CHARACTERIZING LUNAR IMPACT-RELATED FEATURES, EMPLACEMENT AND DEGRADATION PROCESSES – IMPACT MELTS AT COPERNICUS CRATER.
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Introduction: Many questions remain about how well we can characterize the processes that lead to emplacement and degradation of the Moon's regolith, both at the surface and sub-surface, and how well we can correlate those processes to age. Previous work has compared Diviner rock abundance data to Mini-RF surface roughness values to investigate relationships between crater age and regolith degradation [1,2,3]. Those initial studies suggested that the physical properties of crater features of different ages manifest differently depending on the wavelength region used in analysis because the data is detecting physical attributes at different scales and depths in the regolith. Here we focus on integrating Mini-RF-sourced surface roughness values, Diviner rock abundance, and Lunar Reconnaissance Orbiter Camera (LROC) boulder counting to compare the relative degradation rates of similar age features in different regolith settings, both at the surface and sub-surface (< a few meters).

We compare Miniature Radio Frequency (Mini-RF) circular polarization ratio (CPR) values of impact melts associated with Copernicus Crater (9.3°N, 339.9°E) to optical boulder count and thermal-emission derived rock abundance data. We use these comparisons to analyze how the integration of this data can give us insight into surface and subsurface regolith degradation rates and processes, focusing on impact melts within different settings (impact melt ponds vs. impact melt flows).

Background: When studying regolith associated with cratering processes, we can focus our studies on several impact crater features such as melt-free ejecta, melt ponds, ejecta with melt flows, and floor of the crater away from the walls. Examining all of these features give us an opportunity to understand how regolith for each feature type degrades. Using LRO data, [1] investigated the age-dependent characteristics of crater ejecta as a measure of rock degradation rates. Analyzing Diviner rock abundance, the results implied shorter rock survival times than predicted based on downward extrapolation of 100 m crater size frequency. They concluded that all surface rocks disappear over a period of roughly 1 byr and that for older craters the ejecta that remains exists within the subsurface, i.e., they are not visible to Diviner or LROC, but possibly to Mini-RF.

Methods: The suite of instruments onboard the NASA Lunar Reconnaissance Orbiter (LRO) are providing much needed global observations capable of producing information on lunar surface physical properties. These include small-scale roughness and rock abundance at both the surface and at modest depths into the regolith at scales of centimeters to meters [4].

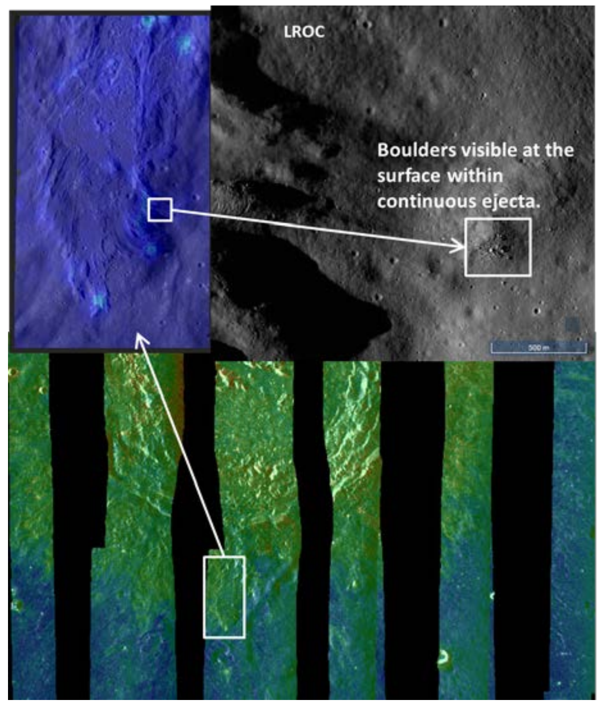

Figure 1. Impact Melt ponds and flows south of Copernicus Crater, within the continuous ejecta. Bright turquoise colors in upper left image correspond with greater Diviner RA values. Bright green colors in lower image correspond to higher Mini-RF CPR values. Individual boulders are visible at the surface in the LROC image (upper right).

Lunar Data Products. Figure 1 shows the same impact melt feature using all three data sets. Mini-RF (bottom image) provides a unique means to analyze the surface and subsurface physical properties of geologic deposits The most common product used for analysis of the Mini-RF data is the circular polarization ratio (CPR). This product can serve as a measure of surface roughness and is defined as the ratio of the backscattered power in the same- sense (SC) polarization that was transmitted relative to the backscattered power in the opposite-sense (OC) polarization.

Diviner's rock abundance (RA) estimates leverage the wavelength dependence of thermal emission for scenes of mixed temperatures. Bandfield and coworkers [3] produced a model for simultaneously solving for the areal fraction of rocks greater than ~0.5 to 1 m in diameter and the temperature of the rock-free regolith using thermal models and nighttime data from three of Diviner's broad thermal channels: Ch. 6 (13–23 µm), Ch. 7 (26–41 µm), and Ch. 8 (50–100 µm). We will be using global 128 pixels per degree maps of Diviner rock abundance for our analysis.

