EVIDENCE FOR ANCIENT MARTIAN LIFE. E. K. Gibson Jr., F. Westall, D. S. McKay, K. Thomas-Keprta, S. Wentworth, and C. S. Romanek, Mail Code SN2, NASA Johnson Space Center, Houston TX 77058, USA.

Three SNC meteorites ranging in age from 4.5 Ga. to 1.3 Ga. to 165 m.y. contain features suggestive of past biogenic activity on Mars [1,2]. Because we do not know what past martian life looks like or its physical or chemical properties, the only tools or criteria which the scientific community have to evaluate evidence of past life is to use evidence for early life on earth. There are features within ALH84001's carbonate globules and the preterrestrial aqueous alteration phases of Nakhla and Shergotty which have been interpreted as possible evidence for past life on early Mars [1,2].

Criteria for Past life

Over the past few decades eight criteria have been established for the recognition of past life within terrestrial geologic samples [3,4]. Those criteria are: (a) Is the geologic context of the sample compatible with past life; (b) Is the age of the sample and its stratigraphic location compatible with possible life; (c) Does the sample contain evidence of cellular morphology and (d) colonies; (e) Is there any evidence of biominerals showing chemical or mineral disequilibria; (f) Is there any evidence of stable isotope patterns unique to biology; (g) Are there any organic biomarkers present; (h) Are the features indigenous to the sample? For general acceptance of past life in a geologic sample, essentially most or all of these criteria must be met.

ALH84001, Nakhla and Shergotty vs. the Criteria for Past Life

How does the scientific information from ALH84001, Nakhla and Shergotty compare to the established criteria?

Geologic context. A martian origin for the three meteorites has been shown by their O-isotopic compositions [5] and trapped martian atmospheric gases [6,7]. The exact martian provenances for these igneous rocks is unknown. However, because of its 4.5 Ga. age, ALH84001 probably originates from the early martian crust (i.e from the ancient southern highlands). Nakhla and Shergotty are undoubtly from younger volcanic provenances. The presence of secondary globules or pancake carbonates in ALH84001 and clays in Nakhla have been interpreted as an indication of relatively low-temperature secondary mineralization by a fluid, possibly water [5,8]. Formation of the secondary carbonates and preterrestrial aqueous alteration at low-temperatures from aqueous fluids would be compatible with past life, but would not require it.

Ages and histories. The crystallization age of ALH84001 is 4.5 Ga and the rock believed to be a sample of the original martian crust. The sample underwent extensive shocking around the 3.9-4.0 Ga [7,9]. Carbonate formation occurred around the 3.94 Ga [10], shortly after the period of extensive bombardment and during a period when the planet had abundant water [11], greater concentrations of atmospheric gases, and higher temperatures. This corresponds to the time when life appeared and developed on Earth [3,12]. Evaporation of the fluids percolating through the impact-cracked surface could have resulted in the formation of carbonates [11-13]. The sample was ejected from Mars ~17 m.y. ago and spent 11,000 years in or on the Antarctic ice sheets. We suggest that the geologic history of ALH84001 can be compared with terrestrial rocks of the same age and that similar biological processes may have been operating concurrently on Mars and Earth. Nakhla's age is 1.3 Ga and Shergotty's age is between 300 and 165 m.y. Both show evidence of preterrestrial aqueous alteration at some period in their history (14,15).

Cellular morphologies. Some structures resembling the mineralized casts of modern terrestrial bacteria and their appendages (fibrils) or by-products (extracellular polymeric substances, EPS)[16-18] occur in the rims of ALH84001 carbonate globules and preterrestrial aqueous alteration regions. Other bacteriomorphs are very small but some are within the size limit of known nanobacteria (i.e. 100-200 nm, [19-21]). Cellular-like features as large as 1 to 2 microns are found in Nakhla [2]. Some of the features in ALH84001 (e.g., filaments) and Nakhla (cellular-like) are similar to terrestrial bacteria and fossil bacteria [3,20,22]. We conclude that the evidence for fossilized microbes and their products is not conclusive, but cannot be readily explained by nonbiological processes and should not be ignored.

