PART ONE

Foundations of Environmental Geology

The objective of Part 1 is to present the five fundamental principles of environmental geology and the important information necessary to understand the rest of the text. Of particular importance are (1) the fundamental concepts of environmental science, emphasizing the geologic environment; (2) the structure of Earth and, from a plate tectonics perspective, how our planet works; (3) geologic information concerning rocks and minerals necessary to understand environmental geology problems and solutions to those problems; and (4) linkages between geologic processes and the living world.

Chapter 1 opens with a definition and discussion of environmental geology, followed by a short history of the universe and the origin of Earth. Of particular importance is the concept of geologic time, which is critical in evaluating the role of geologic processes and human interaction in the environment. Five fundamental concepts are introduced: human population growth, sustainability, Earth as a system, hazardous Earth processes, and scientific knowledge and values. These are revisited throughout the text. Chapter 2 presents a brief discussion of the internal structure of Earth and a rather lengthy treatment of plate tectonics. Over periods of several tens of millions of years, the positions of the continents and the development of mountain ranges and ocean basins have dramatically changed our global environment. The patterns of ocean currents, global climate, and the distribution of living things on Earth are all, in part, a function of the processes that have constructed and maintained continents and ocean basins over geologic time.

Minerals and rocks and how they form in geologic environments are the subjects of Chapter 3. Minerals and rocks provide basic resources that our society depends on for materials to construct our homes, factories, and other structures; to manufacture airplanes, trains, cars, buses, and trucks that move people and goods around the globe; and to maintain our industrial economy, including everything from computers to eating utensils. The study of minerals and rocks aids in our general understanding of Earth processes at local, regional, and global levels. This knowledge is particularly important in understanding hazardous processes, including landslides and volcanic eruptions, in which properties of the rocks are intimately related to the processes and potential effects on human society.

Geology and ecology and the many links between the two are presented in Chapter 4. An ecosystem includes the non-living environment, which is the geologic environment. In addition, the living part of an ecosystem (community of organisms) has many important feedback cycles and links to important landscape and geologic processes. Chapter 4 presents some basics of ecology for geologists and emphasizes their relationship to environmental geology.

O N E

Philosophy and Fundamental Concepts

Learning Objectives

In this chapter we discuss and define geology and environmental geology, focusing on aspects of culture and society that are particularly significant to environmental awareness. We present some basic concepts of environmental science that provide the philosophical framework of this book. After reading this chapter, you should be prepared to discuss the following:

- Geology and environmental geology as a science
- Increasing human population as the number one environmental problem
- The concept of sustainability and important factors related to the "environmental crisis"
- Earth as a system and changes in systems
- The concepts of environmental unity and uniformitarianism and why they are important to environmental geology
- Hazardous Earth processes
- Scientific knowledge and values
- The scientific method
- Geologic time and its significance
- The precautionary principle
- Why solving environmental problems can be difficult

Easter Island
A story of rise and fall of a society that overused its resources.
(Tom Till/Getty Images Inc.)

CASE HISTORY

Easter Island: Are We on the Same Path at a Global Scale?

Easter Island, at 172 km^2, is a small, triangular-shaped, volcanic island located several thousand kilometers west of South America, with a subtropical climate. Polynesian people first reached the island approximately 1,500 years ago. When the Polynesians first arrived, they were greeted by a green island covered with forest, including large plam trees. By the sixteenth century, 15,000 to 30,000 people were living there. They had established a complex society spread among small villages and they raised crops and chickens to supplement the fish, marine mammals, and seabirds that sustained their diet. For religious reasons, they carved massive statues (called moai) from volcanic rock. The statues have the form of a human torso with stone headdress. Most are about 7 m high (21 ft), but some were higher than 20 m. The statues were moved into place at various locations on the island using ropes with tree trunks as rollers.

When Europeans reached Easter Island in the seventeenth century, only about 2,000 people were living on the island. The main symbols of the once-vibrant civilization were the statues, most of which had been toppled and damaged. No trees were growing on the island and the people were living in a degraded environment.

Why Did the Society Collapse? Evidently, the society collapsed in just a few decades, probably the result of degradation of the island's limited resource base. As the human population of the island increased, more and more land was cleared for agriculture while remaining trees were used for fuel and for moving the statues into place. Previously, the soils were protected beneath the forest cover and held water in the subtropical environment. Soil nutrients were probably supplied by dust from thousands of kilometers away that reached the island on the winds. Once the forest was cleared, the soils eroded and the agricultural base of the society was diminished. Loss of the forest also resulted in loss of forest products necessary for building homes and boats, and, as a result, the people were forced to live in caves. Without boats, they could no longer rely on fish as a source of protein. As population pressure increased, wars between villages became common, as did slavery and even cannibalism, in attempts to survive in an environment depleted of its resource base.

Lessons Learned. The story of Easter Island is a dark one that vividly points to what can happen when an isolated area is deprived of its resources through human activity: Limited resources cannot support an ever-growing human population.

Although the people of Easter Island did deplete their resources, the failure had some factors they could not understand or recognize. Easter Island has a naturally fragile environment[1] compared to many other islands the Polynesians colonized.

- The island is small and very isolated. The inhabitants couldn't expect help in hard times from neighboring islands.
- Volcanic soils were originally fertile, but agricultural erosion was a problem and soil-forming processes on the island were slow compared to more tropical islands. Nutrient input to soils from atmospheric dust from Asia was not significant.
- The island's three volcanoes are not active, so no fresh volcanic ash added nutrients to the soils. The topography is low with gentle slopes. Steep high mountains generate clouds, rain, and runoff that nourishes lowlands.
- With a subtropical climate with annual rainfall of 80 cm (50 in), there was sufficient rainfall, but the water quickly infiltrated through the soil into porous volcanic rock.
- There are no coral reefs at Easter Island to provide abundant marine resources.

There is fear today that our planet, an isolated island in space, may be reaching the same threshold faced by the people of Easter Island in the sixteenth century. In the twenty-first century, we are facing limitations of our resources in a variety of areas, including soils, fresh water, forests, rangelands, and ocean fisheries. The primary question from both an environmental perspective and for the history of humans on Earth is: Will we recognize the limits of Earth's resources before it is too late to avoid the collapse of human society on a global scale? Today there are no more frontiers on Earth, and we have a nearly fully integrated global economy. With our modern technology, we have the ability to extract resources and transform our environment at rates much faster than any people before us. The major lesson from Easter Island is clear: Develop a sustainable global economy that ensures the survival of our resource base and other living things on Earth, or suffer the consequences.[1]

Some aspects of the history of Easter Island have recently been challenged as being only part of the story. Deforestation certainly played a role in the loss of the trees, and rats that arrived with the Polynesians were evidently responsible for eating seeds of the palm trees, not allowing regeneration. The alternative explanation is that the Polynesian people on Easter Island at the time of European contact in 1722 numbered about 3,000 persons. This population may have been close to the maximum reached in about the year 1350. Following contact, introduced diseases and enslavement, resulted in reduction of the population to about 100 by the late 1870s.[2] As more of the story of Easter Island emerges from scientific and social studies, the effects of human resource exploitation, invasive rats, and European contact will become clearer. The environmental lessons of the collapse will lead to a better understanding of how we can sustain our global human culture.

1.1 Introduction to Environmental Geology

Everything has a beginning and an end. Our Earth began about 4.6 billion years ago when a cloud of interstellar gas known as a solar nebula collapsed, forming protostars and planetary systems (see A Closer Look: Earth's Place in Space). Life on Earth began about 3.5 billion years ago, and since then multitudes of diverse organisms have emerged, prospered, and died out, leaving only fossils to mark their place in Earth's history. Just a few million years ago, our ancestors set the stage for the present dominance of the human species. As certainly as our Sun will die, we too will eventually disappear. Viewed in terms of billions of years, our role in Earth's history may be insignificant, but for those of us now living and for our children and theirs, our impact on the environment is significant indeed.

A CLOSER LOOK | Earth's Place in Space

The famous geologist Preston Cloud wrote:

> Born from the wreckage of stars, compressed to a solid state by the force of its own gravity, mobilized by the heat of gravity and radioactivity, clothed in its filmy garments of air and water by the hot breath of volcanoes, shaped and mineralized by 4.6 billion years of crustal evolution, warmed and peopled by the Sun, this resilient but finite globe is all our species has to sustain it forever.[3]

In this short, eloquent statement, Cloud takes us from the origin of Earth to the concept of sustainability that today is at the forefront of thinking about the environment and our future.

We Have a Right to Be Here. The place of humanity in the universe is stated well in the *Desiderata:* "You are a child of the universe, no less than the trees and the stars; you have the right to be here. And whether or not it is clear to you, no doubt the universe is unfolding as it should."[4] To some this might sound a little out of place in science but, as emphasized further by Cloud, people can never escape the fact that we are one piece of the biosphere, and, although we stand high in it, we are not above it.[3]

Origin of the Universe. Figure 1.A presents an idealized view of the history of the universe with an emphasis on the origin of our solar system and Earth. Scientists studying the stars and the origin of the universe believe that about 12 billion years ago, there was a giant explosion known as the big bang. This explosion produced the atomic particles that later formed galaxies, stars, and planets. It is believed that about 7 billion years ago, one of the first generations of giant stars experienced a tremendous explosion known as a *supernova*. This released huge amounts of energy, producing a solar nebula, which is thought to be a spinning cloud of dust and gas. The solar nebula condensed as a result of gravitational processes, and our Sun formed at the center, but some of the particles may have been trapped in solar orbits as rings, similar to those we observe around the planet Saturn. The density of particles in individual rings was evidently not constant, so gravitational attraction from the largest density of particles in the rings attracted others until they collapsed into the planetary system we have today. Thus, the early history of planet Earth, as well that of the other planets in our solar system, was characterized by intense bombardment of meteorites. This bombardment was associated with accretionary processes—that is, the amalgamation of various sized particles, from dust to meteorites, stony asteroids, and ice-rich comets many kilometers in diameter—that resulted in the formation of Earth about 4.6 billion years ago.[3,5] This is the part of Earth's history that Cloud refers to when he states that Earth was born from the wreckage of stars and compressed to a solid state by the force of its own gravity. Heat generated deep within Earth, along with gravitational settling of heavier elements such as iron, helped differentiate the planet into the layered structure we see today (see Chapter 2).

Origin of Atmosphere and Water on Earth. Water from ice-cored comets and outgassing, or the release of gases such as carbon dioxide and water vapor, from volcanoes and other processes, produced Earth's early atmosphere and water. About 3.5 billion years ago the first primitive life-forms appeared on Earth in an oxygen-deficient environment. Some of these primitive organisms began producing oxygen through photosynthesis, which profoundly affected Earth's atmosphere. Early primitive, oxygen-producing life probably lived in the ocean, protected from the Sun's ultraviolet radiation. However, as the atmosphere evolved and oxygen increased, an ozone layer was produced in the atmosphere that shielded Earth from harmful radiation. Plants evolved that colonized the land surface, producing forests, meadows, fields, and other environments that made the evolution of animal life on the land possible.[3]

The spiral of life generalized in Figure 1.A delineates evolution as life changed from simple to complex over several billion years of Earth's history. The names of the eras, periods, and epochs that geologists use to divide **geologic time** are labeled with their range in millions or billions of years from the present (Table 1.1). If you go on to study geology, they will

