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The Aswan cliff collapse on comet 67P/Churyumov-Gerasimenko

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Abstract

The ESA Rosetta mission was designed to witness the surface changes occurring on the cometary nucleus while approaching perihelion and how its activity evolves with time [1]. On 10 July 2015, after escorting comet 67P Churyumov-Gerasimenko for almost one year, the Rosetta Navigation Camera captured a large plume of dust that could be traced back to an area encompassing the Aswan escarpment [2] located on the Seth region of 67P [3], Fig. 1. Before such event, high-res images showed a 70 m long and 1 m wide fracture propagating almost perpendicularly from the Aswan scarp edge at its two ends and inward in a semi-circular fashion ~12 m away from the edge at its farthest point [4].

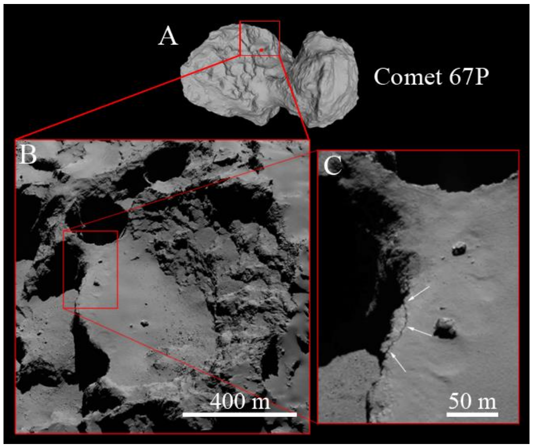

Fig. 1: The location of the Aswan site and fracture.

Five days later, the OSIRIS camera observed a fresh, sharp and bright edge on the Aswan cliff, at the location of the mentioned fracture (Fig. 2). The spectrophotometric study of the images focusing on the bright cometary interior revealed that it was highly saturated in the 600–900 nm range, resulting in a normal albedo with values >0.40 (lower limit) at 650 nm. This value is at least 6 times as bright as the overall surface of the nucleus itself [5] and it is explainable by the presence of fresh exposed water ice [6,7]. On December 26, 2015, the bright cliff was imaged again: the resulting normal albedo at its edge was already 50% less than ~5 months before, meaning that most of the exposed water ice had already sublimated. One year after the collapse (6 August 2016), the cliff has returned to the dark value (<0.12 at 650 nm), similar to the 67P terrains depleted in volatiles [5].

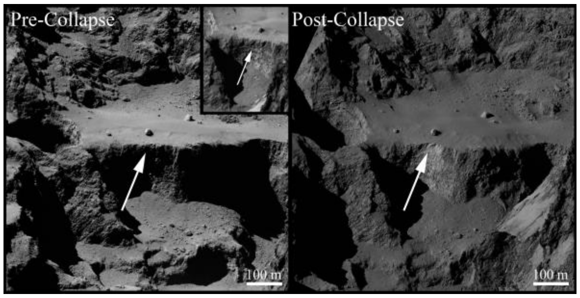

Fig. 2: Pre- and Post-Collapse images taken by the OSIRIS camera on 19 September 2015 and on 8 June 2016, respectively. The white arrows point at the cliff before and after the collapse.

Recent studies have speculated that thermal stresses may influence surface features on 67P [8], eventually predisposing cliff collapses [9]. We therefore investigated whether thermal effects, or thermal cracking could have weakened the already fractured Aswan cliff structure. We derived that in July 2015, at the cliff face, the surface is perpendicularly illuminated for a short time after a long cooling period in shadow (only 90 minutes during the cometary day (12.4 hours)) right after local sunrise. This means that a strong temperature gradient occurs here, with the cliff face's temperature rising from -140°C (130 K) to 50°C (320 K) in less than 20 min, with a maximum of 30 K °C/min shortly after sunrise (Fig. 3).

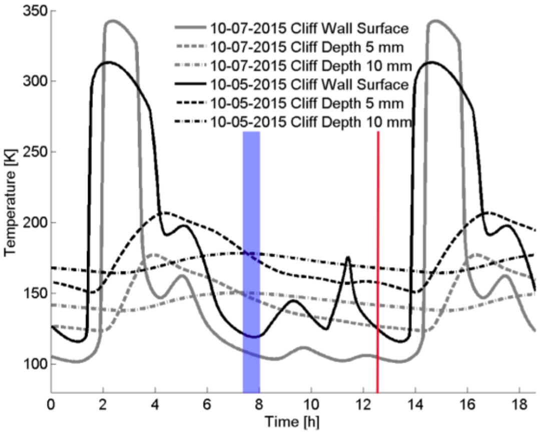

Fig. 3: Modelled temperatures for the cliff wall at three different depths on 10 May and 10 July 2015, respectively. The blue bar shows the observed NavCam outburst cliff collapse time, while the red line indicates the rotation period.

Despite such extreme factors, the collapse occurred during local midnight (blue bar of Fig. 3). Nevertheless, we underline that pervasive fracturing is present over the entire Aswan wall, hence the diurnal thermal gradients, as well as their seasonal and annual variations, may have driven cyclic and cumulative opening of such fractures, in a process similar to that observed on the Earth [10]. If thermal gradients have widened and deepened the fractures into the subsurface volatile-rich strata [11], heat may have been transferred to deeper layers causing the loss of in-depth ice. Moreover, the gas suddenly released by the subliming material could have infiltrated within the fractures [12], broadening them as well. For this reason, we suggest that the cumulative effect led by the thermal gradients could be a factor in weakening the cliff structure, predisposing it to subsequent collapse.

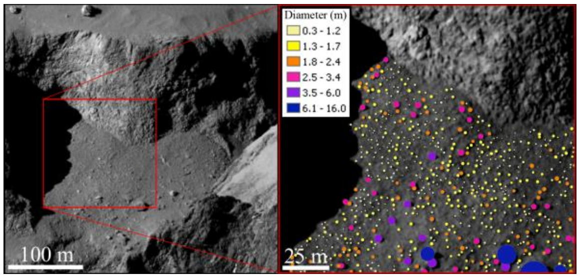

Fig. 4: The post-collapse talus boulder analysis.

Eventually, we studied the new deposit appeared at the cliff feet. We identified all boulders ≥1.5 m in size located on the Aswan talus, before and after the collapse and found that the resulting pre-collapse cumulative number of boulders ≥1.5 m was 11784 km^{-2}, whereas after the breakdown, this number changed to 18438 km^{-2}. Such an increase of density and surface roughness is due to the increase of the number of boulders in the 1.5–3.0-m size range, as a result of the collapse itself [13]. Indeed, the boulders' size-frequency distribution indicates that the crumbling wall has produced predominantly smaller chunks. This is similarly observed on the Earth, where the intrinsic weakening of cliff material owing to penetrative fracturing strongly affects the resulting size of the debris, and typically results in a crumble of finer material, instead of only a few large chunks [14]. In addition, by extrapolating the SFD to smaller sizes (0.50 m), we estimated that 99% of the volume of the collapsed wall is distributed in the talus, in blocks ranging from 0.5 to 10 m in diameter, while 1% of this volume has been lost to space during the collapse forming the outburst plume.

References

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