LAST EPOCH OF RESURFACING ON ASTEROID (101955) BENNU REVEALED BY GLOBAL GEOLOGIC MAP. Erica R. Jawin[1], T. J. McCoy[1], K. J. Walsh[2], H. C. Connolly Jr.[3,4], R.-L. Ballouz[4], A. J. Ryan[4], M. Pajola[5], O. S. Barnouin[6], H. H. Kaplan[7], V. E. Hamilton[2], J. P. Emery[8], D. N. DellaGiustina[4], D. J. Scheeres[9], M. G. Daly[10], C. A. Bennett[4], D. R. Golish[4], M. Perry[6], R. T. Daly[6], E. B. Bierhaus[11], M. C. Nolan[4], H. L. Enos[4], and D. S. Lauretta[4], Smithsonian National Museum of Natural History, Washington, DC, USA (jawine@si.edu), [2]Southwest Research Institute, Boulder, CO, USA, [3]Department of Geology, Rowan University, Glassboro, NJ, USA, [4]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ, USA, [5]INAF-Astronomical Observatory of Padova, Padova, Italy, [6]Johns Hopkins University Applied Physics Laboratory, Laurel, MD, USA, [7]Goddard Space Flight Research Center, Greenbelt, MD, USA, [8]Northern Arizona University, Flagstaff, AZ, USA, [9]University of Colorado, Boulder, CO, USA, [10]Centre for Research in Earth and Space Science, York University, Toronto, Canada, [11]Lockheed Martin Space, Littleton, CO, USA.

Introduction: Bennu is a dark, hydrated, B-type near-Earth asteroid studied by the OSIRIS-REx sample return mission [1,2]. The surface of Bennu is dominated by boulders of various sizes, colors, and morphologies [3–5], and it is actively shedding mass via particle ejection (PE) events [6]. Bennu is thus a complex planetary body despite its small size (~500 m diameter). We created a geologic map of Bennu to facilitate analyses of the asteroid and contextualize the sample that will be returned. Here we present the results of our analysis and implications for the heterogeneous evolution of Bennu's surface.

Due to the microgravity environment on Bennu, topography is subdued [7] with a general lack of distinct stratigraphic contacts on the surface; as such, we defined geologic units by integrating topographic features, geologic features, and surface texture, with texture playing the largest role. We mapped features in 2D projected space as well as 3D space in the Small Body Mapping Tool [8] using a shape model [9] produced from OSIRIS-REx Laser Altimeter (OLA) data together with global mosaics from the Approach [3] and Detailed Survey [10] phases of the mission.

Global geologic investigations and mapping of a similar diamond-shaped rubble pile asteroid, Ryugu [11], suggested the equatorial ridge (Ryujin Dorsum) formed early in the history of Ryugu, followed by the formation of large craters and troughs (Horai and Tokyo Fossae). Ryugu contains at least two units distinguishable by their number density of boulders [11] and subtle brightness and color variations [12].

Topographic Features: Bennu's shape can be defined by two topographic features: the equatorial ridge (ER), extending to approximately 20°N and S latitude, and four longitudinal ridges (dorsa) and adjacent troughs (fossae) that can reach the poles [7,13]. Dorsa and fossae are superimposed on the ER, suggesting they are younger than the ridge.

Geologic Features: We mapped the distribution of craters >10 m in diameter [14], boulders >20 m in diameter, lineaments, PE source regions [15], and morphologies associated with mass movement (e.g., perched, partly buried, or imbricated boulders and a smooth lobate feature) [16] (Fig 1). Craters appear to be concentrated on the ER, suggesting the ridge is an old geologic feature [4]. There are more large boulders present in the southern hemisphere, which may be due to their primordial distribution [13,16]. Mass movement features appear to be spatially correlated with the distribution of large boulders (as large boulders often appear to be partly buried), and are concentrated in several fossae bound by lineaments.

Surface Texture: The morphologic variation on the surface of Bennu is dominantly controlled by the abundance of boulders. The surface can therefore be divided into two dominant morphologies: (1) regions with smooth or knobby surface textures that contain fewer large boulders, and (2) rugged regions that contain abundant boulders.