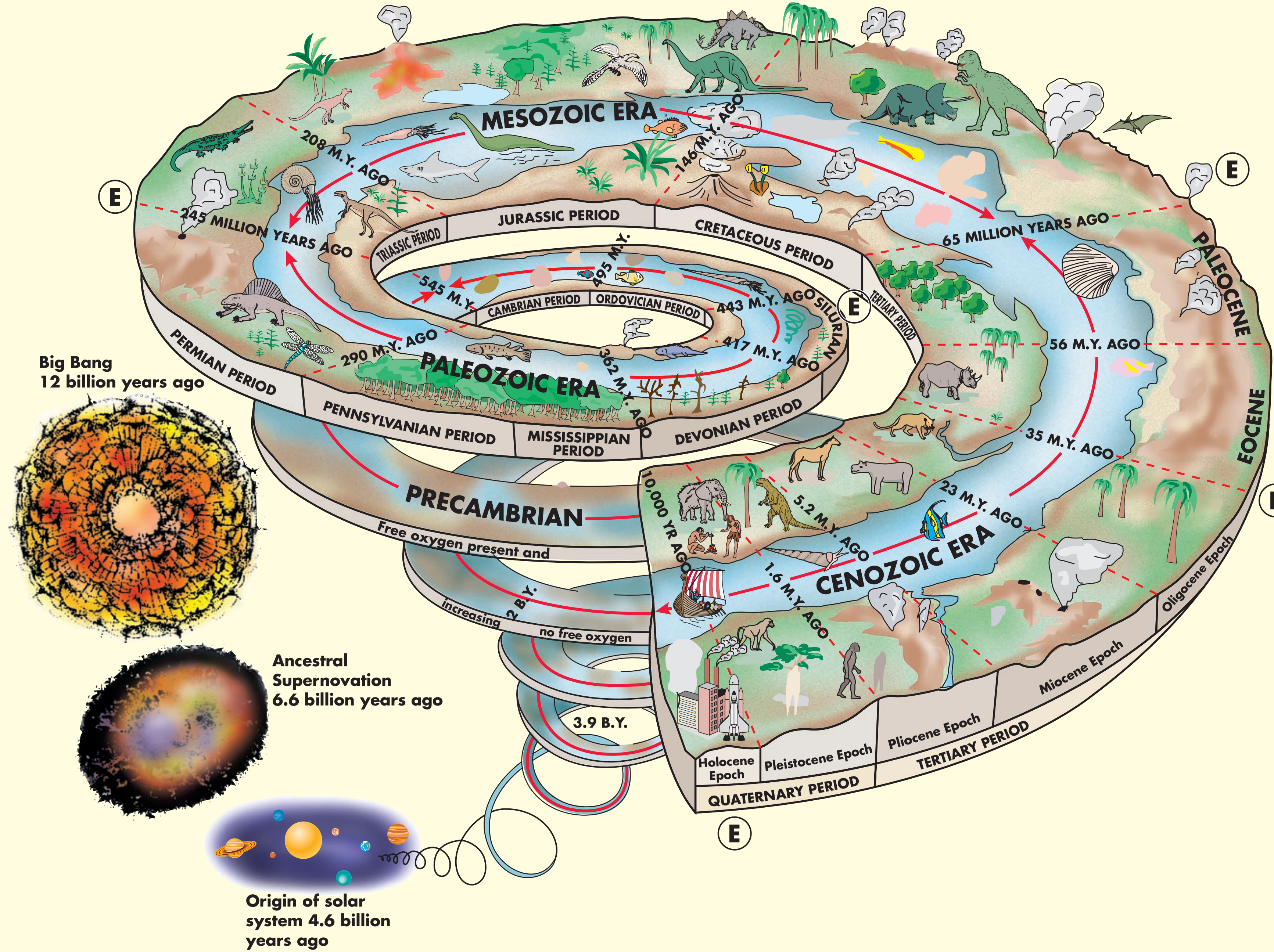
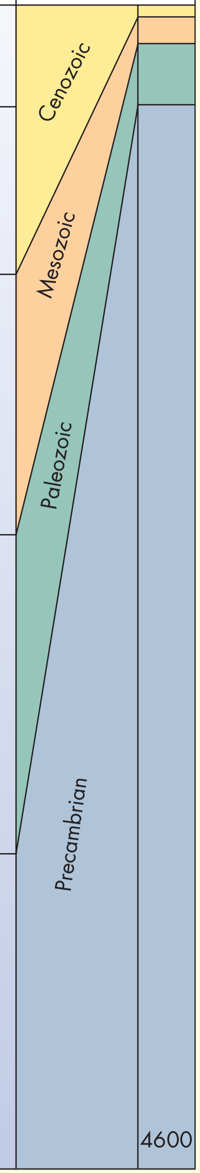


Figure 1.A Earth history Idealized diagram of the history of the universe and Earth, with emphasis on the biological evolution of Earth from simple life-forms of the Precambrian to humans today. Precambrian = 4.6 billion years ago to 545 million years ago. Red arrows are boundaries for eras (Table 1.1). (E) is time of mass extinction event. *(Modified after U.S. Geological Survey; and Cloud, P. 1978.* Cosmos, Earth and man. *New Haven, CT: Yale University Press)*

TABLE 1.1 Geologic Time with Important Events

Era	Period	Epoch	Million Years before Present	Events: Life	Events: Earth	Million Years before Present
Cenozoic	Quaternary	Holocene	0.01	• Extinction event • Modern humans	Ice Age; Formation of Transverse Ranges, CA	
		Pleistocene	1.65	• Early humans		1.65
	Tertiary	Pliocene	5.2		Formation of Andes Mountains	
		Miocene	23	• Grasses • Whales	Collision of India with Asia forming Himalayan Mountains and Tibetan Plateau	
		Oligocene	35	• Extinction event		
		Eocene	56	• Mammals expand		
		Paleocene	65		Rocky Mountains form	65
Mesozoic	Cretaceous		146	• Dinosaur extinction[1], extinction event • Flowering plants	Emplacement of Sierra Nevada Granites (Yosemite National Park)	
	Jurassic		208	• Birds		
	Triassic		245	• Mammals • Dinosaurs	• Supercontinent Pangaea begins to break up	245
Paleozoic	Permian		290	• Extinction event • Reptiles	• Ice Age	
	Carboniferous		363	• Trees (coal swamps) • Extinction event	Appalachian Mountains form	
	Devonian		417			
	Silurian		443	• Land plants • Extinction event		
	Ordovician		495	• Fish		
	Cambrian		545	• Explosion of organisms with shells		545
Precambrian			2500	• Multicelled organisms • Free oxygen in atmosphere and ozone layer in stratosphere	• Ice Age • Ice Age	
			3500	• Primitive life (first fossils)		
			4000		• Oldest rocks	
			4600		• Age of Earth	4600

True Scale (Million Years before Present)



[1]Some scientists believe that not all dinosaurs became extinct but that some dinosaurs evolved to birds.

become as familiar to you as the months of the year. The boundaries between eras, periods, and epochs are based on both the study of what was living at the particular time and on important global geologic events in Earth's history. Relative ages of rocks are based on the assemblage of fossils—that is, evidence for past life such as shells, bones, teeth, leaves, seeds—that are found in rocks or sediments. A general principle of geology, known as the **law of faunal assemblages,** states that rocks with similar fossils are most likely of a similar geologic age. For example, if we find bones of dinosaurs in a rock, we know the rocks are Mesozoic in age. Fossils provide relative ages of rocks; numerical, or absolute, dates depend upon a variety of sophisticated chemical age-dating techniques. These age-dating techniques allow geologists to often pinpoint the geologic age of rocks containing fossils to within a few million years or better.

Evolution as a Process. The evolutionary process as deduced from the fossil record has not been a smooth continuous one but instead has been punctuated by explosions of new species at some times and extinction of many species at other times. Five mass extinction events are shown in Figure 1.A.

Evolution and extinction of species are natural processes, but for those times when many species became extinct at approximately the same time, we use the term *mass extinction*. For example, the dinosaurs became extinct approximately 65 million years ago. Some geologists believe this mass extinction resulted from climatic and environmental changes that naturally occurred on Earth; others believe the planet was struck by a "death star," an asteroid of about 10 km (6 mi) in diameter, that crashed into what is today the Yucatan Peninsula in Mexico. It is believed that another such impact would produce firestorms and huge dust clouds that would circle Earth in the atmosphere for a prolonged period of time, blocking out sunlight, greatly reducing or stopping photosynthesis, and eventually leading to mass extinction of both the species that eat plants and the predators that feed on the plant eaters.[5]

It is speculated that asteroids of the size that may have caused the dinosaurs to become extinct are not unique, and such catastrophic impacts have occurred at other times during Earth history. Such an event is the ultimate geologic hazard, the effects of which might result in another mass extinction, perhaps including humans! (See Chapter 11.) Fortunately, the probability of such an occurrence is very small during the next few thousand years. In addition, we are developing the technology to identify and possibly deflect asteroids before they strike Earth. The history of our solar system and Earth, briefly outlined here, is an incredible story of planetary and biological evolution. What will the future bring? We do not know, of course, but certainly it will be punctuated by a change, and as the evolutionary processes continue, we too will evolve, perhaps to a new species. Through the processes of pollution, agriculture, urbanization, industrialization, and the land clearing of tropical forest, humans appear to be causing an acceleration of the rate of extinction of plant and animal species. These human activities are significantly reducing Earth's biodiversity—the number and variability of species over time and space (area)—and are thought to be a major environmental problem because many living things, including humans, on Earth depend on the environment with its diversity of life-forms for their existence.

Geologically speaking, we have been here for a very short time. Dinosaurs, for example, ruled the land for more than 100 million years. Although we do not know how long our own reign will be, the fossil record suggests that all species eventually become extinct. How will the history of our own species unfold, and who will write it? Our hope is to leave something more than some fossils that mark a brief time when *Homo sapiens* flourished. Hopefully, as we evolve we will continue to become more environmentally aware and find ways to live in harmony with our planet.

Geology is the science of processes related to the composition, structure, and history of Earth and its life. Geology is an interdisciplinary science, relying on aspects of chemistry (composition of Earth's materials), physics (natural laws), and biology (understanding of life-forms).

Environmental geology is applied geology. Specifically, it is the use of geologic information to help us solve conflicts in land use, to minimize environmental degradation, and to maximize the beneficial results of using our natural and modified environments. The application of geology to these problems includes the study of the following (Figure 1.1).

1. Earth materials, such as minerals, rocks, and soils, to determine how they form, their potential use as resources or waste disposal sites, and their effects on human health
2. Natural hazards, such as floods, landslides, earthquakes, and volcanic activity, in order to minimize loss of life and property
3. Land for site selection, land-use planning, and environmental impact analysis

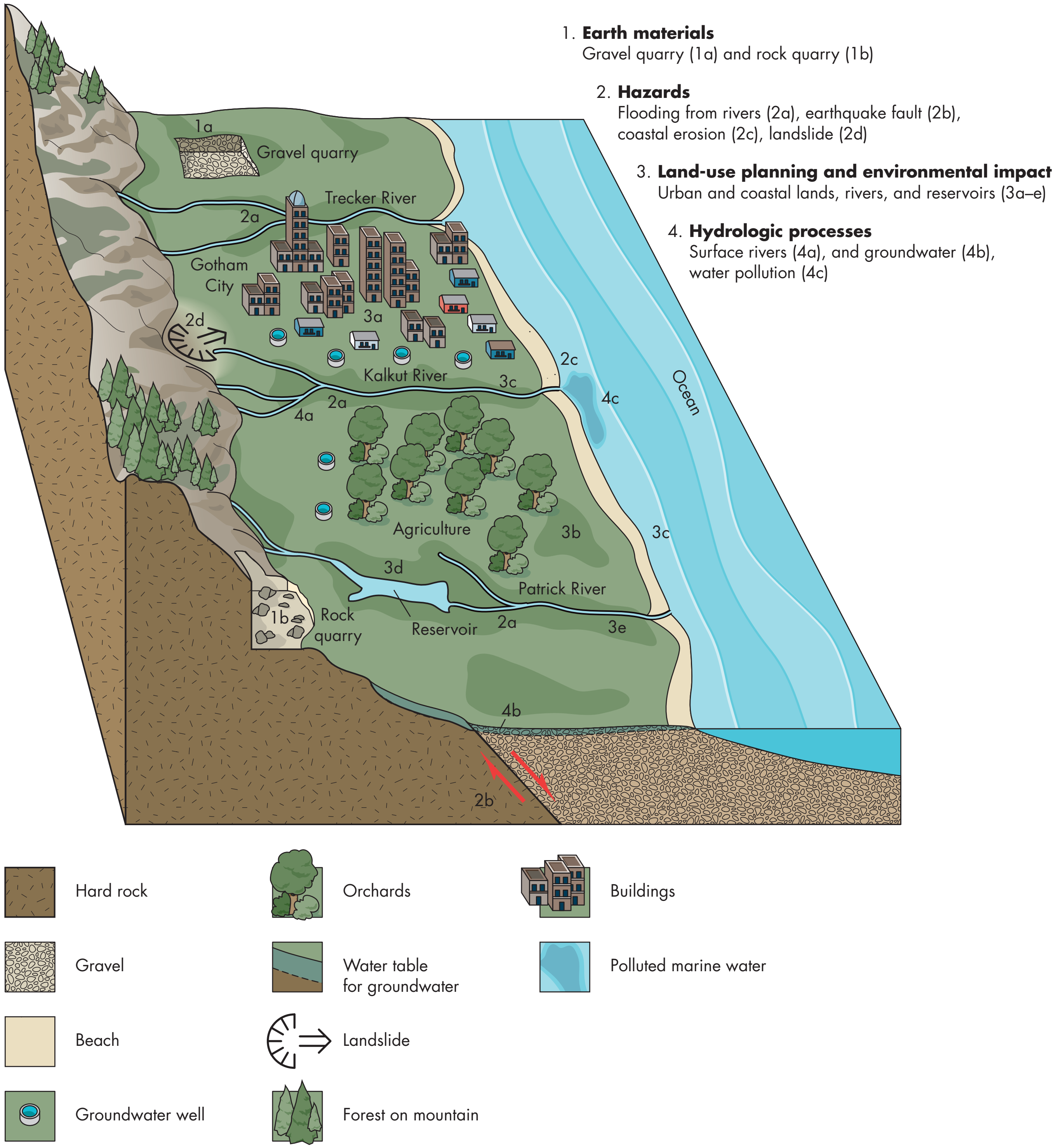


Figure 1.1 **Components of environmental geology** Idealized diagram illustrating four main areas of study for environmental geology. Geologic processes encompass all of the four areas. These offer employment opportunities for geologists, engineers, and hydrologists.

