE SEA	304
CONTINENTAL MARGINS	305
SUBMARINE CANYONS AND TURBIDITY CURRENTS	310
FEATURES OF THE OCEAN BASIN FLOOR	312
Deep-Ocean Trenches Abyssal Plains Seamounts	
MID-OCEAN RIDGES	313
A CLOSE-UP VIEW OF THE OCEAN FLOOR	315
CORAL REEFS AND ATOLLS	316
SEA-FLOOR SEDIMENTS	317
Types of Sea-floor Sediments Sea-floor Sediments and Climatic Change	

Chapter Eleven **The Restless Ocean 324**

- SURFACE CURRENTS 326
- THE IMPORTANCE OF OCEAN CURRENTS 328
- DEEP-OCEAN CIRCULATION 330
- TIDES 331
- TIDAL POWER 334
- WAVES 335
- WAVE EROSION 340
- WAVE REFRACTION AND LONGSHORE
TRANSPORT 340
- SHORELINE FEATURES 342
- SHORELINE EROSION PROBLEMS 345
 - Gulf and Atlantic Coasts | Sea Level Is Rising |
Pacific Coast
- EMERGENT AND SUBMERGENT COASTS 351

PART THREE **THE ATMOSPHERE 357**

Chapter Twelve **Composition, Structure, and** **Temperature 358**

- WEATHER AND CLIMATE 360
- COMPOSITION OF THE ATMOSPHERE 361
- THE OZONE PROBLEM 362
- EXTENT AND STRUCTURE OF THE
ATMOSPHERE 364
- EARTH-SUN RELATIONSHIPS 366
 - Motions of the Earth | The Seasons |
Meteorological Seasons
- RADIATION 370
- MECHANISMS OF HEAT TRANSFER 373
- HEATING THE ATMOSPHERE 373
- SOLAR ENERGY 377
- TEMPERATURE MEASUREMENT AND DATA 378

- CONTROLS OF TEMPERATURE 379
 - Land and Water | Altitude | Geographic Position
- WORLD DISTRIBUTION OF TEMPERATURE 381

Chapter Thirteen **Moisture 386**

- CHANGES OF STATE 389
- HUMIDITY 390
- HUMIDITY MEASUREMENT 392
- NECESSARY CONDITIONS FOR
CONDENSATION 393
- CONDENSATION ALOFT: ADIABATIC TEMPERATURE
CHANGES 394
- STABILITY 396
 - Determination of Stability | Stability and Daily
Weather
- FORCEFUL LIFTING 400
- CLOUDS 401
- FORMATION OF PRECIPITATION 402
- SLEET, GLAZE, AND HAIL 408
- PRECIPITATION MEASUREMENT 410
- FOG 411
 - Fogs Caused by Cooling | Evaporation Fogs

Chapter Fourteen **Pressure and Wind 416**

- PRESSURE MEASUREMENT 418
- FACTORS AFFECTING WIND 420
 - Pressure Gradient Force | Coriolis Effect | Friction
- CYCLONES AND ANTICYCLONES 422
 - Cyclonic and Anticyclonic Winds | Weather
Generalizations about Highs and Lows
- GENERAL CIRCULATION OF THE ATMOSPHERE 425
- GLOBAL DISTRIBUTION OF PRECIPITATION 428
- CIRCULATION IN THE MID-LATITUDES 429

LOCAL WINDS 431

Sea and Land Breezes | Valley and Mountain
Breezes | Chinook and Santa Ana Winds

WIND MEASUREMENT 432

WIND ENERGY 432

Chapter Fifteen **Weather Patterns and Severe Storms 436**

AIR MASSES 438

Source Regions | Weather Associated with Air
Masses

FRONTS 441

Warm Fronts | Cold Fronts | Occluded Fronts

THE MIDDLE-LATITUDE CYCLONE 444

Life Cycle of a Wave Cyclone | Idealized Weather of
a Wave Cyclone | Cyclone Formation

THUNDERSTORMS 449

TORNADOES 453

HURRICANES 457

Chapter Sixteen **Human Impact on the Atmosphere 464**

AIR POLLUTION 467

Sources and Types of Air Pollution | Meteorological
Factors Affecting Air Pollution | Acid Precipitation

