ESTIMATING LUNAR ROCK ABRASION STAGE USING PHOTOMETRIC STUDIES R.M. Marshal[1], O. Rüsch[1], C. Wöhler[2], K. Wohlfarth[2] ,[1]Institut für Planetologie, WWU Münster (rachael.marshal@uni-muenster.de), [2] Image Analysis Group, Technische Universität Dortmund.

Introduction: The study and investigation of local scale geological features (boulders and boulder fields) of planetary/asteroid surfaces can provide insight on the evolution of the regolith and the contribution of various processes to its formation. Numerous studies have employed photometric modelling to study the surface properties of the lunar regolith on a regional and local scale (e.g., [1], [2], [3])

In this study we employ photometric methods to study the properties of boulder fields/rock fragments in a multiscale approach from resolved (meter scale) to sub pixel (cm scale). In both our approaches we use the Hapke model [4] on LROC NAC data [5]. The retrieved properties of boulders, in particular their shape, can in turn shed light into the boulder material strength and surface exposure time [6].

Usually, photometric studies (e.g., [2]) consider the Hapke parameters SSA, b, c, theta_bar as unknown and estimate them by inversion. Here we take a different approach and strongly constrain the possible combinations of the four parameters. The constraint is made possible by the knowledge of the geological context of the surface either above (sub pixel approach) or below (resolved boulder field approach) the image resolution, visually inferred with images.

We are interested in the relative probability of each geologic context for a given region. This information is sufficient to shed light into the possible micro scale geology of a region, namely the shape, and thus degradation, of rocks. We apply these techniques to the boulder fields in the vicinity of the Apollo 16 landing site - North Ray crater.

Method:

The first step in our approach consists of the construction of a set of digital terrain models (DTMs) representative of the most probable geologic contexts. The contexts are concerned with the rock and debris aprons shape and reflect the abrasion stage of the rock – Non-Abraded (flat top), Non-Abraded (angular), Mildly and Highly Abraded (Fig 1). The size frequency distribution of the rocks follows a power-law shape from [1]. The rock abundance is either measured (resolved scale analysis) or set as free parameter (unresolved scale analysis). The size and spatial resolution of the DTM is defined by the scale of the analysis, either resolved or unresolved by LROC NAC.

Analysis 1 – Estimation of Sub Pixel Rock Abundance and degradation

In the approach to estimate erosion stage information of unresolved sub pixel rock, we consider the shadow causing facets to be dominated by features in the range of 1 mm and we neglect the contribution of roughness from the particle/grain size level This is partly in agreement with the inference that the contribution to the Hapke roughness if from the micrometer scale to the resolution of the instrument [4]. This approach gives us a set of options that can explain the reflectance of a NAC pixel.

The Hapke reflectance model [4] is then fitted to the DTM to estimate the average reflectance. We employ multiple iterations of our models with respect to four geological contexts (Fig 1). Using pixel level co-registered LROC NAC images at 55° and 70°, regions of homogenous pixels (reflectances) are selected and compared against the Hapke reflectances of the synthetic DTMs (see Fig 2).

Analysis 2 – Phase Ratio Method to estimate degradation of fully resolved boulder fields.

With this approach, we use phase ratio images that reduces the effect of unknown Hapke parameter values as they get cancelled out while calculating the ratio. The underlying principle of the Normalized Log Phase Ratio (NLPR) technique is that ‘rougher’ surfaces have a steeper phase curve across phase angles or in other words ‘darken’ faster than smooth surfaces. The relative roughness is linked to the degradation information of a boulder field as shown in Figure 4 i.e. roughness increases with decreasing erosion stage.

The synthetic DTMs are illuminated using Hapke reflectance model [4] with parameters shown in Fig .4

Comparison between model and observations is made with the parameter Normalized Log Phase Ratio Difference (NLPRD):

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$$\text{NLPRD} = \frac{log10(\frac{\text{F70}}{F55}) - log10(\frac{\text{B70}}{B55})}{(70-55)}$$

where F denotes an image of a rock-free flat surface and B denotes an image of a rock rich flat surface (see Fig 3). The numbers denote the phase angle. The sample image pairs are shown in Fig 3. The model derived NLPRD lines for different CFA using the synthetic DTMs is plotted in Fig 4.

The NLPRD are calculated for the fully resolved boulder fields from LROC NAC data and the associated CFA is estimated by boulder counts. For a given CFA, we can then extract information of the probable degradation of the boulder field in consideration

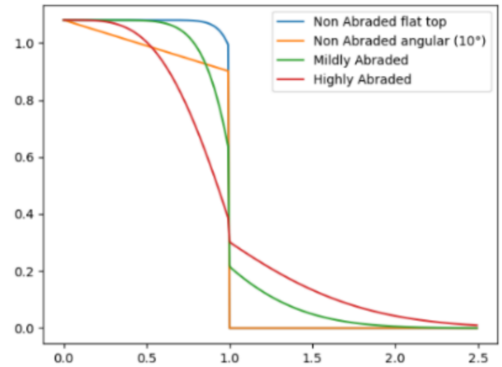

Figure 1: Rock half-profiles used to create the synthetic DTMs. Units are arbitrary.