4. Hydrologic processes of groundwater and surface water to evaluate water resources and water pollution problems
5. Geologic processes, such as deposition of sediment on the ocean floor, the formation of mountains, and the movement of water on and below the surface of Earth, to evaluate local, regional, and global change

Considering the breadth of its applications, we can further define environmental geology as the branch of Earth science that studies the entire spectrum of human interactions with the physical environment. In this context, environmental geology is a branch of *environmental science*, the science of linkages between physical, biological, and social processes in the study of the environment.

1.2 Fundamental Concepts of Environmental Geology

Before we begin to explore the many facets of environmental geology presented in this textbook, there are some basic concepts that need to be introduced. These five fundamental concepts serve as a conceptual framework upon which the rest of the textbook will build. As you read through *Introduction to Environmental Geology*, you will notice that these concepts are revisited throughout the text.

1. ***Human population growth***
2. ***Sustainability***
3. ***Earth as a system***
4. ***Hazardous Earth processes***
5. ***Scientific knowledge and values***

The five concepts presented here do not constitute a list of all concepts that are important to environmental geologists, and they are not meant to be memorized. However, a general understanding of each concept will help you comprehend and evaluate the material presented in the rest of the text.

Concept One: Human Population Growth

The number one environmental problem is the increase in human population

The number one environmental problem is the ever-growing human population. For most of human history our numbers were small as was our input on Earth. With the advent of agriculture, sanitation, modern medicine, and, especially, inexpensive energy sources such as oil, we have proliferated to the point where our numbers are a problem. The total environmental impact from people is estimated by the impact per person times the total number of people. Therefore, as population increases, the total impact must also increase. As population increases, more resources are needed and, given our present technology, greater environmental disruption results. When local population density increases as a result of political upheaval and wars, famine may result (Figure 1.2).

Exponential Growth

What Is the Population Bomb? Overpopulation has been a problem in some areas of the world for at least several hundred years, but it is now apparent that it is a global problem. From 1830 to 1930, the world's population doubled from 1 to 2 billion people. By 1970 it had nearly doubled again, and by the year 2000 there were about 6 billion people on Earth. The problem is sometimes called the population bomb, because the exponential growth of the human population results in the explosive increase in the number of people (Figure 1.3). **Exponential growth** for increase in humans means that the number of people added to the population each year is not constant; rather, a constant percentage of the current population is added each year. As an analogy, consider a high-yield savings account that pays

Figure 1.2 Famine Korem Camp, Ethiopia, in 1984. Hungry people are forced to flee their homes as a result of political and military activity and gather in camps such as these. Surrounding lands may be devastated by overgrazing from stock animals, gathering of firewood, and just too many people in a confined area. The result may be famine. *(David Burnett/Contact Press Images, Inc.)*

interest of 7 percent per year. If you start with $100, at the end of the first year you have $107, and you earned $7 in interest. At the end of the second year, 7 percent of $107 is $7.49, and your balance is $107 plus $7.49, or $114.49. Interest in the third year is 7 percent of 114.49, or $8.01, and your account has $122.51. In 30 years you will have saved about $800.00. Read on to find out how I know this.

There are two important aspects of exponential growth:

- The **growth rate,** measured as a percentage
- The **doubling time,** or the time it takes for whatever is growing to double

Figure 1.4 illustrates two examples of exponential growth. In each case, the object being considered (student pay or world population) grows quite slowly at first,

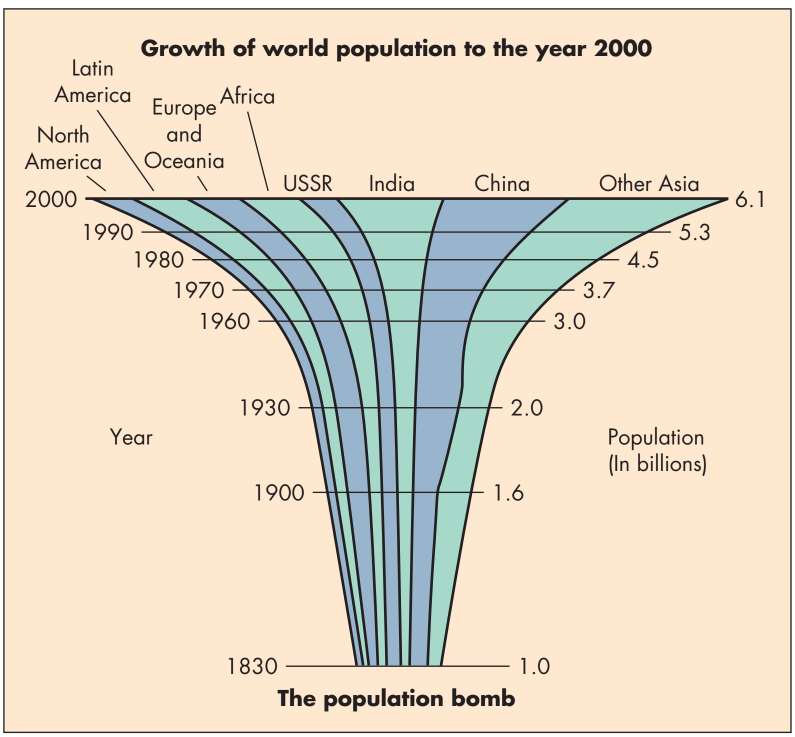


Figure 1.3 The population bomb The population in 2006 is 6.6 billion and growing *(Modified after U.S. Department of State)*

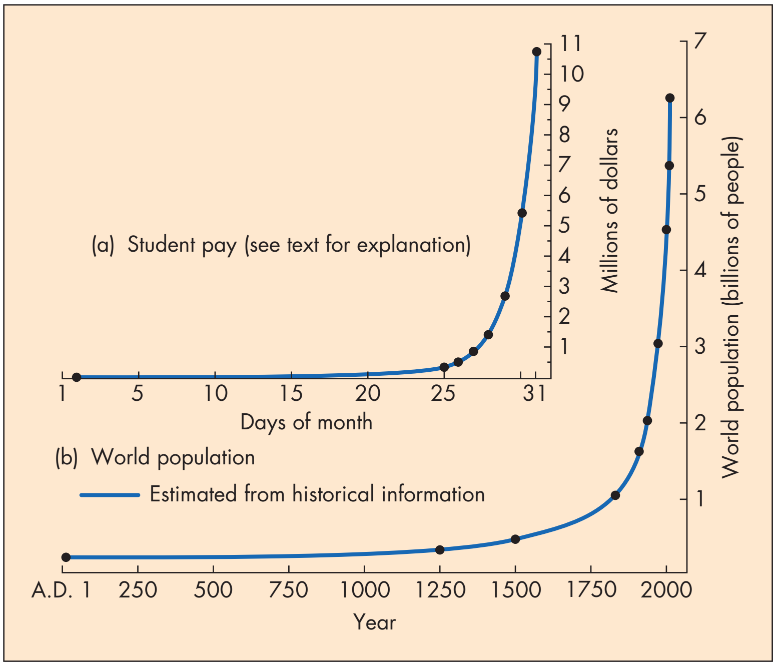


Figure 1.4 Exponential growth (a) Example of a student's pay, beginning at 1 cent for the first day of work and doubling daily for 31 days. (b) World population. Notice that both curves have the characteristic *J* shape, with a slow initial increase followed by a rapid increase. The actual shape of the curve depends on the scale at which the data are plotted. It often looks like the tip of a skateboard. *(Population data from U.S. Department of State)*

begins to increase more rapidly, and then continues at a very rapid rate. Even very modest rates of growth eventually produce very large increases in whatever is growing.

How Fast Does Population Double? A general rule is that doubling time (D) is roughly equal to 70 divided by the growth rate (G):

$$D = 70/G$$

Using this approximation, we find that a population with a 2 percent annual growth rate would double in about 35 years. If it were growing at 1 percent per year, it would double in about 70 years.

Many systems in nature display exponential growth some of the time, so it is important that we be able to recognize such growth because it can eventually yield incredibly large numbers. As an extreme example of exponential growth (Figure 1.4a), consider the student who, after taking a job for 1 month, requests from the employer a payment of 1 cent for the first day of work, 2 cents for the second day, 4 cents for the third day, and so on. In other words, the payment would double each day. What would be the total? It would take the student 8 days to earn a wage of more than $1 per day, and by the eleventh day, earnings would be more than $10 per day. Payment for the sixteenth day of the month would be more than $300, and on the last day of the 31-day month, the student's earnings for that one day would be more than $10 million! This is an extreme case because the constant rate of increase is 100 percent per day, but it shows that exponential growth is a very dynamic process. The human population increases at a much lower rate—1.4 percent per year today—but even this slower exponential growth eventually results in a dramatic increase in numbers (Figure 1.4b). Exponential growth will be discussed further under Concept Three, when we consider systems and change.

Human Population Through History

What Is Our History of Population Growth? The story of human population increase is put in historic perspective in Table 1.2. When we were hunter-gatherers,

TABLE 1.2 How We Became 6 Billion +

40,000–9,000 B.C.: Hunters and Gatherers	
Population density about 1 person per 100 km^2 of habitable areas;* total population probably less than a few million; average annual growth rate less than 0.0001% (doubling time about 700,000 years)	
9,000 B.C.–A.D. 1600: Preindustrial Agricultural	
Population density about 1 person per 3 km^2 of habitable areas (about 300 times that of the hunter and gatherer period); total population about 500 million; average annual growth rate about 0.03% (doubling time about 2,300 years)	
A.D. 1600–1800: Early Industrial	
Population density about 7 persons per 1 km^2 of habitable areas; total population by 1800 about 1 billion; annual growth rate about 0.1% (doubling time about 700 years)	
A.D. 1800–2000: Modern	
Population density about 40 persons per 1 km^2; total population in 2000 about 6.1 billion; annual growth rate at 2000 about 1.4% (doubling time about 50 years)	

*Habitable area is assumed to be about 150 million square kilometers (58 million square miles). Modified after Botkin, D. B., and Keller, E. A. 2000. *Environmental science*, 3rd ed. New York: John Wiley and Sons.

our numbers were very small, and growth rates were very low. With agriculture, growth rates in human population increased by several hundred times owing to a stable food supply. During the early industrial period (A.D. 1600 to 1800) growth rates increased again by about 10 times. With the Industrial Revolution, with modern sanitation and medicine, the growth rates increased another 10 times. Human population reached 6 billion in 2000. By 2013 it will be 7 billion and by 2050 it will be about 9 billion. That is 1 billion new people in only 13 years and 3 billion (about one-half of today's population) in 50 years. By comparison, total human population had reached only 1 billion in about A.D. 1800, after over 40,000 years of human history! Less developed countries have death rates similar to those of more developed countries, but their birth rates are twice those of developed countries. India will likely have the greatest population of all countries by 2050, with about 18 percent of the total world population, followed by China with 15 percent. Together, these two countries will then have about one-third of the total world population by 2050.[6]

Population Growth and the Future

How Many People Can Earth Comfortably Support? Because Earth's population is increasing exponentially, many scientists are concerned that in the twenty-first century it will be impossible to supply resources and a high-quality environment for the billions of people who may be added to the world population. Three billion more people by 2050, with almost all of the growth in the developing countries, is cause for concern. Increasing population at local, regional, and global levels compounds nearly all environmental geology problems, including pollution of ground and surface waters; production and management of hazardous waste; and exposure of people and human structures to natural processes (hazards) such as floods, landslides, volcanic eruptions, and earthquakes.

There is no easy answer to the population problem. In the future we may be able to mass-produce enough food from a nearly landless agriculture, or use artificial growing situations, to support our ever-growing numbers. However, the ability to feed people does not solve the problems of limited space available to people and maintenance or improvement of their quality of life. Some studies suggest that the present population is already above a comfortable **carrying capacity** for the planet. Carrying capacity is the maximum number of people Earth can hold without causing environmental degradation that reduces the ability of the planet to support the population. The role of education is paramount in the population problem. As people (particularly women) become more educated, the population growth rate tends to decrease. As the rate of literacy increases, population growth is reduced. Given the variety of cultures, values, and norms in the world today, it appears that our greatest hope for population control is, in fact, through education.[7]

The Earth Is Our Only Suitable Habitat. The Earth is now and for the foreseeable future the only suitable habitat we have, and its resources are limited. Some resources, such as water, are renewable, but many, such as fuels and minerals, are not. Other planets in our solar system, such as Mars, cannot currently be considered a solution to our resource and population problems. We may eventually have a colony of people on Mars, but it would be a harsh environment, with people living in bubbles.

