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Mini Review

Earliest Life Forms and their Mineral Associations in 3.5Ga Old Rocks

Miryam Glikson*

University of Queensland, Australia

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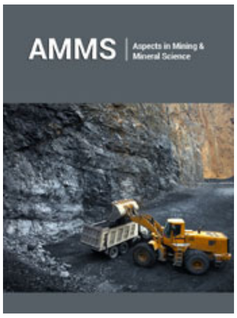

***Corresponding author:** Miryam Glikson, University of Queensland, Australia

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Abstract

3.5Ga rocks in Western Australia and South Africa were in the past and are presently the target for remains of early life forms. Earliest field observations reported Stromatolites. The presence of photosynthesizing life forms in some earliest Archaean rocks is generally debated. The absence of oxygen in the Archaean atmosphere and Archaean oceans has likely supported anaerobic primitive Archaea such as found today in and around sea-floor Hydrothermal environments. These environments were created by intense meteorite bombardment of early Earth, and are believed by most recent researchers of life's beginnings to have been the ideal environment for the synthesis of building blocks of life forms due to concentration of dissolved essential elements, the building blocks for encapsulation of a vesicle to start a cell of an organism in a warm environment. The earliest life forms described in the literature are associated with meteorite-impacted sediments, which may not be entirely accidental. It is debated as what was the precise influence of meteorites on cell formation or indeed whether there is any direct connection. It is agreed that hydrothermal environments where early life is believed to have begun were formed by meteorite impacts. Some microstructures resembling microbial cells observed in meteorites were reported as fossil microbes. Distinction between biogenic versus abiotically formed microstructures is a major obstacle in addressing the issue of earliest life forms.

Keywords: Archaean Eon; Pilbara craton; Barberton greenstone belt; Dresser formation; Apex basalt

Introduction

This review was triggered by a recent revival of interest in earliest life on Earth with the publication of several books by well-known researchers. Most recently; 'The Oldest Rocks on Earth' by Simon Lamb; 'Early Life on Earth' by Sugitani, another book 'Earth and Life'; a history of 4 billion years by Nedelea, and the reprint of Wace's book 'Early Life on Earth'; and yet another book; 'A Brief History of The Earth': 4 billion years of history' by A.H. Knoll. Thus, origin of life on Earth and earliest life forms have been and still are topics of interest to scientists and the wider community since the publication of Darwin's 'On the Origin of Species 'in 1859. Darwin appreciated that the earliest life forms were most likely to have been primitive microbes what are referred today as Archaea. Most Scientists today are in agreement that the first forms of life on Earth were simple anaerobic chemoautotrophic microbes such as are found today in niches of extreme marine habitats in seafloor hydrothermal systems. These systems developed on Earth as soon as liquid water accumulated following the early Earth crust formation from chondritic mantle [1] hand in hand with intense meteorite bombardment [2,3] and the creation of hydrothermal environments. Remnants of some of these rocks are found today in the Pilbara craton of Western Australia and the Greenstone Belt of the Kaapvaal Craton of South Africa. These rock formations were dated at 3.58 b.y. and have been in the past and present the target in the search of first life forms on Earth. Earliest field observations reported Stromatolites.

Mini Review

The presence of photosynthesizing life forms in some earliest Archaean rocks is generally debated. The absence of oxygen in the Archaean atmosphere and oceans is likely to have supported anaerobic primitive Archaea such as found today in Hydrothermal environments. These environments were created by the intense meteorite bombardment of early Earth and are believed by most recent researchers of early life to have provided the ideal conditions for the synthesis of building blocks for encapsulation of a cell as a start of a of life forms due to the concentration of dissolved essential elements in a warm environment. The presence of earliest life forms described in the literature seems to be associated with meteorite impacted sediments. It is debated as to what exactly was the influence of meteorites on cell formation or indeed whether there is any direct connection. It is agreed that the formation of hydrothermal environments where early life is believed to have begun were the product of meteorite impacts. Distinction between biogenic versus abiotic carbonaceous micro-structures is a main problem facing search for microbial remains in earliest rocks on Earth. Several reports of microbial-like forms [4] isolated from Archaean cherts impacted by meteorites proved to be abiogenic cell-like structures identical in morphology to such as have been reported from meteorites. The main question is how to distinguish between biogenic earliest life forms and abiogenic carbonaceous microstructures.

