The Carbon Cycle

Carbon is the second most abundant element in organisms, by mass. Carbon is present in all organic molecules (and some molecules that are not organic such as CO_2), and its role in the structure of biomolecules is of primary importance. Carbon compounds contain energy, and many of these compounds from dead plants and algae have fossilized over millions of years and are known as **fossil fuels**. Since the 1800s, the use of fossil fuels has accelerated. Since the beginning of the Industrial Revolution the demand for Earth's limited fossil fuel supplies has risen, causing the amount of carbon dioxide in our atmosphere to drastically increase. This increase in carbon dioxide is associated with climate change and is a major environmental concern worldwide.

The **carbon cycle** is most easily studied as two interconnected subcycles: one dealing with rapid carbon exchange among living organisms and the other dealing with the long-term cycling of carbon through geologic processes. The entire carbon cycle is shown in Figure 3 below.

The Biological Carbon Cycle

Organisms are connected in many ways, even among different ecosystems. A good example of this connection is the exchange of carbon between heterotrophs and autotrophs by way of atmospheric carbon dioxide. Carbon dioxide (CO_2) is the basic building block that autotrophs use to build high-energy compounds such as glucose. The energy harnessed from the Sun is used by these organisms to form the covalent bonds that link carbon atoms together. These chemical bonds store this energy for later use in the process of respiration. Most terrestrial autotrophs obtain their carbon dioxide directly from the atmosphere, while marine autotrophs acquire it in the dissolved form (bicarbonate, HCO_3^-).

Carbon is passed from producers to higher trophic levels through consumption. For example, when a cow (primary consumer) eats grass (producer), it obtains some of the organic molecules originally made by the plant's photosynthesis. Those organic compounds can then be passed to higher trophic levels, such as humans, when we eat the cow. At each level, however, organisms are performing **respiration**, a process in which organic molecules are broken down to release energy. As these organic molecules are broken down, carbon is removed from food molecules to form CO_2, a gas that enters the atmosphere. Thus, CO_2 is a byproduct of respiration. Recall that CO_2 is consumed by producers during photosynthesis to make organic molecules. As these molecules are broken down during respiration, the carbon once again enters the atmosphere as CO_2. Carbon exchange like this potentially connects all organisms on Earth. Think about this: the carbon in your DNA was once part of plant; millions of years ago perhaps it was part of dinosaur.

The Biogeochemical Carbon Cycle

The movement of carbon through land, water, and air is complex, and, in many cases, it occurs much more slowly than the movement between organisms. Carbon is stored for long periods in what are known as carbon reservoirs, which include the atmosphere, bodies of liquid water (mostly oceans), ocean sediment, soil, rocks (including fossil fuels), and Earth's interior.

As stated, the atmosphere is a major reservoir of carbon in the form of carbon dioxide that is essential to the process of photosynthesis. The level of carbon dioxide in the atmosphere is greatly influenced by the reservoir of carbon in the oceans. The exchange of carbon between the atmosphere and water reservoirs influences how much carbon is found in each. Carbon dioxide (CO_2) from the atmosphere dissolves in water and reacts with water molecules to form ionic compounds. Some of these ions combine with calcium ions in the seawater to form calcium carbonate ($CaCO_3$), a major component of the shells of marine organisms. These organisms eventually die and their shells form sediments on the ocean floor. Over geologic time, the calcium carbonate forms limestone, which comprises the largest carbon reservoir on Earth.

On land, carbon is stored in soil as organic carbon as a result of the decomposition of organisms or from weathering of terrestrial rock and minerals (the world's soils hold significantly more carbon than the atmosphere, for comparison). Deeper underground are fossil fuels, the anaerobically decomposed remains of plants and algae that lived millions of years ago. Fossil fuels are considered a non-renewable resource because their use far exceeds their rate of formation. A **non-renewable resource** is either regenerated very slowly or not at all. Another way for carbon to enter the atmosphere is from land (including land beneath the surface of the ocean) by the eruption of volcanoes and other geothermal systems. Carbon sediments from the ocean floor are taken deep within Earth by the process of **subduction**: the movement of one tectonic plate beneath another. Carbon is released as carbon dioxide when a volcano erupts or from volcanic hydrothermal vents.

