REPRODUCING SPACE WEATHERING ON C-TYPE ASTEROIDS WITH LOW-ENERGY LASER IRRADIATION EXPERIMENTS OF THE MURCHISON METEORITE.

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Introduction: Space weathering is known as the event that produces the mismatch of reflectance spactra between asteroids and meteorites [1]. In terms of space wearthering on C-type asteroids, several laboratory experiments are performed [2,3,4,5]. We performed pulse-laser irradiation experiments to simulate micrometeorite bombardments using the same method as in [6] and found that spectral darkening occurs equally regardless of the laser energy (the energy range was 5-15 mJ). We aim to perform pulse-laser irradiation expriments using lower energy (<5 mJ). Understanding space weathering effects on on C-type asteroids would be useful for understanding the true underlying composition of those asteroids and selecting the sampling sites for the sample return missions such as JAXA Hayabusa2 and NASA OSIRIS-REx.

Experimental: We prepared two pellets of fine powder (<63 μm in diameter) made from a chip of Murchison CM chondrite by the same procedures as in [5]. Two pellets were irradiated with a Nd-YAG laser in vacuum using the same instrument and procedures in [6]. The laser energies were 0.7, 1, 2, and 5 mJ for four different areas of the pellets, which are lower than those in our previous study [5].

Reflectance spectroscopy. Reflectance spectra were measured after irradiation experiments. The analytical conditions and measurement procedures were similar to [5]. Bidirectional UV-Vis-NIR diffuse reflectance spectra were measured over the wavelength range of 0.25-2.5 μm at every 5 nm at Mizusawa VLBI Observatory of NAOJ, Japan. The samples were heated to approximately 100 °C during measurements for removal of adsorbed water. Fourier transform infrared (FT-IR) reflectance spectra were measured over the wavenumber range of 4000-700 cm^{-1} (2.5-14 μm in wavelength) at every 1.9 cm^{-1} using Thermo Fisher Scientific Nicolet iN10 with OMNIC Picta software at Tohoku University, Japan. During measurements, the samples were heated to approximately 100°C and purged in N_2 gas.

Raman spectroscopy. Raman spectra were measured using JASCO NRS-5100 with a 532 nm exciting laser radiation at Tohoku University. The laser was focused on the pellet surface using an objective lens (×20). The spectral resolution was 1 cm^{-1} and the spot size was 5 μm.

FE-SEM/EDS analysis. Several Murchison particles, which were picked up from the 5 mJ-irradiated area, were used for analyses of surface structures and chemical compositions using a field emission scanning electron microscope (FE-SEM) with an energy-dispersive X-ray spectrometer (EDS), JEOL JSM-7001F at Tohoku University.

Results: Reflectance spectra of Murchison pellet samples show several features depending on laser energies. The spectral slope in shorter wavelength and overall albedo decrease with increasing laser energy from 0 mJ to 5 mJ as shown in Figs. 1 and 2. The 0.7- and 3-μm bands, which appear in all spectra, become shallower with increasing laser energies (Figs. 1 and 3). The 0.7- and 3-μm band centers and FWHM values do not show any significant changes regardless of the intensities of laser energy.

Raman spectra of unirradiated and irradiated areas show D and G bands at ~1350 and ~1600 cm^{-1}, indicative of the presence of carbonaceous material. The intensity ratios of D and G bands, graphitization indices, does not change significantly in this study.

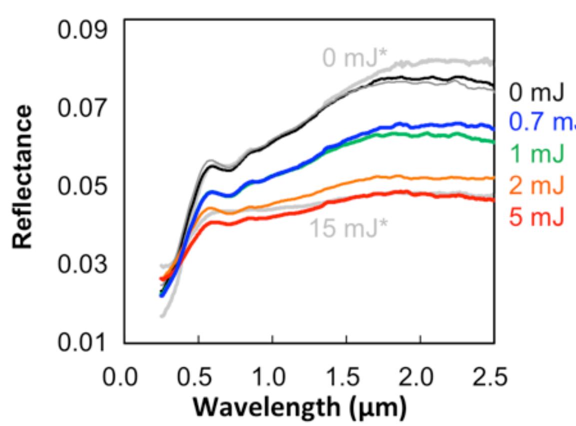

Fig. 1. Reflectance spectra of Murchison samples. Marked as 0 mJ are spectra of unirradiated samples. Spectra marked as "15 mJ*" and "0 mJ*" taken from [5] are also plotted together for comparison.

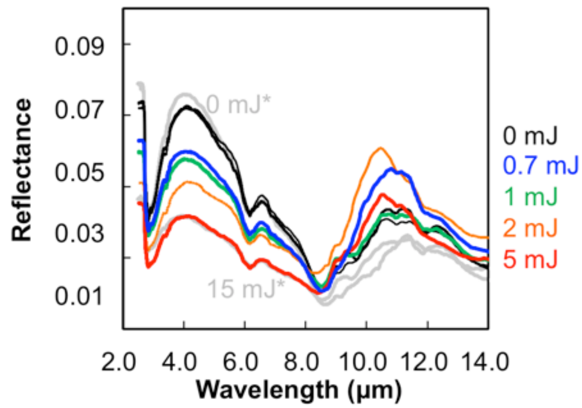

Fig. 2. The IR spectra of Murchison samples over the range of 2.5-14 μm.

