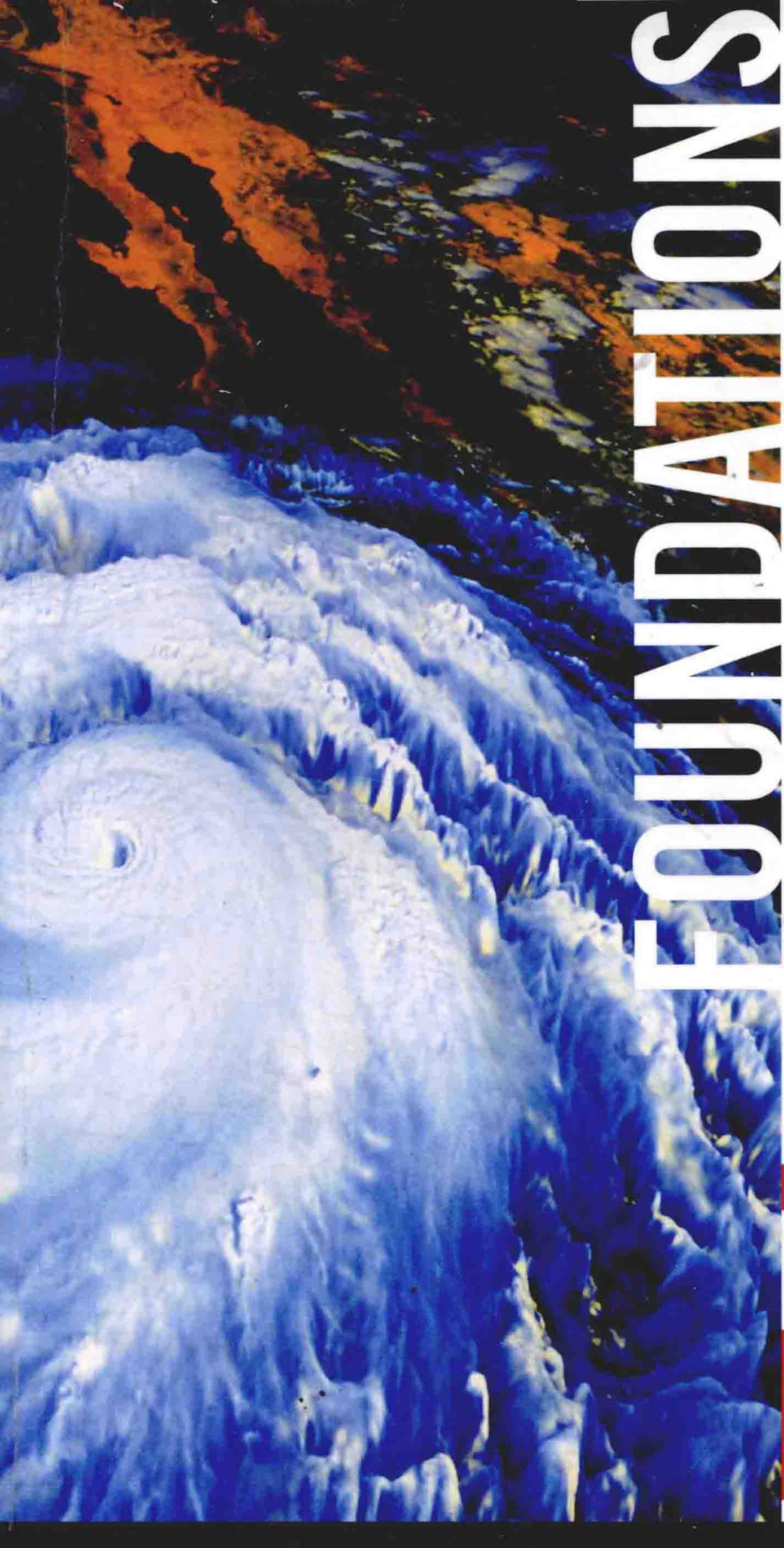

FOUNDATIONS of EARTH SCIENCE

Lutgens

Tarbuck

GEO 1013

THE THIRD PLANET

Custom Edition for the University of Texas at San Antonio

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CONTENTS

From *Foundations of Earth Science*, Third Edition,
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From *Earth: An Introduction to Physical Geology*, Seventh Edition,
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Introduction

