1 Our Unique Planet

We speak for Earth.

—Carl Sagan

Objectives

In this chapter you will learn about:

- the field of environmental science;
- the features and characteristics that make Earth unique;
- the geosphere, atmosphere, hydrosphere, biosphere, ecosphere, and technosphere; and
- the materials and processes of the solid Earth.

The Environment and Environmental Science

Once upon a time, the term *environment* just meant "surroundings." It was used in reference to the physical world separate from ourselves—rocks, soil, air, and water. People gradually came to realize that the organisms that inhabit the physical world—the enormous variety of plants, animals, and microorganisms on this planet, including humans—are an integral part of the environment. It doesn't make sense to define environment without recognizing the fundamental importance of interactivity among organisms, and between organisms and their surroundings. Therefore, we can define **environment** to include all of the components, characteristics,

This satellite image shows North and South America as they would appear from space 35,000 km (22,000 mi) above Earth. The image is a combination of data from two satellites: NASA's Terra satellite collected the land data, and NOAA's GOES satellite collected the cloud-cover data.

and conditions in the natural world that influence organisms, as well as the interactions between and among organisms and the natural world. This definition encompasses the physical–chemical–geologic surroundings of an organism, as well as the other biologic inhabitants of the neighborhood. It implies that there is a range of possible interactions among the various components of the environment, both **biotic** (living) and **abiotic** (nonliving).

Our conceptual understanding of the environment continues to evolve, reflecting the emerging understanding that humans, too, are an integral part. We influence the physical world and other organisms; in turn, we are influenced by them. Therefore, more recent definitions of environment incorporate social, cultural, and economic factors in addition to the components of the natural, biophysical world. For example, human technology is affected by the natural environment through the availability or scarcity of natural resources. Technology, in turn, has profound and sometimes devastating impacts on the natural environment. Understanding the **technosphere**—the built, manufactured, industrialized, and domesticated aspects of the world—is fundamental to our understanding and successful management of the environment.

Environmental science, the focus of this book, is an interdisciplinary combination of basic sciences applied to the study of the environment. By one relatively early definition, environmental science includes "all of nature we perceive or can observe . . . a composite of Earth, Sun, sea, and atmosphere, their interactions, and the hazards they present" (from the U.S. Environmental Science Services Administration, 1968). Environmental science draws its fundamental principles from a number of basic scientific disciplines, particularly biology, geology, chemistry, and physics. These and other scientific disciplines, including hydrology, climatology, oceanography, soil science, statistics, and meteorology, are applied to the study of the environment and contribute to our understanding of this complex planet we inhabit.

Environmental science is a multifaceted discipline, but the study of the environment extends well beyond the realm of science. People are the de facto managers of this planet. We manage the environment—our impacts on the environment, as well as its impacts on human society—through our laws, policies, writings, and other human systems. We draw from disciplines as diverse as philosophy, literature, economics, political science, sociology, management, geography, history, anthropology, art, and even psychology. The application of these disciplines to the environment has given rise to such fields as environmental law, environmental economics, environmental management, and environmental ethics. Although these are not scientific disciplines, they are fundamental to our understanding of the environment.

How would you modify the definition of environment stated above so that it takes into consideration human technology and its interactions with the natural environment? ________________

Answer: One possible definition is that environment encompasses the natural physical, chemical, biologic, and geologic aspects and conditions that influence and are influenced by organisms, including humans; the interactions among them; and social, cultural, and economic factors that influence and are influenced by the natural world. Does this definition include everything that you think it should?

Why do you think it is important to be precise and thorough in defining the concept of environment? ________________

Answer: One reason is that the term *environment* is often used in a legal context, where the wording must be very precise. Another reason for being careful and thorough is that how we define environment reflects, in part, how we view ourselves in relation to other organisms and to the natural world. The impacts of technologic developments on the natural environment sometimes result in degradation of the social or cultural environment; these need to be included in our definition so that they will be taken into consideration when we undertake activities that may alter the natural environment.

Hot Topics in Environmental Science

If you were to take a poll in which you asked citizens of North America and Europe to name the most pressing environmental issues today, you would likely find significant regional variations. People in the northeastern United States and southern Canada might have concerns about the health of the Great Lakes. In the Northwest, people might have concerns about deforestation in old-growth forests. In the Midwest and dry Southwest, the availability of abundant water and the depletion of groundwater supplies might be of concern. People in Western Europe might be most worried about the effects of acid rain on forests and lakes. Some concerns would be common to all regions, including climatic change, the ozone hole, loss of biodiversity, health impacts of air pollution, toxic contaminants in natural waters, overpopulation, energy shortages, and municipal garbage. These are widespread or even global problems that are part of the legacy of industrialization. Throughout this book, we will be looking at the science that underlies these and other environmental problems.