Analysis of the Mini-RF and Diviner data is enhanced with LROC Narrow-Angle Camera (NAC) observations. The NAC consists of two monochrome line scan imagers with resolutions of 0.5 m/pixel. These images will be critical for providing additional geologic context at high spatial resolution. We are using these data, in combination with Mini-RF and Diviner data, to assess the physical properties of impact features observed more readily at the surface. Additionally, we use NAC imagery to determine the size-frequency distribution of surface boulders. Meter-scale boulders observed in LROC data could be distinguished from centimeter- to decimeter-scale scatterers in CPR data. This helps constrain our observations and may produce a better means of assessing whether CPR can discriminate relative degradation rates.

Our methodology for this study consists of three tasks: 1.) Use LROC data to produce boulder counts and characterize impact melt ponds and impact melt flow features at meter scales. 2.) Integrate boulder counts with Diviner data of these features to characterize these features at decimeter to meter scales, and 3.) Integrate LROC and Diviner information with Mini-RF CPR values to characterize differences in roughness at centimeter to decimeter scales.

Preliminary Results: Here we present results from an analysis at Copernicus Crater for two impact melt features south and northeast of Copernicus Crater. Both impact melt flow features are within the continuous ejecta blanket and both are associated with the formation of Copernicus Crater, and are therefore the same relative age. We add this crater analysis to our previous crater study [5] and present preliminary results from integrating analysis of radar, thermal infrared and visual imaging data to physically characterize impact melt features at the surface and subsurface.

Figure 2 shows both impact melt features in LROC data. The image on the left shows the impact melt feature to the south of Copernicus and the image on the right shows the impact melt feature to the northeast of Copernicus. The green and blue dots show the distribution of boulders visible at the surface in the left and right images, respectively. Boulders visible at the surface appear to be distributed more frequently along melt margins and not as much within melt ponds. Both areas also show relatively high RA values and high CPR values compared to other areas around the crater, suggesting increased surface roughness and possible sub-surface centimeter-meter scale blocks as well. We will continue integrating these data sets in order to better constrain the relative ages and degradation rates of regolith associated with various impact features and how their settings, including if they are located within mare or highlands material, factors into their degradation rates. This analysis can also inform Mini-RF planning for future targets for the currently operating bistatic campaign, and how the new Mini-RF bistatic observation mode compares to monostatic observations of the same features.

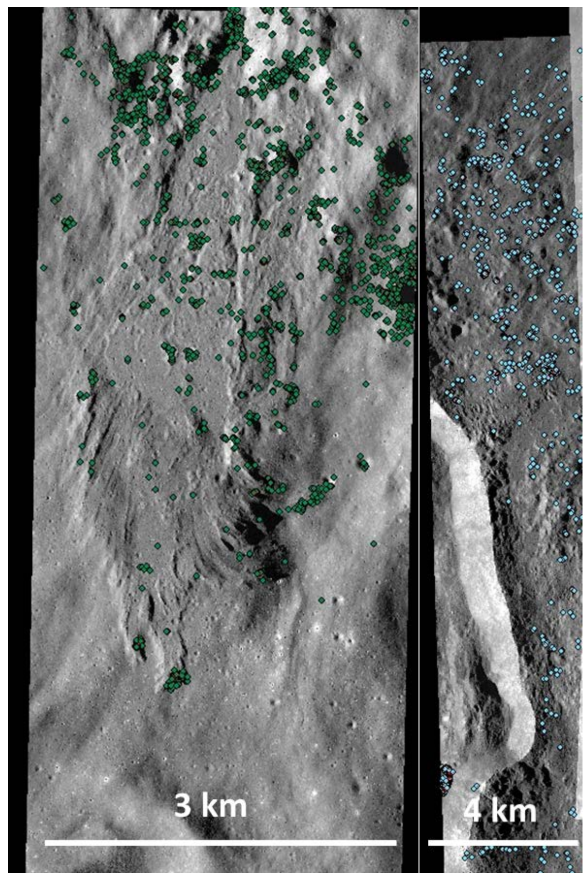

Figure 2. LROC NAC imagery with boulder counts. Left image shows the melt ponds and flows south of Copernicus. Right image shows the melt ponds and flows northeast of Copernicus.

References: [1] Ghent et al. (2014) Geology, 42 (12), 1059-1062. [2] Greenhagen et al. (2016) Icarus, 273, 237-247. [3] Bandfield et al. (2011) J. Geophys. Res., 116. [4] Cahill et al. (2014) Icarus, 243, 173-190. [5] Matiella Novak et al. (2017) LPSC XLVIII, 2554.