CRITERIA FOR EVIDENCE OF ANCIENT LIFE: HOW DOES THE DATA FROM ALH 84001 COMPARE WITH ACCEPTED REQUIREMENTS?

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Criteria for Past life

To accept the evidence of past life or biogenic activity one must determine indubitably that certain biomarker signatures are present in the sample. In the case of martian samples, the criteria for past life have not been established because, if life existed on the planet, we do not know exactly what its characteristics were. Lacking independent evidence about the nature of possible past life on Mars, the scientific community must use, for the time being, the criteria established for ancient samples from the Earth. Over the past few decades eight criteria have been established for the recognition of past life within geologic samples (1,2). Those criteria are: (1) Is the geologic context of the sample compatible with past life? (2) Is the age of the sample and its stratigraphic location compatible with possible life? (3) Does the sample contain evidence of cellular morphology? and (4) colonies? (5) Is there any evidence of biominerals showing chemical or mineral disequilibria? (6) Is there any evidence of stable isotope patterns unique to biology? (7) Are there any organic biomarkers present? (8) Are the features indigenous to the sample? For general acceptance of past life in a geologic sample, essentially all of these criteria must be met.

ALH84001 Data vs. the Established Criteria for Past Life

How does the information from the study of ALH84001 compare to the established criteria?

Geologic context. A martian origin for ALH84001 has been shown by both its O-isotopic compositions [3] and trapped martian atmospheric gases [4,5]. Although the exact martian provenance of this igneous rock is unknown, ALH84001 contains cracks and porosity that, based on textural microstratigraphy, clearly formed on Mars and could conceivably have harbored water-borne microbial cells and colonies introduced after the rock cooled (as known on Earth, [6]). The presence of secondary carbonate globules or pancakes in cracks has been interpreted by most workers as an indication of relatively low-temperature secondary mineralization by a fluid, possibly water. Thus, the most widely-accepted, broad geologic context of this rock is not incompatible with the presence of past life; if the secondary carbonates formed at low-temperature from aqueous precipitation, their formation is completely compatible with past life, but would not require it.

Age and history. ALH84001's isotopic age is 4.5 Ga shows that it is original martian crust. The sample underwent extensive shocking around the 3.9-4.0 Ga [5,7]. Carbonate formation occurred around the 3.9 Ga [8], shortly after the period of extensive bombardment and during a period when the planet had abundant water [9], greater concentrations of atmospheric gases, and higher temperatures. This corresponds to the time when life appeared and developed on Earth [10]. Evaporation of the fluids percolating through the impact-cracked surface would have resulted in the formation of carbonates [11,12]. The sample was ejected from Mars ~17 m.y. ago and spent 11,000 yr in or on the Antarctic ice sheets. We suggest that the geologic history of this rock is understood well enough to relate any possibly life forms to the history of Mars and to compare it to the history of life on Earth.

Cellular morphologies. Some structures resembling the mineralized casts of modern terrestrial bacteria and their appendages (fibrils) or by-products (extracellular polymeric substances, EPS)[13-15] occur in the rims of the carbonate globules. Other bacteriomorphs are very small but some are within the size limit of known nanobacteria (i.e. 100-200 nm, [17,18]). However, although some of the originally identified features may have been coating artifacts or weathered mineral structure artifacts, some are definitely not [16]. Some of the features in ALH84001 (e.g., filaments) are common biogenic markers on Earth. 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 may be the remains of biofilms and their associated microbial communities [13,14]. Biofilms provide major evidence for bacterial colonies in ancient Earth rocks [19]. 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 and disequlibria. Carbonates in ALH84001 contain a population of magnetites having a highly peaked size distribution and unusual rectangular prism shapes that are indistinguishable from some known microbially produced terrestrial magnetites, but match no known nonbiologic magnetite. Their formation can best be explained by biogenic activity and disequilibria of the Fe oxidation potential in the fluid that was the source of the Fe [15,20]. Other irregular magnetite grains could be either biogenic or nonbiogenic in origin. Whisker-like magnetites (<5% total magnetites in carbonate) described by [21-23] are quite different in size, distribution and shape, and may have had an origin unrelated to the rectangular prisms. Nanometer-sized iron sulfides described in [24] are also suggestive of disequilibria related to microbial activity, as is the elemental composition of the carbonates. The recent discovery of chains of magnetites on the surfaces of carbonate globules [25], which resemble the magnetosome chains of magnetotactic bacteria, provide additional support for biogenic activity within ALH84001. Overall, mineral assemblages in the carbonates, as well as their extreme chemical variations, are compatible with known biominerals and known disequilibria related to microbial activity on Earth, although more work needs to be done to distinguish true biominerals and biogenically-related chemical disequilibria from totally nonbiologic minerals and disequilibria.

Biologic isotopic signatures. Stable isotope patterns have shown the presence of indigenous C components with isotopic signatures of -13 to -18 ‰ [26-28], which are in the direction of known biogenic C signatures. Additional detailed study of the C-isotopic signatures is needed to distinguish between indigenous C components within ALH84001 and those introduced after its arrival on Earth. Overall, the C-isotopic signatures of the identifiable non-terrestrial, possibly organic 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 in the form of PAHs associated with carbonate globules[29]-some of which may be a unique product of bacterial decay [30]. The distribution of reduced carbon compounds within the globules is irregular [30-32] Clemett's data on PAHs [29], combined with recent amino acid data [i.e. 33], show that the detected PAHs are most likely to be indigenous to the ALH84001, whereas the detected amino acids most likely result from Antarctic contamination. Exhaustive data must be collected before either component can be used as a biomarker for a specific sample [34].

Indigenous features. In our opinion, the recent studies of [30] have shown conclusively that the PAHs are indigenous to ALH84001 and are not contaminants. Based on isotopic compositions [26,28,35,36] and textures, there is absolutely no question or disagreement that the carbonate globules and their included minerals formed on Mars and are indigeneous to the meteorite. The possible microfossil structures and some organic C components that are embedded in the carbonates are, therefore, almost certainly indigenous, but other possible evidence for life (e.g. amino acids) may be a result of Antarctic contamination.

Summary

Clearly, we have not completely satisfied all of the criteria needed for general acceptance of evidence for life in a sample. We argue that we are close on some (likely biominerals, possible organic biomarkers, and indigenous features) and not so close on others (well-documented geologic context, and evidence for cells and colonies). More- over, there is some evidence existing supporting each of the eight criteria for establishing ancient life. Therefore, the jury is still out on early Mars life as revealed by this meteorite [37]. Continued investigations are still in progress and more data are needed.

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 two 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, 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: this meteorite contains evidence suggestive of early life on Mars [37].

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