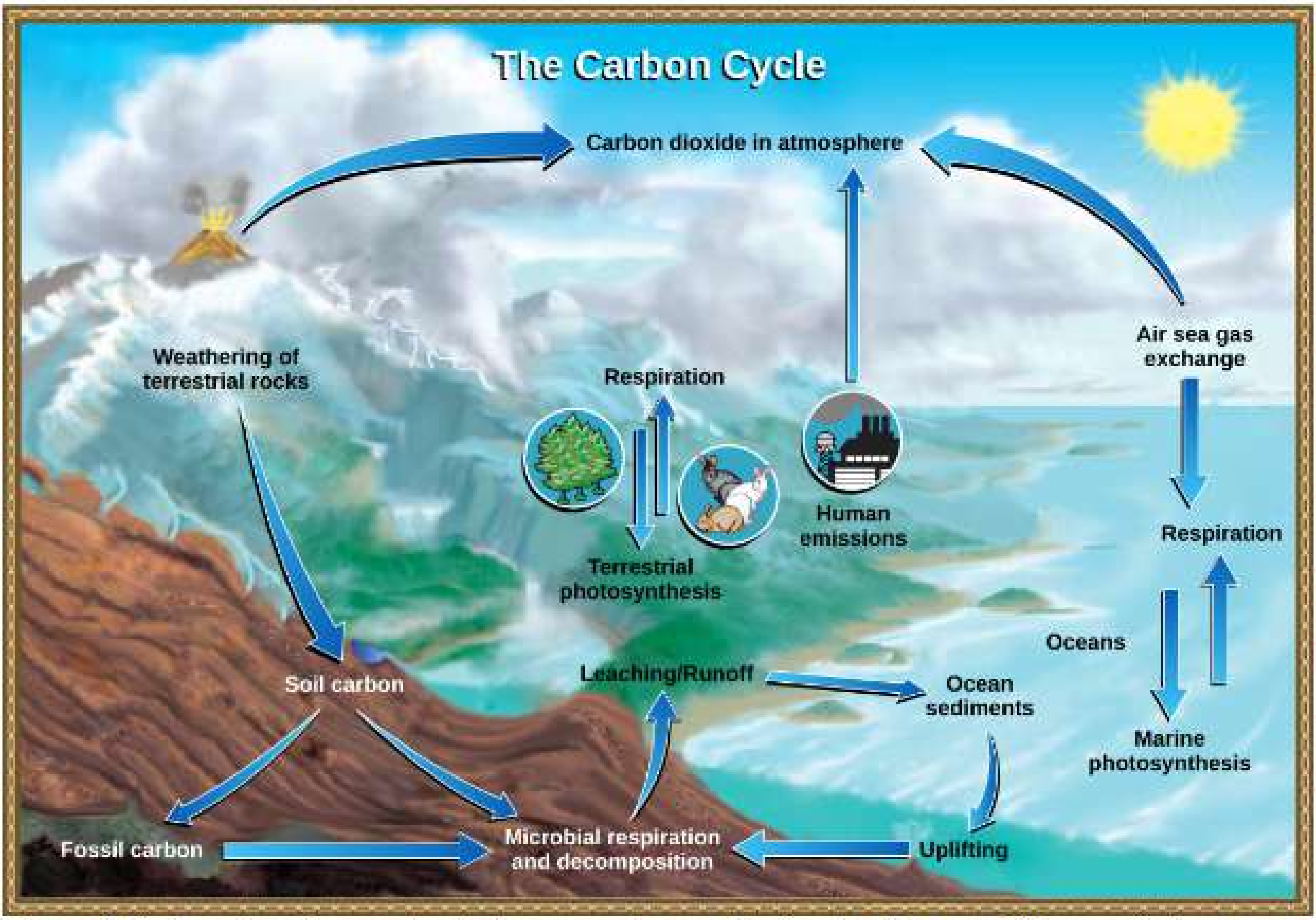

Figure 3. Carbon dioxide gas exists in the atmosphere and is dissolved in water. Photosynthesis converts carbon dioxide gas to organic carbon, and respiration cycles the organic carbon back into carbon dioxide gas. Long-term storage of organic carbon occurs when matter from living organisms is buried deep underground and becomes fossilized. Volcanic activity and, more recently, human emissions bring this stored carbon back into the carbon cycle. (credit: modification of work by John M. Evans and Howard Perlman, USGS)