LUNAR REGOLITH DEPTH VS. SURFACE AGE: NEW MEASUREMENTS IN THE LUNAR MARIA.
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Introduction: The lunar regolith is the unconsolidated layer of rock debris that blankets the surface of the Moon [1, 2, 3]. It is thought that the lunar regolith is primarily formed by rock fracture due to meteorite impact [4, 5, 6]. As a result, regolith depth is expected to grow with time since impact bombardment continues to the present day [5, 7, 8]. Recent studies support the hypothesis that lunar regolith depth will increase with increasing surface age [9, 10, 11, 12, 13, 14, 15]. However, when the results from those studies are combined, the asserted trend of increasing regolith depth with age disappears [16, 17]. One reason that the trend might disappear is because of systematic differences between the methods used in the different studies. Therefore, in this project, we directly test the hypothesis by finding and comparing regolith depths on differently aged surfaces, using the same method at each site.

Method: To determine regolith depths, we used the well-established crater-morphology method [18, 10, 12]. We identified small (< 150 m) lunar craters that had flat floors or concentric rings. We chose this size of craters because they are of the optimal size to determine regolith depths in the range of 1-10 m, which are typical lunar regolith depths.

Experiments [18] have ascertained that for a given rim-to-rim crater diameter, $D_A$, as an overlying loose-layer thickness, $t$, increases, the crater’s morphology will transition from normal, to flat-floored, to concentric. Quantitatively, the experiments show that the layer thickness can be found by measuring both the crater’s rim-to-rim crater diameter, $D_A$, and the crater’s flat-floor diameter, $D_F$:

$$t = \frac{1}{2}(k - \frac{D_F}{D_A})(D_A \tan \alpha)$$

(1)

where $k$, an empirical constant, is about 0.86, and the angle of repose, $\alpha$, is about 31°.

We limited our analysis to well-defined craters with sharp and distinct concentric rings or flat floors. We avoided degraded craters where such features are ambiguous or eroded. For each crater we found, we measured the diameter of the inner feature, $D_F$, as well as the rim-to-rim diameter, $D_A$, for flat-floored and concentric craters [19]. For each crater we used Equation 1 to obtain the local regolith depth.

In this project, we used previously determined surface ages of mapped basaltic lava flows on the lunar surface. The ages were determined using crater size-frequency distributions [20, 21, 22, 23, 24]. Because these ages cover a large percentage of the nearside mare, and because they were all determined by the same group, we chose to use these ages in our work because we expect ages to be internally consistent from one site to another.

Discussion: The wide variability of regolith depth measurements within each site is to be expected. The na-

Figure 1: Locations of our study sites. Sites P58 (green) and P54 (cyan) are located in Oceanus Procellarum and have ages of 1.33 Gy and 1.67 Gy respectively. In Mare Serenitatis, sites S29 (red), S27 (violet) and S16 (blue) have respective ages of 2.44 Gy, 2.90 Gy and 3.43 Gy. Site A01 (gold) has an age of 3.88 Gy and is located in Mare Australe. The location of the Mare Tranquillitatis regolith data reported in [10] are shown in black for comparison. Site names and ages are those given by [24].

Results: Our results are displayed in Figure 2. The figure shows the measured regolith depths for each studied crater grouped by region. The age of each region is plotted on the x-axis. We display the results as a box-and-whisker plot to emphasize the wide variability of the individual measurements within each site. The horizontal line in the middle of each box represents the median regolith depth for that region, which is the measurement often reported in the literature as a site’s regolith depth.

Our results do not show a clear increasing trend of the median regolith depth of a site as surface age increases. Instead, we see that median regolith depths range from about 2 m to about 5 m, both for old surfaces (3.5-4 Gy) and for young surfaces (1.2-1.6 Gy).

Our results do NOT support the assertion that regolith depth increases with time. This extremely surprising result deserves careful consideration given the long history of assuming that regolith depth does increase with time.

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Figure 2: Regolith depth measurements as a function of surface age for all study sites. Regolith depth measurements from sites P58, P54, S29, S27, S16 and A01 are plotted in colors green, cyan, red, violet, blue and gold respectively. We also include Mare Tranquillitatis regolith depth data [10] (black) for comparison. Site names and ages are those given by [24].

nature of the regolith formation process, i.e., variable impactor type, size, and location, causes regolith depth to vary even over relatively short distances. Most of our regolith depth measurements fell between 1 and 15 m, but a handful of outliers (∼10 out of 4500 measurements) extended to depths of up to 40 m. Despite this wide variability, we still expect that, on average, the regolith depth would reflect regional changes in the terrain over time because the lunar surface is subjected to impactors to the present day.

Conclusion: It is crucial that future work investigate why the regolith depth data do not clearly demonstrate an age dependence. One possible interpretation of our results is that the lunar regolith is not getting significantly deeper with age, despite continued bombardment by meteorites. Another interpretation is that there are other factors contributing significantly to regolith generation besides impact cratering, such as different styles of volcanism [25] and thermal breakdown of lunar boulders [26].