MICROMETEORITE BOMBARDMENT SIMULATION ON MURCHISON METEORITE: THE ROLE OF SULFIDES IN THE SPACE WEATHERING OF CARBONACEOUS CHONDRITES. L. C. Chaves [1], M. S. Thompson[1], and M. J. Loeffler[2] [1]Department of Earth, Atmospheric, and Planetary Sciences, Purdue University, West Lafayette, IN, USA (lchavesm@purdue.edu) [2]Department of Astronomy and Planetary Science, Northern Arizona University, Flagstaff, AZ, USA.

Introduction: Space weathering modifies the chemical, microstructural and spectral properties of grains on the surfaces of airless bodies and is driven by micrometeorite bombardment and solar wind irradiation [1]. The microstructural and chemical signatures of space weathering include vesiculated textures, amorphous grain rims, and Fe-bearing nanoparticles [2]. Spectrally, these alterations cause the attenuation of characteristic absorption bands, and changes in spectral slope and reflectance [3]. Both experiments simulating space weathering in the laboratory and the analysis of returned samples from the Moon and asteroid Itokawa have focused on understanding the effect of space weathering on silicate minerals, which are the main constituents of these sample collections [4,5,6]. However, our understanding of how space weathering affects Fe- and Fe-Ni sulfides is less constrained. These minerals have been identified in returned samples from S-type asteroid Itokawa [5,7,8] and are common in the carbonaceous chondrites thought to be compositional analogs for asteroids Bennu and Ryugu, respective targets of the OSIRIS-REx and Hayabusa2 missions [9]. Analyses of Itokawa samples have also identified the presence of FeS nanoparticles, indicating these phases play a controlling role in the development of space weathering features on asteroidal surfaces. The limited laboratory simulations of space weathering of sulfides that have been performed have shown induced spectral changes in these minerals, but a detailed understanding of their microstructural and chemical characteristics is lacking. Here, we analyzed sulfides from the CM2 Murchison meteorite that were altered using pulsed-laser irradiation to simulate the physicochemical conditions experienced during micrometeorite impacts. These results will be compared to analyses of five sulfide-bearing particles from asteroid Itokawa.

Methodology: We simulated the high-temperature, short-duration conditions of micrometeorite bombardment by performing pulsed-lased irradiation of an unpolished, dry cut chip of the CM2 Murchison carbonaceous chondrite [10]. The irradiation was performed under high vacuum (~10^{-8} Torr), using an Nd-YAG laser (1064 nm) with a pulse duration of 6-8 ns, and a pulse energy of 48 mJ. To identify the morphological features and chemical changes produced in the sulfide minerals after irradiation we used scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS) with an FEI Nova NanoSEM200 at Purdue University. An FEI Quanta 3D FEG and a Thermo Scientific Helios G4 UX focused ion beam (FIB) instruments were used to extract two electron transparent thin sections from the Murchison sample for further analysis in the transmission electron microscope (TEM). One section was extracted from a grain compositionally identified as troilite and the second from a pentlandite grain. Analysis of microstructural and chemical changes was performed using the Tecnai T20 TEM at Purdue University.

Results: Several chemical, textural, and microstructural changes were observed in the sulfide grains after the simulated micrometeorite bombardment.

Scanning Electron Microscopy: Unirradiated sulfides typically exhibit smooth and flat surfaces. After irradiation, sulfide surfaces exhibit abundant vesicles and a ubiquitous polygonal fracture pattern that could correspond to melt layers on grain surfaces (Fig. 1). Backscatter electron imaging (BSE) shows

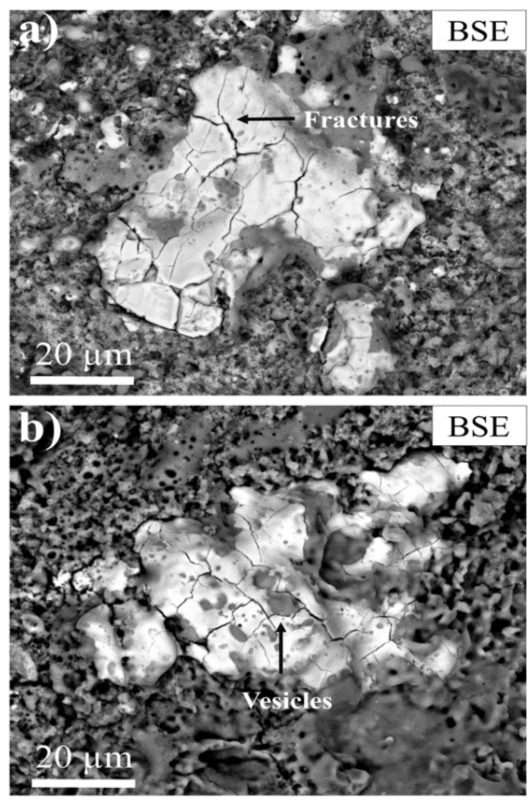

Figure 1: a) and b) BSE images showing two distinct compositions in the melts (light and dark contrast) and the presence of fractures and vesiculation.

regions within the melt with variable chemical composition (Fig. 1). EDS analyses indicate that Fe and S are the most significant elemental components of the bright melt regions, whereas the dark areas are enriched in Si (Fig. 2). Ni is also present in some of these melt deposits. These melts are depleted in Si compared to the matrix.

