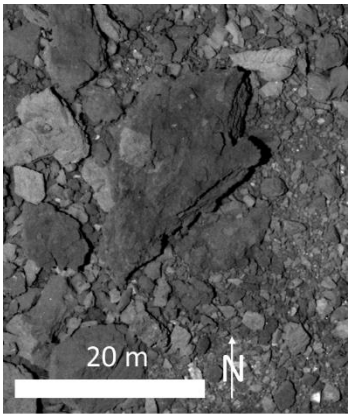
BRECCIATED BOULDERS: EVIDENCE FOR IMPACT MIXING ON BENNU'S PARENT BODY

T.J. McCoy[1] , H.C. Connolly Jr.[2,3], C.M. Corrigan[1], E.R. Jawin[1], S. Sandford[4], J. Molaro[5], D. N. DellaGiustina[3], B. Rizk[3], M. C. Nolan[3], D. S. Lauretta[3], and the OSIRIS-REx Team, [1]Dept. of Mineral Sciences, National Museum of Natural History, Smithsonian Institution, Washington, DC, USA (mccoyt@si.edu), [2]Dept. of Geology, Rowan University, Glassboro, NJ, USA, [3]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ, USA, [4]NASA Ames Research Center, Mountain View, CA, USA, [5]Planetary Science Institute, Tucson, AZ, USA

Introduction. OSIRIS-REx has revealed an abundance of meter-scale brecciated boulders on the surface of asteroid Bennu. On its own, this result is not surprising. Impact bombardment has dominated most of the history of the parent asteroids of hydrated carbonaceous chondrites similar to Bennu. Impacts produced shock effects within individual components [1], shock melting [2], and brecciation [3]. These effects are well-documented in meteorites. Of 30 hydrated carbonaceous chondrites (CI, CM, CR) surveyed, all of them contain solar wind–implanted gases and are regolith breccias [3], suggesting that the surfaces of asteroids are dynamic environments for mixing. The revelation that brecciation is widespread at the meter scale on the surface of Bennu allows us to examine the extent and timing of brecciation.

Brecciation in meteorites: Petrographic study of CI, CM, and CR chondrites reveals widespread evidence of brecciation at the thin section scale [3 and references therein]. In all cases, these are genomict breccias composed of material of the same chemical group with different states of aqueous alteration. CI chondrites exhibit prominent sub-centimeter clasts that differ in texture and mineralogy, including abundance of carbonates. Clasts are angular, and boundaries between clast and host are distinct, suggestive of impact mixing after aqueous alteration. Brecciation in CM chondrites ranges from areas of more extensive aqueous alteration adjacent to areas in which chondrules are only modestly aqueously altered, to CM chondrites (e.g., Nogoya) in which clasts are visible in hand sample. CR2 chondrites exhibit the lowest degree of aqueous alteration, but contain clasts that appear to have experienced more extensive aqueous alteration akin to a CR1. Although brecciation is common at the millimeter to centimeter scale, masses of Murchison—the only >100-kg hydrated carbonaceous chondrite shower—do not exhibit substantial stone-to-stone variations suggestive of brecciation at the decimeter scale.

Brecciated boulders on Bennu: Boulders of the scale of tens of meters on the surface of Bennu exhibit differences in albedo and texture suggestive of brecciation [4,5]. Although many breccias appear monomict, albedo variations in some suggest differences (e.g., extent of aqueous alteration, mineralogy) indicative of genomict breccias with clasts derived from distinct portions of the asteroid. The differences between these clasts will require additional data to discern. Meter-scale genomict breccias suggests a dynamic environment of fragmentation, mixing, and reconsolidation. Impact and thermal cycling may have played a role in fragmentation, with millimeter- to centimeter-scale fragments expected to far outnumber meter-scale fragments. Whether movement of particles occurs via impact mixing, or via migration on the surface or in the interior of asteroids, smaller particles may be easier to move and mix than meter-sized blocks. Processes that reconsolidate breccias, particularly grain boundary melting that is commonly invoked for ordinary chondrites [3], may be more effective at the millimeter to centimeter scale. Although exceptionally rare, impact and shock melts of hydrated carbonaceous chondrites are known both in situ [3] and as clastic material in howardites [6]. To invoke such a process at the meter scale would require shock melt veining of a scale not previously observed in meteorites but known from terrestrial impact breccias. Alternatively, such breccias could form prior to the cessation of aqueous alteration and be cemented by subsequent alteration. In either case, whether by impact melting or aqueous alteration, those processes likely occurred prior to the formation of Bennu as a rubble pile, suggesting that the meter-scale breccia on Bennu predates the formation of the current asteroid and may provide clues to a previous generation of Bennu's parent body(ies) in the asteroid belt.



Meter-scale breccia on Bennu. PolyCam low-altitude flyby image of boulder at 247°E, 6° S

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