CHAPTER 10

Natural Cycles and Energy Flow

IN THIS CHAPTER

Summary: Although the Earth appears to consist of one big environment, it is composed of many smaller, interconnected systems or cycles. The carbon, calcium, hydrologic, and other cycles allow other systems to function. Plants and animals get food through interactions with these cycles in a food web.

KEY IDEA

Keywords

✪ Matter, carbon, organic, conservation of matter, calcium, phosphorus, sulfur, hydrologic cycle, evapotranspiration, photosynthesis, residence time, biomineralization, food web, trophic level, biomass

Geochemical Cycle

A geochemical cycle is like an element's life cycle. As it moves from one place to another, it takes on different forms. In this chapter, we will take a look at several geochemical cycles including the calcium, carbon, and hydrologic cycles. These major Earth cycles have intricate and complex interrelationships that exist at all levels of diverse ecosystems.

Conservation of Matter

All things that take up space and have mass are known as *matter.* Matter exists in three forms, solid, liquid, and gas. Except in unusual circumstances, matter cannot be created or destroyed. It is recycled and transformed in many different combinations, systems, and organisms over and over again. It doesn't disappear; it just moves into another form and cycle.

KEY IDEA

Conservation of matter includes the idea that matter is neither created, nor destroyed, but recycled through natural cycles.

Residence Time

To understand natural cycles, we need to understand *residence time.* Residence time equals the average amount of time a chemical element (e.g., carbon, calcium, or phosphorus) spends in a geological reservoir or cycle.

Carbon dioxide, at about 5% of the atmosphere, has a residence time of 10 years. In contrast, oxygen, which makes up around 20% of the atmospheric volume, has a residence time of 6,000 years. Sulfur dioxide, a very minor atmospheric player, has a residence time of hours to weeks. Amazingly, nitrogen, in amounts that equal 75% of the total atmospheric gases has a residence time of 400 million years. Dinosaurs probably breathed some of the same nitrogen molecules we are breathing today!

Calcium spends its residence time in the atmosphere, oceans, crust, and mantle. Carbon spends its residence time in the atmosphere; oceans; sedimentary, igneous, and metamorphic rocks; and the biosphere.

Carbon

Carbon is the fourth most abundant element in the universe, after hydrogen, helium, and oxygen. Known as the building block of life, carbon is the foundational element of all *organic* substances, from graphite to fossil fuels to DNA. On the Earth, carbon cycles through the land, biosphere, ocean, atmosphere, and the Earth's interior in a major biogeochemical cycle.

KEY IDEA

Organic matter is made up of carbon-containing material from living or nonliving material and includes the organic parts of soil.

The carbon cycle has many different storage spots, also known as reservoirs or *sinks,* where carbon exchanges take place. Carbon can be stored in the atmosphere, oceans, and soil as carbon dioxide, oil, coal, or biomass. The carbon cycle, shown in Figure 10.1, is divided into two types, the *geological carbon cycle,* which has been going on for millions of years, and the *biological carbon cycle,* which stretches from days to thousands of years.

Geologists believe the total amount of carbon that cycles through today's Earth systems was around at the formation of the solar system.

Geological Carbon Cycle

TIP

In the geological carbon cycle, carbon moves between rocks and minerals, seawater, and the atmosphere through weathering. Carbon dioxide in the atmosphere reacts with water and minerals to form calcium carbonate. Calcium carbonate rock (limestone) is dissolved by rainwater through erosion and then carried to the oceans. There, it settles out of the ocean water, forming sedimentary layers on the sea floor. Then, through plate tectonics, these sediments are subducted underneath the continents. With the extreme heat and pressure deep beneath the Earth's surface, the limestone melts and reacts with other minerals, freeing carbon dioxide. This carbon returns to the atmosphere as carbon dioxide during volcanic eruptions, completing the carbon cycle.

