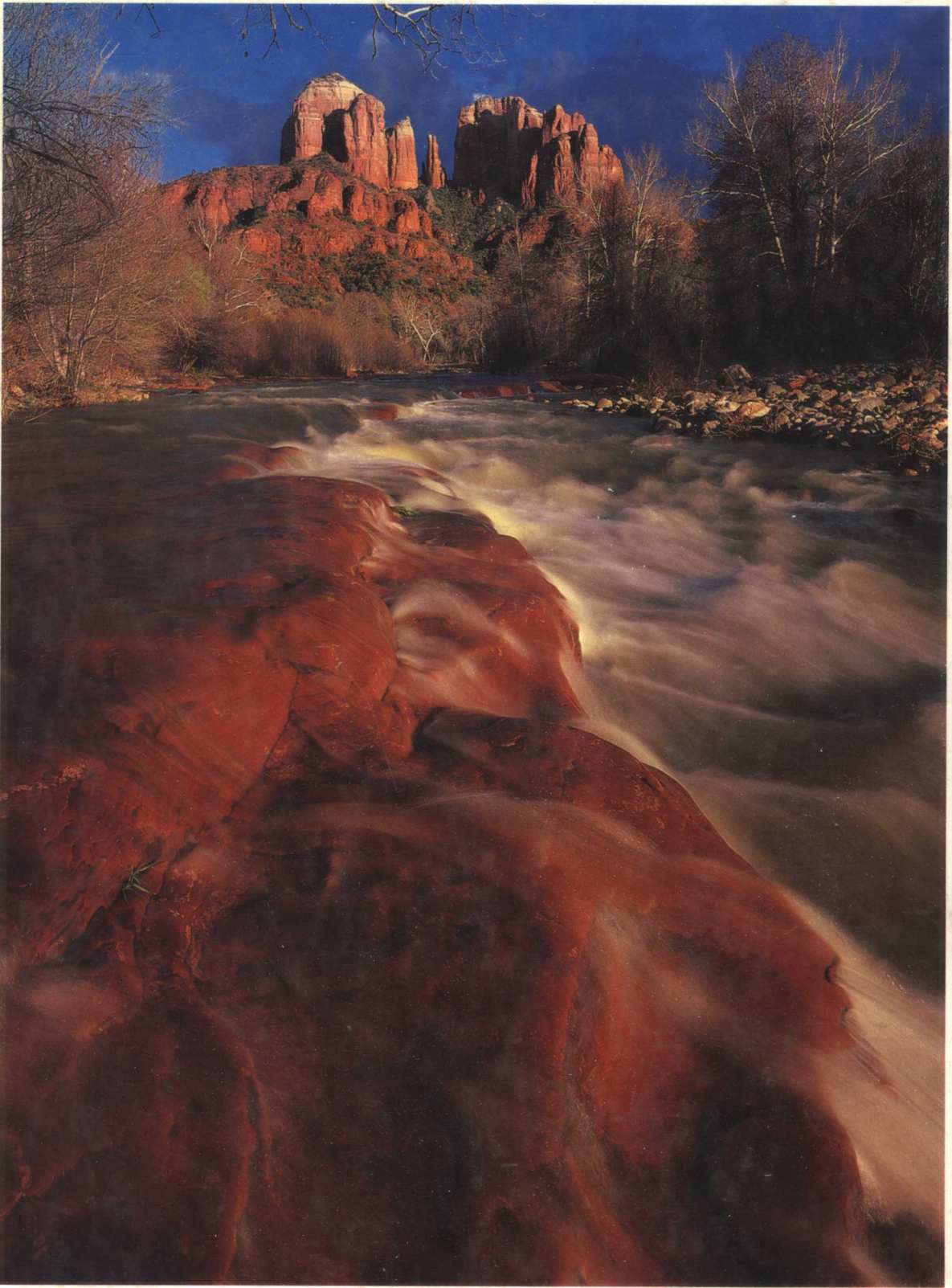


TARBUCK / LUTGENS



EARTH SCIENCE
FIFTH EDITION

EARTH SCIENCE

FIFTH EDITION

**Edward J. Tarbuck
Frederick K. Lutgens**

ILLINOIS CENTRAL COLLEGE

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PREFACE

In recent years, there has been an increased awareness and concern for our physical environment. Probes of our solar system, exploration of the bottom of the sea, and the development of a revolutionary theory in geology have called for new explanations of the earth's long and complex history. These events and many more have helped to include the earth sciences among the most dynamic and exciting disciplines. To help the beginning student share in this excitement and gain a basic understanding of the physical environment, we have attempted to write a text that is highly usable—a tool for learning the basic concepts of earth science. To achieve this goal, the Fifth Edition of *Earth Science*, like its four predecessors, is written concisely, contains useful learning aids, and is well illustrated. Each chapter begins with a brief overview, and concludes with review questions and a list of key terms. The key terms are in boldface type in the body of the text for easy reference. Furthermore, careful attention has been given to the line drawings and photographs, which constitute an important part of the text by serving to clarify concepts and make them less abstract.

