LASER IRRADIATION OF TWO CV3 METEORITES YIELDS DESPARATE WEATHERING EFFECTS.

J. J. Gillis-Davis[1], H. A. Ishii[1], M. Adams[1], H. C. Connolly Jr.[2] [1]University of Hawai'i at Mānoa, Hawai'i Institute of Geophysics and Planetology, 1680 East-West Road, Honolulu, HI 96822, USA; [2]Rowan University, School of Earth and Environment, 201 Mullica Hill Road, Glassboro, NJ 08028 (gillis@higp.hawaii.edu)

Introduction: Asteroids are classified according to their spectral properties [1-3]. Asteroid spectra are then matched with spectra of meteorites to improve understanding of asteroid compositions and geologic evolution. For instance, C-complex asteroids are hypothesized to be analogous to carbonaceous chondrites due to both objects having low albedo and lacking characteristic absorption features [4]. The ability to connect meteorites and asteroids is hampered by modification of the asteroid spectra through space weathering [5-8].

For the purpose of connecting meteorites to asteroid parent bodies [e.g., 4, 9], a fundamental question about C-complex asteroids is, what spectral, compositional, and physical effects occur as these carbon-bearing asteroids are exposed to the space weathering environment? To explore how carbonaceous materials react to space weathering, we conducted nanosecond pulsed laser irradiation experiments on a powdered sample of NWA 3118 (CV3) and compare our results to laser experiments done on Allende (CV3) [10].

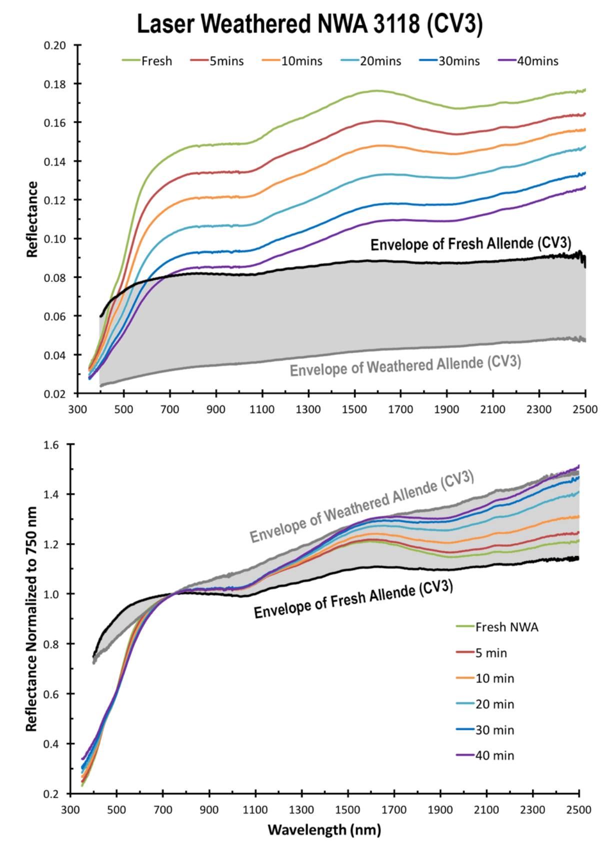

Fig. 1 Absolute (a) and 750 nm normalized (b) reflectance values for laser weathered NWA 3118 in comparison with similar data for laser experiments done on Allende [10], which is also a CV3.

Methods: A 1g rock of NWA was ground in a quartz mortar and pestle and dry-sieved to <75 µm grain size. NWA contains curvilinear thin bands of olivine grains ($Fa_{32–36}$), up to 10 µm in size, enclose pod-like masses of micron to submicron Fe-rich olivine ($Fa_{42–58}$), pyroxenes, sulfides, chondrules typically <2 mm, and minor terrestrial weathering products [11].

Micrometeorite impact heating was simulated using a Nd:YAG (1064 nm), pulsed (20 Hz) laser under vacuum of ~1×10^{-6} torr using an oil-free turbo/roughing pump combo. Pulse duration is 5–7 ns, which is comparable to the timescale of micron-sized micrometeorite impacts [12]. Pulse energy was 30 mJ. Irradiations were performed in 1,200 pulses or 1-minute increments using a rastered beam, for a total of 48,000 laser shots or 40 minutes to simulate approximately 1.2×10^{8} years of micrometeorite exposure. For reproducibility, two 0.3 g aliquots of uncompressed powdered sample of NWA were used for pulsed laser irradiation experiments.

Vis-NIR spectra were measured using a Analytical Spectral Devices Inc. FieldSpec 4 spectrometer. The spectral range is from 0.35–2.5 µm. Spectra were acquired using a standard 30° phase angle (30° incidence and 0° emission). Reflectance was measured relative to multiple Spectralon reflectance standards.

Two electron transparent thin sections were prepared on Cu half-grids at Oregon State University using standard techniques on a Helios dual beam FIB. Microanalyses of two samples were carried out using a (Scanning) Transmission Electron Microscope (STEM). High-Angle Annular Dark Field (HAADF) images were acquired in STEM mode in addition to conventional bright-field and dark-field images and X-ray fluorescence maps at the National Center for Electron Microscopy, Molecular Foundry, Lawrence Berkeley Laboratory on a TitanX 80-300 keV (S)TEM with ChemiSTEM detectors. All maps were collected at 200 kV with a full x-ray fluorescence spectrum at each pixel and processed using Bruker's Esprit 1.9 software. Maps were collected with 0.5 to 9.5 nm/pixel. Relative error, determined chiefly by counting statistics and peak fitting, is < 1% for O, Mg, Al, Si, Ca, S and Fe.

