EXAMINING THERMAL INERTIA OF LAYERED EJECTA CRATERS AND SOUTHERN HEMISPHERE DUNES ON MARS. R. H. Hoover[1]⌘, S. J. Robbins[1], N. E. Putzig[2], L. K. Fenton[3], R. Hayward[4], J. Riggs,[5], and S. Courville[2,6] [1]Southwest Research Institute, Boulder, CO; [2]Planetary Science Institute, Lakewood, CO; [3]SETI Institute, Mountain View, CA; [4]USGS Astrogeology Science Center, Flagstaff, AZ; [5]Northwestern University, Evanston, IL., [6]Colorado School of Mines, Golden, CO; ⌘RHoover@Boulder.SwRI.edu

Synopsis: Investigation of thermal inertia provides insight into the characteristics of near surface materials revealing geologic, erosional and depositional histories. Applying thermophysical analyses, our research investigates 171 southern hemisphere dunes and 50 layered ejecta craters to identify the presence of subsurface volatiles. We used multiple data sets to conduct analyses of derived thermal inertia and two-layer thermal models to characterize the near-surface properties.

Background: Grain-size distribution, induration, rock abundance, and material heterogeneity can be determined through thermophysical analysis [1-3]. The overarching goal of our research is to apply a similar method of thermophysical characterization to identify the potential presence of subsurface volatiles in two different scenarios. Specifically, we analyze apparent thermal inertia (ATI) to advance our understanding of layered ejecta (LE) craters and southern hemisphere dunes on Mars. ATI, derived from brightness temperatures obtained at discrete times of the day, typically exhibits diurnal and seasonal variation as a result of heterogeneity of material within the field of observation [2,3]. By investigating such heterogeneities, we aim to provide insight into the formation mechanisms of LE craters and assist in identifying characteristics responsible for the shift from active to stabilized dunes in the southern hemisphere. We use two datasets derived from the Mars Global Surveyor Thermal Emission Spectrometer (TES) [4] and the Mars Odyssey Thermal Imaging System (THEMIS) [5], to investigate the surface at varying spatial scales. While our results provide insight into near surface properties of LE craters and dunes, they do not provide a complete picture, thus indicating a need for future research and improved modeling.

Layered Ejecta Craters: There are two main types of formation mechanisms of layered ejecta described in the literature. The first is the volatile fluidization class of models [e.g., 6] and the second is the atmospheric model [7]. The fluidized model requires the presence of volatiles while the atmospheric model does not require (but also does not rule out) the presence of volatiles. The fluidized model hypothesizes a fluid-like flow as the result of an impact melting, lubricating, or otherwise using subsurface volatiles to enhance a ground-hugging flow [7], while in the atmospheric model the ejecta blanket interacts with the atmosphere to create the observed flow-like pattern [6]. Identification of evidence supporting the fluidized model could allow for LE craters to be used as proxies for tracking subsurface volatiles.

Southern Hemisphere Dunes: Investigation of dune activity can provide insight into changing climates and the presence of volatiles. Dune fields in the southern hemisphere of Mars have previously been categorized into six classes based on morphology [8]. It has been hypothesized that the shift in morphology from active to stabilized dunes poleward of 60°S is due to the presence of subsurface volatiles [8]. The shift towards stabilization roughly correlates in location to an increase in the presence of water-equivalent hydrogen as detected by the Mars Odyssey Neutron Spectrometer [9, 10]. Additionally, previous research has identified water ice that likely results in the stabilization of dunes in the north polar erg [11]. Analysis of thermophysical properties can be used to identify subsurface volatiles and provide insight into the relationship between ice and dune morphology in the southern hemisphere. Similar to LE craters, if the presence of subsurface volatiles is identified through thermophysical analyses, then degraded, less active dunes may be used as proxies for subsurface volatiles.

Methods: We used TES and THEMIS data to investigate LE craters and dunes. THEMIS images (100 m/pixel resolution) are used to assess grain-size distribution within the ejecta blankets of LE craters and in southern-hemisphere dune fields. TES data (3 km/pixel resolution) are used to model and assess the types of materials present and their geometry. Specifically, we compared TES-derived ATI to that derived from two-component heterogeneity models to identify the presence of a variety of horizontally mixed or vertically layered materials (e.g., dust, sand, duricrust, and 'rock,' where rock is thermally indistinguishable from ice and ice-cemented soil). Our thermophysical analyses are limited to the top few to 10s of centimeters of the surface as constrained by the thermal skin depths of the materials [3].

