EFFECTS OF MICROSECOND PULSE LASER IRRADIATION ON VIS-NIR REFLECTANCE SPECTRUM OF CARBONACEOUS CHONDRITE SIMULANT: IMPLICATIONS FOR MARTIAN MOONS AND PRIMITIVE ASTEROIDS.

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Introduction: Goal of this study is to make a progress in understanding the optical effects of space weathering on small bodies believed to be similar in composition to carbonaceous chondrites: C, G, B, F, T, D, and P asteroids and possibly Martian satellites Phobos and Deimos. The companion work [1] focuses on petrological and mineralogical aspects of this process. One of the main factors of space weathering is meteorite and micrometeorite bombardment leading, in particular, to impact melting of components of the regolith. Studies of lunar regolith [*e.g.*, 2, 3] and laboratory experiments simulating impact melting [*e.g.*, 4, 5] show that the melting products differ from the unmelted material in mineralogy and distribution of chemical components among different phases that results in spectral changes. We simulate impact melting of CM chondrite by pulse laser irradiation of an artificial analog of such a meteorite. The analog is a mixture of 46 wt.% non-magnetic fraction of L5 ordinary chondrite Tsarev, 47 wt.% serpentine, 5 wt.% kerite, and 2 wt.% calcite. It simulates rather well bulk chemistry, including volatiles such as H_2O and CO_2, and only approximately the CM chondrite mineralogy. Thus, we do not expect the mixture to be spectrally similar to CM chondrites, but expect the laser melting products to be similar to those formed by impact melting of natural CM chondrites.

Experimental Method: The experimental technique was similar to that described in [4, 5]: The sample was ground to a particle size mostly smaller than <30 µm and shot by pulse laser in vacuum at $(2\text{-}3)\times10^{-4}$ mm Hg. A solid-state ND-YAG multiple-pulse laser ($\lambda = 1.06$ µm) with pulse frequency of 30-40 KHz was used. Pulse duration was 0.5-1 µsec, and laser power was about 1.2 KW. In comparison with a similar method [6] using 7 nsec pulse laser simulating shock-wave heating by micrometeorites hitting 70 µm regolith particles at 10 km/s for example, our experiment having 100 times longer pulse duraction may simulate either larger target regolith particles or slower projectile micrometeorites. Visbile-near-infrared (Vis-NIR) reflectance spectra of the samples were measured at a bidirectional geometry (30° incidence and 0° emergence) in the range of 0.3-2.6 µm, and the FTIR reflectance spectra were measured at a biconical geometry in the range of 2-25 µm. The unaltered sample was measured with the on-axis setting using Nicolet 740 spectrometer, and the altered ones with the off-axis setting using Nexus 870 spectromeer which minimizes specular component of the reflected light. The FTIR spectrum of each sample is scaled to connect to its Vis-NIR spectrum around 2.5 µm.

Results: The irradiation produced spherical glassy droplets up to 0.3 mm in diameter. The produced sample was sieved into six size fractions. The coarser fraction (>125 µm) apparently consists mostly of altered (melted and then partly crystallized) glassy aggregates. The finer fractions (40-125 µm) consist of both altered and unaltered particles. The <40 µm fraction includes mostly unaltered material. The altered samples contain ~5-20 % of unaltered clasts welded to the altered particles. Examination of altered material under binocular microscope showed that the altered aggregates exhibit vesicular texture. The alteration products are generally opaque, dark and their surfaces are enriched in circular drop-like metal/sulfide features. Backscattered electron (BSE) imaging of unaltered sample shows that homogeneous grain size of the initial material has not been reached: some serpentine clasts are as large as ~100 µm being noticeably larger than the majority of the mixture clasts (<30 µm). Thus, after laser heating some large serpentine particles remained unmelted. The melted droplets do not contain the unmelted clasts in their interiors but in some cases small unmelted clasts stuck to their surfaces. The melt material is partly crystallized forming intersertal texture. The bulk chemistry of the melt is found to be similar in composition to the initial unaltered material. The crystallization of the melt resulted in formation of skeletal, dendrite, and needle-like Mg-rich olivine crystals with very thin (<1 µm) Fe-rich outer zones. The lengths of crystals range from 3 to 30 µm and the widths from 1 to 7 µm. The crystals are cemented by Fe-rich glassy mesostasis. Many fine (0.1-0.5 µm) metal (Fe-rich) inclusions dispersed in mesostasis and many circular metal/sulfide inclusions (<1 to 10 µm in diameter) on the surfaces of droplets.

