

SPECTRAL PROPERTIES OF PHOBOS FROM THE MARS GLOBAL SURVEYOR THERMAL EMISSION SPECTROMETER: EVIDENCE FOR WATER AND CARBONATE T. D. Glotch¹, C. S. Edwards², and D. S. Ebel³, ¹Dept. of Geosciences, Stony Brook University, Stony Brook, NY, timothy.glotch@stonybrook.edu, ²United States Geological Survey, Flagstaff, AZ, ³American Museum of Natural History, New York, NY.

Introduction: The spectral properties of Phobos have been previously investigated at both visible/near-infrared (VNIR) and mid-infrared (MIR) wavelengths [1-7]. These works have shown that Phobos spectra include a broad 0.65 μm feature that may be attributable to Fe-bearing phyllosilicates or Rayleigh scattering by nanophase metallic Fe particles. VNIR spectra of Phobos also include a weak 2.8 micron metal-OH feature that may be diagnostic of desiccated phyllosilicates or solar wind-induced hydroxylation of the Phobos regolith surface. At MIR wavelengths, Phobos displays a variety of spectral classes, which are consistent with tectosilicates, such as feldspars and mixtures of phyllosilicate minerals.

In this work, we re-evaluate MIR spectra of Phobos acquired by the Mars Global Surveyor (MGS) Thermal Emission Spectrometer (TES) experiment. We find that TES spectra are consistent with the presence of bound water and carbonate on the surface of Phobos. The derived spectra are consistent with the mineralogy of D-type asteroids and meteorite analogs such as Tagish Lake.

Methods: We gathered TES spectra from four early mission MGS aerobraking orbits (orbits 476, 501, 526, and 551) and culled the data to include only the highest temperature daytime observations of the Phobos surface (Figure 1). The highest quality spectra all were acquired during orbit 551. These are used exclusively for our analysis. A total of 88 emissivity spectra were chosen with bolometric temperatures > 240 K. This temperature cutoff provides relatively high signal to noise ratio (SNR) spectra while still providing an adequate number of spectra with good geographical coverage of Phobos for our analysis.

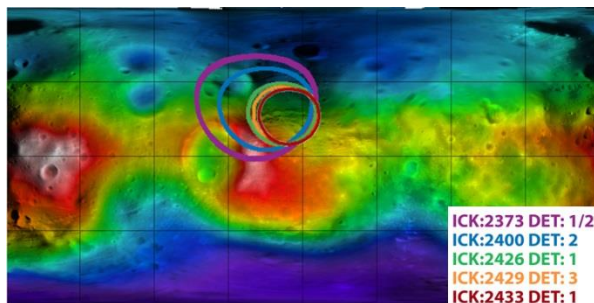


Figure 1. Topographic map of Phobos with the approximate footprints of several TES spectra of Phobos from orbit 551. ICK = incremental counter keeper. DET = detector.

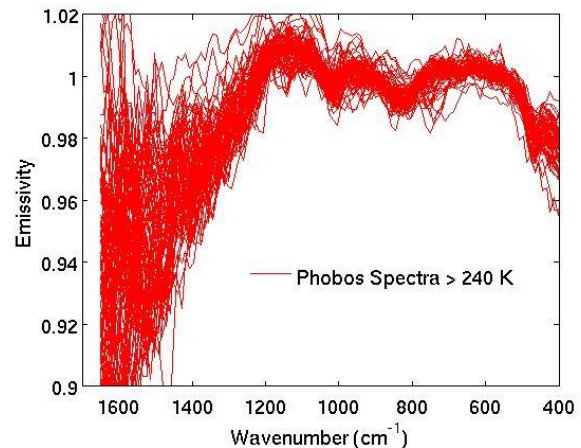


Figure 2. A total of 88 TES emissivity spectra with bolometric temperatures > 240 K were used for this study.

For the surface of Phobos, subpixel temperature mixing is clearly an issue. Therefore, we modeled the radiance of the surface as a linear combination of blackbodies of many different temperatures. The resulting emissivity spectra occasionally have emissivity values greater than unity, but are not affected by strong slopes due to surface anisothermality (Figure 2).

Results: Surface emissivity spectra of Phobos display a variety of spectral shapes while having some features in common. Most spectra display a strong drop in emissivity shortward of the Christiansen Feature (CF), typical of finely particulate silicates. The average Phobos spectrum (Figure 3) displays emissivity minima at 1015, 820, and ~ 460 cm^{-1} . The CF is broad and centered at 1130 cm^{-1} (8.85 μm), indicating an ultramafic composition if the surface is optically immature (devoid of space weathering). It has been shown for the Moon, however, that optically mature surfaces have CF positions that tend to be shifted by ~ 0.2 μm to longer wavelengths compared to optically immature surfaces of the same composition [8]. Assuming the average surface of Phobos is optically mature, the corrected CF position of ~ 8.65 μm indicates a surface that is still very low in silica. The longer wavelength emissivity minima (Figure 3) are not consistent with known olivine or pyroxene fundamental or transparency features. This is in line with VNIR observations, which lack strong 1 and 2 micron Fe^{2+} absorption features, although lack of strong VNIR features may also be the result of optical maturity. Desiccated phyllosilicates [5] may also be responsible for the long wavelength position of the CF.

