TITANOMAGNETITE-BEARING PALAGONITIC DUST AS AN ANALOGUE FOR MAGNETIC AEOLIAN DUST ON MARS.

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Introduction: The Mars Pathfinder magnetic properties experiment included two Magnet Arrays (MAs) which consist of five permanent magnets that have different strengths [1,2]. Each magnet is a cylindrical and ring magnet arranged in a "bulls-eye" pattern beneath a thin surface layer. The design of the MA permits estimation of magnetic properties (saturation magnetization and magnetic susceptibility) of adhering material, principally by the number of magnets that have adhering material and the extent each magnet is saturated. The two MAs passively sample aeolian dust.

By the end of the mission, bull's eye patterns were observed on the four strongest magnets by the IMP (Imager for Mars Pathfinder). The interpretation of the experiment team [1,2,3] is that the average saturation magnetization of Martian aeolian dust is 4±2 Am^2/kg and that its magnetic susceptibility is at least 18×10^{-6} m^3/kg. Furthermore, they argue that the dust particles are composite particles consisting of a strongly magnetic phase and weakly magnetic or nonmagnetic phases. The proportion of the strongly magnetic phase is expected to vary from particle-to-particle, and most dust particles, as opposed to a small subset, contain the strongly magnetic phase. These conclusions are independent of the mineralogical composition of the strongly magnetic phase.

The mineralogical composition of the strongly magnetic phase is not known. The preferred interpretation of the Pathfinder (and also Viking) experiment teams [1-4] is maghemite, which occurs as a cement or stain. They acknowledge that titanomagnetites and/or titanomaghemites (i.e., Fe-Ti spinels) are also possible interpretations for the strongly-magnetic phase.

Identification of the strongly magnetic phase has implications for alteration pathways on Mars. According to [1,2], maghemite implies a three-step process involving dissolution of ferrous iron, oxidation to ferric iron, and precipitation of maghemite as a cement or stain to form composite particles. On the Earth, maghemite is not normally formed by this pathway, but is formed by such processes as dehydroxylation of lepidocrocite and heating of ferric oxides in the presence of organic matter [e.g., 5].

A lithogenic origin is implied by Fe-Ti spinels. Palagonitic tephras that are good spectral analogues of Martian bright regions have Fe-Ti spinels as the strongly magnetic phase [6,7]. The spinels occur as grains within composite particles. The saturation magnetization and magnetic susceptibility for palagonitic tephras (<1 mm size fraction) are ~1-2 Am^2/kg and 7-20 $\times10^{-6}$ m^3/kg, respectively, at 293 K [8]. Both parameter values are at the low end of ranges inferred for Martian dust (4±2 Am^2/kg and $>18\times10^{-6}$ m^3/kg [1,2,3]).

To test the "palagonite" model for Martian dust, magnetic properties experiments were performed with a copy of the Pathfinder MA on Haleakula (Maui) and Mauna Kea (Hawaii) volcanoes.

Methods: MA experiments were done near the summit of Haleakula and near the VLBA telescope and at the Puu Nene cinder cone on Mauna Kea. Procedures are discussed by [9]. The MA is identical to the ones flown on Mars Pathfinder except for the surface coating. It was made at the Oersted Laboratory, Niels Bohr Institute for Astronomy, Physics, and Geophysics, University of Copenhagen, Denmark, and provided courtesy of Drs. Jens Martin Knudsen and Morten Bo Madsen. The gravity difference between the Earth and Mars does not significantly affect application of the experiments to Mars, according to [10]. Low-field magnetic susceptibilities were measured at ~293 K using a Bartington Magnetic Susceptibility Meter and an MS2B sensor.

Results and Discussion: Figure 1 shows images for the three MA experiments. In each case, palagonitic dust was collected by the four strongest magnets. The amount of dust on MA surfaces away from the magnets correlates with a qualitative assessment of wind velocity during the experiments. At Puu Nene, where the wind was strongest, dust particles did not collect on non-magnetic MA surfaces. At the VLBA telescope, where the wind was the weakest, dust collected on non-magnetic surfaces. Haleakula is an intermediate case.

The observation of palagonitic dust adhering to the four strongest magnets is the same observation as for Martian dust [1,2]. Measurement of the magnetic properties of collected palagonitic dust provides a test of the inferred magnetic properties for Martian dust. Unfortunately, sufficient dust to make these measurements could only be obtained from the VLBA experiments, which are described by [9]. Briefly, the magnetic susceptibility ranged from 15×10^{-6} to 19×10^{-6} m^3/kg without any dependence on magnet strength. This range confirms the value of 18 $x10^{-6}$ m^3/kg reported by [3] as the minimum value required for Martian dust to be collected by four magnets.

