Fractures in boulders on asteroid (101955) Bennu: Searching for evidence of thermal cracking.

M. Delbo (1), K. J. Walsh (2), J. L. Molaro (3), M. Al Asad (4), D. N. DellaGiustina (5), M. Pajola (6), C. A. Bennett (5), E. R. Jawin (7), R.-L. Ballouz (5), S. R. Schwartz (5), B. Rizk (5), D. S. Lauretta (5)

(1) UCA-CNRS-Observatoire de la Côte d'Azur, Nice, France (delbo@oca.eu); (2) Southwest Research Institute, Boulder, CO, USA; (3) Planetary Science Institute, Tucson, AZ, USA; (4) York University, Toronto, Canada; (5) Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ, USA; (6) INAF-Astronomical Observatory of Padova, Vic. Osservatorio 5, 35122 Padova, Italy; (7) Smithsonian Institution National Museum of Natural History, Washington, DC, USA.

Abstract: NASA asteroid sample return mission Origins, Spectral Interpretation, Resource Identification, and Security–Regolith Explorer (OSIRIS-REx) [1] arrived at the near-Earth asteroid (101955) Bennu on December 3rd, 2018 [2]. Images of Bennu, obtained by OSIRIS-REx's PolyCam instrument [3] at spatial resolution ranging from 33 cm/pixel to a 1 cm/pixel revealed a surface covered by boulders of different sizes, many of which present fractures and exfoliation features [4] that could be indicative of thermal cracking processes. Many studies claimed this process to be active on asteroids and comets [7-9 and ref. therein], but a definitive proof is stills missing. Here we present our mapping of fractures on boulders across the surface of Bennu. Our preliminary analysis indicates a preferential direction of the fractures. We discuss how this could be related to thermal cracking i.e. a mechanism of fracture propagation driven by surface temperature variations.

Introduction: Formation and propagation of fractures (cracking) on rocks, which can eventually lead to their exfoliation, breakdown, and rockfalls are important landscape evolutionary process on Earth [5,6], Mars [7], and are claimed to be also important on asteroids [8,9] and comets [10]. Different driving forces can cause cracking, including impacts, stresses from thermal cycling, dehydration, volatile loss, freeze-thaw in presence of water, and variation in regional and tectonic stresses.

Morphology of fractures, their arrangements, and spatial density on rocks, boulders and outcrops may clarify which of the aforementioned processes is dominant on the surface of a given planetary body. Moreover, when a weathering process creates fractures, spatial density and the distribution of the fractured to non-fractured terrain ratio may shed light on relative surface unit ages.

In addition, different types of rocks or geological units can react differently to the process generating the fractures (e.g. impacts, thermal cracking). The distribution of the orientation of fractures may indicate the dominant process at play [6]. For instance, in the case of impact-generated fractures on a randomly oriented boulder population, fractures are expected to have propagated along all possible azimuthal directions. On the other hand, rocks in Earth's mid-latitude deserts and on Mars present fractures that are oriented in statistically preferred directions [5,7]. Models show that this preferred direction can be due to fractures propagating along a direction forced by the cyclic Sun-induced thermal stresses [8]. Preliminary observations of the asteroid Bennu by OSIRIS-REx [1,2] reveal a body covered with boulders ranging in size from some tens of meters down to a few centimeters that are the spatial resolution of images acquired so far [3]. Some of the boulders are fractured, and some present arrangements consistent with them having broken down in place [2,4,11].

Observations and Methods: We primarily used a series of images obtained by the OSIRIS-REx Camera Suite (OCAMS), with a scale of 5–6 cm/pixel, during the first and third "baseball diamond" flybys of the Detailed Survey mission phase, which occurred on 7 and 21 March 2019, respectively. Other, lower-resolution images were composited into two global mosaics whose x and y coordinates correspond to the longitude and latitude on the asteroid. We used different visualization tools, such as SAOimageDS9 (ds9.si.edu) and JAsteroid (jmars.mars.asu.edu/j-asteroid-and-3d-shapes), to visually identify and map fractures on boulders. We drew line segments along each fracture. When we identified on a single boulder multiple fractures, we mapped each one of these fracture with a different broken line (Fig. 1). This fracture mapping effort was carried out by different co-authors on similar asteroid regions to minimize the biasing effects of having only one person in charge of fracture identification.

