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Compositional Interpretation of PFS/MEx and TES/MGS Thermal Infrared Spectra of Phobos

M. Giuranna (1), T. L. Roush (2), T. Duxbury (3), R. C. Hogan (4), A. Geminale (1), V. Formisano (1)
(1) Istituto di Fisica dello Spazio Interplanetario INAF-IFSI, Via del Fosso del Cavaliere 100, 00133 Roma, Italy. (2) NASA Ames Research Center, MS 245-3, Moffett Field, CA 94035-1000 USA. (3) Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, 91109 California. (4) Bay Area Environmental Research Institute, C/O MS 245-3, Moffett Field, CA 94035-1000 USA.

Abstract

The origin of the Martian satellites presents a puzzle of long standing. Addressing the composition of Phobos will help constrain theories of its formation. Visible and near-infrared spectra of Phobos lack of deep absorption features, making the compositional interpretation a tricky task. PFS/MEx and TES/MGS observations in the thermal infrared show several spectral features that can be used to investigate the composition of the surface. Our results show that the majority of the spectra are consistent with a dominance of phyllosilicate. Some spectra also suggest the presence of Feldspars/Feldspathoids. The spectral compositional results suggest ultramafic assemblages. Unexpectedly, comparison of the TES and PFS data to the meteorites shows that no class of chondrites provide significant agreement with the spectral features observed.

1. Introduction

The origin of the Martian satellites presents a puzzle of long standing. Addressing the composition of Phobos will help constrain theories of its formation. The satellites of Mars have VNIR spectra similar to outer belt asteroids, suggesting that they were captured [1]. However, dynamicists have had a difficult time explaining their capture from the outer asteroid belt, preferring them to be objects that formed near their current solar distance [1]. It has even been suggested that Phobos is ejecta from a large basin-forming impact on Mars, perhaps the last survivor of a once-larger population [2]. These various scenarios lead to vastly different compositions for Phobos, with associated implications for early Martian history.

2. Dataset

TES is a Michelson interferometer operating from 1700 to 200 cm^{-1} (~6 to 50 μm) with spectral resolutions of 6.25-12.5 cm^{-1} [3], [4]. PFS is a Fourier spectrometer working in two different channels. The SWC covers wavenumbers from 1700 to 8200 cm^{-1} (1.2–5.9 μm) while the LWC operates in the range 250–1700 cm^{-1} (5.9–40 μm) [5]. The spectral resolution is 1.3 cm^{-1} when no apodization function is applied, and about 2 cm^{-1} when Hamming function is applied to the interferograms. In the present analysis we use data from LWC [6]. Both TES and PFS had several opportunities to observe Phobos. At these wavelengths, both instruments can detect the fundamental vibrational modes of materials. The number, position, intensity, and shape of which are dependent upon the atomic masses, inter-atomic force fields, and molecular geometry, providing a sensitive means of determining mineralogy. A linear combination of 3 black bodies is used to perform a least squares fit of the observed radiance. Using these results as inputs, an upper hull is fit to the radiance maxima. Emissivity values are produced by dividing the measured radiance by the hull.

3. Results

3.1 Surface Temperatures

PFS minima (130-160 K) and maxima (290-353 K) derived surface temperatures are in good agreement with the minimum (night, 140 K) and maximum (day, 300 K) brightness temperatures of the satellite surface measured by the Viking orbiter [7]. Compared to the temperatures derived for Phobos by [8] (320-340 K), only those for PFS orbit 6906 approach these values. The explanation for this systematic difference is very likely that during the observations of [8] Mars' heliocentric distance was ~1.38-1.39 AU, very similar to that during PFS orbit 6906 (1.388 AU). We also compare our results with the results of the numerical modeling of the thermal regime of Phobos' surface regolith layer (on seasonal time scales) in [9]. There is a general good agreement, as our derived temperatures are mostly within the range of predicted diurnal temperatures on the Phobos surface, and the variation of surface temperature as predicted by the model is also reproduced by our results (Fig. 1).