When resource and other environmental data are combined with population growth data, the conclusion is clear: It is impossible, in the long run, to support exponential population growth with a finite resource base. Therefore, one of the primary goals of environmental work is to ensure that we can defuse the population bomb. Some scientists believe that population growth will take care of itself through disease and other catastrophes, such as famine. Other scientists are optimistic that we will find better ways to control the population of the world within the limits of our available resources, space, and other environmental needs.

Good News on Human Population Growth. It is not all bad news regarding human population growth; for the first time since the mid-1900s; the rate of increase in human population is decreasing. Figure 1.5 shows that the number of people added to the total population of Earth peaked in the late 1980s and has generally decreased since then. This is a milestone in human population growth and it is encouraging.[8] From an optimistic point of view, it is possible that our global population of 6 billion persons in 2000 may not double again. Although

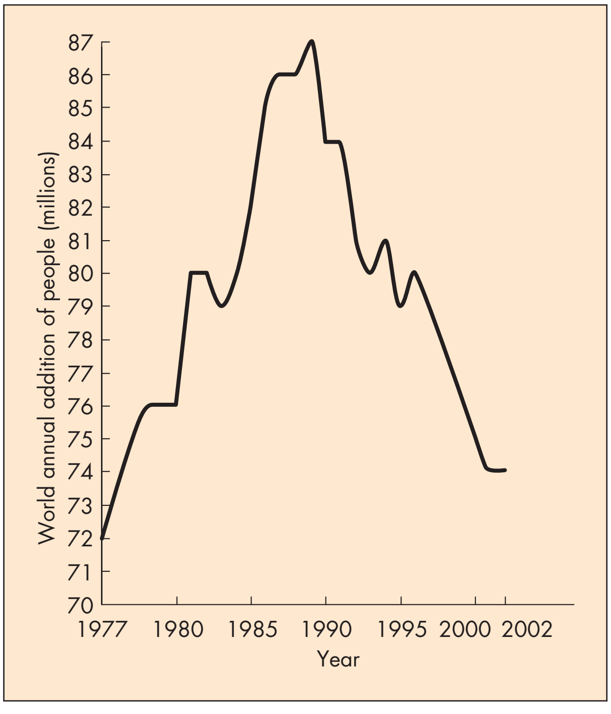


Figure 1.5 Good news on population growth World annual increase in population peaked in the late 1980s. Today it is at a level comparable to the late 1970s. This increase is like adding two Californias each year. *(Data from the U.S. Bureau of the Census and Worldwatch Institute)*

population growth is difficult to estimate because of variables such as agriculture, sanitation, medicine, culture, and education, it is estimated that by the year 2050 human population will be between 7.3 and 10.7 billion, with 8.9 billion being most likely. Population reduction is most likely related to the education of women, the decision to marry later in life, and the availability of modern birth control methods. Until the growth rate is zero, however, population will continue to grow. About 20 countries, mostly in Western Europe but including China, have achieved a total fertility rate (number of children per woman) less than 2.1, which is the level necessary for replacement.

Concept Two: Sustainability

Sustainability is the environmental objective

What is sustainability? **Sustainability** is something that we are struggling to define. One definition is that sustainability is development that ensures that future generations will have equal access to the resources that our planet offers. Sustainability also refers to types of development that are economically viable, do not harm the environment, and are socially just.[7] Sustainability is a long-term concept, something that happens over decades or even over hundreds of years. It is important to acknowledge that sustainability with respect to use of resources is possible for renewable resources such as air and water. Sustainable development with respect to nonrenewable resources such as fossil fuels and minerals is possible by, first, extending their availability through conservation and recycling; and second, rather than focusing on when a particular nonrenewable resource is depleted, focusing on how that mineral is used and develop substitutes for those uses.

There is little doubt that we are using living environmental resources such as forests, fish, and wildlife faster than they can be naturally replenished. We have extracted minerals, oil, and groundwater without concern for their limits or for the need to recycle them. As a result, there are shortages of some resources. We must learn how to sustain our environmental resources so that they continue to provide benefits for people and other living things on the planet.

We stated in Concept One, with respect to humans and resources, that Earth is the only place to live that is now accessible to us, and our resources are limited. To meet future resource demands and to sustain our resources, we will need large-scale recycling of many materials. Most materials can theoretically be recycled. The challenge is to find ways to do it that do not harm the environment, that increase the quality of life, and that are economically viable. A large part of our solid and liquid waste disposal problems could be alleviated if these wastes were reused or recycled. In other words, many wastes that are now considered pollutants can be turned into resources. Land is also an important resource for people, plants, and animals as well as for manufacturing, mining, and energy production; transportation; deposition of waste products; and aesthetics. Owing in part to human population increases that demand more land for urban and agricultural purposes, human-induced change to Earth is increasing at a rapid rate. A recent study of human activity and the ability to move soil and rock concluded that human activity (agriculture, mining, urbanization, and so on) moves as much or more soil and rock on an annual basis than any other Earth process (Figure 1.6), including mountain building or river transport of sediment. These activities and their associated visual changes to Earth (for example, leveling hills) suggest that human activity is the most significant process shaping the surface of Earth.[9] (See A Closer Look: Human Landscape Modification: Ducktown, Tennessee.) We'll discuss land-use planning in Chapter 20.

Figure 1.6 Mining A giant excavating machine in this mine can move Earth materials at a rate that could bury one of the Egyptian Pyramids in a short time. *(Joseph J. Scherschel/NGS Image Collection)*

A CLOSER LOOK | Human Landscape Modification: Ducktown, Tennessee

A Man-Made Desert in Tennessee? The land surrounding Ducktown once looked more like the Painted Desert of Arizona than the lush vegetation of the Blue Ridge Mountains of the southeastern United States (Figure 1.B, part a).[10] The story of Ducktown starts in 1843 when what was thought to be a gold rush turned out to be a rush for copper. By 1855,

Figure 1.B The lasting effects of land abuse (a) Location of Ducktown, Tennessee. (b) The human-made desert resulting from mining activities around Ducktown more than 100 years ago. Extensive soil erosion and loss of vegetation have occurred, and complete recovery will probably take more than 100 years. *(Kristoff, Emory/NGS Image Sales)* (c) Ducktown area in recent years, showing the process of recovery. *(Tennessee Valley Authority)*

30 companies were transporting copper ore by mule over the mountains to a site called Copper Basin and to Ducktown. Huge ovens—open pits 200 m (656 ft) long and 30 m (98 ft) deep—were constructed to separate the copper from zinc, iron, and sulfur. The local hardwood forest was cut to fuel these ovens, and the tree stumps were pulled and turned into charcoal. Eventually, every tree over an area of about 130 km^2 (50 mi^2), or an area equal to approximately four times that of Manhattan Island, was removed. The ovens produced great clouds of noxious gas that were reportedly so thick that mules wore bells to keep from colliding with people and each other. The sulfur dioxide gas and particulates produced acid rain and acid dust that killed the remaining vegetation. This loss of vegetation led to extensive soil erosion, leaving behind a hard mineralized rock cover resembling a desert. The scarred landscape is so large that it is one of the few human landmarks visible from space (Figure 1.B, part b).

People Are Basically Optimistic About Their Future. The devastation resulting from the Ducktown mining activity also produced adverse economic and social change. Nevertheless, people in Ducktown remain optimistic. A sign at the entry to the town states, "Copper made us famous. Our people made us great." The revegetation process started in the 1930s, and most of the area is now covered with some vegetation (Figure 1.B, part c). However, it will probably take hundreds of years for the land to completely recover. The lessons learned from the restoration of the Copper Basin will provide useful information for other areas in the world where human-made deserts occur, such as the area around the smelters in Sudbury, Ontario (Figure 1.C). However, there is still concern for mining areas, particularly in developing countries, where landscape destruction similar to that at Copper Basin is still ongoing.[12]

Figure 1.C Air pollution Area around Sudbury, Ontario, devoid of vegetation because of air pollution from smelters, smokestacks in background. *(Bill Brooks/Masterfile Corporation)*

Are We in an Environmental Crisis? Demands made on diminishing resources by a growing human population and the ever-increasing production of human waste have produced what is popularly referred to as the **environmental crisis.** This crisis in the United States and throughout the world is a result of overpopulation, urbanization, and industrialization, combined with too little ethical regard for our land and inadequate institutions to cope with environmental stress.[10] The rapid use of resources continues to cause environmental problems on a global scale, including

- Deforestation and accompanying soil erosion and water and air pollution occur on many continents (Figure 1.7a).
- Mining of resources such as metals, coal, and petroleum wherever they occur produces a variety of environmental problems (Figure 1.7b).
- Development of both groundwater and surface-water resources results in loss of and damage to many environments on a global scale (see Case History: The Aral Sea: The Death of a Sea).

On a positive note, we have learned a great deal from the environmental crisis, particularly concerning the relationship between environmental degradation and resource utilization. Innovative plans for sustainable development of resources, including water and energy, are being developed to lessen a wide variety of environmental problems associated with using resources.

Figure 1.7a **Logging** Clear-cut timber harvesting exposes soils, compacting them and generally contributing to an increase in soil erosion and other environmental problems. *(Edward A. Keller)*

Figure 1.7b **Mining** Large open pit mines such as this one east of Silver City, New Mexico, are necessary if we are to obtain resources. However, they do cause disturbance to the surface of the land, and reclamation may be difficult or nearly impossible in some instances. *(Michael Collier)*

Do We Need to Save Earth or Ourselves? The environmental slogan of the 1990s was "save our planet." Is Earth's very survival really in danger? In the long view of planetary evolution, it seems highly likely that Earth will outlive the human race. Our Sun is likely to last another several billion years at least, and even if all humans became extinct in the next few years, life would still flourish on our planet. The environmental degradation we have imposed on the landscape, atmosphere, and waters might last for a few hundreds or thousands of years, but they would eventually be cleansed by natural processes. Therefore, our major concern is the quality of the human environment, which depends on sustaining our larger support systems, including air, water, soil, and other life.

Concept Three: Earth as a System

Understanding Earth's systems and their changes is critical to solving environmental problems.

A **system** is any defined part of the universe that we select for study. Examples of systems are a planet, a volcano, an ocean basin, or a river (Figure 1.8). Most systems contain several component parts that mutually adjust to function as a whole, with changes in one component bringing about changes in other components. For example, the components of our global system are water, land, atmosphere, and life. These components mutually adjust, helping to keep the entire Earth system operating.[11]

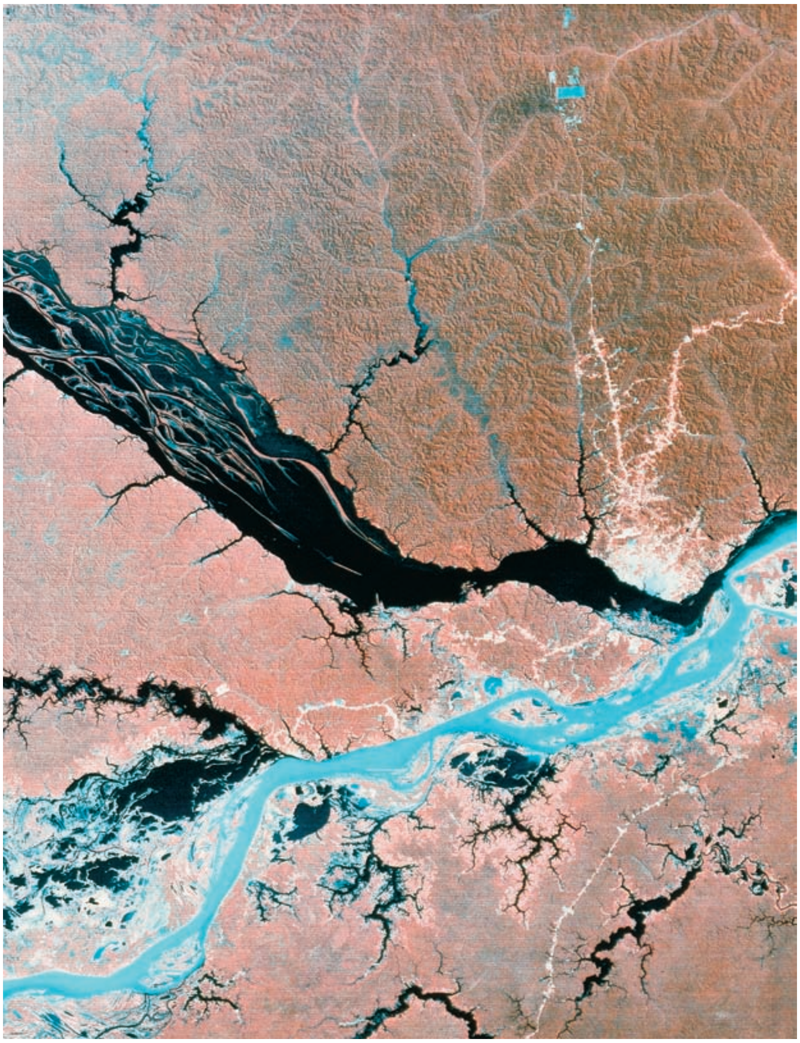


Figure 1.8 River as a system Image of part of the Amazon River system (blue) and its confluence with the Rio Negro (black). The blue water of the Amazon is heavily laden with sediment, whereas the water of the Rio Negro is nearly clear. Note that as the two large rivers join, the waters do not mix initially but remain separate for some distance past the confluence. The Rio Negro is in flood stage. The red is the Amazon rain forest, and the white lines are areas of human-caused disturbances such as roads. *(Earth Satellite Corporation/Science Photo Library/Photo Researchers, Inc.)*

CASE HISTORY | The Aral Sea: The Death of a Sea

The Aral Sea, located between Kazakhstan and Uzbekistan, formerly part of the Union of Soviet Socialist Republics, was a prosperous tourist vacation spot in 1960. Water diversion for agriculture nearly eliminated the Aral Sea in a period of only 30 years. It is now a dying sea surrounded by thousands of square kilometers of salt flats, and the change is permanently damaging the economic base of the region.

