# VARIATIONS IN VISIBLE/NEAR-INFRARED HEMATITE SPECTRA RELATED TO GRAIN SIZE AND CRYSTALLINITY.

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**Introduction:** Drill fines created by the Curiosity rover at Gale Crater, Mars have exhibited variable visible/near-infrared spectral features attributable to the presence of ferrous and ferric minerals [1-4]. Drilled locations within the Murray formation and on the Vera Rubin Ridge (VRR) were shown by the CheMin instrument to contain significant amounts of hematite [e.g., 5]. However, typical hematite spectral features (e.g., absorptions near 530 nm and 860 nm) have varied inconsistently with hematite abundances [1,3,4,6,11]. This suggests that other factors such as hematite grain size or crystallinity, the presence of amorphous materials, and/or photometric effects play a role in the observed spectra. Using laboratory spectra of hematite acquired at difference grain sizes, we document the variability in key spectral features. We also compare spectral parameters computed from Mastcam spectra on Mars of three hematite-bearing ChemCam calibration target (CCCT) samples with known hematite and amorphous material abundances.

**Methods**. Spectra of the HEM103 hematite sample were acquired by [7] in bidirectional geometry (i=30°, e=0°) at five grain size fractions (dry-sieved) ranging from <45 µm to 500-1000 µm using an ASD spectrometer (350-2600 nm). Spectra of the <45 µm HEM102 sample were also acquired by [7] (at i=0°, e=0°) using an Ocean Optics spectrometer (350-860 nm) under four different surface preparations, and spectra of the HEM103 sieved fractions. Spectra of specular hematite GDS69 were acquired by [8] at (wet-sieved) grain size fractions from <10 µm to 150-250 µm. For each size separate we calculated the 535 nm (Fig. 2) and 867 nm (Fig. 3) band depths typical of hematite, as well as the 750-840 nm slope (Fig. 4, [1,3]). We also used Mastcam multispectral images of the CCCT (Sol 838), calibrated with techniques from [2] (Fig. 5). We calculated similar spectral parameters for the hematite-bearing sintered ceramic targets #7-#9. From X-ray diffraction, the CCCT targets were determined to contain 9-10 wt% hematite and amorphous abundances of 47±3, 42±3, and 33±2 wt %, respectively, for targets #7, #8, and #9 [9]. The average grain size associated with each target was ~30 µm.

**Results**. The smallest size fractions exhibited the strongest spectral contrast, including absorptions near 530 nm and 860 nm (Fig. 1). The different surface preparations for the <45 µm HEM102 exhibited nearly identical spectra. The 535 nm and 867 nm band depths decreased sharply as grain size increased, but reached minimum values at sizes ranging from ~300 µm [7] to ~40-80 µm [8] (Figs. 2-3). These differences were likely related to the dry- vs. wet-sieving techniques used. The 750-840 nm slope increased sharply with grain size, but leveled off after 50-100 µm (Fig. 4). Spectral parameter images for the CCCT (Fig. 5) demonstrated increased band depths and near-infrared slopes from #7 to #9, coincident with the decrease in amorphous content of these samples, which otherwise have the same crystalline hematite content [9]. Fig. 6 shows Mastcam spectra of targets #7-#9, and a histogram of 908-1013 nm slope values for each, quantitatively showing the increase in spectral contrast with decreasing amorphous content.

**Conclusions**. The drill samples in the Murray Fm exhibit hematite-like spectra albeit with variable spectral contrast that anti-correlates with CheMin measured hematite content [1,4]. Such variations may represent contributions from other ferric oxide, oxyhydroxide, and/or oxyhydroxysulfate phases (including amorphous components), ferric phyllosilicates [3,4], and grain size [3-6] or photometric effects [10]. In our lab study, smaller grain sizes of crystalline hematite generally exhibit the greatest ferric spectral slopes and band depths, although variations depend on the hematite sample and sieving techniques [7-8]. Multispectral CCCT observations suggest that amorphous content is a key influence on hematite spectral parameters, such that less amorphous (more crystalline) samples exhibit greater spectral contrast [12]. These observations, in combination with studies of gray/red hematite contributions in a silica/sulfate-rich matrix [6], may help explain some of the discrepancies between XRD-measured hematite content and spectra in Curiosity observations on Mars.

