APPARENTLY LAYERED BOULDERS WITH MULTIPLE TEXTURES ON BENNU'S SURFACE.

K. Ishimaru[1], D. S. Lauretta[1], N. Porter[1], D. R. Golish[1], M. Al Asad[2], R. L. Ballouz[1], O. S. Barnouin[3], K. N. Burke[1], M. G. Daly[4], D. N. DellaGiustina[1], B. Rizk[1], and K. J. Walsh[5]. [1]Lunar and Planetary Laboratory, University of Arizona, 1629 E University Blvd, Tucson, AZ, 85721, USA, [2]Department of Earth Ocean and Atmospheric Sciences, University of British Columbia, Vancouver, British Columbia, Canada, [3]The Johns Hopkins University Applied Physics Laboratory, Laurel, MD, USA, [4]The Centre for Research in Earth and Space Science, York University, Toronto, Ontario, Canada, [5]Southwest Research Institute, Boulder, CO, USA. (kana@orex.lpl.arizona.edu)

Introduction: Asteroid (101955) Bennu is a carbonaceous near-Earth asteroid explored by the Origins, Spectral Interpretation, Resource Identification, and Security–Regolith Explorer (OSIRIS-REx) mission, which discovered that Bennu's surface is covered with boulders as large as tens of meters in long axis [1]. Bennu is a top-shaped, rubble-pile asteroid with diameter about 500 m [2]. Because of its small size, the collisional lifetime of Bennu is much shorter than the age of the solar system [3]. It is thought to be an accumulation of fragments of a ~100-km-diameter parent body that experienced aqueous alteration [4].

The OSIRIS-REx Camera Suite (OCAMS) [5] has provided high-resolution images (<2 cm/pix) of the surface of Bennu. We discovered some boulders that exhibit multiple apparently layered textures that are divided by linear boundaries [6]. The layered structures might have formed by parent-body processing [1, 7]; hence, they reflect its geologic history. In this work, linearly layered boulders on the asteroid surface were identified and categorized by texture and average normal albedo.

Methods: Layered boulders were searched through the surface of Bennu using a global mosaic projected on a lidar-based global shape model using Small Body Mapping Tool [8]. The search was mainly focused on the area between ± 70° latitudes to ensure preferable illumination conditions for normal albedo calculations. Detailed observation and measurements of layered boulders were performed using OCAMS PolyCam [5] images with pixel scales of 2 – 5 cm/pix that had been converted into reflectance [9]. Lidar ranging data were acquired by the OSIRIS-REx Laser Altimeter (OLA [10]). OLA shape models used is v16 with spatial resolution of < 5 cm and vertical precision of ± 1.25 cm [11, 12]. All the OLA scans available (typically 10 or more scans for each boulder) were registered using a Poisson reconstruction method to create a digital terrain model (DTM) covering the entire surface of the boulder. The PolyCam images were registered to the corresponding DTM using reconstructed SPICE kernels in USGS's ISIS3 software. Backplanes of images (which are incidence angle, emission angle, phase angle, oblique pixel scale, and body-fixed geographic coordinates) were calculated per pixel using ray-tracing methods [13]. After the registration, the images were photometrically corrected using the RObotic Lunar Observatory (ROLO) photometric function [14], setting all the photometric angles (incidence, emission, and phase angles) to zero. Pixel values of photometrically corrected images are normal albedo. Using the region tool in SAO DS9, a representative area (46 – 2261 pixels) within each texturally distinct layer was selected to calculate the average normal albedo. Three large boulders, Gargoyle, KLR1, and KLR2 were selected for detailed analysis (Fig. 1).

Results: *Normal albedo analysis and physical measurements.* Gargoyle is one of the largest boulders on Bennu, about 14 m tall and 20 m wide, located at 5N 93E. The top unit is about 11 m thick, and the surface is very dark and rough with normal albedo of 3.7 ± 0.8%. The base unit is 3 to 4 m thick and seems brighter and smoother with normal albedo of 5.6 ± 0.4%. The small bright flake on the top of this boulder (Fig. 1A) seems to be sitting on the surface instead of being a part of it, therefore it is not considered as a unit in this work. Its normal albedo is 8.7 ± 0.8%. The top unit contains numerous clasts whose size varies from 16 to 100 cm in longest dimension, whereas there are no visible clasts in the base unit. Both units seem very flaky and exhibit several thin layers with 57.7 cm average thickness around the south part of the boundary. KLR1 (Fig. 1B) is around 10 m, and located at 25N 190E. The west unit, with a normal albedo of 6.9 ± 1.1%, is smooth with a fracture in the middle [6]. The east unit appears to have a rough surface with normal albedo value of 5.2 ± 0.7%. Considering the standard deviation, the normal albedo values of the two units cannot be distinguished. KLR2 is around 20 - 30 m across, located in the southern hemisphere at 25S 3E and defines Bennu's prime meridian. This boulder exhibits three textures: west unit with normal albedo of 6.5 ± 0.6%, middle unit with normal albedo 4.2 ± 0.8%, and east unit with normal albedo 5.7 ± 0.6%. These values distinguish the west unit from the middle unit, and middle unit from the east unit.

