

**INITIAL CHARACTERIZATION OF INTERMEDIATE BENNU PARTICLES TO EVALUATE LITHOLOGIC DIVERSITY AND MINERALOGIC AND REDOX EQUILIBRIA.** K. Righter<sup>1</sup>, K. Thomas-Kep<sup>2</sup>, L. Le<sup>2</sup>, L.P. Keller<sup>1</sup>, A.N. Nguyen<sup>1</sup>, R.S. Harrington<sup>2</sup>, J. Gorce<sup>2</sup>, S. Clemett<sup>2</sup>, A.S. Burton<sup>1</sup>, E.L. Berger<sup>1</sup>, T.J. McCoy<sup>3</sup>, T.J. Zega<sup>4</sup>, S.S. Russell<sup>5</sup>, H.C. Connolly Jr<sup>4,6,7</sup>, and D.S. Lauretta<sup>4</sup>, <sup>1</sup>ARES, NASA Johnson Space Center, 2101 NASA Pkwy, Houston, TX 77058 (kevin.righter-1@nasa.gov), <sup>2</sup>Jacobs Technology, NASA Johnson Space Center, Houston, TX, USA, <sup>3</sup>Dept. of Mineral Sciences, National Museum of Natural History, Smithsonian Institution, Washington, DC, USA <sup>4</sup>Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ, USA, <sup>5</sup>Planetary Materials Group, Department of Earth Sciences, Natural History Museum, London, UK, <sup>6</sup>Department of Geology, Rowan University, Glassboro, NJ, USA, <sup>7</sup>Department of Earth and Planetary Science, American Museum of Natural History, New York, NY, USA

**Introduction:** The OSIRIS-REx spacecraft returned regolith from asteroid Bennu to Earth September 24, 2023 [1]. The Sample Analysis Plan defines multiple hypotheses to be tested, such as the nature of pre-biotic and pre-solar material, formation location of Bennu, geologic history of the asteroid, and its impact/collisional/re-accretion history [2,3]. Science team members at NASA JSC received a portion of aggregate material to characterize, and herein we report the mineralogic composition, surface features, redox equilibria, and overall lithologic diversity in these Bennu particles, all of which will inform additional analyses.

**Methods:** Twelve particles up to ~2 mm were picked from OREX-803017-0 and attached to 2 SEM stubs (OREX-803079-0, OREX-803080-0) using a small piece of carbon sticky tape (Fig. 1A). The six 1-2 mm sized particles in OREX-803079-0 were examined by SEM (Fig. 1A) to determine sample morphology, search for space weathering features, and assess potential contaminants (Table 1). Five angular morphology particles were mounted in Epo-Thin epoxy in a polished mount. One hummocky morphology particle (OREX-803079-241) was removed for additional study before mounting; it contains chondrule-like clasts [4]. All twelve particles will be further characterized using SEM, EMPA, FIB, nano-SIMS, TEM,  $\mu$ -L<sup>2</sup>MS laser microprobe, and soluble organic analyses planned at JSC.

**Results:** All six particles exhibit similar mineralogy dominated by phyllosilicates, magnetite, and sulfides, with minor amounts of carbonate, phosphate, oxide, phosphide, olivine, pyroxene, and organics-rich areas (Table 1). Some features in particles A, B, and D will be described in more detail, as they provide constraints on oxygen fugacity in Bennu materials. Particle A contains magnetite of several textural types including spherulitic, plaque, and a range of framboid sizes (Fig. 1B). The presence of magnetite together with fine grained olivine and pyroxene allows consideration of the equilibrium  $3\text{FeSiO}_3 + \text{Fe}_3\text{O}_4 = 3\text{Fe}_2\text{SiO}_4 + 0.5 \text{O}_2$ . With nearly

