Surface changes on comet 67P/Churyumov-Gerasimenko following outbursts as observed by the Rosetta mission. **M.R. El-Maarry**[1], G. Driver[1], L. Jorda[2], R. Gaskell[3], S. Hviid[4], [1]Birkbeck, University of London, WC12 7HX, London, UK (m.elmaarry@bbk.ac.uk), [2]Laboratoire d'Astrophysique de Marseille, Marseille, France, [3]Planetary Science Institute, Tucson (AZ), USA, [4]Institute of Planetary Research, DLR, Berlin, Germany.

Introduction: Comets display evidence for nearly all fundamental geological processes, which include impact cratering, tectonics, and erosion [e.g., 1]. In addition, they also display sublimation-driven outgassing, which is comparable to volcanism on larger planetary bodies in that it provides a conduit for delivering materials from the interior to the surface. Outgassing has been shown to occur on comet 67P in two main modes [2]: A) a low intensity, yet long-running, activity in the form of jets or filaments that follow the insolation patterns and repeat roughly each comet rotation, and b) sudden high intensity events that resemble outbursts, which are active for a limited amount of time (minutes to hours) and then fade away. Numerous surface changes have been observed on 67P with links to different processes [3]. Given their apparent strong nature, it is probable that outbursts cause visible morphological changes on the surface at their source region. Indeed, cliff collapses reported in [3] and [4] suggest that the collapse was associated with an outburst event. Similarly, the movement of a large 30-m sized boulder may have been triggered by another localized outburst [3]. We are investigating the source regions of outbursts that were reported in [2] to look for surface changes that may occurred as a result of these outbursts so that we can better understand their mechanism and effect on surface evolution.

Fig. 1. Comet 67P/Churyumov-Gerasimenko and a massive outburst that occurred on 29th July, 2015. The event can be traced into a series of scarps in the neck region of the comet's southern hemisphere. OSIRIS image ID: N20150729T132410769ID30F22.

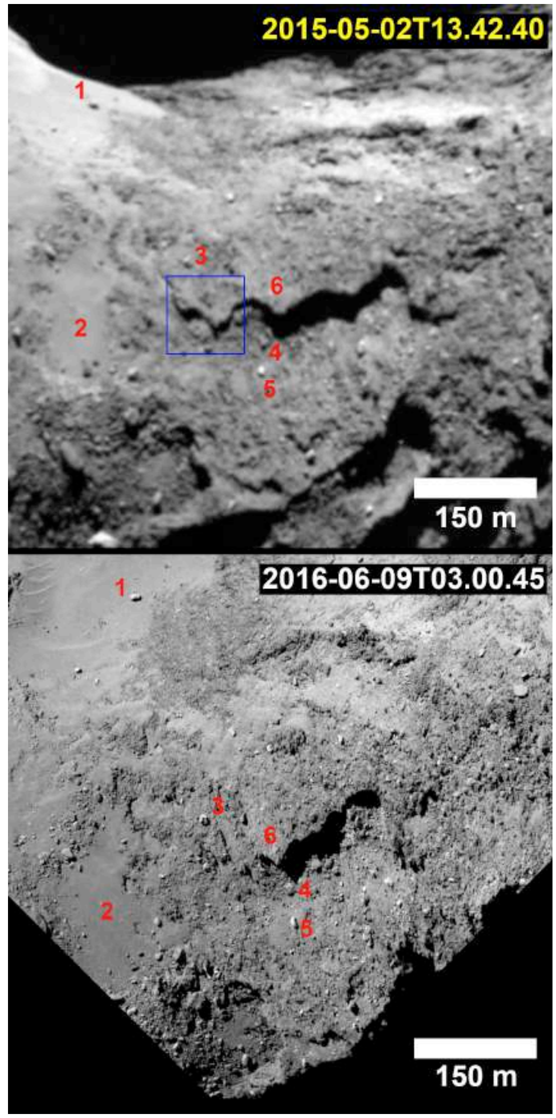

Fig. 2. Close-up on the source region prior and after the outburst event. A few landmarks have been numbered to aid with orientation. However, the images still have different perspectives. The first image (in 2015) was up-sampled to the scale of the 2016 image, which has a resolution of ~50 cm/pixel. The scarps in the blue box in the top image appear to have collapsed in the 2016 images as evident from the lack of shadows and appearance of talus.

Methods: A list of observed outbursts have been catalogued by [2] including their time, morphology, and approximate source location. We use this data to retrieve images from the cameras onboard Rosetta prior and after the outburst events. The Rosetta orbiter carried a scientific camera, OSIRIS [5], as well as a navigational camera, NAVCAM. We uses both datasets since these camera were usually operating at different times from each other. In fact, a few outbursts were detected by the NAVCAM [2]. We also utilize shape models for 67P that were constructed for localized regions of interest to better understand the topography of the affected locations.

