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EVIDENCE FOR SCALLOPED TERRAINS ON 67P

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Abstract. The Rosetta mission of the European Space Agency (ESA) provided detailed data of the surface of the nucleus of comet 67P/Churyumov-Gerasimenko (hereafter 67P). In a previous study we performed a comparative morphometrical analysis on two depressions in the Ash region. The results indicated that these depressions are either shaped by the sublimation and/or by landslides. We continued the analysis on this kind of depression at the cometary scale. We analysed 131 depressions on 67P, exclusively located on the fine particle deposit (FPD) unit, and compared them with thaw depressions on Earth and Mars. The studied depressions have the same morphometrical characteristics than their planetary counterpart. They have the same area/perimeter evolution and present the same slope asymmetry that is characteristics of obliquity driven insolation. This study allowed to highlight that the depressions on 67P are analogs with thaw depressions on Earth and Mars. Moreover, we proved that the FPD is thicker (4.7 m) than predicted in models. The FPD layer is similar to an icy-rich planetary permafrost, in a cometray periglacial system where cometary thaw depressions are shaped by sublimation.

Keywords: 67P, Morphometry, Scalloped terrain, Comparison

1 Introduction

The Rosetta mission provided detailed data of the surface of the nucleus of comet 67P/Churyumov-Gerasimenko. The analysis of these data, and especially the images of the Narrow Angle Camera (NAC) from the Optical Spectroscopic and Infrared Remote Imaging System (OSIRIS instrument; (Keller et al. 2007)), revealed the morphological diversity of the nucleus surface (El-Maarry et al. 2019). Among these morphologies, depressions have been observed in several regions (Fig.1, left panel).

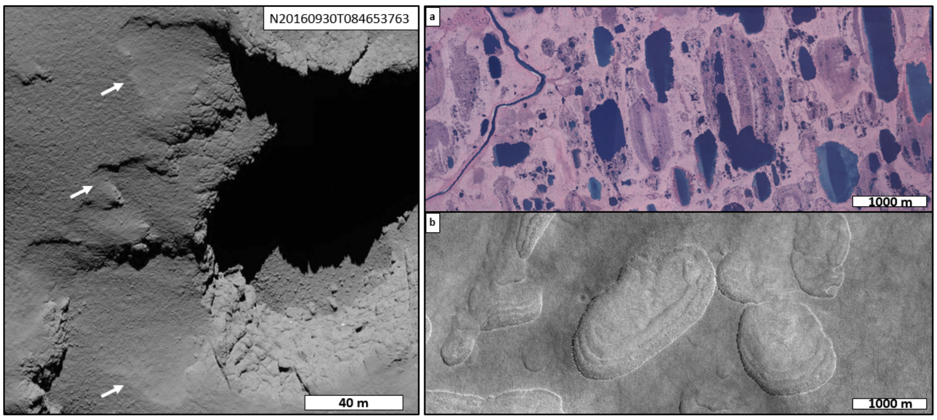

Fig. 1. Left: Example of studied depression located on Ma'at region (NAC image, 1 m/pixel). The white arrows indicate the depressions. **Right:** Example of thaw depressions. (a) Thermokarstic lakes in Alaska on Earth (Digital Orthophoto Quadrangle DOQ, 5 m/pixel). (b) Scalloped terrain in Utopia planitia on Mars (HiRISE image, 50 cm/pixel).

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The origin of these structures remains unclear and several hypotheses have been proposed: (1) the depressions could be indicative of scarp retreat (Vincent et al. 2016; El-Maarry et al. 2017), (2) they mark the location of future cliff collapses (Pajola et al. 2016), and (3) they are seasonal structures shaped by the changes induced by perihelion approach (Groussin et al. 2015). In a previous study, we studied two of these depressions, located in the Ash region, by a comparative morphometrical analysis (Bouquety et al. 2021). We observed that the two depressions grew by several meters during the last perihelion passage, and that this growth is not necessarily linked with cliff collapses. Thus, in that case, the sublimation of ices certainly played a key role in shaping these depressions. On Earth and Mars, there are similar depressions with the same shape and geometry that are controlled by thaw processes. These depressions are called thermokarstic lakes on Earth and scallops depressions on Mars (Fig.1, right panel).

On both planets, these periglacial structures result from the degradation of an ice rich permafrost (Costard & Kargel 1995; Morgenstern et al. 2007; Séjourné et al. 2011). Due to their processes and morphological similarities, we decided to compare the depressions observed on 67P's surface with thermokarstic lakes on Earth and scallops depressions on Mars to constrain their origin.