**References**: [1] Johnson,J., et al., LPSC 2017 #1316; [2] Wellington,D. et al., Amer. Mineral., 102(6), 1202-1217, 2017; Bell, J.,et al. (2017), Earth Space Sci., 4,396–452, doi:10.1002/2016EA000219; [3] Fraeman,A. et al., LPSC 2018, #1557; [4] Jacob,S. et al., this conference; [5] Rampe,E., et al,. LPSC 2017, #2821; [6] Horgan,B., et al., this conference; [7] Cloutis,E. et al., Icarus 197.1 (2008): 321-347; [8] Kokaly,R., et al., USGS Data Ser. 1035, 61 p., https://doi.org/10.3133/ds1035; [9] Vaniman,D., et al., Space Science Rev., 170, 1-4, 229-255, 2012; [10] Johnson,J. et al, this conference; [11] Morris,R., et al., JGR 90.B4 (1985): 3126-3144; [12] Morris,R., and Lauer,H., JGR Morris, 95.B4 (1990): 5101-5109.

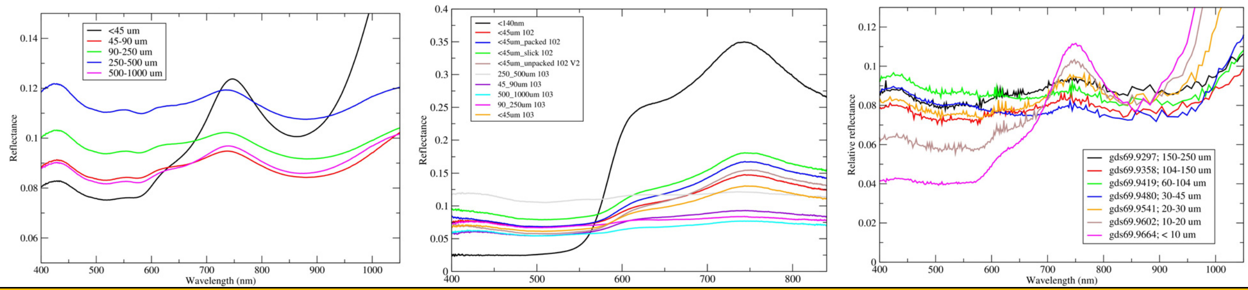



Figure 1. Lab spectra of hematite at different grains sizes from [7] (left-HEM103, middle-HEM102/103) and [8] (right-GDS69).

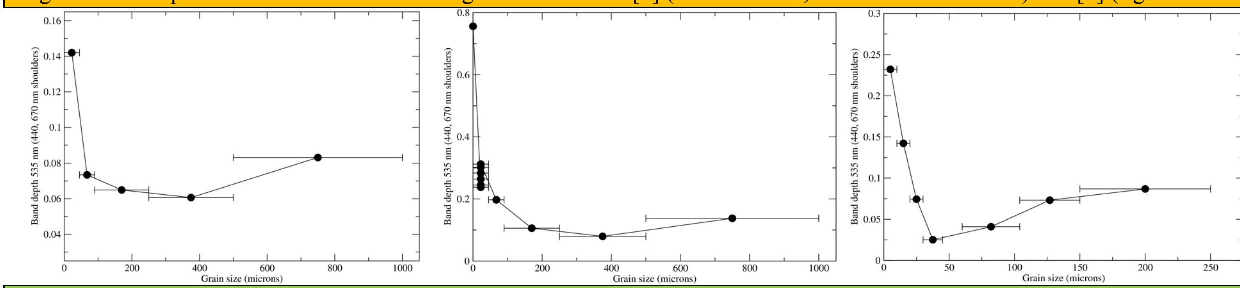



Figure 2. 535 nm band depths of crystalline hematite in different grains size ranges from [7] (left, middle) and [8] (right).

