MINERALOGY OF BENNU FROM SPECTRAL ANALYSIS OF THE SAMPLE RETURNED BY OSIRIS-REx.

V. E. Hamilton[1], L. P. Keller[2], P. Haenecour[4], J. J. Barnes[4], D. Hill[4], H. C. Connolly, Jr.[3,4,5], and D. S. Lauretta[4]; [1]Southwest Research Institute, Boulder, CO, USA (hamilton@boulder.swri.edu); [2]NASA Johnson Space Center, Houston, TX, USA; [3]Rowan University, Glassboro, NJ, USA; [4]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ, USA. [5]American Museum of Natural History, New York, NY, USA.

Introduction: Here we report on preliminary tests of hypotheses related to the mineralogy of Bennu that were generated from spectral data collected during the asteroid operations phase of the Origins, Spectral Interpretation, Resource Identification, and Security–Regolith Explorer (OSIRIS-REx) mission. We focus on whether laboratory spectra confirm the hypotheses that (a) Bennu inorganic materials are dominated by Mg-rich phyllosilicates (with less than 10 vol% anhydrous silicates), contain magnetite, and exhibit signatures of up to three distinct carbonate phases [e.g., 1-4], and (b) the dominant lithologies are comparable in bulk mineralogy to the most aqueously altered carbonaceous chondrites (CCs; petrologic types ≤2.4 in the [5] classification, or types 1 and 2 in the [6] classification) [e.g., 1, 4, 7, 8]. Signatures of organics also were detected [e.g., 9] but are not discussed here.

Analysis of material returned from asteroid Bennu contributes to the broader goals of the OSIRIS-REx mission by allowing us to compare sample data at microscopic scales to meteorites, meter-scale asteroid observations, and disk-integrated ground-based observations. These results allow us to better recognize, and resolve, key gaps in our understanding of primitive solar system bodies.

Samples: Bennu sample OREX-800029-0 is a bulk aggregate; no sieving, grinding, embedding, or polishing was performed. Particle sizes range from a few microns to >1 mm. Sample OREX-500003-100 is one particle mounted in epoxy and polished. Note that we do not yet know how representative these samples are of the entirety of the returned Bennu sample mass.

Analytical methods: Reflectance spectra of particles in the aggregate sample and on the polished mount were collected on a Thermo Scientific Nicolet iN10 Fourier Transform Infrared microscope (μ-FTIR) covering the range 2.5 – 25 μm. Spot sizes measured on particles are up to 300 μm/pixel and a 19 x 10-pixel map of the polished sample was acquired at 100 μm/pixel. Details of data acquisition are described by [10].

Results: Fundamental features of OH^-/H_2O, phyllosilicates, Mg-OH (plus magnetite [4]), and carbonate are evident in the average spectrum of the polished particle. In comparison to spectra of more than 70 CI, CM, and ungrouped C meteorites, the best analogues are Orgueil (CI1), Alais (CI1), MacAlpine Hills (MAC) 02820 (CM1/2), Tarda (C2-ung), and Tagish Lake (C2-ung). There is no evidence of anhydrous phases in the average map spectrum, nor are they observed in individual map spectra.

Spectra of particles in the aggregate tend to fall into two categories with respect to inorganic components: (a) uniformly darker particles with strong phyllosilicate and hydration features and weak to absent carbonate features and (b) mottled particles with prominent phyllosilicate, hydration, and carbonate features. Virtually all particle spectra exhibit a broad Mg-OH feature from ~14.3 to 18.5 μm. A few of the mottled particles also exhibit evidence of magnetite at ~17.8 μm. No spectral features of anhydrous phases have been observed to date. A third, rare (<<1 vol.%) category of particle is small (up to 300 μm) and relatively bright with fundamental features near ~7.7 – 15.4 μm that are consistent with phosphate. Hydrated Na-Mg phosphate has been identified through combined FTIR and scanning electron microscopy [11, 12] in other aggregate samples, e.g., OREX-501006-0.

Discussion: Analysis of telescopic data prior to the arrival of OSIRIS-REx at Bennu (0.4 – 2.4 μm) suggested that Bennu would be most like CI or CM (or "CM1-like", e.g., Moapa Valley) materials having a "blue" continuum slope like magnetite-containing meteorites [13]. The best fit meteorite analogues in that study were a highly heated (700° C) sample of Ivuna (CI1) and a matrix-rich fraction of Mighei (CM2). OSIRIS-REx spectra of Bennu from 0.4 – 100 μm [e.g., 1, 2] confirmed that Bennu has a short wavelength blue slope, shows a phyllosilicate-dominated global average spectrum, and exhibits fundamental features of magnetite. In addition, carbonates were identified [e.g., 3], and limits on anhydrous mineral abundances were proposed, constraining analogues to type 1 and the most highly aqueously altered type 2 meteorites with no large-scale evidence of heating [4, 8]. With the wider wavelength coverage of the spacecraft data, the specific analogy of a CI-like material heated to 700° C was disproven [8].

With the returned sample spectra, we can confirm specifics of the hypotheses generated from the mission asteroid observations. The phyllosilicate fundamental band positions and the presence of an Mg-OH feature are consistent with Mg-rich compositions. Carbonate and magnetite are present, and anhydrous silicates are <<10 vol% of the material measured.

The average polished particle spectrum is consistent with the bulk spectra and mineralogy of the most aqueously altered CCs [4] and XRD mineralogy [14] of Bennu materials. Other than MAC 02820, no available CM provides a good spectral match. The fact that Bennu (and Ryugu [15]) materials are akin to the rarest materials in meteorite collections suggests we have much to learn about how representative meteorites are of the population of small bodies in the Solar System.

Unexpected spectral results from the Bennu sample to date include the position of the hydroxyl feature [16] and the presence of phosphate. The hydration feature is shortward (~2.71 μm) of the 2.74 ± 0.01 μm band position identified from remote sensing data [1, 7], suggesting an even more aqueously altered composition than predicted. Phosphates were not predicted from spectral data collected at the asteroid and their detection will inform reanalysis of those data, but low volumetric abundance is a likely explanation.

Acknowledgments: This work is supported by NASA under Contract NNM10AA11C issued through the New Frontiers Program. We are grateful to the entire OSIRIS-REx Team for making the return of samples from Bennu possible.

References: [1] Hamilton, V. E. et al. (2019) *Nat. Astron.,* 3*,* 332-340. [2] DellaGiustina, D. N. and Emery, J. P. et al. (2019) *Nat. Astron.,* 3, 341-351. [3] Kaplan, H. H. et al. (2020) *Science*, 370, eabc3557. [4] Hamilton, V. E. et al. (2021) *Astron. Astrophys. 650,* A120. [5] Rubin, A. E. et al. (2007) *GCA*, 71, 2361-2382. [6] Van Schmus, W. R. and Wood, J. A. (1967) *GCA*, 31, 747-765. [7] Praet, A. et al. (2021) *Icarus*, 363, 114427. [8] Hamilton, V. E. et al. (2022) *Icarus*, 383, 115054. [9] Simon, A. A. et al. (2020) *Science*, abc3522. [10] Hamilton, V. E. (2018) LPSC 49, Abstract #1759. [11] Barnes, J. J. et al., this meeting. [12] Thomas-Keprta, K. et al., this meeting. [13] Clark, B. E. et al. (2011) *Icarus, 216*, 462-475. [14] King, A. J. et al., this meeting. [15] Yokoyama, T. et al. (2022) *Science*, abn7850. [16] Milliken, R. E. et al., this meeting.