GEOMORPHOLOGY OF COMET 67P/CHURYUMOV-GERASIMENKO. S.P.D. Birch[1], Y. Tang[1], A.G. Hayes[1], R.L. Kirk[2], D. Bodewits[3], H. Campins[4], Y. Fernandez[4], R. de Freitas Bart[1], N.W. Kutsop[1], H. Sierks[5], J.M. Soderblom[6], S.W. Squyres[1], and J-B. Vincent[5,7], [1]Cornell University (sb2222@cornell.edu), [2]USGS Astrogeology Science Center, [3]University of Maryland, [4]University of Central Florida, [5]Max-Plank Institut fuer Sonnensystem-forschung, [6]Massachusets Intitute of Techonlogy, [7]Deutsches Zentrum für Luft-und Raumfahrt (DLR).

Introduction: Comets are among the oldest objects in our solar system, and represent the remnant materials from which all the outer planets and moons were constructed. Modern observations, however, only give us access to their current-day surfaces, which have been altered to unknown and varying degrees throughout the age of the solar system. Therefore, understanding cometary landscape evolution and the associated physical/chemical processes affecting cometary materials is essential to their utility as a window into the formation of the solar system.

New observations from ESA's Rosetta Orbiter of Comet 67P/Churyumov-Gerasimenko (67P/C-G) have revolutionized our understanding of these primitive bodies and the process that affect them. Images of the surface of 67P/C-G have revealed a diverse sedimentary world, where the nucleus is continuously evolving and losing mass throughout each orbit. While previous missions to cometary nuclei have revealed a diversity of morphological features [1,2,3,4], they have not created a detailed dataset that would allow for a detailed study of a comet's surface evolution. With Rosetta's higher resolution images and complete coverage of the nucleus, morphologic signatures indicative of the processes that dominate the comet's surface evolution can now be interrogated.

To gain a more complete understanding of these processes, we have created a detailed geomorphologic map of the portions of the nucleus illuminated before perihelion passage (~70% of the nucleus). Using images from the OSIRIS Narrow Angle Camera (NAC) on board Rosetta, taken from the pre-perihelion mapping phase of the mission, our study reveals the spatial relationships among known features. This allows us to construct a process-based model for the evolution of the landscapes of 67P/C-G in the context of other known cometary nuclei.

Methodology: Our mapping incorporated OSIRIS NAC images acquired before December 2015. Individual images were manually georeferenced and combined into a mosaic in ArcGIS for mapping. Unit definitions also incorporated boulder distributions (see abstract #2796, this meeting), and photoclinometry topographic information. Both datasets allowed us to quantify differences in morphology based on topographic form and sediment size distributions.

Morphologic Units: We broadly segregate our units into "rough" terrains and "smooth" terrains. These units are characterized by their morphologies (Figure 1), topography, and from their boulder distributions.

Rough Terrains: Included as rough terrains are cliffs, talus deposits, bouldered plains and mottled pit terrains. All four units have high local slopes (>25^{o}) and all are covered by large boulders, with much less fine material compared to the smooth terrains.

The cliffs represent the underlying bedrock of the comet nucleus. Regions with high slopes mark locations subjected to sublimation induced erosion and scarp retreat. The cliffs are also most prominent at southern latitudes, which are the latitudes most illuminated during perihelion.

The talus deposits are collections of, primarily, large boulders that appear at the base of cliffs. These large boulders are transported downslope from the cliffs by mass wasting process, forming the talus deposits, which also contribute to the observed jets [5].

Bouldered plains appear similar to talus deposits except that they have no topographic signature. Instead, they are collected within large fields of similarly sized boulders, often surrounded, at lower elevations, by smooth terrains. The process(es) by which the bouldered plains form is less clear than the morphologically similar talus deposits.

The mottled pit terrains are located within the Imhotep region, to the East of the large smooth plains deposit. The topography and morphology of this unit, described in detail in previous works [6], suggests a process unique to this region on 67P/C-G, though perhaps analogous to processes hypothesized for the roundish features on 9P/Tempel and 103P/Hartley.

Smooth Terrains: Smooth terrains include the smooth plains, pitted plains and cauliflower plains units.

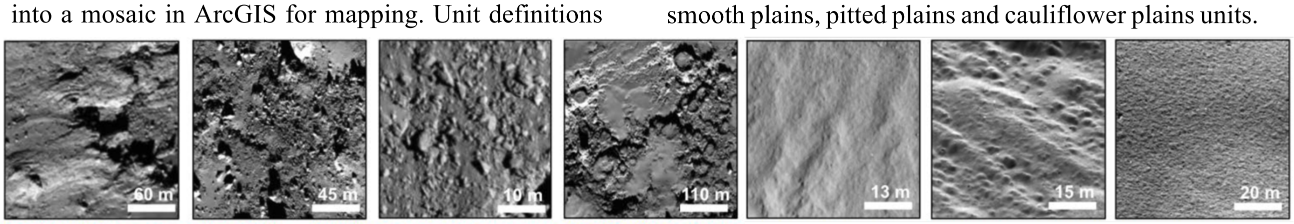

Figure 1 – Examples of each morphologic unit. From left to right: Cliffs, Talus Deposits, Bouldered Plains, Mottled Pit Terrains, Smooth Plains, Pitted Plains, and Cauliflower Plains.

All units are relatively free of boulders, with slopes substantially lower than the rough terrains.