A View of Earth

Introduction
A View of Earth

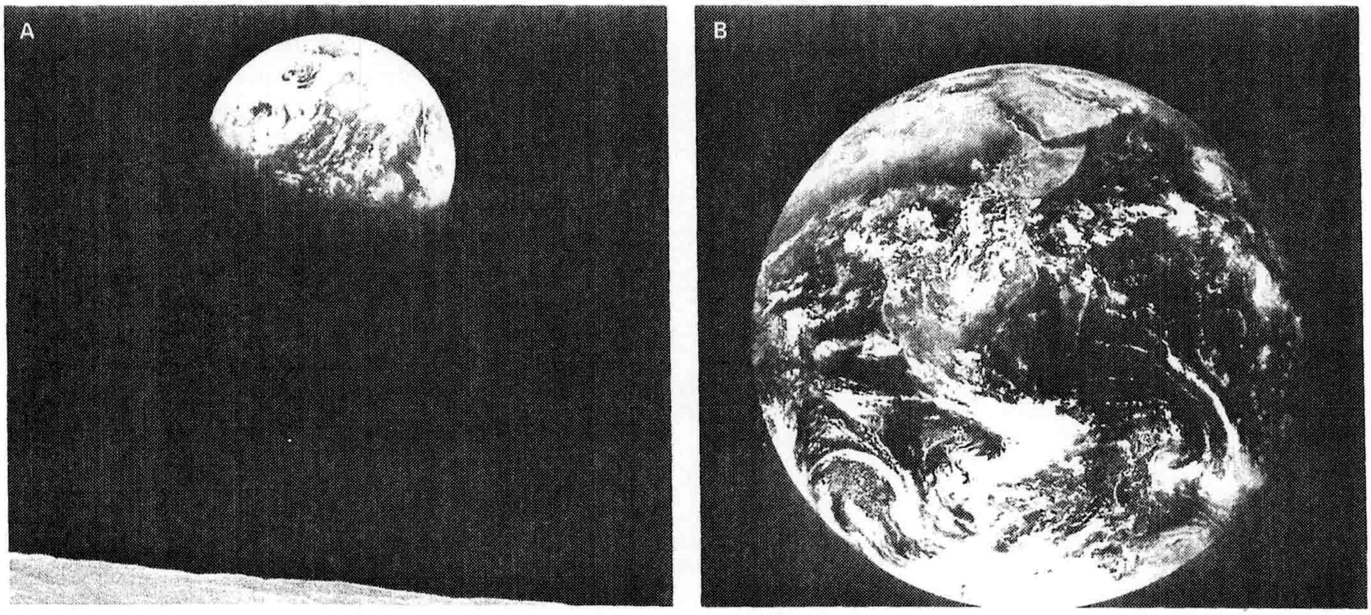
A view such as the one in Figure I.1A provided the *Apollo 8* astronauts as well as the rest of humanity with a unique perspective of our home. Seen from space, Earth is breathtaking in its beauty and startling in its solitude. Such an image reminds us that our home is, after all, a planet—small, self-contained, and in some ways even fragile.

As we look closely at our planet from space, it becomes clear that Earth is much more than rock and soil. In fact, the most conspicuous features in Figure I.1A are not continents, but swirling clouds suspended above the surface and the vast global ocean. These features emphasize the importance of air and water to our planet.

The closer view of Earth from space, shown in Figure I.1B, helps us appreciate why the physical environment is traditionally divided into three major parts: the water portion of our planet, the hydrosphere; and Earth's gaseous envelope, the atmosphere, and, of course, the solid Earth. It needs to be emphasized that our environment is highly integrated and 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 the planet. Thus, Earth can be thought of as consisting of four major spheres: the hydrosphere, atmosphere, solid Earth, and biosphere.

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

Figure I.1 **A.** View that greeted the *Apollo 8* astronauts as their spacecraft emerged from behind the moon. **B.** 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. *(Both photos courtesy of NASA)*