THE CLIMATE OF CITIES 472

The Urban Heat Island | Urban-Induced
Precipitation | Other Urban Effects

HUMAN IMPACT ON GLOBAL CLIMATE 477

Greenhouse Warming | Possible Consequences of a
Greenhouse Warming

INTENTIONAL WEATHER MODIFICATION 481

Cloud Seeding | Fog and Cloud Dispersal | Hail
Suppression | Hurricane Modification | Frost
Prevention

PART FOUR **ASTRONOMY 489**

Chapter Seventeen **The Earth's Place in the Universe 490**

ANCIENT ASTRONOMY 492

Early Greeks | The Ptolemaic System

THE BIRTH OF MODERN ASTRONOMY 495

Nicolaus Copernicus | Tycho Brahe | Johannes
Kepler | Galileo Galilei | Sir Isaac Newton

CONSTELLATIONS AND ASTROLOGY 502

POSITIONS IN THE SKY 505

MOTIONS OF THE EARTH 506

CALENDARS 509

Chapter Eighteen **The Moon, Celestial Observations, and the Sun 512**

THE MOON 514

Lunar Motion | The Lunar Surface | Lunar History

THE STUDY OF LIGHT 523

Nature of Light | Spectroscopy | The Doppler Effect

ASTRONOMICAL TOOLS 526

Refracting Telescopes | Reflecting Telescopes |
Properties of Optical Telescopes | The Largest
Telescopes | Detecting Invisible Radiation

THE SUN 533

Structure of the Sun | The Active Sun | The Solar
Interior

Chapter Nineteen **The Solar System 544**

THE PLANETS: AN OVERVIEW 546

ORIGIN OF THE SOLAR SYSTEM 549

THE PLANETS: AN INVENTORY 551

Mercury: The Innermost Planet | Venus: The Veiled
Planet | Mars: The Red Planet | Jupiter: The Lord of
the Heavens | Saturn: The Elegant Planet | Uranus
and Neptune: The Twins | Pluto: Planet X