What are the most pressing environmental issues facing your local neighborhood, city, or region? How do they differ from the environmental issues in other regions, and how are they similar? How do your local concerns differ from global environmental issues?

If you were to conduct the same poll in a less economically developed country, perhaps in South America, Asia, or Africa, the list of pressing environmental issues might be quite different. The environmental concerns of people in the developing world tend to be more local, more immediate, and relate more directly to daily survival. The list might include land degradation and its impact on food production; lack of clean water for drinking, washing, and cooking; and the lack of fuel wood and other energy sources for cooking. Today almost 2 billion of the world's poorest people lack access to sanitation facilities and wastewater treatment. Approximately 1 billion people do not have access to clean water, and almost 1 billion people are chronically hungry. These problems threaten people's survival; they are part of the legacy of poverty. Some of them are not strictly environmental problems—there are underlying political, social, and economic causes—but the impacts of environmental degradation on human health and well-being are immediate, local, and severe in the developing world.

Until fairly recently, most developing countries were not particularly interested in entering the international dialogue about dealing with problems like ozone depletion or global warming. Why? It's partly an issue of responsibility and blame; some of our current global environmental problems were caused—or were at least initiated—by industrialization in wealthier nations. It's also partly because people in developing countries are simply too busy dealing with the immediate problems of daily survival and with getting food, water, and other basic services to people in need. Now, however, it is widely recognized that regardless of the cause everyone in the world is potentially at risk from the impacts of environmental degradation. All nations and all people bear a common responsibility to deal with these problems.

A concept that has become familiar in international dialogues about global environmental issues is the idea of common but differentiated responsibility of nations. What do you think it means? ________________

Answer: Common but differentiated responsibility refers to the concept that all nations must bear responsibility for dealing with global environmental problems, but different nations have different capacities and resources with which to respond to these problems.

Welcome to Our World

Now that we have covered some basic terminology and concepts, let's begin our study of the environment by taking a look at the planet itself. Earth is one of nine planets in our **solar system**—the Sun and the group of objects orbiting around it, which originated as a system approximately 4.6 billion years ago. The solar system also includes more than sixty moons, a vast number of asteroids, millions of comets, and innumerable floating fragments of rock and dust. The objects in our solar system move through space in smooth, regular orbits held in place by gravitational attraction. The planets, asteroids, and comets orbit the Sun, and the moons orbit the planets (Figure 1.1).

The planets can be separated into two groups on the basis of their characteristics and distances from the Sun. The innermost planets—Mercury, Venus, Earth, and

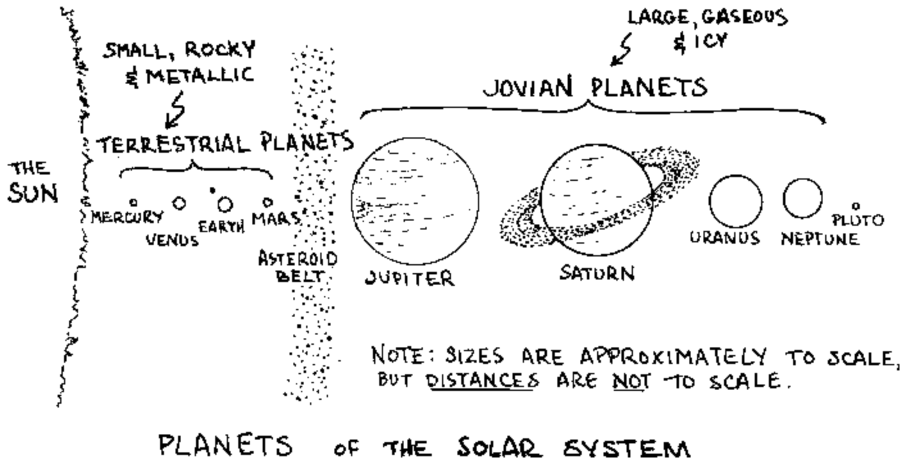

Figure 1.1.

