TRUNCATED HEXA-OCTAHEDRAL MAGNETITES: BIOSIGNATURES IN TERRESTRIAL SAMPLES AND MARTIAN METEORITE ALH84001; Kathie L. Thomas-Keprta[1], Simon J. Clemett[1], Dennis A. Bazylinski[2], Joseph L. Kirschvink[3], David S. McKay[4], Susan J. Wentworth [1], H. Vali[5] and Everett K. Gibson[4]; [1]Lockheed Martin, Mail Code C-23, NASA/JSC, Houston, TX, 77058, email: kthomas@ems.jsc.nasa.gov [2]Iowa State University, Dept. of Microbiology, 207 Science 1, Ames, IA 50011, [3]California Institute of Technology, Division of Geological and Planetary Sciences, 1200 E. California Blvd., Pasadena, CA 91125, [4]NASA/JSC, SN, Houston, TX 77058, [5]McGill University, Dept. of Earth and Planetary Sciences, 3450 University Street, Montreal, Quebec H3A2A7, Canada

Introduction: McKay *et al.* [1] suggested that the fine-grained magnetite (Fe_3O_4) located within Fe-rich rims surrounding the carbonate globules in the Martian meteorite ALH84001 were the fossil remains of Martian microbes. Here we compare magnetite crystals produced by terrestrial magnetotactic bacteria strain MV-1 with a subpopulation of magnetites from ALH84001. We find both to be chemically and physically identical -- specifically, both are single-domain, chemically pure, and exhibit an unusual crystal habit we describe as truncated hexa-octahedral [2]. On Earth such truncated hexa-octahedral magnetites are only known to be produced by magnetotactic bacteria. We suggest that the observation of truncated hexa-octahedral magnetites in ALH84001 are both consistent with, and in the absence of terrestrial inorganic analogs, likely formed by biogenic processes.

Methods: ALH84001 and MV-1 magnetite crystals were extracted from carbonate globules and cells, respectively, and analyzed by transmission electron microscopy (TEM) [3]. Magnetite crystal dimensions and habit were calculated from TEM observation of individual magnetites at multiple tilt angles, while chemical analyses were performed using energy dispersive x-ray spectroscopy (EDX).

Magnetotactic bacteria strain MV-1: Six specific properties of biogenic magnetite can be identified that when met collectively, constitute a rigorous biosignature (i.e., one that is not produced by natural inorganic processes). These are: (1) narrow size-range (i.e., single-domain for uniform magnetization) and shape (restricted width-to-length (W/L) ratios); (2) chemical purity; (3) few crystallographic defects; (4) truncated hexa-octahedral morphology (Fig 1.); (5) elongation along the [111] axis; and (6) alignment in chains within cells. These properties all act to optimize the interaction of the magnetites with a magnetic field. Since the strength of magnetic field interactions are much smaller than thermal energies kT, on thermodynamic grounds alone, chemical and biological processes cannot be influenced by magnetic fields to any measurable degree [4]. Hence the six characteristics, outlined above, have *evolved* through the process of natural selection. No published reports of inorganic truncated hexa-octahedral magnetites are known.

ALH84001 Truncated Hexa-octahedral Magnetites: ALH84001 magnetite crystals are found embedded in ~3.91 Ga old carbonate globules [5] that fill cracks and pore space. Approximately 25% of the Martian magnetites display 5 of the 6 properties described previously. Since our extraction procedure destroyed spatial relationships, the presence aligned magnetite chains could not be evaluated (furthermore, such chains are rarely preservered after cell death).

While the Martian truncated hexa-octahedral magnetite crystals are indistinguishable from those produced intracellularly by magnetotactic bacterium strain MV-1 [2,3] (Fig. 1), they are both chemically and physically distinct from the remaining ~75% of the magnetites in ALH84001. These other magnetites appear analogous to terrestrial inorganic magnetites. We note that intimate mixtures of both biogenic and abiotic magnetite crystals [3] are observed in terrestrial samples of both recent and ancient carbonates.

Summary and Conclusions: Truncated hexa-octahedral magnetites on Earth are exclusively the product of biogenic activity -- no natural or synthetic inorganic process is known that could explain the observation of truncated hexa-octahedral magnetites in a terrestrial sample. Unless there is an unknown and unexplained inorganic process on Mars, which is conspicuously absent on the Earth, we suggest that ALH84001 truncated hexa-octahedral magnetites formed by a mechanism similar to its terrestrial biogenic counterpart. *As such, these crystals are interpreted as Martian magnetofossils and constitute evidence of the oldest life yet found*.

In support of this, early Mars likely had free-standing bodies of liquid water [6], both organic [7] and inorganic carbon (e.g., atmospheric CO_2 [8]), energy sources, and likely possessed a planetary magnetic field [9] which would have been sufficient to support the growth of magnetotactic bacteria.