2 Data and method

We used the same method as in Bouquety et al. (2021). This comparative morphometrical analysis (CMA) allows to study surface features via a morphological and geometrical approach, with a great level of detail, in order to build an interplanetary database which can be used for comparison. All our measurements were made with the ArcGIS software. In order to perform the comparison, we established, from literature, a list of parameters and criteria that can be applied on Earth, Mars and 67P. For each depression we measured 10 parameters: the length, width, area, perimeter, depth, slope (max, min, mean), elongation and the circularity index(Ulrich et al. 2010; Séjourné et al. 2011; Morgenstern et al. 2011; Niu et al. 2014). Based on different dataset and their associated DTM (Earth: DOQ/3DEP; Mars: HiRISE/HiRISE DTM; 67P: NAC/SPC method Jorda et al. (2016)), we measured a total of 432 depressions, namely 200 on Mars (Utopia planitia), 101 on Earth (Arctic coastal plain) and 131 on the whole 67P's surface. The database which was used for the comparison contains 4320 exploitable parameters values (Fig.2).

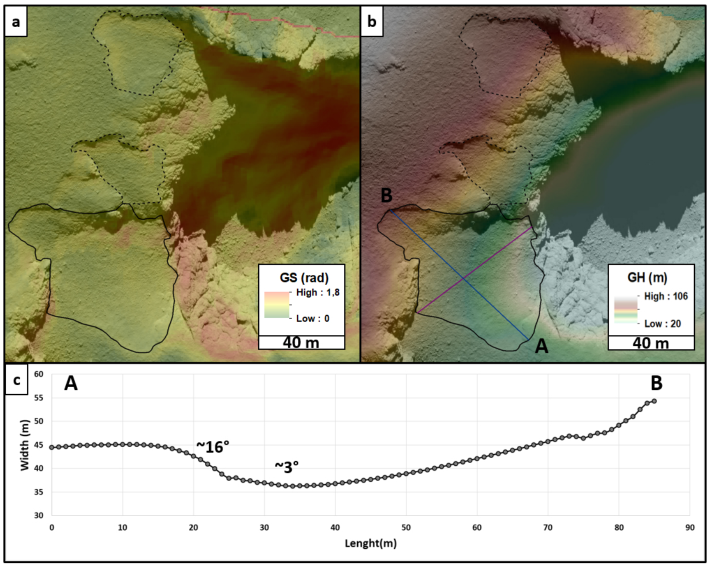

Fig. 2. Example of measurement. (a) Gravitational slopes and (b) gravitational height draped on NAC images. (c) Topographic profile extracted from gravitational height.

3 Results and interpretations

The depressions are distributed all over the comet. Among the 19 regions of the comet, 12 have at least one depression. The depression are exclusively located in terrains covered by fine deposit particules (FDP), and seems to be present in all topographical contexts (flat terrain, cliff edge).The highest depression densities are located on the body, where FPD covers the majority of the region (Thomas et al. (2018); Fig.4, left panel).

The analysis also revealed that the set of measured parameters is consitent with the references known in the litterature. Remarkably, all the measured parameters on 67P depressions are included in the range that characterized scallops terrains on Mars and thermokarstic lakes on Earth (Ulrich et al. 2010; Séjourné et al. 2011; Morgenstern et al. 2011; Niu et al. 2014). Moreover, depressions from 67P follow the same area/perimeter trend as scallops on Mars and thermokarstic lakes on Earth (Fig.3).

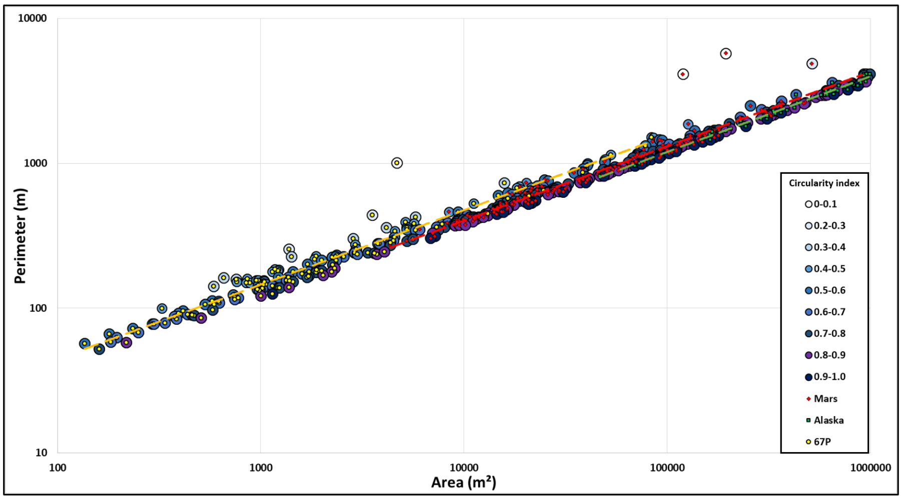

Fig. 3. Area versus perimeter for all the measured depressions on 67P, Mars and Earth. The points in shade of blue indicate the circularity index for each depression and the colored shape inside the body that the depression come from.

Finally, more than 90% of 67P depressions topographic profiles show a slope asymmetry (Fig.2c). This slope asymmetry have been observed on thermokarstic lakes on Earth and scallops on Mars and interpreted to be characteristic of depressions shaped by the obliquity-driven insolation (Morgenstern et al. 2007; Séjourné et al. 2011) These three results indicate that: (1) the depressions from 67P follow the same growth ratio than the scallops and the thermokarstic lakes while keeping their characteristic circularity, and (2) the sublimation induced by perihelion passages is the main erosion process that shaped these depressions on the comet (Bouquety et al. (2021)).

