BIOLOGICAL AND BIOGEOCHEMICAL APPROACHES TO ENVIRONMENTAL AND ECOLOGICAL SUSTAINABLE DEVELOPMENT

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Summary

The main biogeochemical cycles are introduced, including the water cycle, the carbon cycle, the nitrogen cycle, the phosphorus cycle and the sulfur cycle. It is very important to understand these biochemical cycles and keep these cycles stabilized in the nature. Unfortunately, human activities have affected these cycles seriously. We must make great efforts to protect these cycles for maintain the environmental and ecological sustainable development.

1. Introduction

In order to understand the environment and ecological sustainable development, it is necessary to know the biogeochemical cycle. Life depends on the material cycle and the energy cycle in ecosystems. The flow of energy in ecosystems is one way. The energy of sunlight fixed by plants is dissipated through the food chains and ultimately escapes from the system. On the other hand, the material flow circulates around the ecosystems. Organic matter absorbs the nutrients from the environment. The dead bodies of plants and animals are decomposed by bacteria and fungi, then the nutrients in the organic matter are liberated to the abiotic environment.

Of the 92 elements in nature some 30 to 40 have been identified as essential for living organisms. They can be divided into three main groups according to their function: energy elements, macronutrient elements, and micronutrient elements. The energy elements play a key role in the formation of protein and are required in relatively large amounts for life. Carbon, hydrogen, oxygen, and nitrogen are energy elements. The macronutrient elements include phosphorus, potassium, sulfur, sodium, calcium, magnesium, etc. They are required in large quantities for organic matter. There are many micronutrient elements. Iron, copper, zinc, boron, fluorine, iodine, bromine, aluminum, cobalt, manganese, molybdenum, chromium, selenium, silicon, strontium, titanium, vanadium, tin, gallium, etc. are micronutrient elements. They are required in micro amounts, but are still essential for life.

The circulation processes on a global scale of these elements include biological, geological, and chemical systems, and are known as the "biogeochemical cycle," where "bio" means the living part of the system, and "geo" means the abiotic environment. All biogeochemical cycles involve interaction between soil and atmosphere.

The material cycle can be divided into three groups. (a) The water cycle. Water is the origin of life. It is impossible for the biogeochemical cycle to exist without the water cycle. (b) The gaseous cycles. The main reservoir pool of the gaseous materials is the atmosphere. The gaseous cycles link the atmosphere and oceans, and are a global cycle. Oxygen, carbon dioxide, and nitrogen are the main materials of the gaseous cycle, as are vapor, chlorine, bromine, and fluorine and argon. (c) The sedimentary cycles. The reservoir pool of sedimentary elements is the soil and rocks. The sediments can change to the nutrients available for ecosystems by weathering of rocks and decomposition of the sediments, and the sediments can change to rocks. This is a very slow material transfer process and it is on a global scale. The main materials of sedimentary cycles are phosphorus, sulfur, and iodine. Many other elements, such as calcium, potassium, sodium, magnesium, iron, manganese, copper, and silicon, belong to these cycles also. The phosphorus cycle is the typical sedimentary cycle. Phosphorus is released from rocks, precipitates in the oceans through transition, and changes into the content of mineral rocks.

The most important cycles of elements for the ecosystems, besides the cycle of water, are those of carbon, nitrogen, and phosphorous. The sulfur cycle is important too. Indeed, there is an oxygen cycle. But oxygen is combined with hydrogen to form water, and combined with carbon to form carbon dioxide, so it is included in the water and carbon cycles. This is the same with hydrogen.

2. The Water Cycle

The water cycle is essential in nature. Water is necessary for human activities and it constitutes a large percentage of the living tissue of all organisms. About 40% to 60% of the fresh weight of trees is composed of water. It is impossible for any ecosystem to exist without water. The water cycle is the base of the material and energy cycles in ecosystems. Moreover, water can regulate the weather, wash the atmosphere, and clean the environment.