Discussion

The early search for life in the ca3.5Ga old rocks in Western Australia and in South Africa was focused on field observations and lookout for structures reminiscent of known life forms. Earliest field observations reported Stromatolites in the Pilbara Craton [5,6] and more recently by [7]. The presence of Stromatolites in early Archaean rocks has been debated. The organisms that produce such structures are photosynthesizing and live today in relatively shallow marine environments. It is not possible to pin-point the exact timing of presence of Oxygen on Earth but most recent research shows that Oxygen appeared in the atmosphere before it was absorbed by the oceans at 2.3Ga [8]. Structures attributed to stromatolites therefore may be explained as mineral precipitates. These are often suggested as fossil-like entities mimicking biological forms and are not uncommon as end products of cooling saturated solutions of calcite or silica. Mineralized fossil-like forms have been reported from the Martian meteorite ALH84001. The characteristics of these forms are the uniformity in shape and precision in repetitive parts; their biological invalidity has been outlined by [9] and expressed as "self-organizing structures that do not pass the test for biogenicity". The superficial resemblance of structures in the 3.58Ga Barite-chert rocks in the Pilbara to Stromatolites can therefore be misleading. 'Stromatolite'-like structures are seen in the Archaean rocks of Pilbara and Kaapvaal as finely laminated light and dark undulating, wrinkled and folded or just concentric circular mineralized features.

Following some of these structures (towards ground level at the time of deposition) the laminations straighten out and become parallel fine light and dark bands, a typical occurrence today around hot springs and sinter deposits. Study by Lowe DR [10] explained the domal appearance of some of these structures in the 3.5Ga Warrawoona Group rocks in Western Australia and the 3.5Ga Onverwacht Group in South Africa as the result of 'soft sediment deformation of originally flat layers. These kind of structures in sediments may form when hydration of a mineral had occurred, such as for example the anhydrite of the Dead Sea marls (illustrated by Glikson [11]. In the Dead Sea marls the anhydrite was converted to gypsum. In the case of silica and iron precipitates, hydration of the silica or/and oxidation of the iron may bring about changes in volume resulting in contortions and distortions in the form of wrinkles and folds, as seen in terrestrial hot springs. True bioherm -building Stromatolites came later (2.5Ga) as observed in sediments of the Transvaal Supergroup and the Isuzu Groups of South Africa and Zimbabwe and the Fortescue Group in Western Australia [12]. Presented in the pioneering work of [13] in TEM (Transmission Electron Microscopy) observations of microfossils from the Late Precambrian of the Bitter Springs Formation of Australia. The search for early life has since focused on microscopical observations of rocks from the Pilbara craton in Western Australia and the Greenstone Belt of South Africa.

Microscopical and sub-micron size carbonaceous fossils have been the focus of most research of earliest life on Earth in Archaean rocks in the past 20 years. Archaean ocean water was very different from today's oceans, with high levels of dissolved iron and silica from hydrothermal vents and no oxygen; water being significantly hotter than today's sea water, as indicated by Oxygen isotopes of Archaean sediments [14]. These conditions could naturally sustain most simple organisms such as Archaea which thrive today at high temperature of up to 90 degrees C. around hydrothermal vents on the sea floor.

Fossil microbial forms were reported from the 3.5Ga Dresser Formation chert-barite deposit within the Warrawoona Group in the Pilbara [15] from samples collected by Roger Buick. These entities were further described in detail by Buick R et al. [16]. Glikson & Taylor noted the metal content of their outer encasing, predominantly iron sulphides or Barium Zn sulphides which would have enhanced their preservation. The Dresser Formation (c.3490Ma) chert-barite units formed in a seafloor hydrothermal system similar to today's white smokers [17]. Microbial remains encapsulated in silica were observed and isolated from these rocks [17,18]. The ca 3.5Ga black cherts of the Pilbara craton of Western Australia and the Barberton Greenstone Belt of the Kaapvaal Craton of South Africa yielded carbonaceous remains which in TEM displayed images of microbial cells and bundles of microbial cell walls.