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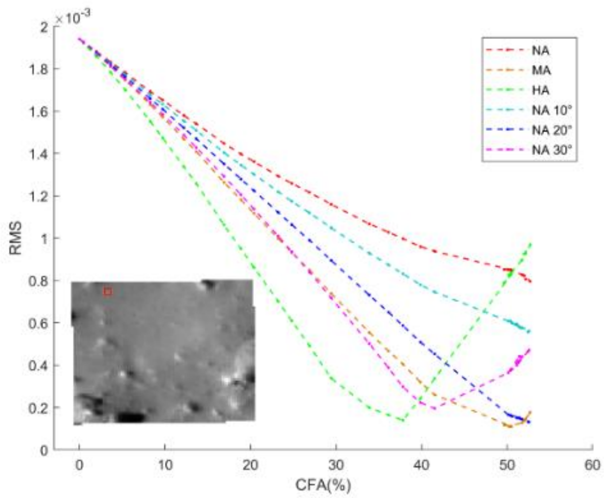

Figure 2: RMS of the fit between model and observation (reflectances) versus rock Cumulative Fractional Area for sub pixel boulder field (red square) in the vicinity of the Apollo 16 Landing site for various geologic contexts. Rock shape is labeled NA for not abraded (angle suffixed for angular rocks), MA for mildly abraded, and HA for highly abraded.

The Hapke roughness of the boulder field of interest is also estimated by finding the best fit pair of Hapke roughness for the flat surface and boulder field that can recreate the calculated NLPRD. This is done via an optimization procedure to check for all pairs within the domain of [0° 45°] [7].

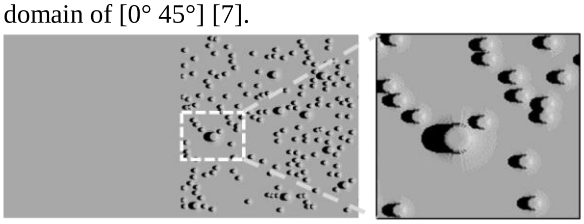

Figure 3: Artificial boulder field image for rocks of mildly abraded state at ~10% rock abundance (cumulative fractional area) at 55° incidence angle. Arbitrary dimensions. Note the reflectance contribution by rock debris aprons.

Discussion:

Analysis 1:

Multiple possibilities exist when trying to interpret a given reflectance value in terms of local scale geology – thus characterizing it into an inverse problem. Nevertheless, some scenarios better explain the data than others.

Figure 2 shows that the mean reflectance of Region 5 (a group of pixels within a boulder field in proximity to the North Ray crater) can be best explained (lowest RMSE) by a boulder field of ~50% CFA consisting of rocks that are 'mildly abraded' (have a fillet) and flat topped (see Fig 1- blue profile). The other geometries provide poorer fits.

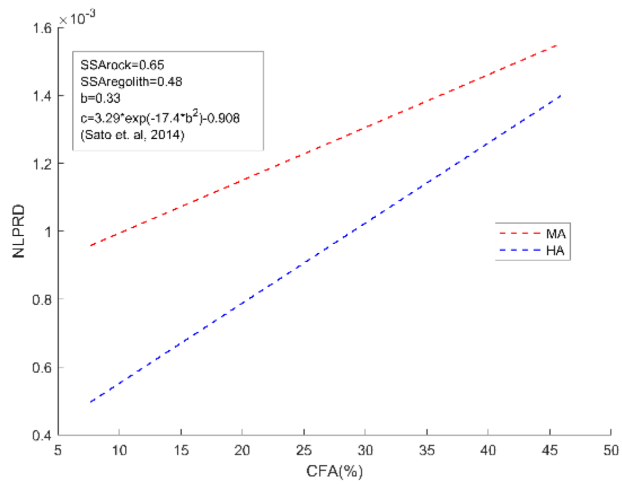

Figure 4: Model lines for the three trials of Analysis 2 as shown in Table 1.

Analysis 2:

The work in progress currently focusses on selecting multiple boulder fields and associated reference 'flat' surfaces that are well defined i.e., do not lie in proximity to a large boulder as it might be situated on a sloping fillet material, bright patches or patches of distinct reflectance within the boulder field are also to be avoided. Depending on where these data points fall on the plot shown in Fig.4, the relative abrasion stage of the boulder field can be estimated and linked to the Hapke roughness metric.

References:

[1] Watkins R.N. et al. (2019) JGR-Planets, 124, 2754–2771 [2] Sato et al. (2014) JGR-P, 119,1775-1805 [3] Lin et al. (2020) A&A,638 [4] Hapke (2012) *Theory of Reflectance and Spectroscopy* [5] Robinson M.S. et al. (2010) SSR,150,81-124 [6] Rüsch and Wöhler (2021) submitted to Icarus arXiv:2109.00052v1 [7] Schmidt and Fernando (2015) Icarus, 260, 73-93.