CONSTRAINING THE THICKNESS OF THE LUNAR REGOLITH USING COLD-SPOT CRATERS.
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Background: Regolith covers nearly the entire surface of the Moon, so understanding regolith is an important first step in interpreting remote sensing and in situ observations and in studying the geologic history of the Moon. Numerous studies have attempted to constrain the thickness of the lunar regolith but significant uncertainty remains (e.g. see references in [1]).

One method for inferring regolith thickness is based on the presence or absence of blocks in a crater’s ejecta blanket. Specifically, the regolith thickness of a unit should be approximately that of the excavation depth of the smallest crater with a blocky ejecta blanket [2]. However, others have argued that the number of ejected blocks does not correlate with regolith thickness (e.g. [3]).

Here we use a recently discovered class of very young craters to determine whether crater age and the breakdown of ejected blocks affected previous studies. Specifically, we look at the block abundance surrounding cold-spot craters in Mare Tranquilitatis and Oceanus Procellarum and compare to the results of [4] who looked at craters in these regions using Lunar Orbiter (LO) images. Cold-spot craters (Figure 1) are surrounded by an annulus of low thermal inertia material (cold at night) extending ~10-100 crater radii [5], but their proximal ejecta is often rocky [1]. The low thermal inertia signature fades within 1 million years [6]. In contrast, 50% of boulders greater than 2 meters in diameter surrounding craters of a similar size are destroyed in 40-80 Myrs and 99% are destroyed in 150-300 Myrs [7]. Therefore, the proximal ejecta blankets of cold-spot craters are expected to retain their original block population and be representative of the local subsurface properties.

Methods: To investigate the effects of crater age on estimates of regolith thickness inferred from blocky craters, we identified cold-spot craters in regions with similar ages to those considered by [4]. Because cold spots fade so quickly, most craters are not cold-spot craters and only one exists within the bounds of the LO images used by [4]. To expand our crater dataset we used [8] to identify nearby units of similar ages and cold-spot craters that fall within those units. The portion of Oceanus Procellarum considered by [4] has an age of ~2.5 Ga, and Mare Tranquilitatis has an age of ~3.6 Ga [8]. Geologic units in Oceanus Procellarum have a very large range of ages, so we considered only units with ages 1.9-3.1 Ga. This represents a balance between including enough craters and limiting the range of surface ages.

Results & Discussion: We find that small cold-spot craters in the regions studied by [4] and nearby similarly-aged geologic units are more often surrounded by blocks than the craters considered by [4]. We find that all craters above 175 m in diameter have at least one block within one crater radius of the crater rim (Figure 2),

Figure 1. An LROC NAC image of a 186 m diameter cold-spot crater at 44.94°W, 0.7°N.

We considered all cold-spot craters in Mare Tranquilitatis which ranges in age from 3.39 to 4.23 Ga [8]. This resulted in ~50 cold-spot craters each in Mare Tranquilitatis and Oceanus Procellarum.

We identified the Lunar Reconnaissance Orbiter Camera (LROC) Narrow Angle Camera (NAC) image best suited for block counting at each cold-spot crater and resampled each image to 1.5 m/pixel, so the smallest block considered is ~3 m at every cold-spot crater. This is comparable to the resolution estimated by [4] for the digital scans of LO photographic prints used in their study. Using Crater Helper Tools in ArcMap, we measured the diameter and coordinates of the cold-spot craters, and counted the number of blocks within one crater radius of the crater rim. We classified each crater as distinctly blocky, one to three blocks, or no blocks. The middle category is to account for the possibility that a small number of blocks could have originated from another nearby crater. We assumed the maximum excavation depth is approximately 10% of the crater diameter [9]. Though more recent scaling estimates exist, we chose [9] to enable comparison with [4].
whereas [4] found this transition occurred at 525 m in diameter. Additionally, they found that more than half of the craters between 175 and 275 m in diameter excavated no blocks. We suggest this difference is caused by crater age and that unbeknownst to [4] blocks surrounding some of the craters they considered had already been broken down into sub-pixel blocks. This may be consistent with more recent work showing that 99% of blocks >2 m are destroyed in only 150-300 Myrs [7].

Older surfaces are expected to have developed a thicker layer of regolith [10]. Though regolith formation rates could depend on the material properties of the initial surface [11]. Based on the largest crater surrounded by no blocks, [4] found thicker regolith in older Mare Tranquilitatis (up to 48 m deep) than younger Oceanus Procellarum (up to 33 m deep). However, we applied the same method to cold-spot craters and found no significant difference between the regolith thickness in the two regions. We found that, based on the largest crater surrounded by no blocks, all regolith is <17.5 m deep in both Mare Tranquilitatis and the portions of Oceanus Procellarum that we considered. This result may suggest that regolith thickness does not vary significantly with surface age. Alternatively, the two-layer rock and regolith model could be too simplistic [1] and, at these crater sizes, blocks in the ejecta blankets could be primarily sourced from blocks mixed in with the regolith rather than a coherent rock layer.

**Conclusion:** By comparing the frequency and distribution of blocky cold-spot craters to the results of [4], we demonstrate the importance of using young craters when estimating regolith thickness based on the blockiness of crater ejecta blankets. We find fewer block-free craters than [4], suggesting that previous work using this method may have overestimated regolith thickness. When using cold-spot craters, we do not find a significant difference between terrains with different ages, which could imply that regolith thickness does not correlate with surface age or that a two-layer rock and regolith model is too simplistic. We will expand this study to additional regions in future work.

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**References:**

Figure 2. The distribution of craters with different block abundances versus crater diameter where the block abundance is categorized as no blocks (yellow), 1 to 3 blocks (red), and many blocks (blue) for A) both regions considered, B) portions of Oceanus Procellarum (see methods section), C) Mare Tranquilitatis. The number of craters in each bin are indicated by the numbers overlying the graph.