# SIMULATION OF MICROMETEORITIC BOMBARDMENT OF PHOBOS AND DARK ASTEROIDS SURFACES BY LASER TREATMENT OF CM2 CARBONACEOUS CHONDRITE MIGHEI

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**Introduction**

Resurfacing of airless small bodies in the Solar system by impacts of micrometeorites is one of the basic processes of "space weathering", changing chemical composition and optical properties of the uppermost layer of regolith on them. To stimulant a process of impact melting and subsequent solidification on the surfaces of Phobos and low-albedo asteroids the solid-state microsecond laser has been used. In this study was irradiated the CM2 chondrite **Mighei**. Carbonaceous chondrites are considered as representing materials of the C- and D-type asteroids and, probably, Phobos [1]. Thus, the purpose of this work was to study the mineralogical, petrological and optical changes in the products of micrometeorite bombardment of carbonaceous chondrite material.

**The description of experiment**

The CM2 chondrite **Mighei** consists largely of fine-grained black matrix and of olivine-rich chondrules, olivine aggregates, carbonates and sulfides. The matrix consists of Fe-rich serpentine-tochilinite intergrowth intimately mixed with carbonaceous material [2]. The meteorite contains up to 2.5 % of carbon, included in carbonaceous material and causing its black color [3]. The sample was ground and sieved to <40 µm. Chemical compositions is presented in the Table1. The irradiation of **Mighei** by the microsecond pulse laser was performed under the same conditions as in previous series our experiments: (2–3) x $10^{-4}$ mm Hg vacuum [4]. The irradiation was accompanied by noticeable sputtering of the melted matter and the ten-fold gas pressure increase in the experiment chamber, obviously due to the volatile release from the melting material. The laser treatment mostly resulted in the formation of spherical glassy droplets of the quenched melt from 20 µm to 100 µm in diameter and their aggregates of 125-300 µm in size. Besides, due to electrostatic forces the initial powdered material formed agglomerate clots up to 1-2 mm in diameter. In some of them, the laser beam made holes of ~100 µm in diameter filled in with the same melt, as the irradiated droplets.

**Spectra**

For spectral studies the irradiated material was sieved into several particle size fractions (<40; 40-75; 75-125; 125-200 and >200 µm). The amount of the altered material progressively drops in the fine separates while the coarsest separates are not contaminated in the unaltered material. So, by grinding the >125 µm irradiated separate, we produced an additional <40 µm fraction non-contaminated in the unaltered material. Visible-near-infrared (Vis-NIR) reflectance spectra were acquired at Brown University using NASA-Keck RELAB bidirectional spectrometer in the range of 0.3-2.6 µm at *i*=30° and *e*=0°. FTIR reflectance spectra were measured in the range of 2-25 µm at biconical geometry using Nicolet 740 spectrometer (also at Brown). The FTIR spectra were merged with Keck-RELAB's spectra at ~2.5 µm to obtain the composite 0.3-25 µm spectra. Although **Mighei** and other CM2 chondrites contain minerals with pronounced absorption bands, Vis-NIR spectra of these meteorites are essentially featureless (Fig.1). Most of the bands are suppressed by the presence of fine-grained spectrally featureless phases (tochilinite, troilite, carbonaceous material). Few absorption bands are detectable in the Vis-NIR region: a complex absorption feature near 2.7-3 µm mostly due to structural OH in the matrix phyllosilicates and tochilinite and absorption features due to charge transfer in $Fe^{3+}$-bearing phyllosilicates (UV-falloff below 0.5 µm and a weaker feature near 0.75 µm). On the whole, spectrum of the irradiated **Mighei** fine fraction shown on Fig. 1 has positive (reddish) slope in the NIR region. The reddening degree of **Mighei** increases with decreasing grain size most probably due to spectral contribution of olivine [5]. The absorption features related to hydrated minerals in the spectra of irradiated **Mighei** are significantly weakened due to dehydration of the material. In the spectrum of the finest fraction a weak broad band near 1 µm is due to crystal field electronic transitions in $Fe^{2+}$ in olivine and Fe-rich glass. Although the irradiated material is dominated by olivine of $Fo_{74}$ crystallized from the melt, olivine-related absorption bands are essentially suppressed and the material remains dark most probably due to abundant submicron inclusions of Fe-rich phase finally dispersed in the glassy mesostasis (see below). Additional factor may be carbonization of organic matter.

**Mineralogy and petrography**

Chemistry analyses and BSE imaging of altered samples were made by Link AN-10000 microprobe facility and SEM (CamScan 4 DV) at the Moscow State University. It is seen on SEM images that the laser irradiation of **Mighei** did not lead to complete melting of all the irradiated matter: in some cases the melt contains inclusions of unmelted angular clasts of two compositional types of olivine ($Fo_{99}$ and $Fo_{82}$). Apparently these two compositional types reflect the presence of two olivines in the initial sample: pure forsterite of the chondrules and more ferrous olivine presenting as single grains included in the matrix. These clasts are 6-35 µm in length and surrounded by thin (~1-2 µm) envelopes of olivine of significantly more ferrous composition ($Fo_{68}$). The experiment products show two types of texture: intersertal and sometimes microporphyritic. In general, the crystallization of the melt was resulted in formation of compositionally zoned (with Fe-rich ~0.5µm rims) skeletal to filamentous olivine ($Fo_{74}$) crystals (8 to 150 µm long and 2 to 13 µm wide). The olivine crystals are embedded in a Fe-rich (FeO 34%) glassy mesostasis. Comparing to the initial material the bulk melt composition (olivine+mesostasis) is depleted in Fe, Ni, S (probably due to FeNi/troilite segregations, which were not analyzed, and to vaporization) and proportionally enriched in all other components (Tab.1). Also there are very fine (0.1-0.5µm) Fe-rich opaque inclusions dispersed in the mesostasis. The melt contains gas bubbles from ~0.1 to 70 µm in diameter and metal/sulfide aggregates up to 60 µm in diameters which include the large gas bubbles, too.

