SIMULATION OF SPACE WEATHERING PROCESSES IN THE UPPERMOST REGOLITH LAYER ON PHOBOS

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Introduction: Spectral results from Mariner 9 and Viking missions, low albedo of the surface and low mean density of Phobos had led to suggestion that this Martian satellite composition was best matched by carbonaceous CM-chondrites [1]. The later work found out that Phobos surface is optically heterogeneous and consists of two spectral units, none of which fits to CM-chondrite spectra [2-4]. "Red" spectral slope, shallow absorption features and lack of 3-μm hydration band appear to be caused by space weathering of the surface material. The goal of this work was simulation of space weathering of regolith on Phobos by micrometeorite bombardment of the surface and following study of optical and mineralogical changes of the "weathered"matter.

Experimental method: To simulate the Phobos material an artificial mixture was prepared consisting of: 46 mass % of non-magnetic fraction of L5 chondrite Tsarev [5], 47% of serpentine, 5% of natural carbonaceous material kerite and 2% of calcite. Chemical compositions of the mixture and its main components are presented in the Tab. 1. The micrometeorite impact melting was simulated by impulse laser irradiation of powdered (mostly to <30μm) sample under (2–3) x 10^{-4} mm Hg vacuum. The solid-state Q-switch Nd:YAG cw pumped laser (λ = 1.064μm, impulse frequency 30–40 KHz, laser power 1.2 KW) was used [6]. Pulse duration was 0.5–1 μsec and laser beam was 100 μm wide. During the laser treatment powdered particles melted forming spherical glassy droplets up to 0.3 mm in diameter and their aggregates. They were sieved into several size fractions. It is seen under binocular microscope that the coarser (>125 μm) fraction contains only the melted (altered) material, while the finer fraction (<125 μm) consists of both altered and unaltered particles. For spectral analyses in this work was used only the >125 μm fraction, the half of which (by weight) was ground into powder.

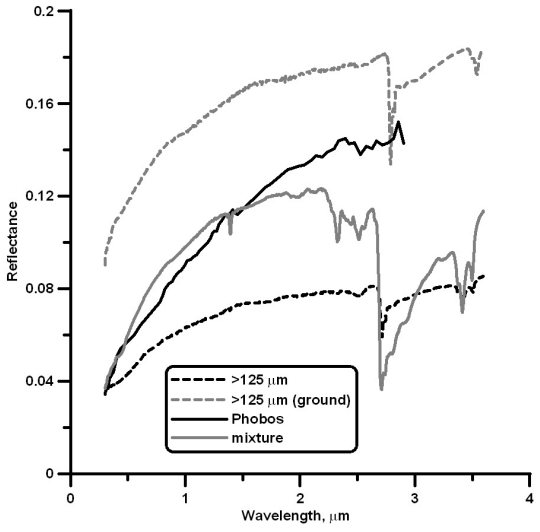

Fig. 1. Reflectance spectra of initial "mixture", of laser-irradiated sample >125 μm fraction and of the trailing hemisphere of Phobos [3].

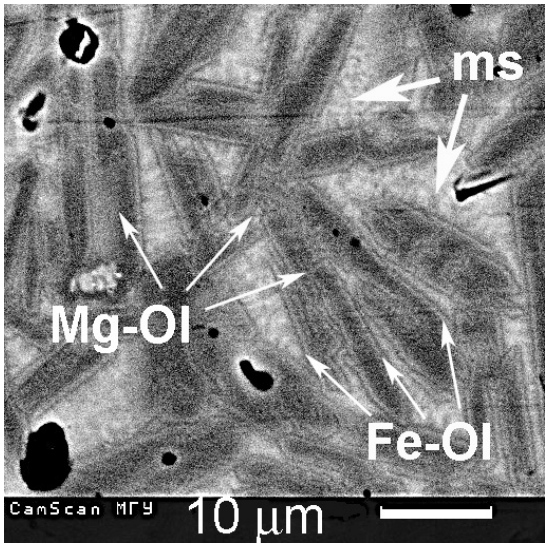

Fig. 2. BSE image of altered glassy droplet: Mg-Ol – elongated Mg-olivine crystals with Fe-olivine envelopes, ms – Fe-enriched mesostasis.