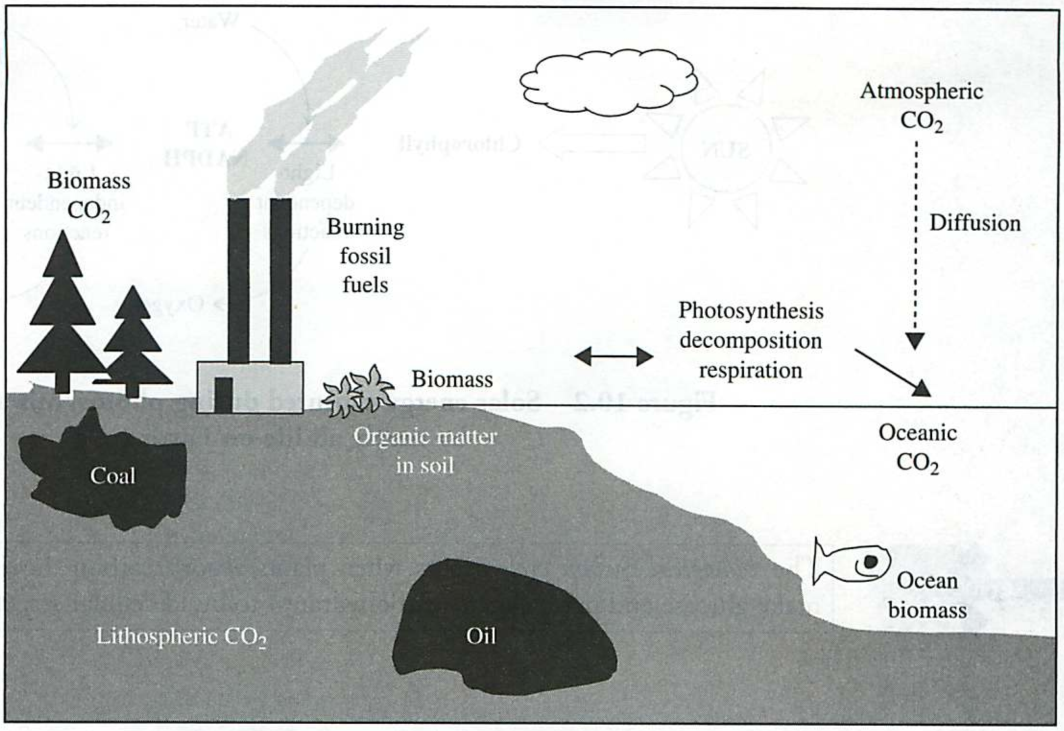

Figure 10.1 The carbon cycle has a big industrial component.

The balance between weathering, subduction, and volcanism controls atmospheric carbon dioxide concentrations over geological time. Some geologists have found that the oldest geological sediments point to atmospheric carbon dioxide concentrations over 100 times current levels.

Conversely, ice core samples from Antarctica and Greenland make glaciologists think that carbon dioxide concentrations during the last ice age were only about one-half of today's levels.

TIP

The amount of carbon stored and exchanged at each step in the cycle controls whether a certain sink is increasing or decreasing. For example, if the ocean absorbs 2 gigatons more carbon from the atmosphere than it releases in any one year, then atmospheric storage will decrease by the difference. Additionally, the atmosphere interacts with plants, soils, and fossil fuels. Everything is intimately interconnected.

The carbon cycle is a closed system. All carbon is squirreled away on the planet somewhere. Geologists are trying to balance out the global carbon equation. When all the sinks are estimated and added up, both sides of the equation should be equal. As population increases and global resources are challenged, experiments in this area are going to be more and more important.

Biological Carbon Cycle

The biosphere and all living organisms play a big role in carbon movement into and out of the land and ocean through *photosynthesis* and *respiration* processes. Photosynthesis defines the series of reactions in plants, bacteria, and algae that capture visible light wavelengths (0.4 to 0.7 μm) and transform light into chemical energy needed for organic molecules to bond. Figure 10.2 illustrates how photosynthesis works.

TIP

On this planet, nearly every living thing depends on the creation of sugars and carbohydrates from photosynthesis and the metabolism (respiration) of those sugars to support biological growth and reproduction.

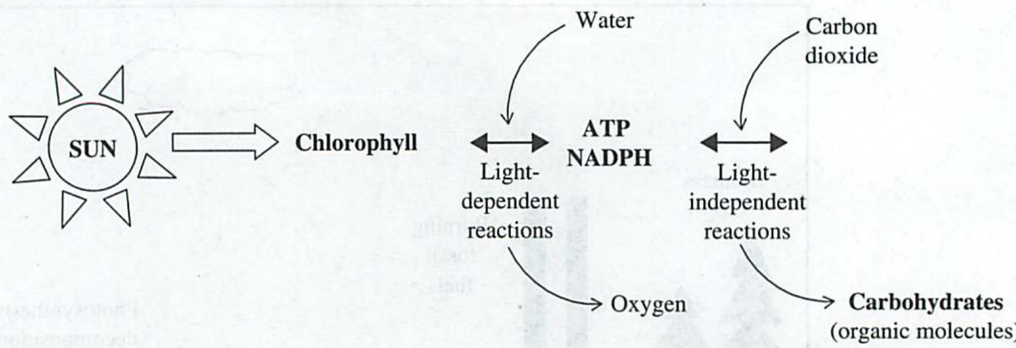

Figure 10.2 Solar energy captured during photosynthesis is used by nearly all life on Earth.

KEY IDEA

The *biological carbon cycle* occurs when plants absorb carbon dioxide and sunlight to make glucose and other sugars (carbohydrates) to build cellular structures.

Plants and animals use carbohydrates during respiration, the opposite of photosynthesis. Respiration converts biological (metabolic) energy back to carbon dioxide. As a process pair, respiration and decomposition (respiration by bacteria and fungi) restore biologically fixed carbon back to the atmosphere. Yearly carbon levels taken up by photosynthesis and sent back to the atmosphere by respiration are 1,000 times higher than carbon transported through the geological cycle each year.

We've seen how photosynthesis and respiration play a big part in the long-term geological carbon cycling. Land plants pull carbon dioxide from the atmosphere. In the oceans, the calcium carbonate shells of dead phytoplankton sink to the sea bed and form sediments. When photosynthesis is higher than respiration, organic matter gradually builds over millions of years and forms coal and oil deposits. These biologically regulated activities characterize atmospheric carbon dioxide removal and carbon storage in geological sediments.

Balance

TIP

Carbon is stored in the following major storage reservoirs:

- Organic molecules in living and dead organisms found in the biosphere
- Atmospheric carbon dioxide
- Organic matter in soils
- Fossil fuels in the lithosphere, sedimentary rock (limestone, dolomite, and chalk)
- Dissolved atmospheric carbon dioxide in the oceans
- In the calcium carbonate of marine creatures' shells

Table 10.1 illustrates the Earth's major carbon stores.

