Hematite at Meridiani Planum: Detailed Spectroscopic Observations and Testable Hypotheses

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1. Introduction. The landing site of the Mars Exploration Rover Opportunity was selected largely on the basis of the discovery of gray crystalline hematite by the Mars Global Surveyor (MGS) Thermal Emission Spectrometer (TES) currently in orbit around Mars [1]. Since the initial discovery, several authors [2-10] have performed detailed spectroscopic and/or geomorphological studies of the gray hematite-bearing regions of Mars. Initial observations by the Mini-TES instrument on Opportunity have confirmed the presence of hematite at Meridiani Planum. Additional detailed measurement by Mini-TES as well as subsequent observations by the Mössbauer spectrometer and Pancam will help to place the hematite in a geologic and geochemical context.

Hypotheses regarding the formation of gray hematite on Mars fall into two general categories—wet and dry. Hematite formational mechanisms involving water include (1) low-temperature precipitation of Fe-oxides or hydroxides from standing, oxygenated, Fe-rich water, followed by subsequent alteration to gray hematite, (2) low-temperature leaching of iron-bearing silicates and other materials leaving a Fe-rich residue (laterite-style weathering) which is subsequently altered to gray hematite, (3) direct precipitation of gray hematite from Fe-rich circulating fluids of hydrothermal or other origin, and (4) formation of gray hematite surface coatings during weathering. Formation of gray hematite under dry conditions occurs by the thermal oxidation of magnetite.

2. Results. Average hematite-rich and hematite-poor soils as seen by Mini-TES are shown in Figure 1. The hematite-rich soil spectrum has characteristic hematite absorption bands centered at 450 and 520 cm^{-1}. The spectrum also contains a broad absorption between 800 and 1200 cm^{-1}, indicating the presence of silicate minerals in the soil. The minimum emissivity of the 520 cm^{-1} hematite band is 0.94, compared to a value of 0.93 for the 450 cm^{-1} band. These absorption bands are not seen in the hematite-poor soil spectrum. The lack of a 390 cm^{-1} feature indicates that the hematite spectrum in dominated by c-face emission [3,9].

The hematite at Meridiani Planum is not uniformly distributed (Figure 2). The highest concentration of hematite is seen above the outcrop just to the northwest. Inside the crater, the hematite concentration is strongest in the western half of the crater, although complete coverage is yet to be obtained.

The first Mössbauer [11] analyses of the soil at Meridiani Planum were taken off of the right-hand side of Figure 2, lack a strong hematite signature, but indicated the presence of some magnetic phase. These results are consistent with the observations made by Mini-TES that the soils in the immediate vicinity of the lander are hematite-poor.

Pancam spectra of the Mini-TES hematite-rich soils show no strong ferric absorption edge that is typical of hematite [12-13]. This strongly suggests that the hematite present at Meridiani Planum is indeed gray, as hypothesized by [1]. Additional Pancam spectra of darker regions of the upper unit in the outcrop contain a 530 nm absorption consistent with the presence of a red crystalline ferric oxide. At this time, it is unclear how or if this red ferric oxide is related to the gray hematite observed by Mini-TES.

3. Discussion. Initial results from Mini-TES indicate that the gray hematite at Meridiani Planum is consistent with the low-temperature formation hypothesis of [9]. The relative emissivities of the 450 and 520 cm^{-1} absorption bands in the hematite spectrum are indicative of a poorly ordered crystalline structure, indicating formation of hematite at low temperature from goethite or some other iron oxyhydroxide. Future Mini-TES observations of hematite-rich soils from close range will provide higher quality spectra that will aid the interpretation of formational mechanisms. Additional mapping of the distribution of red ferric oxide by Pancam and its relation (or lack thereof) to gray hematite may provide insight into the origin and physical properties of the gray hematite.

Because some formation mechanisms for gray hematite call for derivation from a precursor mineral, high-quality Mössbauer spectra will be extremely important for identifying possible remnant precursor phases. Because Mössbauer spectra vary as a function of temperature, information such as crystallinity, magnetic transition, and grain size can be obtained by Mössbauer measurements taken at different times of day.

