The Oldest Fossil Evidence of Life

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Birth of a new field of Paleontology

As with so many other aspects of natural science, Charles Darwin stated the problem:

"If the theory [evolution] be true it is indisputable that before the lowest Cambrian stratum was deposited ... the world swarmed with living creatures. [Yet] to the question why we do not find rich fossiliferous deposits belonging to these earliest periods. . . I can give no satisfactory answer. The case at present must remain inexplicable."

When Darwin published this passage in 1859, the broad outlines of Phanerozoic evolution, the most recent 550 Ma (million years) of the history of life, were already well defined. But the earlier and decidedly longer Precambrian fossil record was *terra incognito*. It was not until a century later, in the mid 1960s with the birth of a new field known as Precambrian paleobiology, that this earliest "missing" fossil record began to be uncovered.

Search for the missing fossil record

Darwin was right — during the Precambrian, the earliest 85% of Earth history, the world did swarm with life. But Darwin also was wrong. He thought that the methods used to search for fossils in younger rocks would bear fruit in the Precambrian as well. In Phanerozoic strata, fossils can be found simply by splitting rocks and examining their surfaces. Not so for the Precambrian. Except for the last few hundred million years of this vast sweep of geologic time, Precambrian life forms were all too small to be seen without a microscope.

The hunt for Precambrian fossils is carried out in the laboratory, using a high-powered microscope, not in the field. Two techniques are especially useful. In one, extremely thin slivers ("petrographic thin sections") of fossil-bearing rock are cemented onto glass microscope slides and scanned to discover tiny three-dimensionally petrified fossils entombed in the mineral matrix. This is a reliable technique. Because the fossils are embedded within the rock there is no chance for them to be confused with contaminants. But it is also tedious and time-consuming. A faster method is to concentrate the fossils by dissolving the rock in mineral acid. Acid-resistant organic-walled fossils are abundant in the sludge-like "palynological maceration" which can be slurried onto a microscope slide for study.

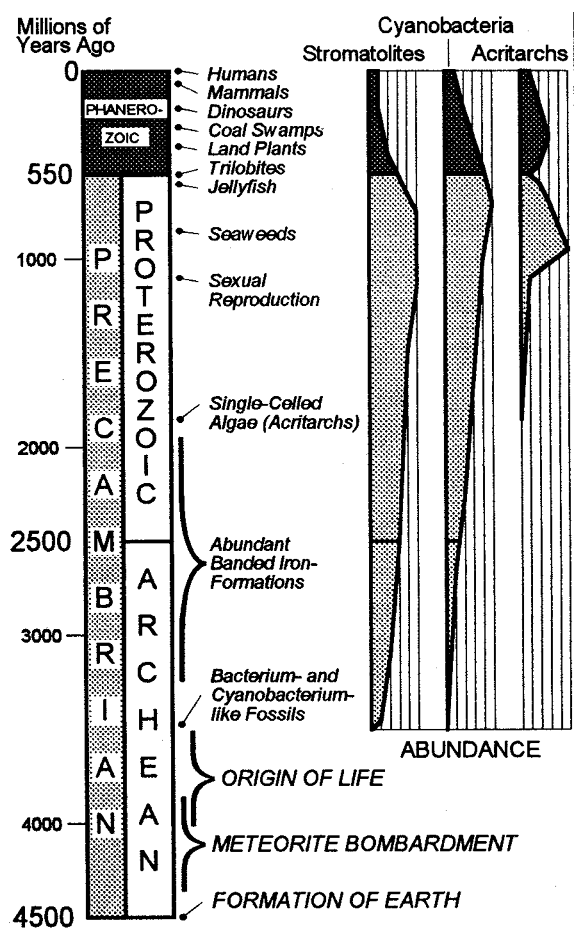

Figure 1. Explanation of Symbols and Abbreviations
Ma = million years
µm = 1 micrometer (micron)
1000 µm = 1 mm (millimeter)

