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S. Awramik: PRECAMBRIAN EVOLUTION AND THE ROCK RECORD

Precambrian time refers to geological time prior to the first appearance of animals with mineralized hard parts (see Fig I-2.5 for geological time scale). Best estimates for this event are around 570 million years ago. Because the rock record begins some 3,800 million years ago the Precambrian encompasses about 84 percent of geologic time. The fossil record for this immense span of time is dominated by prokaryotes and the sedimentary structures produced by them. The first fossil remains that can confidently be considered eukaryotic are found in 1,000 million year old rocks. The first animals may be as old as 700 million years.

Like life, the Earth has changed through time. An understanding of the interrelationship between the physical evolution of the Earth and its life is one goal of paleontology. During the Archean Eon (3,800 to 2,500 million years ago) solar luminosity was lower than at present yet surface temperatures of the Earth were not unlike those of today. Free atmospheric oxygen was absent, the crust of the Earth was thin, and there were higher geothermal gradients. There existed a preponderance of tectonically short-lived but active marine basins. Around 2,500 million years ago, at the beginning of the Proterozoic Eon, some major changes occurred on the Earth. The crust became thicker and continents emerged above wave base on a larger scale. Intercratonic troughs became common, as did extensive, shallow marine environments with mature, multicycled sediments. Around 2,000 million years ago, significant quantities of free oxygen appeared in the atmosphere and, about 1,500 million years ago, the tectonic style began to change over to a regime that resembled modern plate tectonics with large scale horizontal plate motion. The quantity of oxygen as O_2 increased in the atmosphere though the quantitative details are not known. Extrapolating from the metabolic needs for oxygen by all animals it is inferred that by 700 million years ago, the time the first animals appeared, at least 10 percent of the Earth's present atmospheric level of O_2 was already achieved. No physical or chemical signals have been identified that corelate with the explosion of metazoan evolution at the Precambrian-Cambrian transition.

The oldest fossils are those from the 3,500 million year old Warrawoona Group in Western Australia and the Swaziland Supergroup in South Africa. Organic-walled, micron-sized filaments have been preserved three dimensionally in chert, a cryptocrystalline form of quartz. The chert is laminated and this lamination may have been produced by microbial activity. Stromatolites are organosedimentary structures usually found in the form of laminated rocks. Produced by sediment trapping, binding and/or the precipitation activities of microbial communities, stromatolites are known from both the Warrawoona and the Swaziland rocks. The presence of stromatolites indicates complex microbial activity; presumably photoautotrophic bacteria were involved. The fossilized communities of microbes are of such simple morphology that little can be said about them. The fossil record for the remainder of the Archean Eon is spotty, with only a few

