

A scenic landscape photograph of a mountain valley. In the foreground, two waterfalls cascade over dark, jagged rock formations. A river flows through the center of the valley, surrounded by green grass and patches of snow. In the background, dark, silhouetted mountains rise against a sky filled with soft, orange and pink clouds, suggesting a sunrise or sunset.

# *Earth Science*

Ninth Edition

Tar buck • Lut gens



# Earth Science

*Ninth Edition*

Edward J. Tarbuck  
Frederick K. Lutgens

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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.

*Earth Science*, ninth edition, like its predecessors, is a college-level text designed for an introductory course that often has the same name as this text. It consists of four 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 *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.

## Distinguishing 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. The frequent headings and subheadings help students follow discussions and identify the important ideas presented in each chapter. In the ninth edition, improved readability was achieved by examining chapter organization and flow, and writing in a more personal style. Large portions of the text were substantially rewritten in an effort to make the material more understandable.

## Illustrations and Photographs

The Earth sciences are highly visual. Therefore, photographs and artwork are a very important part of an introductory book. *Earth Science*, ninth edition, contains dozens of new high-quality photographs that were carefully selected to aid understanding, add realism, and heighten the interest of the reader.

The illustrations in each new edition of *Earth Science* keep getting better and better. In the ninth edition more than 100 pieces of line art were redesigned. The new art illustrates ideas and concepts more clearly and realistically than ever before. The art program was carried out by Dennis Tasa, a gifted artist and respected Earth science illustrator.

## Focus on Learning

**New to the ninth edition:** To assist student learning, every chapter now concludes with a *Chapter Summary*. When a chapter has been completed, three useful devices help students review. First, the *Chapter Summary* 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 *Review Questions* that help students examine their knowledge of significant facts and ideas. Each chapter closes with some suggested Web sites for further exploration. Moreover, students are reminded to visit the *all-new and greatly improved* Web site for *Earth Science*, ninth edition (<http://www.prenhall.com/tarbuck>). It contains many excellent opportunities for review and exploration.

## Earth as a System



An important occurrence in modern science has been the realization that Earth is a giant multi-dimensional system. Our planet consists of many separate but interacting parts. A change in any one part can produce changes in any or all of the other parts—often in ways that are neither obvious nor immediately apparent. Although it is not possible to study the entire system at once, it is possible to develop an awareness and appreciation for the concept and for many of the system's important interrelationships. Therefore, beginning with an expanded discussion in the Introduction, the theme of "Earth as a system" keeps recurring through all major units of the book. It is a thread that "weaves" through the chapters and helps tie them together.

Several new and revised special interest boxes relate to *Earth as a system*. To remind the reader of this important theme, the small icon you see at the beginning of



this section is used to mark these boxes. Finally, each chapter concludes with a section on *Examining the Earth System*. The questions and problems found here are intended to develop an awareness and appreciation for some of the Earth system's many interrelationships.

## People and the Environment



Because knowledge about our planet and how it works is necessary to our survival and well being, the treatment of environmental issues has always been an important part of *Earth Science*. Such discussions serve to illustrate the relevance and application of Earth science knowledge. With each new edition this focus has been given greater emphasis. This is certainly the case with the ninth edition. The text integrates a great deal of information about the relationship between people and the natural environment and explores applications of the Earth sciences to understanding and solving problems that arise from these interactions.

In addition to many basic text discussions, 17 of the text's special interest boxes involve the "People and the Environment" theme and are quickly recognized by the distinctive icon you see at the beginning of this section.

## Maintaining a Focus on Basic Principles and Instructor Flexibility

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

## More About the Ninth Edition

In addition to adding chapter summaries, strengthening the "Earth as a System" and "People and the Environment" themes and making substantial changes to the photography and art programs, much more is new to the ninth edition.

The ninth edition of *Earth Science* represents a thorough revision. *Every* part of the book was examined carefully with the dual goals of keeping topics current and improving the clarity of text discussions. Based on

feedback from reviewers and our students, we believe we have succeeded.

