Early Archaean life in deep-sea hydrothermal ecosystem

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For many years, the beginning of life on earth during the Archaean period (3800–2500 m.y. ago) had remained an 'enigma clothed in mystery' and had provided considerable grist for speculation and debate. In the earlier half of twentieth century, the term Archaean was a synonym for 'Azoic', meaning lifeless, but over the last fifty years, this perception has changed after discoveries of primitive life forms during this period. In the wake of several reports about such discoveries, new theories on the probable origins of life on earth emerged. Apart from terrestrial pathways (endogenous origins), the proposed theories included extraterrestrial routes also (exogenous origins) based on evidences from objects that had fallen from outer space, but the views about their influence on evolution of life somehow remained in oblivion. However, with advances in remote and *in situ* observations on orbiting objects in the solar system, many prebiotic organic compounds in galactic space, interplanetary dust, comets, meteorites and asteroids came to be recognized[1–3]. Following the spate of recent studies on a meteorite of Martian origin, pointing to possible life on Mars[4], interdisciplinary research on cosmic connection to early life received a great boost. Presently, viability of both terrestrial and extraterrestrial routes continues to be debated, though there is a general agreement that life on earth, whether in a hot or cold setting, emerged first in the oceans[5–8].

Very early life forms in Archaean or pre-Archaean times were called *prokaryotes* – bacteria and single-celled archaea lacking nucleus and these led to development of *eukaryotes* with cells and nuclei, much later during late-Archaean. In the absence of recognizable fossils, the existence of such early life has been inferred mostly from biogenic carbonaceous inclusions, oil and bitumen found occurring within minerals of this period[9–12]. Oldest evidence of life that had lived within a little more than half-billion year after earth formed 4.5 b.y. ago comes from the banded iron formation (BIF) belonging to the Isua supracrustals in Greenland. This has been inferred from graphite inclusions having biogenic C-isotope signature, found locked within apatites (fluorophosphate of calcium) occurring in these BIFs that had formed 3.8 b.y. ago[13]. The parent organisms, apparently primitive cyanobacterial forms, must have lived much before the crystallization of these apatite grains. Direct evidences, as microfossils, scarce during this period, became abundant only after late Archaean and younger geological periods. Some of these life forms, a little more evolved, lived in communities by building layered organo-sedimentary structures, mats of cell filaments, by trapping and binding mud and other sediments. These are the well-known stromatolites (dome-shaped structures) and oncolites (rounded structures). The cyanobacteria and a few other early forms, the precursors of higher animals, are seen even today as living fossils flourishing in diverse marine environments – shallow to deep sea, sunlit oxygenated zones to dark anoxic depths as well as cold and dark ocean bottom to hot submarine volcanic environs. Many of the early organisms that lived in shallow depths or the surface of sea derived their energy through photosynthesis. In course of time, other types like the non-photosynthetic heterotrophs that thrived on organic molecules in the dark anoxic depths and, likewise, autotrophs that manufactured their own organic nutrients out of inorganic substances and similar variants adapted to different Precambrian (4500–544 m.y.) marine environments came to be discovered.

While the dawn of Cambrian period (600–500 m.y.) witnessed an explosion of multicellular forms of life[14], geological evidences about their Precambrian predecessors were scarce. With advanced optical tools aiding their search, microscopic primitive life belonging to the latter age also could be found from a number of localities around the world[9,15–24], including India[7,12,25–28] (Table 1). The Indian occurrences are reported from Archaean strata in southern, eastern and central parts of the country. A recent study of graphites from > 3.0 b.y. Dharwar and Sargur supracrustals in southern India has shown them to be biogenic[12] and, graphites from the adjoining Kolar Schist belt, as derived from methanogenic and methylotrophic microorganisms[12]; stromatolites have also been reported from Sandur Schist belt[25] here. Similar primitive forms were noted in the iron formations at Bonai, in Orissa[7], and recently from Bailadila in Madhya Pradesh, filamentous unicellular forms were recognized in > 3.0 b.y. rocks[28].

Systematic ocean bottom surveys undertaken over the years have revealed unusual habitats for bacterial colonies and other organisms – regions of extreme temperatures (130–175°F) prevailing around present-day hydrothermal volcanic vents and deep-sea mid-ocean ridge systems, where superheated waters carrying sulphur and associated metals gush out. Most of this life happens to be extremely simple primitive forms of bacteria (archaeobacteria). Known as hyperthermophiles or chemolithotrophic microorganisms, these forms met their energy requirements through chemosynthetic reactions involving S, C, and Mn compounds available in the surrounding waters[5,29]. Though vent ecosystems were extensive in Archaean oceans, existence of such primitive thermophilic forms of life has not been discovered so far from the rocks of this age. A breakthrough has been achieved and such heat-loving forms are now reported from Sulphur Springs, a locality forming part of the early Archaean Pilbara craton in Western Australia[20]. These new findings are cyanobacterial filaments from a 3235 m.y. old deep-sea volcanogenic massive sulphide (VMS) deposit made up of sulphides or sulphates of Fe, Cu, As, Zn, Pb and Ba, formed by replacement of volcanic and volcaniclastic rocks. The filamentous microfossils (0.5–20 μm diameter, up to 300 μm long) were non-photosynthetic, anaerobic forms and, as indicated by their replacement by submicroscopic pyrite (FeS_2), derived their energies through reactions involving sulphur[20], abundantly available in the heated waters gushing out of the hydrothermal vents in the ocean bottom.

With the current report of these Sulphur Springs organisms that had lived in a hot hydrothermal habitat, the domains of Archaean life have expanded and, more