Water is composed of hydrogen and oxygen. Hydrogen (the symbol for this chemical element is H) is by far the most abundant element in the known universe. Over 90% of all atoms are hydrogen. The next most common element is helium (He) with an abundance of 8% or 9%. All the other atoms taken together constitute less than 1% of the material in the universe. In contrast, hydrogen is only a minor component of Earth, although its presence in water on Earth's surface has been critical in providing the right conditions for the development of life on the planet.

And oxygen (O) has a unique place in the composition of both the animate and inanimate world. It is the only element that is present in high concentration in the crust, atmosphere, hydrosphere, and biosphere of Earth. For this reason oxygen deserves special consideration.

In contrast, the oxygen in the atmosphere is chemically reactive. The oxygen is mainly present as a free element in the form of the dioxygen molecule (O_2). The reactivity of O_2 is great enough to have a controlling influence on the geochemical cycles of many other elements, such as carbon, hydrogen, nitrogen, sulfur, and iron. Most of the O_2 in the atmosphere has been produced by photosynthesis. In addition, a small amount is produced by the action of ultraviolet (U.V.) light on water molecules in the upper atmosphere.

At present there seems to be a state of equilibrium between the rate of formation and the rate of utilization of O_2 in the atmosphere. This implies that there are fairly rapid feedback mechanisms in the system that counterbalance any changes in rates of formation or removal. The feedback mechanism is probably linked to the carbon cycle and the amount of organic matter incorporated in the ocean sediments. If the concentration of O_2 drops, then more carbon is incorporated in the sediments (i.e. photosynthesis is increased compared to removal processes); if the concentration of O_2 rises, then less carbon is incorporated in the sediments (i.e. removal processes are increased relative to photosynthesis).

Water can adjust the temperature with the change of the state. The evaporation of water requires the absorption of energy and tends to reduce the temperature at the air-water interface. This energy is released again when the water vapor condenses, so the movement of water vapor transfers heat energy from one area to another. As water evaporates most rapidly wherever the temperature is highest and condenses when the temperature drops, the water cycle is effective in reducing the temperature differences between areas. This is the same with the change of water to ice. The concentration of water vapor is so variable (0%–5%) that it is not possible to know whether there is an overall increase or not. It should be noted that water vapor is responsible for more infra-red (I.R.) radiation absorption than any other atmospheric component. However, its effect is usually believed to be approximately constant, with changes driven by other factors. So, the water cycle plays an important role in the variation of temperature.

The reservoir pools of water are the oceans. Oceans occupy about 70% of the earth's surface, and about 97% of water on the earth exists in the oceans. About 2% of water is in the form of glacier ice, and less than 1% exists as ground water under the soil. The rest is in the inland seas, lakes, rivers, and soil. The water in the atmosphere exists as cloud and vapor. The amount of vaporized water from the oceans is greater than the condensed water returned to the oceans. The condition for the continents is the reverse. The amount of vaporized water from the land is less than condensed water that falls to the land as rain or snow.

A part of the surface water returns to the seas and oceans through the rivers (see Figure 1). Another part of the surface water permeates into soil and rocks to form ground water and soil water, which is absorbed by plants. Ground water flows slowly and ultimately returns to the seas and oceans. The water in the atmosphere can be condensed and fall back to the earth as rain or snow.

