MINI-CRATERS ON (101955) BENNU'S BOULDERS: DERIVING THE IMPACT STRENGTH OF C-TYPE OBJECTS. R.-L. Ballouz[1], K.J. Walsh[2], W.F. Bottke[2], D.N. DellaGiustina[1], M. Al Asad[3], P. Michel[4], C. Avdellidou[4], M. Delbo[4], E.R. Jawin[5], E. Asphaug[1], O.S. Barnouin[6], C.A. Bennett[1], E.B. Bierhaus[7], H.C. Connolly Jr.[8,1], M.G. Daly[9], R.T. Daly[6], D.R. Golish[1], J.L. Molaro[10], M. Pajola[11], B. Rizk[1], S.R. Schwartz[1], D. Trang[12], D.S. Lauretta[1]. [1]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ, USA, [2]Southwest Research Institute, Boulder, CO, USA, [3]University of British Columbia, Vancouver, Canada, [4]Laboratoire Lagrange, Université Côte d'Azur, Observatoire de la Côte d'Azur, CNRS, Nice, France, [5]Smithsonian Institution, Washington, DC, USA, [6]The Johns Hopkins University Applied Physics Laboratory, Laurel, MD, USA, [7]Lockheed Martin Space, Littleton, CO, USA, [8]Dept. of Geology, Rowan University, Glassboro, NJ, USA, [9]York University, Toronto, Canada, [10]Planetary Science Institute, Tucson, AZ, USA, [11]INAF-Astronomical Observatory of Padova, Padova, Italy,[12]HIGP/University of Hawaii at Manoa, HI, USA.

Introduction: OSIRIS-REx's Detailed Survey imaging campaign using the PolyCam instrument, part of the OSIRIS-REx Camera Suite (OCAMS) [1], has returned images of the surface of (101955) Bennu with pixel scales down to 1 cm/pixel. The unprecedented resolution of these images have revealed clearly-resolved cavities on Bennu's boulders (Fig. 1). These cavities are near-circular in shape and have diameters that range from 5 cm to 5 m. We have cataloged these cavities in flyby (~ 5 cm/pixel) and orbital images (~ 1 cm/pixel), and have found more than 100 boulders that exhibit at least 1 of these features on their surface.

The most likely mechanism for the creation of these cavities is impacts on Bennu. However, it is unclear whether these mini-craters were formed during Bennu's residence in the main asteroid belt, or if they were formed more recently after Bennu became a near-Earth asteroid (NEA). In order to decouple the signature of the main-belt and near-Earth impactor populations on Bennu's boulders, we use our observations of mini-craters to derive the strength of solid C-type objects against impacts.

The Strength of C-type Objects: The strength of asteroids against collisions is crucial for understanding the surface evolution of airless planetary bodes, the dynamical evolution of asteroids throughout Solar System history, and the incorporation of planetesimals into planets [2,3].

Laboratory data on centimeter-scale meteorites have been extrapolated and buttressed with numerical simulations and analytic formalisms to derive the cratering threshold at the asteroid scale [4–6]. However, thus far it has not been possible to directly assess the strength of the boulders that constitute the building blocks of a rubble-pile asteroid. Apollo lunar rocks and subsequent spacecraft missions to near-Earth asteroids indicate only two modes of impact-induced breakdown of boulders: 1) abrasion by micro-meteorites (sand-blasting), and 2) catastrophic rupture by a single large impact [7–9]. Widespread cratering on boulders has not been observed heretofore. Here we report on hundreds of measurements of craters 4 cm to 4 m in diameter on individual boulders on the surface of the near-Earth asteroid (101955) Bennu, observed in image and laser altimeter data collected by the OSIRIS-REx mission (Figs. 1 & 2).

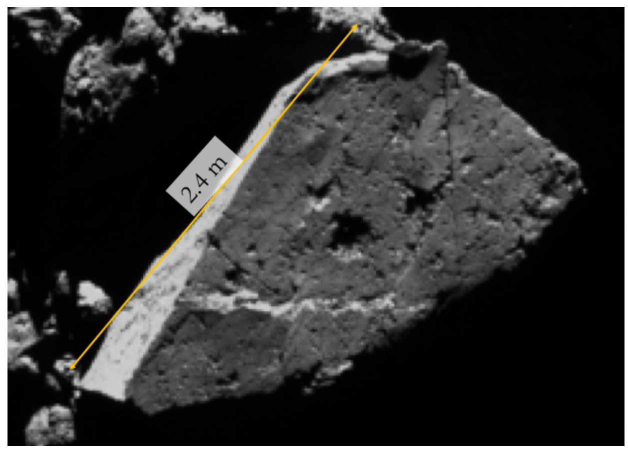

Fig. 1. OSIRIS-REx's Orbital B phase imaged Bennu's surface at pixel scales of ~1 cm/px, resolving centimeter-scale impact features, as evident on this boulder (image 20190703T044506S720_pol, taken July 3, 2019, by the OCAMS PolyCam imager).

