Geomorphologic Evolution of the Imhotep Region of Comet 67P Churyumov-Gerasimenko. M. N. Barrington[1], S. Birch[2], A. Jindal[1], P. Corlies[2] , A. Hayes[1] , J.-B. Vincent[3], [1]Cornell University Ithaca, NY 14853, [2]Massachussets Institute of Technology (MIT) Cambridge, MA 02139, [3]DLR Institute for Planetary Research Berlin, Germany.

Introduction: As some of the oldest materials in the solar system, comets represent the materials from which planets and their volatile envelopes were later constructed. Understanding the geologic processes which have acted upon these materials is therefore necessary to provide essential context that feeds into their analysis as primordial material.

Comet 67P/Churyumov-Gerasimenko (67P) has been extensively studied by the Rosetta mission, which visited the comet from 2014 to 2016. During that period, Rosetta's Optical, Spectroscopic, and Infrared Remote Imaging System (OSIRIS) captured over 8,200 near-angle camera (NAC) images of the surface of 67P [1], with a bias for the northern hemisphere. These landscapes are largely covered by unconsolidated sediment termed smooth terrains [2].

Erosional and depositional processes on 67P are driven by sublimation of volatiles, both from the consolidated nucleus and from the smooth terrains of the comet [3]. The smooth terrains are vast sedimentary deposits of airfall materials that blanket 67P's northern hemisphere [4]. Consisting of water ice-rich centimeter-to-decimeter scale particles, the sediment within these terrains are redeposited from sublimation erosion of nearby consolidated terrains [4]. Numerical models [4] [5] [6] [7] and observations [8] [9] suggest that this deposition occurs at perihelion, when the northern hemisphere is in polar-night [7]. Post-deposition, these newly deposited airfall particles continue to undergo sublimation as underlying surfaces become exposed due to processes such as mass wasting events and scarp migration [10].

Although features associated with sublimation processes have been previously described in these regions, including depressions and honeycombs [11], descriptions of these features only capture an individual moment in time, rather than the more nuanced time-resolved evolution of the broader regional terrains.

The large quantity of images collected of 67P's surface by OSIRIS provide a unique opportunity to study the evolution of the cometary surface with incredible temporal and spatial resolution. Herein, we present and quantify decameter scale morphological changes in the Imhotep region of comet 67P. The time-resolved nature of these changes permit a more detailed examination of the underlying processes that are shaping the surface of 67P.

Methods: In order to determine the regional locations and types of changes occurring on 67P's surface, we first selected a reference image which was collected before the comet's perihelion approach, before major sublimation activities had begun on the surface.

Next, we generated lists of NAC images which overlap at least 30% with the latitudes and longitudes of the reference image, and projected each of these images into the same reference frame as our reference image using an affine transformation.

We created a GUI which then allows the user to cycle through the list of projected images, and compare each of them to the reference image. Differences detected between the projected image and reference image were then marked and classified according to the type of change which occurred. These changes include boulder migration, boulder burial, boulder exposure, scarp migration, honeycomb formation, and pitted plains migration. Images with observed changes were sorted by date, and those representing data collection approximately one to two weeks apart were projected onto a three-dimensional model of 67P using ShapeViewer, and imported into the ArcGIS software environments for further analysis.

Evolution Summary: Sublimation driven morphologic changes occur within a short range of time with respect to the length of the comet's 6.5 year orbit. 67P reached perihelion on August 15th, 2015, placing the comet 1.24 AU away from the Sun. Large scale scarp migrations are the first changes detected in the Imhotep region, first occurring on June 5, 2015, just over two months before the comet reached its closest solar approach. Boulder burials and exposures were the last observed changes to the region, which all present on November 28, 2015, although the end date of observed changes is an upper limit determined by camera coverage and resolution of the region. Changes may have ceased as early as October 26, 2015, however the NAC images of Imhotep at this time were not of sufficient resolution to clearly observe surface changes.

Scarp Migration: The most prominent changes within the region appear in the form of decameter and hectometer scale migration of scarp fronts. These migrations are believed to occur as newly exposed scarp fronts provide a continuous supply of previously buried water-ice. As the volatiles become exposed, they undergo sublimation, removing the uppermost layer of regolith [12].