4. Summary. While preliminary analysis of the Mini-TES spectra of hematite-rich soils at Meridiani Planum are consistent with a low-temperature formation mechanism it is too early to attribute an aqueous origin to it. Targeting of hematite-rich soils (and in the long term, possible hematite outcrops) from close range will provide high quality spectra that will enhance the understanding of the hematite spectrum. Additional observations by Pancam and the Mössbauer spectrometer and the rest of the Athena science payload will provide important insight into the formation of hematite at Meridiani Planum.

References. [1] Christensen, P. R. et al., *J. Geophys. Res.* 105, 9623-9642, 2000. [2] Hynek, B. et al., *J. Geophys. Res.*, 107(E10),5088,doi: 10.1029/2002JE001891, 2002. [3] Lane, M. D., et al. *J. Geophys. Res.* 107(E12), 5126, doi: 10.1029/2001JE001832, 2002. [4] Chapman, M. G., and K. L. Tanaka, *Icarus*, 155, 324-339, 2002. [5] Arvidson, R. E., et al., *J. Geophys. Res.*,108(E10),8073,doi:10.1029/2002JE001982, 2003. [6] Calvin, W. M., et al., *Sixth International Conference on Mars*, abstract 3075, 2003. [7] Fallacaro, A., and W. M. Calvin, *Sixth International Conference on Mars*, abstract 3067, 2003. [8] Catling, D. C., and J. M. Moore, *Icarus*, 165, 277-300, 2003. [9] Glotch, T.D. et al., *J Geophys Res*., submitted. [10] Kirkland, L. et al., *Geophys. Res. Lett.*, in press. [11] Klingelhöfer, G., et al., This Conference. [12] Morris, R. V. et al., *J. Geophys. Res.*, 105, 1757-1817, 2000. [13] Morris, R. V. and D. C. Golden, *Icarus*, 134, 1-10, 1998

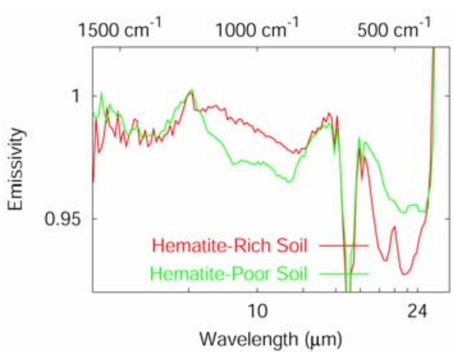

Figure 1. Spectra of hematite-rich and hematite poor soils as seen by Mini-TES. Both spectra show silicate features between 8 and 12 µm, but only the hematite-rich soil shows the characteristic absorptions at long wavelengths.

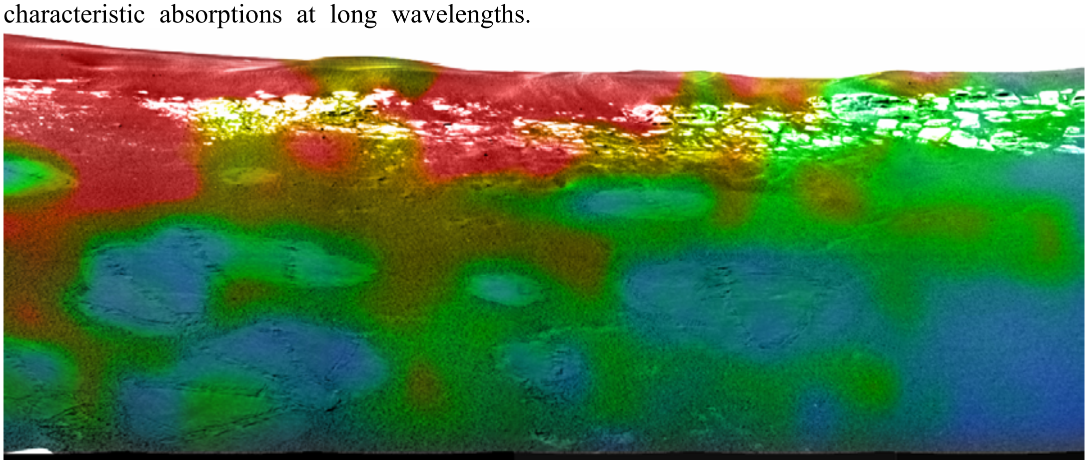

Figure 2. Map of hematite abundance for part of the Meridiani Planumlanding site. Warmer colors indicate higher hematite abundance than cooler colors. Hematite abundance is low on the lander bounce marks, and high above the outcrop and to the west.