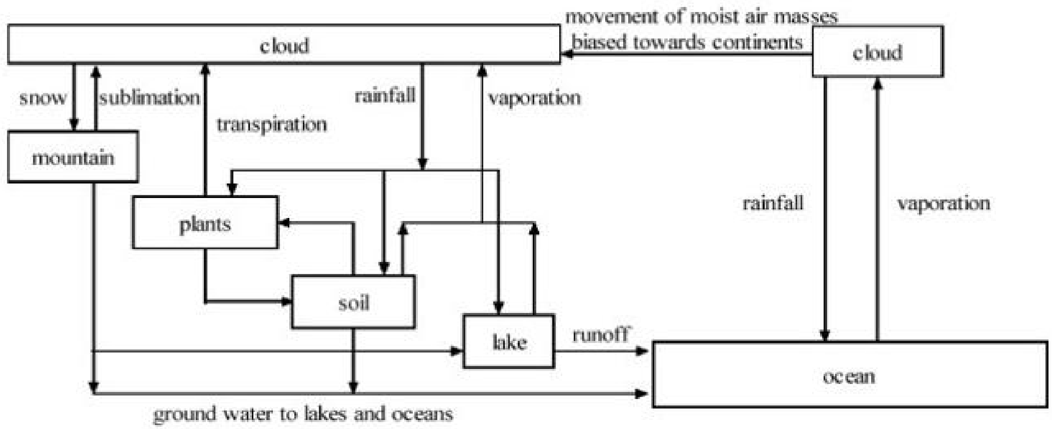

Figure 1. The water cycle

Hydrogen is only a minor component of the earth as a whole, but water is of major importance to the survival of life on the planet. Water covers about 70% of the earth's surface and the properties of this liquid and its vapor control of climatic conditions make life possible on earth. In addition, water's solvent properties control the chemical weathering of rocks, the transfer of nutrients to plants, and the transfer of chemicals inside organisms.

The water cycle is driven by the absorption of solar energy, most of which causes evaporation of water from the oceans and land although a small proportion generates the winds, waves, and currents that aid circulation in both the atmosphere and water masses; 86% of the water evaporated comes from the oceans, but only 78% of the rain and snow that falls comes down on the oceans. There is a net transfer of water from the oceans to the land so that the precipitation on to the land is 57% greater than the evaporation from the land. The extra water added to the land eventually returns to the oceans via surface runoff in rivers or direct seepage of ground water into the oceans. The evaporation of water requires the absorption of energy and tends to reduce the temperature at the air-water interface.

Recently, shortage of water has become a universal environmental problem. It should be noted that water shortages can be of two types. Shortages may result from low supply or from poor water quality. Even if the supply is sufficient, water of the quality needed for human consumption, municipal, and industrial uses may not be available. Water quality and water quantity are aspects of the same problem of water supply. In most water uses, water quality is altered; either the temperature is changed or materials are added. In many cases, however, water is used but not consumed. This is true of both municipal and industrial uses. Water from industry may be drawn from its source (lake, river, reservoir, or underground aquifer) and used to carry away heat, to “scrub” products during manufacturing, or to carry away industrial waste materials. Water is also used by cities to carry away wastes, though industrial and municipal wastewater can be treated and returned to a surface or groundwater reservoir and made available again for other uses. Human activities affect the water cycle.

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Bibliography

Colinvaux P.A. (1986). *Ecology,* 725 pp. New York: Wiley. [This presents a comprehensive discussion of ecology.]

Connell D.W. and Miller G.J. (1984). *Chemistry and Ecotoxicology of Pollution*, 444 pp. New York: Wiley. [This presents a discussion on the relation between environmental chemistry and ecological systems.]

Duvigneaud P. (1987). *La Synthèse Ècologique* (trans. into Chinese Y-B. Li), 383 pp. Beijing: Science Press. [This presents an introduction to ecology.]

Emberlin J.C. (1983). *Introduction to Ecology*, 308 pp. Plymouth, U.K.: Macdonald & Evans. [This presents a brief introduction to ecology.]

Gong S-C., Chen Y-X., Han Y-L., and Zhang J-Z. (1991). *Environmental Chemistry*, 400 pp. [in Chinese.] Shanghai: East China Normal University Press. [This work presents a brief discussion of environmental chemistry.]

He Q., Jing W-Y., and Wang Y-T. (1993). *Introduction to Environmental Science*. [in Chinese], 384 pp. Beijing, Tsinghua University Press. [This presents an introduction of environmental science.]

O’Neill, Peter (1998). *Environmental Chemistry*, 3rd ed., 38 pp, 79 278pp. London: Blackie Academic. [This presents an introduction to the material cycle.]

Biographical Sketch

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