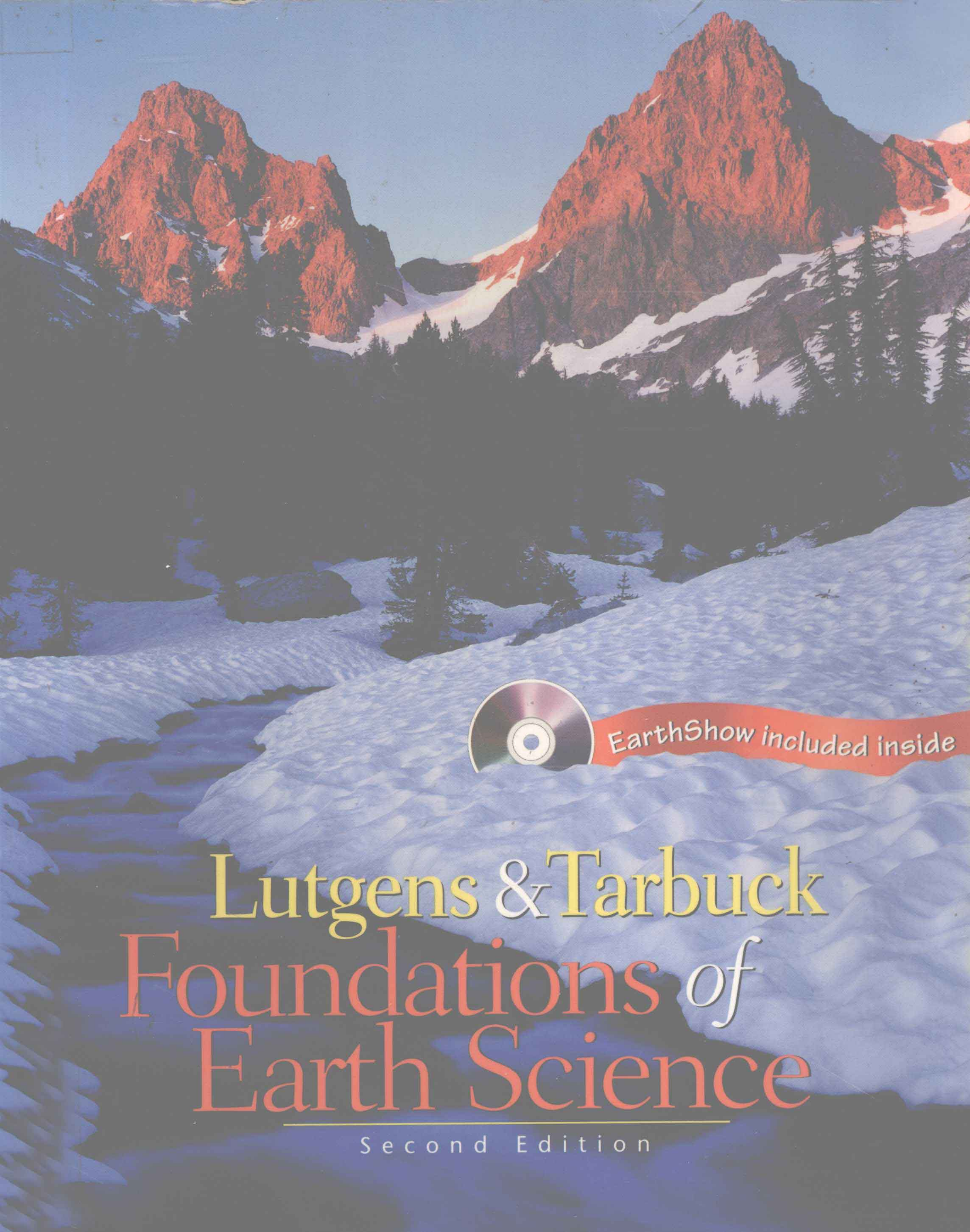

Lutgens & Tarbuck

Foundations of Earth Science

Second Edition

SECOND EDITION

Foundations of Earth Science

Frederick K. Lutgens
Edward J. Tarbuck
Illinois Central College

Illustrated by
Dennis Tasa

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Preface

Earth is a very small part of a vast universe, but it is our home. It provides the resources that support our modern society and the ingredients necessary to maintain life. Therefore, a knowledge and understanding of our planet is critical to our social well being and indeed, vital to our survival.

In recent years, media reports have made us increasingly aware of our place in the universe and the forces at work in our physical environment. We are also beginning to learn that human interactions with natural systems can upset delicate balances. News stories inform us of new discoveries in the solar system and beyond. Daily reports remind us of the destruction caused by hurricanes, earthquakes, floods, and landslides. We have been made aware of ozone depletion, potential global warming, and growing environmental concerns about the oceans. To comprehend, prepare for, and solve these and other concerns requires an awareness of how science is done and the scientific principles that influence our planet, its rocks, mountains, atmosphere, and oceans.