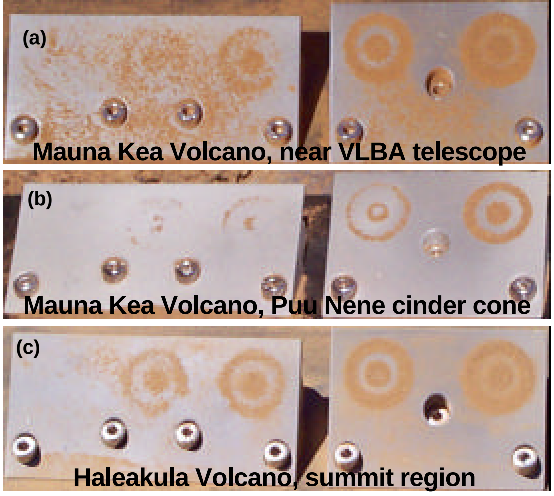

Figure 1. Results of experiments with a Pathfinder Magnet Array (MA) and palagonitic aeolian dust on Mauna Kea and Haleakula Volcanoes (Hawaii). Magnet strength decreases right to left.

Two other conclusions of the Pathfinder MA experiment, that the Martian dust particles are composite particles consisting of a strongly magnetic phase and weakly magnetic or nonmagnetic phases and that most dust particles (rather than a small subset) contain the strongly magnetic phase [1,2], are properties of palagonitic dust. The susceptibility for dust collected from the base plate of the MA and for bulk source soil (<1 mm) in the VLBA experiment are 8 $x10^{-6}$ and 11 $x10^{-6}$ m^3/kg, respectively, implying that the magnets collected a large fraction (~50%) of dust particles. The susceptibilities for the bulk source soils for the Puu Nene and Haleakula experiments were 9.8 $x10^{-6}$ and 10 $x10^{-6}$ m^3/kg, respectively, implying source material magnetically similar to that for VLBA experiments.

Mössbauer spectra (Figure 2) show that the dust collected by the magnets (VLBA experiment) has the same mineralogical composition (with respect to iron-bearing phases) as bulk dust as represented by the sample obtained from the base plate. Note the spectral lines from titanomagnetite, the strongly magnetic phase in palagonitic dust. To first order, the same relative proportion of iron-bearing phases is present independent of the strength of the collecting magnet. Although these spectra do not show that individual dust particles are composite particles, it does show that the dust collected behaves as if composite particles are present.

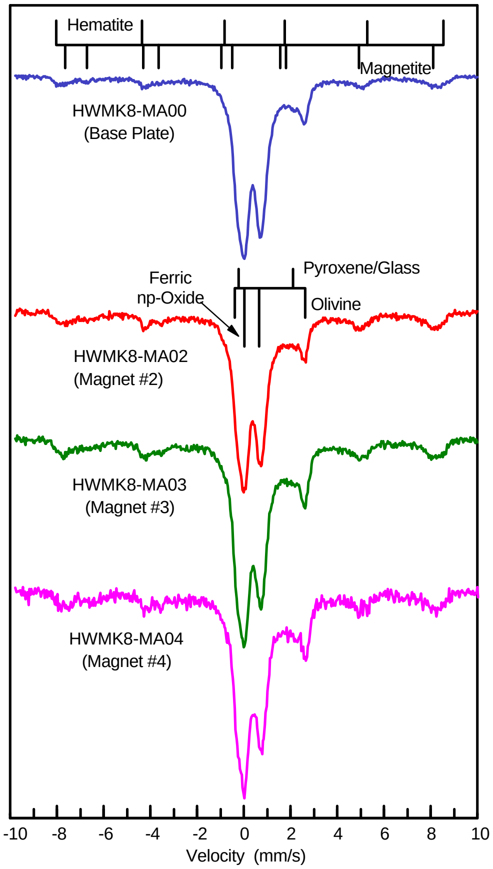

Figure 2. Mossbauer spectra (293 K) for palagonitic dust collected from MA base plate and magnets #2, #3, and #4 for experiment in Figure 1a.

Summary: MA experiments with palagonitic dust on Haleakula and Mauna Kea volcanoes confirm that the minimum magnetic susceptibility for Martian dust collected by the MAs is ~18 $x10^{-6}$ m^3/kg. Palagonitic dust, with lithogenic titanomagnetite as the strongly magnetic phase, satisfies the essential constraints of the Pathfinder MA experiment, namely dust collection by four magnets, composite particles, and a large fraction of dust particles that contain magnetic grains. Thus, the palagonite model for Mars can be extended from the spectral properties of Martian bright regions to magnetic properties. Martian palagonite could be derived by alteration of both volcanic and impact basaltic glass [8].

References: [1] Hviid et al., *Science*, *278*, 1768, 1997; [2] Madsen et al., *JGR*, *104*, 8761 1999; [3] Hargraves et al., *EOS*, *80*, 168, 1999; [4] Hargraves et al., *JGR*, *84*, 8379, 1979; [5] Cornell and Schwertmann, *The Iron Oxides*, 1996; [6] Morris et al., *JGR*, *95*, 14427, 1990; [7] Morris et al., *GCA*, *57*, 4597, 1993; [8] Morris et al., *JGR*, submitted, 1999; [9] Morris et al., LPSXXX, #1802, 1999; [10] J.M. Knudsen and M.B. Madsen, personal communication, 1999.