pure magnetite and magnesium olivine and pyroxene Mg/Fe as measured in the Quick Look sample [5] the equilibrium defines  $f\text{O}_2$  of IW+0.7 to 1.1 with the small range of values attributed to uncertainty in silicate compositions and  $T = 300\text{--}400 \text{ K}$ . Particle A also contains schreibersite  $(\text{Fe,Ni})_3\text{P}$  (Fig. 1C), magnesium phosphate (Na-bearing; Fig. 1D), and calcium phosphate. Some of these phases can be used to constrain  $f\text{O}_2$  according to, for example, the following equilibrium:  $2\text{Fe}_3\text{P} + 3\text{CaMgSiO}_4 + 13/2\text{O}_2 = \text{Ca}_3(\text{PO}_4)_2 + 3\text{MgSiO}_3 + 2\text{Fe}_3\text{O}_4$ . This equilibrium points to  $f\text{O}_2$  of IW+1 at 300–400 K. Particle B contains both magnetite and ilmenite, which in equilibrium define  $f\text{O}_2$  based on exchange of Ti between these phases. Particle D contains a fine-grained magnesite cluster that is associated with magnetite framboids (Fig. 1E), also providing  $f\text{O}_2$  information. EMPA analyses of these phases will constrain  $f\text{O}_2$  as has also been utilized in other carbonaceous chondrites.

**Discussion:** Oxygen fugacity in solar system materials spans from 8 log $f\text{O}_2$  units below to 8 log $f\text{O}_2$  units above the IW buffer [6] and exerts fundamental control of phase stability, the speciation of Fe, and the stability of specific kinds of organic compounds [7]. Values in Bennu samples near IW+1 are consistent with the presence of mixed  $\text{Fe}^{2+}$  and  $\text{Fe}^{3+}$  [8], the presence of phosphide, and the lack of FeNi metal. These values suggest that aqueous alteration has been accompanied by oxidation just above the stability of FeNi metal.

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**References:** [1] Witze, A. (2023) *Nature* 622, 439–440. [2] Lauretta, D.S. et al. (2023) <https://doi.org/10.48550/arXiv.2308.11794>. [3] Lauretta, D.S., et al. (2015) *MaPS* 50, 834–849. [4] Le, L. et al. (2024) this meeting. [5] Thomas-Kep<sup>2</sup>, K. et al. (2024) this meeting. [6] Righter, K. et al. (2016) *Amer. Mineral.* 101, 1928–1942. [7] Naraoka, H. and Hashiguchi, M. (2019) *Geochem. J.* 53, 33–40. [8] Gainsforth, Z., et al. (2024) this meeting.