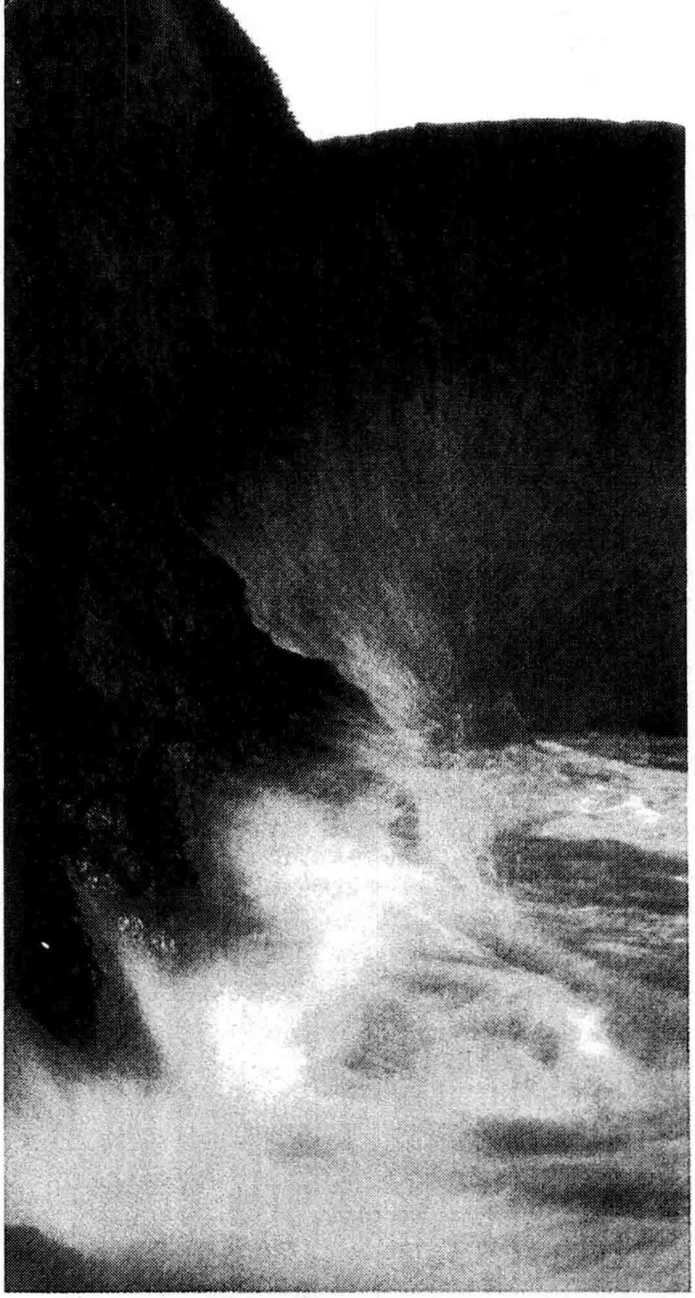


Figure I.2 The shoreline is one obvious meeting place for rock, water, and air. In this scene, ocean waves that were created by the force of moving air break against the rocky shore. The force of the water can be powerful, and the erosional work that is accomplished can be great. *(Photo by Galen Rowell)*

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 water that is continually on the move, evaporating from the oceans to the atmosphere, precipitating to the land, and flowing 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 to an average depth of about 3800 meters (12,500 feet). It accounts for about 97 percent of Earth's water. However, the hydrosphere also includes the fresh water found underground and in streams, lakes, and glaciers. Moreover, water is an important component of all living things.

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.

Atmosphere

Earth is surrounded by a life-giving gaseous envelope called the **atmosphere**. Compared with the solid Earth, the atmosphere is thin and tenuous. One half lies below an altitude of 5.6 kilometers (3.5 miles), and 90 percent occurs within just 16 kilometers (10 miles) of Earth's surface. By comparison, the radius of the solid Earth (distance from the surface to the center) is about 6400 kilometers (nearly 4000 miles)! Despite its modest dimensions, 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 surface of the moon, which has not changed appreciably in nearly 3 billion years.

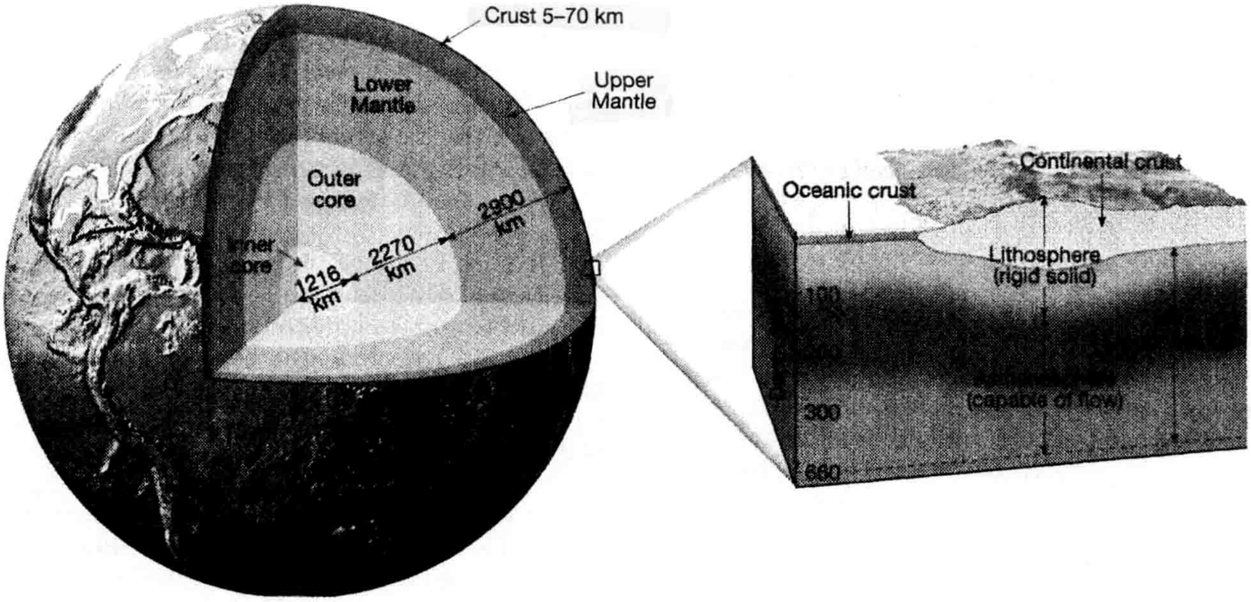


Figure I.3 View of Earth's layered structure. **A.** The inner core, outer core, and mantle are drawn to scale, but the thickness of the crust is exaggerated by about five times. **B.** A blowup of Earth's outer shell. It shows the two types of crust (oceanic, continental), the rigid lithosphere, and weak asthenosphere.

Solid Earth

Lying beneath the atmosphere and the ocean is the solid Earth. Because the solid Earth is not uniform, it is divided into various regions or units. Based on compositional differences, three principal regions are identified: a dense inner sphere called the *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.

