PRESOLAR GRAINS IN ANGULAR AND HUMMOCKY SAMPLES FROM ASTEROID BENNU. A. N. Nguyen[1,*], K. Shimizu[2], L. B. Seifert[1], K. Thomas-Keprta[3], L. Le[2], L. P. Keller[1], S. J. Clemett[4], J. J. Barnes[5], H. C. Connolly Jr.[5,6,7], and D. S. Lauretta[5]. [1]ARES, NASA JSC, Mail Code XI3, Houston, TX, USA; [2]Amentum JETS, NASA JSC, Houston, TX, USA; [3]Barrios JETS, NASA JSC, Houston, TX, USA; [4]Asterion JETS, NASA JSC, Houston, TX, USA; [5]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ, USA; [6]Department of Geology, Rowan University, Glassboro, NJ, USA; [7]Department of Earth and Planetary Sciences, American Museum of Natural History, New York, NY, USA. *Email: lan-anh.n.nguyen@nasa.gov

Introduction: Initial examination of pristine regolith from B-type asteroid (101955) Bennu, returned by the OSIRIS-REx spacecraft, identified morphologically distinct fragments that are dominated by hydrated phases, including phyllosilicates, magnetite, and carbonate [1], in agreement with spacecraft observations [2, 3]. Angular fragments of the Bennu sample are similar to the smooth boulders observed on the asteroid, and hummocky fragments are similar to the more rounded, clastic boulders [1, 4].

A goal of the mission was to determine the types of presolar constituents that were accreted by the parent asteroid and that survived its geologic history. Presolar grains deriving from a variety of stellar sources have been identified in "quick-look" material collected from the avionics deck of the sample return capsule at abundances that are consistent with aqueously altered carbonaceous chondrites [1, 5, 6]. Most of these grains were found in fine aggregate material, precluding identification of their particle of origin.

We extend our analysis of presolar grains to angular and hummocky Bennu particles from within the Touch-and-Go Sample Acquisition Mechanism (TAGSAM) [7]. The abundances and chemical and mineralogical characteristics of presolar grains are sensitive tracers of parent body alteration [e.g., 8]. Their study can therefore place constraints on the origins, histories, and relationship of these different particle morphologies.

Samples: Intermediate angular and hummocky particles (>500 μm) were examined by scanning electron microscopy (SEM) prior to being prepared into polished mounts OREX-803079-0 and OREX-803080-0. The particles were embedded in epoxy and dry-polished using diamond powders. Sample OREX-803079-0 was polished further using the Hitachi ArBlade 5000 broad ion beam milling system. This study focuses on angular particles OREX-803165-0 and OREX-803170-0, and hummocky particle OREX-803172-0 from these mounts. A dry-polished thick section of a larger hummocky stone (OREX-800088-11; ~7.8 mm long) was also analyzed.

Analytical Methods: Sample images, elemental maps, and point spectra of specific minerals were acquired using the JSC JEOL 7600F SEM equipped with Oxford Instruments Ultim Max EDX detectors.

Isotopic mapping at ~100 nm spatial resolution was conducting using the Cameca nanoscale secondary ion mass spectrometer (NanoSIMS) 50L at JSC. In one analysis session on OREX-803165-0, the C, N, and Si isotopes were measured simultaneously. In subsequent sessions, the C, O, and N isotopes were measured. Grains with isotopic anomalies deviating by at least 5σ from the bulk value of the surrounding matrix were considered presolar. San Carlos olivine, graphite (USG-24), and kerogen (KG17) served as isotopic standards.

Presolar grains identified during the C, O, N session were characterized further by NanoSIMS at higher spatial resolution. C-rich presolar grains were remeasured for C and Si isotopes, and O-rich grains were remeasured for ^{16}O, ^{17}O, and Si isotopes. Phase identifications were based on $^{28}Si/^{12}C$ (for SiC and graphite grains) and $^{28}Si/^{16}O$ (for silicates and oxides) ratios, and ^{28}Si images.

Presolar grains were imaged, and their locations identified using the JEOL 7900F SEM at JSC. Two grains, one O-rich and one C-rich, were targeted for chemical and structural analysis by transmission electron microscopy (TEM). An electron transparent cross-section containing both grains (OREX-803172-100) was produced using focused ion beam (FIB) methods. The presolar grains were analyzed using the JEOL 2500SE scanning TEM (STEM) at JSC.

Results: The chemical makeup and mineral constituents of the angular and hummocky particles can be found in [7]. Briefly, both are mainly comprised of fine-grained phyllosilicate matrix with the alteration phases. Anhydrous silicates are present, as well as oxides in a hummocky particle. Unlike the angular particles, the hummocky particles contain clasts between ~30 and 175 μm that are distinct in the chemical maps and backscatter electron images (Fig. 1).

Total areas of 60,625 and 50,736 μm^2 were measured in the hummocky and angular fragments, respectively. A total of 31 presolar SiC, 1 graphite, and 1 oxide were identified in the angular particles. This gave abundances of 55^{+12}_{-10} ppm for presolar SiC, 1^{+2}_{-1} ppm for presolar graphite, and 2^{+4}_{-1} ppm for O-rich presolar grains. Errors are 1 sigma.

