SUBSURFACE MINERAL HETEROGENEITY IN THE MARTIAN CRUST AS SEEN BY THE THERMAL EMISSION IMAGING SYSTEM (THEMIS): VIEWS FROM NATURAL "WINDOWS" (IMPACT CRATERS) INTO THE SUBSURFACE.

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Introduction and Background: Impact craters have been effectively used as a "natural drill" into the crust of the moon, the Earth and on Mars, giving us a glimpse of the mineral and lithologic compositions that are otherwise not exposed or present on surfaces. A lunar study by *Tompkins and Pieters* [1] has demonstrated that Lunar Clementine data could be used to show that numerous craters on the Moon excavated distinct compositions within both the central uplift and craters walls/terraces of several complex craters with respect to the surrounding lunar surface composition. Later, *Tornabene et al* [2] demonstrated how Haughton impact structure was an excellent terrestrial analog for demonstrating the utility of using craters for studying both near-subsurface and the shallow crust of Mars. Using ASTER Thermal infrared (TIR) data, as an analog for THEMIS TIR, three subsurface units were distinguished within the structure as units that were excavated and uplifted by the impact event. These units, if not for the regional tilt and erosion, would otherwise not be presently exposed if not for the Haughton event. Meanwhile, recent studies on Mars by the Opportunity rover [3] revealed our first clear view of outcropping bedrock of sedimentary layers within the walls of Eagle and Endurance craters. Using THEMIS in conjunction with TES, *Bandfield et al* [4] suggested that two craters within the Syrtis Major region may have uplifted and exposed granitoid lithologies within their central uplifts. Olivine-rich materials within craters have been mapped THEMIS and OMEGA in several craters throughout Mars [5-9]. However, *Christensen et al* [6] mentions the occurrence of olivine-rich rocks in two craters in Aurorae Planum, originally discovered by TES [7] and then mapped in detail by THEMIS, may be interpreted as volcanic lava flows that post-date their formation and are not exposed by the impact process. Also, the olivine-rich materials mapped by OMEGA on the floor of Mie crater and two nearby unnamed craters within the Vastitas Borealis [8] may actually be aeolian deposits. However, *Bibring et al* [8] and *Mustard et al* [9] both concluded that both olivine and low-Ca pyroxene as seen by OMEGA may be the dominate minerals within the ancient crust/subsurface of Mars because they were commonly observed spectrally within impact craters, or preferentially in the Noachian crust.

All of these summarized studies indicate that stratigraphic relationships and changes in mineral and lithologic composition with depth as exposed in impact craters may be ascertained from remote sensing data. With such knowledge, inferences regarding the petrogenetic origin and differentiation of the martian crust may be ascertained.

Our purpose is two-fold: 1) to use THEMIS daytime TIR data to map and spectrally identify mineral or lithologic units on Mars that are exposed by the most abundant and convenient natural "windows" into the martian crust: impact craters, and 2) Assess all the craters in previous studies proposed to expose spectrally distinct materials using THEMIS, MOC and MOLA data.

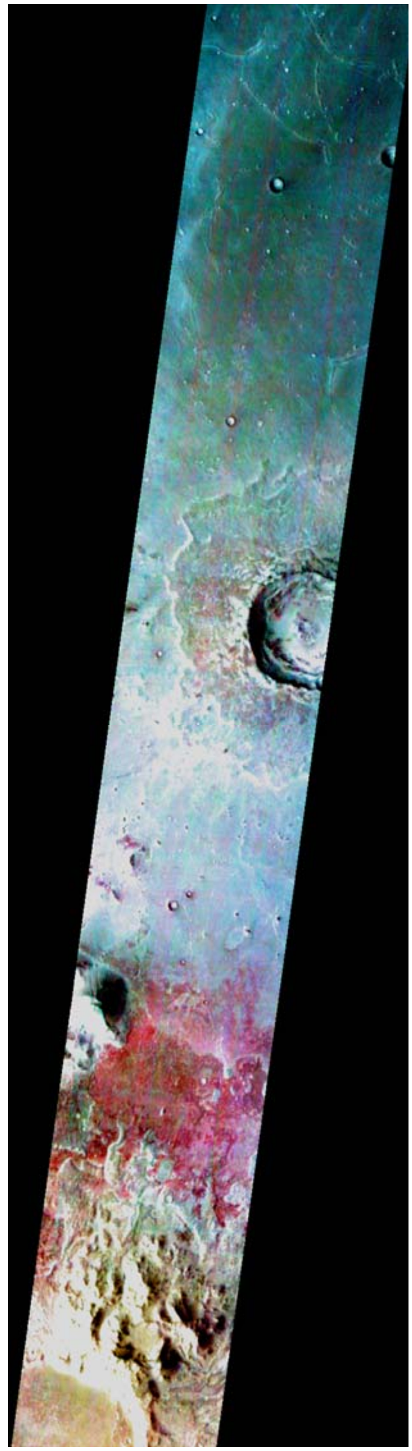

Figure 1. A THEMIS 478-band emissivity image (~ 30 km in width) draped on a THEMIS band-9 brightness temperature image. Three units can be discerned: Olivine-rich materials = magenta, Isidis floor = blue and surface dust = yellow. The magenta unit at the bottom of the Figure is the unit that was uncovered in the TES dataset [7; 13].

