Geomorphologic Evolution of Comet 67P-Churyumov/Gerisamenko

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Background

Comets are comprised of some of the most ancient materials in the solar system, and as such, they represent the substances from which the planets were later formed. By understanding the geologic processes which have acted on cometary bodies, we better understand the context in which to analyze these primordial materials. A detailed understanding of the geomorphologic processes acting on the surfaces of comets is also essential to the future success of comet sample return missions, as it provides necessary data about possible surface evolution which will enable safe touch-and-go sample collection.

Both the surface and coma of comet 67P have been studied extensively since the Rosetta mission's visit to the comet between 2014 and 2016. During this mission, 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, which is largely covered by unconsolidated materials called smooth terrains [2].

Smooth terrains consist of large deposits of airfall materials which blanket many regions in the northern hemisphere of 67P [3]. These terrains undergo erosion and deposition driven by the sublimation of volatile water ice-rich centimeter to decimeter scale particles which have been redistributed as a result of sublimation-driven erosion of the more consolidated terrains [4].
According to numerical models [3] [5] [6] [7] and observations [8] [9], the deposition of airfall materials onto the smooth terrains occur during perihelion, when the northern hemisphere experiences polar night [7]. Once deposited, these materials are redistributed as sublimation exposes new surfaces whose volatiles continue to sublimate, creating a cycle of activity as long as solar insolation is sufficient. These surface changes often occur as mass-wasting events, scarp migration [10], and depression and honeycomb formation [11].

The high spatial and temporal resolution of OSIRIS's images provides a unique opportunity to evaluate not just the date and categorization of such changes on the comet's surface, but the more nuanced evolution of smooth terrain geomorphologies. We therefore present the decameter scale spatial and temporal evolution of smooth terrains in the Imhotep, Ma'at, Hatmehit, Nut, Serquet, and Ash regions of comet 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, and 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 a RANSAC reprojection.

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.

In the case of Ash, as well as several yet-to-be-analyzed regions, an insufficient number of images were able to be reprojected using the RANSAC method due to poor image resolution over key periods of surface evolution. In these cases, images were sorted manually, and likewise projected in Shapeviewer and imported into ArcGIS software where we searched for changes without the assistance of the GUI.

Regional Geomorphologic Evolution

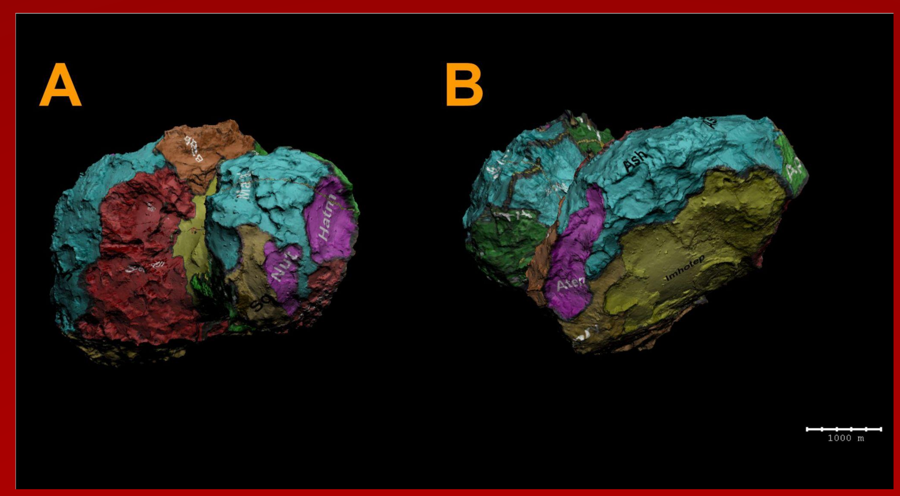

Fig. 1 A) Hatmehit (Pink), Nut (Pink), Ma'at (Blue), and Serquet (Gold) can be seen on the small lobe of 67P. B) Imhotep (Yellow, and Ash (Blue) can be seen on the large lobe of 67P.

Large Lobe:

Imhotep

Located at the base of the large lobe of 67P (Fig. 1), Imhotep is a vast sedimentary basin which undergoes decameter and hectometer-scale geomorphologic evolution. The most readily observable and most common evolutionary feature of Imhotep's surface is scarp migration, which began to take place on June 5, 2015, and ceased migration on November 28, 2015 (Fig. 2). Meter-scale boulder burials and exposures were also observed on November 28, 2015, although viewing geometry and resolution limitations prevent detection at previous dates. Meter-scale boulders exposures and decameter scale scarp migrations also occur in craters on the western edge of the region.