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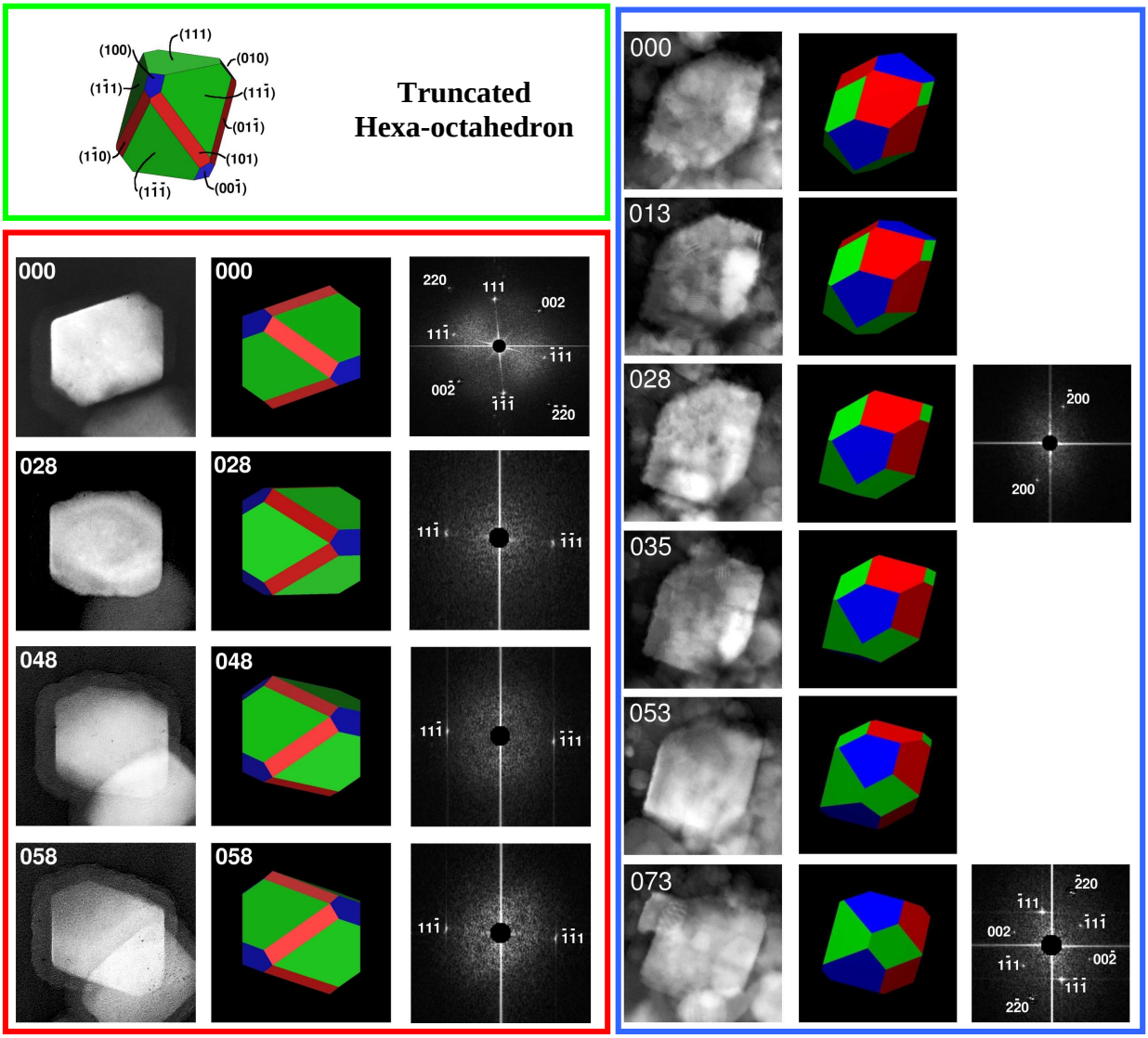

Figure 1: Idealized truncated hexa-octahedral crystal habit of magnetite (green box). A truncated hexa-octahedron is elongated along one of the [111] zone axes and displays eight {111} octahedral (green), six {110} dodecahedral (red), and six {100} cubic (blue) faces.

Example of a single truncated hexa-octahedral MV-1 magnetite examined under incremental TEM stage rotation (red box). Magnetite at 000° is viewed down the [1-10] zone axis. At 058° (~60° rotation) the same magnetite is now viewed approximately down the [-101] zone axis (mirror image of crystal at 000°). Rotation axis is perpendicular to the plane of the page and aligned vertically.

Example of a single, truncated hexa-octahedral ALH84001 magnetite, extracted from carbonate, and rotated a total of 73° (blue box). At 073°, the crystal is viewed down the [110] zone axis. Rotation axis is perpendicualr to the plane of the page and inclined ~20° to the right of the vertical. Note the {100}and {110}faces are expressed to a greater degree than observed for MV-1 magnetite example shown here.