MAPPING REGOLITH THICKNESS ON THE MOON USING A NEW CLASS OF YOUNG CRATERS.

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Introduction: At the Moon, most remote sensing techniques observe the regolith and infer conclusions about the landforms below. Even most rocks returned by the Apollo program were not collected where they originally formed. To understand the geologic history of the Moon it is important to first understand how landforms have been modified since they first formed, which on the Moon requires understanding the breakdown of rock and the formation of regolith. Here we investigate how the thickness of regolith varies spatially to better understand the development of regolith over time.

If the regolith were of uniform thickness, all craters above a certain diameter would penetrate the regolith and all craters below that diameter would not, but this is not what is observed [e.g. 1]. Previous studies have estimated the regolith thickness based on the excavation depth of the smallest crater to excavate blocks [1 and references therein], but this method relies on the assumption that a difference in the ages of the craters does not affect the presence or absence of blocks. However, more recent studies have shown that rocks on the surface of the Moon breakdown nearly an order of magnitude faster than previous estimates [2, 3]. This implies that the blockiness of crater ejecta may depend on both regolith thickness and crater age even for craters that are not obviously degraded.

Our approach capitalizes on one of the unexpected discoveries by the Lunar Reconnaissance Orbiter (LRO) Diviner Lunar Radiometer Experiment (Diviner), a previously unrecognized class of lunar impact craters known as ‘cold-spot’ craters (Fig. 1). These craters are surrounded by low thermal inertia material extending ~10-100 crater radii which appears to be material that has been ‘fluffed-up’ by the impact without the addition of significant ejecta material [6]. This ‘cold-spot’ surrounding the crater fades within ~0.5-1 Myr after impact thus providing a new method for identifying very young craters on the Moon [7]. The rock abundance in the proximal ejecta of these craters varies only with regolith thickness and crater size since they are all very young.

Methods: We use Diviner measurements to calculate the rock abundance [5] in the proximal ejecta blankets of cold-spot craters. The Diviner team has identified over 2,000 lunar craters with prominent ‘cold-spot’ anomalies [7]. However, only 344 of these are larger than a single Diviner pixel. For these larger craters, we calculate the mean Diviner rock abundance in an annulus centered on each crater stretching from one crater radius to three crater radii.

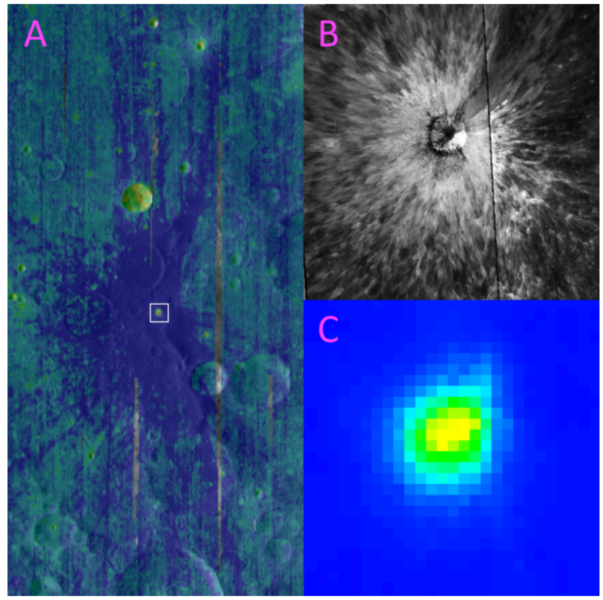

Figure 1: An example cold-spot shown in A) Diviner H-parameter data [4] where blue is low thermal inertia and yellow is high (WAC mosaic underlay shows topography). B) An LROC NAC image of the 0.9 km crater associated with the cold-spot in (A). C) The Diviner rock abundance map [5] of the same region as (B) shows the rock abundance of the proximal ejecta (yellow >10% rock coverage; blue ~0% rock coverage).

The mean rock abundance associated with a cold-spot crater varies with the regolith thickness and the crater diameter since larger craters are able to excavate deeper into any rock underlying the regolith if present. We estimate the excavation depth of each crater based on the scaling law presented in [8]. We assert that any variability in mean rock abundance in the ejecta of craters of the same size is due only to variations in the thickness of the regolith.

Results and Discussion: In general, cold-spot craters in the maria have more rocks in their ejecta blankets than those in the highlands (Fig. 2). This is expected due to the younger surface age of the maria. The highlands have been bombarded over a longer period of time allowing the formation of a thicker layer of regolith. There are some rocky craters in the highlands but they tend to be larger craters which can excavate to greater depths. Figure 2 shows hints of higher rock abundance in the Orientale region (19.4°S, -92.8°E), which has been noted by previous authors as well [e.g. 9, 10].