Over geological history, the amount of carbon dioxide found in the atmosphere has dropped. It is hypothesized that when the Earth's temperatures were a bit higher, millions of years ago, plant life was plentiful because of the greater concentrations of atmospheric carbon dioxide. As time went on, biological mechanisms slowly locked some of the atmospheric carbon dioxide into fossil fuels and sedimentary rock. This carbon balancing process has kept the Earth's average global temperature from huge swings over time.

Table 10.1 Carbon is stored in various areas above and below the earth.

CARBON STORAGE	QUANTITY (BILLIONS OF METRIC TONS)
Atmosphere	580 (1,700)–800 (2,000)
Organic (soil)	1,500–1,600
Ocean	38,000–40,000
Ocean sediments and sedimentary rocks	66,000,000–100,000,000
Land plants	540–610
Fossil fuels	4,000

Geologists are interested in carbon because it is such a versatile element. Not only does carbon exist in the air, land, and sea but humans are made up of approximately 50% carbon by dry weight. Environmental chemists study different ecosystems with carbon balancing accounts using crop productivity, food chains, and nutrient cycling measurements.

KEY IDEA

> The *carbon cycle* involves the Earth's atmosphere, fossil fuels, oceans, soil, plants, and animal life of terrestrial ecosystems.

In addition, carbon dioxide is the main atmospheric greenhouse gas thought to be a result of human activities. Until alternative power sources, like solar power, are developed and used more, atmospheric carbon dioxide increases will result mostly from burning fossil fuels.

Geologists look for patterns when trying to understand seasonal carbon drops and gains in atmospheric carbon dioxide. We've seen how global photosynthesis and respiration have to balance or carbon will either accumulate on land or be released to the atmosphere. Measuring year-to-year changes in carbon storage is tough. Some years have more volcanic eruptions with extra carbon in the air, while other years or decades have less.

However, some measurements are straightforward. The clearing of forests for crops, for example, is well documented, both historically and from satellite data. When forests get a chance to grow back on cleared land, they pull carbon from the atmosphere and start saving it up again in trees and soils. The change between total carbon released to the atmosphere and the total pulled back down governs whether the land is a supplier or reservoir of atmospheric carbon.

KEY IDEA

> *Atmospheric carbon* = fossil fuels + land use changes − ocean uptake − unknown carbon deposit.

When considering the global carbon equation between the atmosphere, fossil fuels, and the oceans, the global carbon tally is not completely known. Research is ongoing to discover the location of unknown carbon reservoirs.

Calcium

Calcium makes up roughly 3.4% of the Earth's crust and has been around since the formation of the Earth. It is found in igneous rocks as *calcium silicates,* and in sedimentary and metamorphic rocks as *calcium carbonates.* When rock weathering takes place by acid rain or plant growth and decay, calcium interacts with water and is transported to another location.

Water helps calcium move from the land to the oceans. High concentrations of dissolved calcium and/or magnesium in fresh water cause *hard water.* When these minerals are concentrated in water, around 89 to 100 parts per million, they don't react well with soap. In fact, mineral rings form in bathtubs, and laundered clothes take on a gray color from undissolved soap scum. Undissolved minerals in hard water are also deposited in plumbing, coffee pots, and steam irons. Frequently, people living in hard water areas use water softeners—chemicals that remove calcium and magnesium ions in an exchange with sodium ions.

TIP

Hard water can have benefits. In the aquatic environment, calcium and magnesium help keep fish from absorbing metals like lead, arsenic, and cadmium into the bloodstream through their gills. Therefore, the harder the water, the less potential for toxic metals to be absorbed by fish. In seawater, calcium concentrations are 100 to 1,000 times higher than land levels, and even greater concentrations are found in deeper, colder waters with little circulation. Calcium can reside roughly a million years in the ocean before it appears on land again. Calcium ions stay in ocean water until they are precipitated out as calcium carbonate.

Although upper ocean levels are highly saturated with calcium and carbonate ions, saturation depends on location and conditions. Photosynthesis and temperature affect warm, shallow water, lowering levels of carbon dioxide. These conditions allow calcium carbonate to precipitate either inorganically or through aquatic organisms.

When calcium carbonate is used by marine inhabitants to build shells, it is called *biomineralization.* As these organisms die, their hard shells sift down to the ocean's floor and gather or dissolve depending on depth, temperature, and pressure. Shells sinking to the deepest parts of the ocean often redissolve because of higher carbon dioxide levels in the colder, deeper waters.

KEY IDEA

> The dividing line separating an area where calcium carbonate dissolves and accumulates is called the *lysocline.*

The calcium carbonate deposited by microorganisms is often mixed with other ocean sediments or washed from the land depending on location. Birds, animals, and humans eat seafood and shellfish, discarding the shells. This returns calcium back to the Earth fairly rapidly.

However, most calcium is transported by plate tectonics. Crustal plates and continental land masses with their mountain-building movement help calcium carbonate deposits move toward the surface in the form of limestone or marble (if changed by pressure and temperature). Figure 10.3 illustrates the different compounds of the calcium cycle.