Results: The albedo of NWA starts at 0.12 @ 550 nm and decreases to 0.06 by the end of 48,000 laser shots (Fig 1). The fresh and laser weathered NWA spectra are brighter and redder in the visible than spectra for Allende. Further, the olivine, pyroxene, and spinel spectral bands are more pronounced in NWA than Allende. The 2-µm band from pyroxene and spinel decreases as the sample is laser weathered. A peculiar feature of NWA is that olivine-related 1µm absorption band gets stronger, rather than weaker, as the sample is laser weathered.

TEM analyses of the weathered NWA sample reveals complex redeposited layering on top of the olivine substrate (Fig 2). Small olivine (Fa_{80}) crystals (typically 50-500 nm) are present within the laser-weathered layers. It is possible they derive from the pod-like masses of Fe-rich olivine ($Fa_{42–58}$), however, the iron content is much too low. Dislocations extend down 500 nm into the olivine (Fa_{32}) bulk crystal. Energy dispersive X-ray mapping shows the presence of <100 nanometer Cr, Fe-bearing minerals, maybe chromite, crystals in the amorphized laser-weathered glassy rims.

Discussion: With incremental laser weathering of Allende [10], overall spectra from Vis-NIR redden and darken, and characteristic absorption bands weaken as a function of laser exposure. However, the visible continuum slope between 450-550 nm did not vary monotonically with laser exposure. Initially, spectra redden with laser irradiation; then, the visible continuum in this region becomes less red while the overall spectra continue to darken (Fig. 1). STEM analyses of Allende revealed that the nanophase component is primarily SMFe in samples experiencing low degrees of laser space weathering, but that FeNiS, FeS and NiS become dominant and control the spectral properties of the sample with increasing weathering.

Conclusions: While both Allende and NWA 3118 are in the same carbonaceous chondrite class CV3 (e.g., exhibiting similar carbon content in matrix, comparable major mineralogy, and presence of CAIs), the physical and physical/spectral effects produced by the laser weathering experiments are different. Spectral effects of Allende are controlled by dispersal of sulfides, which are a minor component of NWA, while possible dispersal of the micron to submicron Fe-rich olivine crystals in NWA 3118 by the laser causes the 1-µm band to increase. Noting characteristic weathering effects of meteorites within a class is important for custom identification of meteorite parent bodies. When information such as this is combined with astronomical surveys, it can provide constraints on the compositional distribution within the Solar System and provide ISRU targets.

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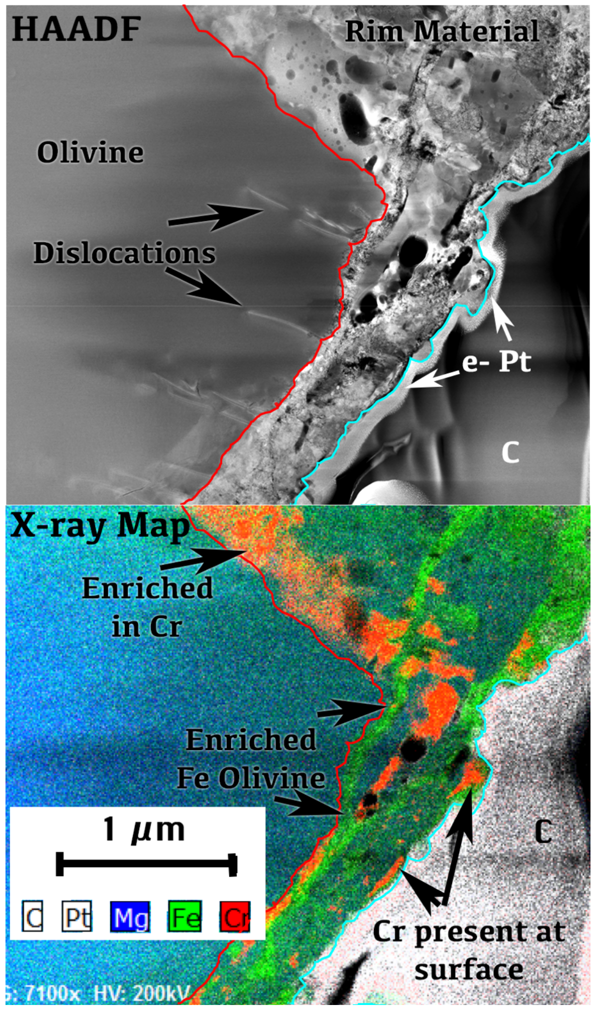

Fig 2 a) HAADF image of olivine grain with superposed amorphous rim material (separated by red line). A thin e-beam-deposited Pt (e-Pt) protective strap covers the rim (denoted by cyan line), which was followed by a thicker C strap. b) X-ray map showing areas of enriched Fe olivine (Fa_{80}, green) relative to host olivine (Fa_{32}) grain and enriched Cr (red).