The Second Edition of *Foundations of Earth Science*, like its predecessor, is a college-level text designed for an introductory course in Earth science. It consists of seven units that emphasize broad and up-to-date coverage of basic topics and principles in geology, oceanography, meteorology, and astronomy. The book is intended to be a meaningful, nontechnical survey for undergraduate students with little background in science. Usually these students are taking an Earth science class to meet a portion of their college's or university's general requirements.

In addition to being informative and up-to-date, a major goal of *Foundations of Earth Science* is to meet the need of beginning students for a readable and user-friendly text, a book that is a highly usable "tool" for learning basic Earth science principles and concepts. To accomplish this goal we have incorporated the following features:

Readability. The language of this book is straightforward and *written to be understood*. Clear, readable discussions with a minimum of technical language are the rule. When new terms are introduced, they are placed in **boldface** and defined. The frequent headings and subheadings also help students follow discussions and identify the important ideas presented in each chapter.

Illustrations and Photographs. The Earth sciences are highly visual. Therefore, photographs and artwork are a very important part of an introductory book. *Foundations of Earth Science*, Second Edition contains hundreds of high-quality photographs that were carefully selected to aid understanding, add realism, and heighten the interest of the reader.

Many illustrations were revised and redesigned for the Second Edition so that ideas and concepts are presented even more clearly and realistically than before. The extensive art program was carried out by Dennis Tasa, a gifted artist and respected Earth science illustrator.

Focus on Learning. To assist student learning, every chapter opens with a series of questions. Each question alerts the reader to an important idea or concept in the chapter. When a chapter has been completed, four useful devices help students review. First, a helpful summary—**The Chapter in Review**—recaps all of the major points. Next is a checklist of **Key Terms** with page references. Learning the language of Earth science helps students learn the material. This is followed by **Questions for Review** that help students examine their knowledge of significant facts and ideas. Finally, a twenty-item chapter test—**Testing What You Have Learned**—wraps up the chapter-end review.

Acknowledgments

Writing a college textbook requires the talents and cooperation of many individuals. Working with Dennis Tasa, who is responsible for all of the outstanding illustrations, is always special for us. We not only value his outstanding artistic talents and imagination, but his friendship as well.

We are also grateful to Professor Ken Pinzke at Belleville Area College. In addition to his many helpful suggestions regarding the manuscript, Ken prepared the chapter-opening questions and the chapter-end summaries and tests that help make the book a usable tool for beginning students. Professor Pinzke is also responsible for preparing the *Student Study Guide* and *Laboratory Manual* that accompany the text.

Our students remain our most effective critics. Their comments and suggestions continue to help us maintain our focus on readability and understanding.

Special thanks goes to those colleagues who prepared in-depth reviews of the manuscript. Their critical comments and thoughtful input helped guide our work and clearly strengthened the text. We wish to thank:

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We also want to acknowledge the team of professionals at Prentice Hall. Thanks to Editor in Chief Paul Corey. We sincerely appreciate his continuing strong support for excellence and innovation. Thanks also to our editor Dan Kaveney. His strong communication skills and energetic style contributed greatly to the project. The production team, led by Ed Thomas, has done an outstanding job. They are true professionals with whom we are very fortunate to be associated.

Fred Lutgens
Ed Tarbuck

The Teaching and Learning Package

The authors and publisher have been pleased to work with a number of talented people to produce an excellent supplements package. This package includes the traditional supplements that students and professors have come to expect from authors and publishers, as well as some new kinds of supplements that involve electronic media.

For the Student

EarthShow CD-ROM

Each copy of *Foundations of Earth Science*, Second Edition comes with *EarthShow*, created by professional photographer and renowned geologic educator, Parvinder Sethi of Radford University. This provides students with a wide array of visual and audio resources for the study of Earth science. This technology has been extensively tested, and has proven to be a very effective study tool.

Internet Support

This site, specific to the text, contains numerous review exercises (from which students get immediate feedback), exercises to expand one's understanding of Earth science, and resources for further exploration. This Web site provides an excellent platform from which to start using the Internet for the study of Earth science. Please visit the site at **http://www.prenhall.com/lutgens**.

Geosciences on the Internet: A Student's Guide

Written by Andrew T. Stull and Duane Griffin, this is a student's guide to the Internet and World Wide Web specific to geology. *Geosciences on the Internet* is available at no cost to qualified adopters of the text. Please contact your local Prentice Hall representative for details.