Soil

Calcium is taken up by plant roots either directly from the soil or from groundwater. When calcium is extracted from the soil via membrane permeability, both active and passive

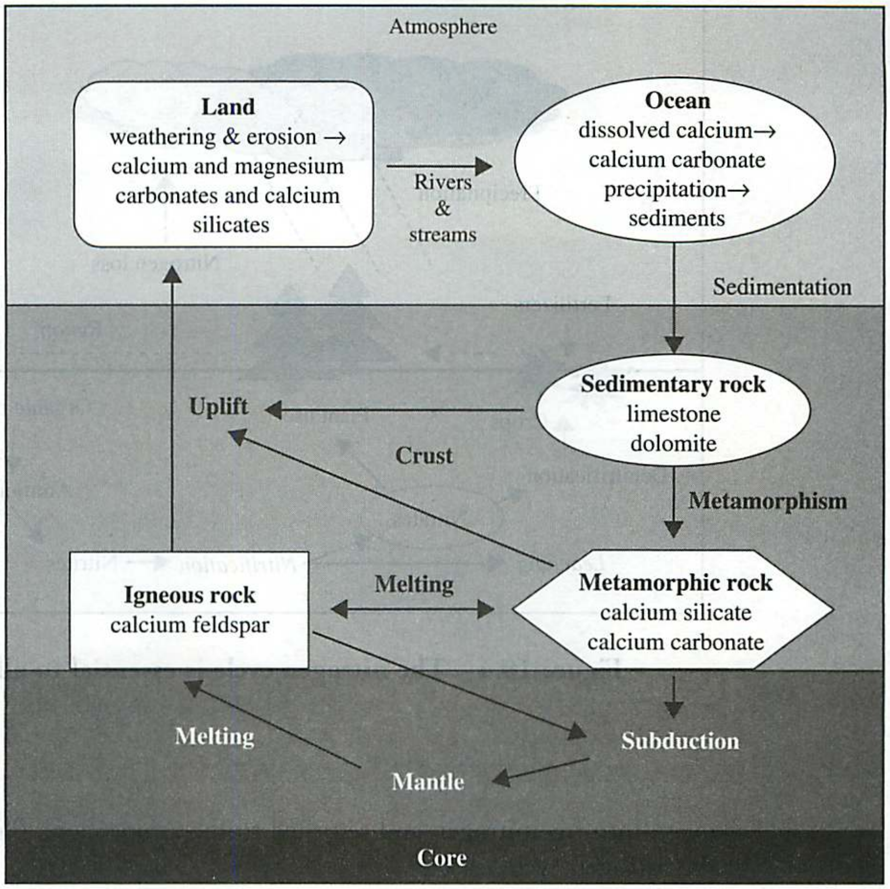

Figure 10.3 Calcium enters and exits sinks in a variety of places.

transport of ions takes place. Calcium is then transferred and stored in the leaves for a time. Calcium returns to the soil when leaves fall. It is stored in woody plant parts until it decays, is burned, or is consumed by an animal.

Nitrogen

Nitrogen (N_2) makes up 79% of the atmosphere. All life on Earth requires nitrogen-containing compounds (e.g., proteins) to survive. However, they can't easily use nitrogen in its gaseous form. To be used by a living organism, nitrogen must be combined with hydrogen and oxygen. Nitrogen is pulled from the atmosphere by lightning or nitrogen-fixing bacteria. During storms, large amounts of nitrogen are oxidized by lightning and mixed with water (rain). This falls and is converted into nitrates. Plants take up nitrates and form proteins.

Plants are consumed by herbivores or carnivores. When these consumers die (organic matter), nitrogen compounds are broken down into ammonia. Ammonia can be taken up by plants again, dissolved by water, or remain in the soil to be converted to nitrates (*nitrification*). Nitrates stored in soil can end up in rivers and lakes through runoff. It can also be

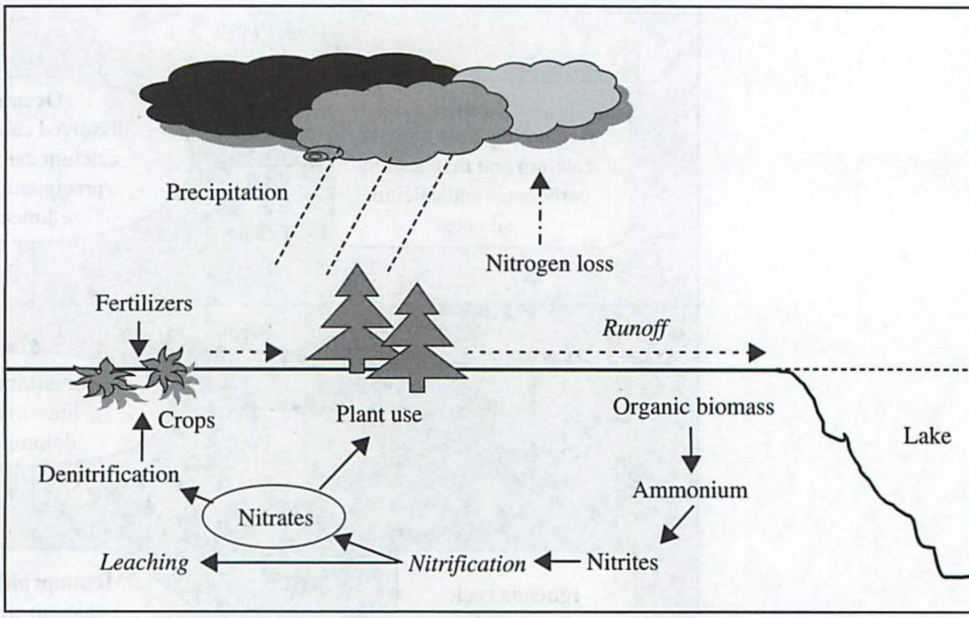

Figure 10.4 The nitrogen cycle is essential to all living systems.

changed into free nitrogen and returned to the atmosphere. Figure 10.4 gives you an idea of the nitrogen cycle.