Reflectance Spectroscopy: Shown in Fig. 1 are reflectance spectra of unirradiated and laser-irradiated samples (ground). Although the spectra cover up to 25 µm, only up to 3.6 µm is plotted here, since this is the range where extraterrestrial bodies are most often observed using ground-based telescopes. Prominent absorption bands of OH at 2.7-3 µm and CH at 3.4-3.5 µm are evident, and a strong UV absorption observed as a falling continuum toward shorter wavelength. Note that this fall-off in the spectra of our unaltered and altered simulant starts at much longer wavelength than in the spectra of natural CM and CI chondrites or C-type asteroids where it occures shortward of 0.5 µm (Fig.2). In this respect the Vis-NIR spectra of our simulant are more similar to those of Phobos, T/D-type asteroids, and Tagish Lake meteorite [7, 8]. In our simulant, however, the reflectance fall-off occurs at shorter wavelength than in Tagish Lake, since the organic component used in our mixture has lower carbon aromaticity [9] than organics in Tagish Lake [10]. In general, our simulant is relatively bright because the intimate mixing of phases, typical of natural carbonaceous chondrite matrices, has not been achieved.

The UV, OH, and CH absorption strengths did not change much for the <40 µm fraction by laser irradiation since it consists mostly of unaltered material. The UV and CH absorption strengths noticeably decreased for the 75-125 µm fraction. The UV, OH, and CH absorption strengths significantly decreased for the >125 µm fraction, which has the lowest content of unaltered material. Shown as a comparison in Fig. 2 are reflectance spectra [11] of Murchison CM2 chondrite and its heated samples in a sealed glass tube at 400, 500, and 600°C with 10^{-5} atm H_2 for one week [12]. Similar trend of decreasing UV, OH, and CH absorption strengths is seen. The 600°C spectrum is particularly similar to the >125 µm fraction in Fig. 1.

Summary: The products we made by irradiating µsec pulse laser onto the carbonaceous chondrite simulant show dehydration, melting, vitrification, etc. These may surely occur by large micrometeorite impacts onto surface regoliths of primitive composition as a part of space weathering. Their reflectance spectra naturally show evidence of dehydration of serpentine, similar to the spectra of heated CM chondrites. The absorption features due to OH and CH are still present even in the most altered fraction due to unaltered particles stuck to the surface of the melt, but competely altered material probably lacks these bands. Thus, the impact melting of surface components may cause an observed lack of water- and organic-related absorptions in the spectra of Martian moons and some dark asteroids if such process is sufficiently effective on these bodies. Our simulant mixture is more easily melted by pulse laser than one of its components - pure L5 Tsarev powder treated by the same method [1]. It may suggest that airless bodies of CM and probably CI composition are more susceptible to impact melting than those of L chondrite composition although the limitation of using a CM chondrite simulant and pulse laser irradiation would surely exist.

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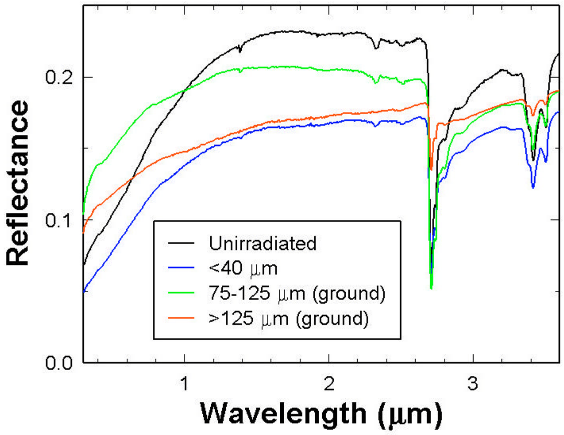

Fig. 1. Reflectance spectra of the original carbonaceous chondrite simulant and the laser-irradiated ones.

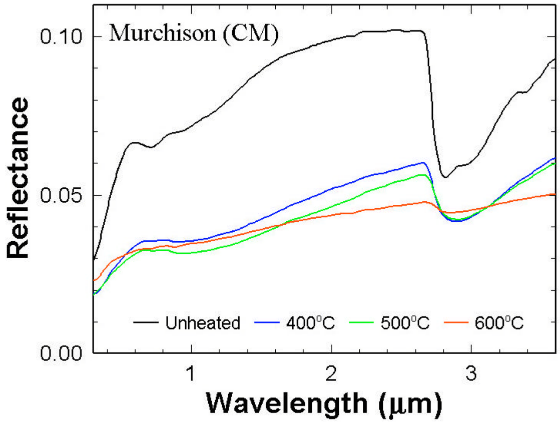

Fig. 2. Reflectance spectra [11] of powder samples of Murchison CM chondrite and its heated samples [12].