INVESTIGATING THE ORIGIN AND EVOLUTION OF LARGE AND GIANT BOULDERS ON COMET 67P/CHURYUMOV-GERASIMENKO.
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Introduction: Thousands of images from the Rosetta mission at comet 67P/Churyumov-Gerasimenko (hereinafter 67P for brevity) show that the nucleus surface is ubiquitously covered by boulders. Numerous studies have looked at the boulders distribution and statistics to better understand their formation mechanism(s) and put the size frequency distribution functions in context with other comets and small bodies in general [e.g. 1, 2]. In this work, we specifically focus on a small subset of boulders on 67P, which we consider "large and giant boulders". For the purposes of this study, we consider "large" boulders to be those with a width of 10-30 m (Fig. 1), whereas "giant" boulders are those with a width exceeding 30 m.

Boulders form through various weathering and erosional processes. For instance, OSIRIS images show extensive boulder populations at 67P at the foots of cliffs, thereby implying that collapsing cliffs (predominantly due to thermal insolation weathering) and scarps in general are a constant source of small boulders. Furthermore, sublimation events leading to jet activity also contribute to the fragmentation and transport of surface materials, which depending on the scale of sublimation events, could result in ejection of boulders permanently away from the nucleus or in their redistribution as fallback if the ejection velocities or their sizes do not allow them to escape the nucleus' gravity [3].

Large and giant boulders are far less frequent and it is not clear what their preferred formation mechanism is. Furthermore, their large size allows us to study the fine-scale morphology of boulders on 67P in general to better understand their origin and evolution.

Morphology and distribution: Large and giant boulders display a variety of morphologies and surface textures (Fig. 1). However, they are predominantly polylithic, occasionally displaying an assemblage of textures or grains that appear to be stuck together. In that respect, they closely resemble lithic breccia on Earth. This does not imply that the large boulders are impact-related, but rather that their polylithic textures may suggest that large boulders "grow" by accreting small grains, potentially during their transport.

Certain boulders display sharp facets, which could imply an association with a high energy event. Other

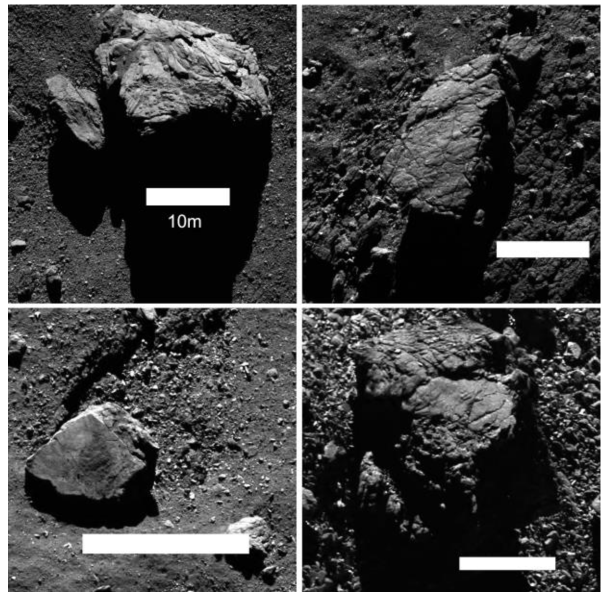

Fig. 1. Examples of large boulders on the surface of comet 67P from Rosetta/OSIRIS/NAC images. Note the polylithic textures visible in at least 3 of the shown examples. The boulder in the lower left shows a rather flat surface but with angular edges suggesting fragmentation. In all the figures, the scale bar indicates 10 meters.

boulders display various fracture patterns, which could have resulted from their transportation or, at longer time scales, weathering due to diurnal and seasonal thermal fluctuations [4].

Distribution-wise, large boulders are predominantly situated in the equatorial and mid-latitudes (up to 45 degrees), with no particular regional or hemispherical preference (Fig. 2). On the other hand, giant boulders appear to be more constrained in their distribution, situated mainly in the equatorial latitudes, with a notable concentration in the Imhotep, Khonsu, and Anhur regions [5-7].

Formation mechanism(s): Given the size of the investigated boulders, we would like to test the hypothesis that the large and giant boulders are produced in high energy outburst events rather than the more frequent sublimation-related activities. Of particular note, 67P displays a number of large irregular depressions on both lobes, specifically Hatmehit, and Nut on the small lobe, and Aten, Khonsu, and possibly Imhotep on the large lobe. These

