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X-ray and ion beam study of natural olivine $(Mg_{1-x}Fe_x)_2SiO_4$

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The short characteristic of crystallographic and physical properties of olivines is presented, and also some features of the experimental methods used for their testing are discussed. The element composition and structure perfection for group of natural olivines with various geneses were diagnosed. The simple way of the natural olivine analysis by X-ray diffractometry method of the olivine textures produced owing to the magnitocrystalline anisotropy of these crystals is offered.

The mineral with name olivine represents a solid solution $(Mg_{1-x}Fe_x)_2SiO_4$ which extreme members have the name forsterite (Mg_2SiO_4) and fayalite (Fe_2SiO_4). Interest to properties and features studying of this mineral is caused by that it is the rock-forming component of the Earth upper mantle and simultaneously represents one of two basic phases forming iron-stony meteorites-pallasites [*Willie.* 1971]. In particular, the comparative analysis of admixture composition and degree of the crystal structure imperfection for olivines with different composition and origin history allows to hope for use of this mineral as the independent detector of particles energy and its atomic weight in cosmic radiation streams.

Olivine group D_{2h}^{16} - P_{bnm} concerns to the rhombic system. Lattice constants of this mineral vary from values a_1=0.4762 nm, b_1=1.0225 nm, c_1=0.5994 nm, corresponding forsterite, to sizes a_2=0.4815 nm, b_2=1.0466 nm, c_2=0.6099 nm, peculiar fayalite. The element composition variation allows to estimate intervals of parameters change featured for a olivine crystal lattice: Δa=0.0053 nm, Δb=0.0241 nm, Δc=0.0105 nm. Structural motive of olivine crystals formation is a hexagonal close-packed array atoms of oxygen (ABAB) with existence of some distortions. Layers are packed along “a” crystallographic axis. That is the reason why the change of this lattice parameter at transfer from Mg_2SiO_4 to Fe_2SiO_4 is smallest. Coordination number of the structure is z=4. At the element composition change from Mg_2SiO_4 to Fe_2SiO_4 the crystal density of olivines varies from 3.2 to 4.4 g/sm^3. Mg_2SiO_4 is colourless. Replacement of Mg on Fe atoms leads to occurrence of a greenish shade, and at considerable concentration of iron - to change of colour to brownish-black. The farsterite crystals interaction with a magnetic field shows diamagnetic behaviour. At Fe atoms appearance in the structure olivine transforms it into paramagnetic anisotropy state. For example, the magnetic susceptibility of $(Mg_{0.98}Fe_{0.02})_2SiO_4$ has values $\chi_c=77.2\cdot10^{-6}$; $\chi_b=58.2\cdot10^{-6}$; $\chi_a=56.9\cdot10^{-6}$ [*Ferre.* 2005]. Experimental investigations show, that for all olivine compositions the next relation $\chi_c>\chi_b\cong\chi_a$ is right.

This work presents the results of experimental investigations of olivines a terrestrial and space origin by methods a X-ray diffractometry, TXRF spectrometry [*Klockenkamper*, 1997] and ion beam analysis [*Chu and all,* 1978]. X-ray diffractometry measurements were carried out with use HZG-4 digital goniometer in conditions of the standard focusing geometry, using symmetric and asymmetrical geometry of an analyzing sample installation. The asymmetrical geometry application is the important experimental means for study of monocrystals when their external surface is not parallel to the crystallographic planes chosen for analysis. TXRF measurements were carried out as with use the special TXRF cell, and on base of the digital goniometer application in the conditions of sliding falling of X-ray primary exciting beam. In both cases X-ray exciting beam was formed by means of a quartz wave guide-resonator.

The ion beam testing of olivine samples has been executed on the ion beam analytical complex Sokol-3 by Rutherford backscattering (RBS) He^+ and H^+ ions with energy $E_0 \approx 1.5$ MeV.