Reflectance Spectra: Visbile-near-infrared (Vis-NIR) reflectance spectra of the samples were measured in the range of 0.3-25 μm using Nicolet 740 and Nexus 870 spectrometers at Brown University. Shown in Fig. 1 are reflectance spectra of unirradiated "mixture", laser-irradiated sample >125 μm fraction, the same ground fraction and of the trailing hemisphere of Phobos [3]. The spectra only up to 3.6 μm are plotted in the figure, since this is the range where primitive asteroids and dark

satellites such as Phobos are often spectrally observed using ground-based telescopes. The UV fall-off in the spectra of our unaltered and altered samples starts at much longer wavelength than in the spectra of natural CM chondrites or C-type asteroids where it occures shortward of 0.5 μm, so in this respect the Vis-NIR spectra of our simulant are more similar to those of Phobos. Deep absorption bands of OH at 2.7-3 μm and CH at 3.4-3.5 μm in the initial mixture are significantly decreased in altered sample. The similar trend of decreasing UV, OH, and CH absorption strengths is also seen in the spectra of heated samples of Murchison CM2 carbonaceous chondrite [7]. In general, our laser-irradiated ground sample (>125 μm) is brighter than Phobos spectrum, but its red continuum and lack of absorption features in the range of 0.3-2.5 μm matches Phobos spectrum within the limits of measurement.

Mineralogy and petrology. Chemistry analysis (tab.1) and BSE imaging of altered samples were made at the Moscow State University using Link AN-10000 microprobe facility and SEM (CamScan 4 DV). Unfortunately, the homogeneous grain size of the initial material has not been achieved, so some serpentine particles are up to ~100 μm across, being coarser than the majority of the "mixture" clasts ($\leq$ 30μm). Some of these large serpentine particles remained unmelted and welded to the glassy droplets forming very porous contact zones. The melted material does not contain the unmelted clasts in the droplet interiors but in some cases small unmelted clasts stuck to droplet surfaces. The melt is partly crystallized forming intersertal texture. The bulk chemistry of the melt is similar to that of the initial material except some depletion in FeO and slight enrichment in CaO and Al_2O_3. The crystallization of the melt was resulted in formation of skeletal needle-like Mg-rich (Fa=6.8 mole % on average) olivine crystals with very thin (<1 μm) Fe-rich outer zones (fig. 2). The crystals are cemented by glassy mesostasis, which is compositionally heterogeneous: the "brighter" zones on BSE images are enriched in Fe comparing to the "darker" ones (Table 1).

Table 1

	CM	Tsarev	Serpentine		"Mixture"		Altered material				
			With LOI	LOI free	With LOI	LOI free	Bulk "melt"			Ol	Meso stasis
							mean	"bright"	"dark"		
SiO_2	32.70	44.84	40.71	47.26	39.24	44.28	45.4	42.5	48.3	42.3	52.3
TiO_2	0.11	0.14	0.02	0.02	0.08	0.09	0.1	0.1	0.1	0	0.1
Al_2O_3	2.56	2.56	0.48	0.56	1.43	1.61	1.9	1.6	2.2	0.1	3.8
FeO	32.92	20.95	4.73	5.49	13.54	15.28	12.7	17.8	7.6	6.5	17.3
MnO	0.25	0.36	0.04	0.05	0.19	0.21	0.3	0.2	0.3	0.2	0.4
MgO	23.04	27.86	39.67	46.05	31.45	35.50	36.4	35.1	37.7	50.3	17.2
CaO	2.18	1.97	<0.01	<0.01	1.93	2.18	2.4	1.9	2.8	0.3	7.1
Na_2O	1.26	<0.01	<0.01	<0.01	<0.01	<0.01	b.d.	b.d.	b.d.	b.d	b.d.
K_2O	0.11	0.15	<0.01	<0.01	0.04	0.05	b.d.	b.d.	b.d.	b.d	b.d
P_2O_5	0.56	0.48	0.03	0.03	0.23	0.26	0.3	0.7	b.d.	b.d.	b.d
Cr_2O_3	1.07	0.62	0.43	0.51	0.47	0.53	0.4	b.d.	0.9	0.3	0.9
S	3.24	n.d,	n.d.	n.d.	n.d.	n.d.	0.1	0.1	0.1	b.d	0.9
Σ	100.0	99.94	86.14	100.0	88.61	100.0	100.0	100.0	100.0	100.0	100.0
LOI			12.98		10.92						
Σ_{LOI}			99.12		99.53						
MG#	55.5	70.3		93.7		80.5	83.6	77.8	89.8	93.2	63.9

Conclusions. The laser irradiation led to the melting of the particles of Phobos regolith analog with formation of skeletal compositionally zoned Mg-olivine crystals cemented by Fe-enriched mesostasis and to dehydration of the sample. The complete lack of 3-μm feature in the altered sample spectrum has not been achieved probably due to remained unmelted serpentine particles. It appears that thin (<1 μm) Fe-olivine envelopes on the olivine crystals and the presence of Fe-enriched mesostasis lead to the general darkening and reddening of the spectra of altered sample. Apparently the same changes take place on Phobos as a result of micrometeorite gardening of the uppermost regolith layer. The red continuum and lack of absorption features approach the spectrum of laser-irradiated analog sample to the Phobos' one (in the range of 0.3-2.5 μm).

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