PULSED-LASER IRRADIATION SPACE WEATHERING OF A CARBONACEOUS CHONDRITE.

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Introduction: Grains on the surfaces of airless bodies experience irradiation from solar energetic particles and melting, vaporization and recondensation processes associated with micrometeorite impacts. Collectively, these processes are known as space weathering and they affect the spectral properties, composition, and microstructure of material on the surfaces of airless bodies, e.g., [1]. Recent efforts have focused on space weathering of carbonaceous materials which will be critical for interpreting results from the OSIRIS-REx and Hayabusa2 missions targeting primitive, organic-rich asteroids.

In addition to returned sample analyses, space weathering processes are quantified through laboratory experiments. For example, the short-duration thermal pulse from hypervelocity micrometeorite impacts have been simulated using pulsed-laser irradiation of target material e.g., [2-3]. Recent work however, has shown that pulsed-laser irradiation has variable effects on the spectral properties and microstructure of carbonaceous chondrite samples [4-5]. Here we investigate the spectral characteristics of pulsed-laser irradiated CM2 carbonaceous chondrite, Murchison, including the vaporized component. We also report the chemical and structural characteristics of specific mineral phases within the meteorite as a result of pulsed-laser irradiation.

Samples and Methods: The Murchison chip was irradiated using a Nd-YAG laser, 48 mJ/pulse, with a spot size of 1 mm, rastered over the surface. A glass slide was placed ~7 mm above the sample to collect the vapor plume resulting from the irradiation event. Reflectance spectra of both the irradiated surface and the vapor deposit were obtained using an ASD FieldSpec 3 Spectrometer (0.35-2.5 μm). We observed the morphological characteristics of the irradiated chip and the vapor deposit using the JEOL 7600F field emission scanning electron microscope (SEM) at JSC. Electron transparent thin sections were prepared using the FEI Quanta 3D focused ion beam (FIB) instrument. Each section was analyzed using the JEOL 2500SE scanning transmission electron microscope (STEM) equipped with a Thermo thin window energy-dispersive X-ray spectrometer (EDX).

Results and Implications: The UV-VIS-NIR reflectance spectrum collected from the irradiated Murchison sample is slightly darker than the unirradiated material, while the vapor deposit is strongly reddened [6]. SEM analysis of the surface of the irradiated meteorite shows melt textures including vesiculation likely formed by the outgassing of volatile species during irradiation. FIB sections were made from the vapor deposit, the matrix of the meteorite, and individual olivine and pentlandite (Fe-Ni-Sulfide) grains. The irradiated matrix material is vesiculated and displays melt spherules which EDX indicates are rich in Fe, Mg, and Si. Nanoparticles are present on the surface of the irradiated matrix material and EDX maps and high resolution imaging indicate pentlandite is the dominant composition. The olivine grain exhibits a very thin (~15 nm) layer of melt with olivine composition, though enriched in Ca compared to the underlying grain. There is also a volatile rich (e.g., Fe, S) vapor deposit superimposed on the olivine-composition glass, with nanoparticles dispersed throughout (Fig. 1). The pentlandite grain exhibits evidence of melting, including vesiculated textures and localized fine-grained, recrystallized regions. The composition of the melted pentlandite rim is the same as the core of the grain. The microstructure and composition of the vapor deposit on the glass slide indicate several distinct emplacement events. EDX analyses indicate thin, amorphous layers are enriched in volatile (Fe and S) elements and likely formed through vapor deposition. Thicker, pancake-shaped deposits with more refractory compositions are likely spatter that impacted the glass slide. Nanoparticles are present throughout the vapor deposit and selected area electron diffraction patterns indicate compositions including magnetite, Fe-Ni-S (pentlandite) and troilite.

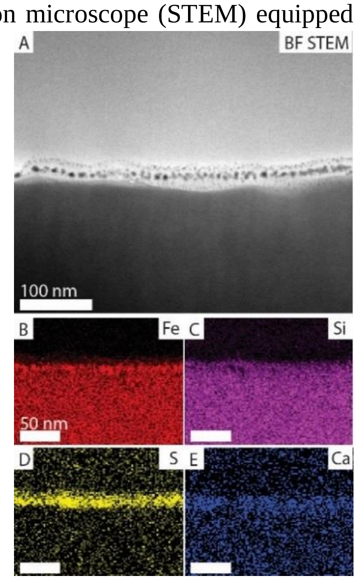

Figure 1: a) Bright field STEM image of the surface of the olivine grain including nanoparticles. EDX maps of the region showing b) Fe, b) Si, c) S, and e) Ca.

Conclusions: The diverse nature of nanoparticle compositions, and predominance and Fe-Ni-S grains in the melt and vapor deposits may be responsible for the variable response of spectral characteristics observed in laboratory-weathered carbonaceous chondrites (e.g., reddening vs. bluing) [4-5].

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