CONSTRANTS ON THE ORIGIN OF MARTIAN CLAY MINERALS FROM THERMAL INFRARED SPECTROSCOPY AND THERMAL INERTIA. J. R. Michalski¹, R. Fergason², E. Z. Noe Dobre³, N. Mangold¹, F. Poulet¹, and Damien Loizeau². ¹Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove, Pasadena, CA, 91109, USA. (Joseph.R.Michalski@jpl.nasa.gov), ²Arizona State University, Tempe, AZ, 85287, USA. ³IDES-Orsay, CNRS and Universite of Paris-Sud, 91405 Orsay Cedex, France. ⁴IAS, Universite of Paris-Sud, France.

Introduction: Clay minerals previously detected on Mars using near infrared spectroscopy [1-2] may represent aqueous alteration products related to sedimentary, hydrothermal, diagenetic, metamorphic, igneous, or low-temperature chemical weathering processes [3-4]. Interpretation of their geologic context and mineralogical associations is critical to understanding the relationship of these deposits to Martian climate change, habitability of the surface, and fundamental geological processes in the upper crust.

In previous work, clay minerals were identified and mapped using OMEGA spectral data ($\lambda=0.5-3 \mu m$) [1-2] and in this work, we analyze several of the largest of these deposits using thermal infrared spectral data ($\lambda=6-30 \mu m$). While the near infrared is traditionally considered better for identification of clay minerals, the thermal infrared region provides complimentary information about the mineralogy of clays [5], additional constraints on the abundance/grain-size/texture, and the opportunity to detect additional minerals that are either undetectable with near-infrared (e.g. plagioclase or anhydrous silica) or potentially masked by the presence of clays (e.g. zeolites).

Background: In the near infrared, clays are primarily detected from three absorption features: a strong H-O-H spectral band near ($\lambda=1.9 \mu m$), a metal (Mg, Fe, Fe, Al)-OH band at ($\lambda=2.2-2.35 \mu m$), and a weak O-H band located near ($\lambda=1.4 \mu m$). In the thermal infrared, clay minerals are detected from several anhydrous lattice vibrations: a (Si,Al)-O absorption located at 9.3-9.8 $\mu m$, Si-O-(Al, Fe, Mg) absorptions at 18.7-25 $\mu m$, and (Si,Al)-O bending absorptions at 21-25 $\mu m$. For this reason, thermal infrared spectroscopy provides a different, complimentary perspective on the mineralogy of clay-bearing materials [5].

We wish to constrain the physical state of Martian clays, in addition to their mineralogy, and both near infrared and thermal infrared spectroscopic detections are sensitive to the physical properties of minerals (e.g. particle size, texture, etc.). While clay minerals are by definition composed of small crystals, the aggregates of these crystals can form coarse particles which spectroscopically behave as larger grains. Therefore we consider both coarse and fine particle sizes in analyzing spectra of clay-bearing surfaces. Aside from particle size alone, the issue of texture is important to detecting clays and estimating their abundances [5]. The texture of natural surfaces can cause minerals to be easily detectable by one technique and undetectable with another simply because of the scattering/emitting properties of the surface.

Methodology: We are utilizing thermal infrared data from the TES and THEMIS instruments to analyze the composition and thermal inertia of clay-bearing surfaces previously identified with OMEGA.

TES data processing. TES data have been extracted over the clay-bearing regions using two techniques. The first is a simple ratio technique which uses radiometrically calibrated data, processed to emissivity, but uncorrected for atmosphere. In this technique, we ratio the (surface+atm) emissivity over clay-bearing surfaces with adjacent surfaces that do not show clay minerals to: a) determine if there are any thermal infrared spectral differences between these surfaces and b) to interpret major mineralogical differences between these surfaces based on absorptions that occur in the ratio spectra. To constrain the error associated with this method, we have also applied the technique to two separate, compositionally uniform terrains in order to understand the effects of instrument noise and elevation differences in the ratio spectra (Figure 1). In one region (west of Olympus Mons), we determine the average emissivity and standard deviation over a terrain of low, uniform elevation ($\Delta$ elevation < 15 meters), and uniform albedo (0.266 ±0.004). The spectral variance over a uniform terrain gives a first-order approximation of the instrument effects manifested in the ratio spectra. The results provide a construct from which to interpret the significance of spectral differences identified in the ratio spectra of clay-bearing surfaces. Also for error analysis, we performed spectral ratios over compositionally uniform, but topographically variable terrain on the dusty southeast flank of Olympus Mons. Because in the actual analysis of clay-bearing deposits it is necessary to ratio spectra across terrain units of different elevations, it is important to constrain how large of a $\Delta$ elevation must be present to impact the spectral ratio results due to increased atmospheric path. The results show that in usual atmospheric conditions, spectral effects due to suspended dust or CO$_2$ are not problematic over elevation differences up to ~1000 m. Aside
from the spectral ratio method, the other major TES data processing technique is the extraction of surface emissivity spectra by removing known atmospheric spectral shapes using a linear unmixing algorithm [7].

