ONSET DIAMETER OF ROCKY EJECTA CRATERS IN WESTERN ELYSIUM PLANITIA, MARS: CONSTRAINTS FOR REGOLITH THICKNESS AT THE INSIGHT LANDING SITE.

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Introduction: We provide new data for the regolith thickness across the Hesperian to Early Amazonian-aged ridged plains of western Elysium Planitia [1,2] using the onset diameter of rocky ejecta craters. We focus our analysis on the location of the four candidate landing ellipses for the InSight (Interior Exploration using Seismic Investigations, Geodesy and Heat Transport) mission, slated to launch in 2016 (Figure 1). One of the primary science objectives of InSight is to constrain the geothermal flux of the interior of Mars [3]. The Heat Flow and Physical Properties Package (HP^3), a percussive "mole", is designed to acquire this measurement from a depth of up to 5 m. To achieve this depth, the surface materials at the landing site must be a regolith that is loosely consolidated without tabular flat rocks larger than ~10 cm diameter.

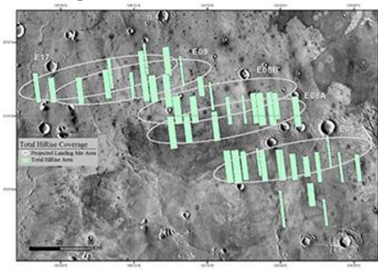

Figure 1: Four finalist ellipses for the InSight mission in western Elysium Planitia. Note that Ellipse 8 is broken into A and B ellipses. THEMIS daytime infrared mosaic as background (THEMIS ASU).

Martian regolith is generated through impact cratering, aqueous weathering, volcanism, aeolian erosion and deposition. However, for the majority of Martian history, comminution of surface material by impact gardening was likely the dominant process [4]. Using impact production rates, Hartmann et al. [4] estimated that Late Hesperian to Early Amazonian surfaces (in the absence of resurfacing processes) experienced 3 to 14 m of impact gardening. The ridged plains at the InSight landing site are of similar-age [1,2] and lack evidence for significant resurfacing. Therefore, the region should also exhibit loose surface material.

Methods: Rocky ejecta craters are relatively fresh impact structures that exhibit boulder-sized rocks in their continuous ejecta blanket, within an annulus of 1 crater diameter (D) from the rim (Figure 2). This ejecta is sourced from a depth that is approximately 10% of D [5]. Catling et al. (2011) [6] determined the onset diameter at which rocks appeared in the ejecta of relatively fresh craters to constrain the near surface stratigraphy of the Vastitas Borealis Formation. In their work, they suggested the presence of a regionally-extensive shallow, 100 m to 200 m thick basaltic bedrock unit that was contributing to the excavation of large rocks during impact. They also demonstrated that small craters with D < 200 m do not exhibit rocks in their ejecta and interpreted this to indicate the presence of a 10 to 20 m-thick surface regolith on top of the bedrock unit. Above 2 km in diameter, craters also did not show rocks in their ejecta. This provides the depth limit for the competent rocky layer.

We observe similar onset diameter relationships in western Elysium Planitia (Figure 2). Due to landing site selection activities we now have access to a regionally extensive HiRISE (25 cm pixel^{-1}) dataset to quantitatively evaluate onset diameter relationships across a broad range of crater diameters and over a single, spatially restricted terrain unit.

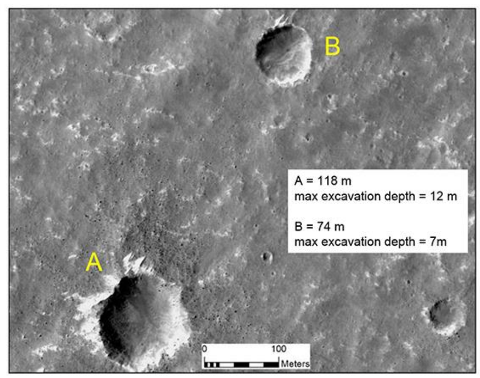

Figure 2: HiRISE image displaying two craters with similar preservation. Crater A has rocks in its ejecta blanket. Crater B does not.

To date, we have mapped 1556 rocky ejecta craters across 27 HiRISE images covering nearly 3000 km^2. For each crater, we mapped the crater itself and its rocky ejecta. The craters and their ejecta were then classified into 5 classes, spanning a range of degradational states from relatively pristine (class 1) to nearly degraded (class 5) to track how craters and their rocky ejecta degrade with time and to ensure that non-rocky ejecta craters were not included in our analysis. Criteria for crater rim and interior classifications include continuity of the rim, the presence or absence of bedforms and infill, the presence or absence of craters that superpose the rim or infill, and interior slope characteristics. Criteria for ejecta classifications include the continuity of rocky ejecta around the crater, the presence or absence of bedforms between the rocks and against the rim, the occurrence of smooth mantle infilling between or over the rocks, and the occurrence of craters that superpose the ejecta.

