INVESTIGATING THE EFFECTS OF SIMULATED MICROMETEORITE IMPACTS ON A CARBONACEOUS CHONDRITE THROUGH COORDINATED ANALYSIS.

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Introduction: Space weathering modifies the surfaces of airless bodies via micrometeorite impacts and solar wind irradiation. Together, these processes alter the microstructure, chemical composition, and reflectance properties of surface material [1]. While considerable work has been done to understand the effects of space weathering on lunar and ordinary chondritic materials, e.g., [2,3], there are fewer constraints on how hydrated, organic-rich materials respond to these processes. With ongoing sample return missions OSIRIS-REx and Hayabusa2 to carbonaceous asteroids Bennu and Ryugu, respectively, it is important to understand how space weathering affects surface materials on these asteroids, especially in the context of early results, e.g., [4,5]. In advance of sample return, we can investigate the effects of space weathering on carbonaceous materials by performing experiments in the laboratory, e.g., [6,7]. Here we present coordinated analytical results of pulsed laser irradiation experiments designed to simulate the progressive space weathering of a carbonaceous chondrite by micrometeorite impact processes.

Samples and Methods: We rastered an Nd-YAG pulsed laser (λ=1064 nm, ~6 ns pulse duration, energy 48 mJ/pulse) over the surface of three dry-cut rock chips of the CM2 Murchison meteorite, 1x, 3x, and 5x, respectively. We collected reflectance spectra from both the raw and irradiated regions over the wavelength range of 0.35-2.5 µm using an ASD FieldSpec 3 Spectrometer. We analyzed organic functional group chemistry using the μL^2MS instrument at Johnson Space Center (JSC). We prepared electron-transparent thin sections of multiple phases from the meteorite using the FEI Quanta 3D focused ion beam (FIB) for analysis in the JEOL 2500 transmission electron microscope (TEM) at JSC. Finally, we used a radiative transfer model to investigate the spectral effects of submicroscopic Fe-bearing nanoparticles embedded in and on silicate grains, enabling us to correlate microstructural and chemical features observed in the irradiated samples to measured reflectance data.

Results and Discussion: Spectral analyses show that the irradiated regions are darker and bluer than the raw material, but become progressively brighter with each laser raster. We see the progressive weakening of most absorption features with irradiation, e.g., the 0.7 µm feature associated with phyllosilicates. Organic spectral maps spanning the raw and irradiated regions of the 1x and 5x lasered samples both show an increase in the concentration of aromatic species in the surface (Fig. 1). Results from the TEM analyses of sulfide, olivine, and matrix phases reveal the presence of amorphous surface layers consistent with melting and vaporization processes and abundant nanoparticles (5-50 nm in size) of varying compositions. High resolution TEM and energy dispersive x-ray spectroscopy (EDS) chemical maps indicate the nanoparticle compositions include metallic Fe, Fe_3O_4 (magnetite), Fe-S (troilite), and Fe-Ni-sulfide (pentlandite). The results of our radiative transfer models predict that nanophase (<40 nm) magnetite particles enclosed in silicate hosts cause overall samples darkening, with the effect becoming more pronounced for microphase (>40 nm) particles. Both nano- and micro-phase magnetite nanoparticles cause bluing of the reflectance spectrum. Similarly, both nano- and microphase inclusions of troilite cause darkening, but nanophase troilite causes reddening, whereas microphase particles cause bluing.

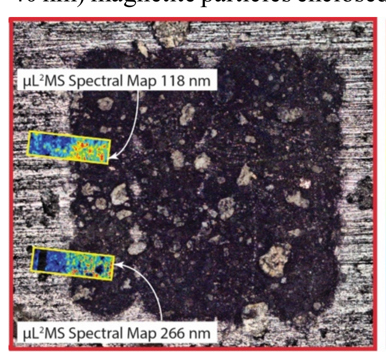

Figure 1: μL^2MS maps of the raw and irradiated regions of the 1x lasered sample. The color bar represents organic concentration from low (blue) to high (red).

These results demonstrate the complexity of space weathering on carbonaceous surfaces. Our radiative transfer modeling shows that particle size and composition play a significant role in the observed spectral effects. Evolving populations of these particles offers an explanation for the inconsistency in spectral results among laboratory experiments. The development of nanophase magnetite may be relevant to the detection of this phase on Bennu [4].

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