The outer portion of the solid Earth is also divided based on how materials behave when various forces and stresses are applied. The term *lithosphere* refers to the rigid outer layer that includes the crust and uppermost mantle (Figure I.3B). Beneath the rigid rocks that compose the lithosphere, the rocks become weak and are able to slowly flow in response to the uneven distribution of heat deep within Earth.

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 fourth "sphere," the **biosphere**, includes all life on Earth and penetrates parts of the solid Earth, hydrosphere, and atmosphere. 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 the solid Earth, hydrosphere, and atmosphere would be very different.

As you learn about Earth, it will become clear that our planet is a dynamic body with many separate but interacting parts or *spheres*. The hydrosphere, atmosphere, biosphere, and solid Earth and all of their components can be studied separately. However, the parts are not isolated. Each is related in some way to the others to produce a complex and continuously interacting whole that we call the *Earth system*.

The Earth Sciences

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. 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.

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 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 4.5-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.

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.

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 con-

Figure I.4 This researcher is examining the partially cleaned skull of the *Tyrannosaurus rex* known as "Sue" at Chicago's Field Museum of Natural History. 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 Ira Block)*

ditions 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?

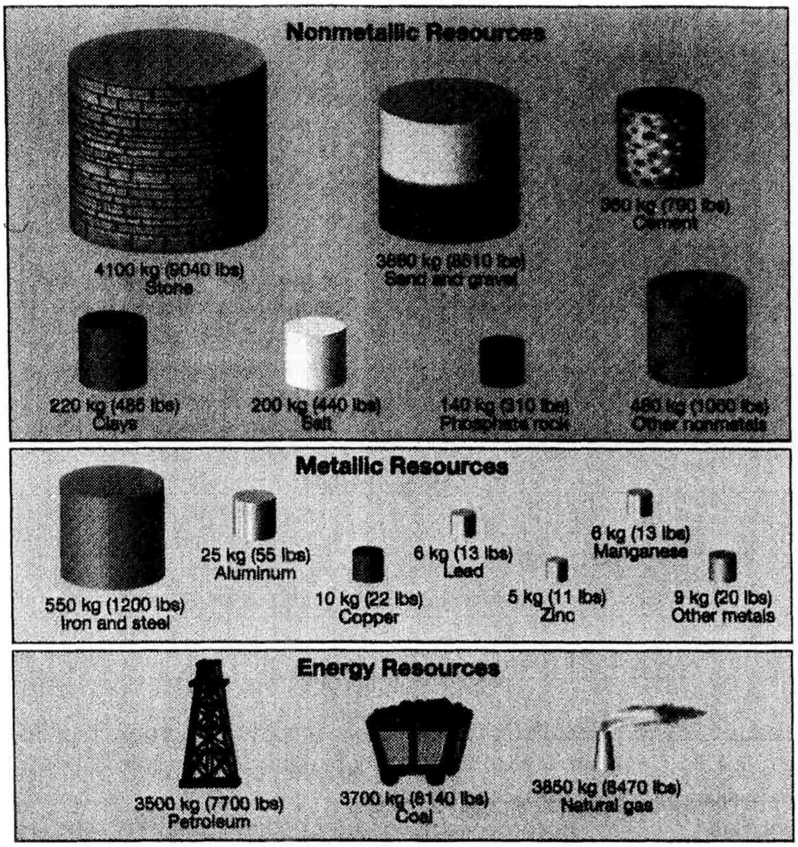


Figure I.5 The annual per capita consumption of nonmetallic and metallic mineral resources for the United States is nearly 10,000 kilograms (22,000 pounds, or 11 tons)! About 94 percent of the materials used are nonmetallic. The per capita use of oil, coal, and natural gas exceeds 11,000 kilograms (12 tons).

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, volcanic eruptions, floods, and hurricanes are just five 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.

