ABLATION SPHERULES OF THE SIKHOTE-ALIN IRON METEORITE SHOWER.

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Introduction: Meteorite ablation spherules have close relations to fusion crusts and are formed by ablation and separation from meteoroids during their entry into the atmosphere [1]. Textures and compositions of ablation spherules can provide some information on the parameters of the entry heating. MAS should be rare relative cosmic spherules but there are a few layers in the Antarctic ice sheet rich in cosmic matter that has been considered as products of meteorite ablation events [2, 3, 4]. However, the main meteorite masses responsible for the horizons are absent and the comparison of the dispersed matter with the parent bodies is impossible. The ablation spheres found at a region of the Sikhote-Alin (SA) meteorite shower fall [5], 1947, give an unique possibility to study them using data on the well-characterized iron meteorite.

Samples and techniques: In the work we used spherules magnetically collected at the main crater field of the SA meteorite shower in 1948 – 1949 [5]. The spheres were sectioned and studied using standard methods of optical microscopy, ASEM (an JEOL JSM 6400 microscope), and EMPA (an JEOL JXA-8200 microprobe). The bulk compositions of spheres were obtained by averaging broad beam EMP analyses. Total number of studied spheres is 159.

Results: The spherules have black colour and shiny or dull lustre and are similar in the appearance to artificial produced spheres, e.g. by welding. Their shapes are spherical (~ 80%) or ovoid. Vast majority of the spherules contains central vesicles that occupy 1/3-2/3 of spherule diameters. Some spherules contain open cavities. Vesicle surfaces are covered either clusters of needle-like dendrites of magnetite (Fig. 1) or aggregates of magnetite crystals (Fig. 2).

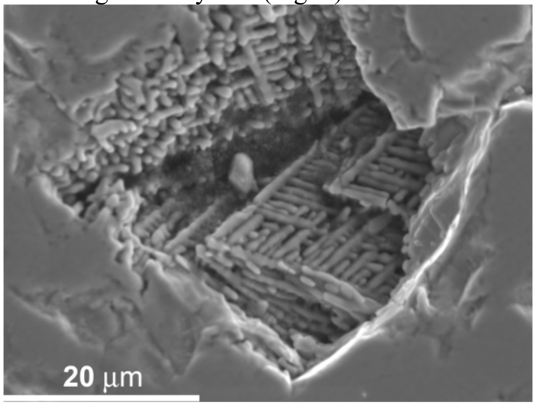

Fig. 1. Magnetite dendrites covered inner surface of a central vesicle in a fine-grained ablation spherule.

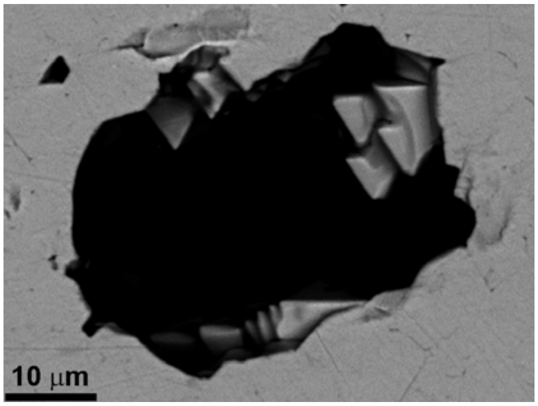

Fig 2. Magnetite tetrahedral crystals in a central vesicle of a coarse-grained ablation spherule.

All but two spherules consist of Ni-containing magnetite, sometimes with wustite. There is also a phase close in the composition to iron phosphate that occupies an intergranular space, a silicate glass is present too.

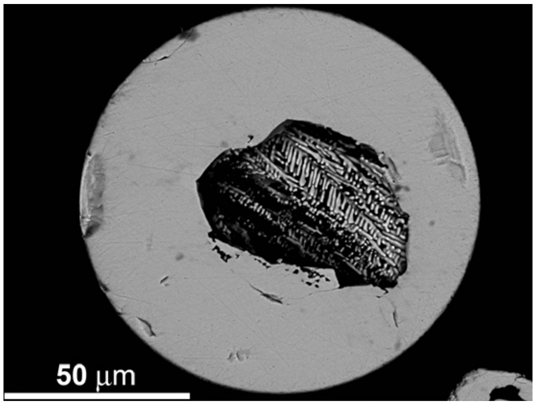

Fig. 3. BSE image of fine-grained ablation spherule.