In 1960, the area of the Aral Sea was about 67,000 km^2 (around 26,200 mi^2). Diversion of the two main rivers that fed the sea has resulted in a drop in surface elevation of more than 20 m (66 ft) and loss of about 28,000 km^2 (10,800 mi^2) of surface area (Figure 1.D). Towns that were once fishing centers on the shore are today about 30 km (19 mi) inland. Loss of the sea's moderating effect on weather is changing the regional climate; the winters are now colder, and the summers warmer. Windstorms pick up salty dust and spread it over a vast area, damaging the land and polluting the air.

The lesson to be learned from the Aral Sea is how quickly environmental damage can bring about regional change. Environmentalists, including geologists, worry that what people have done to the Aral region is symptomatic of what we are doing on many fronts on a global scale.[13] Today an ambitious restoration project is underway to save the northern, smaller part of the lake. A low dam has been constructed across the lake just south of where the Syr Darya flows into the lake (see Figure 1.D). With water conservation of the river water, more water is flowing in the lake and the dam keeps the water in the northern part of the lake bed. Water levels there are rising and some fishing has returned. This is a promising sign, but much more needs to be done.

(a)

(b)

Figure 1.D Dying sea (a) The Aral Sea is a dying sea, surrounded by thousands of square kilometers of salt flats. *(Courtesy of Philip P. Micklin)* (b) Water diversion for agriculture has nearly eliminated the sea. The two ships shown here are stranded high and dry along the shoreline, which contains extensive salt flats formed as the Aral Sea has evaporated. *(David Turnley/CORBIS)*

Input-Output Analysis

Input-output analysis is an important method for analyzing change in open systems. Figure 1.9 identifies three types of change in a pool or stock of materials; in each case the net change depends on the relative rates of the input and output. Where the input into the system is equal to the output (Figure 1.9a), a rough steady state is established and no net change occurs. The example shown is a university in which students enter as freshmen and graduate four years later at a constant rate. Thus, the pool of university students remains a constant size. At the global scale, our planet is a roughly steady-state system with respect to energy:

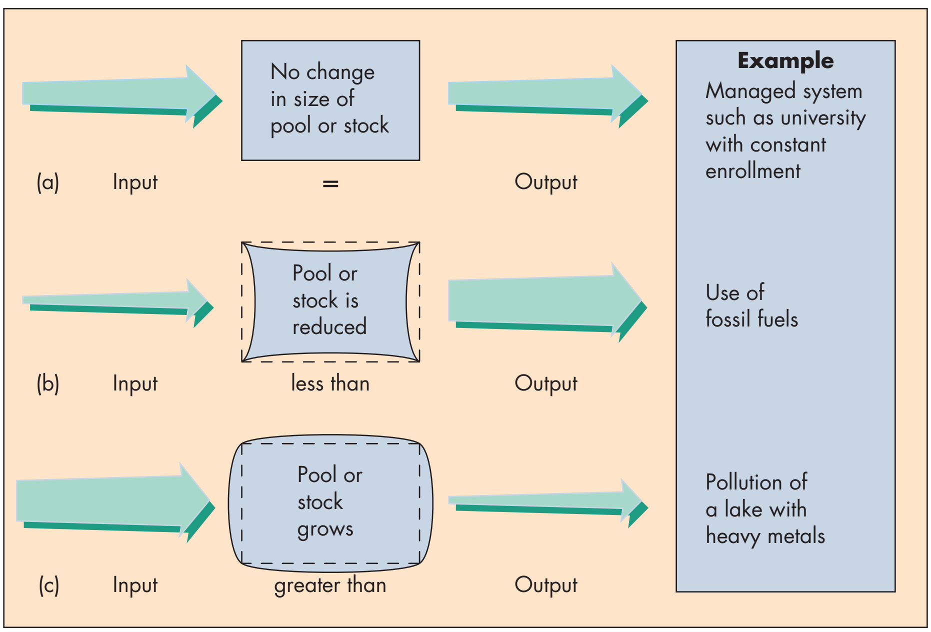


Figure 1.9 Change in systems Major ways in which a pool or stock of some material may change. *(Modified after Ehrlich, P. R., Ehrlich, A. H., and Holdren, J. P. 1977.* Ecoscience: Population, resources, environment, *3rd ed. San Francisco: W. H. Freeman)*

Incoming solar radiation is roughly balanced by outgoing radiation from Earth. In the second type of change, the input into the system is less than the output (Figure 1.9b). Examples include the use of resources such as fossil fuels or groundwater and the harvest of certain plants or animals. If the input is much less than the output, then the fuel or water source may be completely used up, or the plants or animals may become extinct. In a system in which input exceeds output (Figure 1.9c), the stock of whatever is being measured will increase. Examples include the buildup of heavy metals in lakes from industrial pollution or the pollution of soil and water.

How Can We Evaluate Change? By evaluating rates of change or the input and output of a system, we can derive an **average residence time** for a particular material, such as a resource. The average residence time is a measure of the time it takes for the total stock or supply of the material to be cycled through a system. To compute the average residence time (T; assuming constant size of the system and constant rate of transfer), we take the total size of the stock (S) and divide it by the average rate of transfer (F) through the system:

$$T = S/F$$

For example, if a reservoir holds 100 million cubic meters of water, and both the average input from streams entering the reservoir and the average output over the spillway are 1 cubic meter per second, then the average residence time for a cubic meter of water in the reservoir is 100 million seconds, or about 3.2 years (Figure 1.10). We can also calculate average residence time for systems that vary in size and rates of transfer, but the mathematics is more difficult. It is often possible to compute a residence time for a particular resource and then to apply the information to help understand and solve environmental problems. For example, the average residence time of water in rivers is about 2 weeks compared with thousands of years for some groundwater. Thus, strategies to treat a one-time pollution event of oil spilled in a river will be much different from those for removing oil floating on groundwater that resulted from a rupture of an underground pipeline. The oil in the river is a relatively accessible, straightforward, short-term problem,

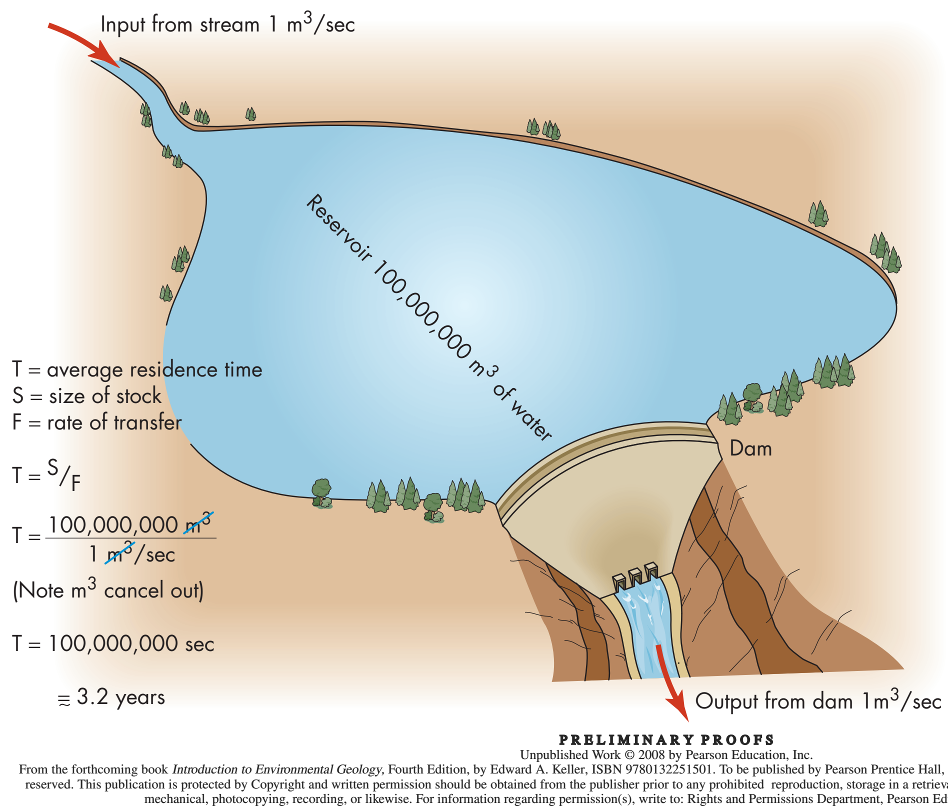


Figure 1.10 Average residence time Calculation of the average residence time for a cubic meter of water in a reservoir where input = output = 1 m^3 per second and the size of the reservoir is constant at 100,000,000 m^3 of water.

whereas polluted groundwater is a more difficult problem because it moves slowly and has a long average residence time. Because it may take from several to hundreds of years for pollution of groundwater to be naturally removed, groundwater pollution is difficult to treat.

Predicting Changes in the Earth System

The idea that "the present is the key to the past," called **uniformitarianism,** was popularized by James Hutton, referred to by some scholars as the father of geology, in 1785 and is heralded today as a fundamental concept of Earth sciences. As the name suggests, uniformitarianism holds that processes we observe today also operated in the past (flow of water in rivers, formation and movement of glaciers, landslides, waves on beaches, uplift of the land from earthquakes, and so on). Uniformitarianism does not demand or even suggest that the magnitude (amount of energy expended) and frequency (how often a particular process occurs) of natural processes remain constant with time. We can infer that, for as long as Earth has had an atmosphere, oceans, and continents similar to those of today, the present processes were operating.

Present Human Activity Is Part of the Key to Understanding the Future. In making inferences about geologic events, we must consider the effects of human activity on the Earth system and what effect these changes to the system as a whole may have on natural Earth processes. For example, rivers flood regardless of human activities, but human activities, such as paving the ground in cities, increase runoff and the magnitude and frequency of flooding. That is, after the paving, floods of a particular size are more frequent, and a particular rainstorm can produce a larger flood than before the paving. Therefore, to predict the long-range effects of flooding, we must be able to determine how future human activities will change the size and frequency of floods. In this case, *the present is the key to the future*. For example, when environmental geologists examine recent landslide deposits (Figure 1.11) in an area designated to become a housing development, they must use uniformitarianism to infer where there will be future landslides as well as to predict what effects urbanization will have on the magnitude and frequency of future landslides. We will now consider linkages between processes.