Figure 1 shows TXRF spectrum of $(Mg_{0.88}Fe_{0.12})_2SiO_4$ olivine monocrystal having a terrestrial origin. The orientation of its reflecting surface has (0k0) configuration. The spectrum is characterized by a low intensity of the background component and is free from matrix effects. He allows to estimate the relative content in the sample of matrix elements Si and Fe and concentration of basic impurities (Ca and Mn). At the same time, despite the highest sensitivity of TXRF spectroscopy the spectrum does not allow to estimate adequately the content of all matrix elements featured for olivine structure. Such estimation can be carried out on the basis of RBS spectra approximation. Figure 2 presented RBS experimental spectra of He^+ and H^+ collected for case of the olivine crystal random orientation. On inserts the geometry of measurements is shown. Detailed approximation of spectra has shown, that the composition of the sample corresponds to $(Mg_{0.93}Fe_{0.07})_2SiO_4$.

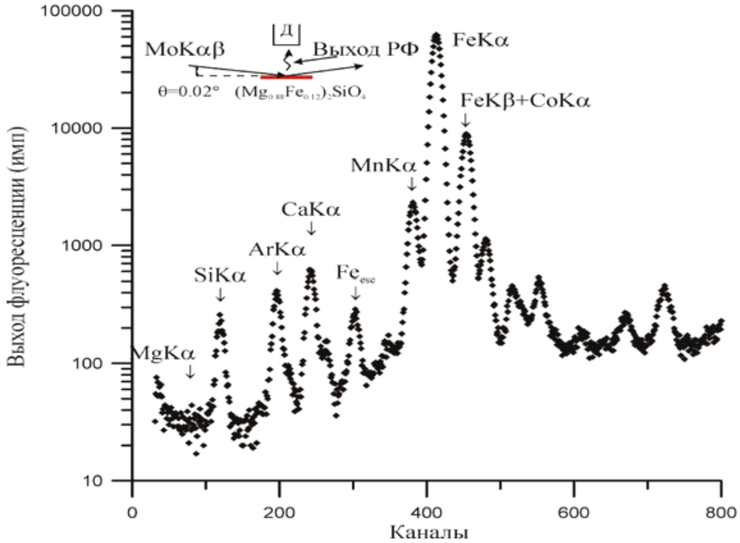

Fig. 1. TXRF spectrum collected for $(Mg_{0.88}Fe_{0.12})_2SiO_4$, monocrystal at MoKα flux excitation. The channel step δE=15.5 eV, every second channel is shown.

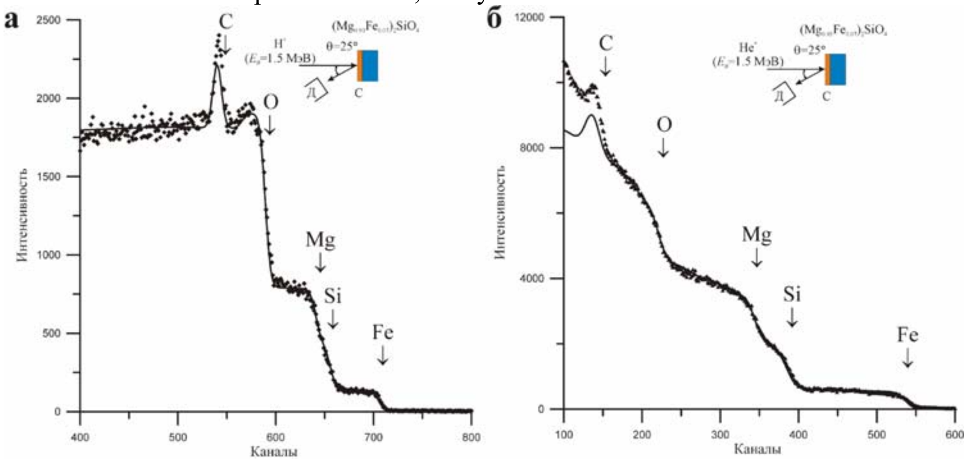

Fig. 2. RBS spectra of He^+ and H^+ collected for random oriented and mechanical polished $(Mg_{0.93}Fe_{0.07})_2SiO_4$ monocrystal. On the sample surface the carbon film with thickness near 20 nanometers is observed. The channel step δE=1.9 keV, every third channel is shown.