Food Chains, Webs, and Trophic Levels

Photosynthesis is the foundation of all ecosystems. Plants are known as *primary producers* of biological material or *biomass.* Some organisms that produce biological material and eat plants are called *secondary producers.*

TIP

A *food chain* is the path that food follows. For example, if you eat a slice of cheese, you can trace it back to a cow (cheese is from milk) that ate plants for the energy and nutrients to make milk. Predatory species may eat several types of prey (food). A wolf may eat a rabbit that has just eaten a carrot. Then a few hours later, the wolf may come upon an injured deer which it kills and eats. The deer may have been grazing on grass before it was felled by the wolf. When individual food chains become interconnected, they are known as a *food web.* Adding microorganisms, worms, and insects, the web becomes even more complex.

A *trophic level* describes an organism's placement within a food chain or web. A carrot is at the producer level, while rabbits and chipmunks are primary consumers. There are several levels of consumers.

Some consumers, called *scavengers* (e.g., vultures and hyenas) feed from dead carcasses. *Detritivores* (e.g., ants and beetles) consume litter, debris (detritus), and dung, while *decomposers* (e.g., fungi and bacteria) finish off the process by breaking down and recycling organic matter. Figure 10.5 illustrates how organisms in an ecosystem get food (e.g., producer, primary, secondary, or tertiary consumers), as well as multilevel consumers (e.g., scavengers, parasites, and decomposers). The combination of all producers and consumers is called an *ecological pyramid.*

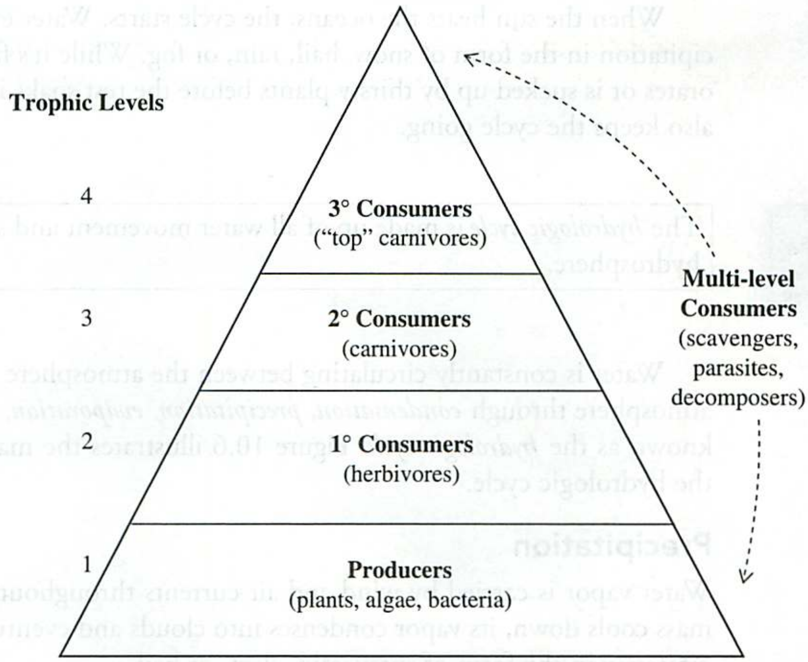

Figure 10.5 Lower organisms are producers, while herbivores and carnivores are consumers.

Mineral Cycles: Phosphorus and Sulfur

Phosphorus and sulfur are key minerals necessary for growth. At the cellular level, phosphorus is important in energy-transfer reactions. Too much phosphorus overstimulates plants and algae and is a major problem in water runoff and pollution.

The phosphorus cycle starts when the mineral leaches from rocks over a long time period. This form of phosphorus is taken in by producers, combined in organic molecules, and ultimately ingested by consumers. It goes back into the environment through decomposition of organic matter. Some phosphorus washes into rivers and eventually makes its way to the sea. Deep ocean sediments hold a significant amount of phosphorus.

TIP

Sulfur plays an important part in proteins and controls the acidity of rainfall, surface water, and soil. Geological inorganic sulfur is found primarily in rock and such minerals as iron disulfate (iron pyrite) or calcium sulfate (gypsum). It gets into the air and water by weathering, gases from seafloor vents, and volcanism.

The sulfur cycle is affected by sulfur's many oxidation states, such as hydrogen sulfide (H_2S), sulfur dioxide (SO_2), sulfate ion (SO_4^{-2}), and elemental sulfur. Besides geological cycling, sulfur bacteria can anchor sulfur or release it into the environment. These bacteria are affected by pH, light, temperature, and oxygen concentrations.

The burning of fossil fuels also releases sulfur into the environment. Sulfur dioxide and other sulfur-containing atmospheric gases cause health problems, damage buildings and plants, and reduce atmospheric visibility.

Hydrologic Cycle

The hydrosphere, crust, and atmosphere combine to make up the biosphere. The hydrosphere includes all the water in the atmosphere and on the Earth's surface.

When the sun heats the oceans, the cycle starts. Water evaporates and then falls as precipitation in the form of snow, hail, rain, or fog. While it's falling, some of the water evaporates or is sucked up by thirsty plants before the rest soaks into the ground. The sun's heat also keeps the cycle going.

KEY IDEA

The *hydrologic cycle* is made up of all water movement and storage throughout the Earth's hydrosphere.