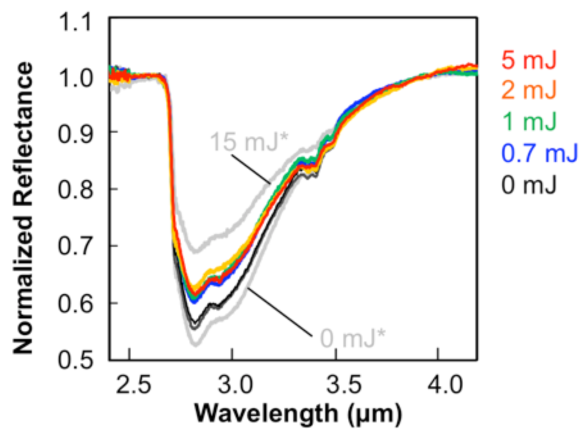

Fig. 3. Normalized spectra of the 3-μm band.

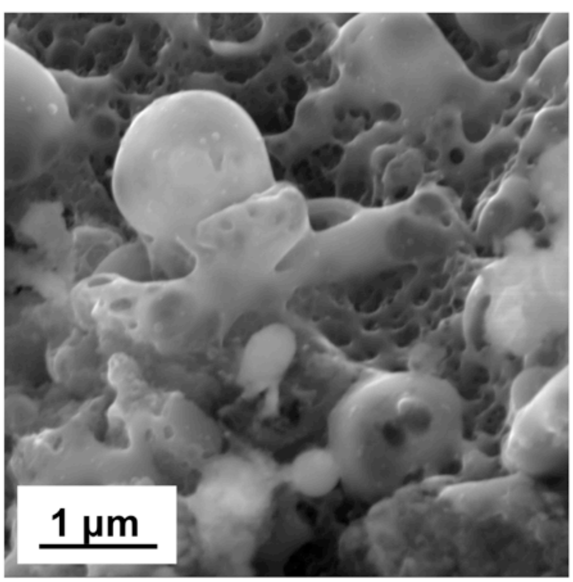

Fig. 4. Secondary-electron image showing melting and bubbling of silicates by 5-mJ laser irradiation at the surface of the powder particle.

Several Murchison particles of ~60 μm in diameter were collected from the surface of 5 mJ irradiated area. Figure 4 shows the melted/bubbled structures possibly produced by laser heating over melting point followed by rapid cooling. The S/Fe/(Mg+Si) ratios of the melted/bubbled structures are consistent with those of FeS-rich splash particles from 15-mJ irradiated area analyzed in [5].

Discussion: Reflectance spectra of laser-irradiated areas with 0.7-5 mJ have intermediate UV slopes, albedos, and the 0.7- and 3-μm band depths between those of 0 mJ and higher energies (>5 mJ in [5]) (Figs. 1-3). We consider there are several mechanisms responsible for changing spectra darker and bluer, as common effects in case of irradiation with higher energies [5]. (1) The breakdown of serpentine which has high reflectance and the 0.7- and 3-μm bands would be a cause of the spectral bluing, darkerning and decreasing of the 0.7 and 3-μm band depths. (2) The deposition of FeS-rich silicate particles would have two types of effects on spectral properties; (i) producing bluing and darkening mainly in shorter wavelength range as the fine particles (<1 μm in size; [5]), and (ii) inducing dramatical darkening over the whole wavelength range as the opaque material. However, the overall darkening seems to be saturated at a laser energy of 5 mJ. It was reported that the Murchison heated at 900℃ shows higher reflectance and less carbon content compared with unheated Murchison [7]. The carbon loss due to oxidation of carnonaceous material would occur mainly with laser energies >5 mJ, and inhibit spectral darkening. The graphitization may have minor effect in Vis-NIR range because Raman spectra measured at ~1 μm in depth showed no significant change with increasing laser energies.

Summary: UV-Vis-IR spectra of Murchison samples irradiated with pulse laser of 0.7-5 mJ show bluing and darkening. These changes are consistent with the results of experiments with higher irradiation energy in our previous study [5]. Serpentine dehydration and amorphization, and deposition of FeS-rich particles generated by laser heating could be the major cause of spectral bluing and darkening.

References: [1] Hapke B. (2001) *J. Geophys. Res. 106,* 10039–10073. [2] Hiroi T. et al. (2004) *LPS XXXV*, Abstract #1616. [3] Hiroi T. et al. (2013) *LPS XLIV*, Abstract #1276. [4] Gillis-Davis J.J. et al. (2013) *LPS LXXV,* Abstract #2494. [5] Matsuoka M. et al. (2015) *Icarus, 254,* 135-143. [6] Yamada M. et al. (1999) *Earth Planets Space, 51,* 1255–1265. [7] Yamashita S. et al. (to be submitted).