Ash

Ash is a vast region of smooth terrains located in the northern hemisphere of the large lobe of 67P, directly above Imhotep (Fig. 1). The scale of the region requires that it be broken into five smaller sub-sections for analysis. Preliminary results from the first sub-region of Ash yields very interesting results. The first observable changes are detected on May 16, 2015. These include three boulder burials, the apparent formation of three scarp fronts, and a large amount of deposition which blankets local topography. The second sub-region of Ash enters into polar night early in 2015, providing limited information on the its evolution. No changes have been observed in the Ash 2 sub-region at this time, although analysis of Ash is still ongoing.

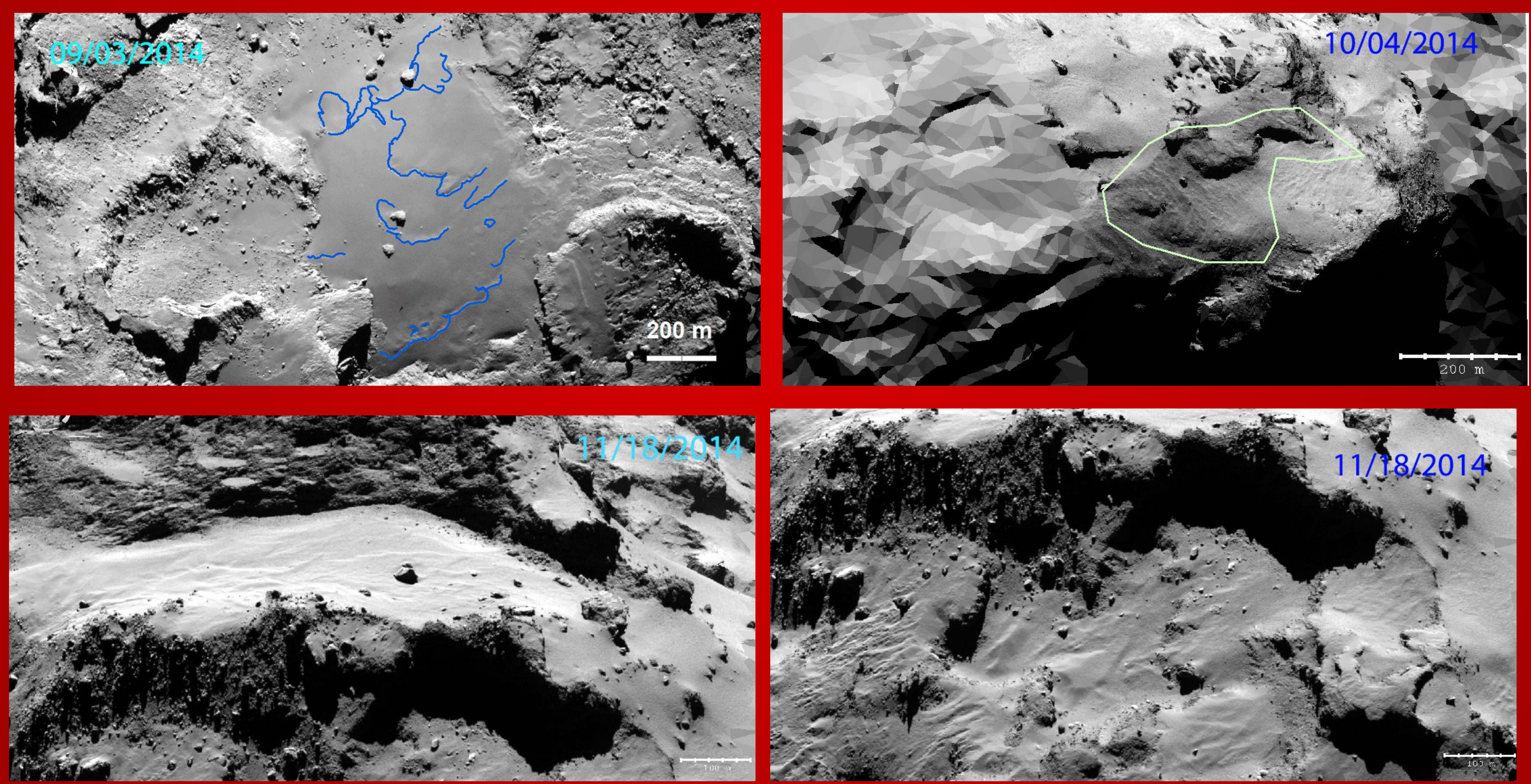

Fig. 2 -- **Top Left:** Imhotep: Examples of decameter to hectometer scale scarp migrations. Starting locations of scarp fronts are marked in blue on August 3, 2014, migrating scarps are shown in green, and final scarp front locations are shown in red on November 28, 2015. **Top Right:** Ash 1: Large scale deposition is circled in light green, a cliff separation is circled in peach, and boulder burials are indicated with bright blue dots. **Bottom Left:** Serquet: Initial locations of plain crests are shown in green. The Right crest's progress is shown in blue, then yellow. The left crest's progress is shown in pink. Pink dots indicate locations of boulder burials as the plains migrate. **Bottom Right:** Nut: As plains migrate across the region, boulders are exposed (blue), buried, dark green, and migrate (initial positions in purple, final locations in pink).

