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Evidence for exclusively inorganic formation of magnetite in Martian meteorite ALH84001

D.C. GOLDEN,[1] D.W. MING,[2,*] R.V. MORRIS,[2] A.J. BREARLEY,[3] H.V. LAUER JR.,[4] A.H. TREIMAN,[5] M.E. ZOLENSKY[2], C.S. SCHWANDT,[4] G.E. LOFGREN,[2] AND G.A. MCKAY[2]

[1]Hernandez Engineering Inc., 16055 Space Center Boulevard, Suite 725, Houston, Texas 77062, U.S.A.
[2]Astromaterials Research and Exploration Science Office, Mail Code SA13, NASA Johnson Space Center, Houston, Texas 77058, U.S.A.
[3]Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, New Mexico 82131-1126, U.S.A.
[4]Lockheed Martin, Mail Code C23, P.O. Box 58561, Houston, Texas 77258-8561, U.S.A.
[5]Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston, Texas 77058-1113, U.S.A.

ABSTRACT

Magnetite crystals produced by terrestrial magnetotactic bacterium MV-1 are elongated on a [111] crystallographic axis, in a so-called "truncated hexa-octahedral" shape. This morphology has been proposed to constitute a biomarker (i.e., formed only in biogenic processes). A subpopulation of magnetite crystals associated with carbonate globules in Martian meteorite ALH84001 is reported to have this morphology, and the observation has been taken as evidence for biological activity on Mars. In this study, we present evidence for the exclusively inorganic origin of [111]-elongated magnetite crystals in ALH84001. We report three-dimensional (3-D) morphologies for ~1000 magnetite crystals extracted from: (1) thermal decomposition products of Fe-rich carbonate produced by inorganic hydrothermal precipitation in laboratory experiments; (2) carbonate globules in Martian meteorite ALH84001; and (3) cells of magnetotactic bacterial strain MV-1. The 3-D morphologies were derived by fitting 3-D shape models to two-dimensional bright-field transmission-electron microscope (TEM) images obtained at a series of viewing angles. The view down the {110} axes closest to the [111] elongation axis of magnetite crystals ($[111]\cdot\{110\} \neq 0$) provides a 2-D projection that uniquely discriminates among the three [111]-elongated magnetite morphologies found in these samples: [111]-elongated truncated hexa-octahedron ([111]-THO), [111]-elongated cubo-octahedron ([111]-ECO), and [111]-elongated simple octahedron ([111]-ESO). All [111]-elongated morphologies are present in the three types of sample, but in different proportions. In the ALH84001 Martian meteorite and in our inorganic laboratory products, the most common [111]-elongated magnetite crystal morphology is [111]-ECO. In contrast, the most common morphology for magnetotactic bacterial strain MV-1 is [111]-THO. These results show that: (1) the morphology of [111]-elongated magnetite crystals associated with the carbonate globules in Martian meteorite ALH84001 is replicated by an inorganic process; and (2) the most common crystal morphology for biogenic (MV-1) magnetite is distinctly different from that in both ALH84001 and our inorganic laboratory products. Therefore, [111]-elongated magnetite crystals in ALH84001 do not constitute, as previously claimed, a "robust biosignature" and, in fact, an exclusively inorganic origin for the magnetite is fully consistent with our results. Furthermore, the inorganic synthesis method, i.e., the thermal decomposition of hydrothermally precipitated Fe-rich carbonate, is a process analogue for formation of the magnetite on Mars. Namely, precipitation of carbonate globules from carbonate-rich hydrothermal solutions followed at some later time by a thermal pulse, perhaps in association with meteoritic impact or volcanic processes on the Martian surface.