DIFFUSE AND MINERAL CARBONATES FOUND IN SAMPLES OF ASTEROID BENNU RETURNED BY THE OSIRIS-REx SPACECRAFT. S. A. Sandford1,7, Z. Gainsforth2, M. A. Marcus3, G. Domínguez2, L. P. Keller2, G. Cody4, J. P. Dworkin5, D. P. Glavin6, H. C. Connolly Jr.,8,9,10 and D. S. Lauretta9. 1NASA Ames Research Center, Moffett Field, CA, USA, 2Space Sciences Laboratory, University of California, Berkeley, CA, USA, 3Lawrence Berkeley National Laboratory, Berkeley, CA, USA, 4California State University San Marcos, San Marcos, CA, USA, 5NASA Johnson Space Center, Houston, TX, USA, 6Carnegie Institution for Science (CIS), Washington, DC, USA, 7NASA Goddard Space Flight Center (GSFC), Greenbelt, MD, USA, 8Rowan University, Glassboro, NJ, USA, 9Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ, USA, 10American Museum of Natural History, New York, NY, USA, *Email: scott.a.sandford@nasa.gov

Introduction: Spectral analysis of the surface of asteroid (101955) Bennu visited and sampled by the OSIRIS-REx spacecraft [1] indicates the presence of organic compounds and carbonates [2]. Here we investigate several Bennu particles returned by the OSIRIS-REx spacecraft using the analytical technique of X-ray absorption near edge spectroscopy (XANES) to search for and characterize organics and carbonates [3]. We compare our findings to carbonaceous chondrites and samples from asteroid (162173) Ryugu.

Samples: One focused ion beam (FIB) section (OREX-501005-101) of a Bennu particle found outside the OSIRIS-REx sample collector, and two FIB sections (OREX-803031-100, OREX-803031-101) of Bennu particles from aggregate sample OREX-803019-0, were approximately 10 × 10 μm in size and varied in thickness from <100 nm to 600 nm to optimize for different experiments. All FIB sections were mounted on Cu FIB half-grids.

Analytical Methods: Synchrotron-based XANES spectroscopy was performed with the scanning-transmission X-ray microscopy instrument at beamline 5.3.2.2 at the Advanced Light Source (ALS), Berkeley, CA. Hyperspectral data stacks were acquired over energy ranges that covered the C-K, N-K, O-K, and Fe-L absorption edges from portions of the FIB sections. The hyperspectral maps were taken at a spatial resolution of ~40 nm/pixel and up to 0.1 eV energy resolution.

Results: Individual maps taken at 295 eV in the C edge demonstrate that C is present in multiple locations and forms within the samples (Fig. 1), including organic nanoglobules and discrete C-containing minerals like carbonates. Diffuse carbon is also seen within the phyllosilicates that dominate the samples.

Spectra of the samples show absorption peaks that demonstrate that organic carbon is present in a variety of chemical functional forms, including aromatic C=C bonding (285.0 eV), aromatic ketone functional groups (286.5 eV), and carboxyl –COOH groups (288.5 eV), consistent with studies of insoluble organic material (IOM) and in situ chondritic carbonaceous matter [4,5].

Spectra at many locations show a dominant peak near 290.4 eV that is characteristic of CO3 groups. In some locations, the energy of the band is consistent with normal carbonate minerals (Fig. 2), an identification that is supported by additional C-extended X-ray absorption fine structure and the presence of a Ca-L edge at 349.7 eV. However, diffuse organic matter is often intimately mixed with matrix phyllosilicates. C-XANES spectra of this more diffuse carbon lack carbonate extended fine structure, and a small energy shift indicates that the carrier is a molecular carbonate species distinct from normal carbonate minerals (Fig. 2). This carbon is part of a carbonate whose detailed chemical form has yet to be fully determined. This spectral feature of diffuse carbon has been noted before in some Type 1-2 chondrite matrices [5] where it has been suggested to originate from organic matter bound to phyllosilicate interlayer sites [6]. This peak is absent from all IOM spectra, indicating this clay-mixed carbon is lost or modified during the acid extraction process. These carbonates have also been seen within phyllosilicates found in Ryugu samples [7,8].

Discussion: The detection of organics and carbonates in the Bennu samples analyzed for this study is consistent with and confirming their detection by the OSIRIS-REx spacecraft at Bennu. A variety of organic chemical functional groups and at least two different forms of carbonate functional groups (discrete carbonate minerals and diffuse carbonate are associated with the phyllosilicate matrix that dominates the samples) have been detected.

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Fig. 1 Left: TEM image of OREX-501005-101 with nanoglobules circled. Right: C-XANES map showing aromatic (red), carbonate (green), and aliphatic (blue) carbon. Color intensities are scaled to show optimal contrast.

Fig. 2: Carbonate feature within carbonate crystal (yellow) and within phyllosilicate (orange) and phyllosilicate neighboring sulfides (purple). The two species are separated by a 0.2 eV shift.