CHARACTERIZING SPACE WEATHERING FEATURES IN GRAINS FROM ASTEROID RYUGU. L. E. Melendez[1], M. S. Thompson[1], L. P. Keller[2], and C. J. Snead[2] [1]Department of Earth, Atmospheric, and Planetary Sciences, Purdue University, West Lafayette, IN, USA (melendl@purdue.edu); [2]ARES, NASA Johnson Space Center, Houston, TX.

Introduction: Airless bodies such as asteroids are characterized by a lack of a protective atmosphere to guard against the effects of micrometeorite bombardment and solar wind irradiation. These processes, cumulatively known as space weathering, alter the microstructural and chemical properties of grains on asteroidal surfaces, signatures of which are recognized as vesiculated textures, amorphous grain rims, and Fe-bearing nanoparticles. The accumulation of these features also causes changes in the optical properties of the surface regolith, complicating the interpretation of remote sensing data and the characterization of returned samples [1,2].

Historically, space weathering studies have focused on anhydrous silicate minerals, reflecting the main components of the available returned samples from the Moon and S-type asteroid Itokawa [3,4]. In contrast, space weathering studies of primitive, organic-rich carbonaceous materials are at an earlier stage. Laboratory experiments to simulate solar wind irradiation and micrometeoroid impacts using carbonaceous analogs have revealed novel and complex microstructural and chemical changes, including the decrease in organic species concentrations and the reduction of Fe^{3+} [5]. In 2020, the Hayabusa2 mission returned over 5 g of regolith particles from near-Earth C-type asteroid Ryugu – a unique opportunity to study space weathering on carbonaceous materials [6]. Early analyses have established that the surface morphology and chemical signatures of space weathering in returned samples bear resemblance to laser irradiation experiments simulating micrometeoroid bombardment. Subsequent studies have indicated that micrometeoroid impacts may have been the primary space weathering mechanism operating on Ryugu [7].

To improve our understanding of space weathering, we are characterizing its effects directly in returned samples and comparing them to the library of analog laboratory experiments [5, 8]. Here we perform a preliminary coordinated mineralogical and chemical analysis using multiple electron beam techniques to examine the effects of space weathering on returned grains from the surface of Ryugu.

Methods: We were allocated Hayabusa2 particle A-0052, collected from the site of the first touchdown, by the Japan Aerospace Exploration Agency (JAXA). Due to the friable nature of the sample, several small fragments were shed from the main mass. We transferred several <500 µm fragments to a SEM mount covered with carbon tape. The fragments were coated with evaporated carbon and initial examination was done using the Quanta 3D FEG focused ion beam scanning electron microscope (FIB-SEM) at NASA Johnson Space Center (JSC) to obtain backscatter (BSE) and secondary electron (SE) images from the fragments. We used the FIB to extract one electron transparent thin section from the surface of one of the fragments for further analysis in the scanning and

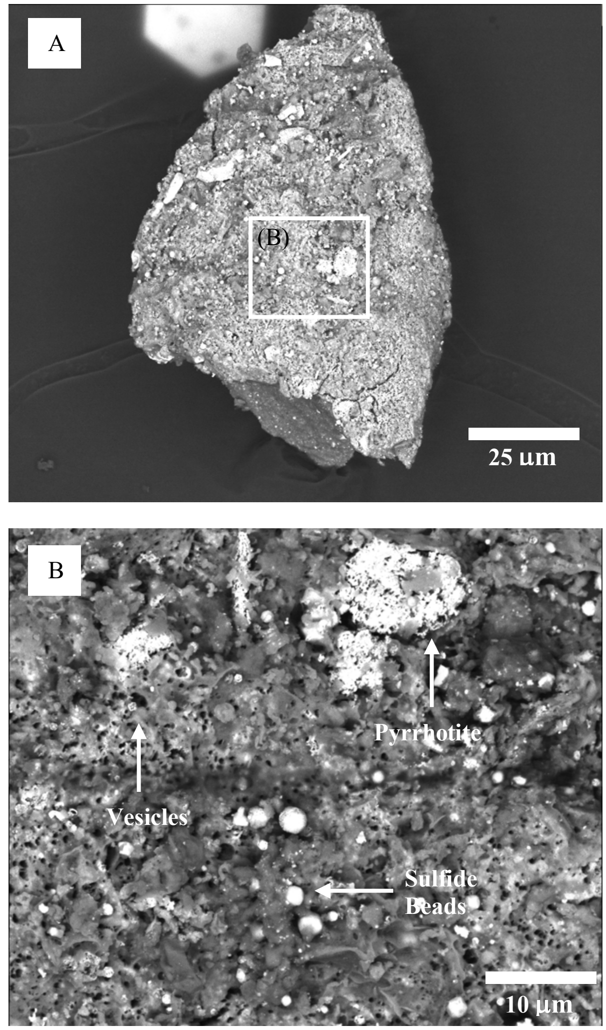

Figure 1. (A) Backscattered electron image of a space-weathered particle (Fragment 2) from grain A-0052. (B) High magnification BSE image of Fragment 2, which has a melt layer with bubbles and several rounded Fe-Ni sulfide beads.

