ION IRRADIATION EXPERIMENTS ON THE MURCHISON CM2 CARBONACEOUS CHONDRITE: SIMULATING SPACE WEATHERING OF PRIMITIVE ASTEROIDS.

L. P. Keller[1], R. Christoffersen[2], C. A. Dukes[3], R. A. Baragiola[3], and Z. Rahman[2]. [1]ARES, Code XI3, NASA/JSC, Houston, TX 77058 (Lindsay.P.Keller@nasa.gov). [2]Jacobs, NASA/JSC, Code XI, Houston, TX, 77058. [3]Laboratory for Atomic and Surface Physics, University of Virginia, Charlottesville, VA 22904.

Introduction. Remote sensing observations show that space weathering processes affect all airless bodies in the Solar System to some degree. Sample analyses and lab experiments provide insights into the chemical, spectroscopic and mineralogic effects of space weathering and aid in the interpretation of remote-sensing data. For example, analyses of particles returned from the S-type asteroid Itokawa by the Hayabusa mission revealed that space-weathering on that body was dominated by interactions with the solar wind acting on LL ordinary chondrite-like materials [1, 2]. Understanding and predicting how the surface regoliths of primitive carbonaceous asteroids respond to space weathering processes is important for future sample return missions (Hayabusa 2 and OSIRIS-REx) that are targeting objects of this type. Here, we report the results of our preliminary ion irradiation experiments on a hydrated carbonaceous chondrite with emphasis on microstructural and infrared spectral changes.

Samples and Methods. A polished thin section of the Murchison CM2 carbonaceous chondrite was irradiated with 4 kV He^+ (normal incidence) to a total dose of $1x10^{18}$ He^+/cm^2 over an area of ~5x5 mm^2. The irradiated area included abundant matrix and chondrules. We obtained *ex situ* Fourier-transform infrared (FTIR) reflectance spectra from multiple areas of matrix, ~150 μm^2 in size, using a Hyperion microscope on a Vertex Bruker FTIR bench. A JEOL 7600F field emission scanning electron microscope (SEM) was used to study the morphological effects of the irradiation. Following the SEM analyses, we extracted thin sections from both irradiated and unirradiated regions in matrix using focused ion beam (FIB) techniques. We used electron beam deposition for the protective carbon strap to minimize surface damage artifacts from the FIB milling. The FIB sections were analyzed using the JEOL 2500SE scanning and transmission electon microscope (STEM).

Results and Discussion. Optical examination showed that the irradiated area was visibly darker than the un-irradiated parts of the thin section. FTIR reflectance spectra were collected from irradiated and unirradiated regions of fine-grained matrix. The irradiated matrix showed lower reflectance in the near-IR and a red-sloped continuum compared to the un-irradiated matrix spectra. The depth of the 3 µm feature is decreased in the irradiated regions relative to unirradiated material (Fig. 1) however, no differences were observed in the 10 µm silicate feature. Many irradiation studies of silicates show the preferential loss of oxygen from irradiated surfaces (*e.g.*, [3]), but based on the FTIR results, at least some of the oxygen loss from irradiated Murchison matrix is in the form of OH.

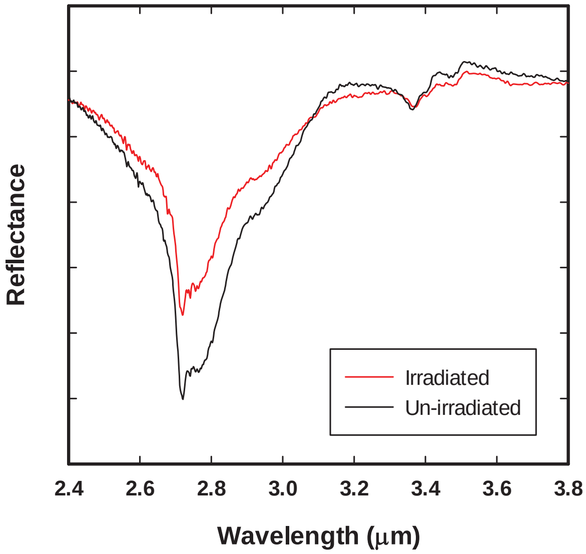

Figure 1. FTIR spectra from irradiated (red) and unirradiated matrix regions of matrix. The spectra have been normalized to the 10 µm silicate feature.

SEM imaging shows that the irradiated matrix regions have a “bubbly” or “frothy” texture, with numerous sub-µm rounded holes and voids relative to the un-irradiated material (Fig. 2). TEM analysis of the FIB sections show that the frothy texture in the irradiated matrix results from the formation of irregulary-shaped 50-100 nm voids at the sample surface. In addition, there are smaller (20-50 nm dia.) vesicles in some of the surface exposed grains.

High-resolution imaging shows that the phyllosilicates (mainly serpentine group minerals) have been rendered amorphous from the irradiation to a depth of ~150-200 nm. Assuming a target density of ~1.3 (the density of serpentine with 50% porosity), and allowing for reasonable changes in target density during the irradiation, there is excellent agreement between the total thickness of the amorphized layer and the He^+ ion damage depth obtained from SRIM calculations [4].