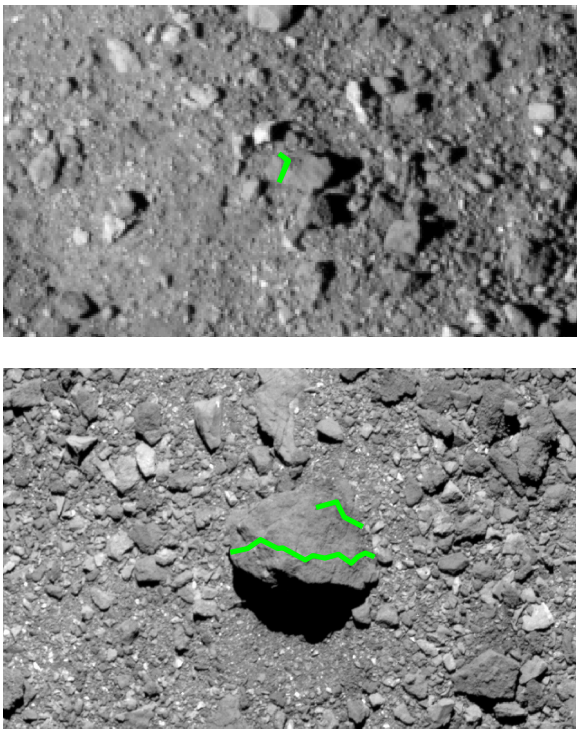

Figure 2: Example of fracture mapping on boulders at the centre of two different images. (Top) A broken line made of two segments (green) was used. Image is 20181201T064101S472_pol from the Preliminary Survey phase of the mission [3][4][5][7]. This image has a spatial resolution of 0.323 m/pixel and a phase angle of about 49.9°.
(Bottom) Example fracture mapping using a broken line made of several segments (green) from image 20190321T203550S089_pol that has a spatial resolution of 4.67 cm/pixel and was obtained at a phase angle of 30.25 deg. Results presented will be based on the Detailed Survey images, which have a spatial resolution of 5–6 cm/pixel.

Preliminary Results: We will present the global mapping of fractures on the boulders on Bennu. Preliminary results from our boulder mapping indicate that the fractured boulders are a few percent of the total boulder population. It also appears that there is a preferential direction of the fractures. Fracture mapping is still ongoing, at the time of writing of this abstract, and will be completed at the time of the meeting. We will present updated results and discuss the possible preferred direction of the fractures, which likely indicates a preferential fracture propagation mechanism.

Acknowledgements: This material is based upon work supported by NASA under Contracts NNM10AA11C and NNG12FD66C issued through the New Frontiers Program. Marco Delbo acknowledges support from the Centre National d'Études Spatiales, as well as the Academies of Excellence on Complex Systems and Space, Environment, Risk and Resilience of the Initiative d'EXcellence 'Joint, Excellent, and Dynamic Initiative' (IDEX JEDI) of the Université Côte d'Azur. Maurizio Pajola was supported for this research by the Italian Space Agency (ASI) under the ASI-INAF agreement no. 2017-37-H.0. We are grateful to the entire OSIRIS-REx Team for making the encounter with Bennu possible.

References: [1] Lauretta, D.S., and DellaGiustina, D.N. et al. (2017) Sample Return from Asteroid (101955) Bennu. Space Sci. Rev. 212, 925-984. [2] Lauretta, D.S. et al. (2019) The unexpected surface of asteroid (101955) Bennu. Nature 568, 55-60. [3] Rizk, B. et al. (2018) OCAMS: The OSIRIS-REx Camera Suite. Space Sci. Rev. 214, 26. [4] Walsh, K.J. et al. (2019) Craters, boulders and regolith of (101955) Bennu indicative of an old and dynamic surface. Nat. Geosci. 12, 242-246. [5] McFadden, L. D., Eppes, M. C., Gillespie, A. R. & Hallet, B. (2005) Physical weathering in arid landscapes due to diurnal variation in the direction of solar heating. Geological Society of America Bulletin 117, 161. [6] Collins, B. D. & Stock, G. M. (2016) Rockfall triggering by cyclic thermal stressing of exfoliation fractures. Nat. Geosci. 9, 395–400. [7] Eppes, M.-C. et al. (2019) Cracks in Martian boulders exhibit preferred orientations that point to solar-induced thermal stress. Nat. Commun. 6, 6712. [8] Molaro, J. L., Byrne, S. & Le J L. (2017) Thermally induced stresses in boulders on airless body surfaces, and implications for rock breakdown. Icarus 294, 2471. [9] Delbo, M. et al. (2014) Thermal fatigue as the origin of regolith on small asteroids. Nature 508, 233–236. [10] Attree, N. et al. (2018) Thermal fracturing on comets. Applications to 67P/Churyumov-Gerasimenko. A&A 610, A76. [11] DellaGiustina, D.N. and Emery, J.P. et al. (2019) Properties of rubble-pile asteroid (101955) Bennu from OSIRIS-REx imaging and thermal analysis. Nat. Astron. 3, 341-351.