

**NANOSCALE MINERALOGY OF BENNU SAMPLES RETURNED BY OSIRIS-REx.** L. P. Keller<sup>1</sup>, T. J. Zega<sup>2</sup>, T. J. McCoy<sup>3</sup>, P. Haenecour<sup>2</sup>, M. S. Thompson<sup>4</sup>, A.J. King<sup>5</sup>, K. Thomas-Keprta<sup>6</sup>, L. Le<sup>7</sup>, V. Tu<sup>7</sup>, L. B. Seifert<sup>1</sup>, H. C. Connolly Jr.<sup>2,8,9</sup>, and D. S. Laurretta<sup>2</sup>. <sup>1</sup>NASA JSC, Houston, TX; <sup>2</sup>Lunar & Planetary Lab., Univ. Arizona., Tucson, AZ; <sup>3</sup>National Museum of Natural History, Smithsonian Inst., Washington, D.C.; <sup>4</sup>Dept. Earth, Atmospheric & Planetary Sciences, Purdue Univ., West Lafayette, IN; <sup>5</sup>Planetary Materials Group, Natural History Museum, London, UK; <sup>6</sup>Barrios Technology/Jacobs, NASA JSC, Houston, TX; <sup>7</sup>Jacobs, NASA JSC, Houston, TX; <sup>8</sup>Dept. Geology, Rowan Univ., Glassboro, NJ; <sup>9</sup>Dept. Earth & Planetary Science, American Museum of Natural History, New York, NY. (Lindsay.P.Keller@nasa.gov).

**Introduction:** The OSIRIS-REx spacecraft returned regolith samples from asteroid Bennu and an initial sample was allocated for quick-look (QL) analyses [1,2]. These QL particles were recovered from the avionics deck of the sample canister and were used to test the hypothesis that this dust is broadly representative of the bulk sample. The QL sample analyses showed that the materials are dominated by hydrated silicates, sulfides, magnetite, phosphates, and abundant organic matter, in addition to other minor/trace phases [1,2]. Here we report our preliminary transmission electron microscope (TEM) observations for the nanoscale mineralogy of Bennu samples.

**Samples and Methods:** We analyzed electron-transparent cross sections of an aggregate of particles from the QL sample prepared by focused ion beam (FIB) milling. The FIB sections (OREX-501005-100 and -101) were extracted using the FEI Quanta3D FIB at JSC and analyzed using the JEOL 2500SE scanning and transmission electron microscope (STEM) equipped with a JEOL 60 mm<sup>2</sup> thin window silicon drift detector (SDD) for energy-dispersive X-ray (EDX) analyses.

**Results and Discussion:** The mineralogy of the FIB sections is dominated by coarse- and fine-grained phyllosilicates with finely dispersed FeNi-sulfides, carbonates, magnetite, and organic matter.

The coarse phyllosilicates occur in “pods” up to several micrometers in size that lack sulfide or magnetite inclusions (Fig. 1). The coarse phyllosilicates are well-crystalline and consist of interstratified saponite and serpentine exhibiting ~1 nm and 0.7 nm basal spacings, respectively (Fig. 2). The interstratification extends from single serpentine layers up to packets 10-15 basal layers wide. Rare chrysotile forms of serpentine are also observed. EDX analyses show that the coarse phyllosilicates are Mg-rich with Mg/Mg+Fe (at.) ~88. Compared to the coarse phyllosilicates, the fine phyllosilicates show much smaller crystal sizes, poorer crystallinity, are more Fe-rich (Mg/Mg+Fe (at.) ~74) and are intergrown with numerous FeNi-sulfide grains. The fine-grained phyllosilicate/sulfide regions also show higher carbon abundances than the coarse-grained phyllosilicate pods.

Magnetite is common in the sections as clusters of framboidal, plaquette, and rarer spherulitic [3] forms.

Sulfides are abundant and are dominated by fine-grained pyrrhotite and pentlandite. Pyrrhotite (Po) and pentlandite (Pn) are commonly intergrown (Fig. 3) and are crystallographically oriented with [111] Pn parallel to [001] Po, consistent with exsolution during slow cooling from higher temperatures [e.g., 4]. Trace chromite is associated with some of the coarse-grained Po-Pn intergrowths. Rare Fe-bearing Zn-rich sulfides are observed. We obtained electron diffraction data from two such Zn-rich grains – one grain (Zn:Fe, 60:40) is consistent with the wurtzite structure and the other with sphalerite. Cu-bearing sulfides are also a rare component with a stoichiometry consistent with chalcopyrite (CuFeS<sub>2</sub>).

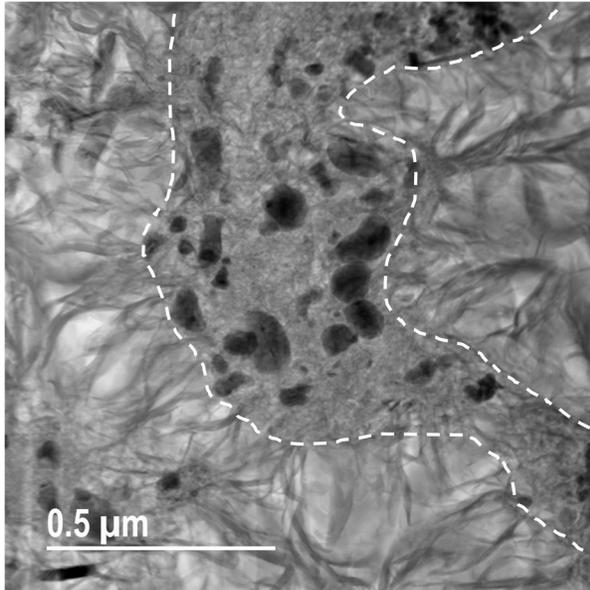
SEM studies suggest the presence of a variety of carbonates in Bennu samples including calcite, dolomite, magnesite, and breunnerite [2]. In the FIB sections analyzed thus far we have observed clusters of rhombohedral Mn- and Fe-bearing magnesite. The magnesite is a solid solution among magnesite, siderite, rhodochrosite and calcite with an average composition of (Mg<sub>0.74</sub>Fe<sub>0.14</sub>Mn<sub>0.08</sub>Ca<sub>0.02</sub>)CO<sub>3</sub>. The magnesite is often closely associated with framboidal magnetite. Calcite is also observed in the FIB sections and is pure CaCO<sub>3</sub>.