Mars—are small, rocky, and relatively dense. These planets are similar in size and chemical composition. They are called **terrestrial planets** because they resemble *Terra* ("Earth" in Latin). With the exception of Pluto, the outer or **jovian planets**—Jupiter, Saturn, Uranus, and Neptune—are much larger than the terrestrial planets but much less dense, with very thick atmospheres of hydrogen, helium, and other gases. You can learn more about the solar system by reading *Astronomy: A Self-Teaching Guide*, by Dinah L. Moché (John Wiley & Sons, 2004).

The terrestrial planets have many things in common beyond their small sizes, rocky compositions, and positions close to the Sun. They have all been subjected to volcanic activity and intense meteorite impact cratering. They have all been hot and, indeed, partially molten at some time early in their histories. During this partially molten period, the terrestrial planets separated into layers of differing chemical composition: a relatively thin, low-density, rocky **crust** on the outside; a metallic, high-density **core** in the center; and a rocky **mantle** in between. This separation process happened to all of the terrestrial planets, including Earth. In the context of environmental science, the physical Earth—distinct from the organisms that inhabit it—is referred to as the **geosphere**. The term *geosphere* is used in reference to the planet and the whole physical environment—the atmosphere, the hydrosphere, and the solid Earth.

What are the four terrestrial planets, and why are they given this name?

Answer: Mercury, Venus, Earth, and Mars. They are all similar to Earth (*Terra*).

What Makes Earth Unique?

In spite of the similarities among the terrestrial planets, the history and specific characteristics of Earth are different enough from those of the other terrestrial planets to make this planet habitable. If you look at a photograph of Earth taken from space, you immediately notice the blue-and-white **atmosphere**, an envelope of gases dominated by nitrogen, oxygen, argon, and water vapor, with traces of other gases. Other planets have atmospheres, but no other planet in the solar system has an atmosphere of this particular chemical composition.

The atmosphere contains clouds of condensed water vapor that form because water evaporates from the hydrosphere, another unique feature. The **hydrosphere** ("watery sphere") consists of the oceans, lakes, and streams; underground water; and snow and ice. Planets farther from the Sun are too cold for liquid water to exist on their surfaces; planets closer to the Sun are so hot that any surface water evaporated long ago. Only Earth has just the right surface temperature to have liquid water, ice, and water vapor in its hydrosphere.

Another unique feature of Earth is the **biosphere**, the "living sphere." The biosphere comprises innumerable living things, large and small, which belong to millions of different species, as well as recently dead plants and animals that have not yet completely decomposed. The **ecosphere** is the physical environment that permits or facilitates the existence of the biosphere. On Earth, the ecosphere extends from the deepest valleys and the bottom of the ocean to the tops of the highest mountains and well into the lower part of the atmosphere. Even the great polar ice sheets host a variety of life forms. Although many new planets have been discovered orbiting distant stars that seem similar to our own Sun, we don't yet know of another planet that offers an ecosphere or hosts a biosphere.

The nature of Earth's solid surface is also special; it is covered by an irregular blanket of loose debris called **regolith** (from the Greek *rhegos*, meaning "blanket"). Earth's regolith forms as a result of **weathering**, the continuous chemical alteration and mechanical breakdown of surface materials through exposure to the atmosphere, hydrosphere, and biosphere. The weathered, broken-down materials are picked up by moving wind, water, and ice, carried downhill under the influence of gravity, and eventually deposited. Weathering and the transport of weathered materials together comprise the process of **erosion**, which is part of the global **rock cycle** (Figure 1.2). Soil, mud in river valleys, sand in the desert, rock fragments, and other unconsolidated debris are all part of the regolith. Some other planets and planetary bodies are blanketed by loose, fragmented material, but in those cases the fragmentation has been caused primarily by the endless pounding of meteorite impacts. Earth's regolith is unique because it forms as a result of complex interactions of

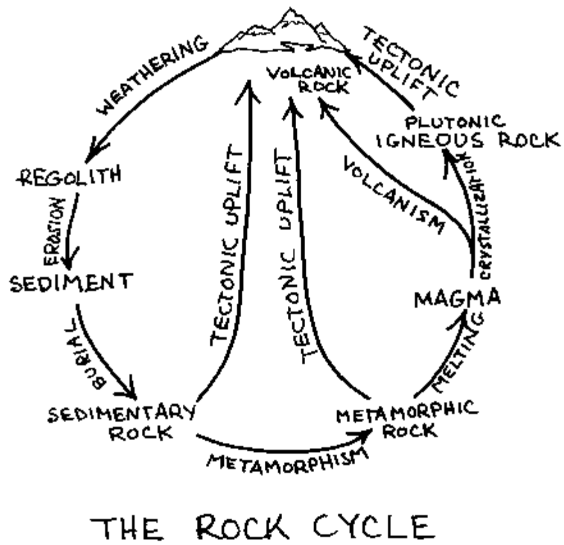

Figure 1.2.

physical, chemical, and biologic processes, usually involving water. It is also unique because it teems with life; most plants and animals live on or in the regolith or in the hydrosphere.