Figure 1.11 Urban development The presence of a landslide on this slope suggests that the slope is not stable and further movement may occur in the future. This is a "red flag" for future development in the area. *(Edward A. Keller)*

Environmental Unity

The principle of **environmental unity**, which states that one action causes others in a chain of actions, is an important principle in the prediction of changes in the Earth system. For example, if we constructed a dam on a river, a number of changes would occur. Sediment that moved down the river to the ocean before construction of the dam would be trapped in the reservoir. Consequently, beaches would be deprived of the sediment from the river, and the result of that deprivation may be increased coastal erosion. There being less sediment on the beach may also affect coastal animals such as sand crabs and clams that use the sand. Thus, building the dam would set off a chain or series of effects that would change the coastal environment and what lived there. The dam would also change the hydrology of the river and would block fish from migrating upstream. We will now consider global linkages.[11]

Earth Systems Science

Earth systems science is the study of the entire planet as a system in terms of its components (see A Closer Look: The Gaia Hypothesis). It asks how component

A CLOSER LOOK | The Gaia Hypothesis

Is Earth Analogous to an Organism? In 1785 at a meeting of the prestigious Royal Society of Edinburgh, James Hutton, the father of geology, said he believed that planet Earth is a superorganism (Figure 1.E). He compared the circulation of Earth's water, with its contained sediments and nutrients, to the circulation of blood in an animal. In Hutton's metaphor, the oceans are the heart of Earth's global system, and the forests are the lungs.[15] Two hundred years later, British scientist and professor James Lovelock introduced the **Gaia hypothesis,** reviving the idea of a living Earth. The hypothesis is named for Gaia, the Greek goddess Mother Earth.

The Gaia hypothesis is best stated as a series of hypotheses:

- ***Life significantly affects the planetary environment.*** Very few scientists would disagree with this concept.
- ***Life affects the environment for the betterment of life.*** This hypothesis is supported by some studies showing that life on Earth plays an important role in regulating planetary climate so that it is neither too hot nor too cold for life to survive. For example, it is believed that single-cell plants floating near the surface of the ocean partially control the carbon dioxide content of the atmosphere and thereby global climate.[15]
- ***Life deliberately or consciously controls the global environment.*** There are very few scientists who accept this third hypothesis. Interactions and the linking of processes that operate in the atmosphere, on the surface of Earth, and in the oceans are probably sufficient to explain most of the mechanisms by which life affects the environment. In contrast, humans are beginning to make decisions concerning the global environment, so the idea that humans can consciously influence the future of Earth is not an extreme view. Some people have interpreted this idea as support for the broader Gaia hypothesis.

Gaia Thinking Fosters Interdisciplinary Thinking. The real value of the Gaia hypothesis is that it has stimulated a lot of interdisciplinary research to understand how our planet works. As interpreted by most scientists, the hypothesis does not suggest foresight or planning on the part of life but rather that natural processes are operating.

Figure 1.E Home Image of Earth centering on the North Atlantic Ocean, North America, and the polar ice sheets. Given this perspective of our planet, it is not difficult to conceive it as a single large system. *(Earth Imaging/Getty Images Inc.)*

systems (subsystems of the Earth system) such as the atmosphere (air), hydrosphere (water), biosphere (life), and lithosphere (rocks) are linked and have formed, evolved, and been maintained; how these components function; and how they will continue to evolve over periods ranging from a decade to a century and longer.[14] Because these systems are linked, it is also important to understand and be able to predict the impacts of a change in one component on the others. The challenge is to learn to predict changes likely to be important to society and then to develop management strategies to minimize adverse environmental impacts. For example, the study of atmospheric chemistry suggests that our atmosphere has changed over millenia. Trace gases such as carbon dioxide have increased by about 100 percent since 1850. Chlorofluorocarbons (CFCs), used as refrigerants and aerosol-can propellants, released at the surface have migrated to the stratosphere, where they react with energy from the Sun, causing destruction of the ozone layer that protects Earth from harmful ultraviolet radiation. The important topics of global change and Earth systems science will be discussed in Chapter 19, following topics such as Earth materials, natural hazards, and energy resources.

Concept Four: Hazardous Earth Processes

There have always been Earth processes that are hazardous to people. These natural hazards must be recognized and avoided when possible, and their threat to human life and property must be minimized.

We humans, like all animals, have to contend with natural processes such as storms, floods, earthquakes, landslides, and volcanic eruptions that periodically damage property and kill us. During the past 20 years, natural hazards on Earth have killed several million people. The annual loss was about 150,000 people, and financial damages were about $20 billion.

Natural Hazards That Produce Disasters Are Becoming Superdisasters Called Catastrophes. Early in human history, our struggle with natural Earth processes was mostly a day-to-day experience. Our numbers were neither great nor concentrated, so losses from hazardous Earth processes were not significant. As people learned to produce and maintain a larger and, in most years, more abundant food supply, the population increased and became more concentrated locally. The concentration of population and resources also increased the impact that periodic earthquakes, floods, and other natural disasters had on humans. This trend has continued, so that many people today live in areas likely to be damaged by hazardous Earth processes or susceptible to the adverse impact of such processes in adjacent areas. An emerging principle concerning natural hazards is that as a result of human activity (population increase and changing the land through agriculture, logging, mining, and urbanization) what were formerly disasters are becoming catastrophes. For example,

- Human population increase has forced more people to live in hazardous areas such as floodplains, steep slopes (where landslides are more likely), and near volcanoes.
- Land-use transformations including urbanization and deforestation increase runoff and flood hazard and may weaken slopes, making landslides more likely.
- Burning vast amounts of oil, gas, and coal has increased the concentration of carbon dioxide in the atmosphere, contributing to warming the atmosphere and oceans. As a result, more energy is fed into hurricanes. The number of hurricanes has not increased, but the intensity and size of the storms have increased.

We can recognize many natural processes and predict their effects by considering climatic, biological, and geologic conditions. After Earth scientists have identified potentially hazardous processes, they have the obligation to make the information available to planners and decision makers, who can then consider ways of avoiding or minimizing the threat to human life or property. Put concisely, this process consists of assessing the risk of a certain hazard in a given area and basing planning decisions on that risk assessment. Public perception of hazards also plays a role in the determination of risk from a hazard. For example, although they probably understand that the earthquake hazard in southern California is real, the residents who have never experienced an earthquake first hand may have less appreciation for the seriousness of the risk of loss of property and life than do persons who have experienced an earthquake.

Concept Five: Scientific Knowledge and Values

The results of scientific inquiry to solve a particular environmental problem often provide a series of potential solutions consistent with the scientific findings. The chosen solution is a reflection of our value system.

What Is Science? To understand our discussion of scientific knowledge and values, let us first gain an appreciation for the conventions of scientific inquiry. Most scientists are motivated by a basic curiosity about how things work. Geologists are excited by the thrill of discovering something previously unknown about how the world works. These discoveries drive them to continue their work. Given that we know little about internal and external processes that form and maintain our world, how do we go about studying it? The creativity and insight that may result from scientific breakthroughs often begin with asking the right question pertinent to some problem of interest to the investigators. If little is known about the topic or process being studied, they will first try to conceptually understand what is going on by making careful observations in the field or, perhaps, in a laboratory. On the basis of his or her observations, the scientist may then develop a question or a series of questions about those observations. Next the investigator will suggest an answer or several possible answer to the question. The possible answer is a **hypothesis** to be tested. The best hypotheses can be tested by designing an experiment that involves data collection, organization, and analysis. After collection and analysis of the data, the scientist interprets the data and draws a conclusion. The conclusion is then compared with the hypothesis, and the hypothesis may be rejected or tentatively accepted. Often, a series of questions or multiple hypotheses are developed and tested. If all hypotheses suggested to answer a particular question are rejected, then a new set of hypotheses must be developed. This method is sometimes referred to as the **scientific method.** The steps of the scientific method are shown in Figure 1.12. The first step of the scientific method is the formation of a question—in this case, "Where does beach sand come from?" In order to explore this question, the scientist spends some time at the beach. She notices some small streams that flow into the ocean; she knows that the streams originate in the nearby mountains. She then refines her question to ask specifically, "Does beach sand come from the mountains to the beach by way of streams?" This question is the basis for the scientist's hypothesis: Beach sand originates in the mountains. To test this hypothesis, she collects some sand from the beach and from the streams and some rock samples from the mountains. She then compares their mineral content. She finds that the mineral content of all three is roughly the same. She draws a conclusion that the beach sand does come from the mountains, and so accepts her hypothesis. If her hypothesis had proved to be wrong, she would have had to formulate a new hypothesis. In complex geologic

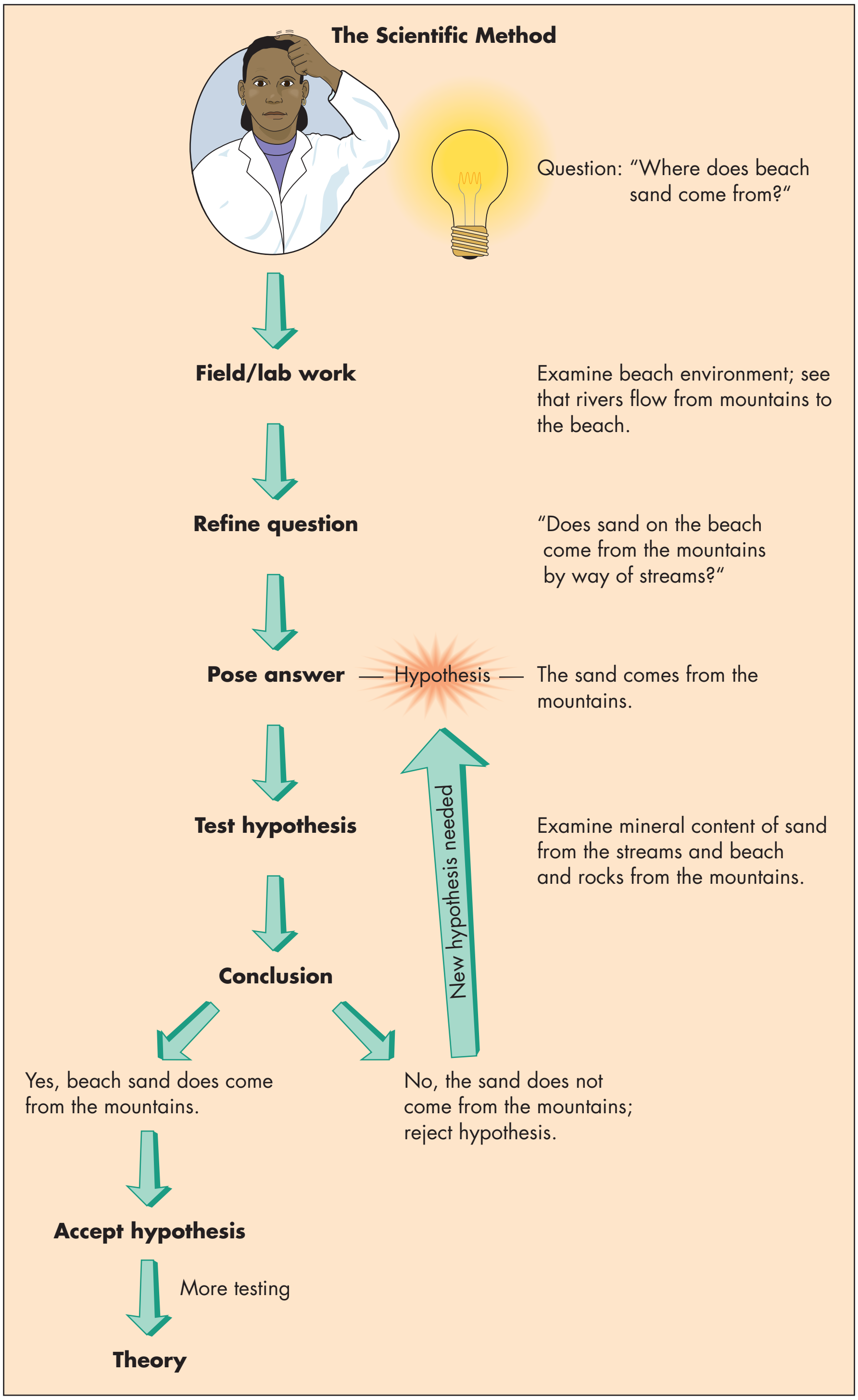


Figure 1.12 Science The steps in the scientific method.

problems, multiple hypotheses may be formulated and each tested. This is the method of multiple working hypotheses. If a hypothesis withstands the testing of a sufficient number of experiments, it may be accepted as a **theory.** A theory is a strong scientific statement that the hypothesis supporting the theory is likely to be true but has not been proved conclusively. New evidence often disproves existing hypotheses or scientific theory; absolute proof of scientific theory is not possible. Thus, much of the work of science is to develop and test hypotheses, striving to reject current hypotheses and to develop better ones.

Laboratory studies and fieldwork are commonly used in partnership to test hypotheses, and geologists often begin their observations in the field or in the laboratory by taking careful notes. For example, a geologist in the field may create a *geologic map*, carefully noting and describing the distribution of different Earth materials. The map can be completed in the laboratory, where the collected material can be analyzed.

