INVESTIGATION OF THE ORDINARY CHONDRITES MARKOVKA AND POLUJAMKI USING XRF, XRD, MOSSBAUER AND XANES SPECTROSCOPIES

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Introduction: The study of the chemical composition, iron-containing phases and iron oxidation sate allow us to find the structural features, like a Ca-Al rich inclusions (CAIs), and describe the physicochemical processes of meteorites history, such as the aqueous alteration and the thermal metamorphism of the parent bodies. For instance, iron in meteorites before entering Earth atmosphere can exist as Fe^0 in Fe-Ni metal, Fe^{2+} in silicates and sulfides and Fe^{3+} in phyllosilicates and magnetite. During the meteorite evolution, iron as Fe^0 and Fe^{2+} is transformed into Fe^{3+}-rich phases [1,2]. Therefore, determination of the iron oxidation state is of importance for determination of the aqueous alteration parameters in the early Solar System. Here we present a complex investigation of previously poorly studied [3-6] ordinary chondrites Markovka and Polujamki (H4 petrologic type meteorites) done on the basis of 2D X-ray fluorescence (XRF), X-ray diffraction (XRD), Mössbauer spectroscopy and X-ray absorption near-edge structure (XANES) spectroscopy.

Methods: The stone meteorites were polished by the diamond tip and were studied on the basis of 2D XRF analysis. XRD profiles, ^{57}Fe Mössbauer spectra and Fe *K*-edge XANES spectra were obtained for the samples in the form of powder. Micro-XRF with 2D-surface resolution of 25 μm of the meteorite samples were done using M4 TORNADO (Bruker) spectrometer. We have made the visualization of the chemical maps in the selected areas which allowed us to do further advanced analysis, such us elements identification and quantitative analysis. The XRD profiles were measured using a D2 Phaser (Bruker) diffractometer and qualitative and quantitative phase analysis was done. Mössbauer measurements were performed at 15, 50, 100, 150, 200, 250 and 300 K in the closed-cycle helium CCS-850 (Janis Research) cryostat using the MS1104Em spectrometer. Fe *K*-edge XANES spectra were measured using the laboratoy R-XAS Looper (Rigaku) spectrometer installed in the Southern Federal University (Russia).

Results: According to the XRF maps of Fe, Ni, Si, Mg, S, Ca, Al, Mn, Ti, P and Cr the meteorites contain generally Fe-Ni and Mg-Si components. Mn is generally co-located with Si and Mg, consistent with the presence of Mg-silicates, while Ti, Cr, P and S are more localized (with scale about 100 μm) and not correlated with Si. The chondrites contain a significant amount of sulfur, that is opposite located to Mg-Si component like as Fe and Ni. The CAIs and the areas with high content of S, K, P and Cr was found in the meteorites.

According the data of Mössbauer spectroscopy speciation of Fe phases is similar in both metheorites and can be described by goethite (α-FeOOH) 46%, olivine 20%, hematite (a-Fe_2O_3) 14%, pyroxene 10%, troilite (FeS) 7% and Fe-Ni alloy (less than 3%). XRD patterns indicate additional presence of magnesium silicates and nacrite, while metallic iron of Fe-Ni alloys were not distinguishable using laboratory diffractometer.

The average oxidation states of the Fe in meteorites was obtained using XANES spectroscopy. It was estimated by two methods based on the energy position of the absorbtion edge and the energy position of the pre-edge centroid [1]. The averaged values of Fe oxidation state were then determined. It was found that the iron oxidation states of Markovka and Polujamki chondrites are +2.2 and +2.3 respectively (±0.1).

Conclusions: The XRF maps of the Markovka and Polujamki ordinary chondrites showed the CAIs and the areas with high content of S, K, P and Cr. According to XRD and Mössbauer spectroscopy, Fe-containing phases of the meteorites consist mainly of olivine, pyroxene, hematite and goethite with less amount of troilite and Fe-Ni alloy. The iron oxidation states of the meteorites obtained by XANES spectroscopy are +2.2 and +2.3 for Markovka and Polujamki respectively. Consequently, the studied meteorites did not undergo significant aqueous alteration.

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