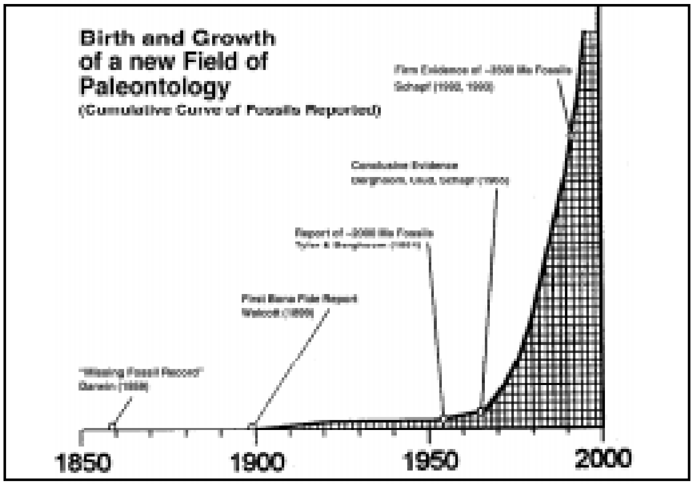

Figure 2. Birth and growth of a new field of palentology. (Cumulatige curve of fossils reported).

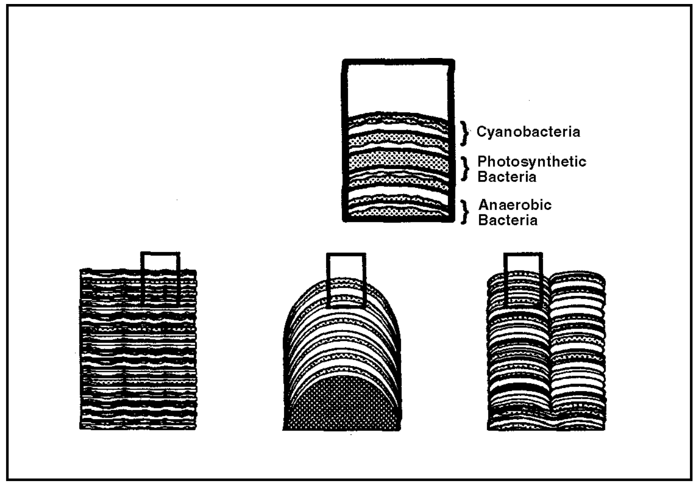

Figure 3. Types of Stromatolites. A. Upper Layers of stromatolites 1. Cyanobacteria, 2. Photosynthetic Bacteria, 3. Anaerobic Bacteria, B. Flat-Layered, C. Domical, D. Columnar

Stromatolites

A major breakthrough came in the mid-1960s when it was recognized that thinly layered centimeter- to meter-sized rock masses known as stromatolites can be richly fossil-bearing. To the stratified microbial menagerie that builds such structures, stromatolites are rather like high-rise apartment houses: Light- using photosynthetic cyanobacteria and other oxygen- consuming (aerobic) microbes occupy the penthouse floors; beneath these, on the upper floors, are photosynthetic bacteria (that rely on dim light that seeps through the cyanobacterial layer above) and other microbes (facultative aerobes) that consume oxygen if it is present but can survive in its absence as well; and the lower floors and basement are inhabited by strict anaerobes, bacteria for which oxygen is a deadly poison.

Mineral debris accumulates on the uppermost layer, and the whole structure can become lithified. The shape of a stromatolite reflects its environment — flat-layered forms are typical of quiet water settings whereas mound-shaped and columnar types occur in regions of turbulent wave action. Stromatolites are very common in Precambrian limestones, rocks made up of the mineral calcite, but the best microsopic fossils occur in stromatolites that have been petrified by fine grained quartz, silicified like the logs of a fossil forest.