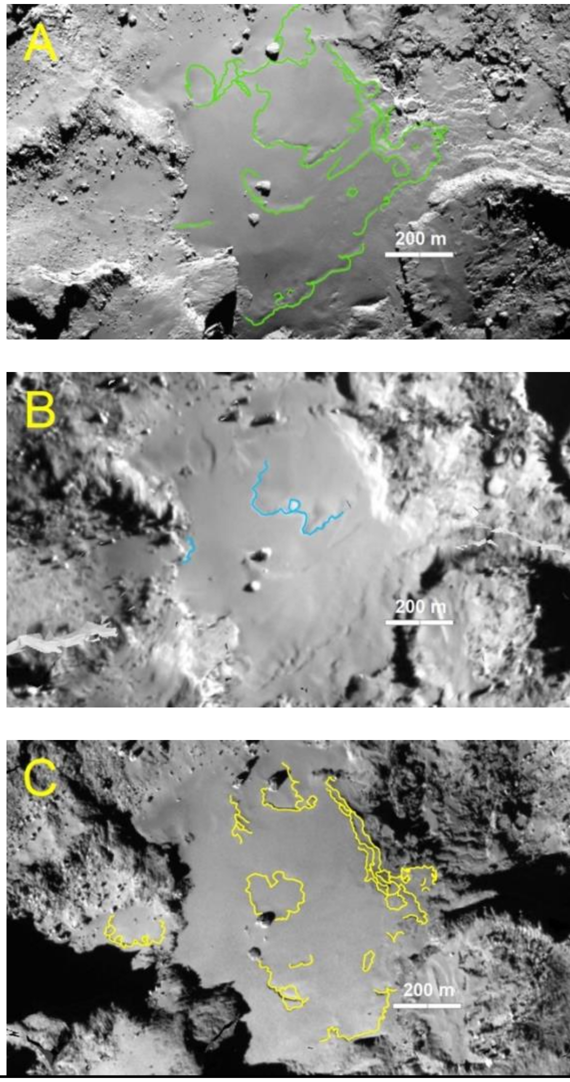

Fig. 1 – A) Imhotep as observed on September 3, 2014, with the original positions of major scarps in the Imhotep region of 67P before perihelion. B) Imhotep on June 5, 2015, in which changes (in this case, the expansion of the large central scarp and the creation of a new, small scarp) were first detected. C) Imhotep on December 6, 2015, with the final positions of the major scarps of the Imhotep region.

Boulder Exposure and Burial: Boulders can be exposed as scarps migrate across the surface of the smooth terrains, which act to erode overlaying regolith materials. Equally, deposition of materials can bury boulders, obscuring them from view. We assume that boulders are buried, though they may, albeit less likely, be launched from the region entirely [8]. All boulder-related activity is observed in the same image, from November 28, 2015, although it is possible that the first boulder exposure occurred much sooner, as scarp migrations which would have exposed/buried boulders appear to have occurred as early as September 24, 2015.

Resolution and phase angle limitations prevent greater certainty of when these boulders may have been exposed/buried. Three boulders in the region are either partially or entirely exposed, and two boulders are buried in the basin.

There also is evidence of gravitational redistribution of one boulder from a cliff into the Imhotep basin. This boulder did not appear in our reference image, and is proximal to a large cliff. However, it is also possible that a scarp migrating across the region exposed a large buried boulder, as the original position of the supposed fallen boulder could not be determined. No other boulders were observed to be transported into the basin.

Conclusions and Future Work: The evidence of erosional activities (i.e. scarp migration, boulder exposures) and depositional signatures (the presence of airfall deposits and the burial of boulders) combine to describe a basin which undergoes a variety of changes within the span of just a few months. This is consistent with previous conclusions of the Imhotep region [5]. Several other types of changes, such as the expansion/burial of honeycombs [11], and the redistribution of boulders due to mass-wasting events [10] did not occur in the Imhotep basin, but are expected to be seen in other regions of the comet. The search for decameter scale changes is an ongoing project, and will continue to focus on the remaining smooth terrain, cauliflower plains, and pitted plains regions across 67P, with the ultimate goal of characterizing the temporal evolution of the entire comet's surface.

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