3.2 Surface composition

Our compositional interpretation of thermal emission data relies upon several digital spectral libraries. One contains measured emissivity for a variety of materials (carbonates, nitrates, borates, halides, oxides, phosphates, arsenates, vanadates, sulphates, chromates, molybdates and silicates), (TES library). Additionally, a digital library containing spectra of terrestrial rocks, lunar materials, and various meteorites reflectivities was used (ASTER spectral library). The RELAB spectral library is also used for comparison. It contains spectra of lunar samples. Additionally, we compared Phobos spectra with a limited number of materials that are residues of the processing of various organic precursors. Such samples are analogs for the processed products of ultraprimative materials found in the outer solar system. Our results show that the majority of the spectra are consistent with a dominance of phyllosilicate (Figs. 2 and 3), particularly in the areas around Stickney crater. The spectral compositional results suggest ultramafic assemblages. This is consistent with the position of the Christiansen Frequency (CF) in the TES data. Some spectra also suggest the presence of Feldspars/Feldspathoids, although for these spectra the position of the CF is different than that observed in laboratory spectra. Comparison of the TES and PFS data to the meteorites shows that no class of chondrites provide significant agreement with the spectral features observed. The position of the CFs is in agreement (expecially with achondrites), but the other spectral features observed in TES and PFS spectra are not present in meteorites spectra. The lack of consistency of the PFS and TES spectra to analogs of ultraprimitive materials (organic residues) suggests that an origin via capture of a transneptunian object is not supported by these observations.

4. Figures

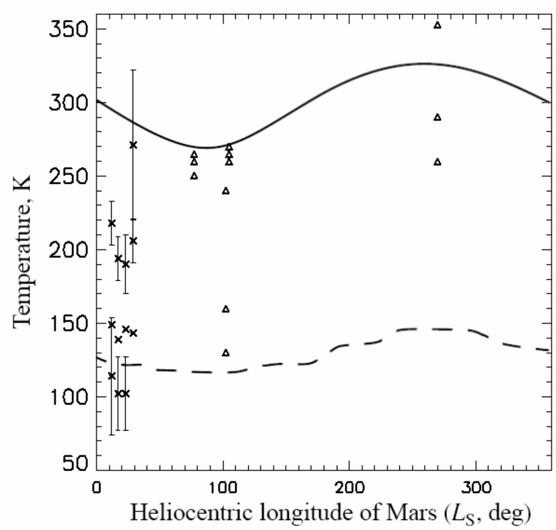

Figure 1: Comparison of PFS (triangles) and TES (×) derived temperatures with calculated seasonal variations of the maximum (solid line) and minimum (dashed line) diurnal temperatures on the Phobos surface from [9].

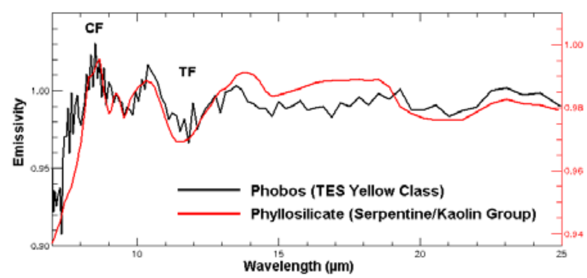

Figure 2: Example of spectral match for TES spectra.

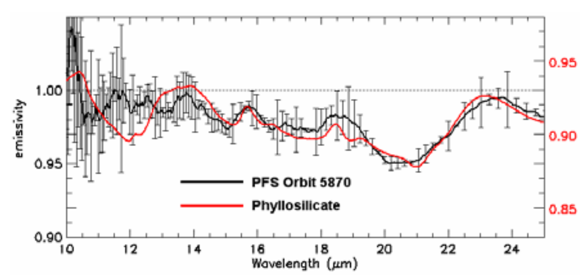

Figure 3: Example of spectral match for PFS spectra.

5. Summary and Conclusions

The lack of deep absorption features in the reflectance (visible and near-infrared) spectra of Phobos have allowed a number of possible analogs to be ruled out, though they have also made it difficult to make any positive identifications. Our observations in the thermal infrared show several spectral features that can be used to investigate the composition of the surface. Our results show that the majority of the spectra are consistent with a dominance of phyllosilicate. The presence of a phyllosilicate component implied by our analysis is very intriguing. If confirmed it may represent altered material incorporated during formation, emplacement onto the surface from the local environment (e.g. Mars), or in situ alteration. Unexpectedly, comparison of the TES and PFS data to the meteorites shows that no class of chondrites provide significant agreement with the spectral features observed. Two independent approaches of compositional analyses yield very similar results. If we collect and summarize all the compositional clues for the origin of Phobos currently available, including our results. We find that the most likely scenario is the in-situ formation of Phobos, although a capture of achrondrite-like meteorites is not ruled out. A more definitive answer to the origin of Phobos will certainly benefit from in-situ measurements, or sample return. The future Russian Phobos-Grunt mission (Phobos Sample Return), to be launched in 2011, will certainly contribute to our understanding regarding the origin of Phobos.

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