Water is constantly circulating between the atmosphere and the Earth and back to the atmosphere through *condensation, precipitation, evaporation,* and *transpiration.* This cycle is known as the *hydrologic cycle.* Figure 10.6 illustrates the many ways water moves through the hydrologic cycle.

Precipitation

Water vapor is carried by wind and air currents throughout the atmosphere. When an air mass cools down, its vapor condenses into clouds and eventually falls to the ground as *precipitation* in the form of snow, rain, sleet, or hail.

TIP

Water can take a variety of paths and time periods to get back into the atmosphere. Some of these paths include the following:

- Absorption by plants
- Evaporation from the sun's heating
- Storage in the upper levels of soil
- Storage as groundwater deep in the Earth
- Storage in glaciers and polar regions
- Storage or transport in springs, streams, rivers, and lakes
- Storage in the oceans

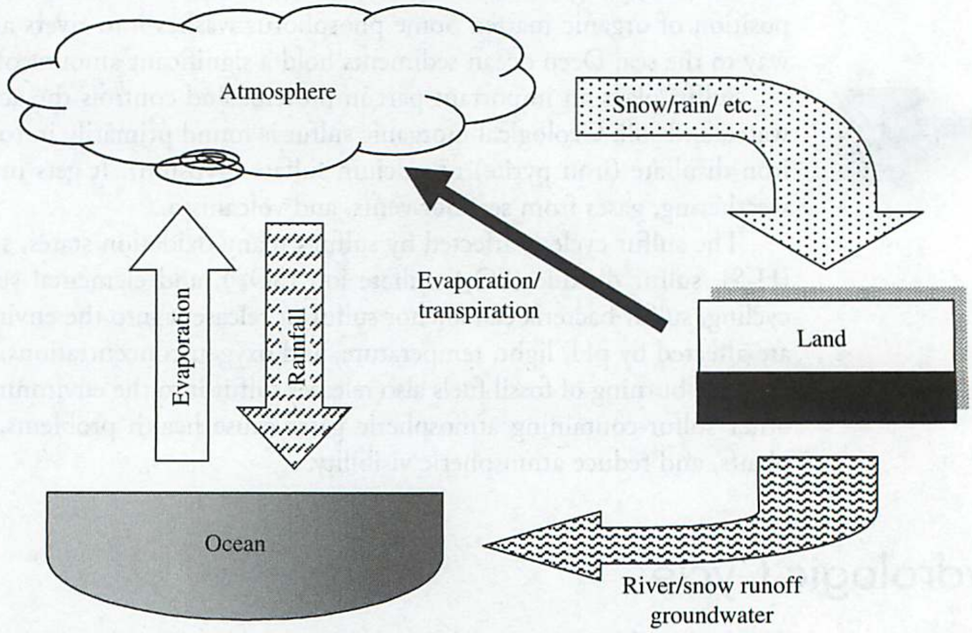

Figure 10.6 The hydrologic cycle is a dynamic system.

TIP

When water is stored for any length of time, it resides in a *water reservoir.* A reservoir is a holding area. Nature's reservoirs are oceans, glaciers, polar ice, underground storage (*aquifers*), lakes, rivers, streams, the atmosphere, and the biosphere (within living organisms). Surface water in streams and lakes returns to the atmosphere as a gas through evaporation.

Water held inside plants returns to the atmosphere as a vapor through a biological process called *transpiration.* When plants pull water up through their roots from the soil, use some of the dissolved minerals to grow, and then release the water back through the leaves, the entire cycle is known as *evapotranspiration.* This happens the most during times of high temperatures, wind, dry air, and sunshine. In temperate climates, this is summertime.

When air currents rise into the colder atmospheric layers, water vapor condenses and sticks to tiny particles in the air; this is called *condensation.* When water vapor coats enough particles (dust, pollen, or pollutant), it forms a cloud. When the air is saturated, gravity wins, and water falls as precipitation.

KEY IDEA

Precipitation can take the form of rain, snow, sleet, or hail depending on the temperature and other atmospheric conditions.

Although the hydrologic cycle balances what goes up with what comes down, in polar regions rain is stored as snow or ice on the ground for several months in winter. In glacial areas, storage extends from years to thousands of years. Then, as temperatures climb in the spring, water is released. When this happens in a short period of time, flooding occurs.

Evaporation

The sun provides energy, which powers evaporation. When water is heated, its molecules get excited and vibrate so much that they break their chemical bonds. Solar energy causes water to evaporate from oceans, lakes, rivers, and streams. Warm air currents scoop water vapor into the atmosphere.

KEY IDEA

When water changes its form from a liquid to a gas, it is said to *evaporate.*

Because of the huge amount of water in the oceans, it makes sense that roughly 80% of all evaporation comes from the oceans, with 20% coming from inland water and plant transpiration. Wind currents transport water vapor around the world, influencing air moisture worldwide. Hydrologists (scientists who study the Earth's water cycle) estimate that 100 billion gallons of water a year are cycled through this process.

Without the hydrologic cycle, life on Earth would not have developed. Nearly every creation story tells how oceans were formed before continents and their inhabitants. We use water for everything, both internally and externally. Without water, life would not exist on Earth: it is second in importance only to the air we breathe.

Condensation

Water condensation takes place when the air or land temperature changes. Water shifts form when temperatures rise and fall. You see this in the early morning when dew forms on plants.