Study Guide

Written by experienced college educator Ken Pinzke in conjunction with the authors, the *Study Guide* complements the text by providing students with additional tools for learning Earth science more effectively. Each chapter of the *Study Guide* contains a chapter overview, learning objectives, a comprehensive review, key terms, a vocabulary review, and a practice test with corresponding answers. Professor Pinzke's publications have helped thousands of students master the Earth sciences.

For the Professor

Transparency Set
More than 125 full-color acetates of illustrations from the text are available free of charge to qualified adopters.

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***The New York Times—Themes of the Times*—Changing Earth**

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In this manual Ken Pinzke gives new instructors the benefit of his years of teaching experience and experienced instructors a ready source of new ideas to complement their teaching style. The *Manual* contains a variety of lecture outlines, teaching tips, advice on how to integrate visual supplements, and many suggested test questions.

Test Item File
The *Test Item File* provides instructors with a wide variety of test questions.

PH Custom Test
Based on the powerful testing technology developed by Engineering Software Associates, Inc. (ESA), *Prentice Hall Custom Test* allows instructors to create and tailor exams to their own needs. With the online testing program, exams can also be administered online and data can then be automatically transferred for evaluation. The comprehensive desk reference guide is included along with online assistance.

For the Laboratory

Applications and Investigations in Earth Science
Written by Ed Tarbuck, Fred Lutgens, and Ken Pinzke, this full-color laboratory manual contains 22 exercises that provide students with hands-on experiences in geology, oceanography, meteorology, astronomy, and Earth science skills.

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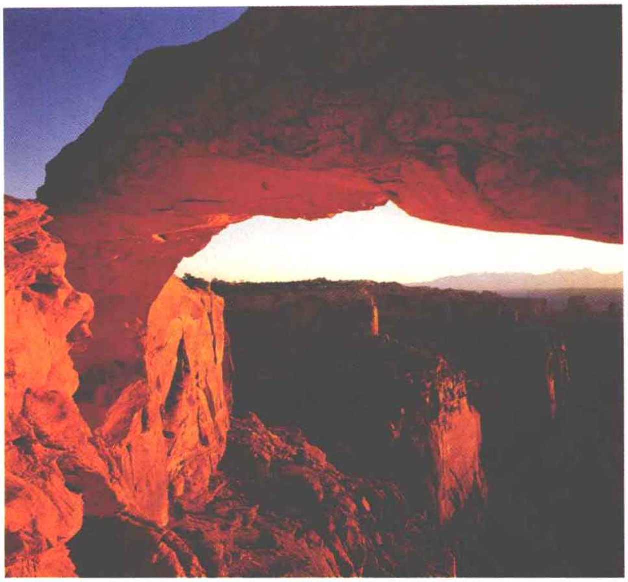

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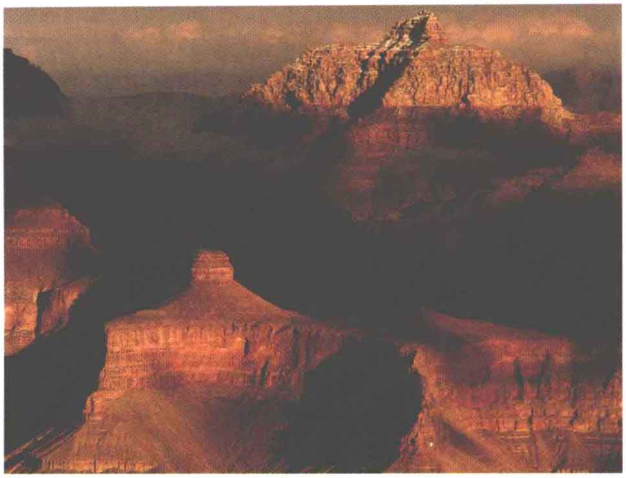

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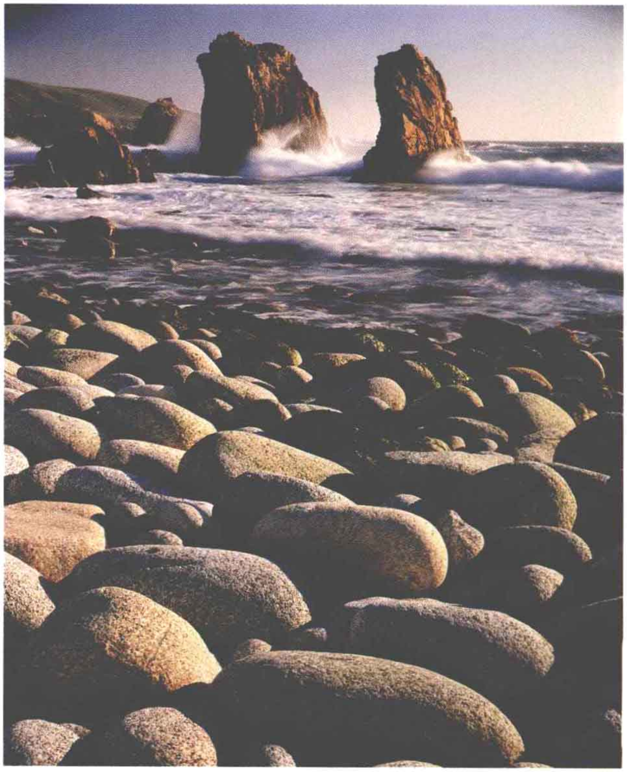