Microbial colonies. We have proposed that some of the features in ALH84001, Nakhla and Shergotty may be the remains of biofilms and their associated microbial communities [16,17]. Biofilms provide major evidence for bacterial colonies in ancient Earth rocks [22]. It is possible that some of the clusters of microfossil-like features might be colonies although that interpretation depends on whether the individiual features are truly fossilized microbes.

Biominerals. Carbonates in ALH84001 contain a population of magnetites having a highly restricted single-domain size distribution and unusual morphology (rectangular prism) that are indistinguishable from some known, microbially-produced terrestrial magnetites, but match no known nonbiologic magnetite [18,19,21]. We suggest these magnetites may be formed by biogenic processes [21]. Other magnetite grains may inorganic [19,21]. Whisker-like magnetites (<5% total magnetites in carbonate) described by [23-25] may have had an origin unrelated to the rectangular prisms [21]. Work is in progress on searching for magnetites within alteration phases of Nakhla and Shergotty. The recent discovery of chains of magnetites on the surfaces of carbonate globules [26], which resemble the magnetosome chains of magnetotactic bacteria, provide additional support for biogenic activity within ALH84001. The discovery of single domain, chemically pure magnetite, within carbonate globules known to have been formed on Mars is our strongest evidence in support of ancient martian life [21].

Biologic isotopic signatures. Stable isotope patterns have shown the presence of indigenous C components with isotopic signatures of -13 to -18 ‰ [27,28], which are in the direction of known biogenic C signatures [3]. Additional detailed study of the C-isotopic signatures is needed to distinguish between indigenous C components within ALH84001, Nakhla and Shergotty. Overall, the C-isotopic signatures of the identifiable nonterrestrial, reduced C, are compatible with biologic C-isotopic fractionation, when compared with the signature of the martian cabonates, but they do not prove that it occurred.

Organic biomarkers. Possible organic biomarkers are present within ALH84001 and Nakhla in the form of PAHs associated with carbonate globules[29]and preterrestrial aqueous alteration regions-some of which may be a unique product of bacterial decay [29]. PAHs in ALH84001 are distributed in regions containing carbonate globules [30,31] and are most likely indigenous, whereas the other organics, such as amino acids [32] are most likely from Antarctic contamination. Exhaustive data must be collected before either component can be used as a biomarker for a specific sample [33].

Indigenous features. Recent studies have shown conclusively that the PAHs are indigenous to ALH84001 and Nakhla and are not contaminants [29,31]. Based on isotopic compositions [27,28,34] and textures, there is no question or disagreement that the carbonate globules or embedded magnetites in ALH84001 and the preterrestrial aqueous alteration products in Nakhla and Shergotty were formed on Mars and are indigenous to the meteorites. Possible microfossil structures and some reduced C components that are embedded in the carbonates and preterrestrial aqueous alteration products are, therefore, almost certainly indigenous, but other possible evidence for life (e.g. amino acids, [32]) may be a result of terrestrial contamination [35].

Summary

Although the data are compelling, we have not satisfied all of the eight criteria for past life described above. However continued investiagations are in progress and more data are needed.

Therefore, the jury is still out on early Mars life as revealed by these meteorites [36].

We are reminded that the concept of plate tectonics operating on the earth required 40 to 50 years before it was accepted in the scientific community. More recently, the hypothesis that the K-T boundary was produced by a large bolide or comet impacting the earth only reached acceptance after 15 to 18 years. Science does not move swiftly in accepting radical ideas. Our hypothesis was presented in August 1996. We believe that after 3 years it stands stronger today than when originally presented. To date, no fatal strikes have been made to any of our original four lines of evidence [1], despite several misconstrued press releases. While details of the hypothesis are evolving as new data is generated, we believe that our basic premise remains intact: these meteorites contains evidence suggestive of early life on Mars [36].

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