The important variable that distinguishes geology from most of the other sciences is the consideration of time (see the Geologic Time Scale, Table 1.1). Geologists' interest in Earth history over time periods that are nearly incomprehensible to most people naturally leads to some interesting questions:

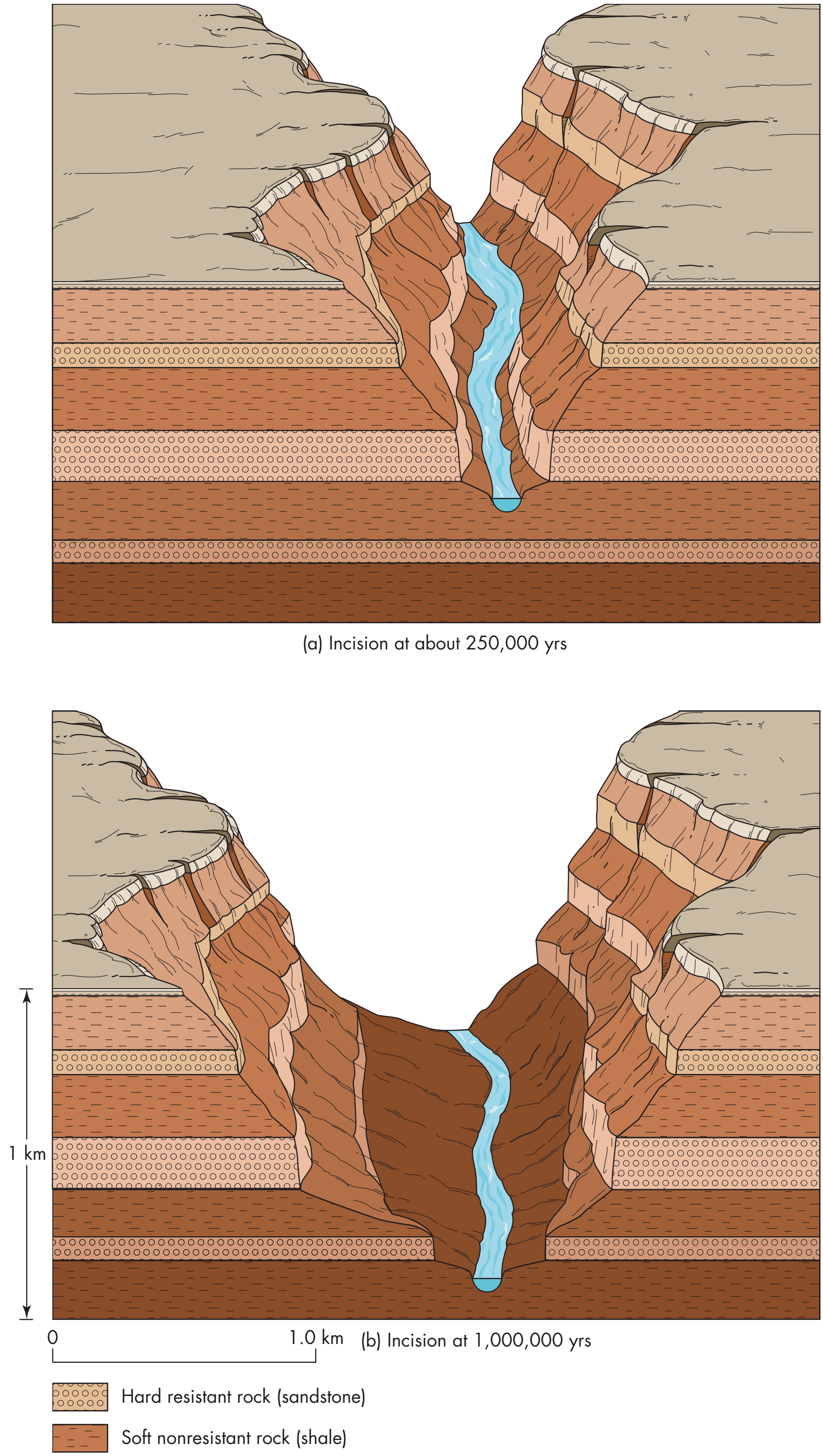
- How fast are mountains uplifted and formed?
- How fast do processes of erosion reduce the average elevation of the land?
- How fast do rivers erode canyons to produce scenic valleys such as Yosemite Valley and the Grand Canyon (Figure 1.13)?
- How fast do floodwaters, glaciers, and lava flows move?

As shown in Table 1.3, rates of geologic processes vary from a fraction of a millimeter per year to several kilometers per second. The fastest rates are more than a trillion times the slowest. The most rapid rates, a few kilometers per second, are for events with durations of a few seconds. For example, uplift of 1 m (3.3 ft.) during an earthquake may seem like a lot, but when averaged over 1,000 years (the time between earthquakes), it is a long-term rate of 1 mm per year (0.039 in. per year), a typical uplift rate in forming mountains. Of particular importance to environmental geology is that human activities may accelerate the rates of some processes. For example, timber harvesting and urban construction remove vegetation, exposing soils and increasing the rate of erosion. Conversely, the practice of sound soil conservation may reduce rates.

TABLE 1.3 Some Typical Rates of Geologic Processes

Slow Rates	■ Uplift that produces mountains. Generally 0.5 to 2 mm per year (about 0.02 to 0.08 in. per year). Can be as great as 10 mm per year (about 0.39 in. per year). It takes (with no erosion) 1.5 million to 6 million years to produce mountains with elevations of 3 km (around 1.9 mi).
	■ Erosion of the land. Generally 0.01 to 1 mm per year (about 0.004 to 0.039 in. per year). It takes (with no uplift) 3 million to 300 million years to erode a landscape by 3 km (about 1.9 mi). Erosion rate may be significantly increased by human activity such as timber harvesting or agricultural activities that increase the amount of water that runs off the land, causing erosion. Rates of uplift generally exceed rates of erosion, explaining why land above sea level persists.
	■ Incision of rivers into bedrock, producing canyons such as the Grand Canyon in Arizona. Incision is different from erosion, which is the material removed over a region. Rates are generally 0.005 to 10 mm per year (about 0.0002 to 0.39 in. per year). Therefore, to produce a canyon 3 km (around 1.9 mi) deep would take 300 thousand to 600 million years. The rate of incision may be increased several times by human activities such as building dams because increased downcutting of the river channel occurs directly below a dam.
Intermediate Rates	■ Movement of soil and rock downslope by creeping in response to the pull of gravity. Rate is generally 0.5 to 1.2 mm per year (about 0.02 to 0.05 in. per year).
	■ Coastal erosion by waves. Generally 0.25 to 1.0 m per year (0.82 to 3.28 ft per year). Thus, to provide 100 years' protection from erosion, a structure should be built about 25 to 100 m (about 82 to 328 ft) back from the cliff edge.
Fast Rates	■ Glacier movement. Generally a few meters per year to a few meters per day. ■ Lava flows. Depends on type of lava and slope. From a few meters per day to several meters per second.
	■ River flow in floods. Generally a few meters per second.
	■ Debris avalanche, or flow of saturated earth, soil, and rocks downslope. Can be greater than 100 km (62 mi) per hour.
	■ Earthquake rupture. Several kilometers per second.

Figure 1.13 **Eroding a valley** Idealized diagram of progressive incision of a river into a sequence of horizontal rocks. The side slope is steep where rocks are hard and resistant to incision, and the rate of incision is generally less than about 0.01 mm per year (about 0.0004 in. per year). For softer rocks, where the side slope is gentle, the rate of incision may exceed 1 mm per year (0.039 in. per year). If the canyon incised about 1 km (0.62 mi) in 1 million years, the average rate is 1 mm per year (0.039 in. per year). *(Modified after King, P. B., and Schumm, S. A., 1980.* The physical geography of William Morris Davis. *Norwich, England: Geo Books)*



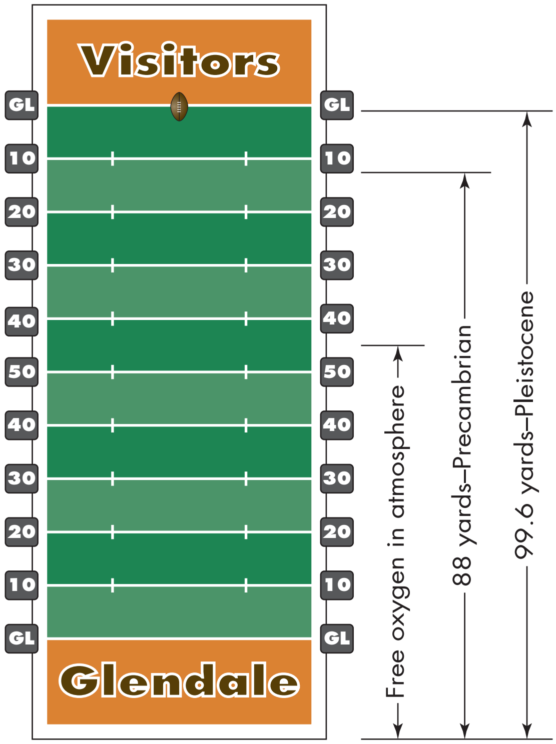


Figure 1.14 Time Geologic time as represented by a football field. See the text for further explanation.

Humans evolved during the Pleistocene epoch (the last 1.65 million years), which is a very small percentage of the age of Earth. To help you conceptualize the geologic time scale, Figure 1.14 illustrates all of geologic time as analogous to yards on a football field. Think back to your high school days, when your star kick-off return player took it deep into your end zone. Assume that the 100 yard field represents the age of Earth (4.6 billion years), making each yard equal to 45 million years. As your star zigs and zags and reaches the 50 yard line, the crowd cheers. But in Earth history he has traveled only 2,250 million years and is still in a primitive oxygen-deficient environment. At the opponent's 45 yard line, free oxygen in the atmosphere begins to support life. As our runner crosses the 12 yard line, the Precambrian period comes to an end and life becomes much more diversified. At less than half a yard from the goal line, our star runner reaches the beginning of the Pleistocene, the most recent 1.65 million years of Earth history, when humans evolved. As he leaps over the 1 inch line and in for the touchdown, the corresponding period in Earth history is 100,000 years ago, and modern humans were living in Europe. Another way to visualize geologic time is to imagine that one calendar year is equal to the age of Earth, 4.6 billion years. In this case, Earth formed on January 1; the first oxygen in the atmosphere did not occur until July; and mammals did not make their appearance until December 18. The first human being arrived on the scene on December 31 at 6 P.M.; and recorded history began only 48 seconds before midnight on December 31!

In answering environmental geology questions, we are often interested in the latest Pleistocene (the last 18,000 years), but we are most interested in the last few thousand or few hundred years of the Holocene epoch, which started approximately 10,000 years ago (see Appendix D, How Geologists Determine Time). Thus, in geologic study, geologists often design hypotheses to answer questions integrated through time. For example, we may wish to test the hypothesis that burning fossil fuels such as coal and oil, which we know releases carbon dioxide into the atmosphere, is causing global warming by trapping heat in the lower atmosphere. We term this phenomenon the greenhouse effect, which is discussed in detail in Chapter 19. One way to test this hypothesis would be to show that before the Industrial Revolution, when we started burning a lot of coal and, later, oil to power the new machinery of the time period, the mean global temperature was significantly lower than it is now. We would be particularly interested in the last few hundred to few thousand years before temperature measurements were recorded at various spots around the planet as they are today. To test the hypothesis that global warming is occurring, the investigator could examine prehistoric Earth materials that might provide indicators of global temperature. This examination might involve studying glacial ice or sediments from the bottoms of the oceans or lakes to estimate past levels of carbon dioxide in the atmosphere. Properly completed, studies can provide conclusions that enable us to accept or reject the hypothesis that global warming is occurring.

Our discussion about what science is emphasizes that science is a process. As such it is a way of knowing that constitutes a current set of beliefs based on the application of the scientific method. Science is not the only way a set of beliefs are established. Some beliefs are based on faith, but these, while valid, shouldn't be confused with science. The famous Roman philosopher Cicero once concluded that divine providence, or as we call it now, *intelligent design*, was responsible for the organization of nature and harmony that maintained the environment for all people. As modern science emerged with the process of science, other explanations emerged. This has included explanations for biological evolution by biologists, the understanding of space and time by physicists, and the explanation that continents and ocean basins form through plate tectonics by geologists.

Culture and Environmental Awareness

Environmental awareness involves the entire way of life that we have transmitted from one generation to another. To uncover the roots of our present condition, we must look to the past to see how our culture and our political, economic, ethical, religious, and aesthetic institutions affect the way we perceive and respond to our physical environment.