Why does Earth have an ecosphere, whereas all other known planets do not?

Answer: A combination of just the right size and composition (especially the presence of water) and optimal distance from the Sun make the surface conditions on Earth perfectly suited for hosting life.

Earth, Inside and Out

Earth, like the other terrestrial planets, is composed primarily of **rock**, a naturally formed, solid, coherent aggregate. The basic building blocks of rocks are **minerals**—naturally occurring, inorganic elements or chemical compounds that have specific chemical compositions, orderly internal atomic structures, and characteristic physical properties. **Geology** is the scientific study of these and other Earth materials and processes. If you are interested in learning more about the science of the Earth, you can read *Geology: A Self-Teaching Guide*, by Barbara Murck (John Wiley & Sons, 2001).

Three basic families of rocks are recognized. They are:

1. **sedimentary rocks**, which form as a result of the deposition, consolidation, and cementation of unconsolidated rock and mineral fragments (**sediment**) in low-temperature and low-pressure conditions near Earth's surface;
2. **igneous rocks**, which solidify from molten rock (**magma** or **lava**) on the surface (**volcanic rocks**) or deep underground (**plutonic rocks**); and
3. **metamorphic rocks**, which are rocks that have been altered as a result of exposure to very high pressures and/or temperatures.

As everyone knows, rocks are quite durable. However, we live on a planetary surface that is extremely active and ever changing. Winds blow, waves break, streams flow, and glaciers grind away at the surface. These constant, restless energetic forces, driven partly by gravity and partly by solar energy, interact with surface materials, eventually breaking down rocks and minerals to form regolith. Geologic evidence shows that weathering and erosion have been operating throughout most of Earth history—well over 4 billion years. But if these forces are constantly at work, inevitably wearing down and washing away Earth's surface materials, then why are there any mountains left standing? The answer is that other forces are acting on the surface from the inside. Internal forces constantly uplift the surface, creating great mountains and rugged topography that seem to defy the forces of weathering and erosion. Here is how it works.

The outermost, rocky part of Earth is the crust, as mentioned above. **Continental crust** (Figure 1.3) is relatively thick (average thickness 45 km, or 30 mi) and is made mostly of plutonic rocks called granite. **Oceanic crust**, which underlies the great ocean basins, is relatively thin (average thickness 8 km, or 5.4 mi) and is made mostly of volcanic rocks called basalt. Beneath the crust is the mantle, which is also made of plutonic igneous rocks, but they are different from the rocks of the continental crust. At the center of Earth is the core made of iron-nickel metal. Together, the crust and the outermost part of the mantle make up the **lithosphere**, a thin, cold, brittle, rocky layer. The mantle below the lithosphere is very hot, so it is malleable, like putty, even though it is made of solid rock. The part of the mantle immediately beneath the lithosphere is called the **asthenosphere**; it is especially weak and squishy because it is close to the temperature at which rocks begin to melt.

The lithosphere is made of solid rock about 100 km (60 mi) thick, on average. In comparison to the size of the planet as a whole, the lithosphere is an exceedingly

