



Reevaluation of the "Life-on-Mars" Hypothesis: Origin of ALH84001 Carbonate-Magnetite Assemblages

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The Mars meteorite ALH84001 is a sample of the ancient Martian surface with a crystallization age of 4.5 Ga. Internal cracks and fissures within this meteorite preserve evidence of early Martian hydrothermal activity in the form of carbonate-magnetite assemblages, with disk-like appearance, that are dated at 3.9 Ga. The mechanism(s) by which these carbonate disks formed, and in particular the origin of the embedded nanocrystal magnetites, has been a subject of considerable debate ever since the suggestion that biological processes could, in part, be responsible [1]. Subsequently, a number of alternative purely "inorganic mechanisms" have been advocated which all invoke the partial thermal decomposition of sideritic carbonate ($3\text{FeCO}_3 \rightarrow \text{Fe}_3\text{O}_4 + 2\text{CO}_2 + \text{CO}$) as the origin of the nanophase magnetite. The primary difference between these "inorganic mechanisms" lies in the timescale of the decomposition event, ranging from a gradual thermal pulse ("slow bake"), in the Martian subsurface [2] to the nearly instantaneous heating and rapid radiative cooling ("fast bake"), associated with the ejection of the meteorite from the Martian regolith [3]. We have investigated the viability of these "inorganic mechanisms" through a combination of experimental and theoretical modeling studies, in concert with new TEM observations of ALH84001 carbonate extracted in situ using focused ion-beam techniques. In our experimental studies, samples of the natural carbonate Roxbury siderite, which is compositionally similar to the most Fe-rich component of the ALH84001 carbonate disks, were subject to thermally decomposed over a range of heating regimes. Detailed TEM characteriza-

tion of samples before and after heating demonstrated that irrespective of the heating rates, which differing by over ten orders of magnitude, the product of thermal decomposition always was always a mixed [Mg,Mn]-ferrite. These findings, which are supported by both kinetic thermodynamic equilibrium modeling studies, are not similar to the chemically pure magnetites characteristic of ALH84001 carbonate. TEM/EDX analysis of the FIB extracted thin-sections has provided the most comprehensive description of ALH84001 carbonates to date. Our new observations indicate that at least a significant fraction of magnetites in ALH84001 carbonate, by virtue of either composition or spatial location within the carbonate disk, could not be the product of thermal decomposition. These include the presence of chemically pure magnetites embedded in carbonate containing little to no detectable iron and impure magnetites with minor amount of Cr, an element which is unable to substitute into the trigonal (R-3c) carbonate structure. Perhaps the most interesting finding, enabled by the ability to examine large area thin-sections of carbonate in which both spatial and structural integrity have been maintained, is the presence of textural and chemical evidence for episodic exposure of the ALH84001 carbonate disks to fluids after formation. Based on our results we argue than a thermal decomposition model for the origin of magnetites in ALH84001 is incorrect. Instead an allochthonous origin for the magnetites is the explanation most consistent with our findings and is possibly related to the textural and chemical evidence suggesting intermittent exposure of the carbonate to fluids with variable compositions after formation.

[1] McKay et al. (1996) *Science* 273, 924-930; [2] Treiman (2003) *Astrobiology* 3, 369; [3] Brearley (1998) *LPSC 29,CD-ROM* 1451.