

BIOGENIC ACTIVITY IN MARTIAN METEORITE ALH84001-STATUS OF THE STUDIES. E.K. Gibson, Jr.¹, D.S. McKay², K. Thomas-Keptra³, C.S. Romanek⁴, S.J. Clemett⁵ and R.N. Zare⁵: ¹SN4, Planet. Sci. Branch, NASA-JSC, Houston, TX 77058; ²SN, ES and SSE Div., NASA-JSC, Houston, TX 77058; ³LESC, NASA-JSC, Houston, TX 77058; ⁴SREL, Drawer E, Univ. of Georgia, Aiken, SC 29802; ⁵Dept. of Chem., Stanford Univ., Palo Alto, CA 94305.

Several lines of evidence were given by McKay et al. (1) to suggest the presence of biogenic activity within the martian meteorite ALH84001: (i) The presence of secondary carbonate globules were found within fractures and cracks of the 4.5 Gy old igneous rock; (ii) The formation age of the carbonates are believed to be younger than the crystallization age of the host igneous rock; (iii) SEM and TEM images of the carbonate globules and associated mineralogical phases resemble terrestrial biogenic structures and fossilized nanobacteria; (iv) The presence of magnetite and iron sulfide phases may have resulted from oxidation and reduction reactions known to be important in terrestrial microbial systems; and (v) The presence of polycyclic aromatic hydrocarbons (PAHs) associated carbonate globules indicating potential indigenous organic molecules. As noted in (1), none of these observations is in itself conclusive proof for the existence of past life on Mars. Although there are alternative explanations for each of these phenomena taken individually, when they are considered collectively, particularly in view of their close spatial association, we concluded that they may represent the first direct evidence for primitive life on early Mars.

Since the initial report, additional supporting evidence (2-8) and opposing views (9-14) including alternative inorganic explanations have been offered. Major controversies continue over the age of the carbonates, the temperature at which they formed and the source of the PAHs.

Knott et al. (15) suggested the carbonates were formed around 3.6 Gy, whereas Wadhwa and Lugmair (16) noted the formation may be as late as 1.3 Gy. Turner et al. (17) later argued that the 3.6 Gy date is not well defined and additional studies are needed to define the carbonate formation date. In particular, (17) argued that their Ar-Ar age is really the age of the maskelynite, and would only be an upper limit on the age of the carbonate providing that the carbonate formed at low temperatures.

Formation temperatures for the carbonates were initially proposed to be between 0° and 80°C based upon oxygen isotopic compositions (18). It was suggested (9) that the formation temperatures were greater than 650°C and formed during impact processes and remobilization. Valley et al. (19) have made *in situ* oxygen isotope measurements and show that the combination of isotopic and chemical data indicate low temperatures in the range estimated by (18). Bradley et al. (11) reported the presence of ribbon-like, forms with screw dislocations, and twinned magnetite within carbonate phases from ALH84001. Based upon the whisker morphologies and the screw dislocations, they suggested the magnetite formed at greater than 500°C from fumarole-like processes. However, other workers (20) have reported similar whisker-like magnetites produced by bacteria. Dobeneck et al. (21) have reported twinned magnetite can be produced by bacteria at room temperatures. As yet, no one has reported screw dislocations in biogenic magnetite, and defect-free magnetite seems to be the norm for biogenic magnetite. However, no one has yet looked at the whisker-shaped biogenic magnetite for screw dislocations. Thomas et al. (22) present evidence for a chain of magnetite crystals within the ALH84001 carbonate which appears to be similar to magnetotactic-like magnetite chains produced by terrestrial bacteria. Although (11) reported whisker-like It is clear that magnetites can be produced by a variety of processes and caution must be applied when interpreting these components. Undoubtedly, the spatial relationships among mineral grains and the microenvironments in which these precipitates provide a very important clue to their origins. Studies of the minor and trace volatile elements within the carbonates by Flynn and coworkers (23) fail to find volatile elements normally associated with terrestrial fumaroles or volcanic events.

Microstructures and "nanobacteria"-like features within ALH84001 are spherical, elongated, and segmented in shape. The small sizes were criticized (24) as being too small to be bacteria. However, it was noted that nanobacteria of sizes down to 100 nanometers and possibly as small as 50 nanometers are common within the terrestrial environment (5,25,26). Dwarf bacteria, bacteria desiccated after death and during mineralization, bacteria spores, and even viruses have been proposed to explain some of these nanosize forms. Studies of organisms recovered at 0.3 to 1 km depth within the Columbia River Basalts (27,28), have shown features which have the same sizes and morphologies as those observed within ALH84001 and which are likely formed by microorganism activity. Some of these features are thread-like iron-rich forms and fragments likely produced by larger bacteria. Some of the ALH84001 features may similarly be fossilized fragments and forms which are the products of microorganisms rather than the microorganisms themselves.

Recognition of biofilms produced by bacteria within terrestrial environments has recently shown that three-dimensional organic networks can be produced by microbial communities (26,28). Presence of biofilms within subsurface Columbia River basalts, which are associated with the subsurface organisms, along with biofilms from travertine deposits (26,28) show the microbial production and importance of such processes. McKay et al. (29) and Steele and colleagues (30)

have documented the occurrence of possible biofilms within ALH84001. Other features which may be biogenic include possible mineralized organisms in the 1-2 micrometer size range.

Ion microprobe studies by Valley et al. (19) noted the presence of carbon enriched in ^{12}C composition occurring within selected regions of the carbonate globules. Flynn et al. (23) noted the irregular distribution of a carbon phase (either graphite or organic carbon) within the carbonate globules. The carbon isotopic values of -65‰ for a component within ALH84001 is suggestive of a microbial bacteria signature (2). The measured range of greater than 100 per mil in carbon isotopic compositions (+40‰ to -65‰) within the carbonate globules (2,18,31) show the wide varieties of carbon phases present within ALH84001.

Indigenous organic components within ALH84001 were shown to be present as polycyclic aromatic hydrocarbons (PAHs). The PAHs are typically associated with the carbonate phases (8). The signature of the PAHs spectra within ALH84001 is unique and not identical to those of carbonaceous chondrites, ordinary chondritic meteorites, interplanetary dust particles and typical terrestrial soils or contaminants. Becker et al. (10) suggested that cycling of Antarctic melt-water containing trace concentrations of organic components through the meteorite would enrich PAHs within the carbonate phases. They proposed that the PAHs observed within ALH84001 were terrestrial components and not from Mars. If the quantities of Antarctic melt-water required by (10) cycled through ALH84001, the isotopic systematics of the sample would likely be altered and alteration products formed. Alteration products are minimal in this meteorite. Additionally, Clemett et al. (32) have measured PAHs within micrometeorites and IDPs collected from both north and south polar ices of widely different ages. They failed to find any enrichment of PAHs in the samples and documented two orders of magnitude variation in PAHs concentration among particles collected from the same site on the same day. Because of the porosity of these particles, one might expect the particles to absorb PAHs from polar ices.

In the five months since the publication of our hypothesis about possible evidence for past biogenic activity within ALH84001 (1), we feel that our arguments have been strengthened with the new data. Researchers from other fields of science have acquired supporting data for this hypothesis. Additional experiments are needed to further clarify the hypothesis on the origin of the carbonate globules. Many of these studies are underway and will be reported in the future.

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