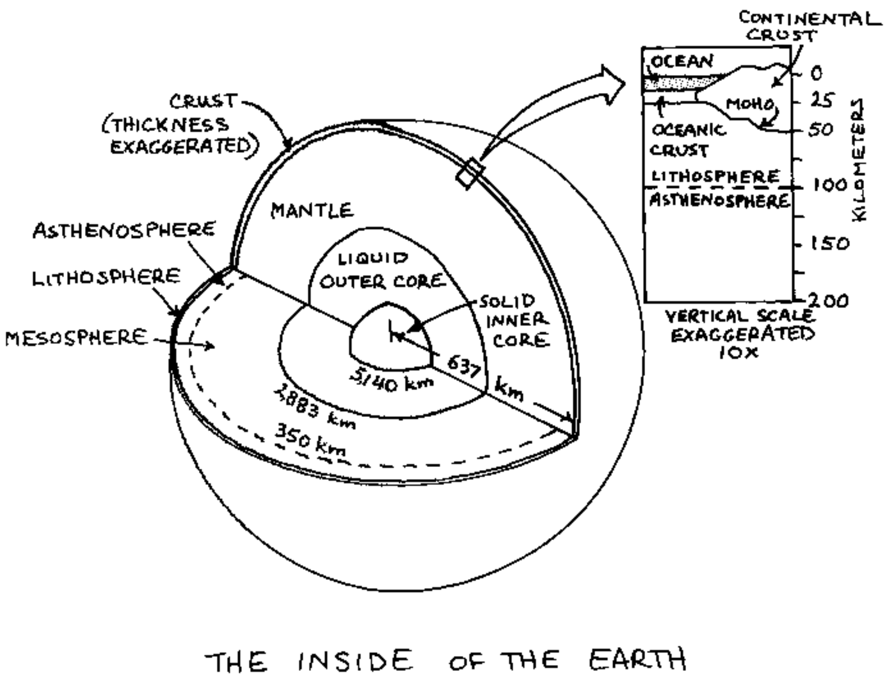

Figure 1.3.

thin shell (Figure 1.3). It has about the same relative thickness as the glass shell of a lightbulb or the skin of an apple.

If you were to do an experiment in which you placed a thin, cool, brittle shell (like the lithosphere) on top of hot, weak material that is rather squishy (like the asthenosphere), what do you think would happen? You might predict that the thin shell would break into pieces. In fact, that is precisely what has happened to the lithosphere—it has broken into a number of large fragments, or **plates**. Today there are six large plates, each extending for several thousands of kilometers, and a large number of smaller plates (Figure 1.4). Note that these are *lithospheric* plates, not crustal plates. The plates are made of the crust *and* the solid rock of the mantle just beneath. Some lithospheric plates, like the Pacific Plate, are capped mainly by oceanic crust; others, like the North American Plate, are capped mainly by continental crust.

You can experiment with plates and plate motion by carefully heating wax in a pan, then letting it cool until it forms a thin skin or crust. If you try this, be careful—molten wax is very hot. Be sure to wear eye protection, and use care in handling hot pans.

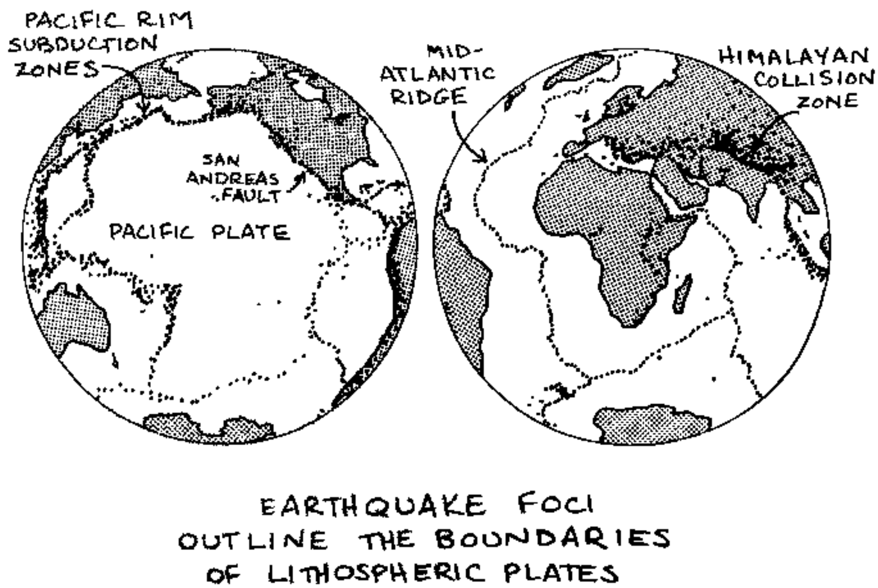

Figure 1.4.

Think again about the expected behavior of thin, brittle fragments floating on top of hot, squishy material. You might expect that movements in the underlying material would cause the brittle fragments to shift about. Again, that is exactly what happens to Earth's lithospheric plates. When movements occur in the hot mantle, the lithospheric plates shift and interact with one another. If a plate happens to be capped by continental crust, the continent moves along with the rest of the plate. You may already be familiar with this process; it is called **continental drift**. The study of the movement and interactions of lithospheric plates is referred to as **plate tectonics** (from the Greek word *tekton*, meaning "carpenter" or "builder").

