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BIOGEOCHEMICAL CYCLES

As discussed in Plate 43, the flow of energy in the biosphere is in one direction only: from the sun, through living organisms, into the environment, and out into space. Matter, on the other hand, cycles constantly from organism to organism as well as to and from the environment, which acts as a reservoir. The cyclic pathways taken by various elements in passing through living organisms and the earth, its atmosphere, and its bodies of water are generally called biogeochemical cycles. This plate illustrates one of the most important of those cycles, the nitrogen cycle.

Color titles and structures A through J. Reserve a blue-green color for L. Leave A¹, E¹, F¹, J¹, and J² uncolored for now.

Proteins and nucleic acids are essential to life, and in order to make them, every living organism must obtain nitrogen in a suitable form. The earth's atmosphere is approximately 79 percent *nitrogen* and serves as a nitrogen reservoir. However, the nitrogen atoms in the air are tightly joined in diatomic ("two-atom") molecules (N_2), and no animal or plant known can separate them to use them. To be useful, the nitrogen must first be "fixed," that is, attached to atoms of some other elements to form a compound.

A small amount of this *nitrogen fixation* results from the passage of *ultraviolet light* and *lightning* through the air, causing nitrogen to react with oxygen to form *nitrate ions* (NO_3^-). Additional amounts of nitrate and *ammonia* (NH_3) are put into the atmosphere by *volcanoes,* by combustion of fossil fuels (coal, oil, and natural gas), and by forest fires. *Rain* eventually brings this fixed nitrogen to the soil—as ammonium ion (NH_4^-), once it contacts water, though it is still commonly referred to as "ammonia" to simplify discussion.

Color arrow E¹, titles K through P, and their corresponding parts of the illustration. Use blue-green for L. Color J¹ as well.

The abiotic processes described above are actually responsible for only a small fraction of the nitrogen fixation that occurs. The bulk of it is carried out by *nitrogen-fixing bacteria* in the soil and by *cyanophytes* (blue-green algae; Plate 32) which live mostly as a scum on submerged objects in lakes and ponds. The most efficient nitrogen fixers are bacteria found in nodules on the roots of certain *plants,* notably the legumes (alfalfa, beans, peas, lentils, clover), where they have a symbiotic relationship (Greek: *sym,* "together"; *bios,* "life") in which the bacteria obtain some nutrients from the plant but provide ammonia in return, which the plant can use to make amino acids. Commercial processes for fixing atmospheric nitrogen to produce chemical *fertilizers* also add nitrogen to the soil (about 10 percent of what biological fixations add). *Animals* are totally unable to fix nitrogen or even to utilize inorganic nitrogen compounds. They must *consume* already formed amino acids in their food.

Color titles and structures Q through W, including F¹ and J².

The *excretions* of animals and the dead bodies of all living organisms are broken down in the soil by *decomposers* in the process of *ammonification,* which produces ammonia. Then bacteria called *nitrifying bacteria* convert the ammonia to *nitrite ion* (NO_2^-), following which a different group of nitrifying bacteria convert the nitrite ion to nitrate ion (NO_3^-). (The two processes together are called *nitrification.*) Nitrate is readily taken up by the roots of plants and utilized.

Color the remainder of the plate, including A¹.

If soil becomes too compacted or remains too wet, air cannot penetrate and conditions become anaerobic, allowing certain bacteria called *denitrifying bacteria* to convert nitrate to *nitrous oxide* (N_2O) or nitrogen gas (N_2), which is then lost to the atmosphere. If oxygen is available, they will use oxygen instead of nitrate, and the nitrogen loss is avoided. That is why it is important for farmland to be kept well drained and plowed.

Additional nitrogen is lost from the soil by erosion and carried into streams, rivers, and ultimately the ocean. There it cycles through aquatic organisms. Eventually, some nitrogen is lost to *sediments* at the bottoms of oceans or lakes too deep for the nitrogen to be recycled by currents. It will remain there until major upheavals of the earth's crust bring those sediments to the surface again. This does not mean that we are running out of nitrogen. While supplies of fossil fuels last, the opposite is true, and in some farming areas, the use of large amounts of chemical fertilizers sometimes results in population explosions of algae, which clog waterways, and health problems from pollution of drinking water.

Dozens of other elements cycle in similar ways. In the phosphorus and calcium cycles, certain kinds of rock serve as the reservoirs. Some ecologists are concerned that we may be mining too much phosphate rock for fertilizers and detergents, since we have greatly speeded up the rate of transfer of phosphate to deep ocean sediments, which will not return to the surface for millions of years.

BIOGEOCHEMICAL CYCLES•

NITROGEN CYCLE★
ATMOSPHERIC NITROGEN A, A¹
SUN B
ULTRAVIOLET LIGHT C
LIGHTNING D
NITROGEN FIXATION E, E¹
NITRATE ION F, F¹
VOLCANO G
FACTORY H
RAIN I
AMMONIA J, J¹, J²
NITROGEN-FIXING BACTERIA K
NITROGEN-FIXING CYANOPHYTES L

FERTILIZER M
PLANT N
ANIMAL O
CONSUMPTION P
EXCRETION Q
DEATH R
AMMONIFICATION S
DECOMPOSERS T
NITRIFICATION U
NITRIFYING BACTERIA V
NITRITE ION W
DENITRIFICATION X
DENITRIFYING BACTERIA Y
NITROUS OXIDE Z
LOSS TO SEDIMENT ZZ