LASER AND ELECTRON WEATHERING EXPERIMENTS ON MURCHISON (CM2) METEORITE.

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In order to gain further insight into the processes that modify asteroid surfaces, we conducted laser and electron weathering experiments of Murchison carbonaceous chondrite (CC) meteorite.

Space weathering is the general term for a set of complex processes affecting the regoliths of airless bodies: solar wind irradiation, impact vaporization and condensation, and impact comminution and melting. These effects tend to redden, darken, and reduce spectral contrast of the Moon and S-type asteroids [1,2].

In contrast, the low albedo surfaces of primitive asteroids (e.g., C-complex spectral types of [3] B, C, Cb, Ch, Cg, Cgh, K, and L) exhibit divergent reddening or blueing spectral trends as a function of age [4-7]. Laser and ion irradiation studies of CC have not provided conclusive insight into the asteroid spectral discrepancy as spectral effects vary from one experiment to another; with reddening or blueing and darkening or brightening [5,8-13].

How space weathering would affect the presence of the 3-µm absorption band, which is related to water and phyllosilicates in C-type asteroids, and the 3.4 µm band, due to organic carbon, is a research area of great interest; especially for potential mission [14], ISRU targets [15], and asteroid-meteorites connections.

This work focuses on Murchison, and CC meteorites in general, for two reasons: The first is to provide data on how color varies as a function of exposure age, composition, petrologic type and grain size. These data will solidify a spectral link between carbonaceous chondrites and C-complex asteroids. This capability is important because C-complex asteroids represent one of the largest asteroid groups, possibly composing 75% of Main Belt Asteroids [16] and a similar percentage of smaller (< 1km) Near Earth Asteroids [17], the most promising population for water-based ISRU [15]. The second reason we focus on CC is to gain insight on how the 3-µm absorption band is created, modified or destroyed by space weathering. It is estimated that approximately two-thirds of C-complex asteroids exhibit a 3-µm band [18,19]; Evidence for how it responds to different forms space weathering is vital for understanding the distribution of water in our Solar System.

Methods: Previous experimental setups typically examined a single component of space weathering at room temperature. The experiments we conducted simulated micrometeorite bombardment and the electron component of the solar wind – Protons will be explored in future experiments. Experiments were performed at ultra-high vacuum (5×10^{-11} torr), achieved via clean, oil-free, magnetically levitated turbo molecular pumps, and at two temperatures (5K and 150K). The temperature span was chosen to replicate the characteristic pole-equator temperature range of about 5K to 165 K [20] of low-albedo asteroids at a distance of 2 to 3 AU from the Sun. Irradiation experiments were done with electrons only (5 keV @ 10 µA for 5 hours), CO_2 laser only (10.6 µm @ 10 W cm^{-2} for 5 hours), and both energies simultaneously for 5 hours. Control experiments were conducted under identical conditions, but without subjecting the sample to radiation. After irradiation, a temperature program desorption (TPD) was run from experiment temperature to 300 K @ 1 K/min.

In situ analyses were conducted before, during and after irradiation by three instruments. (1) Infrared spectra from 1-20 µm (10,000-500 cm^{-1}) were recorded with a Thermo Nicolet 6700 FTIR spectrometer. This range enables us to monitor not only the formation of water but also the modification of organics. (2) Products released into the gas phase were measured with a Reflectron Time-of-Flight Mass Spectrometer (ReTOF-MS), which monitors the complete product spectrum simultaneously based on the mass-to-charge ratios of the ionized neutral molecules. (3) A quadrupole mass spectrometer (QMS) with electron impact ionization at 70 eV. This setup also helps to identify water (H_2O) and carbon dioxide (CO_2) molecules subliming from the irradiated sample.

Post-irradiated samples were taken to the UH Advanced Electron Microscopy Center for micro-analysis. Electron transparent samples were prepared using the FEI Helios NanoLab 660 DualBeam focused ion beam instrument (FIB). Micro-textures, micro-petrography, micro-chemistry and microstructures of the space-weathered amorphous rims were examined using brightfield, darkfield images, high-angle annular dark field (HAADF), diffraction patterns, and, energy filtered imaging and chemical analysis and mapping via EDS using an FEI 80 – 300 kV Titan, dual Cs-corrected, monochromated (scanning) transmission electron microscope, or Super(S)TEM.

Results & Discussion: Here we report results for the 150K experiments. Infrared spectra show no water formation for single energy experiments (i.e., electrons or laser irradiation). However, dual irradiation experiments did yield evidence for formation of water via the ν_3 asymmetric stretching at 3.0 µm (3332 cm^{-1}) and 3.3 µm (3151 cm^{-1}). There also was a small peak for CO_2 around (2350 cm^{-1}). ReTOF-MS and QMS data taken during TPD also support formation of these as well as small organic molecules only during dual irradiation experiments.

