CHARACTERIZING REGOLITH BREAKDOWN ON THE MOON USING LRO OBSERVATIONS OF YOUNG, FRESH CRATER EJECTA.

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Introduction: We will be comparing Miniature Radio Frequency (Mini-RF) circular polarization ratio (CPR) roughness values, collected in the current bistatic mode, of a fresh crater south of Anaxagoras crater (70.5°N, 349.8°E) to optical boulder count and thermal-emission derived rock abundance data. We will use these comparisons to analyze how bistatic Mini-RF CPR data can give us insight into surface and subsurface regolith degradation rates and processes, focusing on crater ejecta. Previous studies have shown variation in the correlation of Diviner Lunar Radiometer (Diviner) thermal infrared rock abundance data to Mini-RF monostatic radar surface roughness data and demonstrated the differing rates of regolith degradation at the surface and sub-surface [1,2]. These initial studies suggest that the physical properties of features of different ages manifest differently depending on the wavelength region used in analysis. We have also previously performed an integrated analysis of monostatic radar, thermal and visual imaging data to physically characterize these features to better constrain processes that control regolith formation and evolution, both at the surface and in the sub-surface [3]. Here we focus on integrating newly collected bistatic data with our ongoing analysis comparing Mini-RF roughness, Diviner rock abundance, and Lunar Reconnaissanice Orbiter Camera (LROC) imagery boulder counting to provide more robust constraints on the relative ages and degradation rates of regolith through the physical characterization of lunar features of different ages, such as crater ejecta.

Background: When studying regolith associated with cratering processes, we can focus our studies on impact crater features such as melt-free ejecta, melt ponds, ejecta with melt flows, and floor of the crater away from the walls. All of these features give us access to regolith at centimeter to meter scales, and an opportunity to understand how regolith for each feature type degrades. Using LRO data, Greenhagen et al. [2] 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.

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 surface roughness and rock abundance at both the surface and at modest depths into the regolith [4].

Lunar Data Products. The Mini-RF instrument aboard LRO is currently acquiring bistatic radar data of the lunar surface at both S-band (12.6 cm) and X-band (4.2 cm) wavelengths with the Arecibo Observatory (AO) in Puerto Rico and the Goldstone DSS-13 antenna in California. Mini-RF provides a unique means to analyze the surface and subsurface physical properties of geologic deposits, including their wavelength-scale roughness, the relative depth of the deposits, and some limited compositional information. The most common product derived and used from radar for analysis 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 returned to the instrument receiver. Recent studies using Mini-RF's new bistatic operating mode have shown it to be useful for analyzing CPR roughness for crater ejecta [5] and we will be using these same methods in this study.

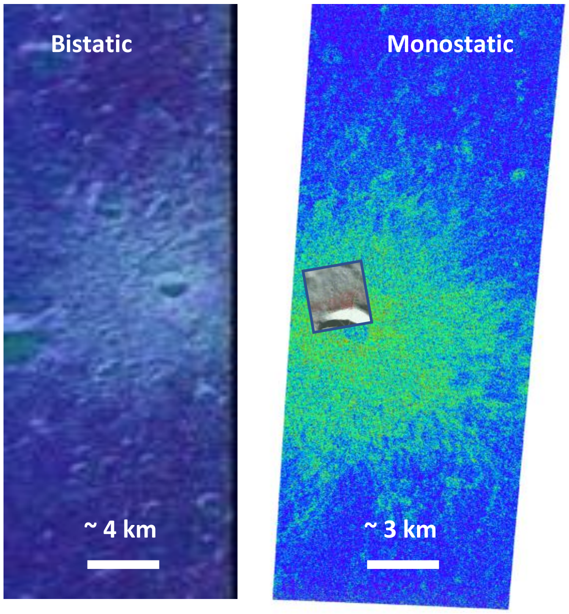

Figure 1. Small crater south of Anaxagoras in Mini-RF CPR data. Bright greenish-blueish colors correspond with greater CPR values.

Diviner's rock abundance estimates leverage the wavelength dependence of thermal emission for scenes of mixed temperatures. Bandfield and coworkers [6] 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 will be 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 will employ 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 will use NAC imagery for our size-frequency boulder counting effort. Meter-scale boulders observed in LROC data could be distinguished from centimeter-scale scatterers in CPR data. This helps constrain our observations and may produce a better means of assessing whether CPR can discriminate relative age.