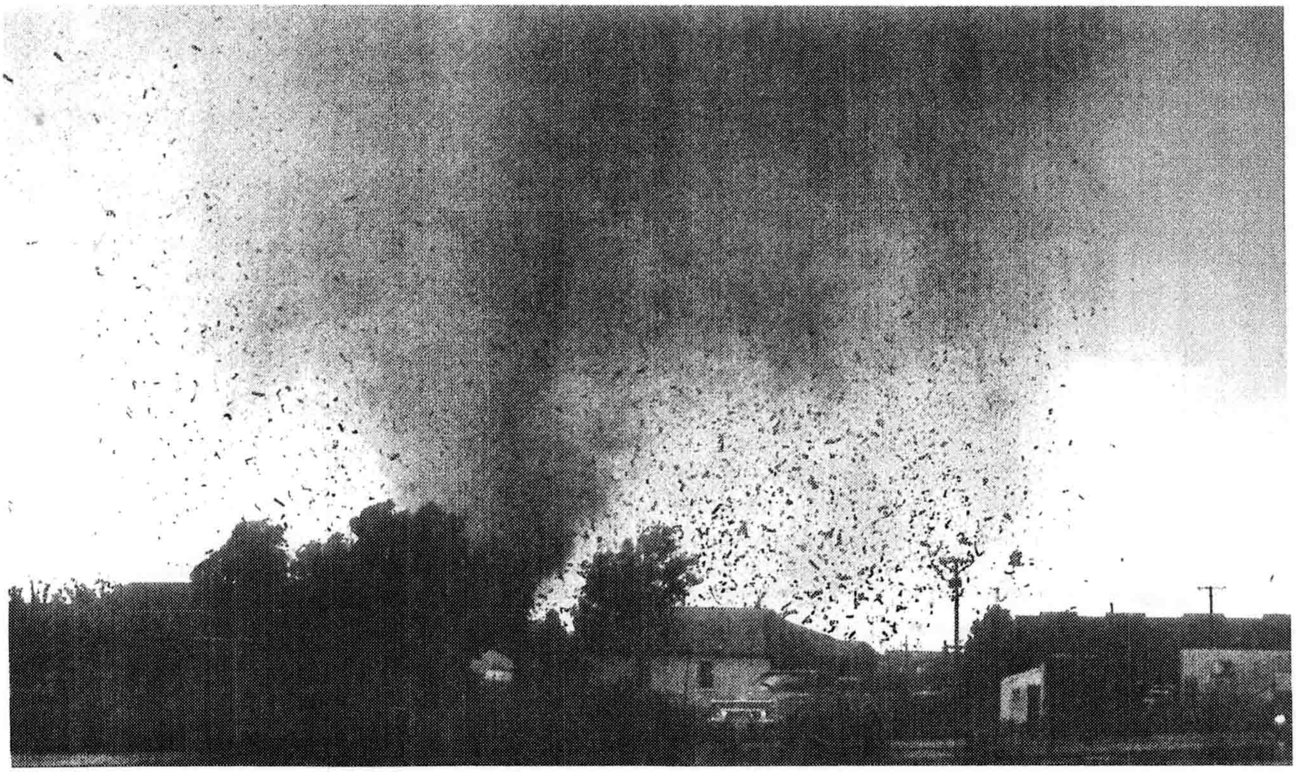
It is clear that as world population continues its rapid growth, pressures on the environment will increase as well. Therefore, an understanding of Earth is not only essential for the location and recovery of basic resources but also for dealing with the human impact on the environment and minimizing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

Figure I.6 Pudong, China, on a moderately smoggy day. 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 F. Hoffman/The Image Works)*

Figure I.7 Tornado destroying buildings in Pampa Texas. There are many Earth processes and phenomena that are hazardous to people, including volcanoes, earthquakes, landslides, floods, hurricanes, and tornadoes. *(Photo by Alan R. Moller/Tony Stone Images)*



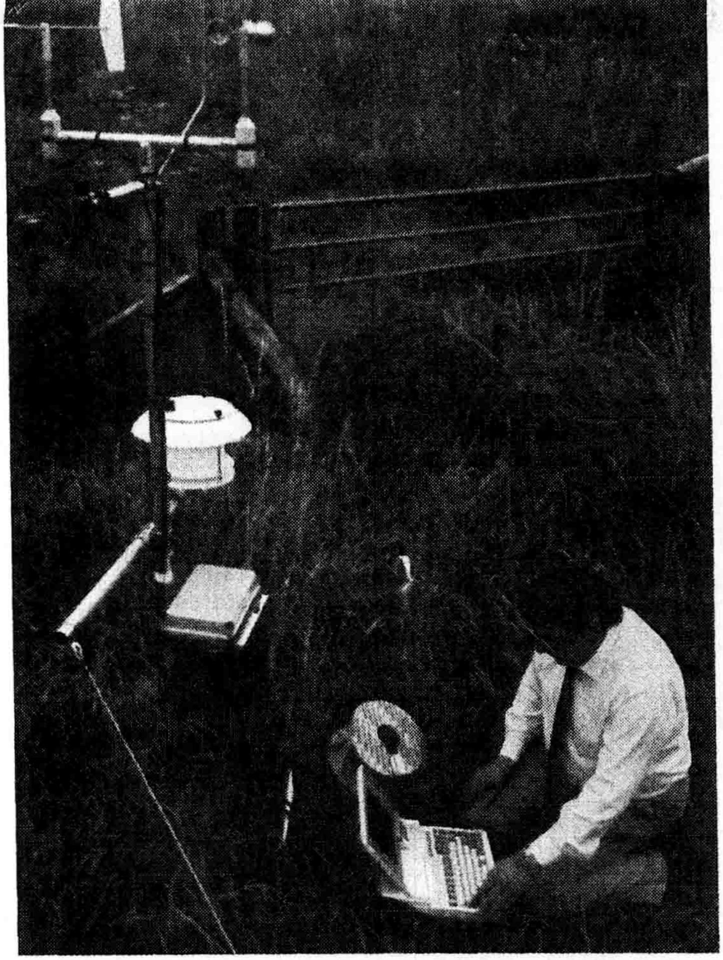


Figure I.8 An automated weather station. The meteorologist is downloading the accumulated data into a laptop computer. *(Photo by David Parker/Science Photo Library/Photo Researchers, Inc.)*

use this knowledge to predict what will or will not 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 *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.

The history of science is littered with discarded hypotheses. One of the best known is the idea that 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 Earth.