**THEMIS data processing.** THEMIS daytime thermal infrared data were used to map surface compositions. After radiometric calibration, a first order atmospheric emission correction (radcorr) was applied [8], but no correction was made for atmospheric transmission. Emissivity images and decorrelation stretched images were used to identify compositional heterogeneity in the scenes. Nighttime and daytime infrared images were used to produce thermal inertia mosaics of clay-bearing areas using methods described by Fergason et al. [9].

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**Figure 1:** Application of TES processing techniques to compositionally homogeneous terrains to demonstrate validity of the methodology. Two four-panel plots in “A” and “B” show areas in the Olympus Mons region with nearly uniform albedo, thermal inertia, and dust cover index values [6] (and thereby assumed uniform surface composition). The Δ elevation in “A” is <15 m and in “B” is >18 km. The average of 78 surface spectra are shown in “C” along with 1-σ bounding spectra around the average emissivity spectrum and around a hypothetical uniform ratio spectrum. Systematic variations are seen in spectral contribution of the atmospheric CO$_2$ and suspended dust as a function of elevation (D). While the effect of CO$_2$ gas in the 12-18 μm region is strong and variable, the ratio spectra across a Δ elevation of up to ~ 1 km show little contribution from atmospheric dust (E). The ratio-derived atmospheric spectral shape over Δ elevation of 18.9 km is comparable to the atmospheric spectral shapes derived using target transformation in previous work [7].
Results: In this abstract, we present an example of detailed results from one deposit in the Mawrth Vallis area (Figure 2), but we are producing results for a range of clay deposits on Mars.

Mawrth Vallis. In the western Mawrth Vallis area is an exposure of light- and medium-toned, layered bedrock where OMEGA data show evidence for multiple clay minerals (Al- and (Fe/Mg-bearing) [1-3]. TES thermal inertia and THEMIS nighttime data indicate that this surface is composed of relatively coarse-grained materials – consistent with HRSC and MOC image data, which suggest that the surface is made up of bedrock and patchy eolian cover. THEMIS decorrelation stretch and emissivity data suggest subtle compositional difference (in the 9-12 μm region) between the clay-bearing deposit and surrounding terrains. Detailed analysis of TES spectral ratios and atmospherically corrected surface emissivity data support the interpretation of minor compositional differences between the two surfaces (Figure 3). TES spectra of the clay bearing deposits as well as the adjacent terrains show absorptions in the 8-12 and 18-30 μm regions indicative of silicate materials. The relative positions of TES absorptions over the light-toned, clay-bearing and adjacent dark-toned surfaces suggest that the clay-bearing surface may be composed of slightly more silicic materials. However, the clay-bearing surface does not show strong absorptions that can obviously be attributed to clay minerals.

Other clay deposits. Other deposits in the Mawrth Vallis area and elsewhere on Mars show some similar trends to those presented here. As noted previously [1-2], many of the deposits occur in rocky surfaces and THEMIS nighttime infrared mapping supports the conclusion that many of the clay deposits are in fact coarse-grained surfaces. To date, our spectroscopic analyses do not show any deposits that have strong thermal infrared spectral features obviously attributable to clay minerals in surfaces where OMEGA has detected clays.

Implications: These results have important implications for the mineralogy and abundance/grain-size/texture of Martian clay minerals. To date, we have not identified any surfaces with obvious thermal infrared spectral features of clay minerals, or where OMEGA clays are associated with detectable quartz, cristobalite, carbonate, or sulfate, based on thermal infrared analyses. Many of the clay deposits have broad silicate absorptions, which could correspond to certain zeolites and feldspars, ± pyroxene and silicate glass. In each case, this suggests one of more of the following – clay minerals: 1) are of low abundance, 2) occur within porous bedrock with low spectral contrast, or 3) have contrasting grain sizes with other materials in the same pixels such that the pixel spectrum is dominated by coarser grained materials in the thermal infrared. The geologic context of each clay mineral deposit detected so far is somewhat unique and as such, there is no reason to assume a unified interpretation of clay mineral abundance/grain-size/texture for all clay deposits on Mars. However, at this point, the clay-bearing deposits we have investigated seem to show evidence for a significant component of non-clay silicates. Scenarios consistent with this observation include sedimentary contexts where the clays occur in association with clastic basalt/clastic plagioclase, or diagenetic contexts where the clays occur in association with partially altered silicate glass. Alternatively, some of the clay minerals may be best explained by their occurrence in bedrock with porous, irregular sur-
face textures (physically similar to the Burns Formation), which facilitate efficient scattering in the near infrared, but lead to blackbody cavity effects and low spectral contrast in the thermal infrared. In this case, most of the spectral signal from the clay-bearing surfaces in the thermal infrared may actually come from eolian surface cover rather than the clay-bearing rock itself.


Figure 3: TES footprints overlayed on THEMIS daytime IR are shown between two orbits (ocks) in “A” and “B.” We present data from multiple orbits to determine the reliability of derived surface spectra. Emissivity data (uncorrected for atm) are shown in “C” and “D,” along with ratio spectra between pixel on and off the clay deposit. In both cases, the ratios show some spectral difference between the surfaces above the 1-σ level. Surface spectra (corrected for atm) are shown in “E” and “F.” In both cases, the spectra on the clay deposits show only subtle difference from the surrounding terrain. The clay deposit absorbs slightly less near λ = 11 μm and at λ > 25 μm.