What is the lithosphere? _______________

Answer: The outer 100 km (60 mi) of Earth; the crust and the upper part of the mantle.

Internal Forces

Lithospheric plates move and shift their positions in response to movements in the mantle beneath. As the plates move, they interact with one another mainly along their edges. Plate margins are where the most violent and intense types of geologic activity originate. Plates can interact in three basic ways: they can move away from each other (diverge); they can move toward each other (converge); or they can slide past each other. Consequently, there are three basic kinds of plate margins (Figure 1.5):

1. **Divergent margins** are huge fractures in the lithosphere where plates move apart from one another, forming great rift valleys on continents and under the oceans. They are characterized by earthquakes caused by the splitting and frac-

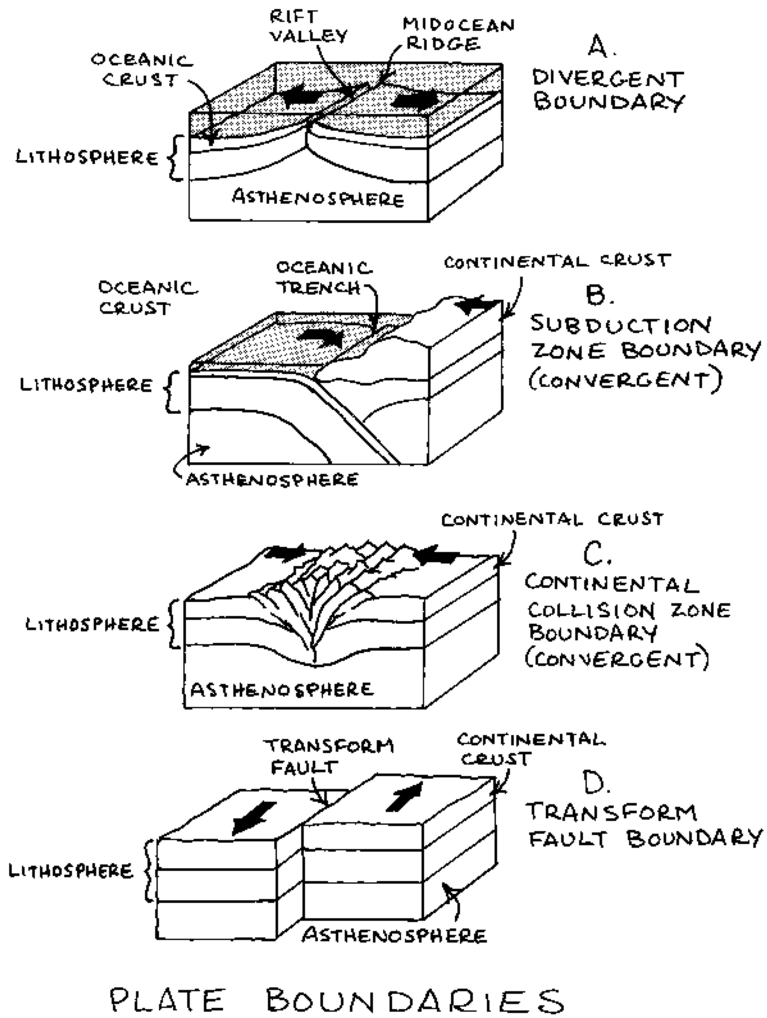

Figure 1.5.

turing of rocks, and by volcanic activity that occurs when melted rock from deep within the mantle wells up through the fractures.

2. **Convergent margins** occur where two plates move toward each other, slowly colliding. At ocean–ocean and ocean–continent convergent margins, a process called **subduction** occurs, in which oceanic crust is forced down into the mantle (Figures 1.5B and 1.6). The downgoing plate melts when it reaches a depth within Earth where the temperature is sufficiently high. Thus, convergent plate margins that involve oceanic crust are characterized by active volcanism. Other convergent plate margins—those that involve only continental crust—are characterized by the uplifting of great mountain chains like the Himalayas (Figure 1.5C). All convergent plate margins are marked by intense earthquakes.

3. **Transcurrent** or **transform fault margins** are huge fractures in the lithosphere where two plates slide past each other, grinding along their edges and causing earthquakes as they go. A famous modern example is the San Andreas Fault in California, where the Pacific Plate is moving north–northwest relative to the North American Plate.