Earth Science is a broad and nonquantitative survey at the introductory level of topics in geol-

ogy, oceanography, meteorology, and astronomy. The Fifth Edition of *Earth Science* has been thoroughly revised and updated. Extensive rewriting has made many discussions more timely and more readable. The Fifth Edition contains substantial new material including a new section on the nature of scientific inquiry in the Introduction. Additional treatment of environmental topics includes expanded discussions of geothermal energy, earthquake destruction and prediction, and volcanic hazards. A major new section on shoreline erosion problems has been added. The treatment of plate tectonics has been brought up to date, and there has been a substantial revision of the discussion on mountain building. Chapter 9, Geologic Time and Earth History, has been strengthened with expanded sections on radiometric dating, relative dating, and unconformities. An entirely new section dealing with life of the geologic past has been added.

Among the changes to the unit on the atmosphere is new material on tornadoes as well as an updating of discussions on human impact on global climate and intentional weather modification. The astronomy unit includes rewritten discussions on optical telescopes and H-R diagrams in

addition to an updated treatment of lunar history and new data from *Voyager 2* on Uranus and its satellite.

In previous editions of *Earth Science* special attention was given to the quality of photographs and artwork. This emphasis has been maintained in the Fifth Edition, which includes more than 60 new color photographs. These images were selected not only to instruct students, but also to heighten their interest. Furthermore, because we feel a carefully planned and executed art program is critical in a text such as ours, the already excellent art program has been strengthened. There are 115 new or substantially redrawn pieces of line art.

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. 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 thank the many individuals, institutions, and state and federal agencies that provided information, photographs, and illustrations for use in this text. Special gratitude goes to those colleagues who were kind enough to review all or part of the manuscript. Over the years their critical comments have greatly improved this text. Our thanks go to Diane Weber who typed much of the manuscript, Dennis Tasa for his imaginative production of the line art, and to Rex Davidson, our production editor, who along with the many other fine people at Merrill Publishing skillfully transformed our manuscript into a finished product. Finally, a special debt of gratitude goes to our wives, Karen and Nancy, for their patience, encouragement, and help.

EJT
FKL

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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 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 (Figure I.2). Indeed, the most conspicuous features are not the continents but the swirling



FIGURE I.1
View of the earth that greeted *Apollo 8* astronauts as their spacecraft came from behind the moon. (Courtesy of NASA)



FIGURE I.2

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

clouds suspended above the surface and the vast global ocean. From such a vantage point, we can appreciate why the earth 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 interaction as air comes into contact with rock, rock with water, and water with air.

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).*

*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.

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 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

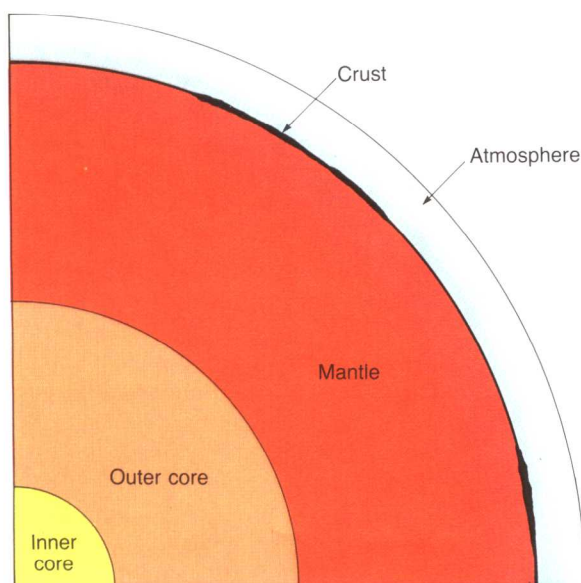


FIGURE 1.3

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.

fraction of the total, they are much more important than their meager percentage indicates, for they are 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.

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 com-

position 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 necessary to learn something about the other members of our solar system. Moreover, it is necessary 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.

THE NATURE OF SCIENTIFIC INQUIRY

As members of a modern society, we are constantly reminded of the significant benefits derived from scientific investigations. What exactly is the nature of this inquiry?

All science is based on the assumption that the natural world behaves in a consistent and predictable manner. This implies that the physical laws which govern the smallest atomic particles also operate in the largest, most distant galaxies. Evidence for the existence of these underlying patterns can be found in the physical world as well as the biological world. For example, the same biochemical processes and the same genetic codes

that are found in bacterial cells are also found in human cells. The overall goal of science is to discover the underlying patterns in the natural world and then to use this knowledge to make predictions about what should or should not be expected to happen given certain facts or circumstances.

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 scientific *facts* through observation and measurement (Figure 1.4). These data are essential to science and serve as the springboard for the development of scientific theories and laws.