Preliminary Results: We focus here on a couple of surface changes. We plan to present more results in the meeting.

Cliff collapse in the southern hemisphere: Two notable cliff collapses in the northern hemisphere were reported earlier in literature. [3] gave an overview of surface changes and included two examples in the Ash and Seth regions in the comet's large lobe [6]. The second of theses, also dubbed the "Aswan Cliff" was the focus of a dedicated study reported in [4] because it was observed to be associated with a plume event [4], whereas the such a relation could not be easily established for the collapse in the Ash region. We report here on a third cliff collapse that occurred in the southern hemisphere in the Sobek region [7], which corresponds to the neck region in the 67P's southern hemisphere (Fig. 1). Due to the close alignment of the 67P's southern summer solstice with perihelion passage, the southern hemisphere is subjected to higher solar input, resulting in higher levels of activity and more intensive erosion [8]. The location of the collapsing cliff in Sobek is consistent with the inferred source region of one of the strong outbursts reported in [2].

Rolling boulder in Khonsu region: A massive bounder with dimensions of ~20x30x40 m was observed to move in the Khonsu region, and was reported earlier in [3]. The boulder had moved in the period between Aug and Oct 2015 [3]. [3] also demonstrated analytically that a massive outburst could be capable of moving the boulder. Indeed, the area surrounding the initial position of the boulder is consistent with the location of outbursts that were observed (albeit the observed outburst occurred after the boulder had already moved to its current location). We plan to utilize pre- and post-perihelion DTMs of the region to better quantify the changes that occurred in the region and gain a better understanding of the mechanisms that led to the boulder's displacement. Analysis of regional slopes in a pre-perihelion DTM (also prior to the boulder displacement) indicates that the area has gentle slopes of 10-20 degrees. However, the movement of the boulder has occurred downslope, which is consistent with a mass-wasting mechanism for the final displacement.

Conclusions and summary: we are undergoing an intensive search for surface changes on comet 67P making use of the wealth of data that was collected over two years, which could help constrain the processes that drive surface evolution in comets on a seasonal, and possibly longer term, scales. Focusing on regions that have been subjected to strong outbursts gives us the highest chance of detecting surface changes and better understanding the effect of sublimation-driven outgassing in comets.

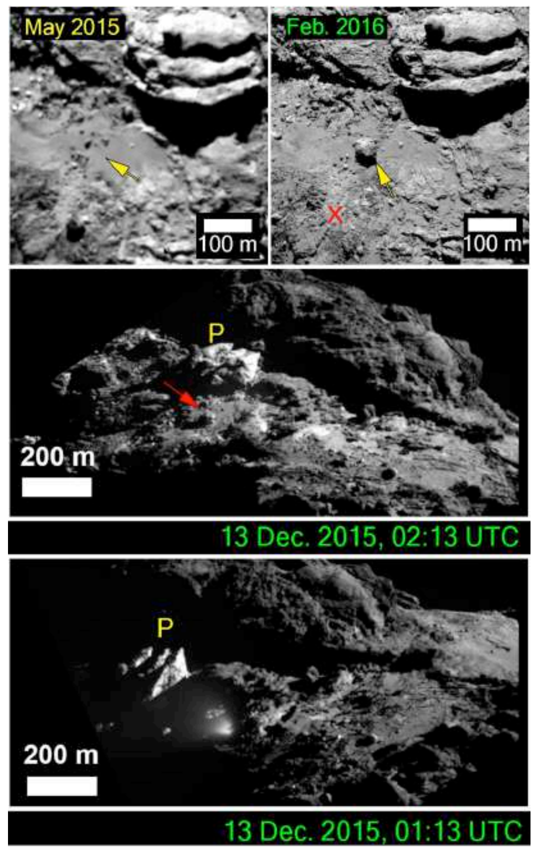

Fig. 3. Upper panel: movement of boulder in Khonsu region. Middle panel: Another view of the region in Dec 2015 to aid in the orientation of the lower panel. Lower panel: Outburst event in proximity to the boulder, which had moved between Aug and Oct 2015 . All figures were adapted from [3].

References: [1] Sunshine, J., et al. (2016), JGR 121, doi:10.1002/2016JE005119. [2] Vincent, J-B., et al. (2016), MNRAS, 462, S184-S194. [3] El-Maarry M.R. et al. (2017), Science 355,1392–139. [4] Pajola, M., et al. (2017), Nature Astronomy 1, doi:10.1038/s41550-017-0092. [5] Keller H.U., et al. (2007), Space Sci. Rev. 128, 433–506. [6] Thomas, N., et al. (2015), Science DOI: 10.1126/science.aaa0440. [7] El-Maarry M.R. et al. (2016), A&A, v. 593, A110. [8] Keller H.U., et al. (2015), A&A. v. 583, A34.