In the hummocky particles, a total of 29 presolar SiC, 2 graphite, and 24 O-rich grains were identified.

Three of the O-rich grains are oxides, and the remainder are silicates. Eighteen of the O-rich presolar grains were identified in three clasts (Fig. 1) that were Si- and Mg-poor, and S- and Fe-rich. These clasts were also rich in C and N. Abundances of presolar SiC and graphite overall are 36^{+8}_{-7} and 2^{+3}_{-1} ppm, respectively. For O-rich presolar grains, the abundance in the matrix is 7^{+4}_{-3} ppm, and the abundance in the three clasts is 87^{+26}_{-20} ppm.

Section OREX-803172-100 was obtained from one of the Si-poor clasts with an elevated abundance of O-rich presolar grains. The section contains a very ^{17}O-rich grain (16_1a; δ^{17}O = 20,360 ‰). The grain measures ~100 × 20 nm. TEM analysis indicates 16_1a is an amorphous silicate with Mg/Si = 2, consistent with an olivine composition. Some Fe-enrichment is observed in the matrix surrounding grain 16_1a, but a continuous rim is not present. The ^{15}N-poor (δ^{15}N = –830 ‰) presolar grain in the section (15c) is a single SiC crystal (~315 × 60 nm) of the 3C polytype. The grain is Al and N-bearing and has an oxidized rim.

Discussion: The C, N, and Si isotopic compositions indicate most of the presolar SiC grains are derived from asymptotic giant branch (AGB) stars and are consistent with the mainstream, Z, and Y types of SiC [9]. Also identified were SiC of type X from supernovae, type N from novae, and type AB grains from J-type carbon stars, born-again AGB stars, or supernovae. The presolar graphite have AGB star or supernova origins.

Most of the O-rich presolar grains have ^{17}O enrichments or modest ^{18}O depletions indicative of AGB or supernova origins [10]. Grain 16_1a is the most ^{17}O-rich and could come from a binary star or nova. Nova grains are extremely rare and represent just 1 % of identified presolar grains. A ^{17}O-poor grain and a ^{18}O-rich grain are likely from supernovae.

The abundances of presolar SiC and graphite grains in the angular and hummocky fragments, and in the clasts in the hummocky fragments, were within error of each other. They are also consistent with the abundances determined in the quick-look sample OREX-501018-100 [1, 6]. The overall abundance of 45 ppm for presolar SiC indicates the Bennu sample was not thermally metamorphosed at high temperatures, which would result in a reduced abundance. However, the TEM analysis of presolar SiC 15c shows it experienced some oxidation, which may have occurred on Bennu's parent asteroid at lower temperatures, or in a nebular setting.

Presolar silicate grains are rapidly altered by hydration, and their abundance serves to gauge parent body aqueous alteration. The abundance of O-rich presolar grains in the angular particles and hummocky matrix are within error of each other and consistent with the hydrated lithology of Ryugu [8, 11]. The elevated abundances of O-rich presolar grains in three clasts in the hummocky sample indicate they are less altered than the surrounding matrix in which they are embedded, and the angular particles. These abundances are similar to the primitive chondrites Northwest Africa (NWA) 852 (CR2) [12], Asuka 12236 (CM2.9) [13], and Miller Range (MIL) 090019 (CO3.1) [14], and to exogenous clasts in Ryugu [8]. The less-altered Bennu clasts also share similar chemical characteristics to the Ryugu clasts, but they do not have similarly high presolar SiC abundances. The Bennu clasts and Ryugu exogenous clasts therefore do not share a common origin.

While remote observations and initial analyses of Bennu samples indicated extensive aqueous alteration occurred on the parent asteroid, the elevated presolar silicate abundances and chemistry of some clasts show that primitive material more akin to type 2–3 chondrites than type 1 is preserved.

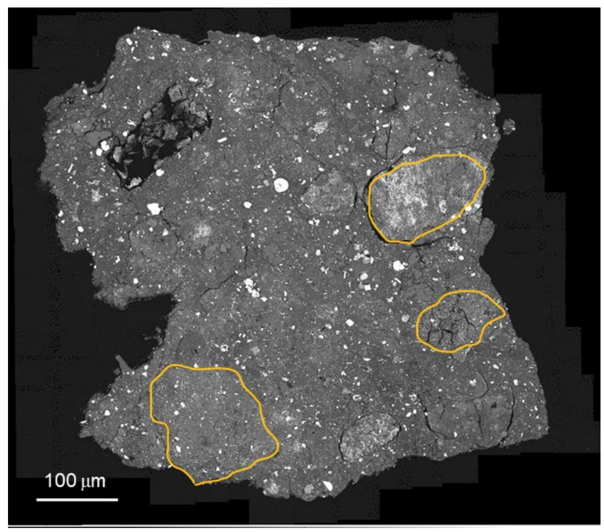

Figure 1: Backscattered electron image of a hummocky particle from Bennu, OREX-803172-0, containing three primitive clasts (outlined).

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