METEORITE ALLAN HILLS (ALH) 84001: IMPLICATIONS FOR MARS' INHABITATION AND HABITABILITY. Allan H. Treiman. Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston TX 77058 <treiman@lpi.usra.edu>

Introduction: Meteorite ALH 84001, home to putative signs of ancient martian life, is the most intensely studied martian sample. As such, it provided evidence (albeit a single point) on potentially habitable conditions on early Mars, and a case study in what sorts of evidence might be acceptable as signs of extraterrestrial life.

ALH 84001 & Mars Life: The meteorite ALH 84001 is an orthopyroxenite – composed primarily of that mineral with lesser chromite, augite, glass of plagioclase- and silica-rich compositions, olivine, and apatite; it was first classified as an diogenite (asteroidal), and was later recognized as Martian [1]. It includes disc-shaped and hemispherical globules of (primarily) Fe-Mg carbonate minerals [2] that contain sub-micron magnetite grains [3] and organic matter [h4]. The meteorite has experienced several intense shock events [5,6].

McKay et al. [4] proposed that ALH 84001 contained signs of ancient Martian life – that the combination of chemically zoned carbonate globules, bacteria-shaped objects, polycyclic aromatic hydrocarbons, and magnetite grains that resembled those from magnetotactic bacteria constituted a strong biosignature. Anders [7] argued that these characteristics could (and do) arise from simple inorganic processes, and that [4] was inherently biased towards biogenic origins.

Carbonate Globules. Chemically zoned Fe-Mg carbonates occur in carbonaceous chondrite meteorites [7], where they are certainly abiotic. Similar globules also occur in volcanics on Earth [k8], and seem to be a common alteration product. The carbonate globules formed at low temperatures, as implied by their strong chemical zoning [2,9], and proven by clumped oxygen isotopes [10].

Organic Matter. The organic matter in ALH 84001 includes complex polycyclic aromatic hydrocarbons (PAHs) [l11,12], which are known to form abiotically in Fischer-Tropsch-like reactions [7]. Much of the organic matter is indigenous (i.e., Martian) [13], although the rock has been invaded by terrestrial biota [14]. No martian PAHs of convincing biogenic heritage have been reported.

"Nanobacteria". McKay et al. [h4] figured several sub-micron cylindrical objects on broken surfaces of ALH84001, and inferred that they were mineralized Martian bacteria. These observation have been replicated, i.e. the objects in [4] have not been reimaged, and additional objects have not been reported. The bacteria-shaped objects are, most likely, artefacts produced by gold-coating (for SEM analysis) of ridges on a weathered mineral surface [15].

Magnetite Grains. The carbonate globules in ALH 84001 contain a variety of submicron grains of magnetite, which are concentrated in clearly defined layers. A quarter of these magnetites were suggested as biosignatures, based on their size distribution, shapes [16] and compositions [17], all seen as distinctive of grains from magnetotactic bacteria However, these magnetite grains are not of the distinctive magnetotactic shape [18], their size distribution is consistent with inorganic processes [19], and their compositions are consistent with abiotic formation [20].

Summary. Although some people remain convinced that ALH 84001 contains proof of ancient martian life [21] the preponderance of evidence is that all the putative biosignatures reported in ALH 84001 are either natural inorganic products or analytical artefacts.

Habitability on Mars:

Early Aqueous Environment. From the chemical zoning and isotope thermometry, it is clear that the ALH 84001 carbonate globules formed at low temperature [2,10], and thus from aqueous fluids. The changes in the carbonate compositions (from $CaCO_3$-rich cores to $(Fe,Mg)CO_3$ mantles to $MgCO_3$ rims) bespeaks regular and oscillating changes in fluid compositions [22,23]

The aqueous history was, however, more complex. The rock must have contained open (fluid-filled) spaces, into which the carbonate hemispheres could have grown unimpeded [5,8]. These open spaces were crushed closed in the later impact shocks that produced the rock's plagioclase-composition glasses. composition glass, interpreted as shock melts [5,6].

But how could these void spaces form? ALH 84001 was (at that point) a shocked plutonic rock, and unlikely to have had primary void space. It was noted that carbonate hemispheres were spatially associated with olivine [24], which led to the suggestion that the void spaces formed by the dissolution of olivine [25], as described in terrestrial analogs [8].

There is evidence (albeit thin) of aqueous activity after formation of the carbonate globules, but before the shock event that crushed the rock's porosity. Phyllosilicates are reported in the carbonate globules [26-28], with textures suggesting formation after the carbonates [27,28]. The aqueous history of ALH 84001 then includes: (1) dissolution of igneous olivine; (2) deposition of carbonate minerals, dominantly Fe-Mg; and (3) alteration of the carbonates to form phyllosilicates.

This sequence of aqueous alteration nearly identical to that in the nakhlite meteorites [29,30], although to different extents. Most nakhlites contain little carbonate remaining, it having been replaced by phyllosilicate; and the nakhlites contain late-stage amorphous silicate 'gel,' which has not been noted in ALH 84001. Thus, it is possible that aqueous alterations in both the ALH 84001 and the nakhlites represented the same sort of process on Mars (e.g., impact induced hydrothermal systems [31]), albeit separated by several thousand million years.

For ALH 84001, its aqueous alteration history appears to represent a series of potentially habitable environments (although not, with available data, inhabited [32]). The waters were carbonate-rich and neutral-to-alkaline (presence of carbonates and absence of jarosite etc.), saline (presence of halite), and ranging from low to high oxidation states (ferrous carbonates to ferric-bearing phyllosilicates). These conditions are different from those inferred for the Gale Crater Lake – near-neutral, low salinity, low in carbonate and of varying oxidation states [33-35]. The oxygen isotope composition of the ALH 84001 carbonates indicates an atmospheric component [ak], suggesting that the carbonate was remobilized from older sedimentary carbonate deposits [37].

Later Desiccated Environment. There is minimal evidence that ALH 84001 encountered any liquid water in the billions of years after its carbonate globules (and phyllosilicates) were deposited. The meteorite's glasses, of plagioclase- and silica-rich composition, are intact. There have been no reports that the glasses have been altered (e.g. to form clay minerals) or devitrified (e.g., to form a crystalline silica phase).

Of similar significance is the preservation of highly strained orthopyroxene [5,6], recognized by spatially varying optical extinction positions. Orthopyroxene alters readily in aqueous environments [38], and one would expect shock-strained opx to be even more susceptible to aqueous alteration.

Conclusions: The enormous wealth of data collected on the ALH 84001 martian meteorite provides a benchmark of sorts for investigating and understanding ancient habitable environments on Mars, and their potential or putative inhabitants. The long controversy about whether ALH 84001 preserves evidence of ancient martian life helps understand what type of evidence can be accepted as proof. Understanding the chemistry of the aqueous deposits in ALH 84001 provides another data point on the range of possible habitable environments on early Mars.

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