TEM analyses reveal no mineral alteration for the electron irradiated samples, slight deformation for the laser-only irradiated samples, and alteration more typical of space weathering for the dual irradiated samples We targeted olivine, pyroxene, and sulfides for FIB sectioning. Analyses of laser irradiated samples (Fig. 1) show no amorphous rim or depletion of sulfur from the exterior of the sample. In addition, clay minerals near the surface have not lost their layered structure, which would happen if devolatized. In the dual irradiated sample, TEM images and bright-field images show an amorphous silicate rim superposed over a sulfide grain, which has interior fractures. EDS measurements show the rim is depleted in sulfur and show the presence of Si and Mg (and higher Fe composition), elements which are not present in the host grain.

Conclusions: Electrons, while energetic, yielded little in the way of either chemical, spectral, or physical changes to the sample. Laser irradiation alone did surprisingly little to modify the chemical, spectral, or physical changes of the sample. Combined electron-micrometeorite impact exposure, however, had crucial cumulative effects that lead to H_2O and CO_2 formation.

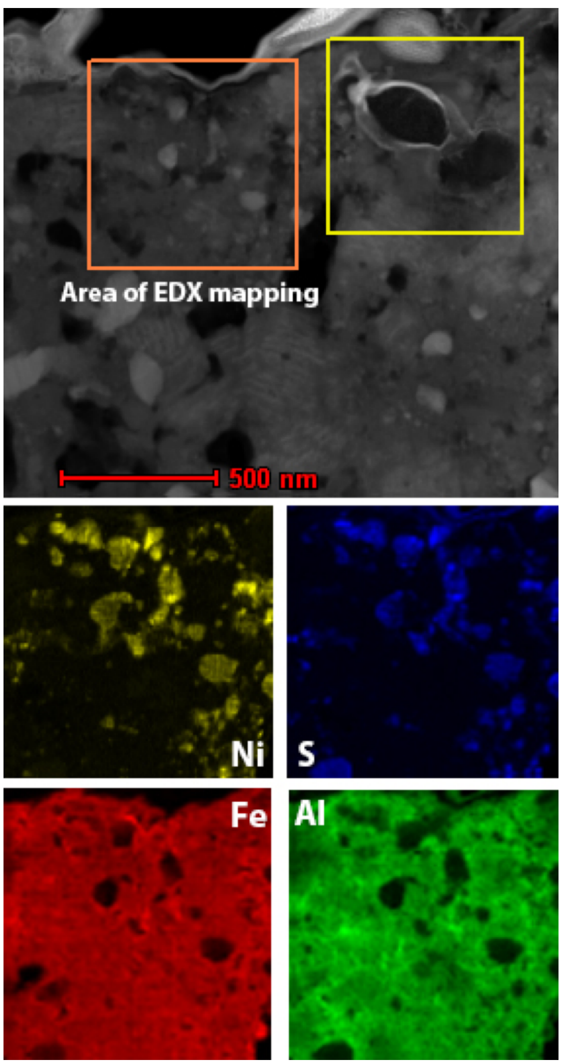

Fig 1. Bright Field image of laser irradiate Murchison sample. EDS maps show the distribution of Ni, S, Fe, and Al.

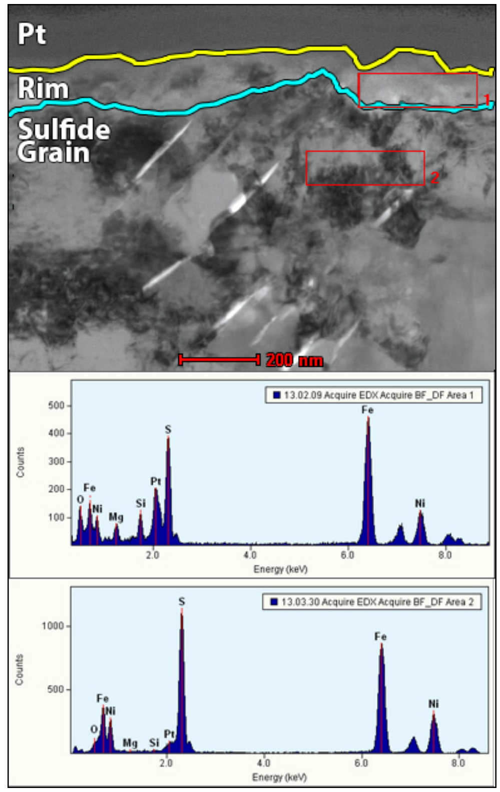

Fig 2. TEM bright-field image (top) showing a silicate rim on top of a sulfide (pyrrhotite) grain. EDS compositions of area 1 (rim) show Si, Fe, and Mg (Pt is from protective layer), while area 2 (host grain) exhibits more S and Ni and no indication of silicate material.

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