As water vapor rises, it gets cooler and eventually condenses, sticking to minute particles of dust in the air. Condensation describes water's change from its gaseous form (vapor) into liquid water. Condensation generally takes place in the atmosphere when warm air rises and then cools and loses its ability to cling to water vapor. As a result, extra water vapor condenses to form cloud droplets.

Rainfall differences are affected by a land's topography (shape). For example, mountain topography changes wind patterns, which change precipitation patterns. A rain shadow occurs when warm, moist air is forced to rise over high mountain passages, where it cools and condenses into rainfall. Dry air continues on over the mountains. Depending on climatic conditions, clouds form, winds blow them around the globe, and water vapor is distributed. When clouds can't hold any more moisture, they dump it as snow, rain, or other form of precipitation.

Transport

Next in the hydrologic cycle, transport describes the movement of atmospheric water. Commonly, this water moves from the oceans to the continents. Some of the Earth's moisture transport is visible as clouds, which consist of ice crystals and/or tiny water droplets. Clouds are propelled from one place to another by the jet stream, surface circulations (e.g., land and sea breezes), or other mechanisms. However, a typical 1-kilometer-thick cloud contains only enough water for roughly 1 millimeter of rainfall, whereas the amount of moisture in the atmosphere is usually 10 to 50 times greater.

Transpiration

Another type of evaporation adding to the hydrologic cycle is transpiration. This is a little more complicated. During transpiration (or evapotranspiration), plants and animals release moisture through their pores. This water rises into the atmosphere as vapor.

Transpiration is most easily seen in the winter when you see your breath. When exhaling carbon dioxide and used air, you also release water vapor and heat. Your warm, moist exhalation on a frosty winter morning becomes a small cloud of water vapor.

Transpiration from the leaves and stems of plants is also crucial to the air-scrubbing capability of the hydrologic cycle. Plants absorb groundwater through their roots deep in the soil. Some plants, like corn, have roots a couple of meters in length, while some desert plants have to stretch roots over 20 meters down into the soil. Plants pull water and nutrients up from the soil into their leaves. It is estimated that a healthy, growing plant transpires 5 to 10 times as much water volume as it can hold at one time. This pulling action is driven by water evaporation through small pores in a leaf. Transpiration adds approximately 10% of all evaporating water to the hydrologic cycle.

› Review Questions

Multiple-Choice Questions

1. When calcium carbonate is used to build the shells of sea creatures, it is called

(A) lime
(B) condensation
(C) sublimation
(D) biomineralization
(E) transfiguration

2. By dry weight, approximately what percent of carbon are humans composed of?

(A) 20%
(B) 50%
(C) 65%
(D) 70%
(E) 90%

3. Scientists have studied the carbon cycle in all the following geochemical reservoirs except

(A) the oceans
(B) soil
(C) fossil fuels
(D) the Earth's core
(E) plant life

4. Carbon-containing material from living or non-living sources is called

(A) pyroclastic material
(B) inorganic material
(C) organic material
(D) sublimation
(E) biomineralization

5. When freshwater has high concentrations of calcium and/or magnesium, it is commonly called

(A) calciferous
(B) hard water
(C) soft water
(D) mineralization
(E) lime

6. The residence time of oxygen in the atmosphere is

(A) 12 weeks
(B) 300 years
(C) 1,000 years
(D) 6,000 years
(E) 1 million years

7. When plants pull water from the soil, use the dissolved minerals to grow, and release the water back through the leaves, it is known as

(A) evapotranspiration
(B) respiration
(C) condensation
(D) transport
(E) condensation

8. Plants are known as primary producers of

(A) methane
(B) biomineralization
(C) biomass
(D) water pollution
(E) limestone

9. The idea that matter is neither created, nor destroyed, but recycled through natural cycles is known as

(A) conservation of matter
(B) origin of species
(C) residence time
(D) transconfiguration
(E) respiration

10. All the following are natural water reservoirs except

(A) aquifers
(B) living organisms
(C) streams
(D) limestone
(E) the atmosphere

11. A plant's reaction that captures visible light wavelengths (0.4 to 0.7 μm) and transforms them into chemical energy is known as

(A) sublimation
(B) biomineralization
(C) biomass
(D) evapotranspiration
(E) photosynthesis

12. Organisms that consume litter, debris, and dung are called

(A) carnivores
(B) herbivores
(C) detritivores
(D) parasites
(E) omnivores

13. When ammonia is taken up by plants, dissolved by water, or remains in the soil to be converted to nitrates, it is known as

(A) calcification
(B) residence time
(C) photosynthesis
(D) nitrification
(E) neutralization

14. The location where planetary water is stored for a length of time is called

(A) sink hole
(B) geological cycle
(C) lake
(D) karst
(E) water reservoir

15. Inorganic sulfur is found primarily in rock and minerals as iron pyrite and

(A) gneiss
(B) iron oxide
(C) gypsum
(D) limestone
(E) granite

16. All things that take up space and have mass are known as

(A) sedimentary rock
(B) heavy metals
(C) matter
(D) carnivores
(E) core materials

17. A growing plant transpires up to ___ times as much water volume as it holds at one time.

(A) 2
(B) 10
(C) 18
(D) 22
(E) 25

18. When the temperature of the air or land changes,

(A) condensation of water vapor occurs
(B) populations migrate
(C) leaves change color
(D) snow falls
(E) transpiration is increased