All of these types of plate interactions are occurring today, as they have occurred throughout most of Earth history. We don't often notice plate motion because lithospheric plates move very slowly—usually between 1 and 10 cm (0.4 and 4 in) per year. But we feel the earthquakes and observe the volcanic activity along active

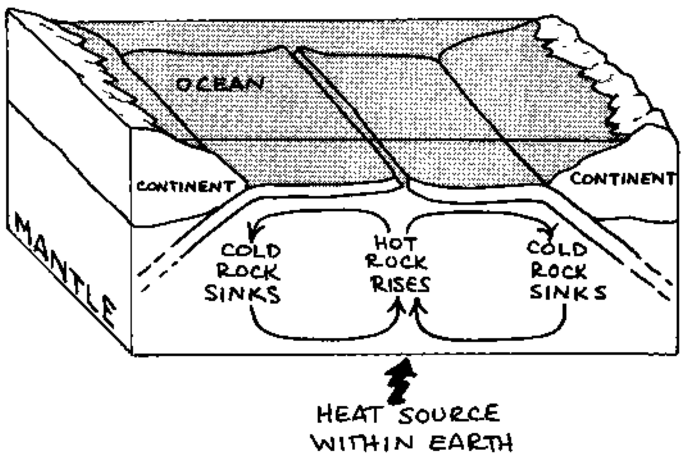

Figure 1.6.

plate margins. The scars and remnants of ancient plate interactions are also preserved in the rock record for us to study.

What causes plate motion? Thermal movement in the mantle is at least partly responsible (see Figure 1.6). Movement in the mantle, in turn, is caused by the release of heat from inside the Earth. The temperature in Earth's interior is high—about 5,000°C (more than 9,000°F) in the core. Some of this heat is left over from the planet's origin, but some of it is generated by the constant decay of naturally occurring radioactive elements. This heat must be released; if it were not, Earth would eventually become so hot that its entire interior would melt.

Some of Earth's internal heat makes its way slowly to the surface through **conduction**, in which heat energy is transferred from one atom to the next. However, conduction is a slow way to transfer heat. It is faster and more efficient for a packet of hot material to be physically transported to the surface. This is similar to what happens when a fluid boils on a stovetop, as in the wax experiment described earlier in this chapter. If you watch a fluid such as wax or spaghetti sauce as it boils, you will see that it turns over and over. Packets of hot material rise from the bottom of the pot to the top. As it reaches the surface, the hot fluid cools, then sinks back down to the bottom of the pot, where it is reheated. The continuous motion of material from bottom to top and down again is called a convection cell, and this type of heat transfer is called **convection**.

Even though Earth's mantle is mostly solid rock, it is so hot that it releases heat by convection. Rock deep in the mantle heats up and expands, making it buoyant. As a result, the rock moves toward the surface very slowly in huge convection cells of solid rock. Near the surface, the hot rock moves along the surface while losing heat to the atmosphere, just like the spaghetti sauce. As the rock cools, it becomes denser (cool rock is denser, or heavier, than hot rock) and sinks back into the deeper parts of the mantle. This convection cycle provides an efficient way for Earth to get rid of some of its internal heat.

The movement of lithospheric plates, formation of new crustal material through volcanism and tectonic uplift, and recycling of plates back into the mantle is called the **tectonic cycle**. Convection, plate motion, and interactions along plate margins create some of the most distinctive geologic and topographic features of the Earth's surface: deep oceanic trenches where lithospheric plates sink back into the mantle; midocean ridges and continental rift valleys where plates split apart; and high folded and crumpled mountain chains that form where continents collide. Plate tectonism is also responsible for generating earthquakes and volcanic eruptions, among other geologic processes that make the surface of Earth such a dynamic, active place.

So, we can now add plate tectonics to our list of unique features. Earth differs from all other known planets because of the unique relationship between its thin, brittle lithosphere and the hotter, weaker rocks that lie below in the asthenosphere. Plate tectonic activity has been an important process throughout much of Earth history. It is responsible for the uplifting of mountains, eruptions of volcanoes, intensities of earthquakes, movement of continents, and formation of deep ocean basins. It has even influenced the formation and chemistry of the atmosphere, the development of climatic zones, and the evolution of life, as you will learn in later chapters.

What is the cause of lithospheric plate motion? ________________

Answer: The release of heat through convection in the mantle.