Of special interest is a new section on "Marine Life Zones" in Chapter 12 and a new related special interest box (Box 12.2) on "Hydrothermal Vent Communities". Moreover, Chapter 16 includes a substantial new discussion of "El Niño and Global Weather" and a related new box (Box 16.2), "Tracking El Niño from Space".

## Supplements

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



**GEODE II CD-ROM.** A revision of the popular

*GEODE CD* by Dennis Tasa of Tasa Graphic Arts, Inc., Edward J. Tarbuck, and Frederick K. Lutgens. *GEODE II* is a dynamic program that reinforces key concepts by using animations, tutorials, and interactive exercises. A special *GEODE II* icon appears throughout the book wherever a text discussion has a corresponding *GEODE II* activity. A copy of *GEODE II* has been included with this text. This special offering gives students two valuable products (*GEODE II* and the textbook) for the price of one.

**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/tarbuck>.

**Study Guide:** Written by experienced educator Kenneth Pinzke, the study guide helps students identify the important points from the text, and then provides them with review exercises, study questions, self-check exercises, and vocabulary review.

### For the Professor

**Transparency Set:** More than 150 full-color acetates of illustrations from the text are available free of charge to qualified adopters.

**Slides:** More than 200 slides of images taken from the text, many of which were taken by the authors, are also available to qualified adopters.

**Presentation Manager:** This user-friendly navigation software enables professors to custom-build multimedia presentations. *Prentice Hall Presentation Manager 3.0* contains several hundred images from the text, as well as selected animations from GEODE II. The CD-ROM allows professors to organize material in whatever order they choose; preview resources by chapter; search the digital library by keyword; integrate material from their hard drive, a network, or the Internet; or edit lecture notes and annotate images with an overlay tool. This powerful presentation tool is available at no cost to qualified adopters of the text.

**The New York Times Themes of the Times—Changing Earth:** This unique newspaper-format supplement features recent articles about geology from the pages of the *New York Times*. This supplement, available at no extra charge from your local Prentice Hall representative, encourages students to make connections between the classroom and the world around them.

**Instructor's Manual:** Written by Kenneth Pinzke of Belleville Area College, the Instructor's Manual is intended as a resource for both new and experienced instructors. It includes a variety of lecture outlines, additional source materials, teaching tips, advice about how to integrate visual supplements (including the Web-based resources), and various other ideas for the classroom.

**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.

## 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 developed the Web site, prepared the chapter summaries, and the instructor's guide. In addition, he revised the student study guide and the laboratory manual that are available to accompany *Earth Science*. Ken is an important part of our team and a valued friend as well.

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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, as always, has done an outstanding job. They are true professionals with whom we are very fortunate to be associated.

Edward J. Tarbuck  
 Frederick K. Lutgens

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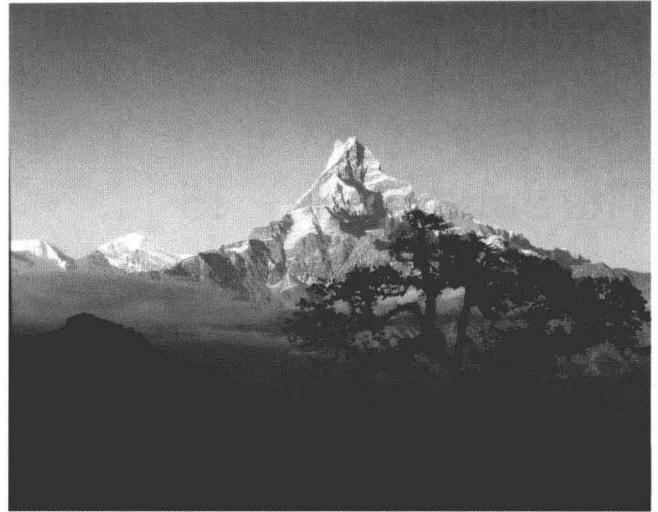
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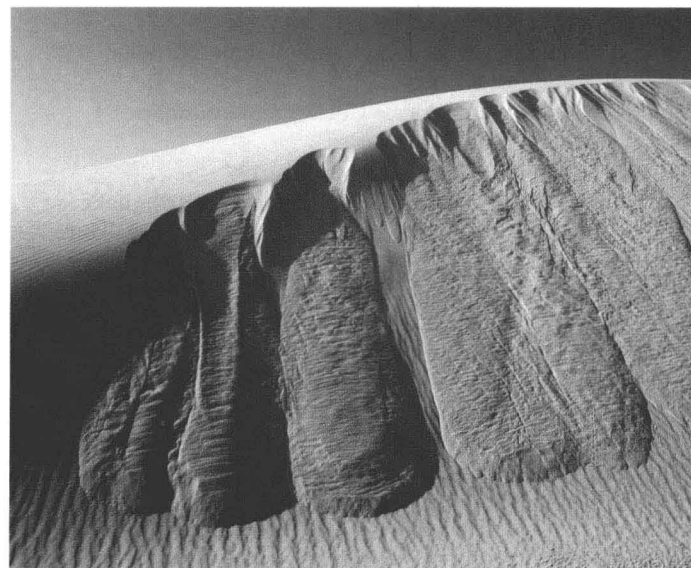
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# Introduction