THE MINOR MEMBERS OF THE SOLAR SYSTEM 567

Asteroids | Comets | Meteoroids

Chapter Twenty
Beyond Our Solar System 574

PROPERTIES OF STARS 576

Distances to the Stars | Stellar Magnitudes | Color

BINARY STARS 579

STELLAR CLASSIFICATION 580

HERTZSPRUNG-RUSSELL DIAGRAM 581

VARIABLE STARS 583

UNUSUAL STARS 585

Dwarfs | Neutron Stars | Black Holes

STELLAR EVOLUTION 587

STAR CLUSTERS 591

INTERSTELLAR MATTER 592

THE MILKY WAY 593

GALAXIES 595

RED SHIFTS 597

THE BIG BANG 598

Appendices

APPENDIX A

Metric and English Units Compared 601

APPENDIX B

Mineral Identification Key 603

APPENDIX C

The Earth's Grid System 606

APPENDIX D

Topographic Maps 609

APPENDIX E

Star Charts 614

APPENDIX F

World Climates 620

APPENDIX G

World Soils 628

GLOSSARY 633

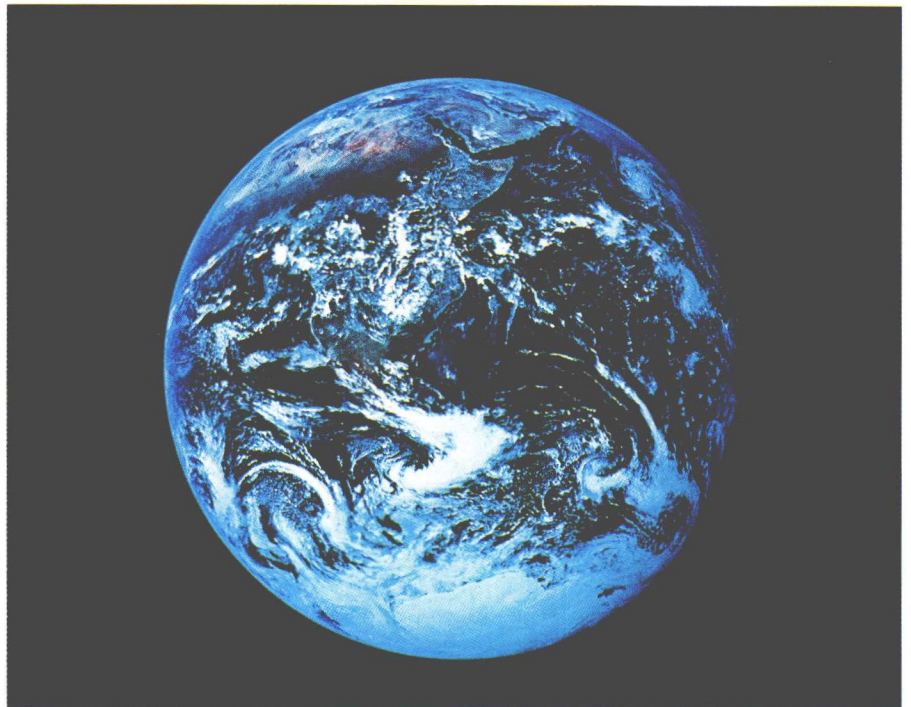
INDEX 651

Introduction

A view of the earth from space affords us a unique perspective of our planet (Figure I.1). At first, it may strike us that the earth is a somewhat fragile-appearing sphere surrounded by the blackness of

FIGURE I.1

View of the earth from *Apollo 17*. (Courtesy of NASA)



space. In fact, it is just a speck of matter in an infinite universe. As we look more closely, it becomes apparent that the earth is much more than just rock and soil. Indeed, the most conspicuous features are not the continents but the swirling clouds suspended above the surface and the vast global ocean. From such a vantage point, we can appreciate why the earth's physical environment is traditionally divided into three major parts: the solid lithosphere, the liquid hydrosphere, and the gaseous atmosphere. However, the earth is not dominated by rock, water, or air alone. Rather, it is characterized by continuous interactions as air comes into contact with rock, rock with water, and water with air (Figure I.2). Moreover, the biosphere, the totality of life-forms on our planet, extends into each of the three physical realms and is an equally integral part of the earth.



FIGURE I.2

The shoreline is one obvious meeting place for rock, water, and air. In this scene, ocean waves that were created by the force of moving air break against the rocky shore. The force of the water can be powerful and the erosional work that is accomplished can be great. (Photo by E. J. Tarbuck)

THE EARTH'S STRUCTURE

The solid earth, or **lithosphere**, may be divided into three principal units: the dense **core**; the less dense **mantle**; and the **crust**, which is the light and very thin outer skin of the earth (Figure I.3).^{*} The crust is not a layer of uniform thickness; rather, it is characterized by many irregularities. It is thinnest beneath the oceans and thickest where continents exist. Although the crust may seem insignificant when compared with the other units of the solid earth, it was created by the same general processes that were responsible for the earth's present structure. Thus, the crust is important in understanding the history and nature of our planet.

The **hydrosphere** is the water portion of our planet. This dynamic mass of liquid is continuously on the move, from the oceans to the air, to the land, and back again. The global ocean is obviously the most prominent feature of the hydrosphere, blanketing nearly 71 percent of the earth's surface and accounting for about 97 percent of the earth's water. However, the hydrosphere also includes the fresh water found in streams, lakes, and glaciers, as well as that found in the ground. Although these latter sources constitute just a tiny fraction of the total, they are still very important because they provide the water essential to human life as well as the needs of many other organisms. In addition, the movement of water in streams, glaciers, and underground is responsible for sculpturing and creating many of our planet's varied landforms.

The earth is surrounded by a life-giving gaseous envelope called the **atmosphere**. This blanket of air, hundreds of kilometers thick, is an integral part of the planet. It not only provides the air that we breathe but also acts to protect us from the sun's intense heat and dangerous radiation. The energy exchanges that continually occur between the atmosphere and the earth's surface and between the atmosphere and space produce the effects we call weather.

^{*}In recent years, since the development of the theory of plate tectonics (Chapter 6), the term *lithosphere* is also used more specifically to denote the rigid outer layer of the earth, which includes the crust and upper mantle.