The average TES spectrum also displays a clear emissivity maximum at 1590 cm^{-1} ($6.3\text{ }\mu\text{m}$), consistent with surface hydration. The strength of this feature varies from spectrum to spectrum, perhaps as a result of surface hydration heterogeneity or the comparatively lower SNR in this portion of the spectrum. This hydration feature may be due to water bound in minerals or transient water formed through interaction of the solar wind with the Phobos surface. The relatively strong 1590 cm^{-1} features found in the TES data are somewhat surprising due to the lack of a strong $3\text{ }\mu\text{m}$ water band in VNIR observations of Phobos, although some CRISM spectra display a weak $2.8\text{ }\mu\text{m}$ M-OH band [5].

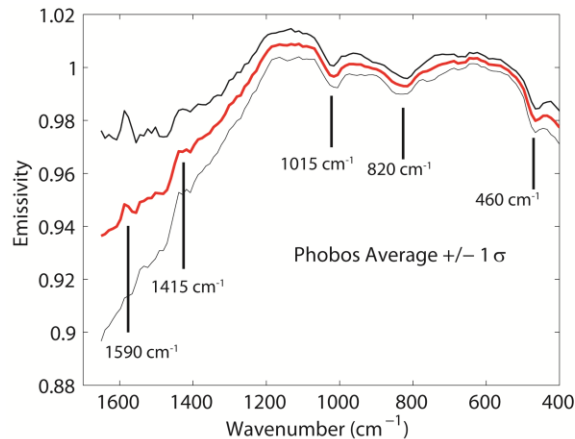


Figure 3. Average TES Phobos spectrum, compiled from the 88 high quality spectra shown in Figure 2.

The presence of a 1590 cm^{-1} band in TES data is supported by factor analysis and target transformation (FATT) analysis [9]. Using this technique, we convert the TES spectra to mutually orthogonal eigenvectors and then map the eigenvectors to “target” spectra. A good match to a target spectrum is indicative of the presence of that phase in the scene. Figure 4 shows an emissivity spectrum of montmorillonite acquired under ambient conditions and a modeled spectrum from the TES eigenvectors. Although the overall spectrum is poorly fit, indicating that montmorillonite is not a component of the TES spectra, the region between ~ 1300 and 1650 cm^{-1} is well fit, supporting the detection of a surface hydration feature.

Finally, some spectra display emissivity maxima at 1415 cm^{-1} ($\sim 7\text{ }\mu\text{m}$), which has been shown to be consistent with small amounts of carbonates intimately mixed with silicates [10]. In this portion of the spectrum, carbonates have a strong absorption coefficient, while silicates and other phases generally have absorption coefficients several orders of magnitude lower, leading to the complex spectral structure shown in Figure 3.

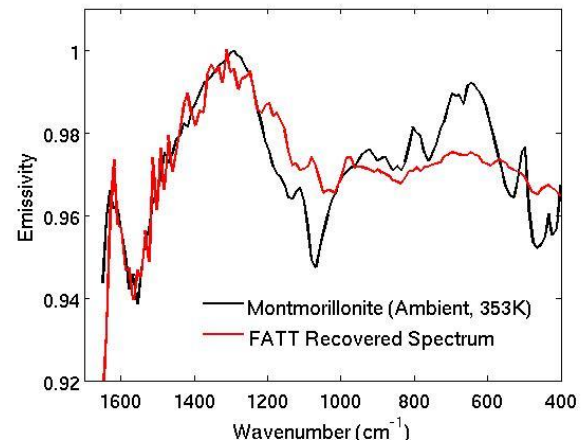


Figure 4. Measured and modeled phyllosilicate spectra. The short wavelength portion of the spectrum (~ 1300 - 1600 cm^{-1}) is fit well, supporting the presence of a hydration feature at 1590 cm^{-1} .

Conclusions and Future Work. TES spectra of Phobos provide a wealth of information about its surface composition. MIR stretching and bending modes between 10 and $20\text{ }\mu\text{m}$ and a broad CF feature at $8.85\text{ }\mu\text{m}$ are consistent with low silica phases, perhaps including desiccated phyllosilicates, as suggested by [5-6]. At shorter wavelengths, TES spectra indicate the presence of water, which may be either a transient surface phenomenon or bound in minerals. Additionally, complex spectral structure between ~ 1400 and 1600 cm^{-1} is indicative of carbonate intimately mixed with the silicate component of the regolith. This observation may support the hypothesis that Phobos is a captured D-type asteroid, similar in composition to CI and CM chondrites. Future work will include acquisition of MIR and VNIR spectra in a simulated Phobos environment to compare to remotely acquired data. We will acquire spectra of silicate/carbonate mixtures and powders of the Tagish Lake meteorite, which is carbonate-bearing, using the Planetary and Asteroid Regolith Spectroscopy Environmental Chamber (PARSEC) instrument at Stony Brook University [11].

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References: [1] Murchie, S. and S. Erard (1996), *Icarus*, 123, 63-86. [2] Murchie, S. et al. (1999), *J. Geophys. Res.*, 104, 9069-9079. [3] Rivkin, A. S. et al. (2002), *Icarus*, 156, 64-75. [4] Fraeman, A. A. et al. (2012), *J. Geophys. Res.*, 117, E00J15. [5] Fraeman, A. A. et al. (2014), *Icarus*, 229, 196-205. [6] Giuranna, M. et al. (2011), *Planet. Space Sci.*, 59, 1308-1325. [7] Pieters, C. M. et al. (2014), *Planet. Space Sci.*, 102, 144-151. [8] Lucey, P. g. et al. (2010), *LPSC XLI*, abstract 1600. [9] Malinowski, E. R. (1991), *Factor Analysis in Chemistry*, 2nd Ed., John Wiley. [10] Bandfield, J. L. et al. (2003) *Science*, 301, 1084-1087. [11] Shirley, K. A., and T. D. Glotch (2015), *LPSC XLVI*, abstract 2025.