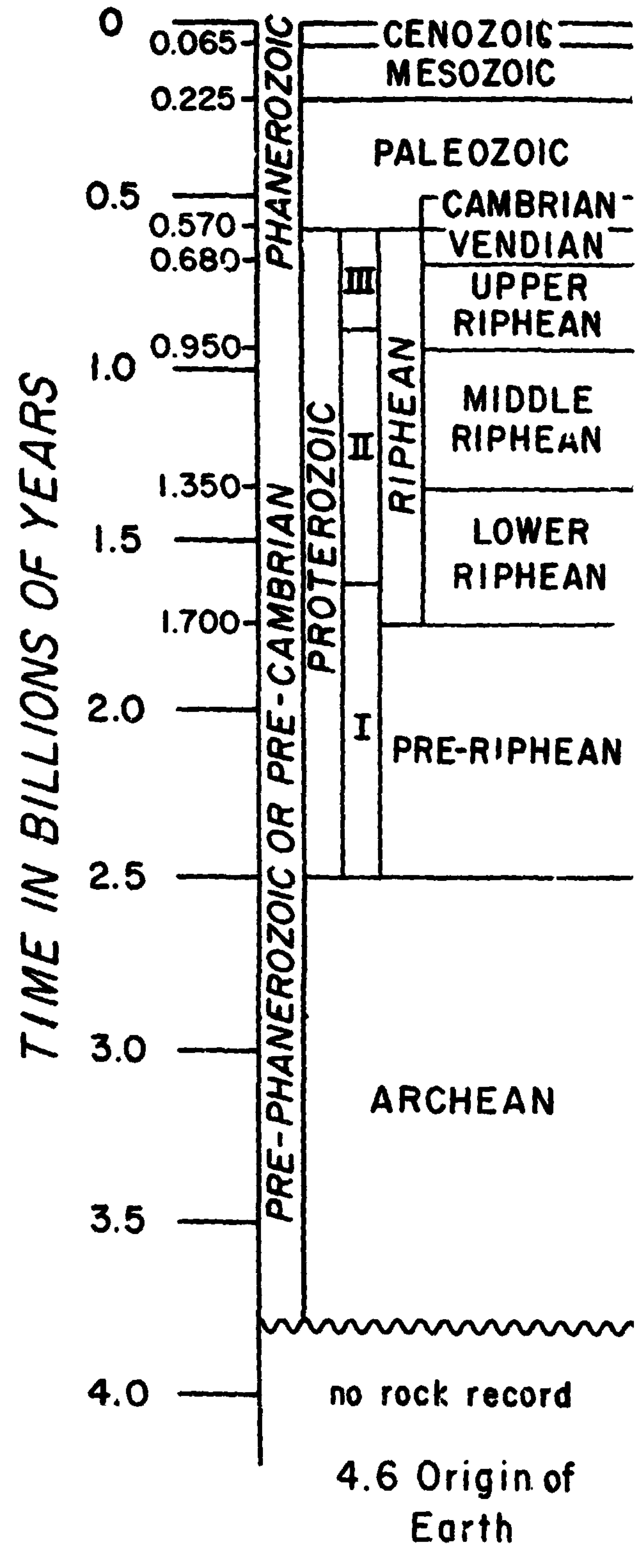

Figure I-2.5. Geological time scale.

good examples of microfossilization. Eventually stromatolites become more noticable in shallow water in tectonically inactive geological environments. By the early Proterozoic, stromatolites become abundant and exhibit diverse and complex morphologies.

A major benchmark in the history of life is recorded by the fossils of the 2,000 million year old Gunflint Iron Formation of Lake Superior, Canada. Well-preserved, abundant and diverse microfossils are found in both stromatolitic and non-stromatolitic cherts. Fossils resembling modern coccoid and filamentous cyanobacteria as well as iron-oxidizing bacteria are common. Bizarre forms of uncertain taxonomic affinity are well represented in the Gunflint. The first plankters are also found in the Gunflint Iron Formation. So, by 2,000 million years ago, stromatolite-building microbes were diverse and plankton had appeared. Generally speaking, early Proterozoic microbes of the Gunflint and other formations were small (less than 10 um in diameter) and dominated by cyanobacteria-like forms.

Stromatolitic fossil microbes throughout the remainder of the Proterozoic Eon show a tendency towards increased size and morphological complexity. Unlike many modern stromatolites, multitrichomous filaments are very rare. Yet, by the middle and late Proterozoic Eon stromatolitic microbiotas had become surprisingly "modern" in appearance. The diversity of carbonate stromatolites increased markedly during this interval. Stromatolites reached the height of their morphological complexity by about 800 million years ago. Then, from 680 to 570 million years ago, stromatolite diversity sharply decreased. The number of Proterozoic stromatolitic microfossil localities is few, somewhere in excess of 200, but there are thousands of stromatolite localities that do not contain any preserved microfossils.

The first abundant remains of plankton are found around 1,000 million years ago in clastic rocks. These microfossils, which have acid-resistant organic walls, measure from a few to several tens of microns in diameter. Most researchers agree that these microfossils are remains of eukaryotic plankton. Microfossils show an increase in diversity throughout the remainder of the Proterozoic, undergoing some extinctions during the latest Proterozoic (700 to 600 million years ago). Eukaryotic microbes apparently diversified rapidly again in the earliest Cambrian time.

The fossil record of Precambrian life is not representative of all habitats and groups of organisms; there is an obvious bias towards organisms with the greatest preservation potential. Benthic cyanobacteria and cyanobacteria-like microbes within microbial mat habitats had the greatest potential to be preserved. Other prokaryotes are exceptionally rare. Only the form of the microorganism is preserved, and in most cases, this form has been altered by fossilization. Assigning affinities, primarily based on morphological comparisons with modern analogs, involves guesswork. Yet the original reports on the microfossils of the Gunflint delivered 30 years ago by Barghoorn and Tyler were greeted by much skepticism.

Seminal papers did not appear until 1965. The fossil record of the first 84 percent of Earth history is just beginning to become understood and has not come close to reaching its full potential.

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