Theory

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**. In everyday language we may say "that's only a theory." But a scientific theory is a well-tested and widely accepted view that scientists agree best explains certain observable facts. It is not enough for scientific theories to fit only the data that are already at hand. Theories must also fit additional observations that were not used to formulate them in the first place. Put another way, theories should have predictive power.

Scientific theories, like scientific hypotheses, are accepted only provisionally. It is always possible that a theory that has withstood previous testing may eventually be disproved. As theories survive more testing, they are regarded with higher levels of confidence. Theories that have withstood extensive testing, such as the theory of plate tectonics or the theory of evolution, are held with a very high degree of confidence.

Scientific Methods

The process just described, in which scientists gather facts through observations and formulate scientific hypotheses that may eventually become theories, is termed 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. Rather, it is an endeavor that involves creativity and insight. Rutherford and Ahlgren put it this way: "Inventing hypotheses or theories to imagine how the world works and then figuring out how they can be put to the test of reality is as creative as writing poetry, composing music, or designing skyscrapers."*

There is no fixed path that scientists always follow that leads unerringly to scientific knowledge. Nevertheless, many scientific investigations involve the following steps: (1) the collection of scientific facts through observation and measurement (Figure I.9); (2) the development of one or more working hypotheses to explain these facts; (3) development of observations and experiments to test the hypothesis; and (4) the acceptance, modification, or rejection of the hypothesis based on extensive testing.

Other scientific discoveries represent purely theoretical ideas, which stand up to extensive examination. Still other scientific advancements have been made when a totally unexpected happening occurred during an experiment. These serendipitous discoveries are more than pure luck, for as Louis Pasteur said, "In the field of observation, chance favors only the prepared mind."

Scientific knowledge is acquired through several avenues, so it might be best to describe the nature of scientific inquiry as the *methods* of science rather than the scientific method.

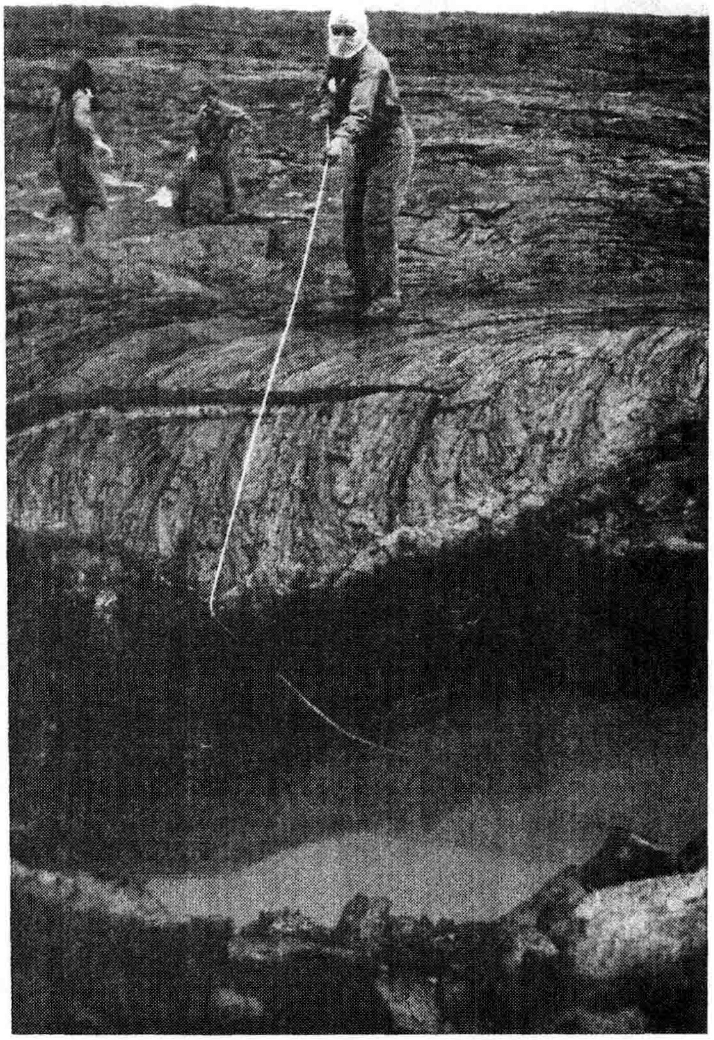


Figure I.9 Geologist taking lava sample from a "skylight" in a lava tube. Near Kilauea Volcano, Hawaii. *(Photo by G. Brad Lewis/Tony Stone Images)*

Studying Earth Science

In this book, you will discover the results of centuries of scientific work. You will see the end product of millions of observations, thousands of hypotheses, and hundreds of theories. We have distilled all of this to give you a "briefing" in Earth science.

But realize that our knowledge of Earth is changing daily, as thousands of scientists worldwide make satellite observations, analyze drill cores from the seafloor, study earthquake waves, develop computer models to predict climate, examine the genetic codes of organisms, and discover new facts about our planet's long history. This new knowledge often updates hypotheses and theories. Expect to see many new discoveries and changes in scientific thinking in your lifetime

Key Terms

atmosphere (p. 2)
astronomy (p. 4)
biosphere (p. 3)
Earth science (p. 4)
geology (p. 4)
hydrosphere (p. 2)
hypothesis (p. 8)
meteorology (p. 4)
oceanography (p. 4)
theory (p. 8)

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*F. James Rutherford and Andrew Ahlgren, *Science for All Americans* (New York: Oxford University Press, 1990), p. 7.