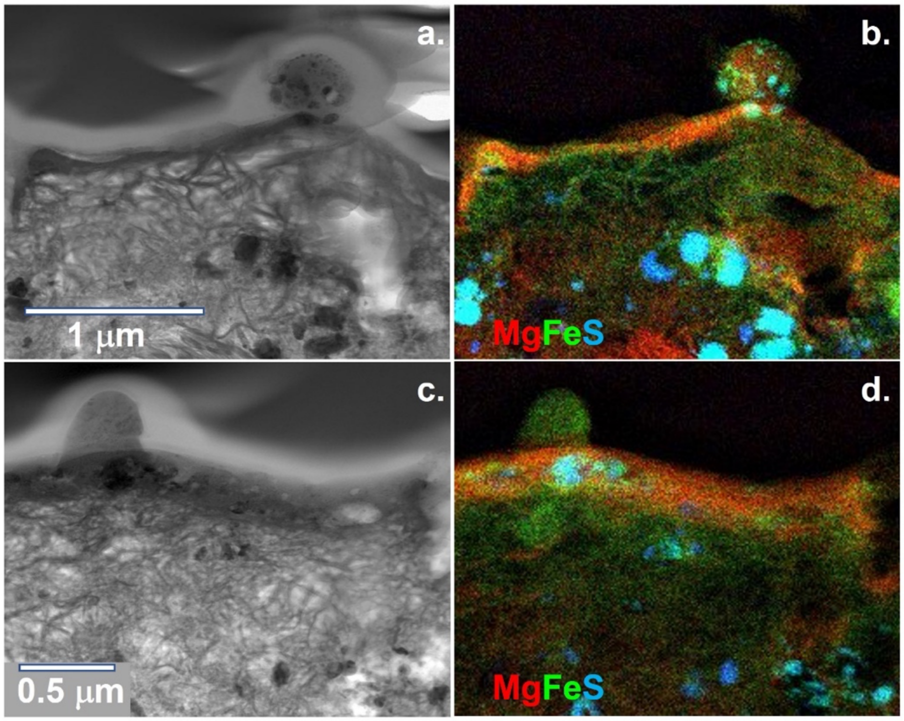

Figure 2. (A) BF STEM image from the FIB section showing a region with a sub-μm impact spherule on the surface and a darker melt layer on the grain surface. (B) a composite RGB image showing Mg (red) Fe (green, and S (blue) and the Mg-rich melt layer and spherule with nanophase Fe and FeS inclusions. (C) a BF STEM image from another region showing a 200 nm thick Mg-rich melt layer on the grain surface and another melt droplet. (D) a composite RGB image showing the distribution of Mg, Fe, S in the altered layer.

transmission electron microscope (STEM). We obtained brightfield and darkfield STEM images and elemental maps of the FIB section using a JEOL 2500SE STEM equipped with a silicon drift detector for energy-dispersive X-ray spectrometer (EDX) analyses and quantitative EDX mapping using a 2 nm incident probe.

Results and Discussion: The SEM images of the ten fragments from A-0052 revealed a rough surface texture with a matrix primarily composed of fine-grained phyllosilicates, numerous FeNi sulfides including large, hexagonal pyrrhotites, framboidal magnetites. STEM imaging and analyses confirmed the presence of Mg-rich phyllosilicates, magnetite, sulfides, and in addition, dolomites grains and carbon nanoglobules, consistent with previous studies of Ryugu samples [e.g., 9].

We identified a region on one fragment showing numerous spherules and highly vesiculated, frothy surface textures (Fig. 1). These features are reminiscent of the deposits observed in laser-irradiation experiments that simulated micrometeoroid impacts [8]. The FIB section sampled this region and our STEM analyses showed space weathering features on the surface including impact spherules and melt layers up to 200 nm thick. Both the spherules and the melt layers contain nanophase Fe metal and Fe-Ni sulfide grains. Some of the melt layers are vesiculated (Fig. 2c). and are compositionally distinct (Mg-rich) relative to the underlying materials.

Conclusion: We used SEM/FIB and STEM analyses to characterize the space weathering features on a Hayabusa2 fragment that formed as the result of impact processes on the Ryugu regolith. Our work builds on and expands on the preliminary results presented by Noguchi et al. [10]. Additional analyses of this fragment will expand our understanding of space weathering on carbonaceous materials in preparation for Bennu's sample return by OSIRIS-REx in 2023.

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