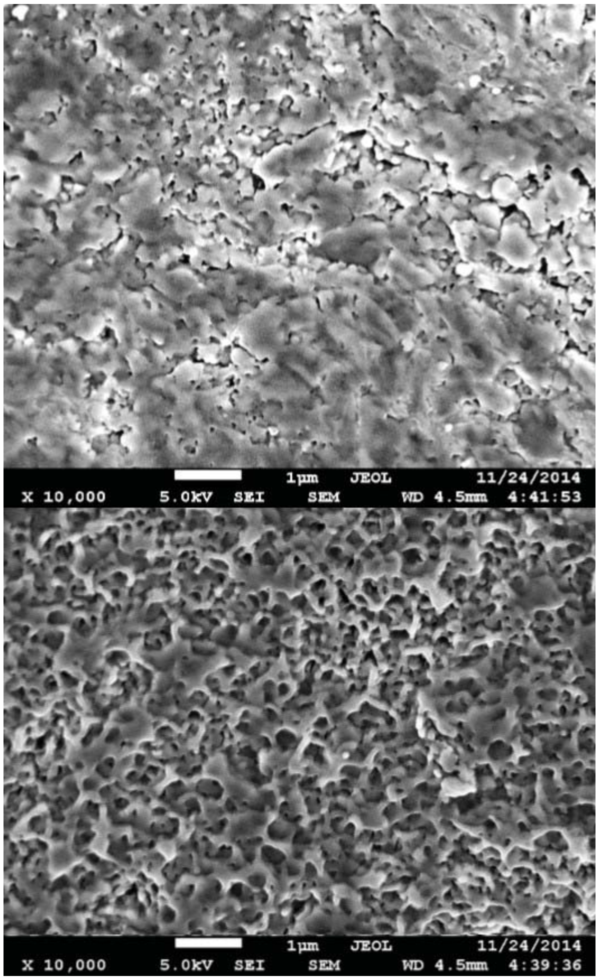

Figure 2. SEM images of typical fine-grained matrix regions in the un-irradiated (top) and irradiated (bottom) areas of the Murchison sample. Note the “frothy” texture in the irradiated region from implantation effects.

Dark-field STEM imaging reveals abundant nanophase (2-5 nm) inclusions in the amorphized phyllosilicates (Fig. 3). The nanophase grains are Fe-rich, and analyses are underway to determine their exact mineralogy and oxidation state. Minor Fe-Ni and S-bearing nanophase inclusions occur throughout Murchison matrix. Larger (µm-sized) FeNi sulfides exposed at the surface show a preferential loss of sulfur by sputtering and the development of a thin 5-10 nm rim of nanophase Fe metal, similar to experimentally irradiated FeS [5]. A sub-µm $CaCO_3$ grain also appears to have been amorphized by the He^+ irradiation.

Conclusions. Irradiation of Murchison matrix with 4 keV He^+ produced several results including: the amorphization of the phyllosilicates to a depth of ~200 nm, blistering and void development, a loss of OH from the hydrated silicates, and the formation of nanophase Fe-rich inclusions within the amorphized phyllosilicates. Follow on analyses will focus on the spectral changes in the VIS-NIR spectral region.

References. [1] Noguchi, T. *et al.* (2014) *MAPS*, 49, 188-214. [2] Keller, L. P. and Berger, E. L. (2014) *EPS*, 66, 71-80. [3] Loeffler, M. J. *et al.* (2009) *JGR*, 114, E03003. [4] Ziegler, J.F. *et al.* (2006) Stopping and Range of Ions in Matter http://srim.org. [5] Keller, L. P. *et al.* (2013) *LPSC XLIV*, #2404.

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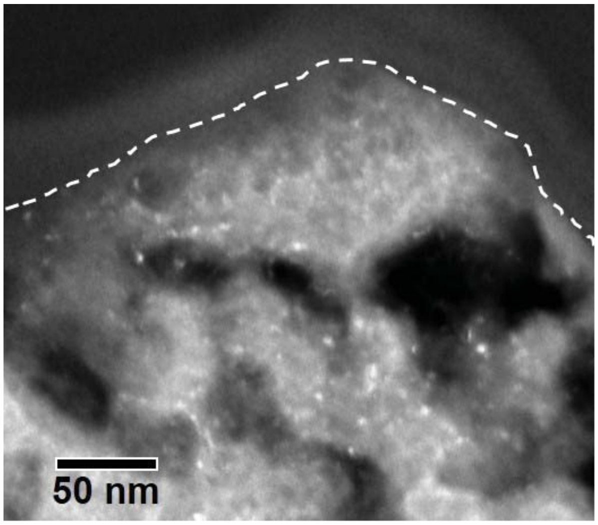

Figure 3. Dark-field STEM image of the amorphized surface of Murchison matrix. The dark regions are irregularly shaped voids. The bright specks indicate individual 2-5 nm Fe-rich particles in the amorphized phyllosilicate. The white dashed line indicates the uppermost surface of the sample.