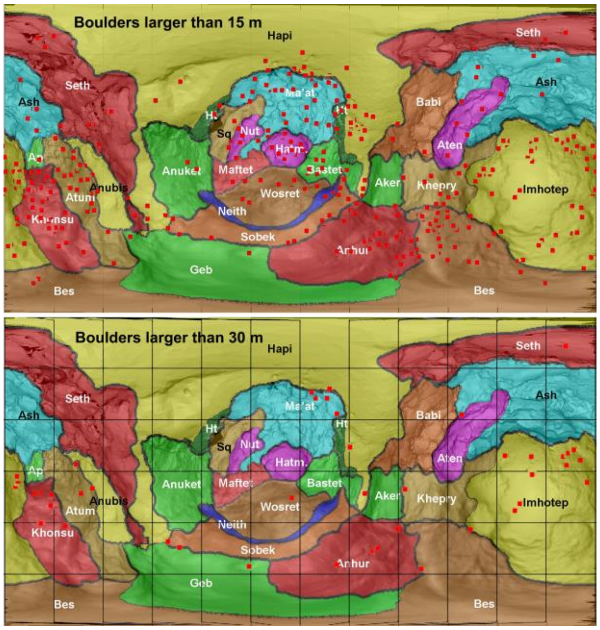

Fig. 2. Distribution of boulders larger than 15 m (top) and 30 m (bottom) on the surface of 67P.

depressions have been suggested by previous studies to have been formed by large-scale outbursts [e.g. 5,6,8], and so could have been the source region for the investigated boulders. To test this, we run a gravitational dust transport model based on similar methodology by [3] for these different depressions while varying the ejection speed and taking into account the rotation of the comet. By running this model for tens of thousands of "particles", we derive a surface impact probability distribution for each ejection speed case, which we can then try to correlate to the boulders distribution on the surface of 67P.

Fig. 3 shows an example of such an approach assuming the Hatmehit depression as a source region with ejections speeds ranging from 0.1 to 0.4 m/s. Lower ejection speeds lead to a higher impact probability close to the source region. As ejection speeds increase the probability distribution becomes more randomized and the body's irregular gravitational potential starts to have a more commanding effect on the distribution. These results are in broad agreement with [9] who have carried out a similar analysis for Hatmehit, albeit not to specifically assess the distribution of large boulders. We plan to build up on our initial simulations to look for potential consistencies between certain depressions and the distribution of the large and giant boulders.

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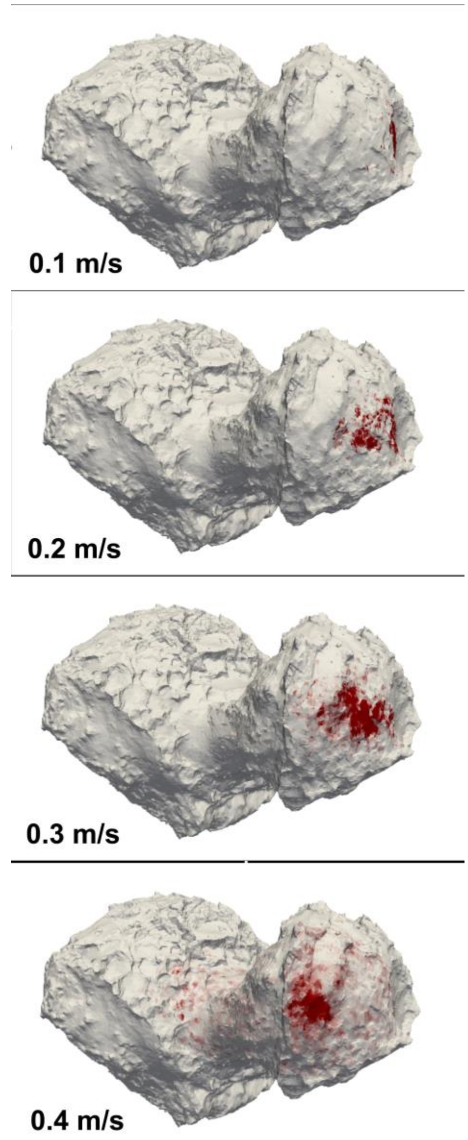

Fig. 3. Impact probability distribution for particles ejected from the Hatmehit depression with varying ejection speeds. Note the change in distribution and extend as ejection speeds increase. Speeds exceeding 0.5 m/s lead to a rather global distribution over the entire comet. Speeds of ~1 m/s would lead to particle escape rather than fallback.

References [1] Pajola, M. et al. (2015), *A&A* 583, A37. [2] Pajola, M. et al. (2015), *A&A* 592, L2. [3] Thomas, N. et al. (2015a), *A&A* 583, A17. [4] El-Maarry, M.R. et al. (2015a), *GRL* 42, 5170-5178. [5] Thomas, N. et al. (2015b), *Science* 583, aaa0440. [6] El-Maarry, M.R. et al. (2015b), *A&A* 583, A26. [7] El-Maarry, M.R. et al. (2016) *A&A* 593, A110. [8] Giacomini, L. et al. (2016), *MNRAS* 462, S352-S367. [9] Czechowski, L. and Kossaki K.J. (2021), *P&SS* 209, 105358.