Cyanobacteria

Because cyanobacteria inhabit the upper, most commonly silicified layers of stromatolites, they can be preserved in profusion. The early fossil record of these microbes is therefore exceptionally rich, and virtually all types of living cyanobacteria are known also from Precambrian strata. Like their modern relatives, the fossils come in a wide variety of shapes — single cells, colonies of cells, and twisted cellular filaments, some enclosed by gelatinous tubes.

As a group, cyanobacteria have survived for literally billions of years. The success of these tiny microorganisms comes from their capability to thrive almost anywhere - in acid hot springs, alkaline lakes, salty brines, ice fields, oceans, deserts, forest floors, even in crevices within rocks. Their influence on the environment has been truly remarkable, for cyanobacteria are the organisms that invented the process of oxygen-generating photosynthesis, the biologic engine that powers the living world. Their fossil record can be traced to nearly 3,500 Ma ago — about three-quarters the age of the Earth — but the oxygen they pumped into the oceans of that time could not build up. It was scavenged by mineral-forming chemical reactions that produced a rusty rain that fell to the ocean floor to form rocks known as banded iron-formations. Cyanobacteria “rusted the world,” and it was not until a billion or more years later, after the iron was used up, that an oxygen- rich atmosphere finally became established.

Acritarchs

Single-celled planktonic algae known as “acritarchs” (from the Greek word *akritos*, meaning confused or uncertain) are so named because their relations to living groups of algae are difficult to determine. They are abundant in offshore Pre-cambrian shale deposits, so there is no doubt that they lived as floating phytoplank-

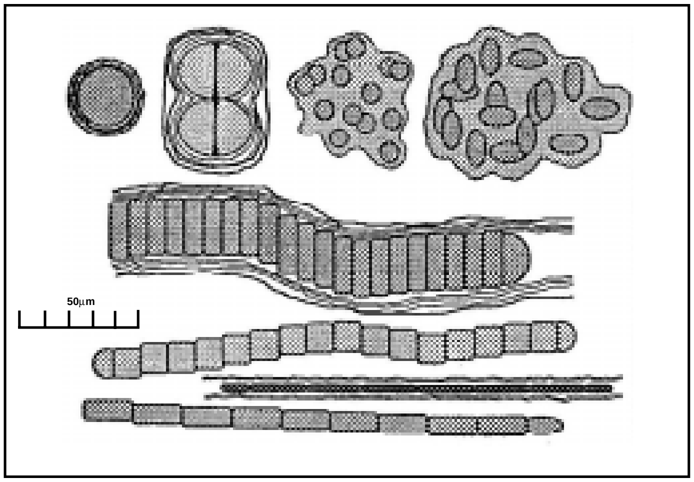

Figure 4. Cyanobacteria, coccoidal, ellipsoidal, and filamentous

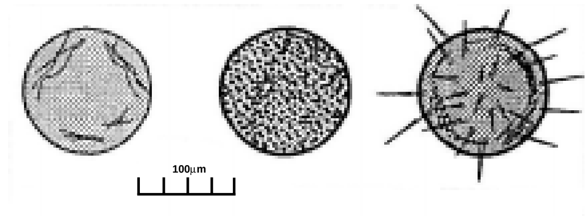

Figure 5. Spheroidal and Spiny acritarchs

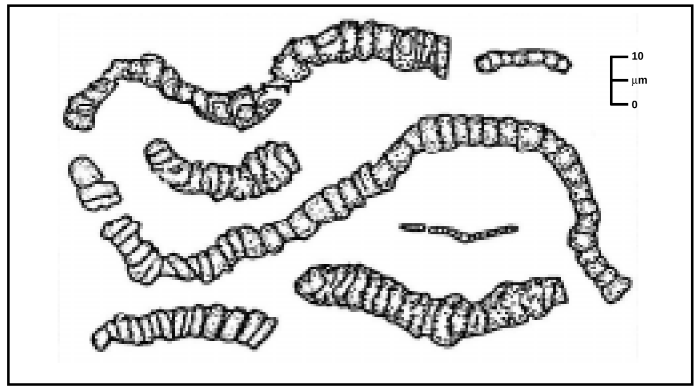

Figure 6. ≈3500 Ma Apex Fossils

ton, but whether they were red algae, green algae, or members of some other group is uncertain. Most are many tens to hundreds of microns in size, much larger than single-celled cyanobacteria, and many are rather complicated, having spines and other types of elaborate structures protruding from their surfaces.

