USING THERMAL INERTIA TO UNDERSTAND THE FORMATION PROCESSES OF LAYERED EJECTA CRATERS.

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Synopsis: Understanding the formation and morphological characteristics of craters can provide insight into surface geology. Specifically, layered ejecta (LE) craters, found on Mars and other planetary bodies, have been hypothesized to have formed as a result of interactions with subsurface volatiles or with the atmosphere. This research investigated ejecta deposits using thermal inertia to inform the formation processes of LE craters on Mars.

Layered Ejecta Craters: Layered ejecta (LE) craters are found on Mars [e.g. 1,2] and several other solid surface planetary bodies including Europa [3], Ganymede [3], Charon [4], Dione [4] and Tethys [4]. Formation processes are still debated and there are two primary models that are used to explain the formation of LE craters. The first, which we will refer to as the volatile fluidization model, indicates that an impactor strikes a volatile rich surface, which then causes the melting or vaporization of the volatiles, and results in an outward flow of material [5,6]. The second model, which will be referred to as the atmospheric entrainment model, indicates that material ejected during the impact interacts with the atmosphere to create outward movement of material [7,8]. Subsequent research has investigated the possibility of the formation processes being a combination of the two models [9,10]. Research presented here investigates the thermophysical properties of crater ejecta on Mars to determine grain size distribution, model horizontal mixtures and vertical layering and to identify materials present within the ejecta. Identification of materials and their grain size distributions will give insight into the formation processes of LE craters.

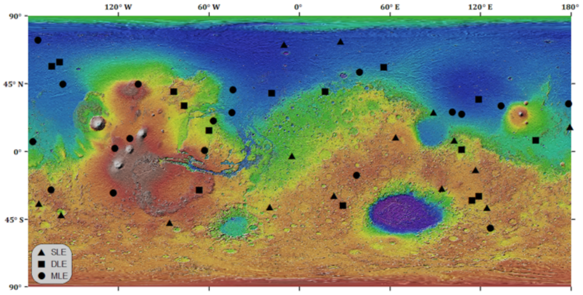

Figure 1: Location of 50 craters investigated in this study

Methods: Fifty craters, >6km in diameter, were selected as a representative sample of LE craters. Craters were selected based on morphometric type, image coverage, spatial distribution and preservation state. Craters selected for investigation are shown above in Figure 1. The main categorical classification of craters used in this study, as established by Barlow et al., (2000) [11] is single-, double- or multi-layered craters (SLE, DLE, or MLE, respectively).

Once selected, craters were investigated using apparent thermal inertia (ATI) values derived from brightness temperatures obtained by the Mars Odyssey Thermal Imaging System (THEMIS) [12] and the Mars Global Surveyor Thermal Emission Spectrometer (TES) [13]. Values derived from THEMIS, at 100 m/pixel, are used to identify grain size distribution within ejecta deposits for all 50 craters. THEMIS images for all 50 craters were processed through a publicly accessible online resource, MARSTHERM. However, only 39 were included in analysis because processed images for 11 of the craters were flagged as low quality in the MARSTHERM tool. Processed THEMIS images were integrated into ArcGIS to qualitatively assess the grain size distributions within each ejecta deposit. Values derived from TES, with a 3 km/pixel scale, are used to identify large-scale heterogeneities by examining their diurnal and seasonal variations [14,15] and comparing them to values calculated for two-component heterogeneity models created for a variety of materials (e.g., dust, sand, rock/ice, duricrust) with either horizontal mixing or vertical layering representing the top few cm of the surface [16]. The TES analysis was limited to craters >9km in diameter (42 craters) to account for the resolution of TES. We use the results of these comparisons to classify the physical characteristics of the crater ejecta deposits and to determine if the observed characteristics best match with hypotheses associated with the volatile fluidization model, atmospheric entrainment model, or neither.

A third analysis conducted in this research is a statistical model investigating the thermal trends between all craters >1km that are classified as the 8 most common morphometric crater types, based on Barlow et al. (2000) [17], and as identified in the Robbins and Hynek (2012) crater database [2]. A statistical model, based on the distribution of data, is developed to determine the influence of measured crater properties (explanatory variables) on the variance observed in the thermal inertia. This model is subsequently validated based on the model's ability to predict thermal inertia using the model's explanatory variables.

Results:

THEMIS Analysis: Several different characteristics and patterns were identified in the processed THEMIS images and as such we established 5 THEMIS Classes. A summary and description of each Class is described in Table 1.

Class Type	Description	# of craters
Class 1	ATI of LE is greater than that of surroundings	9
Class 2	ATI of LE is less than that of surroundings	3
Class 3	Edge of LE has greater ATI than that of surroundings	12
Class 4	Edge of LE has less ATI than that of surroundings	2
Class 5	ATI of LE is same as that of surroundings or no distinct pattern found	13

Table 1: Summary of THEMIS analysis results

TES Analysis: Of the models created for comparison to the 42 craters used in this analysis, 23 had matches to currently available two-layer heterogeneity models. A summary of the materials and layers identified is presented in Table 2.

	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	0	0	2
Dust-crust mix	1	0	1	2
Dust-rock mix	0	3	1	4
Inconclusive	4	6	9	19

Table 2: Summary of TES analysis results

Statistical Analysis: The best fit model, based on the probability distribution function (PDF) of data, is a bimodal probability distribution due to two prominent modes. A model was conducted for each separate mode and results for both modes identified dust cover as a significant factor influencing thermal inertia. Additionally, both models identify the interaction between layer type (SLE, DLE or MLE) and other morphological characteristics (i.e., the diameter, or the ejecta edge shape or terminate) as significant variables. Neither model identified a single morphological variable as the most significant factor in determining thermal inertia values.

Interpretations: Results of our THEMIS and TES analyses are equivocal and do not provide overwhelming evidence in support of either the volatile fluidization or atmospheric entrainment hypothesis. However, individual THEMIS Classes identified may have potential implications regarding the formation processes and the target materials of LE craters. A summary of potential implications is listed in Table 3.

THEMIS ATI Class	Interpretation
Class 1	Target material was consolidated and contained relatively low amounts of volatiles (neither hypothesis)
Class 2	Target material contained high amounts of volatiles resulting in higher amounts of fines in the ejecta deposit (either hypothesis)
Class 3	Target material contained high amounts of volatiles resulting in higher amount of ground flow (fluidized hypothesis)
Class 4	Target material contained low amounts of volatiles and therefore minimal ground flows occurred (atmospheric model)
Class 5	Dust cover inhibits thermal analysis (neither hypothesis)

Table 3: Summary of potential implications

Additionally, the identification of a thermal rock signature may indicate the presence of subsurface ice since rock and ice have equivalent thermal signatures. In total, 11 crater ejecta deposits exhibited a potential rock/ice signature, which would have implications regarding the volatile fluidization hypothesis. Additionally, 8 crater ejecta deposits have observations consistent with hypotheses associated with the atmospheric entrainment model. Specifically, these models matched finer grain material over coarser grained material (e.g. dust over rock).

Statistical analyses identified some patterns in thermal behavior. Specifically, our statistical models indicate that the most significant influence on the observed thermal inertia is a complex interaction between crater type and other observed crater characteristics and morphologies. Statistical modeling is ongoing and future iterations of the model will attempt to capture these complexities to identify the significant influences on thermal inertia.

References:

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