Craters on (101955) Bennu's boulders

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Introduction: The OSIRIS-REx mission's observation campaigns [1] using the PolyCam instrument, part of the OSIRIS-REx Camera Suite (OCAMS) [2 3], have returned images of the surface of near-Earth asteroid (NEA) (101955) Bennu. These unprecedented-resolution images resolved cavities on Bennu's boulders (Fig. 1) that are near-circular in shape and have diameters ranging from 5 cm to 5 m. We made hundreds of measurements of these cavities in image and laser altimeter data and found more than 100 boulders that exhibit at least one on their surface (Fig. 1).

The most likely mechanism for the creation of these cavities is impacts. 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). We use our observations of mini-craters to derive the strength of solid C-type objects against impacts. Our results have implications for Bennu's history in the main-belt and in near-Earth space.

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 [4,5].

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 [6–8]. 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 spacecraft missions to near-Earth asteroids indicate only two modes of impact-induced breakdown of boulders: 1) abrasion by micro-meteorites (sandblasting), and 2) catastrophic rupture by a single large impact [9–11]. Widespread cratering on boulders has not been observed heretofore.

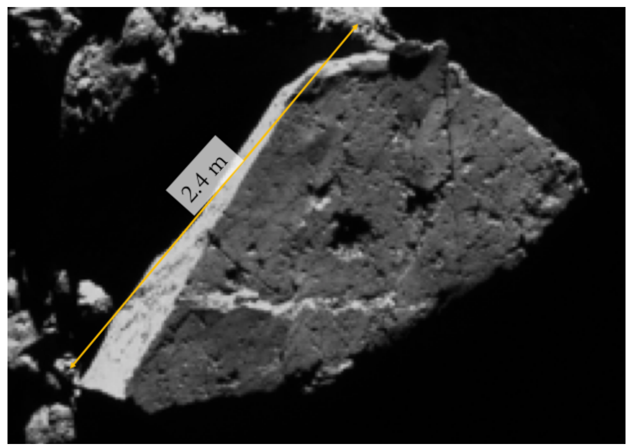

Figure 1 Centimeter-scale impact features on the surface of a boulder (image 20190703T044506S720_pol, taken July 3, 2019, by the OCAMS PolyCam imager; 1 cm/pixel).

We developed 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 [12–14]. 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 [6] and laboratory experiments [15]. Here, we extend that analysis to objects of smaller size.

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) but effectively ceases in near-Earth space as their collisional lifetime (~50 Myr) becomes greater than the dynamical lifetime of NEAs (<10 Myr) [16].

Towards a mini-crater clock for NEA surfaces: Detailed analysis of the surface density of mini-craters on Bennu's boulders may provide a new way to determine relative ages of different regions of the surface. This can be used as a basis of comparison or calibration for alternative approaches to chronology, such as assessments of the small crater population on Bennu's surface [12] or space-weathering on Bennu's surface [17]. Our findings may be validated by analyzing the cosmic ray exposure ages of the returned sample.

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