The fossil forms were compared to the potential modern analogue, the hyperthermophile archaeon *Methanocaldococcus jannaschii* derived from an active hydrothermal environment and subjected to high temperature, in simulated conditions of the Archaean- sea. The organic remains of *Methanocaldoccocus* obtained from the experiments and observed in TEM were identical to the organic remains derived from the rock samples of the Dresser Formation and the Barberton Greenstone belt after their demineralization and removal of silica that encapsulated the carbonaceous remains in the whole rock sample. The residue from the heated experimental samples demonstrated the resilient nature of the thermophiles that died at 90 deg. C and disintegrated at 132 deg. C. The strong presence of silica in the whole rock samples is not accidental; it was a common effluent in the hydrothermal systems of the early oceans. It was noted by Westall et al. [2] that silica-gel was an important pathway for concentration of prebiotic molecules. The striking resemblance of the remains of the Archaeon *Methanocaldococcus* to the microbial remains from the Archaean of Western Australia and South Africa provide the strongest evidence of earliest primitive microbes.

Chert from the c.3474-3459 Ma Apex basalt, Salgash sub-group of Western 21, yielded graphitic carbonaceous material [19,20]. The difference between the Apex graphite and standard graphite mineral is the pronounced absence of bi-reflectance in the Apex material. Very rapid heating of carbonaceous matter may lead to high reflectance without optical anisotropy. Spheroidal micro structures and multi-layered tubes in this chert are consistent with Fullerenes [21]. No microbial remains would survive the high temperature that the Apex basalt was subjected to [21]. The Apex Basalt, perfect spheroidal micro- structures [22] of varying sizes and displaying 'budding' in some are identical to micro-structures observed in TEM of the Allende meteorite [23] and the Lake Tagish meteorite [24] carbonaceous matter. [25] suggested an extra-terrestrial origin for some Strelley Pool carbonaceous remains. These carbonaceous remains were subject to temperatures exceeding 1000 degrees C, are therefore evidence to the abiotic formation of carbon-based structures resembling microbial cells.

In contrast, biologically produced cells undergo thermal degradation leading to their breakdown and disintegration at temperatures of 100 degrees C; marking the limit of life as demonstrated experimentally [17,18]. A detailed analytical study by [19] disputes a biological nature of the carbonaceous structures of the Apex Basalt and explain that the Apex Basalt carbonaceous matter shares spectral similarities with abiotic organic residue from chondritic meteorites. Multiple meteorite impacts have been reported [3,26] for the Apex basalt and the South African equivalent, the Hoegenog Formation in the Kaapvaal Craton. De Gregorio et al. suggest that the Strelley Pool (3.426-3.350Ma) carbonaceous matter on the other hand may represent the thermally degraded biogenic remains of microbial communities that lived around hydrothermal vents. Study by Sugitani et al. [25,27] of Strelley Pool carbonaceous matter closely resembles De Gregorio et al's 'kerogen' recognised filamentous and other micro structures suggestive of remnants of thermally degraded microbial remains, that have been swept towards the high temperature parts of the hydrothermal system. The same study described in detail the various clumps of carbonaceous matter as circular, spindle-shaped and thread-like bundles. Both studies; that of DeGregorio et al. [19] and Sugitani et al. [25] were subjected to rigorous analytical methodologies. The probable biogenic carbonaceous matter derived from dike-like cherts in both studies appear in similar shapes, namely strings, clots of varied shape and carbonaceous matter surrounding quartz grains. The wide temperature range reported for organic remains in the Dresser Formation [17] supports mixing of organic remains in a temperature-varied hydrothermal vent environment.