**Table 1.** Chemical composition of the initial material and microprobe analyses of melted products

| | Initial **Mighei** | | Irradiated **Mighei** | | |
|---|---|---|---|---|---|
| | Matrix | Bulk sample | Bulk melt | Ol | Meso stasis |
| $SiO_2$ | 32.54 | 33.96 | 38.72 | 38.38 | 40.83 |
| $TiO_2$ | - | 0.14 | 0.15 | 0.06 | 0.36 |
| $Al_2O_3$ | 2.55 | 2.53 | 3.38 | 1.47 | 7.51 |
| FeO | 32.21 | 28.01 | 25.91 | 22.15 | 33.75 |
| MnO | 0.33 | 0.4 | 0.33 | 0.31 | 0.36 |
| MgO | 21.44 | 21.07 | 26.59 | 35.53 | 7.12 |
| CaO | 1.73 | 1.55 | 2.41 | 1.31 | 6.02 |
| $Na_2O$ | 0.56 | 1.24 | 0.64 | 0.26 | 0.51 |
| $K_2O$ | - | 0.27 | - | - | - |
| $Cr_2O_3$ | 0.58 | 0.65 | 0.62 | 0.56 | 0.80 |
| $P_2O_5$ | 0.29 | 0.39 | - | 0.07 | - |
| $SO_3$ | 5.81 | 7.68 | 0.43 | 0.08 | 1.23 |
| CoO | н.о. | 0.33 | 0.18 | - | 0.33 |
| NiO | 1.87 | 1.79 | - | - | - |
| ∑ | 99.42 | 100.01 | 99.38 | 100.2 | 98.81 |

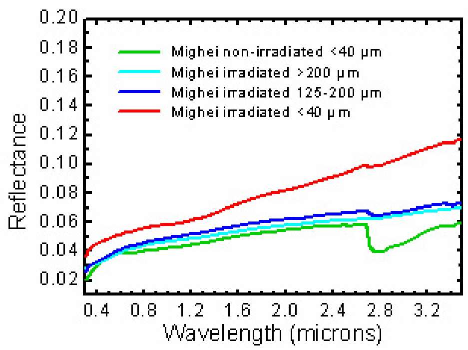


**Fig. 1.** Reflectance spectra of non-irradiated and irradiated powdered samples of **Mighei**

**Discussion**

The laser pulses used in our experiments are equivalent in energy to impacts by 10 μm micrometeorite particles if their density is 2-3 g/sm$^3$ and velocity ~14-17 km/s. So we simulated a part of process of the "space weathering", thus supplementing experiments of other authors who used the nanosecond pulses [6-8]. The laser treatment of **Mighei** completed the series of our experiments with three types of samples: **Mighei** (this study), ordinary chondrite L5 **Tsarev** and the artificial simulant of CM chondrite (**CM***) [9]. In these experiments, the laser pulse heating led to local melting, formation of the melt droplets and their subsequent quenching with partial crystallization. This resulted in formation of compositionally zoned Mg-olivine crystals cemented by Fe-rich glass contains dispersed very fine (0.1 to 1μm) Fe-rich opaque inclusions. The olivine composition is obviously dependent on the Mg/Fe ratio in the initial material. The volatile components ($H_2O$ of phyllosilicates and $CO_2$ of carbonates) have undoubtedly escaped from the melting products. This led to practically complete disappearance of the 3 μm absorption bands and to overall smoothing of the spectral curve of the irradiated **Mighei**. Preliminary comparison of spectra of irradiated **Mighei** with those of low-albedo asteroids shows, that the spectra of our experimental products are "redder" than C-asteroids and are close to spectra P-, D-, and T-asteroids, majority of which also lacks the 3 μm absorption feature. Preliminary comparison of our spectra with spectra of Phobos has shown, that irradiated **Mighei** samples have a slope of the spectrum curves being intermediate between those of two optically different materials which have been detected on this satellite [10].

**Conclusions**

Results of our experiments, as well as works of other researchers (see, e.g., [6-8]), show that chemistry and mineralogy of mature regolith on S-asteroids (parent bodies of ordinary chondrites), on C- and D-asteroids (parent bodies of carbonaceous chondrites) and on Phobos (possible parent body of carbonaceous chondrite Kaidun [11]) have to be noticeably different from those of unaltered materials of those bodies, that should be reflected in the reflection spectra of the bodies. In particular, the obvious cause of spectrally observed dehydration of surfaces of C- and D-asteroids, as well as Martian satellites, is micrometeorite bombardment leading to formation on these bodies of mature dehydrated regolith.

*The work was supported by RFBR grant 02-05-65156*

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*Electronic Scientific Information Journal "Herald of the Department of Earth Sciences RAS" № 1(22)'2004*
*Informational Bulletin of the Annual Seminar of Experimental Mineralogy, Petrology and Geochemistry – 2004*
*URL: http://www.scgis.ru/russian/cp1251/h_dgggms/1-2004/informbul-1_2004/planet-7e.pdf*
*Published on 1, July, 2004*

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