Main accent of the investigations was concentrated on X-ray diffractometry of olivine monocrystals. Figure 3 show the pattern of such measurements. The pattern presents the diffraction fragment of (020) reflex area for $(Mg_{0.88}Fe_{0.12})_2SiO_4$ sample and also the angular scan of this reflex registered in the conditions of the motionless detector. Values of FWHM for both sections of reciprocal lattice point, which actually represent the shown fragments, allows to expect rather high perfection of a crystal lattice olivine a crystal. At the same time, RBS measurements executed in parallel with the diffraction study have not shown channeling ion effect for this crystal.

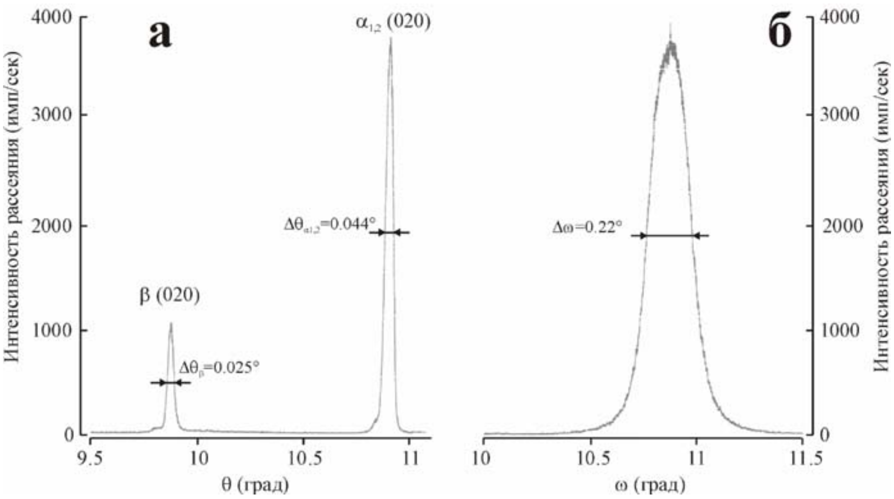

Fig. 3. The pattern of (020) reflex area diffraction fragment for $(Mg_{0.88}Fe_{0.12})_2SiO_4$ monocrystals received with FeKαβ (a) radiation using and its scan (b), fixed at the motionless detector (2θ=21.76°).

In addition to study of terrestrial origin olivines the group of olivine monocrystals extracted from stony-iron meteorites (pallasites) has been analyzed. Results of these investigations are resulted in the table. The table shows, that the olivine element composition is grouped about two concentration positions: $(Mg_{0.93}Fe_{0.07})_2SiO_4$ and $(Mg_{0.86}Fe_{0.14})_2SiO_4$. Available data do not allow to connect the olivine composition with level of its monocrysallinity. Unfortunately, the smallest sizes of there crystals have not allowed to execute ion beam testing for them.

Table 1. Results of diffractometric investigation of mocrystalline olivines of extraterrestrial origin.

№	Reflection section, mm^2	Orienta-tion	Deflection ψ=(ω-θ)	Reflex (hlk)	FHWM $\Delta\theta/\theta_0$	Olivine element composition	Crystallinity level
1.	3	(020)	≈0.2°	(020)	$3\cdot10^{-2}$	$(Mg_{0.84}Fe_{0.16})_2SiO_4$	low
2.	4	(134)	≈0.13°	(134)	$8\cdot10^{-3}$	$(Mg_{0.88}Fe_{0.12})_2SiO_4$	middle
3.	3	(020)	≈0.7°	(020)	$4\cdot10^{-2}$	$(Mg_{0.84}Fe_{0.16})_2SiO_4$	high
4.	5	(131)	<0.1°	(131)	$1\cdot10^{-3}$	$(Mg_{0.91}Fe_{0.09})_2SiO_4$	high
5.	5	(101)	≈3.6°	(101)	$1\cdot10^{-3}$	$(Mg_{0.88}Fe_{0.12})_2SiO_4$	high
6.	4	(021)	≈0.5°	(021)	$2\cdot10^{-3}$	$(Mg_{0.93}Fe_{0.07})_2SiO_4$	middle
7.	7	(002)	≈3.1°	(002)	$1.3\cdot10^{-3}$	$(Mg_{0.86}Fe_{0.14})_2SiO_4$	texture
8.	4	(041)	≈3.8°	(041)	$1\cdot10^{-3}$	$(Mg_{0.92}Fe_{0.08})_2SiO_4$	high
9.	5	(112)	≈13°	(112)	$6\cdot10^{-3}$	$(Mg_{0.94}Fe_{0.06})_2SiO_4$	middle

