ASTEROID (101955) BENNU'S CRATER POPULATION: MORPHOLOGIES, SIZE-FREQUENCY DISTRIBUTION, AND CONSEQUENCES FOR SURFACE AGE(S).

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Overview: Using image data from the Approach and Preliminary Survey phases of the OSIRIS-REx mission, we identify and categorize candidate impact structures on Bennu. In an unbinned cumulative size-frequency distribution (SFD), we find that there is a change in the population between 50 m and 100 m to a "shallower slope". In addition, there is a range of crater morphologies present on the surface.

Description of Candidate Crater Types: Prior to Hayabusa's visit to asteroid Itokawa, all asteroids visited by spacecraft were at least tens of kilometers in size. Craters on these objects are recognizable as impact craters due to characteristics present in crater populations on planets and moons—raised rims, bowl shapes, and, in some cases, ejecta patterns. In contrast, craters observed on Itokawa have unusual morphologies [1]; notably, the craters are shallow and lack raised rims. The combination of these morphologies removes the usual topographic contrast that makes craters visually striking on other surfaces. The irregular shape and generally rough surface of Itokawa further confounded the identification and classification of impact craters.

Our initial image-based observations of Bennu reveal a suite of crater morphologies, from clear bowl shapes and raised rims, to shallow circular features with little contrast in texture between interior and exterior, and shallow features that are distinct due to surface textures that differ between interior and exterior.

As a result of these broad morphologies, and the preliminary nature of the observations available in image and lidar data, we use the nomenclature "candidate craters", and currently use three classification types (Figure 1).

Type 1 – the most likely impact craters. These have raised rims, depressed crater floors, and may have different textures between inside and outside the crater.

Type 2 – intermediate likelihood to be an impact crater. These have fewer and/or less distinct characteristics of a Type 1 crater.

Type 3 – the most uncertain impact origin. A circular feature is present, but the perimeter may not be well defined, and topographic, textural, or other contrasts are minimal or non-existent.

Spatial Distribution of Craters: Bennu's impact craters are globally distributed; however, there are po-tentially meaningful asymmetries in the spatial distribution. Figure 2 plots the approximate locations and sizes of the Type 1 craters (solid lines) and the Type 2 and 3 craters (dashed lines). There appears to be a lower abundance of candidate craters between roughly 150° and 220° longitude.
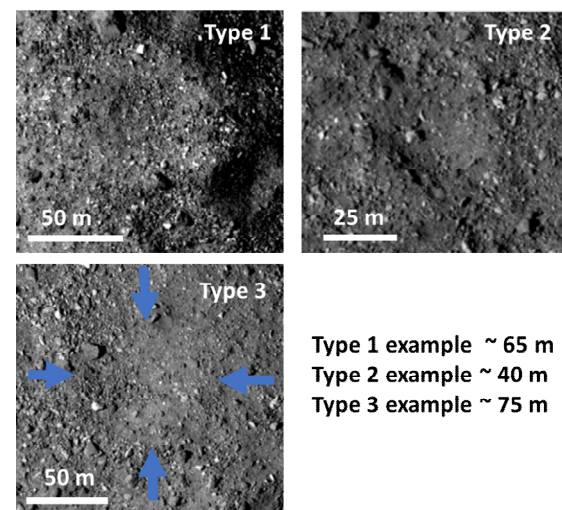

Type 1 example ~ 65 m
Type 2 example ~ 40 m
Type 3 example ~ 75 m

Figure 1. Example crater types, and their approximate diameters, on Bennu. Arrows for the Type 3 example point to the approximate circular boundary of the feature. Diameters of each crater example are given in the legend.

Relationship(s) with Boulders: Current observations reveal three types of spatial relationships between candidate craters and boulders: (1) an increase in boulder density inside the candidate crater relative to outside the candidate crater; (2) a decrease in boulder density inside the candidate crater relative to outside; and (3) an annulus of high boulder density surrounding the candidate crater. The first case tends to be associated with larger candidate craters, while the second tends to be associated with smaller candidate craters. Currently there is only one example of the third case, and the annulus surrounds what may be the largest impact structure on Bennu.