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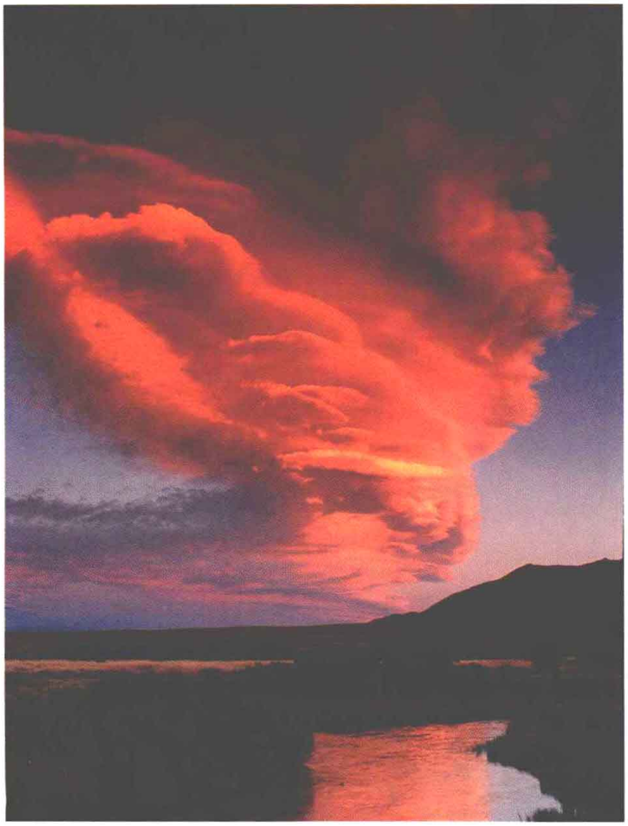

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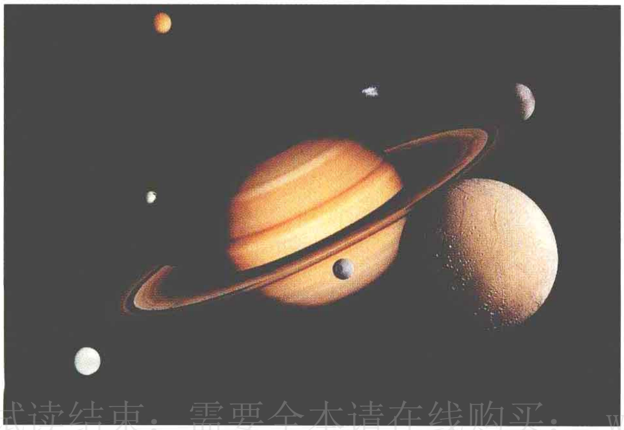

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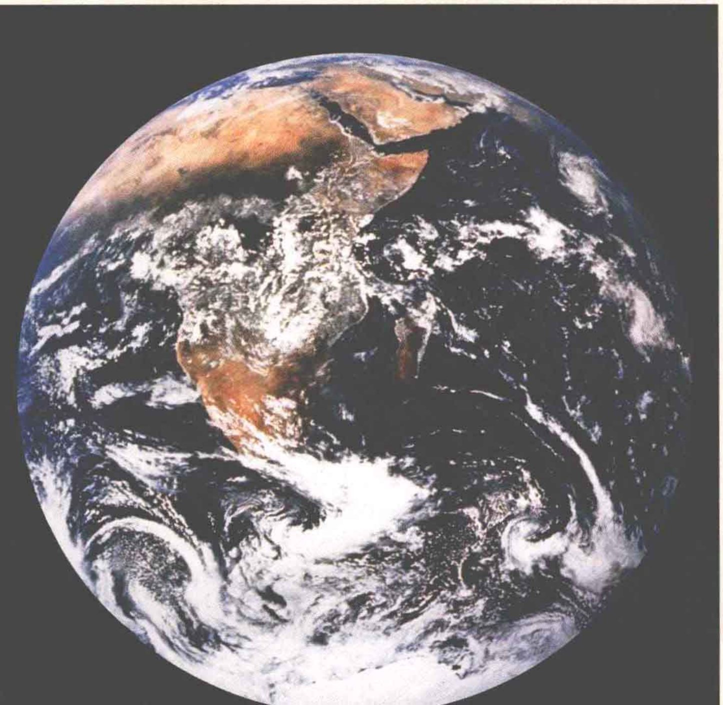
Introduction