Once a set of scientific facts (or principles) that describe a natural phenomenon are gathered, in-

vestigators try to explain how or why things happen in the manner observed. They can do this by constructing a tentative (or untested) explanation, which we call a scientific *hypothesis*. Often several hypotheses are advanced to explain the same factual evidence. For example, there are currently five major hypotheses that have been proposed to explain the origin of the earth's moon. Until recently, the most widely held hypothesis argued that the moon and the earth formed simultaneously from the same cloud of nebular dust and gases. A newer hypothesis suggests that a Mars-sized body impacted the earth, thereby ejecting a huge quantity of material into earth orbit that eventually accumulated into the moon. Both hypotheses will be submitted to rigorous testing that will undoubtedly result in the modification or rejection of one, or perhaps both, of these proposals. The history of science is littered with discarded hypotheses. One of the best known is the idea that the earth was at the center of the universe, a proposal that was supported by the apparent daily motion of the sun, moon, and stars around the earth.

When a hypothesis has survived extensive scrutiny and when competing hypotheses have been eliminated, a hypothesis may be elevated to the status of a scientific *theory*. A scientific theory is a well-tested and widely accepted view that scientists agree best explains certain observable facts. However, scientific theories, like scientific hypotheses, are accepted only provisionally. It is always possible that a theory which has withstood previous testing may eventually be disproven. As theories survive more testing, they are regarded with higher levels of confidence. Theories that have withstood extensive testing, as for example, the theory of plate tectonics or the theory of evolution, are held with a very high degree of confidence.

Some concepts in science are formulated into scientific laws. A scientific *law* is a generalization about the behavior of nature from which there has been no known deviation after numerous observations or experiments. Scientific laws are generally narrower in scope than theories and can usually be expressed mathematically. Examples include Newton's laws of motion and the laws of thermodynamics. Scientific laws describe what happens

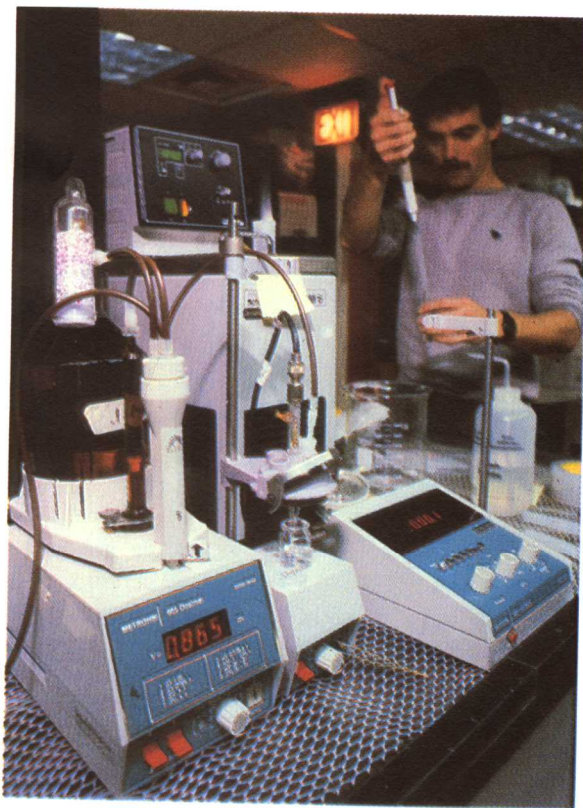


FIGURE 1.4

Scientist analyzing sea-floor samples collected by the drilling ship *JOIDES Resolution*. (Courtesy of Ocean Drilling Program)

FIGURE I.5

Temperature probe of active lava flow, Kilauea Caldera.
(Photo by Norman Banks,
U.S. Geological Survey)



in nature, but they do not explain how or why things happen this way. Also, unlike hypotheses, which are inventions of the mind to explain scientific facts, scientific laws are based on observations and measurements and thus are rarely overthrown or seriously modified. Nevertheless, even scientific laws are not necessarily “perpetual truths.” As the mathematician Jacob Bronowski so ably stated, “Science is a great many things, but in the end they all return to this: Science is the acceptance of what works and the rejection of what does not.”

The processes just described, in which scientists gather facts through observations and formulate scientific hypotheses, theories, and laws, is called the *scientific method*. Contrary to popular belief, the scientific method is not a standard recipe that scientists apply in a routine manner to unravel the secrets of our natural world. Neither is this process a haphazard one. Some scientific

knowledge is gained through the following steps: (1) the collection of scientific facts (or laws) through observation and measurement (Figure I.5); (2) the development of a working hypothesis to explain these facts; (3) construction of experiments to validate the hypothesis; and (4) the acceptance, modification, or rejection of the hypothesis based on extensive testing. Other scientific discoveries represent purely theoretical ideas, which stood up to extensive examination. Still other scientific advancements have been made when a totally unexpected happening occurred during an experiment. These so-called serendipitous discoveries are more than pure luck; for as Louis Pasteur said, “In the field of observation, chance favors only the prepared mind.” Since scientific knowledge is acquired through several avenues, it might be best to describe the nature of scientific inquiry as the *methods* of science, rather than *the* scientific method.

PART ONE

