BOULDER SIZE FREQUENCY DISTRIBUTIONS ON COMET 67P/CHURYUMOV-GERASIMENKO.
Y. Tang[1], S. P. D. Birch[1], A. G. Hayes[1], R. de Freitas Bart[1], S.W. Squyres[1], [1]Department of Astronomy, Cornell University, Ithaca, NY (yt342@cornell.edu),

Introduction: Rosetta, ESA's mission to 67P/Churyumov-Gerasimenko (67P), has provided the first global high resolution coverage of a cometary surface. Using images and other data from Rosetta's OSIRIS Narrow Angle Camera (NAC), we analyzed the boulder size-frequency distribution and surface morphologies using ~18 cm/pixel images from a surface-spacecraft distance of 10 km. Through our analyses we were able to identify seven distinct morphological units on the comet surface, each with their own boulder size-frequency distribution. The distributions follow a power law, implying a fragmentation mechanism. Our analysis also allows for the estimation of the size-frequency distribution of centimeter-sized boulders with only low resolution images.

Boulder Counting: Boulder counts were performed to better understand the surface properties and formation mechanisms for each of the observed terrain types. Each boulder is measured along its long axis and counted. When counting, we only select boulders larger than 3 pixels to prevent inaccurate counting of small boulders and restrict our analysis to fully resolved features. In this work, we counted all boulders ≥50 cm in diameter.

For smaller boulders, analysis used ROLIS images from the Philae lander, which can resolve boulders down to diameters of ~1.5 cm. The ROLIS image taken from 9 m above the surface of 67P also provided the highest resolution imagery of the surface. We require that any scaling relationship we derive accurately fits both the NAC and ROLIS images.

We fitted the boulder sizes with a power law based on a fractal distribution [1], a distribution that is widely seen in the solar system. It relates the cumulative number of boulders (N) to their diameter (d_i):

$$N(D > D_i) = N_0 \left(\frac{1}{1-b}\right)\left(d_{max}^{1-b} - d_i^{1-b}\right) \propto d_i^{-s} \quad (1)$$

where $b = s + 1$ is the fractal dimension.

Using this method we find that, to within 95% confidence, the distribution accurately describes both datasets. The fractal dimension for the area covered in the ROLIS images is in accordance with that of the morphological unit that it is situated in (Figure 1). Thus, it is possible to scale larger boulder size-frequency distributions to smaller boulders, and predict grainsizes, within a given morphologic unit, for scales below the resolution of NAC imagers.

Morphologic Relationships: By mapping the distinct morphological units, which likely are the results of distinct processes, we hope to provide a better understanding of the evolution of surface of 67P throughout the comet's orbit.

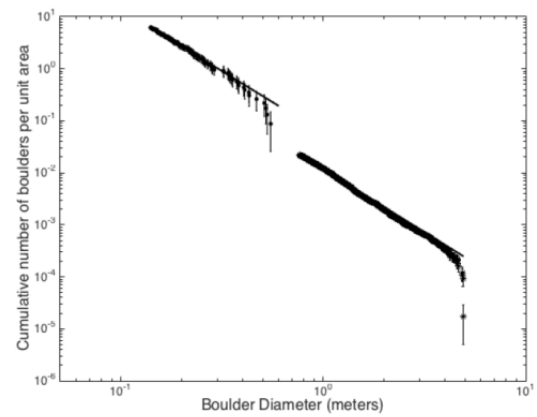

Figure 1 - Cumulative size-frequency distributions of boulders derived from the ROLIS camera onboard the Philae from 9 m above the surface (left), and the OSIRIS NAC of the pitted plains (right). The exponent s is the same within error (s = 2.39 ± 0.06 for ROLIS and s = 2.41 ± 0.02 for NAC), for boulders in both datasets.

From the high resolution ~18 cm/pixel images, we were able to separate the surface into seven morphological units, four "rough" terrains and three "smooth", and delineate their boundaries using ArcGIS (see abstract #2036, this meeting). The "rough" terrains are cliffs, talus deposits, bouldered plains, and mottled pit terrains, while "smooth" terrains are smooth plains, pitted plains, and cauliflower plains. We then quantified the boulder size distribution for each unit separately (Figure 2).

This method is verified by measuring the variance of the exponent s from Equation 1 within a given unit. For each morphological unit, there are multiple regions in the images we examined, and the exponent s for each region is calculated and compared. Overall, the variances for the smooth terrains are smaller, while for rough terrains, such as cliffs, variations are higher. However, it should be noted that for some regions, a low number of boulders may skew the value of the exponenet s. This is especially true for the cauliflower plains, which has large areas (>300 m^2) that are completely free of any boulders, suggesting that our

boulder counting statistics may not be of use in specific scenarios with such small number statistics.

In addition, these distributions accurately scale to boulders smaller than the resolution limit, as verified by the fit for the 9 m ROLIS image and the pitted plains morphologic unit, the unit that Philae landed in.

Implications: The division of 67P's surface into seven distinct morphological units, as well as the association of each unit to a modeled fractal dimension, allows us to predict of the surface properties at centimeter scales, even with lower resolution images. This makes it possible to estimate the boulder sizes and centimeter-scale surface properties anywhere on 67P.

The fractal dimension also relates to the relative amount of fine material within a given unit. A larger fractal dimension implies more fine materal. For each morphological unit, its fractal dimension can be combined with its topographic location to aid in creating formation models and understanding the relationships that may exist with other units.

An example of the relationship between topography and the exponent *s* can be seen between cliffs, talus deposits, and smooth plains units. Talus deposits are boulder dominated areas that are located downslope from cliffs. Smooth plains are often situated further downslope from the talus deposits within gravitational lows [2]. The exponent *s* for these units also gets progressively more negative as slope decreases suggesting down slope fining of materials. This correlation suggests an evolutionary model where mass wasting process such as sublimation and jet erosion promote failure of the cliffs, resulting in the formation of large boulders that comprise the talus deposits [3]. The boulders within the talus deposits are then further broken down to form the smooth material in the plains.

Thus, by using the morphological units and their associated topographic relations and fractal dimensions, it is possible to quantitatively understand the surface processes that act to form the landscapes of 67P, providing a better understanding for the evolution of a cometary surface.

References: [1] Turcotte D.L. (1986) *JGR, 91,* 1921-1926. [2] Groussin O. et al. (2015) *A&A, 583,* A32. [3] Vincent J-B. et al. (2016), *A&A, 587,* A14.

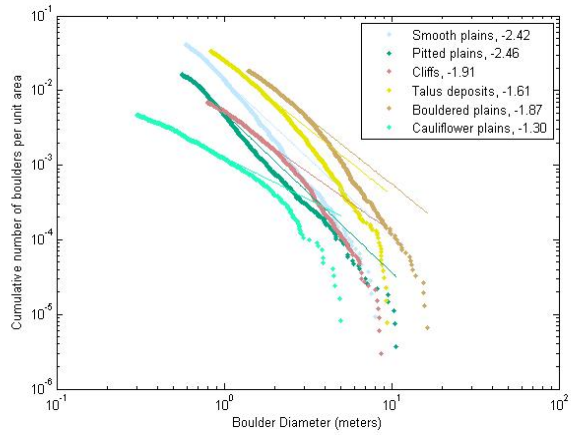

Figure 2: The boulder distributions and the fitted power law according to Equation 1 for all units except the mottled pit terrains. Values for the exponent *s* of each unit are shown in the top right.