A View of Earth

A view of Earth from space gives us a unique perspective of our planet (Figure I.1). At first, it may strike us that Earth is a fragile-appearing sphere surrounded by the blackness of space. In fact, it is just a speck of matter in a vast universe. As we look more closely at our planet from space, it becomes clear that Earth is much more than rock and soil. The swirling clouds suspended in the atmosphere and the vast global ocean are just as prominent as the continents.

From such a vantage point we can appreciate why Earth's physical environment is traditionally divided into three major parts: the solid earth; the water portion of our planet, the hydrosphere; and Earth's gaseous envelope, the atmosphere. However, our environment is highly integrated. It is not dominated by rock, water, or air alone. Rather, it is characterized by continuous interactions as air comes in contact with rock, rock with water, and water with air. Moreover, the biosphere, which is the totality of all plant and animal life on our planet, interacts with each of the three physical realms and is an equally integral part of Earth.

Figure I.1 Africa and Arabia are prominent in this image of Earth taken from Apollo 17. The tan cloud-free zones over the land coincide with major desert regions. The band of clouds across central Africa is associated with a much wetter climate that in places sustains tropical rain forests. The dark blue of the oceans and the swirling cloud patterns remind us of the importance of the oceans and the atmosphere. Antarctica, a continent covered by glacial ice, is visible at the South Pole. *(Courtesy of NASA-Science Source-Photo Researchers, Inc.)*



The interactions among Earth's four spheres are uncountable. Figure I.2 provides an easy-to-visualize example. The shoreline is an obvious meeting place for rock, water, and air. In this scene, ocean waves that were created by the drag of air moving across the water are breaking against the rocky shore. The force of the water can be powerful and the erosional work that is accomplished can be great.

Let us take a brief tour of Earth's four "spheres." Earth is sometimes called the *blue planet*. Water more than anything else makes Earth unique. The **hydrosphere** is a dynamic mass of water that is continually on the move, from the oceans to the atmosphere, to the land, and back to the ocean again. The global ocean is certainly the most prominent feature of the hydrosphere, blanketing nearly 71 percent of Earth's surface and accounting for about 97 percent of Earth's water. However, the hydrosphere also includes the fresh water found in streams, lakes, and glaciers, as well as that found underground.

Although these latter sources constitute just a tiny fraction of the total, they are much more important than their meager percentage indicates. In addition to providing the fresh water that is so vital to life on the continents, streams, glaciers, and groundwater are responsible for sculpturing and creating many of our planet's varied landforms.

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

If, like the Moon, Earth had no atmosphere, our planet would be lifeless because many of the processes and interactions that make Earth's surface such a dynamic place could not operate. Without weathering and erosion, the face of our planet might more closely resemble the lunar surface, which has not changed appreciably in nearly 3 billion years.

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 H. Richard Johnston/Tony Stone Images)*

Lying beneath the atmosphere and the ocean is solid Earth. It is 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 Earth (Figure I.3). The crust is not a layer of uniform thickness. It is thinnest beneath the oceans and thickest where continents exist. Although the crust may seem insignificant when compared with the much thicker units of solid Earth, it was created by the same general processes that formed Earth's present structure. Thus, the crust is important in understanding the history and nature of our planet.

Much of our study of Earth focuses on the more accessible surface features. Fortunately, these features represent the outward expressions of Earth's dynamic interior. By examining the most prominent surface features and their global extent, we can obtain clues to the dynamic processes that shape our planet.

The fourth "sphere," the **biosphere,** includes all life on Earth and consists of the parts of the solid Earth, hydrosphere, and atmosphere in which living organisms can be found. Plants and animals depend on the physical environment for the basics of life. However, organisms do more than just respond to their physical environment. Through countless interactions, life-forms help maintain and alter their physical environment. Without life, the makeup and nature of solid Earth, hydrosphere, and atmosphere would be very different.

The Earth Sciences

Earth Science is the name for all the sciences that collectively seek to understand Earth and its neighbors in space. It includes geology, oceanography, meteorology, and astronomy.

In this book, Units One through Four focus on the science of **geology,** a word that literally means "study of Earth." Geology is traditionally divided into two broad areas—physical and historical.