The spherules can be divided on two groups according to their textures. The first group is present by fine-grained spherules having central vesicles lined with needle-like magnetite dendrites (Fig. 3). The group dominates among the fraction < 0.15 mm in size. Magnetite is only phase in these spherules. The NiO and CoO contents range mainly from 4.3 to 6.8 wt.% and from 0.5 to 0.6 wt.%, respectively. Both low in NiO (0.1-0.5 wt.%) and high in NiO (>10 wt%) magnetite is rare. Coarse-grained spherules with 10 – 50 μm in size crystals of magnetite (Fig. 4) are attributed to the second group that dominate in the fraction > 0.3 mm in size. Magnetite of the group contains 0.5 – 11.5 wt % of NiO and 0.6 – 0.7 wt.% of CoO. Some spherules of this group contain wustite that occupies central parts of the spherules. An interstitial iron-phosphate phase contains some SiO2 (~0.5 wt%), a composition of the Si-containing phase is close to fayalite but contains also Al2O3 and MgO.

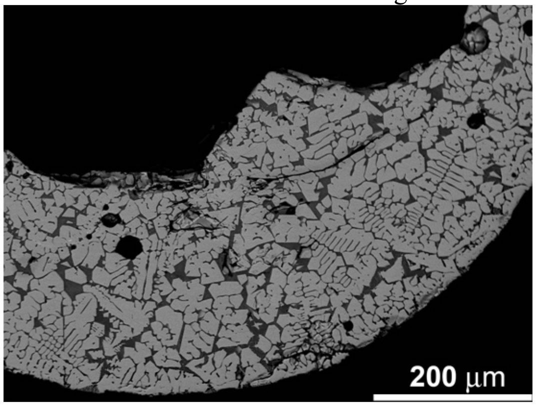

Fig. 4. BSE image of coarse-grained ablation spherule part, magnetite is gray, interstitial P-containing phase is very dark gray, epoxy is black.

Bulk compositions of all spherules are characterized by dominance of particles with NiO concentrations range from 3 to 6 wt.%. Average atom Fe/Ni ratios for bulk compositions of fine-grained and coarse-grained spherules are 18,0±2,7 и 15,7±3,9, respectively (Fig. 5). P2O5 contents in coarse-grained spherules vary from 0.1 to 0.7 wt.% and is less than 0.1 wt.% in fine-grained spherules.

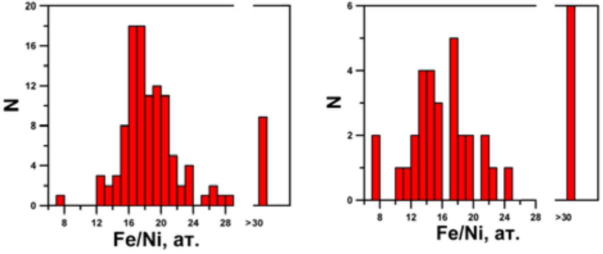

Fig 5. Distributions of Fe/Ni atom ratios for fine-grained ablation spherules (left) and coarse-grained ablation spherules (right).

Discussion: Between all spheres we discriminate only two particles as terrestrial because of a lack of Ni and presence of some elements in concentrations that are non-characteristic for iron meteorites. Compositions of most of the Ni-containing spherules are close to a composition of the SA meteorite [5] although a fraction of the spherules have higher or lower Ni and Co contents (Fig. 5). The spherules have textures and mineralogy sharply distinct from obvious background type I cosmic spherules [6]. We conclude that the spherules originated by ablation of the SA meteoroid.

The spherules formed by fast crystallization of magnetite from melt as it follows from the quench textures. According to a melting diagram of the Fe-O system [7] magnetite starts to crystallize at 1600ºC. The temperature should be a minimal estimation of heating of the fusion crust. The SA iron contains also rare chromite nodules. Hence, one should expect a presence of Cr in a fraction of the ablation spherules due to high degree of melt homogenization by the fusion crust formation [1]. However, Cr is absent in magnetite and other phases. We suppose that the heating was not high enough for melting of $FeCr_2O_4$ and the highest estimation of the temperature is 2180ºC. Also we estimate the oxygen fugacity during the ablation to lie in range from 10^{-4} to 10^{-1} atm using Ni-NiO and Fe_3O_4-Fe_2O_3 buffers. This high oxygen fugacity should lead to oxidation of troilite inclusions on ablated surfaces and escape of SO_2 or SO_3. Shreibersite and rabdite disseminated in the SA meteorite (~1.4 %) should oxidize too. We propose a reaction of phosphorous oxides with iron oxides with formation of an interstitial phase (glass?) close in composition to $Fe_3(PO4)_2$. The Si presence in the phase is intriguing because the SA iron is very poor in silicates and we exclude a possibility of contamination of the spherules by terrestrial SiO_2.

The presence of the fine-grained and coarse-grained spherules is connected with different rates of cooling and the distinction in the composition. The coarse-grained spherules contain the interstitial phase rich in P, which evaporation can reduce cooling rates of the spherules.

The studied spherules were collected at the end point of the SA meteorite trajectory and, hence, had to be formed at low altitude. The high oxidation degree of meteorite metal supports it. It has been shown [8] that the SA meteorite body started to break at altitude of 12.3 km. That is one of reasons of the mineralogical, chemical, and textural distinction from type I cosmic spherules that form at higher altitudes.

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