The second relationship—fewer boulders inside a crater—appears particularly pronounced at smaller diameters. In some of these craters, boulders are en-

tirely absent, and at roughly 0.3–0.5 m/pix image scale, the crater interiors appear nearly smooth. Smooth regions do not appear inside the currently identified candidate crater population for diameters larger than ~40 m, and smooth regions appear in almost every candidate crater less than this diameter. This transition in morphology suggests the presence of a sub-surface layer of finer-grained material at depths < 4 m, assuming an approximate ten-to-one crater-diameter-to-excavation-depth relationship [2]. The appearance of this smoother material in small craters but not larger craters suggests this finer-grained material may be restricted to a relatively shallow depth.
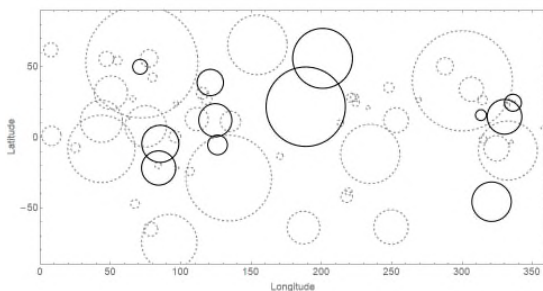

Figure 2. The spatial distribution of candidate craters: Type 1 (solid lines), and Types 2 and 3 (dashed lines). The sizes and locations are approximate. Due to the projection, some larger craters appear to overlap, which is not the case for the actual craters on Bennu.

Morphologies Indicative of Age: If all candidate craters (Types 1 to 3) are in fact impact craters, their relative morphologies may be indicative of relative age. Seismic shaking from impacts [e.g. 3], regolith movement from YORP spin-up or spin-down [e.g. 4], and ejecta distribution of more recent impacts from later impacts will all serve to degrade and soften characteristic impact features over time. In this scenario, the candidate crater types approximately correspond to relative age, where Type 1 craters are the most recent, and Type 2 and 3 craters are progressively older.

The relative abundance of crater types, their specific morphologies, and their spatial locations together provide important constraints on short- and long-term timescales of processes active on Bennu.

Surface Age(s): The relative morphologies and crater SFD enable estimates of Bennu's relative and absolute surface age(s).

Bennu's collisional history was dominated by its life in the Main Belt [5]. The number of large (where "large" is relative to the crater diameter in comparison with Bennu's mean radius) craters suggests the shape of Bennu is old. In particular, the superposition of several craters over the equatorial bulge suggests that the bulge dates back to Bennu's formation, and is not an outcome of more recent shape evolution.

Figure 3 plots the cumulative crater SFD for Bennu. (The cumulative data are normalized by surface area.) There is a break in the slope of the SFD for all crater types between 50 m – 100 m diameter. The underabundance of smaller craters suggests an active process is reworking the surface at a rate faster than the impact rate.
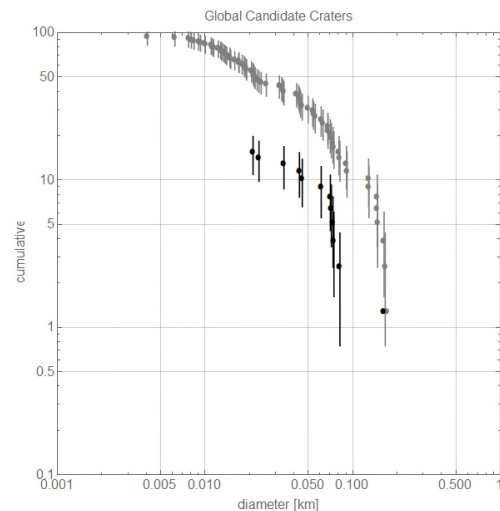

Figure 3. The cumulative (total craters per unit area) SFD of Type 1 candidate craters only (black points), and all types (gray points).

Conclusions: The morphology and SFD of Bennu's crater population illuminates multiple dimensions of Bennu's history, structure, and current processes. Similarities between craters observed on Bennu and Itokawa suggest scale of the target body plays an important role in the formation and evolution of impact craters; differences between Bennu and Itokawa suggest that there may be compositional and porosity effects that are relevant as well.

Upcoming, high-resolution data from all instruments (visible imaging, topography from lidar, and spectral data) will further our understanding of Bennu's crater population, and the consequences for the history and current state of Bennu.

References: [1] Hirata et al. (2009) *Icarus, 200,* 486-502. [2] Melosh, H.J (1989) Impact Cratering: A Geologic Process, Oxford Univ. Press. [3] Yamada T. M. et al. (2015) *Icarus, 272,* 165-177. [4] Hirabayashi M. (2015) *MNRAS,* 454, 2249-2257. [5] Bottke W. F. (2005) *Icarus,* 179, 63-94.