Preliminary Results: Here we add a small (< 2 km), fresh crater south of Anaxagoras to our previous crater samples [3] and present preliminary results from integrating analysis of radar, thermal infrared and visual imaging data to physically characterize crater ejecta at the surface and subsurface. Previous work [3] involved S-band data (12.6 cm) and this particular crater has been well characterized now by Mini-RF at both S- and X-band (4.2 cm), providing an opportunity to look for differences in the cm to 10s of cm boulder size/frequency distribution. Figure 1 shows bistatic and monostati Mini-RF CPR images side by side to compare differences with respect to surface roughness observations. As expected, the ejecta surrounding this crater is rougher than the surrounding terrain in both images.

Figure 2 is a global rock abundance image, produced from Diviner data, centered on this study's crater. Areas of greater rock abundance are highlighed in yellow and green and is also associated with the crater's ejecta. Looking at the region more closely in LROC NAC imagery (Figure 3), we can see the area is populated with hundreds of boulders ranging in size from about 1 m to about 25 m across the longest axis. We will continue integrating these data sets in order to better constrain the relative ages and degradation rates of regolith through the physical characterization of lunar features of different ages, such as crater ejecta. This analysis will also help us better understand how the new Mini-RF bistatic observation mode compares to monostatic observations of the same features.

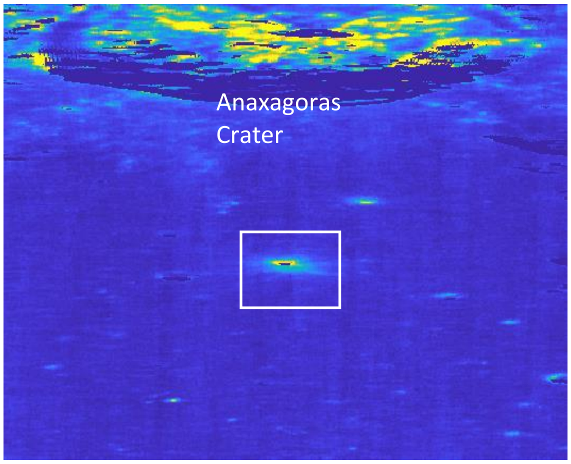

Figure 2. Diviner Rock Abundance with Anaxagoras in the upper part of the image. The crater inside the white box is the focus of this study.

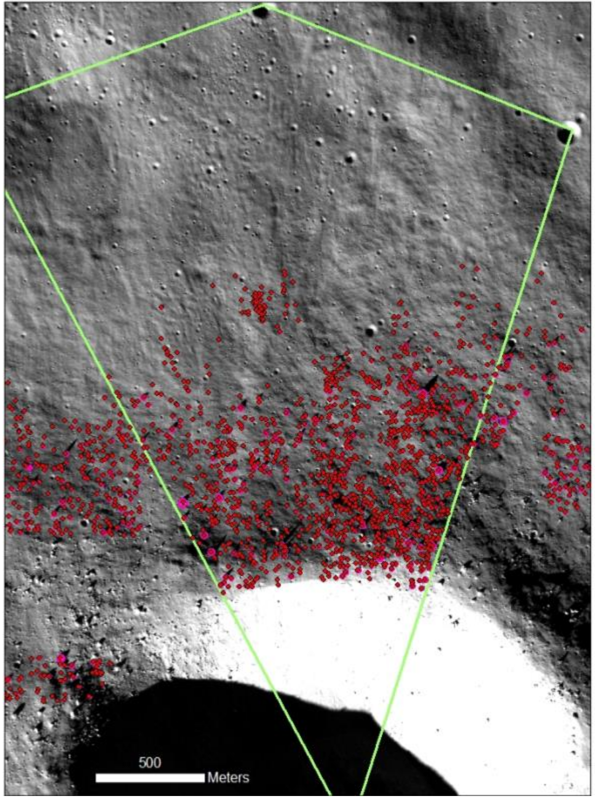

Figure 3. LROC NAC image used for preliminary boulder size-frequency counts. Boulders are circled in red. Enlgarged from small box in Figure 1.

References: [1] Ghent et al. (2014) *Geology, 42 (12)*, 1059-1062. [2] Greenhagen et al. (2016) *Icarus, 273*, 237-247. [3] Matiella Novak et al. (2017) *LPSC XLVIII*, 2554. [4] Cahill et al. (2014) *Icarus, 243*, 173-190. [5] Patterson, et al. (2017), *Icarus*, 283, 2-19; [6] Bandfield et al. (2011) *J. Geophys. Res., 116*.