An ethical approach to maintaining the environment is the most recent development in the long history of human ethical evolution. A change in the concept of property rights has provided a fundamental transformation in our ethical evolution. In earlier times, human beings were often held as property, and their masters had the unquestioned right to dispose of them as they pleased. Slaveholding societies certainly had codes of ethics, but these codes did not include the idea that people cannot be property. Similarly, until very recently, few people in the industrialized world questioned the right of landowners to dispose of land as they please. Only within this century has the relationship between civilization and its physical environment begun to emerge as a relationship involving ethical considerations.

Environmental (including ecological and land) ethics involves limitations on social as well as individual freedom of action in the struggle for existence in our stressed environment. A **land ethic** assumes that we are responsible not only to other individuals and society, but also to the total environment, the larger community consisting of plants, animals, soil, rocks, atmosphere, and water. According to this ethic, we are the land's citizens and protectors, not its conquerors. This role change requires us to revere, love, and protect our land rather than allow economics to determine land use.[16] The creation of national parks and forests is an example of protective action based on a land ethic. Yellowstone National Park, in Wyoming and Montana, was the first national park in the United States, established in March 1872. Yellowstone led to the creation of other national parks, monuments, and forests, preserving some of the country's most valued aesthetic resources. Trees, plants, animals, and rocks are protected within the bounds of a national park or forest. In addition, rivers flow free and clean, lakes are not overfished or polluted, and mineral resources are protected. Last, the ethic that led to the protection of such lands allows us the privilege of enjoying these natural areas and ensures that future generations will have the same opportunity. We will now change focus to discuss why solving environmental problems tends to be difficult and introduce the emerging environmental policy tool known as the precautionary principle.

Why Is Solving Environmental Problems So Difficult?

Many environmental problems tend to be complex and multifaceted. They may involve issues related to physical, biological, and human processes. Some of the problems are highly charged from an emotional standpoint and potential solutions are often vigorously debated.

There are three main reasons that solving environmental problems may be difficult:

- Expediential growth is often encountered. Expediential growth means that the population of change may be happening quickly whether we are talking about an increase or decrease.
- There are often lag times between when a change occurs and when it is recognized as a problem. If the lag time is long, it may be very difficult to even recognize a particular problem.
- An environmental problem involves the possibility of irreversible change. If a species becomes extinct, it is gone forever.

Environmental policy links to environmental economics are in their infancy. That is, the policy framework to solve environmental problems is a relatively new arena. We are developing policies such as the precautionary principle and finding ways to evaluate the economics of gains and losses from environmental change. For example, how do you put a dollar amount on aesthetics or living in a quality environment? What the analysis often comes down to is an exercise in values clarification. Science can provide a number of potential solutions to problems but which solution we pick will depend upon our values.

Precautionary Principle

What Is the Precautionary Principle? Science has the role of trying to understand physical and biological processes associated with environmental problems such as global warming, exposure to toxic materials, and depletion of resources, among others. However, all science is preliminary and it is difficult to prove relationships between physical and biological processes and link them to human processes. Partly for this reason, in 1992, the Rio Earth Summit on sustainable development supported the **precautionary principle.** The idea behind the principle is that when there exists a potentially serious environmental problem, scientific certainty is not required to take a precautionary approach. That is, better safe than sorry. The precautionary principle thus contributes to the critical thinking on a variety of environmental concerns, for example, manufacture and use of toxic chemicals or burning huge amounts of coal as oil becomes scarcer. It is considered one of the most influential ideas for obtaining an intellectual, environmentally just policy framework for environmental problems.[17]

The precautionary principle recognizes that scientific proof is not possible in most instances, and management practices are needed to reduce or eliminate environmental problems believed to result from human activities. In other words, in spite of the fact that full scientific certainty is not available, we should still take cost-effective action to solve environmental problems.

The Precautionary Principle May Be Difficult to Apply. One of the difficulties in applying the precautionary principle is the decision concerning how much scientific evidence is needed before action on a particular problem should be taken. This is a significant and often controversial question. An issue being considered has to have some preliminary data and conclusions but awaits more scientific data and analysis. For example, when considering environmental health issues related to burning coal, there may be an abundance of scientific data about air, water, and land pollution, but with gaps, inconsistencies, and other scientific uncertainties. Those in favor of continuing or increasing the use of coal may argue that there is not sufficient proof to warrant restricting its use. Others would argue that absolute proof of safety is necessary before a big increase in burning of coal is allowed. The precautionary principle, applied to this case, would be that lack of full scientific certainty concerning the use of coal should not be used as a reason for not taking, or postponing, cost-effective measures to reduce or prevent environmental degradation or heath problems. This raises the question of what constitutes a cost-effective measure. Determination of benefits and costs of burning more coal compared to burning less or treating coal more to clean up the fuel should be done, but other economic analysis may also be appropriate.[17,18]

There will be arguments over what is sufficient scientific knowledge for decision making. The precautionary principle may be difficult to apply, but it is becoming a common part of the process of environmental analysis and policy when applied to environmental protection and environmental health issues. The European Union has been applying the principle for over a decade, and the City and County of San Francisco in 2003 became the first government in the United States to make the precautionary principle the basis for its environmental policy.

Applying the precautionary principle requires us to use the principle of environmental unity and predict potential consequences of activities before they occur. Therefore, the precautionary principle has the potential to become a proactive, rather than reactive, tool in reducing or eliminating environmental degradation resulting from human activity. The principle moves the burden of proof of no harm from the public to those proposing a particular action. Those who develop new chemicals or actions are often, but not always, against the precautionary principle. The opponents often argue that applying the principle is too expensive and will stall progress. It seems unlikely that the principle will be soon applied across the board in the United States to potential environmental problems. Nevertheless, it will likely be invoked more often in the future. When the precautionary principle is applied, it must be an honest debate between all informed and potentially affected parties. The entire range of alternative actions should be considered, including taking no action.

Science and Values

We Are Creatures of the Pleistocene. There is no arguing that we are a very successful species that until recently has lived in harmony with both our planet and other forms of life for over 100 thousand years. We think of ourselves as modern people, and certainly our grasp of science and technology has grown tremendously in the past several hundred years. However, we cannot forget that our genetic roots are in the Pleistocene. In reality our deepest beliefs and values are probably not far distant from those of our ancestors who sustained themselves in small communities, moving from location to location and hunting and gathering what they needed. At first thought this statement seems inconceivable and not possible to substantiate considering the differences between our current way of life and that of our Pleistocene ancestors. It has been argued that studying our Pleistocene ancestors, with whom we share nearly identical genetic information, may help us understand ourselves better.[19] That is, much of our human nature and in fact our very humanity may be found in the lives of the early hunters and gatherers, explaining some of our current attitudes toward the natural world. We are more comfortable with natural sounds and smells like the movement of grass where game is moving or the smell of ripe fruit than the shril noise of horns and jackhammers and smell of air pollution in the city. Many of us enjoy sitting around a campfire roasting marshmallows and telling stories about bears and rattlesnakes. We may find a campfire comforting even if smoke stings our eyes because our Pleistocene ancestors knew fire protected them from predators such as bears, wolves, and lions. If you want to liven up a campfire talk, start telling grizzly bear stories!

Solutions we choose to solve environmental problems depend upon how we value people and the environment. For example, if we believe that human population growth is a problem, then conscious decisions to reduce human population growth reflects a value decision that we as a society choose to endorse and implement. As another example, consider flooding of small urban streams. Flooding is a hazard experienced by many communities. Study of rivers and their natural processes leads to a number of potential solutions for a given flood hazard. We may choose to place the stream in a concrete box—a remedy that can significantly reduce the flood hazard. Alternatively, we may choose to restore our urban streams and their floodplains, the flat land adjacent to the river that periodically floods, as greenbelts. This choice will reduce damage from flooding while providing habitat for a variety of animals including raccoons, foxes, beavers, and muskrats that use the stream environment; resident and migratory birds that nest, feed, and rest close to a river; and a variety of fish that live in the river system. We will also be more comfortable when interacting with the river. That is why river parks are so popular.

The coastal environment, where the coastline and associated erosional processes come into conflict with development, provides another example for science and values. Solutions to coastal erosion may involve defending the coast, along with its urban development, at all cost by constructing "hard structures" such as seawalls. Science tells us that consequences from the hard solution generally include reduction or elimination of the beach environment in favor of protecting development. Science also tells us that using appropriate setbacks from the erosion zone of coastal processes provides a buffer zone from the erosion, while maintaining a higher quality coastal environment that includes features such as beaches and adjacent seacliffs or dune lines. The solution we pick depends upon how we value the coastal zone. If we value the development more than the beach, then we may choose to protect development at all cost. If we value the beach environment, we may choose more flexible options that allow for erosion to take place naturally within a buffer zone between the coast and development.

By the year 2050, the human population on our planet will likely increase to about 9 billion people, about 3 billion more than today. Thus, it appears that during the next 50 years crucial decisions must be made concerning how we will deal with the increased population associated with increased demands on resources including land, water, minerals, and air. The choices we make will inevitably reflect our values.

SUMMARY

The immediate causes of the environmental crisis are overpopulation, urbanization, and industrialization, which have occurred with too little ethical regard for our land and inadequate institutions to cope with environmental stress. Solving environmental problems involves both scientific understanding and the fostering of social, economic, and ethical behavior that allows solutions to be implemented. Beyond this, complex environmental problems can be difficult to solve due to the possibility of exponential growth, lag times between cause and effect, and irreversible consequences. A new emerging policy tool is the precautionary principle. The idea behind the principle is that when a potentially serious environmental problem exists, scientific certainty is not required to take a precautionary approach and find a cost-efficient solution. Some environmental problems are sufficiently serious that it is better to be safe than sorry.

Five fundamental concepts establish a philosophical framework for our investigation of environmental geology:

1. The increasing world population is the number one environmental problem.
2. Sustainability is the preferred solution to many environmental problems.
3. An understanding of the Earth system and rates of change in systems is critical to solving environmental problems.
4. Earth processes that are hazardous to people have always existed. These natural hazards must be recognized and avoided when possible, and their threat to human life and property minimized.
5. Results of scientific inquiry to solve a particular environmental problem often result in a series of potential solutions consistent with the scientific findings. Which solution we choose reflects our value system.

Key Terms

average residence time (p. 21)
carrying capacity (p. 13)
doubling time (p. 11)
Earth systems science (p. 23)
environmental crisis (p. 17)
environmental geology (p. 8)
environmental unity (p. 23)
exponential growth (p. 10)
Gaia hypothesis (p. 23)
geologic time (p. 5)
geology (p. 8)
growth rate (p. 11)
hypothesis (p. 25)
input-output analysis (p. 20)
land ethic (p. 30)
law of faunal assemblages (p. 8)
precautionary principle (p. 31)
scientific method (p. 25)
sustainability (p. 15)
system (p. 18)
theory (p. 26)
uniformitarianism (p. 22)

Review Questions

1. What is environmental geology?
2. Define the components of the scientific method.
3. What are the roots of the so-called environmental crisis?
4. Why are we so concerned about the increase in human population?
5. What is sustainability?
6. Define the principle of environmental unity, and provide a good example.
7. What is exponential growth?
8. What is Earth systems science, and why is it important?
9. What do we mean by average residence time?
10. How can the principle of uniformitarianism be applied to environmental geology?
11. What is the Gaia hypothesis?
12. What is the precautionary principle and why is it important?
13. Why is solving complex environmental problems often difficult?

Critical Thinking Questions

1. Assuming that there is an environmental crisis today, what possible solutions are available to alleviate the crisis? How will solutions in developing countries differ from those in highly industrialized societies? Will religion or political systems have a bearing on potential solutions? If so, how will they affect the solutions?
2. It has been argued that we must control human population because otherwise we will not be able to feed everyone. Assuming that we could feed 10 billion to 15 billion people on Earth, would we still want to have a smaller population than that? Why?
3. We state that sustainability is the environmental objective. Construct an argument to support this statement. Are the ideas of sustainability and building a sustainable economy different in developing, poor countries than in countries that are affluent and have a high standard of living? How are they different, and why?
4. The concept of environmental unity is an important one today. Consider some major development being planned for your region and outline how the principle of environmental unity could help in determining the project's potential environmental impact. In other words, consider a development and then a series of consequences resulting from it. Some of the impacts may be positive and some may be negative in your estimation.
5. Do you believe we have a real connection to our Pleistocene ancestors? Could such a connection explain our childlike love of baby animals or the storytelling around a camp fire? Is the human race's long history of hunting and gathering, during which our genetic evolution occurred, reflected in our values?
6. Is the Gaia hypothesis science? How could you test the main parts? Which would be hard to test? Why?
7. Defend or criticize the notion that increase in human population is *the* environmental problem and that sustainability is the solution.
8. Do you think the precautionary principle should be applied to the problem of controlling the growth of the human population? If you do, how could it be applied?