Additional field meant in the work, is connected with the magnetic textures allowing rather easily to classify polycrystalline and powder olivine fractions on size of lattice parameter “c”. As it has been noted above, the magnetic susceptibility of paramagnetic olivines demonstrates maximum along an axis "c", that allows to build the crystalline texture in a magnetic field with enough value induction, fixing the textures in tablets of epoxy sealant. Figure 4 shows patterns, received for $(Mg_{0.93}Fe_{0.07})_2SiO_4$ of a terrestrial origin in conditions of texturing and random distribution of its polycrystalline fraction. The diffraction fragment of the texturing fraction demonstrates (00l) type reflexes only, and intensities of the peaks are incomparably above of intensities corresponding to the reflexes which are characterized the pattern of the random sample. The angular evolvent of (004) reflex shown on the insertion allows to differ the olivine monocrystal from the texture ensemble. In the result, the using of olivine textures in many cases can facilitate interpretation of geological breeds genesis by such way of the olivine fractions diagnostics.

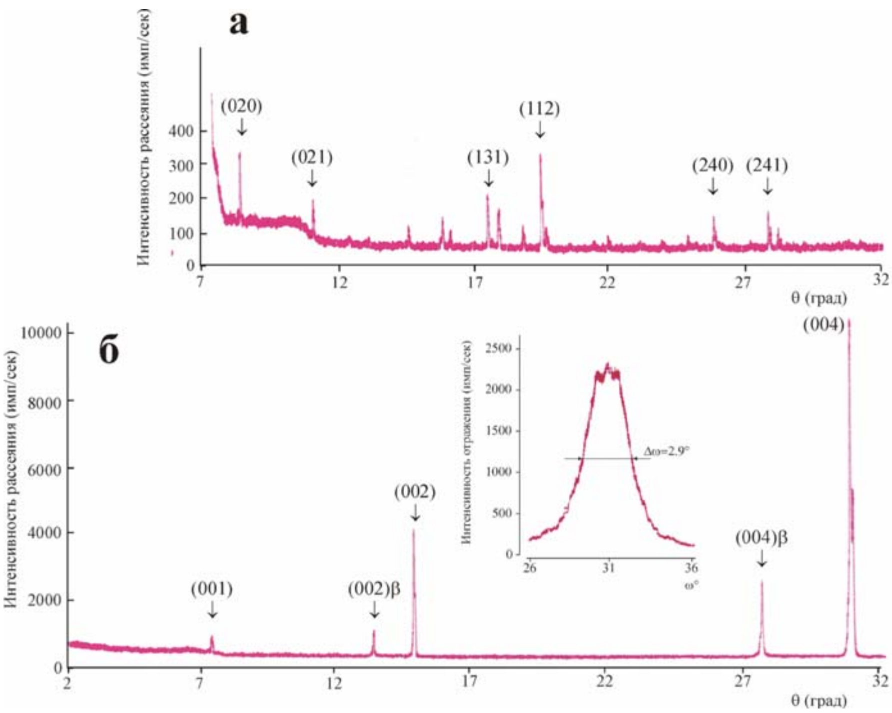

Fig. 4. Patterns of $(Mg_{0.93}Fe_{0.07})_2SiO_4$ olivine samples collected by using of CuKα radiation for the polycrystal ensemble with its random orientation (a) and in condition of the texture state with (00l) primary orientation (b). The insertion presents the (004) reflex angular evolvent collected in condition of the detector position (2θ=61.82°).

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