Figure 1A: Six particles examined in detail

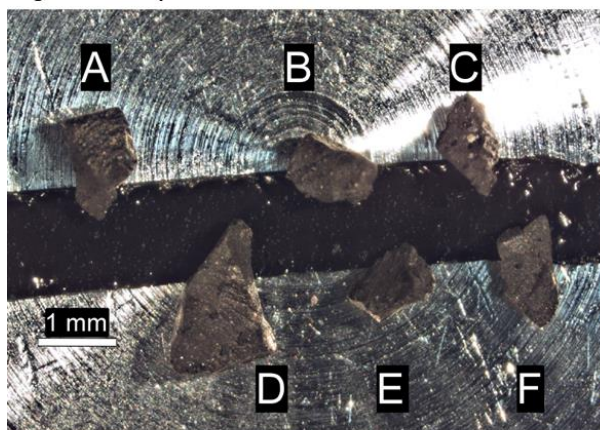


Figure 1B: Four different scales of magnetite framboids in Particle A

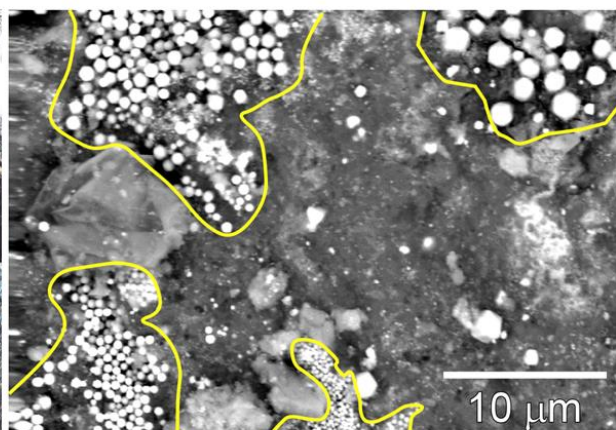


Figure 1C: Schreibersite found in Particle A

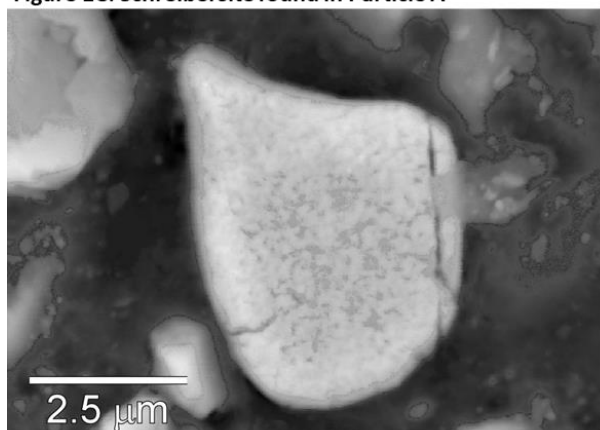


Figure 1D: Mg-Na-phosphate found in Particle A

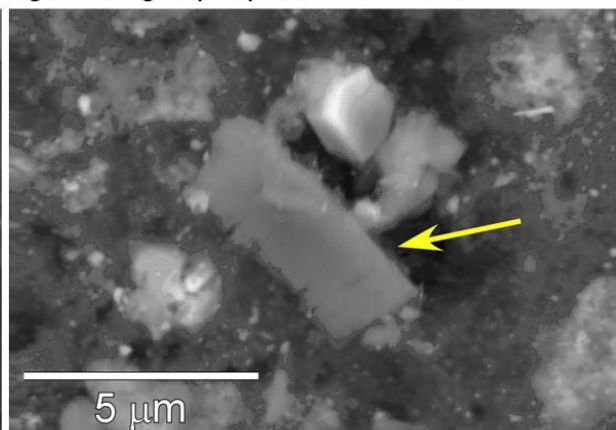


Figure 1E: Fine-grained magnesite cluster with magnetite framboids (bright regions), particle D

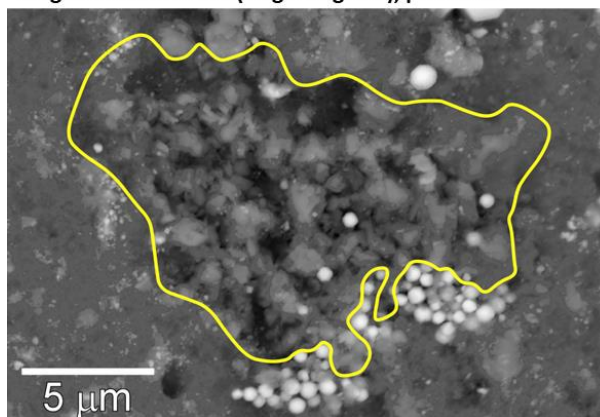


Table 1

| Particle | Particle size (mm) | lithology | notes                             |
|----------|--------------------|-----------|-----------------------------------|
| A        | 1.4 x 0.89         | angular   | mgnt, phosphide, phosphate        |
| B        | 1.1 x 0.93         | angular   | mgnt, ilm                         |
| C        | 1.45 x 0.92        | hummocky  | clasts                            |
| D        | 2.0 x 1.4          | angular   | magnesite, mgnt, phyllo, sulfides |
| E        | 1.1 x 0.96         | angular   | phyllo, mgnt, sulf                |
| F        | 1.2 x 0.77         | angular   | phyllo, mgnt, sulf                |