We develop a new method to derive the cratering efficiency and the disruption threshold of C-type objects by combining scaling laws and observations of craters on C-type boulders and asteroids [10–12]. We postulate that the largest crater on a boulder of a given size signifies an impact energy close to that required for disrupting that boulder. This type of analysis has been previously done for the study of the largest craters on planetary bodies larger than tens of kilometers using scaling laws [4] and laboratory experiments [13]. Here, we extend that analysis to objects of arbitrary size.

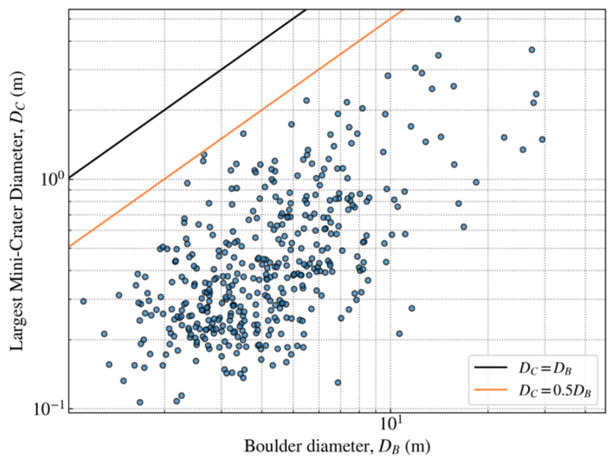

Fig. 2. A global search using the Bennu basemap [17] revealed 414 boulders with one or more impact features. For each boulder with impact features, its diameter (D_B), and its largest impact features (D_C). We find that a majority of boulders have impact features that have diameters below 50% of the host boulder's diameter (solid orange line).

We find that the crater to impactor size ratio on C-type objects is ~ 15, and that the collisional disruption of 1-m radius boulders on the surface of Bennu is efficient in the main belt (~ 1 Myr, Fig. 3), but effectively ceases in near-Earth space as the collisional lifetime (~50 Myr) becomes greater than the dynamical lifetime of near-Earth asteroids (<10 Myr) [14]. The relative ease in disruption of 1m-size C-type boulders on the surface may explain the relatively young cosmic ray exposure (CRE) ages of carbonaceous chondrites [15].

Towards a mini-crater clock for NEA Surfaces: The detailed comparison of the surface density of mini-craters on Bennu's boulders may provide us with a new way to provide relative ages of different regions of the surface. This can be used as a basis of comparison or calibration point to alternative approaches, such as an assessment of the small crater population [10], or space-weathering on Bennu's surface [16]. Our findings may be validated by analyzing the cosmic ray exposure ages of the returned sample.

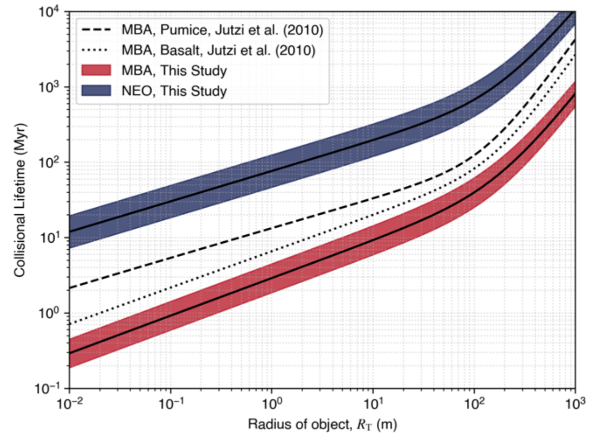

Fig. 3. C-type objects are weaker than porous pumice and non-porous basalt targets of the same size [6]. The red curve shows our derived collisional lifetime for C-type objects that are main belt asteroids (MBA) which have average impacts speeds of 5 km/s and a main-belt population and impact probability given by [3]. The blue curve shows the collisional lifetimes for C-type objects in near-Earth space based on impact speeds of 23 km/s and an NEO impactor population given by [18] and impact probability given by [3].

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