Plate Tectonics

A Unifying Theory

CHAPTER

5

FOCUS ON LEARNING

To assist you in learning the important concepts in this chapter, you will find it helpful to focus on the following questions:

1. What lines of evidence were used to support the continental drift hypothesis?
2. What was one of the main objections to the continental drift hypothesis?
3. What is the theory of plate tectonics?
4. In what major way does the plate tectonics theory depart from the continental drift hypothesis?
5. What are the three types of plate boundaries?
6. What is the evidence used to support the plate tectonics theory?
7. What models have been proposed to explain the driving mechanism for plate motion?

Composite satellite image of western Europe, Africa, and the Arabian Peninsula. *(Image by Worldsat International, Inc.)*

Early in this century, most geologists believed that the geographic positions of the ocean basins and continents were fixed. During the last few decades, however, vast amounts of new data have dramatically changed our understanding of the nature and workings of our planet. Earth scientists now realize that the continents gradually migrate across the globe. Where landmasses split apart, new ocean basins are created between the diverging blocks. Meanwhile, older portions of the seafloor are carried back into the mantle in regions where trenches occur in the deep ocean floor. Because of these movements, blocks of continental material eventually collide and form Earth's great mountain ranges. In short, a revolutionary new model of Earth's tectonic* processes has emerged.

This profound reversal of scientific understanding has been appropriately described as a scientific revolution. Like other scientific revolutions, considerable time elapsed between the idea's inception and its general acceptance. The revolution began early in the twentieth century as a relatively straightforward proposal that the continents drift about the face of Earth. After many years of heated debate, the idea of drifting continents was rejected by the vast majority of Earth scientists. However, during the 1950s and 1960s, new evidence rekindled interest in this proposal. By 1968, these new developments led to the unfolding of a far more encompassing theory than continental drift—a theory known as *plate tectonics*.

Continental Drift: An Idea Before Its Time

The idea that continents, particularly South America and Africa, fit together like pieces of a jigsaw puzzle originated with improved world maps. However, little significance was given this idea until 1915, when Alfred Wegener, a German meteorologist and geophysicist, published *The Origin of Continents and Oceans*. In this book, Wegener set forth his radical hypothesis of **continental drift**.[†]

Wegener suggested that a supercontinent he called **Pangaea** (meaning "all land") once existed (Figure 5.1). He further hypothesized that, about 200 million years ago, this supercontinent began breaking into smaller continents, which then "drifted" to their present positions.

Wegener and others collected substantial evidence to support these claims. The fit of South America and Africa, and the geographic distribution of fossils, rock structures, and ancient climates all seemed to support the idea that these now-separate landmasses were once joined. Let us examine their evidence.

Evidence: The Continental Jigsaw Puzzle

Like a few others before him, Wegener first suspected that the continents might have been joined when he noticed the remarkable similarity between the coastlines on opposite sides of the South Atlantic. However, his use of present-day shorelines to make a fit of the continents was challenged immediately by other Earth scientists. These opponents correctly argued that shorelines are continually modified by erosional processes, and even if continental displacement had taken place, a good fit today would be unlikely. Wegener appeared to be aware of this problem, and, in fact, his original jigsaw fit of the continents was only very crude.

A much better approximation of the true outer boundary of the continents is the continental shelf. Today, the seaward edge of the continental shelf lies submerged, several hundred meters below sea level. In the early 1960s, scientists produced a map that attempted to fit the edges of the continental shelves at a depth of 900 meters (3000 feet). The remarkable fit that was obtained is shown in Figure 5.2. Although the continents overlap in a few places, these are regions where streams have deposited large quantities of sediment, thus enlarging the continental shelves. The overall fit was even better than the supporters of continental drift suspected it would be.

Evidence: Fossils Match Across the Seas

Although Wegener was intrigued by the jigsaw fit of the continental margins that lie on opposite sides of the Atlantic, he at first thought the idea of a mobile Earth improbable. Not until he came across an article citing fossil evidence for the existence of a land bridge connecting South America and Africa did he begin to take his own idea seriously. Through a search of the literature, Wegener learned that most paleontologists were in agreement that some type of land connection was needed to explain the existence of identical fossils on the widely separated landmasses.

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[*] Tectonics refers to the deformation of Earth's crust and results in the formation of structural features such as mountains.

[†] Wegeners's ideas were actually preceded by those of an American geologist, F. B. Taylor, who in 1910 published a paper on continental drift. Taylor's paper provided little supporting evidence for continental drift, which may have been the reason that it had a relatively small impact on the scientific community.

