The Origin of Life on Earth—Life from Nonlife

Geologists estimate from radioisotope dating that the earth is approximately 4.6 billion years old. The oldest fossils are of cyanobacteria that come from 3.5-billion-year-old rocks (stromatolites) from Australia and South Africa. Thus, it took no more than 1 to 1.5 billion years for life to originate.

In trying to explain how life may have arisen, scientists first needed to know the conditions that existed on the earth after its formation. In 1929, J. B. S. Haldane described the atmosphere of primordial earth as a reducing atmosphere (with little free oxygen present) containing primarily hydrogen, water, ammonia, and methane. In 1953, Stanley Miller and Harold Urey constructed a reaction vessel in which they duplicated the atmosphere Haldane described. They heated the mixture to 80° C and provided the atmosphere with an electrical spark to simulate lightning. Over the course of a week, they removed samples from their system and found a variety of common amino acids and other organic acids.

The previous scenario for the origin of the first organic compounds, although once widely accepted, is under increasing scrutiny. Recent evidence suggests that carbon dioxide and nitrogen gas, not methane and ammonia, were the major components of the earth's primitive atmosphere. These conditions are much less favorable for the formation of organic compounds using the Miller/Urey apparatus.

Scientists have begun to look for new explanations of the origin of the first organic chemicals and at older explanations, which are being revived. One of these is that life may have begun deep in the oceans, in underwater hot springs called hydrothermal vents. These vents could have supplied the energy and raw materials for the origin and survival of early life-forms. A group of bacteria, called archaebacteria, that tolerate temperatures up to 120° C and seem to have undergone less evolutionary change than any other living species supports this vent hypothesis.

Another explanation for the origin of the earth's first organic molecules is that they came from outer space. Astronomers are detecting an increasing diversity of organic compounds (such as amino acids and other hydrocarbons) in meteorites that have collided with the earth. Investigations of the most recent pass-by of Halley's comet revealed that comets may be relatively rich in organic compounds. Even though many scientists think that the first organic compounds could have come from space, no microbial life-forms have been detected in space, and conditions in outer space are incompatible with life as we know it.

A second step in the origin of life must have been the hooking together of early organic molecules into the polymers of living organisms: polypeptides, polynucleotides, and carbohydrates. Organic molecules may have become isolated in tidepools or freshwater ponds, and as water was lost through evaporation, condensation reactions could have occurred. Alternatively, reacting molecules may have been concentrated by adsorption on the surfaces of clay or iron pyrite particles, where polymerization could occur.

The final steps in the origin of life are the subject of endless speculations. In some way, organic molecules were surrounded by a membranelike structure, self-replication occurred, and DNA became established as the genetic material. A "chicken-or-the-egg" paradox emerges if DNA was the first genetic material. DNA codes for proteins, yet proteins are required for DNA replication, transcription, and translation. Thomas R. Cech and Sidney Altman suggested a possible way around this paradox in the early 1980s. They discovered a certain type of RNA that acts like an enzyme, cutting and splicing itself into a functional molecule. The first organisms could have been vesicles of self-replicating RNA molecules. Other scientists think that proteins may have been the first genetic material and that DNA was established as the code-carrying molecule secondarily. No self-replicating proteins, however, have been found.

The nutrients produced in the primordial environment would have limited early life. If life were to continue, another source of nutrients was needed. Photosynthesis, which is the production of organic molecules using solar energy and inorganic compounds, probably freed living organisms from a dwindling supply of nutrients. The first photosynthetic organisms probably used hydrogen sulfide as a source of hydrogen for reducing carbon dioxide to sugars. Later, water served this same purpose, and oxygen liberated by photosynthetic reactions began to accumulate in the atmosphere. Earth and its atmosphere slowly began to change. Ozone in the upper atmosphere began to filter ultraviolet radiation from the sun, the reducing atmosphere slowly became an oxidizing atmosphere, and at least some living organisms began to utilize oxygen. About 420 million years ago, enough protective ozone had built up to make life on land possible. Ironically, the change from a reducing atmosphere to an oxidizing atmosphere also meant that life could no longer arise abiotically.