Geologic Units: To define geologic units, we integrated the topographic features, geologic features, and surface texture, which resulted in the creation of two units referred to as the "Smooth Unit" and "Rugged Unit" (Fig 1). Surfaces in the Smooth Unit have few large boulders or mass movement features, and can occur on dorsa and fossae. The mission's sample collection site and three candidate sites, and several PE source regions, are located in the Smooth Unit. Surfaces in the Rugged Unit contain 89% of the mapped large boulders and 85% of mass movement features, which are located largely in fossae. These two units effectively describe the surface of Bennu and demarcate regions that are also distinct in other global maps of Bennu, including OLA surface roughness, surface slopes, thermal roughness [17], and OTES spectral maps identifying the presence of thin dust coatings on coarser particles and rocks [18].

Formation and Relative Ages of Units: Few stratigraphic contacts are present on Bennu that enable clear assessments of the relative ages of the two units. However, the distribution of geologic features may be useful: for example, the concentration of mass movement features in the Rugged Unit suggests that this process may have played a role in its formation or modification. The mass movement features likely formed recently, during the current spin-rate epoch (in the past few hundred thousand years); during this period, mass movement may have excavated large boulders and erased small craters in the mid-latitudes, while burying boulders and craters near the equator [16]. In contrast, the paucity of mass movement in the Smooth Unit suggests it may be older and less active.

The distribution of the reddest (youngest) craters on Bennu can also be used as a proxy for age [5]. The Rugged Unit contains a lower concentration of the reddest craters on Bennu, with a factor of ~3 fewer craters per unit area relative to the Smooth Unit. The relative paucity of the youngest craters in the Rugged Unit suggests that it has been experiencing resurfacing in the past ~500 kyr based on the production function of these craters [5], while the Smooth Unit may have been relatively inactive over this time. Several PE source regions are present in the Rugged Unit, however little to no morphologic distinction is apparent at the source regions [6], so mass movement is likely a more dominant agent of surface change relative to PE. Additionally, the presence of PE source regions in both units is consistent with the wide-ranging operability of PE mechanisms such as thermal fracturing and/or meteoroid impacts [19,20].

Implications for Global Evolution: The ER appears to be oldest feature on Bennu due to the abundance of superimposed craters, dorsa, and fossae. Additionally, both geologic units cross the ER, suggesting that it does not greatly affect the formation or modification of other features on the surface of Bennu. This differs from Ryujin Dorsum on Ryugu, which has a visible relationship to other features such as the distribution of mass movement morphologies [11].

The dorsa and fossae may be the next oldest features on Bennu, formed due to internal deformation [13], but also shaped by the formation of large craters (e.g., 60°E, 60°N). Large boulders are abundant in several fossae and may be related to their evolution, but some large boulders are also present on dorsa; therefore topography is not the only control on the boulder distribution or the geologic unit boundaries. Surface modification likely continued after the formation of the dorsa and fossae, potentially owing to changing slopes on the surface due to YORP-related spin changes [e.g., 16].

We hypothesize that recent surface activity was dominated by mass movement, which changed the surface boulder distribution and erased small (red) craters. Enhanced modification in certain regions, potentially determined by the presence of dorsa/fossae, large craters, and partly exposed boulders, may have contributed to the formation of the Rugged Unit.

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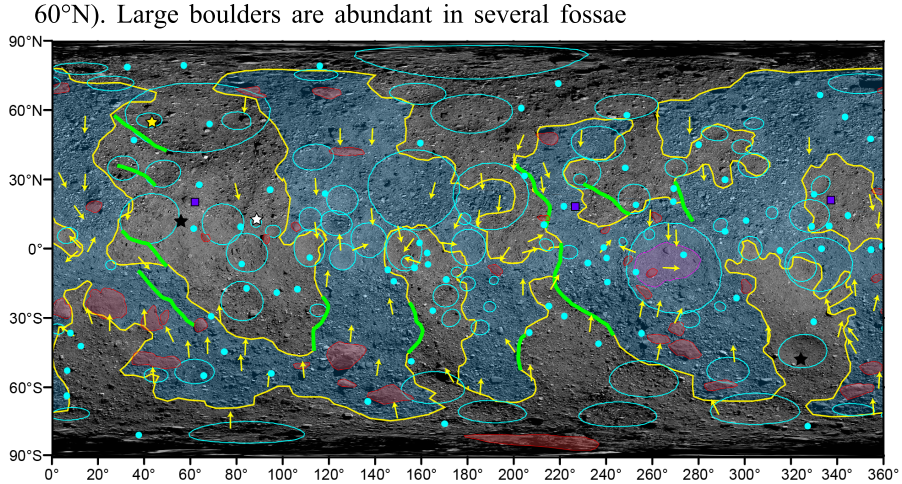

Fig 1. Global geologic map of Bennu showing the distribution of features and geologic units on the Detailed Survey global mosaic [10].