Possible Relic Biogenic Activity in Martian Meteorite ALH84001: A Current Assessment. E. K. Gibson, Jr.[1], D. S. McKay[2], K. Thomas-Keprta[3], C. S. Romanek[4], S. J. Clemett[5] and R. N. Zare[5]: [1]SN4, Planetary Sciences Branch, NASA-JSC, Houston TX 77058; [2]SN, ES and SSE Division, NASA-JSC, Houston TX 77058; [3]LESC, NASA-JSC, Houston, TX 77058; [4]SREL, Drawer E, University of Georgia, Aiken SC 29802; [5]Department of Chemistry, Stanford University, Palo Alto CA 94305.

In the initial report by McKay et al. (1) on ALH84001 several lines of evidence were given to suggest the presence of biogenic activity on Mars: (i) the presence of the carbonate globules within fractures and pores of a 4.5 Gy old igneous rock after the primary cryustallization event; (ii) formation age of the carbonates is younger than the age of the host igneous rock but older than the carbonate's age; (iii) SEM and TEM images of carbonate globules and assorted features resemble terrestrial biogenic structures and fossilized nanobacteria; (iv) the occurrance of magnetite and iron sulfide particles could have resulted from oxidation and reduction reactions known to be important in terrestrial microbial systems; and (v) presence of 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, it was 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 contradictory evidence (9-14), including alternative inorganic explanations have been presented.

The time and temperatures of carbonate formation in ALH84001 continues to be hotly debated. Knott et al. (15) suggests the carbonates were formed at 3.6 Gy, whereas Wadhwa and Lugmair (16) noted the formation may be as late as 1.3 Gy. Turner et al. (17) argue that the 3.6 Gy date is not well defined and additional studies are needed to define the carbonate formation date.

Temperatures of formation for the carbonates was initially shown 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 magnetite within carbonate phases from ALH84001. Based upon twinning structures, they suggest the magnetite formed at greater than 500°C from fumarole-like processes. However, (20) have reported similar whisker-like or ribbon-like magnetites produced by bacteria. Dobeneck et al. (21) have reported twinned magnetite can be produced by bacteria. 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. It is clear that magnetites can be produced by a variety of processes and caution must be applied when interpreting these components. Undoubtly, 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 (23) fail to find volatile elements normally associated with terrestrial fumaroles or volcanic events. Within the rims of the carbonate globules the intergrowths of magnetite and sulfides clearly represent a disequilibrium assemblage. We believe that the spatial relationships can best be described as the end product of microbial action of bacteria occurring at temperatures below 100°C.

The size of the microstructures and "nanobacteria"-like features within ALH84001 range in size from 20 to 500 nanometers. These structures are spherical, elongated, and segmented in shape and several appear to be dividing. The small sizes were initially criticized (24) as being too small to be bacteria. However, it was noted that such sizes of bacteria are common within the terrestrial environment (5,25,26). Studies of organisms recovered at 1 to 2 km depth within the Columbia River Basalts (27,28), have shown organisms which have the same sizes and morphologies as those observed within ALH84001.

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 features. McKay et al. (29) and Steele (30) have documented the occurrence of biofilms within ALH84001 associated with the carbonates. Perhaps it is these biofilms within selected regions of ALH84001 which produce the unusually light carbon isotopic signatures reported by Wright et al. (2). Ion microprobe studies by Valley et al. (19) noted the presence of carbon within selected regions of the carbonate globules

which is enriched in ^{12}C composition. 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 variety of carbon forms present within ALH84001.

Indigenous organic components within martian materials was shown by (1) 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 the same as 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 through the meteorite would enrich PAHs within the carbonate phases. They believe that the PAHs observed within ALH84001 are terrestrial components and not from Mars. If the quantities of Antarctic water required by (10) cycled through ALH84001, the isotopic systematics of the sample should be altered and alteration products formed. None have been observed and we feel that their model is incorrect. In support, Maurette 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. 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 (l), 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 carbonatre globules. Many of these studies are underway and will be reported in the future.

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