The spectacular eruption of a volcano, the magnificent scenery of a rocky coast, and the destruction created by a hurricane are all subjects for the Earth scientist. The study of Earth science deals with many fascinating and practical questions about our environment (Figure I.1). What forces produce mountains? Why is our daily weather so variable? Is climate really changing? How old is Earth and how is it related to the other planets in the solar system? What causes ocean tides? What was the Ice Age like? Will there be another? Can a successful well be located at this site?

The subject of this text is **Earth science**. To understand Earth is not an easy task because our planet is not a static and unchanging mass. Rather, it is a dynamic body with many interacting parts and a long and complex history.

**Figure I.1** Sunset on Machapuchare Peak in the Himalaya's of Nepal. These mountains are the highest on Earth. Understanding the forces that created this majestic range is just one of the many areas of Earth science study. (Photo by Galen Rowell/Mountain Light Photography, Inc.)



**Figure I.2** View of Earth that greeted the *Apollo 8* astronauts as their spacecraft emerged from behind the Moon. (Courtesy of NASA)

## A View of Earth



### Introduction A View of Earth

A view such as the one in Figure I.2 provided the *Apollo 8* astronauts as well as the rest of humanity with a unique perspective of our home. Seen from space, Earth is breathtaking in its beauty and startling in its solitude. Such an image reminds us that our home is, after all, a planet—small, self-contained, and in some ways even fragile.

As we look closely at our planet from space, it becomes apparent that Earth is much more than rock and soil. In fact, the most conspicuous features in Figure I.2 are not continents, but swirling clouds suspended above the surface the vast global ocean. These features emphasize the importance of water on our planet.

The closer view of Earth from space shown in Figure I.3 helps us appreciate why the physical environment is traditionally divided into three major spheres: the water portion of our planet, the hydrosphere; Earth's gaseous envelope, the atmosphere; and, of course, the solid Earth. It should be emphasized that our environment is highly integrated and 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, the totality of life-forms on our planet, extends into each of the three physical realms and is an equally integral part of the planet. Thus, Earth can be thought of as consisting of four major spheres: the hydrosphere, atmosphere, solid Earth, and biosphere.

The interactions among the spheres of Earth's environment are uncountable. Figure I.4 provides us with one 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.