19. When plants absorb carbon dioxide and sunlight to make glucose and build cellular structures, it is known as the

(A) calcium cycle
(B) sulfur cycle
(C) hydrogen cycle
(D) phosphorus cycle
(E) biological carbon cycle

20. Matter exists in three forms, solid, liquid, and

(A) metallic
(B) ice
(C) nuclear
(D) gas
(E) pyrotechnic

❯ Answers and Explanations

1. D—As these organisms die, their shells fall to the ocean floor and gather or dissolve.

2. B

3. D—Direct sampling is impossible, but computer modeling and analysis have been done.

4. C

5. B—When this water evaporates, a lot of minerals are left behind.

6. D—Although it is a long time, it is much less than nitrogen.

7. A—Water is released to the atmosphere as a vapor from the leaves.

8. C—*Biomass* is a shortened way to describe biological material.

9. A—This principle is also called conservation of mass.

10. D

11. E—Photosynthesis is the main way plants get energy from the sun.

12. C—These organisms consume accumulations of disintegrated material.

13. D

14. E

15. C—A hydrated sulfate of calcium and used for making plaster of Paris.

16. C

17. B

18. A—Water shifts form (e.g., ice, water, vapor) when temperatures rise and fall.

19. E—Carbon plays important structural and processing functions in most life forms.

20. D

Free-Response Questions

1. The geological carbon cycle is intricate with several players. Nature is all about balance. This might be the case with increases in atmospheric carbon dioxide. It may take a long time for the oceans to increase their uptake of carbon dioxide. When the land, sea, and air are overloaded, nature has a tough time keeping up. How does deforestation create imbalances in carbon dioxide levels?

2. The annual rainfall of the state of Washington is more that 450 cm/year, while other areas in the United States get only 20 cm/year or less. High rainfall amounts are found mainly on the western side of the Cascade Mountains, while light rainfall is found on the eastern, or rain shadow, side of the mountain. How do mountains affect rainfall patterns?

3. Limestone is a bedded sedimentary rock made up mostly of calcium carbonate. It's the most important of the carbonate rocks, consisting of sedimentary carbonate mud and calcium-based sand and shells. Limestone is fairly insoluble. However, when plant roots and soil organisms of all sizes give off carbon dioxide, which in turn combines with groundwater, the result is carbonic acid. Carbonic acid dissolves limestone, releasing calcium. How does limestone help proliferate the geological carbon cycle?

Free-Response Answers and Explanations

1. Because the carbon cycle is a closed system, extreme changes in carbon dioxide levels can directly affect weather patterns and adversely affect our environment. Because plant life pulls carbon dioxide from the atmosphere to create glucose and other carbohydrates, helping to keep CO_2 levels in balance, deforestation hinders this invaluable process.
2. Rainfall differences are affected by a land's topography (shape). Like the Himalayas, the Cascade Mountain Range alters precipitation by creating a rain shadow. When warm, moist air is forced to rise due to mountain passages, it cools and condenses creating rainfall, while the dry air continues on over the mountains creating an arid climate, or rain shadow, on the other side. Mountain topography changes wind patterns, which change precipitation patterns.
3. Limestone, which erodes through weathering, falls into oceans creating sedimentary rock that over time is subducted deep into the Earth's crust. There, extreme temperatures and pressures cause the limestone to react with other chemicals through metamorphism, thus freeing carbon dioxide. The carbon dioxide is later released back into the atmosphere through volcanism.

› Rapid Review

- The change between total carbon released to the atmosphere and the total pulled back down governs whether the land is a supplier or reservoir of atmospheric carbon.
- Known as the building block of life, carbon is the foundational element of all organic substances.
- The carbon cycle involves the Earth's atmosphere, fossil fuels, oceans, soil, and plant life of terrestrial ecosystems.
- Precipitation can be rain, snow, sleet, or hail depending on temperature and other atmospheric conditions.
- Transpiration is another type of evaporation in the hydrologic cycle.
- When elements move from one Earth storage form to another, it is known as a geochemical cycle.
- All things that take up space and have mass are known as matter.
- Conservation of matter states that matter is neither created, nor destroyed, but recycled through natural cycles.
- Residence time equals the average amount of time a chemical element (e.g., carbon, calcium, or phosphorus) spends in a geological reservoir or cycle.
- Photosynthesis defines a series of reactions in plants, bacteria, and algae that capture visible light wavelengths (0.4 to 0.7 μm) and transform light energy into chemical energy needed for organic molecules to bond.
- The biological carbon cycle occurs when plants absorb carbon dioxide and sunlight to make glucose and other sugars (carbohydrates) to build cellular structures.
- High concentrations of dissolved calcium and/or magnesium in freshwater cause hard water.
- Water takes a variety of paths and time periods to get back into the atmosphere including
  - Absorption by plants
  - Evaporation from the sun's heating
  - Storage in the upper levels of soil
  - Storage as groundwater deep in the Earth

  - Storage in glaciers and polar regions
  - Storage or transport in springs, streams, rivers, and lakes
  - Storage in the oceans
- Besides geological cycling, sulfur cycles through organisms such as sulfur bacteria that anchor sulfur or release it into the environment.
- Nitrogen (N_2) makes up 79% of the atmosphere, and all life on Earth requires nitrogen-containing compounds (e.g., proteins) to survive.
- At the cellular level, phosphorus is important in energy-transfer reactions.
- The dividing line that separates an area where calcium carbonate dissolves and accumulates is called the lysocline.
- When calcium carbonate is used by marine inhabitants to build shells, it is called biomineralization.