Layered boulder formation. This work is designed to test two hypotheses of multi-texture layered boulder formation. One is brecciation in the parent body. Boulders could be fractured by thermal fatigue [6], impact, or internal pressure, and fragments with various textures could be melded together by melting or internal pressure. Second, Bland and Travis [15] modelled a mud convection in a 100-km asteroid parent body and showed that particle size sorting could occur. Catastrophic disruption of a parent body with a size-sorted interior could produce some rock fragments that include a boundary between two textures. The thickness of the layers observed in the boulders suggest that the size sorting could have occurred at scales of 1 to 10 m. It is possible for both situations to occur in one parent body. By mapping and characterizing the layering in some boulders on Bennu, we will be able to give some constraints on the interior environment of the parent body.

Conclusion: We found apparently layered boulders in PolyCam images of Bennu's surface and performed local shape model registration and photometric correction to analyze them in detail. The layer units can be largely divided into two texture groups, one is rough and dark (4 – 5 % normal albedo), and the other is smooth and bright (5 – 7% normal albedo). The thickness of the layers are in ~1-10 m scale, and it might reflect size sorting in the interior of the parent body.

Acknowledgments: This material is based upon work supported by NASA under Contract NNM10AA11C issued through the New Frontiers Program. We are grateful to the entire OSIRIS-REx Team for making the encounter with Bennu possible.

References:

[1] DellaGiustina D. N. et al. (2019) *Nature Astronomy, 3,* 341-351. [2] Barnouin O. S. et al. (2019) *Nature Geoscience, 12,* 247-252. [3] Bottke W. F. et al. (2005) *Icarus, 179,* 63-94. [4] Lauretta D. S. (2015) *Meteoritics & Planetary Science, 50,* 834849. [5] Rizk B. et al. (2018) *Space Sci Rev, 214*, 26. [6] Molaro J. L. et al. (2020) *Nat. Commun. 11,* 2913. [7] Walsh K. J. et al. (2019) *Nature Geoscience, 12*, 242-246. [8] Ernst C. M. et al. (2018) *Lunar and Planetary Science Conference, 49,* Abstract #1043. [9] Golish D. R. et al. (2020) *Space Sci Rev, 216,* 12. [10] Daly M. G. et al. (2017) *Space Sci Rev, 212,* 899-924. [11] Daly M. G. et al. (2020) *Sci. Adv., 6,* eabd3649. [12] Barnouin O.S. et al. (2020) *Planetary and Space Science 180,* 104764 [13] DellaGiustina et al. (2018) *Earth and Space Science*, 5, 929– 949. [14] Golish D. R. et al. (2020) *Icarus, 113724.* [15] Bland P. A. & Travis B. J. (2017) *Sci. Adv., 3,* e1602514.

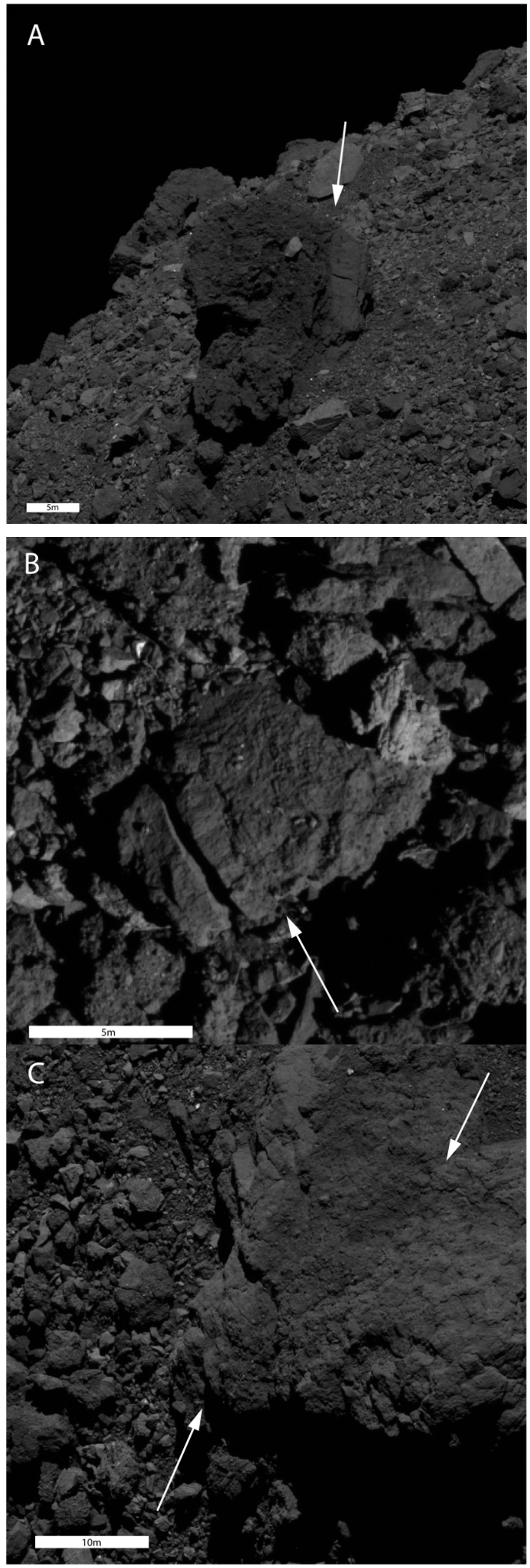

Fig. 1 PolyCam images of the layered boulders. Up is Bennu north (+z). Arrows indicate linear boundaries between textual units. A: Gargoyle, B: KLR1, C: KLR2.