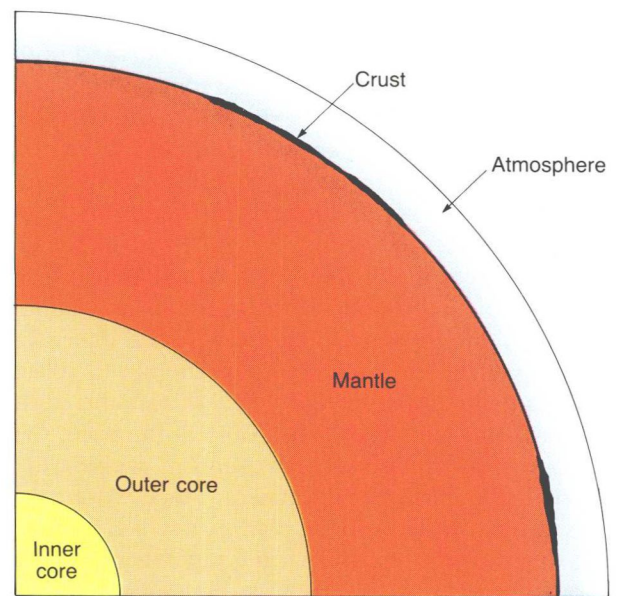


FIGURE I.3

Cross-sectional view of the earth's layered structure. The inner core, outer core, and mantle are drawn to scale, but the crust's thickness is exaggerated by about three times.

The **biosphere** includes all life on earth and consists of the parts of the lithosphere, hydrosphere, and atmosphere in which living organisms can be found. Plants and animals depend on the physical environment for the basics of life. However, it should be emphasized that organisms do more than just respond to their physical environment. Indeed, through countless interactions, life-forms help maintain and alter their physical environment. Without life, the makeup and nature of the lithosphere, hydrosphere, and atmosphere would be very different.

THE EARTH SCIENCES

Earth science is a name for all the sciences that collectively seek to understand the earth and its neighbors in space. **Geology**, which literally means "the study of the earth," examines the origin and development of the solid earth, as well as its composition and the processes that operate beneath and upon its surface. In many instances, it requires significant

consideration of the hydrosphere and atmosphere. **Meteorology** and **climatology** are concerned with the activities and structure of the atmosphere, and **oceanography** deals with the dynamics of the oceans. At the boundary between the ocean and the atmosphere, oceanography and meteorology merge, and in a similar manner, oceanography merges with geology at the ocean floor.

The study of the earth is not confined to investigations of the lithosphere, hydrosphere, and atmosphere and to their many interactions and interrelationships. The earth sciences also attempt to relate our planet to the larger universe. Because the earth is related to all of the other objects in space, the science of **astronomy** is very useful in probing the origins of our own environment. Since we are so closely acquainted with the planet on which we live, it is easy to forget that the earth is just a tiny object in a vast universe. Indeed, the earth is subject to the same physical laws that govern the great many other objects that populate the infinite expanses of space. Thus, to understand the theories of the earth's origin, it is useful to learn something about the other members of our solar system. Moreover, it is helpful to view the solar system as a part of the great assemblage of stars that comprise our galaxy, which, in turn, is but one of many galaxies.

POPULATION, RESOURCES, AND ENVIRONMENTAL ISSUES

Materials from the earth are the basis of modern civilization. The mineral and energy resources that are extracted from the crust are the raw materials from which the products used by society are made. Few people who live in highly industrialized nations realize the quantity of resources needed to maintain their present standard of living. For example, the annual per capita consumption of metallic and non-metallic mineral resources for the United States is nearly 10,000 kilograms (11 tons). This is each person's prorated share of the materials required by industry to provide the vast array of products modern society demands. Figures for other highly industrialized countries are comparable.

Resources are commonly divided into two broad categories. Some are classified as **renewable**, which means that they can be replenished over relatively

short time spans. Plants and animals for food, natural fibers for clothing, and forest products for lumber and paper are all common examples. Energy from flowing water, wind, and the sun are also considered renewable. By contrast, many other basic resources are classified as **nonrenewable**. Important metals such as iron, aluminum, and copper fall into this category, as do our most important fuels; oil, natural gas, and coal. Although these and other resources continue to be formed in the earth, the processes that create them are so slow that significant deposits take millions of years to accumulate. In essence, the earth contains fixed quantities of these substances. When the present supplies are mined or pumped from the ground, there will be no more. Although some nonrenewable resources, such as aluminum, can be used over and over again, others, such as oil, cannot be recycled.

