Linking physical and thermal analysis of Bennu samples to remote observations by OSIRIS-REx

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The arrival of the OSIRIS-REx spacecraft to near-Earth asteroid (NEA) Bennu came with the surprise discovery of a surface dominated by large boulders [1]. This observation has led to insights into boulder thermal and physical properties and the dynamical and surface evolution of their host asteroids [3-5]. The survey of Bennu showed that boulders effectively armor the surface against impacts, frustrating the formation of small (<~ 2 m) craters [6]. The armoring process instead results in small craters formed on boulder surfaces [3]. Particle ejection events were hypothesized to have formed from impacts on boulders [7] and/or thermal processing [8]. The alignment of meter-scale fractures on boulders is consistent with cracking induced by diurnal temperature variations [9], though these observations may have been biased by lighting conditions in optical imaging [10].

Regolith production has been hypothesized to be influenced by the heterogeneity of its boulder population. Bennu's surface has two main populations of very dark and somewhat brighter boulders with contrasting thermal and physical properties [5,11,12]. Because of these differences, these sub-populations are thought to break down differently. The brighter, more angular boulders were hypothesized to be denser and stronger yet more easily comminuted, whereas the darker, rugged boulders would be less dense and more friable, yet less effectively comminuted by mechanical weathering processes [5,13]. Thus, the scarcity of fines was hypothesized to be driven by inhibited production due to the high porosity of the dark, rugged boulders which dominate the asteroid's surface [13]. Alternatively, the near-surface layer may be of sufficiently high porosity (>50%), as evidenced by its response to the OSIRIS-REx sampling event, that any fines produced by boulder comminution would percolate to deeper layers [14].

Preliminary analysis of samples returned to Earth has revealed that there are at least two distinct particle morphologies [15], with notable similarities to Bennu's boulders despite the difference in scale. The hummocky lithology is rough, lowest in density, and similar in morphology to dark, low-thermal-inertia boulders. The angular lithology is intermediate in density and similar in appearance to brighter, higher-thermal-inertia boulders. Further investigations into these similarities between sample and boulder morphologies is required to better understand their inter-relationships.

High-resolution shape models of the samples can provide insight into comminution processes. Stones of interest were analyzed using structured light scanning (SLS) and X-ray computed tomography (XCT), providing detailed 3D shapes at scales of a few to tens of microns [15]. Some of the stones fit together like puzzle pieces. It is unclear whether these stones were split on the surface of the asteroid or upon sampling and delivery to the curation facility. Strength measurements [16], combined with numerical simulations that track the stresses experienced by particles from the time of collection to preliminary examination, can provide further insight [17].

Micro-scale impact craters are present on some particles. One such micro-crater appears to have a central pit surrounded by a circular spall region. A larger extended spall region is approximately 5.5 mm long and wide. If an impact onto this particle ejected a spalled fragment, that fragment would have an axis ratio of ~0.16. In comparison, particles that were observed ejecting from the surface of Bennu had effective diameters of 2.2 to 61 mm (median of 7.4 mm) and axis ratios of 0.07 to 1.0 (median of 0.27) [18]. Measurements using the Small Body Mapping Tool [19] show that this micro-crater has a depth-to-diameter ratio, d/D, ~ 0.39, which is comparable to the d/D measured for craters on Bennu's large (>5 m) boulders [3]. This high d/D is likely reflective of the porous and weak nature of the samples. An open question has been whether NEAs hold on to the byproducts of hypervelocity impacts, despite their microgravity environments. The answer appears to be yes, given the observation of micro-craters, but the exact mechanics of how these fragments are retained remains a mystery.

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