Why do you think oceanic crust undergoes subduction but continental crust does not? ________________

Answer: Oceanic crust is much denser than continental crust; therefore, continental crust rides up and over a colliding plate, whereas the denser oceanic crust is forced down into the mantle.

So . . . what makes Earth unique? Let's summarize: We know of no other planet where plate tectonics has played and continues to play such an important role in shaping both the land and the physical environment. We know of no other planet where water exists near the surface in solid, liquid, and gaseous forms. No other planet yet discovered offers an ecosphere or hosts a biosphere or would have been hospitable to the origin and evolution of life as we know it. There are billions upon billions of stars in the universe, so it is almost inevitable that there are billions of planets; surely a few of those planets must be Earthlike and therefore capable of supporting life. However, if life does exist on a planet somewhere out in space, we haven't found it so far.

After reading this chapter, you should have a basic understanding of some of the factors that shape our relationship to the physical, chemical, biologic, and geologic world. In environmental science a lot of attention is paid to the interactions and interrelationships among the various spheres introduced in this chapter: the geosphere, atmosphere, and hydrosphere; the ecosphere; the biosphere; and the technosphere. We will revisit many of the topics and ideas introduced in this chapter in greater detail later in the book. In the meantime, you can test your knowledge and retention of this introductory material by trying out the Self-Test.

SELF-TEST

These questions are designed to help you assess how well you have learned the concepts presented in chapter 1. The answers are given at the end. If you get any of the questions wrong, be sure to troubleshoot by going back into that part of the chapter to find the correct answer.

1. Which one of the following is not a terrestrial planet?
   a. Mars
   b. Venus
   c. Mercury
   d. Neptune

2. The irregular blanket of loose debris that covers the surface of Earth is called the ________________.
   a. lithosphere
   b. regolith
   c. asthenosphere
   d. mantle

3. The *plates* in plate tectonics are made of fragments of ________________.
   a. continents
   b. oceanic crust
   c. lithosphere
   d. mantle

4. The weak layer of the mantle immediately underlying the lithosphere is called the ________________.

5. Earth has two fundamentally different types of crust: ________________ crust is made mainly of basaltic rocks, and ________________ crust is made mainly of granitic rocks.

6. Earth formed approximately 4.6 million years ago. (True or False)

7. The abiotic components of the environment are the living organisms that make up the biosphere. (True or False)

8. The term *technosphere* refers to the built, manufactured, industrialized, and domesticated parts of the world. (True or False)

9. Summarize the features that make Earth unique.

10. Briefly describe the processes of weathering and erosion.

11. What is convection, and how does it work inside the Earth?

12. What is the difference between the biosphere and the ecosphere?

13. What are the three main types of plate margins?

ANSWERS

1. d   2. b   3. c   4. asthenosphere

5. oceanic; continental   6. False   7. False   8. True

9. Presence of an ecosphere and biosphere; liquid water at the surface; surface temperature amenable to life; role of plate tectonics; characteristics of the regolith; composition of the atmosphere.

10. The process of weathering occurs when surface rocks and minerals disintegrate, either by chemical alteration or mechanical breakdown. Erosion happens when the weathered fragments are picked up by moving wind, water, or ice, carried downhill, and deposited.

11. Convection is a mechanism of heat transfer in which hot material is physically transported from a hot area to a cooler area. Inside the Earth, hot rock near the core becomes buoyant and rises toward the surface, where it cools. Through cooling, the rock becomes denser and eventually sinks back into the mantle, to be heated once again.

12. These terms are sometimes used interchangeably. *Ecosphere* refers specifically to an environment that is favorable to the existence of life. *Biosphere* refers to the actual living organisms—the life that is hosted by the ecosphere. Sometimes biosphere is used specifically to refer to Earth's ecosphere.

13. The three main types of plate margins are:
    i. divergent
    ii. convergent
    iii. transform or transcurrent fault

KEY WORDS

abiotic
asthenosphere
atmosphere
biosphere
biotic
conduction
continental crust
continental drift
convection
convergent margin
core
crust
divergent margin
ecosphere
environment
environmental science
erosion
geology
geosphere
hydrosphere
igneous rock
jovian planet
lava
lithosphere
magma
mantle
metamorphic rock
mineral
oceanic crust
plate
plate tectonics
plutonic rock
regolith
rock
rock cycle
sediment
sedimentary rock
solar system
subduction
technosphere
tectonic cycle
terrestrial planet
transcurrent or transform fault margin
volcanic rock
weathering