When life began on earth

Recent discoveries have enabled scientists to date important turning points in the early evolution of life

by Louise A. Purrett

More than 23 centuries ago, Aristotle taught that life could arise spontaneously from nonliving matter, transformed by a vital force in the elements of earth, air, fire and water. By Aristotle's time this idea, called abiogenesis, had already been around for several hundred years, and it held for 2,000 more. It was accepted dogma that toads and snakes sprang from moist soil and worms from decaying meat. It wasn't until the middle of the last century that the theory crumbled and was supplanted by the realization that life comes only from pre-existing life.

Yet in a way the proponents of abiogenesis may have been right. Though the condition that only life can generate life has held for billions of years, there must have been a time early in the earth's history when life first began. Many scientists now believe that the ancient precursors of all terrestrial life arose spontaneously from inorganic matter on the primeval planet. Paleobotanists and chemists are now finding out how and when this could have occurred. Several recent findings are particularly intriguing.

Answers to the question of when life began depend on the answer to another question: What is life? The distinction between living and nonliving matter, say some scientists, is arbitrary. In the process of evolution, atoms combined into molecules, molecules formed cells and cells eventually joined together into more and more complex organisms. What point on the continuum from atom to man can we say is the dividing point between living and nonliving matter? There are even a few scientists who talk about "thinking" neutrons and protons. Most scientists consider "life" to be a macromolecule which can replicate, such as a nucleic acid.

In 1936 the Russian biochemist A. I. Oparin hypothesized that the precursors of life—organic molecules—could have formed spontaneously under the conditions believed to prevail on earth billions of years ago. Energy from sunlight, volcanic activity and lightning could have caused the methane, ammonia, water vapor and hydrogen cyanide then in the atmosphere to combine into amino acids, purines and monosaccharides which in turn would form progressively more complex molecules. In a classic experiment in 1953, Stanley Miller, now of the University of California at San Diego, circulated methane, ammonia and hydrogen past electrical discharges. Within a week, a variety of organic compounds had been synthesized.

Since then, a number of researchers have conducted similar experiments. One of them, Cyril Ponnamperuma, now of the University of Maryland, believes that life must have started very early in the earth's lifespan. "People used to think that the primeval elements had to sit around in the ocean for millions of years before something happened. We now know that once the right molecules accumulated at the right time and in the right arrangement, life could begin almost instantaneously. Evolution is what takes time."

Until recently, however, it was not known just how valid these experiments were. The confirmation, says Ponnamperuma, has come only recently, with strong evidence that the Murchison meteorite contains not only amino acids of extraterrestrial origin but also hydrocarbons similar to those produced in the laboratory experiments (SN: 12/5/70, p. 429), and with the discovery of organic compounds in interstellar space (SN: 10/10/70, p. 299). These findings, says Ponnamperuma, "prove, to my satisfaction at least, that chemical evolution can take place elsewhere and that the experiments in the lab are true ones."

In the latest issue of the Proceedings of the National Academy of Sciences, Yecheskel Wolman of the Hebrew University in Jerusalem and William J. Haverland and Stanley Miller of the University of California at San Diego, report that all the nonprotein amino acids found in the Murchison meteorite can be produced by the action of electric discharge on a mixture of methane, nitrogen, ammonia and water. There was also a striking similarity in the relative abundances of the different amino acids in the meteorite and in the lab experiment.

There are more than just laboratory experiments and theories, however. Geological evidence also points to an early origin of life. A substantial number of rocks about 2.5 billion years old have fossil microorganisms. The oldest fossils have been found in the Swaziland sequence, a group of sedimentary rocks in the southeastern Transvaal re-

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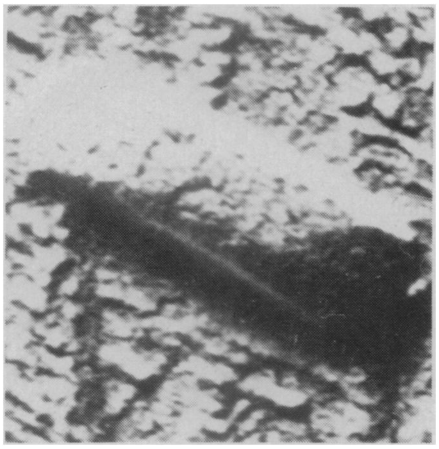
Kvenvolden: South African rock may record the beginning of photosynthesis.



E. S. Barghoorn

Bacterium: Oldest known microfossil.

gion of Africa. Rocks near the bottom of this 64,000-foot-thick sequence have been dated at 3.36 billion years. In an intermediate layer of the series, a group of cherts known as the Fig Tree formation, Elso S. Barghoorn of Harvard University and J. William Schopf, now of the University of California at Los Angeles, have found the oldest fossil organisms to date. These were a rod-shaped bacterium-like organism and spherical microfossils similar to modern blue-green algae. Barghoorn estimates that the surrounding rocks, and therefore the fossils, are about 3.2 billion years old.