Methods: Our first step toward finding craters that expose spectrally distinct materials was to create a list of craters that are relatively well-preserved and have distinct crater morphologic features (i.e. intact ejecta blankets, sharp rims, walls, terraces and central uplifts). We first used the Martian crater database, maintained in Arcinfo-format by Nadine Barlow [10-12], to constrain the number of craters in our list to only those that possessed an intact ejecta blanket. Next, these craters were then assessed in both visible and TIR images and using the TES-derived dust index map. THEMIS nighttime TIR images can be used as a proxy for thermal inertia and were used to ascertain if the craters possessed distinct thermophysical units that correlate 1:1 with crater morphological features. THEMIS daytime images covering the crater in question taken prior to 4:30 LST (images within the 3:00-hour LST are best) and with average temperatures of 240K [4] were sought as they are best for making good spectral distinctions. Then, a decorrelation stretch or minimum noise fraction transform was applied to the THEMIS daytime TIR data to observe if any spectrally distinct units were present. In addition, MOLA DEMs can be used to determine the spectral unit's relationship, if any, to elevation. Finally, high-resolution visible imagery, if available, we sought to distinguish if these spectral units possessed good evidence for being bedrock exposures vs. aeloian deposits.

Preliminary results and future studies: After an extensive look at hundreds of martian impact craters, and including the craters from other studies [4-9], craters from within the Isidis Planitia, Ares Valles, Nili Fossae, Acidalia Planitia and in the vicinity to the Valles Marineris regions have been identified as having the traits outlined above. Several examples are described here in further detail below.

Well documented olivine-rich surface deposits have been mapped by TES in the southern portion of the Isidis Basin [7; 13]. However, a close examination of an 18-km diameter impact crater, situated approximately 50 km north of the TES-documented deposits, reveals that this unit is exposed from just below the surface (Fig. 1). This strongly suggests that the olivine-rich unit must occur just below the Isidis plains materials. The olivine-rich materials are exposed within the ejecta blanket, crater wall and down dropped terrace blocks adjacent on the crater floor (Fig. 1). THEMIS VIS (V09409006) and MOC (S06-01873p) images reveal that the crater walls are rocky, layered and possess a relatively low albedo (suggesting little to no dust-cover). In the future, we will attempt to map the extent of the subsurface olivine-rich unit by observing the extent of the occurrence of this spectral unit in association with other fresh-appearing craters within the Isidis Basin.

Deposits rich in olivine have also been mapped by both THEMIS and TES within a portion of Ares Valles [5]. An 18-km impact structure (Fig. 2) within a 42-km impact structure has exposed and excavated this olivine-rich material as a ~250-m thick exposure within the crater wall and within the ejecta blanket. It should be noted that this unit is only exposed within one side of the crater wall and is preferentially concentrated within the northwestern portion of the of the ejecta blanket, that is, toward the center of the larger 42-km diameter crater that contains the 18-km diameter crater. These observations suggest that the older and larger impact may have excavated/uplifted the olivine-rich materials to shallower levels in the surface only to be later exposed by the smaller 18-km diameter impact. If true, the subsurface occurrence of one olivine-rich unit, not two [5], is sufficient to explain how olivine-rich units occur at lower elevations within Ares Valles and also at higher elevations outside of the valley. Further, evidence for this hypothesis will be sought in the vicinity of Ares Valles by carefully examining geologic and stratigraphic relationships of the olivine-rich unit in THEMIS imagery, as well as other datasets.

At this point, the crater in Acidalia Planitia and the two craters in the vicinity of Valles Marineris have not been extensively studied. What appears to be very compelling about these craters is that they appear to possess spectrally distinct units in association with their central uplifts. The Acidalia crater (D_a=29 km) occurs within the TES-defined surface unit: surface type 2. Surface type 2 continues to have a controversial lithologic interpretation (i.e. weathered basalt [14] or andesite [15], etc.). Determining the lithologic character of this central uplift using THEMIS, TES and other available datasets may shed some additional insight into the matter. The two craters in the vicinity of Valles Marineris are interesting in the sense that may expose materials in their central uplifts that may be exposed further down section in the Valles Marineris itself. Further mapping of both these areas will be needed to determine the geologic context and origin of these spectral units.

References: [1] Tompkins S. and Pieters C. M. (1999), *MAPS*, *34*, 25-41. [2] Tornabene, L.L., et al. (2005), *MAPS*, *(in press)*. [3] Squyres S. W., et al. (2004), *Science*, *306*, 1698-1703. [4] Bandfield J. L., et al. (2004), *JGR.-Planets*, *109*. [5] Rodgers A. D., et al. (2005), *JGR-Planets*, *110*. [6] Christensen P. R., et al. (2005) *Nature*, *436*, *doi:10.1038*. [7] Hamilton V. E., et al. (2003), *MAPS*, *38*, 871-885. [8] Bibring J. -P., et al. (2005), *Science*, *307*, 1576-1581. [9] Mustard J. F., et al. (2005), *Science*, *307*, 1594-1597. [10] Roddy D. J., et al. (1998*a*), LPSC XXIX, #1874. [11] Roddy D. J., et al. (1998*b*), LPSC XXIX, #1879. [12] Barlow N. G., et al. (2000), *JGR -Planets*, *105*, 26,733-26,738. [13] Hoefen T. M., et al. (2003), *Science*, *302*, 627-630. [14] Wyatt M. B. and McSween H. Y. (2002), *Nature*, *417*, 263-266. [15] Bandfield J. L., et al. (2000), *Science*, *287*, 1626-1630.

Figure 2. A THEMIS 578-band emissivity image (up is NW) draped on a THEMIS band-9 brightness temperature image (crater D ~ 18 km). Olivine-rich materials occur in both the ejecta and the wall rock as a magenta-colored unit.