Like other types of algae, acritarchs were both oxygen-producing (photosynthetic) and oxygen-using (aerobic). They are known earliest in rocks deposited 1,850 Ma, near the time that oxygen first became plentiful in the atmosphere. Their subsequent evolution was lethargic. Only a few types of simple sphere-shaped acritarchs are known until about 1,100 Ma. These forms were probably non-sexual, unable to take advantage of the variation inherited by offspring in sexually reproducing forms of life. 200 Ma later, however, the group “exploded” — perhaps due to the invention of sexual reproduction .- and by 900 Ma many new types appeared. Because these forms evolved rapidly, older deposits contain different types of acritarchs than those found in younger strata. Late Precambrian acritarchs can therefore be used in “biostratigraphy,” a branch of paleontology in which fossils are used to determine the relative age of the rock units in which they occur.

When did life begin?

The origin of life cannot be dated precisely. However, the oldest fossils known microscopic cellular filaments petrified in the Apex chert of Western Australia — provide a minimum date: Life was present at least 3,500 Ma.

The record-setting Apex fossils are cyanobacterium-like microbes, organisms far too complicated to have been the first forms of life, so the origin of life must have occurred much earlier. Just how much earlier, however, can only be guessed. And the window of opportunity may have been rather small — only a few hundred million years in duration — because up until about 3,900 Ma the Earth was being blasted by incoming meteorites, some evidently powerful enough to have vaporized the world’s oceans. Living systems may have been present earlier than 3,900 Ma ago, even perhaps originating many times, but all such life forms would have been wiped out as meteorite bombardment sterilized the planet!

• How and when did life gain a foothold on our planet?

• How far into the remote geologic past can the fossil record ultimately be traced?

• How did evolution in its embryonic stages proceed so far, so fast, so early?

These fundamental questions are being asked for the first time by Precambrian paleobiologists, scientists investigating an exciting new field of paleontology.

Suggested Reading

The following nontechnical articles and books may be available at your local library, and should be available at many college and university libraries.

The evolution of the earliest cells, by J. W. Schopf. In: *Scientific American*, pages 110-138. March, 1978.

End of the Proterozoic Eon, by A. H. Knoll. In: *Scientific American*, pages 64-73. October, 1991.

The oldest fossils and what they mean, by J. W. Schopf. In: *Major Events in the History of Life* (edited by J. W. Schopf), pages 29-63. Published by Jones and Bartlett Publishers, Boston. 1992.

Metabolic memories of Earth's earliest biosphere, by J. W. Schopf. In: *Evolution and the Molecular Revolution* (edited by C. R. Marshall and J. W. Schopf), pages 87-1 15. Published by Jones and Bartlett Publishers, Boston. 1995.

More technical discussions can be found in the following articles and books available at many college and university libraries.

Earth's Earliest Biosphere, Its Origin and Evolution (edited by J. W. Schopf), 543 pages. Published by Princeton University Press, Princeton NJ. 1983.

The Proterozoic Biosphere, A Multidisciplinary Study (edited by J. W. Schopf and C. Klein), 1348 pages. Published by Cambridge University Press, New York. 1992.

Microfossils of the Early Archean Apex chert: New evidence of the antiquity of life, by J. W. Schopf. In: *Science*, Volume 260, pages 640-646. April 30, 1993.

Disparate rates, differing fates: Tempo and mode of evolution changed from the Precambrian to the Phanerozoic, by J. W. Schopf. In: *Proceedings of the National Academy of Sciences USA*, Volume 91, pages 6735-6742. July 1994.

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