Organic matter is abundant in the FIB sections in the form of sub- $\mu$ m carbonaceous nanoglobules and finely disseminated carbonaceous material intergrown with the fine phyllosilicates (Fig. 4). Both solid and hollow nanoglobules are observed – EDX analyses show they contain significant O, N, and S, in addition to C with an approximate composition of C<sub>82</sub>O<sub>12</sub>N<sub>5</sub>S<sub>1</sub> (at%).

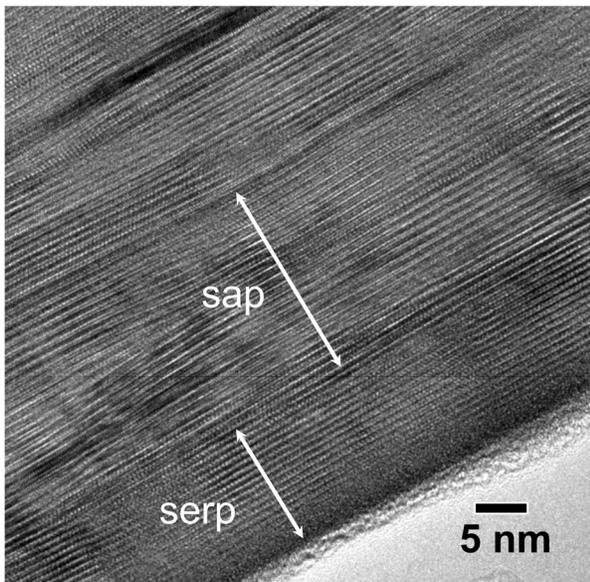
**Conclusions:** The nanoscale mineralogy and petrography of Bennu samples are consistent with organic-rich, highly aqueously altered type 1 carbonaceous chondrite materials extending down to the nanometer-scale.

**Acknowledgments:** This research was supported by NASA under Contract NNM10AA11C issued through the New Frontiers Program. Electron microscopy was performed in the Electron Beam Analysis Labs at NASA/JSC.

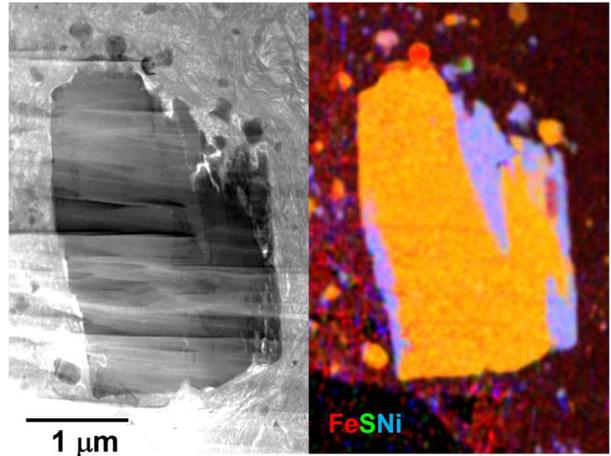
**References:** [1] Zega T. *et al.* (2024) this vol. [2] Thomas-Keprta K. *et al.* (2024) this vol. [3] Dobrica E. *et al.* (2023) *GCA* 346, 65. [4] Francis C. A. *et al.* (1976) *Am. Min.* 61, 913.



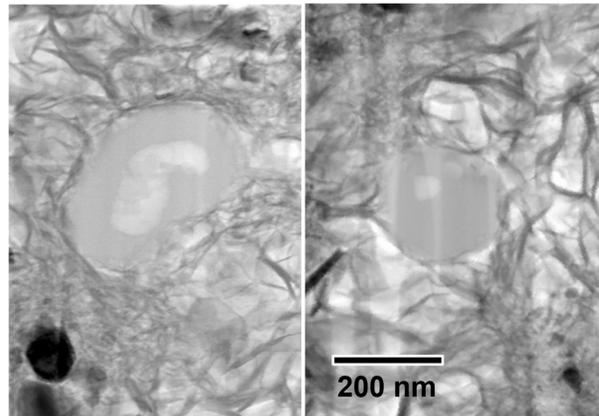
**Figure 1.** Brightfield STEM image showing the texture of the coarse phyllosilicates and the fine-grained phyllosilicates intergrown with FeNi sulfides (between the dashed white lines).



**Figure 2.** A high-resolution TEM image showing a typical interstratification of serpentine (serp) and saponite (sap) in the coarse phyllosilicates.



**Figure 3.** Brightfield STEM (left) and corresponding RGB (Fe-S-Ni) composite image (right) of a sulfide grain showing exsolved pentlandite in pyrrhotite. Horizontal lines in the STEM image are FIB milling artifacts.



**Figure 4.** Brightfield STEM images of carbon nanoglobules in Bennu samples.