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Rock Magnetic Constraints on the origin of putative biological magnetite in the Martian ALH84001 Carbonates

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McKay et al. (1996) discussed 4 lines of evidence that were consistent with the possible presence of ancient life on Mars. Although none of these have been falsified, the one that has triggered the most intense debate concerns the claim that some of the fine-grained magnetite crystals embedded in small carbonate deposits might have been formed by the magnetotactic bacteria. These magnetite particles, when examined by high-resolution transmission electron microscopy, are indistinguishable from particles only produced by magnetotactic bacteria on Earth (Thomas-Keprta et al., 2001). Unfortunately, the magnetic and microscopic analyses done to date do not allow us to provide a direct statistical test of the probability that these particles are of biological origin, vs. the hypothesis they form from high-temperature decomposition of siderite (FeCO3).

In the past decade, developments in superconducting magnetometry and electron microscopy now provide new experimental approaches that can be applied to this problem. First, the new Ultra-High Resolution Scanning Magnetic Microscopes (UHRSMMs) can detect magnetic moments 3 to 4 orders of magnitude below the sensitivity of the best superconducting rock magnetometers, and robust dipole-fitting routines allow the 3-D vector magnetic moment of tiny particles to be resolved quantitatively. We have shown recently that individual fragments of the famous ALH84001 carbonate blebs can be imaged clearly using this technique, opening the possibility of experimental tests that should distinguish low-temperature (biological) from high-temperature (thermal decomposition) magnetite. Magnetite produced by thermal decomposition of carbonate during shock heating should carry a relatively strong Thermo-Remanent Magnetization (TRM), whereas biological magnetite trapped during carbonate growth should have a much weaker detrital magnetization (DRM). Fuller et al. (1988) reported a simple technique that compares the relative intensities of the Natural Remanent Magnetizations (NRMs) to Isothermal and Anhysteretic magnetizations (IRMs and ARMs) that can easily distinguish TRMs from DRMs; this new sensitivity now be applied to these particles. Second, because the magnetotactic bacteria use genetic control to manufacture their magnetite crystals, particles within the same cell are of very similar size and shape. When these cells die and leave their magnetite crystals in the sedimentary record as magnetofossils, they produce clumps of similarly-sized crystals because they stick together magnetically with very strong force (Kobayashi et al., 2006). Sediment transport and removal processes cannot disaggregate them, but they do get scrambled together during extraction and high-resolution TEM studies. We therefore need to do very high-resolution studies that can demonstrate the position of these crystals within the carbonate matrix of the ALH 84001 carbonate precipitates. We propose to use the new focused ion-beam (FIB) milling techniques available at the Earth-Life Science Institute of TiTech to make 3-dimensional reconstructions, at a 5 to 10 nanometer scale, of rectangular chunks of the ALH84001 carbonate. At this resolution, the putative magnetosomes will be represented by up to 500 voxel elements, each with definitive elemental composition. We should be able to determine whether clusters of particles within these carbonates are of similar size and shape, as expected from collapsed magnetosome chains. It will then be very simple to do statistical tests to determine whether these clumps are non-random assemblages sampled from the background crystal size distribution. The debate about life on Mars may rise again!

Fuller et al.,1988, Geophys. Res. Lett., v. 15, p. 518-521.
Kobayashi, et al.,2006,: Earth and Planetary Science Letters, v. 245, no. 3-4, p. 538-550.
McKay et al.,1996, Science, v. 273, no. 5277, p. 924-930.
Thomas-Keprta, et al.,2001, Proc. Natl. Acad. Sci. USA, v. 98, no. 5, p. 2164-2169.

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