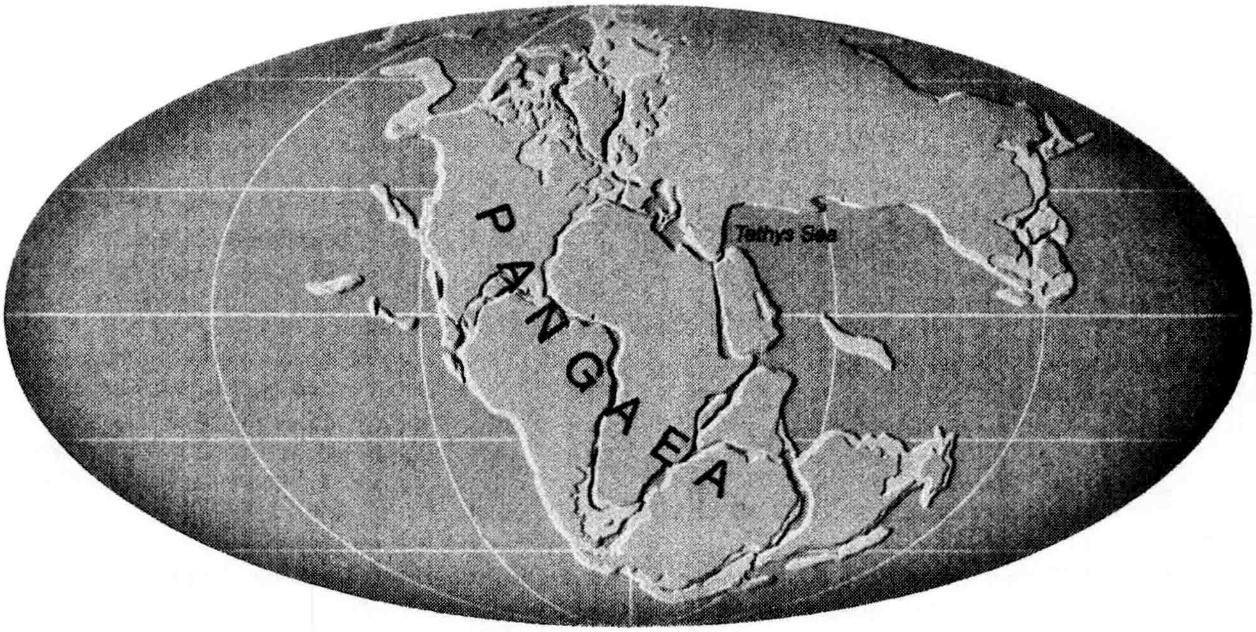

Figure 5.1 Reconstruction of Pangaea as it is thought to have appeared 200 million years ago. *(After R. S. Deitz and J. C. Holden.* Journal of Geophysical Research *75: 4943. Copyright by American Geophysical Union)*

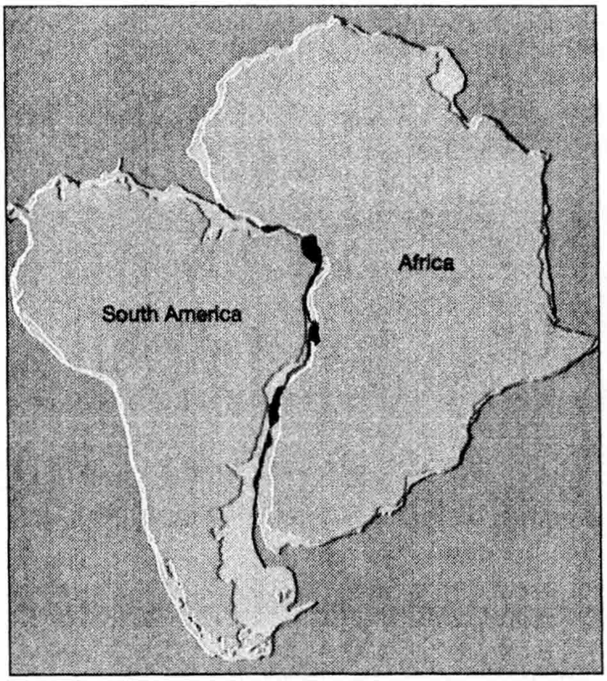

Figure 5.2 This shows the best fit of South America and Africa along the continental slope at a depth of 500 fathoms (about 900 meters). The areas where continental blocks overlap appear in brown. *(After A. G. Smith. "Continental Drift," in* Understanding the Earth, *edited by I. G. Gass. Courtesy of Artemis Press.)*

To add credibility to his argument for the existence of the supercontinent of Pangaea, Wegener cited documented cases of several fossil organisms that had been found on different landmasses but which could not have crossed the vast oceans presently separating the continents. The classic example is *Mesosaurus*, a presumably aquatic, snaggle-toothed reptile whose fossil remains are limited to eastern South America and southern Africa (Figure 5.3). If *Mesosaurus* had been able to swim well enough to cross the vast South Atlantic Ocean, its remains should be more widely distributed. As this is not the case, Wegener argued that South America and Africa must have been joined—somehow.

How did scientists explain the discovery of identical fossil organisms separated by thousands of kilometers of open ocean? The idea of land bridges was the most widely accepted solution to the problem of migration. We know, for example, that during the most recent glacial period, the lowering of sea level allowed animals to cross the narrow Bering Strait between Asia and North America. Was it possible, then, that one or more land bridges once connected Africa and South America? We are now quite certain that land bridges of this magnitude did not exist, for their remnants should still lie below sea level. But they are nowhere to be found.