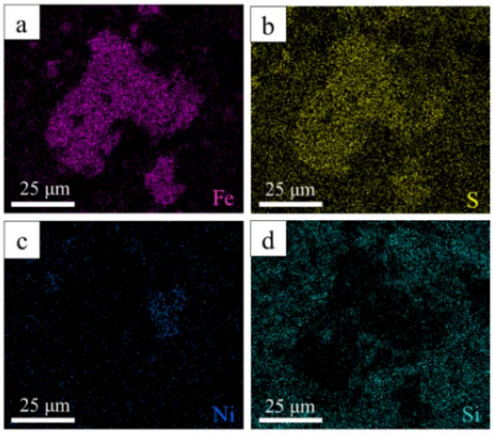

Figure 2: EDS chemical maps of melt showing enrichment of a) Fe, b) S, c) Ni in the melt and depletion of d) Si compared to the matrix.

Transmission Electron Microscopy (TEM): Bright field transmission electron microscope (BF TEM) images show the presence of a melt layer across the uppermost region of the FIB section (Fig. 3). The thickness of this melt varies from 100 nm to 500 nm. Vesicles are present in the melt and are predominantly concentrated at the intersection of the layer and the underlying unaltered sulfide. The vesicles are not consistent in shape and include circular, elongated or irregular forms. Vesicles range from 10 nm to 350 nm in diameter. There is evidence for small nanoparticles in isolated regions of the melt layer ranging in size from ~5 nm to 15 nm in diameter (Fig. 3b).

Discussion: The laser irradiation produced melt textures consistent with space weathering features in returned samples. Compositionally, these melts are Fe-rich with localized Ni enrichments. These melt textures present smooth appearance, fractures and vesicles that are similar to previous laser irradiation experiments of FeS [11]. Nanometer sized vesicles have been also identified in TEM analyses in ion irradiated pyrrhotite [12], however, the vesicles produced in this study do not present euhedral shapes. Similarly, vesiculated rims have been identified in naturally space weathered silicates and sulfides from asteroid Itokawa [13] where vesicles are distributed along the rim or located above the unaltered zone [8]. However, the vesicles in the sulfide grain on Murchison are predominantly located in the melt-grain intersection. In addition to vesiculated textures, previous laser irradiation experiments of Murchison have shown that pentlandite, troilite, and magnetite

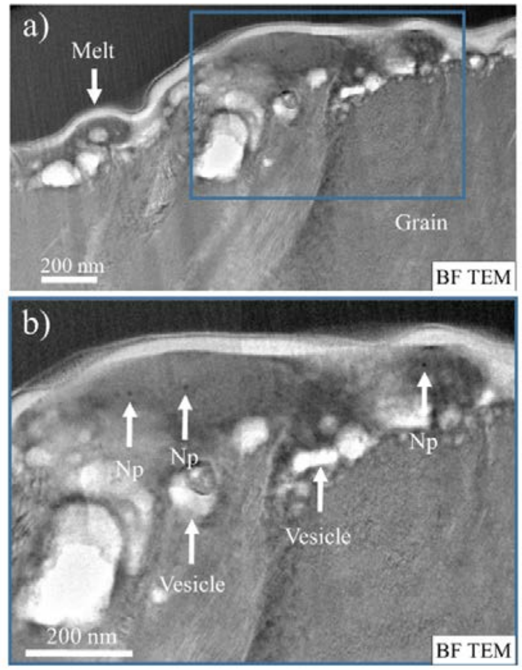

Figure 3: BF TEM images showing the a) melt layer and b) vesicles and nanoparticles at the top of a sulfide grain.

nanoparticles are formed after irradiation of sulfide-bearing meteorites and range in size from 2-30 nm in diameter [10]. Similarly, TEM studies on a pyrrhotite grain from asteroid Itokawa have found a layer of nanophase metallic iron in the uppermost region of the sulfide grain [14]. In contrast, the nanoparticles embedded in the melt layer observed here have a more restricted size range (~5-15 nm) compared to nanoparticles found in agglutinates and silicate grains from lunar soils [3]. To determine the composition of the nanoparticles produced after irradiation, we will perform high resolution transmission electron microscopy (HRTEM) and EDS analyses. These results will be compared to analyses of five regolith particles from asteroid Itokawa.

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