The crater data was then analyzed by plotting all rocky ejecta craters on size frequency distribution (SFD) plots using both incremental and cumulative methods. Roll overs in the small crater diameter bins on the SFD plots were observed and analyzed to determine whether they can be attributed to the occurrence of a meters-thick regolith that buffered the impact from the excavation of rocks.

Results: Figure 2 illustrates an example pair of craters that show similar rim preservation (class 3) but are of different sizes. Crater A is 118 m in diameter and exhibits a well-preserved rocky ejecta blanket. Crater B is 74 m in diameter and completely lacks rocks in its ejecta. Based on their proximity and similar characteristics we suggest that both craters have experienced a similar level of degradation over a similar period of time. The lack of rocks surrounding Crater B therefore cannot be attributed to surface degradation. Rather, the lack of rocks at Crater B implies that the impact did not excavate rocks. Using excavation relationships of primary craters [5] we estimate a max excavation depth of rocks in the ejecta blanket of A at ~12 m. At B, the maximum excavation depth for material in the continuous ejecta blanket should be ~ 7 m. We suggest that this indicates the presence of a regolith that is at least 7 m deep at this location.

Figure 3 highlights the cumulative and incremental SFD plots for all rocky ejecta craters across the 4 ellipses. At D > 130 m all rocky ejecta craters follow the standard crater production functions for Mars [7]. The data roughly follow the ~500 Ma isochron suggesting that any impact that occurred in the last 500 Ma at this location that has a D > 130 m should exhibit rocks in its ejecta. Craters older than this time include degraded craters that no longer exhibit rocks in their ejecta. However, a significant roll over begins in the distribution on both plots at D < 130 m. At D < 50 m, the roll over flat lines on the cumulative plot and tips over on the incremental plot. In other words, at D < 50 m there are very few if any classified rocky ejecta craters within the InSight region. From D > 50 to < 130 m there are some rocky ejecta craters but less than the standard production of impacts on Mars over the last 500 Ma.

Discussion and Conclusions: The roll over in the SFD can be attributed to the presence of a buffering regolith that is several meters deep across the entire landing region. For D > 50 m but < 130 m, some of the craters exhibit rocky ejecta while others don't. We interpret this to indicate that the regolith may be heterogeneous in thickness across the region, ranging from ~ 5 m to up to 13 m thick. The lack of craters with rocks in their ejecta relative to the density of craters that should exist within the D = 50 m bin suggest that the regolith is at least 5 m thick across ~97% of the total measured area.

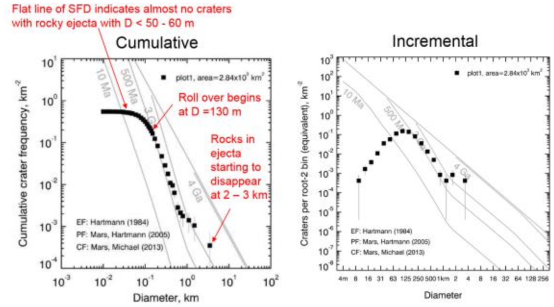

Figure 3: SFDs for rocky ejecta craters across the InSight region.

Other explanations for the roll over in SFD plots include resolution roll off, human count error, and the decline in slope that is typical of small crater degradation, either through rapid resurfacing or steady state processes that operate to preferentially degrade smaller craters [8,9]. At D < 130 m, the roll over occurs at too large of a diameter to consider resolution as an issue. Furthermore, 50 to 100-m-sized rocky ejecta craters are obvious in HiRISE and relatively few in number. It is very unlikely that human error could have played a role in such a dramatic reduction in slope. We also discount any process that could have rapidly resurfaced smaller craters. We observe no lava units (e.g., lobate margins) or erosional landforms (e.g., fluvial channels, pedestal craters, yardangs) within the landing ellipses. Finally, the steady and preferential degradation of small craters is a likely process that operated across Elysium Planitia. Our observations of the degradational state of craters indicate that burial and modification by aeolian materials is the most likely mechanism by which the craters are degraded here. However, this process typically manifests in a crater SFD as a steady decrease in the slope as each subsequently smaller crater bin experienced more relative degradation compared to the larger diameter bin (more similar to the 130 m to 1 km diameter range). This therefore cannot account for the dramatic reduction in slope of the SFD. We conclude that our observations are consistent with the presence of a regolith.

References: [1] Tanaka, K. et al. (2005) *USGS Map* 2888. [2] Golombek, M. et al. (2013) *44th LPSC*, #1691. [3] Banerdt, W. et al. (2012) *43rd LPSC*, #2838. [4] Hartmann, W.K. et al. (2001) *Icarus* 149, 37-53. [5] Melosh, J. (1996), in *Impact Cratering: a Geologic Process*, Oxford Univ. Press. [6] Catling et al. (2011) LPSC, #2529. [7] Ivanov, B.A. (2001) Space Sci. Rev., 96, 87-104. [8] Hartmann, W.K. (1971) Icarus 15, 410-428. [9] Hartmann, W.K. (2005) I*carus* 174, 294-320. [10] Hartmann, W.K. & Neukum, G. (2001) Space Sci. Rev., 96, 164-194.