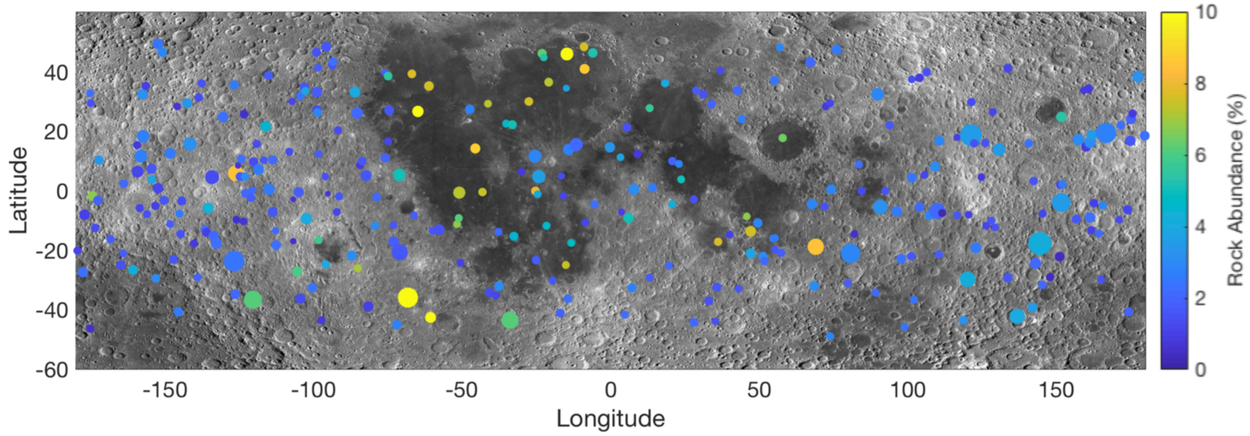

Figure 2: The mean rock abundance in the proximal ejecta blankets of large (D>250 m) cold-spot craters. Circle size is proportional to crater diameter.

If the regolith layer were of uniform thickness, then the rock abundance in the ejecta blankets of cold-spot craters would increase with increasing crater diameter, but the observations are more complex (Fig. 3). The rock abundance in the ejecta of cold-spot craters in the highlands does increase slightly with increasing crater diameter but there are significant deviations from this trend. In the maria, the rock abundance in the ejecta of cold-spot craters spans a wide range of values for craters of all sizes. For a given crater diameter, the range of observed rock abundance values is greater in the maria than in the highlands which suggests more variability in regolith thickness in the maria than in the highlands.

It should be noted that the 'regolith' layer will also contain rocks of various sizes, so rocks in crater ejecta may come from the layer that is nominally regolith rather than a coherent rock layer below the regolith. Another consideration when interpreting these observations is that Diviner rock abundance is only sensitive to rocks larger than approximately 1 m in diameter [5], so the true rock abundance in crater ejecta is higher than reported in Figures 2 and 3. Impact melt typically shows a low rock abundance in Diviner measurements, which is interpreted to mean that it is already mantled in lower thermal inertia regolith. However, cold-spot craters may be young enough that any impact melt is not masked by regolith, which would result in an overestimate of rocks excavated by the impact. Friable breccia boulders are expected to have a lower thermal inertia than coherent rocks, so although they present a challenge in identifying boulders in visible imagery, we expect them to have a negligible effect on our results.

Future Work: Our preliminary results demonstrate that the rockiness of cold-spot craters' proximal ejecta varies with regolith thickness. We will develop crater scaling laws to relate the rock abundance in crater ejecta to the approximate regolith thickness. We will also extend our study to smaller cold-spot craters by using visible imagery from the LRO camera (LROC).

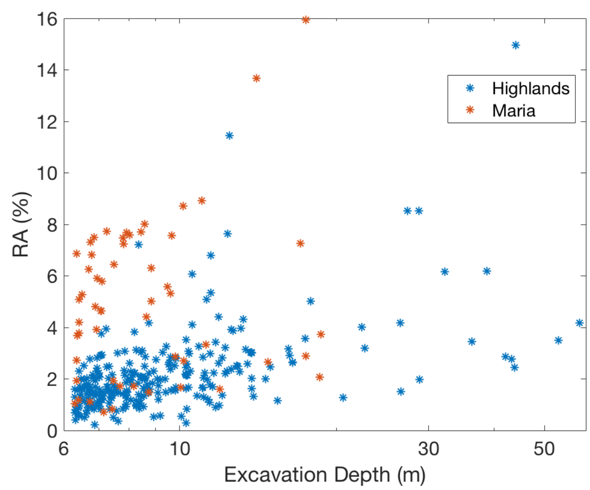

Figure 3: The rock abundance (RA) in ejecta blankets vs. inferred excavation depth for cold-spot craters in the maria (red) and highlands (blue). An excavation depth of 10 m corresponds to an approximately 400 m diameter crater [8].

References: [1] Wilcox B. B. et al. (2005) *Meteoritics & Planet. Sci., 40, Nr. 5*, 695-710. [2] Basilevsky A. T. (2013) *Planetary and Space Sci. 89*, 118-126. [3] Ghent R. R. et al. (2014) *Geology v. 42 no. 12,* 1059-1062. [4] Hayne, P. O. et al. (2017) *JGR, 122,* 2371-2400. [5] Bandfield J. L. et al. (2011) *JGR, 116,* E00H02. [6] Bandfield J. L. et al. (2014) *Icarus, 231,* 221-231. [7] Williams J.-P. et al. (2018) *JGR, 123,* 2380-2392. [8] Sharpton V. L. (2014) *JGR, 119,* 154-168. [9] Ghent R. R. et al. (2008) *Geology v. 36 no. 5*, 343–346. [10] Haber J. T. (2018) *LPSC XLIX*, #2463.