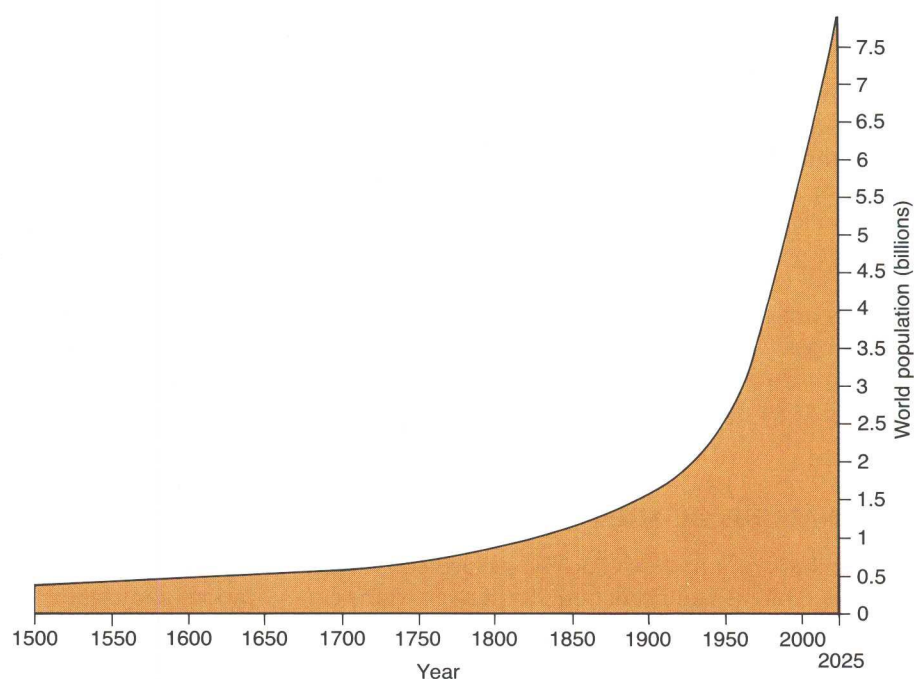
A glance at Figure I.4 shows that the population of our planet is growing rapidly. Although it took until the beginning of the nineteenth century for the number to reach 1 billion, just 130 years were needed for the population to double to 2 billion. Between 1930 and 1975 the figure doubled again to 4 billion and by the year 2000 an estimated 7 billion people will inhabit the planet. Clearly, as population grows, the demand for resources expands as well. However, the rate of mineral and energy resource usage has climbed more rapidly than the overall growth of population. This fact results from an increasing standard of living. This is certainly true in the United States, where about 6 percent of the world's population uses approximately 30 percent of the annual production of mineral and energy resources.

How long will the remaining supplies of basic resources be adequate to sustain the rising standard of living in today's industrialized countries and still provide for the growing needs of developing regions? How much environmental deterioration are we willing to accept in pursuit of basic resources? Can alternatives be found? If we are to cope with an increasing per capita demand and a growing world population, it is important that we have some understanding of our present and potential resources.

Today we face a broad array of environmental problems related to human activities. Some are local, some are regional, and still others are global in extent. Serious difficulties face developed and develop-

FIGURE I.4

Growth of world population. It took until 1800 for the number to reach 1 billion. By the year 2000 an estimated 7 billion people will inhabit the planet. The demand for basic resources is growing faster than the rate of population increase. (Data from the Population Reference Bureau)



ing nations alike. Urban air pollution, acid rain, ozone depletion, and global warming are just a few that pose significant threats. Other problems involve the loss of fertile soils to erosion, the disposal of toxic wastes, and the contamination and depletion of water resources. The list continues to grow.

FIGURE I.5

A number of people died when a section of the Nimitz Freeway (Interstate 880) in Oakland, California, collapsed during an earthquake on October 17, 1989. An earthquake is just one of many natural hazards with which people must cope. (Photo by Warren Faidley, courtesy of Weatherstock)

