Mineralogy of basaltic sands at Meridiani Planum from the Miniature Thermal Emission Spectrometer and comparison to orbital observations.

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Introduction: The Miniature Thermal Emission Spectrometer (Mini-TES) instrument aboard the Mars Exploration Rover Opportunity has been used to acquire thousands of spectra from the surface of Meridiani Planum [1]. The Mini-TES measures thermal infrared energy at a similar spectral resolution and range to that of the Thermal Emission Spectrometer (TES) aboard the Mars Global Surveyor orbiting spacecraft. This similarity between the two instruments provides a unique opportunity for detailed surface-to-orbit comparisons. In addition, complementary compositional information from the APXS and Mössbauer instruments are also available. This new combination of datasets will be used to refine the modal mineralogy of Meridiani basaltic sands and to evaluate the accuracy of mineral abundance determination from orbit.

From orbit, basaltic sands dominate the spectral signature measured by TES both inside and outside of the hematite region in Meridiani Planum [2-4]. Globally, low-albedo regions are dominated by basaltic lithologies. Therefore, this work focuses on the basaltic sands component of the landing site, and compares the emissivity and derived mineralogy of basaltic sands from Mini-TES to derived surface emissivity and mineralogy of the Opportunity landing site and surrounding low-albedo surfaces with TES data. The Mini-TES data used in this work is a single basaltic sand endmember that was previously derived by [5]. *Glotch et al.* [5] applied factor analysis and target transformation techniques to the Mini-TES dataset acquired between Sols 1-350, and found that seven independently-varying endmember components are present in that dataset. These are: hematite, silica/sulfate-rich outcrop, basaltic sand, fine-grained dust, two atmospheric dust opacity shapes, and blackbody. The derived basaltic shape should be free of influence from dust, outcrop, and hematite components, unlike previous studies of basaltic sands using Mini-TES [1,6].

Methods: To estimate the modal mineralogy from TES spectra measured from orbit, and from the basaltic endmember derived by [5], we employ linear least squares fitting techniques similar to that of *Ramsey and Christensen* [7] with a spectral library composed of common igneous and secondary minerals. Least squares fitting is performed in three different ways: (1) iterative removal of negative percentages until only positive percentages remain in the solution [7-8], (2) same as (1), except that small (<2%) negative percentages are allowed to remain in the solution until the last iteration, when only endmembers modeled with positive concentrations are allowed, and (3) simultaneous least squares fitting with non-negativity constraints. These techniques represent a modification to the previous approach to modeling TES spectra. Model results from these three methods are compared to evaluate the effects of insignificant endmember percentages on the final answer. Here, we present results of only one of the three models.

To date, endmember selection and least squares fitting have been applied without guidance from other available compositional data. However, future work will incorporate mineralogic and chemical constraints imposed from APXS and Mössbauer measurements. An example of a possible constraint is the olivine-to-pyroxene ratio from the Mössbauer measurements of basaltic soils. Results from unconstrained and constrained models will be compared and discrepancies will be evaluated.

Surface emissivity is derived for the landing site and surroundings from TES data using the methods of [9-10]. Because a single TES pixel is much larger than the area traversed by Opportunity during the first 350 sols, and because multiple TES spectra are needed to improve the signal-to-noise, the data selection area for the landing site was expanded to consist of a 0.4° by 0.4° box centered on the midpoint between Eagle and Endurance Craters (Figure 1). For comparison to regional and global emissivity of low albedo regions, regional spectra previously derived by *Rogers* [11] are used.

Preliminary results: *Surface-orbit emissivity comparisons.* Surface emissivity of the landing site measured by TES may be reasonably well-modeled with the hematite (10%), silica/sulfate-rich outcrop (25%), and basaltic sand (65%) endmembers of *Glotch et al.* [5] (Figure 2). Surface dust is not required to model the spectrum, indicating that it is not a significant component in the vicinity of the landing site, consistent with ground observations [1,12] and with the TES-derived albedo (~0.13). Note that hematite abundance is underestimated because of the restricted wavelength range (no data < 379 cm^{-1}) of the Mini-TES endmember derived by [5]. Use of a full mineral library, from 300-1301 cm^{-1}, instead of the endmembers derived by [5], produces hematite abundance of ~25%.

Comparison of basaltic sands modal mineralogy derived from Mini-TES and TES. For the following discussion, it is important to remember that the TES measurements include outcrop and hematite components, precluding direct comparison to the Mini-TES basalt shape. To minimize these differences, the hematite component was removed from the TES-derived mineralogy and the remaining modes were normalized to 100%. Once normalized for hematite abundance, TES-derived mineralogy of the landing site and Mini-TES-derived mineralogy of the basaltic soils component are similar, with most phases (except plagioclase) modeled to within ~5% (absolute) of each other. Derived pyroxene mineralogy from TES spectra of the landing site is dominated by high-Ca clinopyroxene and pigeonite, similar to derived mineralogy for Mini-TES spectra [5]. The similarity between surface and orbit-derived mineralogy is surprising; it was expected that the sulfate/high-silica phases would contribute more significantly to the emissivity measured from orbit. This result may be partially explained by differences in wavelength range used for modeling. The Mini-TES instrument SNR is higher at wavenumbers < ~379 cm^{-1}; therefore, data in this wavelength range was not used to derive the basaltic endmember [5]. If the TES spectra are fit using the same wavenumber range as the Mini-TES spectrum, relative abundances of high-silica phases increase, and pyroxenes decrease, as expected.