Results: *Craters:* We investigated 50 LE craters with diameters >5km that are globally distributed. Our analysis of THEMIS data revealed several different patterns that are categorized and described in Table 1. For our TES analysis, we investigated 42 craters, excluding those with diameters <9km due to the 3km TES pixel resolution. 23 craters had matches between

TES ATI and heterogeneity models, with 11 exhibiting a thermal signature of rock/ice and 19 classified as inconclusive, summarized in Table 2.

Class Type	Description
Class 1	ATI of LE is higher than that of surroundings
Class 2	ATI of LE is lower than that of surroundings
Class 3	Edge of LE has higher ATI than that of surroundings
Class 4	Edge of LE has lower ATI than that of surroundings
Class 5	ATI of LE is same as that of surroundings or no distinct pattern found

Table 1: THEMIS Classes identified in our analysis.

Heterogeneity Model	SLE	DLE	MLE	Total
Crust over dust	3	1	3	7
Dust over crust	1	1	1	3
Dust over rock	1	1	3	5
Sand over rock	2	-	-	2
Dust-crust mix	1	-	1	2
Dust-rock mix	-	3	1	4
Inconclusive	4	6	9	19

Table 2: Heterogeneity model matches to TES ATI for Single-, double- and multi-layer craters (SLE, DLE and MLE, respectively).

Dunes: We have compiled results of THEMIS and TES analysis for incorporation into the Mars Digital Dune Database [12], which will include a description of THEMIS variations within each dune field and identification of the best-fitting heterogeneity model for the TES data. We completed THEMIS analysis for 30% of the 171 dune fields using MARSTHERM, a publicly accessible online tool (http://marstherm.psi.edu). We identified several THEMIS patterns which include: 1) crests of dune fields that have a higher ATI compared to surrounding material or interdunes, 2) interior of the dune field that has a lower ATI compared to the edge of the dune field, 3) dune field that has a lower ATI compared to surrounding material, and 4) dune field with no discernible pattern observed within the dune field or compared to surrounding materials. The remaining 70% of the dune fields were not characterized due to poor quality of data or errors with processing the THEMIS data. We used TES data to investigate all 171 of the dune fields to identify a best-fit heterogeneity model. Of the 171 dunes, 53% had matches to two-layered heterogeneity models. Dunes with morphological classes of sharp and sharp intermediate primarily match those with TES ATI best fit by the ‘crust over dust’ heterogeneity model. Sand sheets primarily match with the ‘dust over sand’ model. Other types of dune morphology do not dominantly match to a single model type. Additionally, nine dune fields exhibited a thermal signature of rock which may indicate ice or ice-cemented soil.

Discussion: The results of our analysis of THEMIS and TES data for LE craters are equivocal and did not provide an overwhelming amount of evidence to support either the fluidized or atmospheric model. Additionally, we found no trends in thermal response for SLE, DLE or MLE craters. Crater degradation states and dust cover affect thermophysical properties and may inhibit the identification of trends. More specifically, TES and THEMIS data only represent the top few to 10s of cm of the near surface and may include dust and erosive features that could obfuscate deeper-sourced thermal behaviors.

Our thermal analysis of southern hemisphere dunes did not reveal an overwhelming trend providing evidence indicating that subsurface ice is responsible for the shift between active and stabilized dunes. However, the lack of detection of subsurface ice may be more of an indication of the limitations of our current data and methods than an indication of the absence of ice. Also our analysis indicates that sharp and sharp intermediate dunes typically have a similar thermal response while sand sheets are typically identified to be consistent the ‘dust over sand’ thermal model. Current model capabilities only encompass two-layered models and therefore do not represent more complex arrangements of near-surface materials. Additionally, our preliminary analyses of slope effects indicate that dune slopes affect thermal behavior, and such effects may also inhibit the thermal identification of subsurface ice.

Conclusions: Our thermophysical analysis of LE craters did not provide overwhelming evidence to distinguish between formation mechanisms, but future work incorporating additional datasets may yet provide a means to distinguish between these hypotheses. While we identified some discernible patterns for dune classes of sharp, sharp intermediate and sand sheet, future work incorporating models of three or more layers and slope models may provide more insight into dune behavior and identification of near surface materials.

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