## Hydrosphere

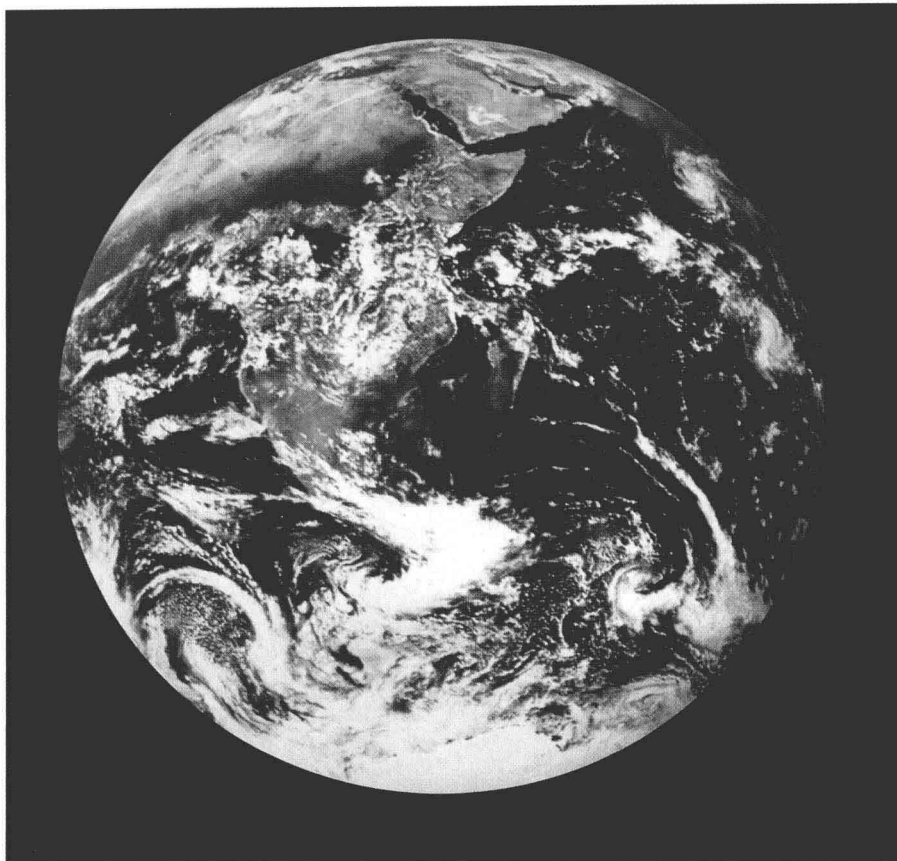
Earth is sometimes called the *blue* planet. Water more than anything else makes Earth unique. The **hydrosphere** is a dynamic mass of liquid that is continually on the move, from the oceans to the atmosphere, precipitating back to the land, and running back to the ocean again. The global ocean is certainly 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 freshwater 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 freshwater 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.

## Atmosphere

Earth is surrounded by a life-giving gaseous envelope called the **atmosphere**. This thin blanket of air is an





**Figure 1.3** Africa and Arabia are prominent in this image of Earth taken from *Apollo 17*. The tan cloud-free zones over the land coincide with the major desert regions where vegetation is relatively sparse. 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 white swirling cloud patterns remind us of the importance of the hydrosphere and the atmosphere. Antarctica, a continent covered by glacial ice, is visible at the South Pole. (Courtesy of NASA/Science Source/Photo Researchers, Inc.)

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.

If, like the Moon, Earth had no atmosphere, our planet would not only be lifeless but also many of the processes and interactions that make the 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.

### Solid Earth

Lying beneath the atmosphere and the ocean is the 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 1.5). 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. By examining the most prominent surface features and their global extent, we can obtain clues to the dynamic processes that shape our planet.

The two principal divisions of Earth's surface are the continents and the ocean basins. The most obvious

difference between these two diverse provinces is their relative levels. The average elevation of the continents above sea level is about 840 meters (2750 feet), whereas the average depth of the oceans is about 3800 meters (12,500 feet). Thus, the continents stand on the average 4640 meters (about 4.6 kilometers or nearly 3 miles) above the level of the ocean floor.

### Biosphere

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, it is important to note 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 solid Earth, hydrosphere, and atmosphere would be very different.

To summarize this brief view of Earth, we have seen that the physical environment consists of the hydrosphere, atmosphere, and solid Earth. These three parts are characterized by countless interactions. In addition, the biosphere extends into each of the spheres of the physical environment, and must also be considered an integral part of our planet.