Comparison of TES landing site emissivity/mineralogy with non-hematite areas in Meridiani. With the exception of spectral features due to coarsely crystalline hematite, the surface emissivity derived for the landing site is similar to low-albedo surfaces located hundreds of km from the hematite deposit in Meridiani Planum (Figure 3). This is consistent with previous results comparing TES data from the hematite unit ("Ph") to dark cratered terrain to the south ("DCT") [13]. While mostly similar, there are small differences between TES spectra of the landing site and non-hematite regions of Meridiani Planum. Differences in derived mineralogy, once normalized for hematite abundance, are primarily related to pyroxene abundance. Pigeonite is modeled at 15% from TES spectra acquired in the vicinity of the landing site, however it is not used in the least-squares solution for the average low albedo surface just outside of the Meridiani hematite unit. This suggests that some, albeit small, mineralogic variations are present between the basaltic sands near Opportunity and sands outside of the hematite unit.

References: [1] Christensen, P. R. et al., *Science (306)* 2004 [2] Christensen, P. R. et al., *JGR (105)*, 2000 [3] Christensen, P. R. et al., *JGR (106)*, 2001 [4] Glotch, T. D. et al., *JGR (109),* 2004 [5] Glotch, T. D. et al., submitted [6] Yen, A. S. et al., *Nature (436)* 2005 [7] Ramsey , M. S. and P. R. Christensen, *JGR (103)*, 1998 [8] Bandfield, J. L. *JGR (107)* 2002 [9] Bandfield, J. L. et al., *JGR (105)*, 2000 [10] Smith, M. D. et al., *JGR (105)*, 2000 [11] Rogers, A. D., *Ph.D. Diss., ASU,* 2005 [12] Bell, J. F. III et al., *Science (306)*, 2004 [13] Arvidson, R. E. et al., *JGR (108),* 2003.

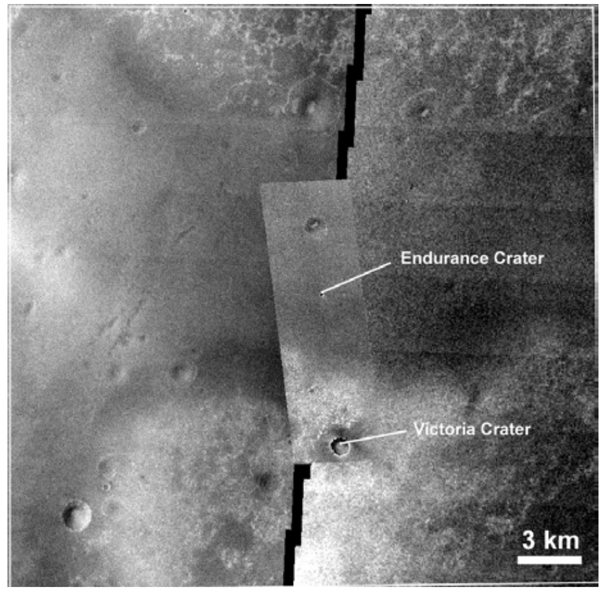

Figure 1. Area used for extraction of TES spectra. THEMIS VIS and a single MOC NA image are shown.

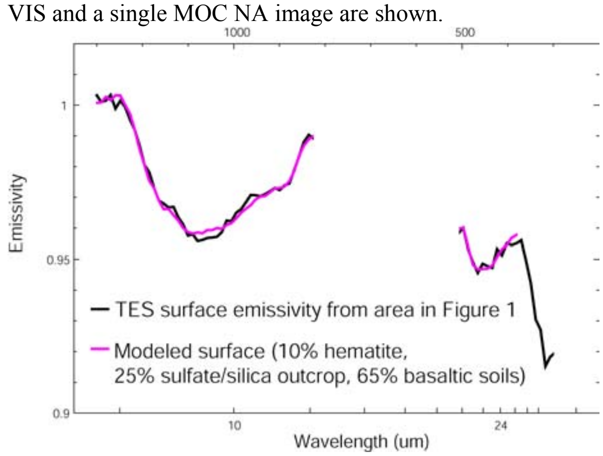

Figure 2. Modeled TES surface emissivity using Mini-TES derived endmembers [5].

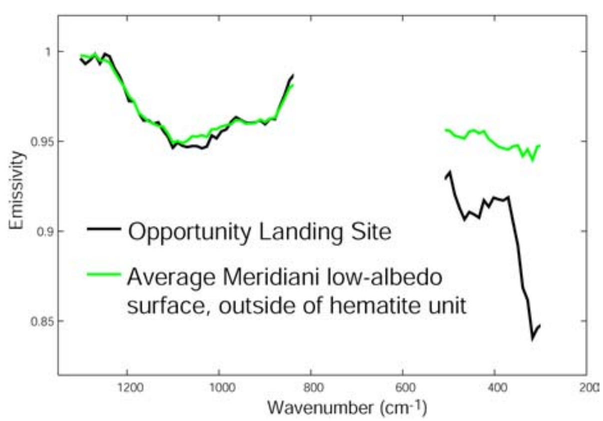

Figure 3. TES surface emissivity of landing site compared with regional low-albedo surfaces. Spectral differences are mostly due to hematite.