

Comets, Carbonaceous Meteorites, and the Origin of the Biosphere

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Abstract

The biosphere comprises the Earth's crust, atmosphere, oceans, and ice caps and the living organisms that survive within this habitat. The discoveries of barophilic chemolithoautotrophic thermophiles living deep within the crust and in deep-sea hydrothermal vents, and psychrophiles in permafrost and deep within the Antarctic Ice Sheet indicate the Earth's biosphere is far more extensive than previously recognized. Molecular biomarkers and Bacterial Paleontology provide evidence that life appeared very early on the primitive Earth and the origin of the biosphere is closely linked with the emergence of life.

The role of comets, meteorites, and interstellar dust in the delivery of water, organics and prebiotic chemicals has long been recognized. Deuterium enrichment of seawater and comets indicates that comets delivered oceans to the early Earth. Furthermore, the similarity of the D/H ratios and the chemical compositions of CI carbonaceous meteorites and comets indicate that the CI meteorites may be remnants of cometary nuclei with most volatiles removed. Comets, meteorites, and interstellar dust also contain complex organic chemicals, amino acids, macromolecules, and kerogen-like biopolymers and may have played a crucial role in the delivery of complex organics and prebiotic chemicals during the Hadean (4.5-3.8 Gyr) period of heavy bombardment. The existence of indigenous microfossils of morphotypes of cyanobacteria in the CI and CM carbonaceous meteorites suggests that the paradigm that life originated endogenously in the primitive oceans of early Earth may require re-consideration. Recent data on the hot (300-400 K) black crust on comet P/Halley and Stardust images of P/Wild 2 showing depressions, tall cliffs, and pinnacles, indicate the presence of thick, durable, dark crusts on comets. If cavities within the ice and crust sustain vapor pressures in excess of 10 millibar, then localized pools of liquid water and brines could exist within the comet. Since life exists on Earth wherever there is liquid water, it is suggested that comets might also harbour viable and/or cryopreserved microbiota.

This paper considers the significance of comets and meteorites to the Origin and Evolution of the Biosphere and presents recent images of freshly fractured interior surfaces of CI (Orgueil) and CM (Murchison) meteorites obtained with the Environmental (ESEM) and Field Emission Scanning Electron Microscope (FESEM). These images and EDAX elemental data indicate the presence of the mineralized remains of a complex suite of trichomic prokaryotes within the meteorites. These well-preserved microfossils are interpreted as representing morphotypes of cyanobacterial mat communities. EDAX and 2-D X-ray analysis show that the microfossils bear signatures of biogenic elements that differ significantly from living cyanobacteria and overlay the signature of the meteorite mineral matrix. The lithified, carbonized and embedded microfossils cannot be dismissed as recent contaminants and are interpreted as both indigenous and biogenic. Morphotypes of cyanobacteria and sulphur bacteria in meteorites

supports the hypothesis that comets and meteorites may have contributed to the Origin and Evolution of the Biosphere by the delivery of water, carbon, and organic prebiotic chemicals and possibly even complex biomolecules and intact cryopreserved and viable microorganisms to the early Earth.

1 Introduction

The origin and evolution of the biosphere is one of the most profound and interesting multidisciplinary problems of modern science. It encompasses two of the most fundamental questions of Astrobiology concerning the origin and the distribution of life: *Is life on earth endogenous or exogenous?* And, *Is life restricted to Earth or is life a Cosmic Imperative?*

Although the possibility of the exogenous origin of life (panspermia) was considered by Von Helmholtz (1871) and Arrhenius (1903), the prevailing paradigm during the last century has been that life arose in the primordial oceans as a result of endogenous prebiotic synthesis of organics, which is strongly dependent on the reducing state of the primitive atmosphere (Miller, 1957; Miller and Urey, 1959; Miller and Orgel, 1974). During the past two decades an enormous amount of new information has been obtained concerning the structure, physical properties and chemical composition of asteroids and cometary nuclei and the composition and ultramicrostructure of interstellar dust and meteorites. These observations suggest that these bodies may have played a far more significant role in the origin and evolution of the biosphere than previously envisioned.

Pioneering work on the theory of origin of life (Oparin, 1924) and the nature of the biosphere (Vernadsky, 1924, 1926) first appeared in Russia in 1924 and translations of these works of (Bernal, 1966, and Vernadsky, 1998) have made their profound early contributions to the problems of the origin of life and the nature of the biosphere to be more widely recognized in the west. Vernadsky's concept of the biosphere includes living organisms on the planet as well as the inorganic elements of nature that provide the medium for their habitat. In this sense, the biosphere comprises the lithosphere, hydrosphere, and atmosphere as well as the sum of all living organisms and the myriad physical, chemical, and environmental interactions between the biotic and abiotic components.

The complex interrelationships that exist between the microbial world and the atmosphere, hydrosphere, cryosphere, and lithosphere are becoming better understood as research in Geomicrobiology and the BioGeosciences proceeds. Recent discoveries in Microbiology, Astrobiology, and Bacterial Paleontology have provided important new information concerning the spatial, temporal, physicochemical and environmental distribution of life on Earth. These discoveries have required drastic revisions of many long held paradigms and established that the biosphere is far more extensive and complex than previously thought possible. Enormous regions of planet Earth that were previously thought to be "barren" and totally inhospitable to life are now known to contain rich and complex ecosystems of exotic and important microorganisms. Brock and Freeze (1969) found that *Thermus aquaticus* was able to live at astonishingly high temperatures (> 80 °C) in Yellowstone's Great Fountain geyser. This discovery established that microorganisms could live at temperatures that were previously thought to destroy DNA, proteins and other life-critical biomolecules. The *Taq* polymerase enzyme that protects these thermophiles has brought forth a revolution in genomics, phylogenetics and biotechnology. In 1977, the deep sea research vessel *Alvin* descended to a depth of 2.6 km on the East Pacific Rise and discovered 'black smoker' deep