4 Discussions and conclusions

Our morphometrical analysis allowed to conclude that depressions on 67P are analogues to scalloped terrain on Mars and thermokarstic lakes on Earth. The FPD layer, on which depressions are formed, could be considered as an active layer where sublimation creates an erosion to shape the depressions. Despite the mean depth of the depressions (4.7 m), it was not possible to observe the underlying consolidated material. Thus, the depth of the depression is the minimum thickness of the FPD. We constructed a map of the minimum thickness of the FPD layer according to the region (Fig.4, right panel). This FPD layer is thicker than predicted in models (between few millimeters to 2 m; Hu et al. (2017); Oklay et al. (2017)).

This study bring evidence that the FPD could be considered as an active layer, icy rich, similar to a planetary permafrost, where sublimation occurred, and that this layer contains enough water ice to explain the surface erosion.

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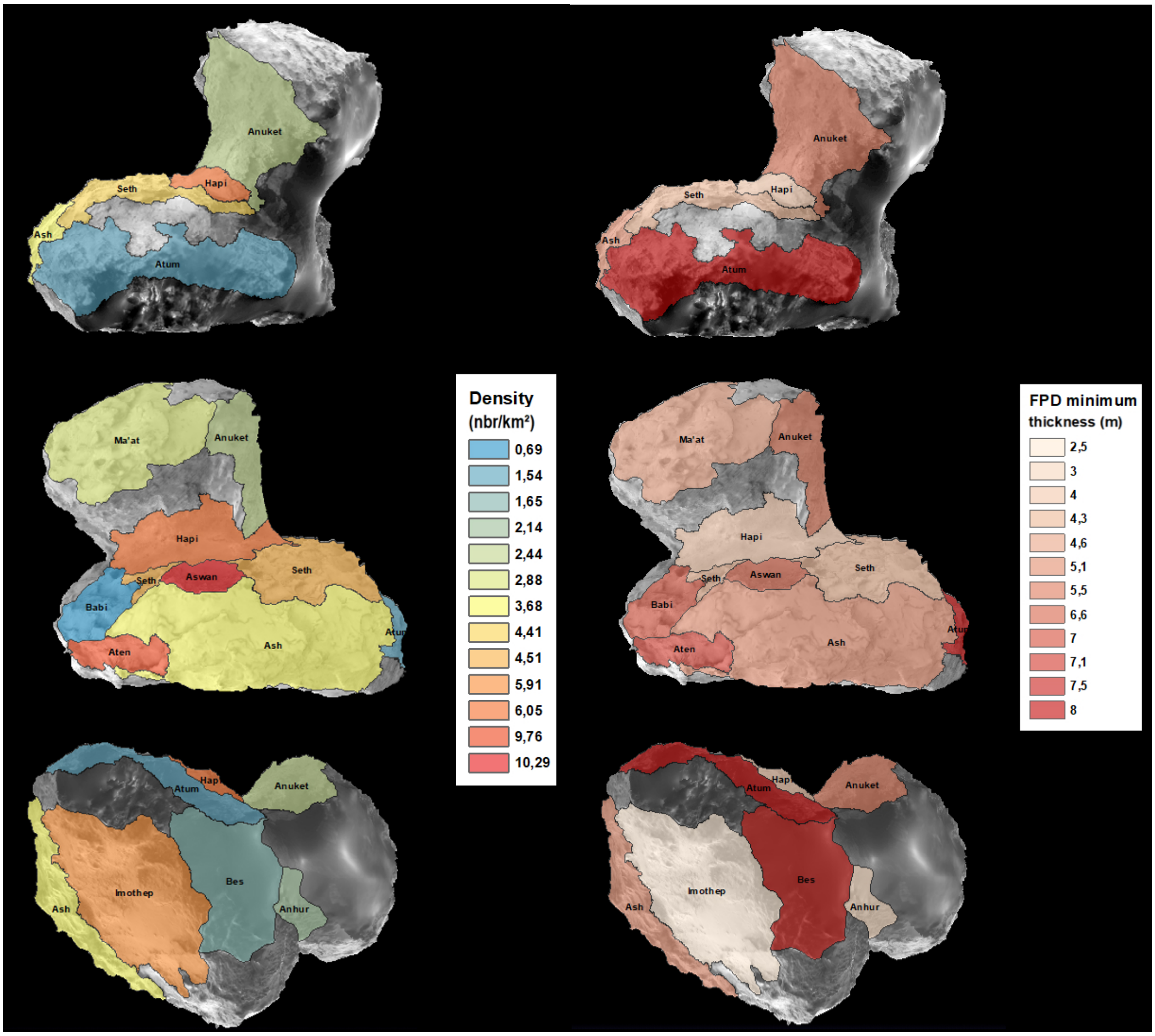

Fig. 4. Left: Density map of the measured depression according to the region. **Right:** Minimum thickness of the FPD layer calculated from the mean depth values of the depression according to the regions.