Physical geology examines the materials that make up Earth and seeks to understand the many processes that operate beneath and upon its surface. Earth is a dynamic, ever-changing planet. Forces within Earth create earthquakes, build mountains, and produce volcanic structures. At the surface, external processes break rock apart and sculpture a

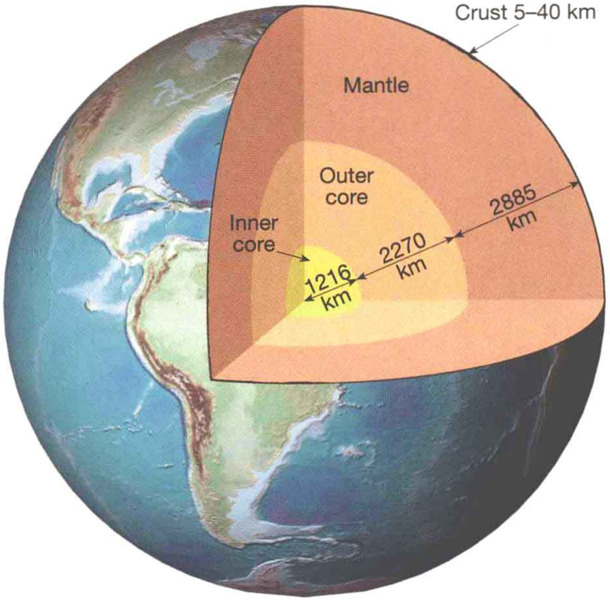


Figure I.3 View of Earth's layered structure. The inner core, outer core, and mantle are drawn to scale, but the thickness of the crust is exaggerated by about five times.

broad array of landforms. The erosional effects of water, wind, and ice result in diverse landscapes. Because rocks and minerals form in response to Earth's internal and external processes, their interpretation is basic to an understanding of our planet.

In contrast to physical geology, the aim of *historical geology* is to understand the origin of Earth and the development of the planet through its 4.6-billion-year history. It strives to establish an orderly chronological arrangement of the multitude of physical and biological changes that have occurred in the geologic past (Figure I.4).

Unit Five, *The Oceans,* is devoted to oceanography. **Oceanography** is actually not a separate and distinct science. Rather, it involves the application of all sciences in a comprehensive and interrelated study of the oceans in all their aspects and relationships. Oceanography integrates chemistry, physics, geology, and biology. It includes the study of the composition and movements of seawater, as well as coastal processes, seafloor topography, and marine life.

Unit Six, *The Atmosphere,* examines the mixture of gases that is held to the planet by gravity and thins rapidly with altitude. Acted on by the combined effects of Earth's motions and energy from the Sun, the formless and invisible atmosphere reacts by producing an infinite variety of weather, which, in turn, creates the basic pattern of global climates. **Meteorology** is the study of the atmosphere and the processes that produce weather and climate. Like oceanography, meteorology involves the application of other sciences in an integrated study of the thin layer of air that surrounds Earth.

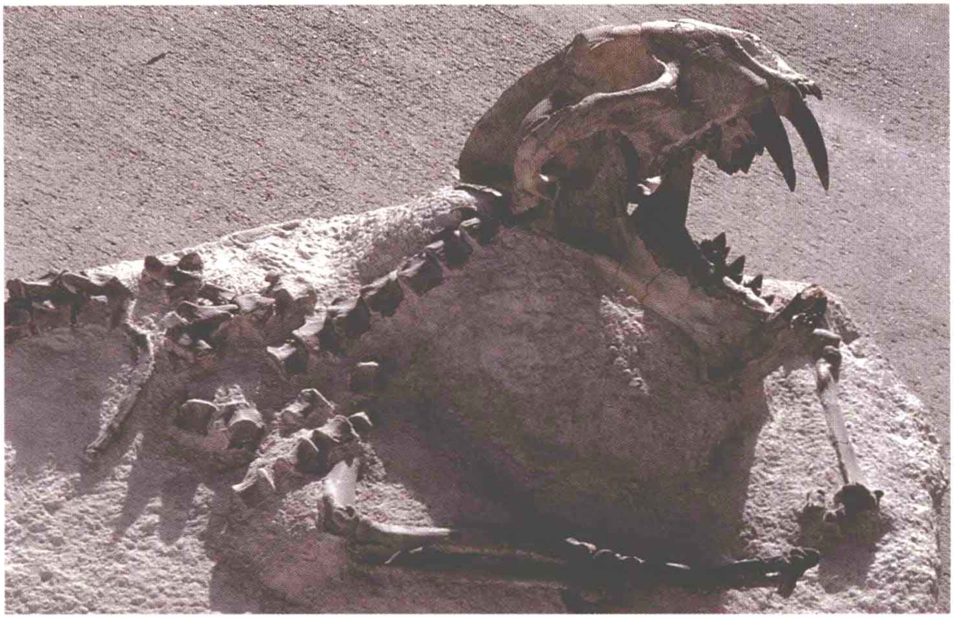


Figure I.4 Partially exposed skeleton of an extinct sabre-toothed cat. This lion-sized cat roamed the White River Badlands of South Dakota during the Oligocene epoch. The aim of historical geology is to understand the development of Earth and its life through time. Fossils are essential tools in that quest. *(Photo by T.A. Wiewandt/DRK Photo)*