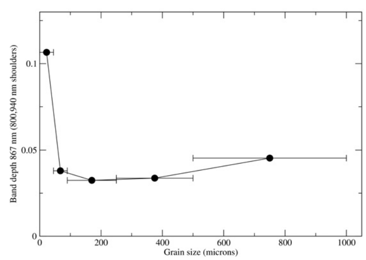
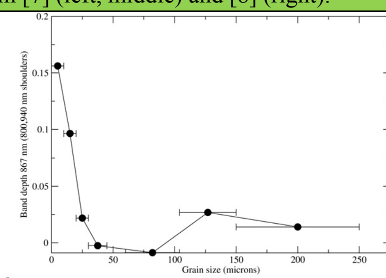



Figure 3. 867 nm band depths of crystalline hematite in different grains size ranges from [7] (left) and [8] (right).



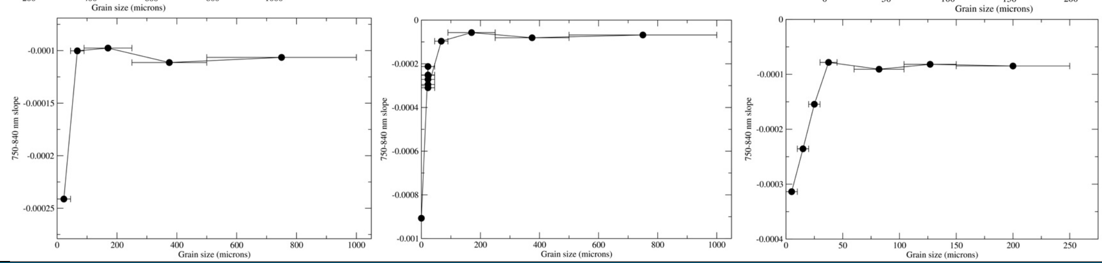




Figure 4. 750-840 nm slopes of crystalline hematite in different grains size ranges from [7] (left, middle) and [8] (right).

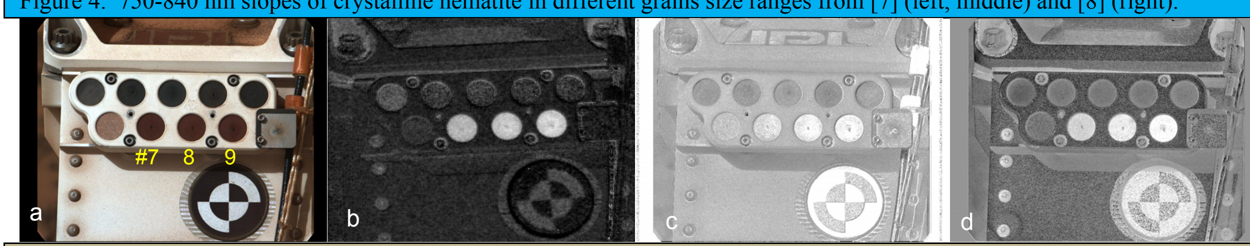
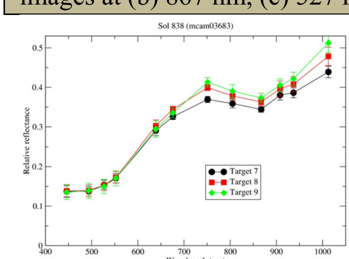
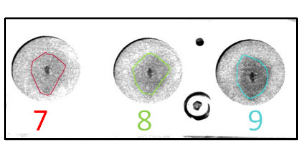



Fig. 5. (a) Bayer color Mastcam M100 image of CCCT (mcam03683, Sol 838, targets #7-#9 marked); band depth images at (b) 867 nm, (c) 527 nm; (d) 908-1013 nm slope image. Brighter tones = stronger band depths and slopes.



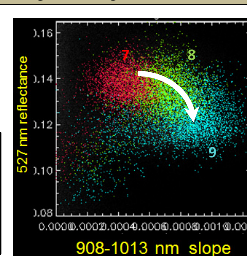




Fig. 6. Mastcam spectra of CCCTs #7-#9 (left); regions of interest on labeled targets (middle) used for histogram of 908-1013 nm slope vs. 527 nm reflectance for targets #7-#9 (right), demonstrating increase in slope from #7→#9, coincident with decrease in amorphous content.