There are two main kinds of black chert deposits in the Apex Basalt with different geological-depositional history and very different characteristics: Stratified cherts and cross cutting carbonaceous cherts were reported by Hofmann [28] from the Barberton Greenstone belt. The carbonaceous remains reported by both studies, namely that of DeGregorio et al. [19] & Sugitani et al. [25] have been isolated from a cross -cutting dike chert. It is a chert unit brecciated, siliceous crosscutting the Apex pillow basalts that yielded the carbonaceous remains. De Gregorio et al suggest a hydrothermal origin for the carbon-rich dike chert, a natural habitat today for primitive microbial communities. The West Australian Apex deposit and the South African age equivalent rocks were subject to intensive meteorite bombardment (Byerley et al.).

The findings of extra-terrestrial carbonaceous matter in some cherts and terrestrial biogenic carbonaceous organic matter in the same geological formation highlight the need for detailed fine-tuning analysis of the chert sampling techniques. The relationship of the various and numerous chert units to the basalt is complex due to the meteorite impacts. The presence of biogenic degraded microbial remains and chondritic meteorite micro structures in the Strelley Pool same chert may only be explained by mixing of impacted sediments with preserved hydrothermal deposits.

Conclusion

Methodologies and experiments adopted in analyses of carbonaceous remains in Archaean rocks of Western Australia and South Africa present the rare remains of microorganisms of undisputed biogenicity. Clearly morphologically outlined micro structures that retain a microbial shape are represented by the carbonaceous remains resembling the archaeon *Methanocaldococcus janaschii* derived from the Dresser Formation in the Pilbara Craton and equivalent formation in South Africa are unique. With the exception of these Archaea, the scarcity of undisputed identifiable microbial remains in earliest sedimentary rocks on Earth may be explained by the chance and time it takes for basic building blocks of cells such as dissolved H_2, CH_4 to slowly be encapsulated within clay or sulphur bubbles into vesicular cell-like entities [29]. compared the conditions in Archaean hydrothermal systems to the modern 'Lost City' hydrothermal field where the basic material for cell formation is in high concentration. Amorphous carbonaceous matter in the form of clumps, strings and surrounding mineral grains has been isolated from Strelley Pool cherts.

These have been interpreted as the thermally degraded microbial populations, the term 'kerogen' is used by DeGregorio et al. [19] although this term has been reserved in the literature for organic remains in younger sediments [30]. propose extraterrestrial sources for the beginning of life on Earth. The main extraterrestrial sources for organic molecules on Earth are interplanetary particles, meteorites and cometary impacts. Amino acids and many organic compounds are contained in chondritic meteorites that hit Earth.

The problem with amino acids and other organic compounds delivered to Earth by meteorites is the high temperature that they are subjected incoming to Earth, which would render them chemically non-reactive, like graphite the inert end product of the thermal maturation of carbonaceous matter [31] used shock experiments simulating impacts of chondritic meteorites into an early Earth- ocean mixture of Carbon, Fe, Ni, N and water, and as a result recovered organic molecules such as amino acids and fatty acids.

The association of earliest carbonaceous matter with meteorite impacts may not be entirely accidental. The hydrothermal environments resulting from meteorite impacts created cradle of life conditions. Essential elements dissolved in the hot waters provided the basic building blocks of life. The extremely harsh conditions of hydrothermal environments today such as the White Smoker of 'Lost City' hydrothermal field contain high concentrations of dissolved basic building blocks for the formation and growth of vesicles or proto cells. Impacts generate hydrothermal systems [2]. Numerous bolides impacts had been identified in the Apex Basalt and Strelley Pool and their South African time-equivalent deposits. A large impact structure situated at the base of the Apex Basalt has recently been discovered by Tim Johnson [3]. Indirectly earliest life on Earth had been triggered by meteorites creating the specialized environment for life's beginning. Further detailed studies of Archaean sediments containing organic matter in the localities mentioned is bound to yield microbial remains [32]. suggested stony meteorites as a target with possible other planetary sources of building blocks for biogenic cells. Chemical Element is brought to Earth by meteorites but they are just basic building blocks. The synthesis of elements into organic compounds is presently and had been in the past occurring in hydrothermal environments on Earth.

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