Smooth plains appear as isolated, spatially small patches of granular materials. They have few large boulders, and a significantly higher fraction of fine material than the rough terrains. They appear embedded within other regions, in local gravitational lows. The unit has relatively low slopes over much of the unit (<8°), with variations of a few degrees.

The pitted plains are the terrain type the Philae lander first touched down on. The layer appears as a granular regolith with meter-scale pits observed throughout. The pitted terrains also appear to have “dune-like” features [7] and boulders with “wind-tails” that give rise to a higher local slopes compared to the other plains units (~13°). The pitted plains also lack any large boulders. The preference for the pitted plains to form primarily around equatorial latitudes also suggests a relation to solar insolation.

The cauliflower plains appear to drape the underlying topography, with cliff units outcropping from underneath. The cauliflower plains are the flattest unit topographically (<4°) and are most common in the Ash and Ma’at regions in the northern hemisphere. Large portions of the cauliflower plains have previously been interpreted as airfall deposits [8]. Our mapping agrees with this interpretation, as the unit is remarkably flat, and it also outcrops at numerous stratigraphic levels, suggesting that these plains are deposited from above.

Results: Our geomorphologic mapping reveals a complex terrain of consolidated bedrock material overlain by sedimentary deposits. The northern half of the nucleus is covered in sedimentary materials, and the more southern latitude landscapes are relatively sediment free, exposing the underlying bedrock (Figure 2). Putative flow deposits are located around the equatorial regions, suggesting that sediment transport processes and landscape evolution occurs on 67P/C-G by insolation driven processes.

The landscapes of the two lobes of 67P/C-G show no obvious morphological differences, as units are uniformly distributed with respect to longitude. However, this does not imply that the comet’s bi-lobed shape is not the result of a gentle merger, as sediment transport and erosion likely mask any primordial differences.

The model we propose to explain our mapping incorporates previously imaged nuclei, where the nuclei visited to date are similar, differing only in where they lay along a prescribed evolutionary track. In the context of other nuclei, 67P/C-G appears to have a relatively ancient surface. A test of our hypothesis could come in the form of observing Kuiper Belt Objects (e.g., 2014 MU69 by the New Horizons mission) or Centaurs that formed in the outer portions of the protoplanetary disk and have yet to enter the inner solar system. Their surfaces should be more similar to those of 81P/Wild 2 [2] and 67P/C-G than the more eroded cometary surfaces of 19P/Borrelly [1], 9P/Tempel 1 [3], and 103P/Hartley 2 [4].

Dominated by variations in local solar insolation, thermal fracturing and sublimation are the dominant mechanisms that act to erode the comet’s surface. Cliffs and talus deposits around pits are able to produce sediment and reduce relief in discrete locations, primarily at latitudes corresponding to maximum solar insolation. Over successive orbits, the nucleus of 67P/C-G may be expected to erode non-uniformly across the surface, leading to larger deposits of smooth terrains, and the destruction of pits into more topographically variable remnant highs.

References: [1] Soderblom L.A. et al. (2002) *Science, 296,* 1087. [2] Brownlee D.E. et al. (2004) *Science, 304,* 1764. [3] Thomas P.C. (2007) *Icarus, 187*, 4. [4] A’Hearn M.F. et al. (2011) *Science, 332*, 1396. [5] Vincent J.-B et al. (2016) *A&A, 587*, A14. [6] Auger A.-T et al. (2015) *A&A, 583*, A35. [7] La Forgia F. et al. (2015) *A&A, 583*, A41. [8] El Maarry M.R. et al. (2015) *A&A, 583*, A26.

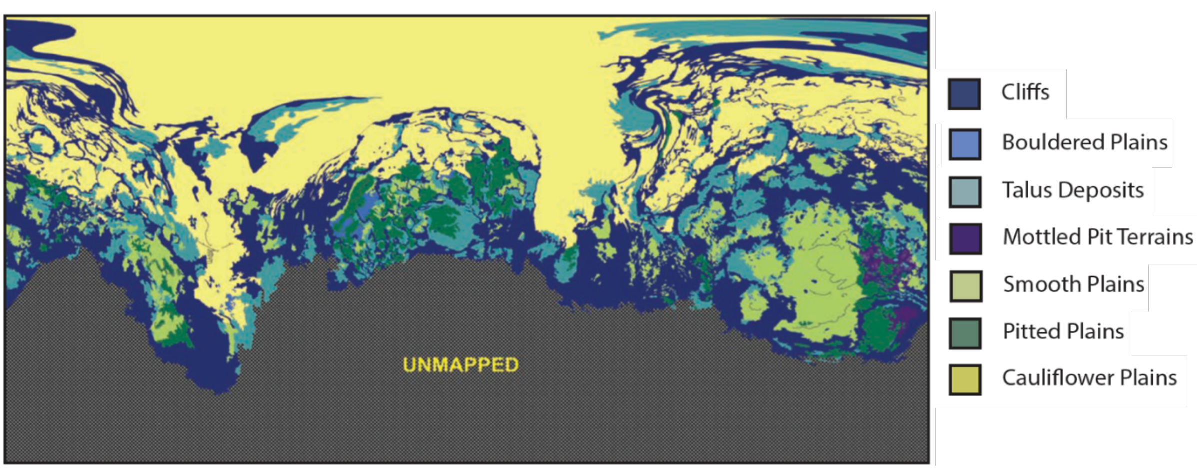

Figure 2 – Geomorphologic map of 67P/C-G in an equicylindrical projection. Images of the southern hemisphere were unavailable to our study. A legend is shown to the right.