Small Lobe:

Hatmehit

Hatmehit is a second large sedimentary basin located on the base of the small lobe of 67P (Fig. 1). The center of the basin is composed of pitted and smooth plains, while its periphery is largely composed of talus deposits created by the rim surrounding the region [13]. Scarp migrations can be observed within the basin, although they migrate meters rather than hectometers as in Imhotep. Boulder burials, exposures and migrations are also observable in this region. Evolution of the region began as boulder burials occurred on May 10, 2015. The migrations of one curvilinear scarp and one meter-scale boulder occur on December 17, 2015. The observable evolution of this region ceases on February 27, 2016 with the exposure of two boulders and migration of two scarps within the basin.

Nut

Nut is a depression located in the northern hemisphere on the small lobe of the comet (Fig. 1). While it is clear that the region undergoes a variety of morphologic changes during the span of Rosetta's mission, a dearth of usable images of the region limits the ability to discern when changes in the region actually occurred. The first observed changes in the region, two boulder migrations and three boulder exposures, are not observed until January 17, 2016. The final observable changes occurred on February 27, 2016, although limitations in resolution may have prevented these changes from being observed in previous images. These changes indicated large-scale redistribution of material that caused the migration of pitted plains, two more boulder migrations, and 17 boulder exposures.

Serquet

Seruet is a swath of pitted plains adjacent to the Nut region, at a topographically higher location (Fig. 1). Surface activity is first observed on May 10, 2015 as pitted plains begin to migrate in the region. The migration of this crest can be tracked further on May 16, 2015 and June 25, 2015. Also on June 25, 2015, the migrating crest passes over a local boulder, partially burying it as regolith is redistributed across the surface. The final changes are observed on February 27 2016 and include 12 boulder exposures, one boulder partial burial, and the further migration of the pitted plains.

Ma'at

Ma'at is a large region of smooth, pitted, and cauliflower plains which wraps around the northern hemisphere of the small lobe of 67P (Fig. 1). No changes have been observed in the Ma'at region at this time.

Spatial and Temporal Relationships

The evolution of most of these smooth terrain-dominated regions begins in a short window of time, ranging from May 10-June 5, 2015. While we cannot conclude that evolution of the Nut region began any sooner than the first observed change on January 17, 2016, the observed evolution of the nearby region Serquet starting May 10, 2015 may suggest that Nut's evolution began near the same time.

The final observed changes in the geomorphologies of each region also appear to have occurred within a short timespan, ranging from November 28, 2015- February 27, 2016. This does not include the current final date of observed changes in the Ash region, which is a tentative upper limit and may be better constrained as the analysis of the Ash region continues.

Boulder burials and exposures are observed in almost every region observed so far, with the exception of Ma'at. Boulder migrations are only observed in two regions so far, Nut and Hatmehit, which contain bouldered terrains and talus deposits respectively, and are located adjacent to nearby cliffs. Scarp migrations are also only present in two regions, Imhotep and Hatmehit, which both span either side of the equator of 67P. Of these two regions, Imhotep is the only one to undergo scarp migrations at the hectometer scale. In the more northern regions, the migration of plains is more common, although few meter to decameter scale scarp migrations are observed in the first sub-region of Ash, which had not entirely entered into polar night during the period of heightened activity in 2015. The redistribution of fine-grained regolith is observed in both Nut and Ash, although a DTM of Ash 1 is necessary to determine if the deposition is related to material settling into areas of low gravitational potential as in Nut, related to large-scale deposition of airfall materials, or an artifact related to changes in viewing geometry.

Conclusions and Future Work

The data collected so far show diverse geomorphologic activity occurring on the surface of comet 67P. The changes observed on the surface appear to exhibit trends in the beginning and cessation of erosional and depositional activity which are coincident with an increase in solar insolation accompanying the comet's perihelion approach on August 15, 2015. The similarity in start dates of evolution across multiple regions while compelling is also likely connected to the availability of high-resolution images of each region during peak activity.

Further investigation will be needed to determine if the concentration of scarp migrations near the equator is observable in other equatorial regions. A DTM is necessary to determine the scale of the deposition observed in the Ash 1 sub-region. Most importantly, the continued collection of data from the remaining smooth terrains will better inform the nature of the spatial and temporal relationships between distinct regions, as well as the evolution of the comet as a whole. For this region, future work will also include the creation of global maps which will detail the nature of these spatial and temporal relationships.

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Zoom link:
https://cornell.zoom.us/j/91262561041?pwd=aWpUaHVLM3o3WDBoRnlwbW0wTDZZdz09