Recently, Schopf, Dorothy Z. Oehler, also of UCLA, and Keith A. Kvenvolden of NASA's Ames Research Center found evidence for a major step in the development of life as we know it: the point at which photosynthesis may have begun. Plants carrying out photosynthesis selectively use more of the lighter stable isotope of carbon, ^{12}C, than of the heavy isotope ^{13}C. Organic matter deposited in sediments formed from photosynthetic organisms would thus have a greater proportion of the light isotope than is present in the atmosphere. If the ratio of ^{13}C to ^{12}C in the atmosphere is arbitrarily set at zero, negative values on the scale would indicate greater proportions of ^{12}C. In this way, in sedimentary rocks the isotopic ratios in organic matter produced by living organisms range from minus 20 to minus 40 parts per thousand. This ratio has been found to vary little with time. If ancient rocks could be found in which the proportion of the heavy isotope is substantially greater, they may represent a time predating photosynthesis.

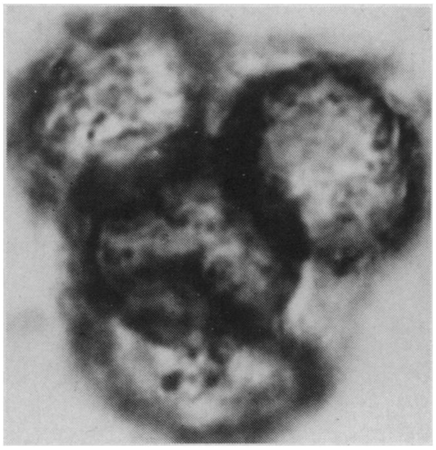
The researchers analyzed the carbon isotope ratios in 39 cherts and limestones from 32 locations in the Swaziland sequence. The carbon isotope ratios for most of the sequence range from minus 25.0 to minus 33.0. At about 3.3 billion years, however, there is a change: Rocks older than that point contain organic matter with a greater proportion of the heavy isotope. Values range from minus 14.3 to minus 18.9. The researchers tentatively conclude that the relatively constant carbon isotope ratios for the period from 3.3 billion years ago to the present means that throughout this time there have been autotrophic organisms, capable of making their own food by photosynthesis. The isotope values found in the rocks older than 3.3 billion years, they point out, are comparable to those of the primordial organic matter found in meteorites.

The researchers add that there are other possible explanations for the change in isotope ratios. Some kind of major geological event may, for example, have altered the distribution of carbon isotopes.

It is believed that there were forms of life capable of reproduction in existence before life forms capable of photosynthesis. These organisms, called heterotrophs, had to depend on the limited supply of organic molecules already present on the earth for food. Autotrophs marked a significant evolutionary advance and are the basis of life as we know it.

The age of 3.3 billion years for the beginning of photosynthesis coincides roughly with another date—the time when whatever event magnetized the moon apparently ended. Some scientists tentatively suggest that there may be a connection. From fossil magnetism in rocks brought back from the moon, NASA scientists have concluded that the moon once had a magnetic field of its own generated by an internal dynamo or acquired by exposure to an external magnetic field, and that the field was active as late as 3.2 billion years ago (SN: 5/27/72, p. 346). They are not sure what caused the field or ended it, but Charles Sonett of the Ames Research Center and others believe the magnetic evidence is consistent with one theory that says the moon was captured by the earth about 3.3 billion years ago. If the moon were a derelict captured by the earth, the interactions between the two bodies, suggests Sonett, would have changed terrestrial conditions. Tidal friction caused by the moon's gravity would have caused terrestrial heating and would tend to de-spin the earth, lengthening its days. These changes, says Sonett, would have affected terrestrial life.

Schopf, however, sees "no real evident relationship" between the beginning of photosynthesis and possible capture of the moon. The origin of the moon is still very much up in the air, he notes, and even if it were captured, the effects on photosynthesis would depend on the conditions on earth prior to that time. If for example the earth were frozen, photosynthesis, which requires liquid water, could not occur. But there is evidence, he says, that water was in a liquid state before 3.3 billion years ago. Nor would slowing down of the earth have any obvious effects on photosynthesis, he says.



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Sexuality 900 million years ago.

Last December, Schopf reported discovery of another evolutionary benchmark—the earliest evidence yet of sexuality. Primitive life forms reproduced by mitosis, asexual reproduction in which a single-celled organism divides to form two duplicate cells, each with the same complete set of chromosomes as the original cell. The next reproductive step was meiosis, in which a cell divides into four cells each with only half the chromosomes that were present in the parent. These cells give rise to gametes which then fuse. The result is a cell with a new combination of chromosomes. Meiosis, says Schopf, "introduced a fantastic increase in genetic variability," with a consequent rapid increase in the rate of evolution.

In the Bitter Springs formation in central Australia, Schopf found packets of four cells in the tetrahedral arrangement that results when meiosis occurs in plants. The surrounding rocks, says Schopf, are about 900 million years old; he estimates that sexuality probably first appeared about a billion years ago. "This is just at the right time in terms of evolution. Prior to that time, everything was very primitive and evolution was slow. Between that time and about 600 million years ago, there was a great increase in the rate of evolution."

Though these major evolutionary turning points have been fairly well dated, the major questions are still open: When and where did life begin? At this point, scientists know only that life appeared on earth at least 3.5 billion years ago. There is even some question as to whether life actually originated on the earth. The discovery of formaldehyde in the Allende meteorite (SN: 4/8/72, p. 231) suggests that the seeds of life could have come from life existing elsewhere, which resurrects the ancient question of abiogenesis. ☐