Unit Seven, *Astronomy,* demonstrates that the study of Earth is not confined to investigations of its four interacting "spheres." The Earth sciences also attempt to relate our planet to the larger universe. Because Earth is related to all other objects in space, the science of **astronomy**—the study of the universe—is very useful in probing the origins of our own environment. Because we are so closely acquainted with the planet on which we live, it is easy to forget that Earth is just a tiny object in a vast universe. Indeed, Earth is subject to the same physical laws that govern the countless other objects that populate the expanses of space. Thus, to understand explanations of our planet'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.

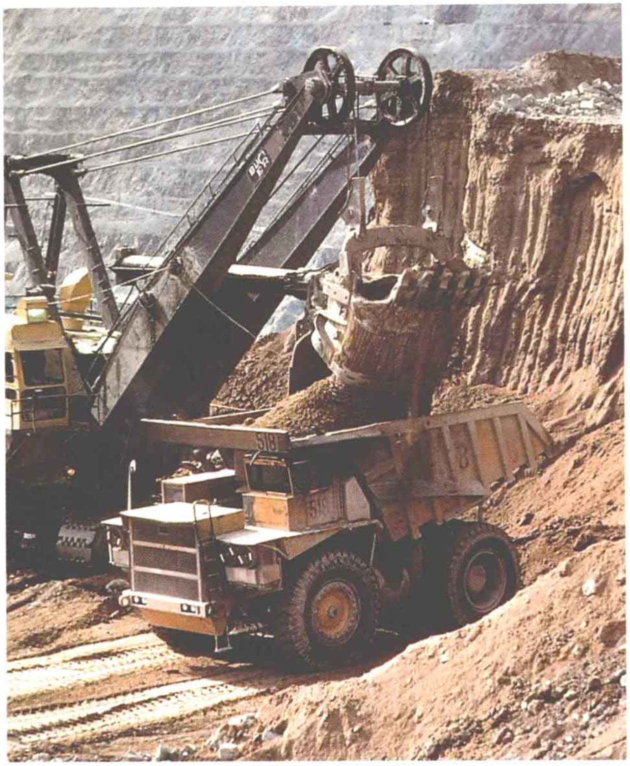


Figure I.5 As world population grows, demand for mineral and energy resources climbs. Earth scientists must deal with the search for additional supplies of traditional and alternative resources as well as the environmental impact of their extraction and use. *(Photo by Craig Aurness/WestLight)*

Resources and Environmental Issues

Environment refers to everything that surrounds and influences an organism. Some of these things are biological and social, but others are nonliving. The factors in this latter category are collectively called our *physical environment.* The physical environment encompasses water, air, soil, and rock, as well as conditions such as temperature, humidity, and sunlight. The phenomena and processes studied by the Earth sciences are basic to an understanding of the physical environment. In this sense, most of Earth science may be characterized as environmental science.

However, when the term *environmental* is applied to Earth science today, it usually means relationships between people and the physical environment. Application of the Earth sciences is necessary to understand and solve problems that arise from these interactions.

Resources

Resources are an important environmental concern. Resources range from water and soil to metallic and nonmetallic minerals and energy. These materials are the very 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 (Figure I.5).

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 nonmetallic 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. Common examples are plants and animals for food, natural fibers for clothing, and forest products for lumber and paper. 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 form, the processes that create them are so slow that significant deposits take millions of years to accumulate. In essence, 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.

How long will the remaining supplies of basic resources last? How long can we sustain the rising standard of living in today's industrial 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 demand and a growing world population, it is important that we have some understanding of our present and potential resources.

Environmental Problems

In addition to the quest for adequate mineral and energy resources, the Earth sciences must also deal with a broad array of other environmental problems. Some are local, some are regional, and still others are global in extent. Serious difficulties face developed and developing nations alike. Urban air pollution, acid rain, ozone depletion, and global warming are just a few that pose significant threats (Figure I.6). 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.

In addition to human-induced and human-accentuated problems, people must also cope with the many natural hazards posed by the physical environment (Figure I.7). Earthquakes, landslides, floods, and hurricanes are just four of the many risks. Others such as drought, although not as spectacular, are nevertheless equally important environmental concerns. In many cases, the threat of natural hazards is aggravated by increases in population as more people crowd into places where an impending danger exists or attempt to cultivate marginal lands that should not be farmed.

It is clear that as world population continues its rapid growth, pressures on the environment will increase as well. Therefore, an understanding of Earth is not only essential for the location and recovery of basic resources, but also for dealing with the human impact on the environment and minimizing

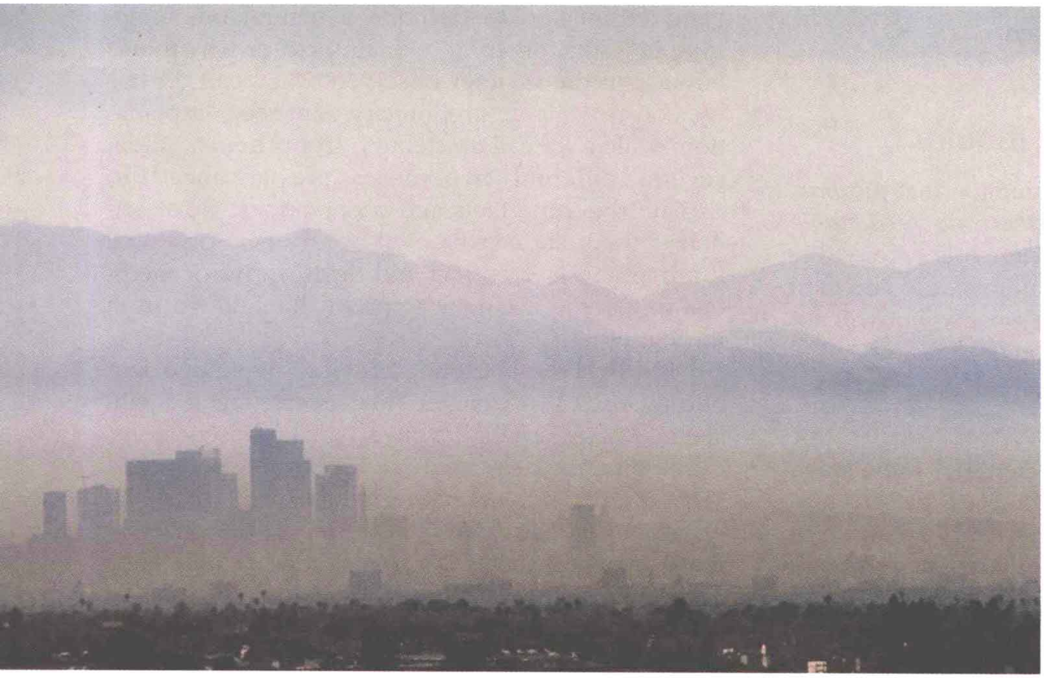


Figure I.6 Air pollution in downtown Los Angeles. Air quality problems affect many cities. Fuel combustion by motor vehicles and power plants provides a high proportion of the pollutants. Meteorological factors determine whether pollutants remain "trapped" in the city or are dispersed. *(Photo by Ted Spiegel/Black Star)*

Figure I.7 A helicopter rescues a man stranded on the roof of his Olivehurst, California, home after a levee broke along the Feather River. Huge floods occurred in California's Central Valley in January 1997. There are many Earth processes and phenomena that are hazardous to people, including volcanoes, earthquakes, landslides, floods, hurricanes, and tornadoes. *(Photo by John Trotter/The Sacramento Bee)*

the effects of natural hazards. Knowledge about our planet and how it works is necessary to our survival and well-being. Earth is the only suitable habitat we have, and its resources are limited.

The Nature of Scientific Inquiry

All science is based on the assumption that the *natural world behaves in a consistent and predictable manner.* The overall goal of science is to discover the underlying patterns in the natural world and then to use this knowledge to predict what will or will not happen, given certain facts or circumstances.

Collecting Facts

The development of new scientific knowledge involves some basic, logical processes that are universally accepted. To determine what is occurring in the natural world, scientists collect *facts* through observation and measurement (Figure I.8). These data are essential to science and serve as the springboard for the development of scientific theories.

Hypothesis

Once facts have been gathered and principles have been formulated to describe a natural phenomenon, investigators try to explain how or why things happen in the manner observed. They can do this by constructing a preliminary, untested explanation, which we call a scientific **hypothesis.** Often, several different hypotheses are advanced to explain the same facts and observations. Next, scientists think about what will occur or be observed if a hypothesis is correct and devise ways or methods to test the accuracy of predictions drawn from the hypothesis.

If a hypothesis cannot be tested, it is not scientifically useful, no matter how interesting it might seem. Testing usually involves making observations, developing models, and performing experiments. What if test results do not turn out as expected? One possibility is that there were errors in the observations or experiments. Of course, another possibility is that the hypothesis is not valid. Before rejecting the hypothesis, the tests may be repeated or new tests may be devised. The more tests the better.