Mineralogical and chemical study of Divnoe ungrouped primitive achondrite.

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Introduction:

The study of primitive achondrites is important to understand the low-temperature igneous differentiation in the early solar system and the link between chondrites and differentiated meteorites. The Divnoe meteorite is one of primitive achondrites which was found in 1981 in Stavropol province, Russia [1]. Divnoe is somewhat similar to brachinite especially in its similarity of oxygen isotopes, but their mineral compositions are distinct [2]. Thus, Divnoe does not belong to any known primitive achondrite groups. However, some meteorites possibly grouped together with Divnoe have been recently found from hot and cold deserts (e.g., RBT 04239 and Tafassasset) [3], and it may be possible to establish a new primitive achondrite group, sharing the common parent asteroid. Therefore, it is necessary to better understand mineralogy and chemistry of Divnoe in comparison with other primitive achondrites.

A characteristic texture of olivine similar to crystallographic preferred orientation (CPO) has been reported for Divnoe [4]. CPO is a kind of petrofabric texture which develops during the transformation caused by the dislocation creep and/or crystal accumulation [5]. The dislocation creep is a common transformation mechanism of major constituent minerals in the lower crust and upper mantle of the Earth [6]. The existence of CPO in Divnoe thus may shed light on mantle convection in the parent body since similar texture has been reported in an olivne diogenites [7]. Alternatively, it was formed by some other mechanism which has been unknown in primitive achondrites. In this study, we performed EBSD (Electron Back Scatter Diffraction) analysis of Divnoe to quantitatively evaluate its petrofabric texture and discuss its origin. We also measured its bulk elemental composition to further understand its petrology and mineralogy.

Sample and Experimental Procedures:

We first observed two polished thin sections of Divnoe (#11 and #16) that were prepared from the same rock chip by optical microscopy. Mineral compositions and elemental mapping were obtained by electron probe micro analyzer (EPMA, JEOL JXA 8800). Then, we analyzed one of the thin sections (Divnoe #11) using FEG-SEM (JEOL JSM5900LV) equipped with EBSD detector and obtained crystal orientation maps using HKL's CHANNEL 5 software.

Bulk chemical compositions of Divnoe were measured using ICP-MS at Tokyo Metropolitan University. The procedures are similar to [8].

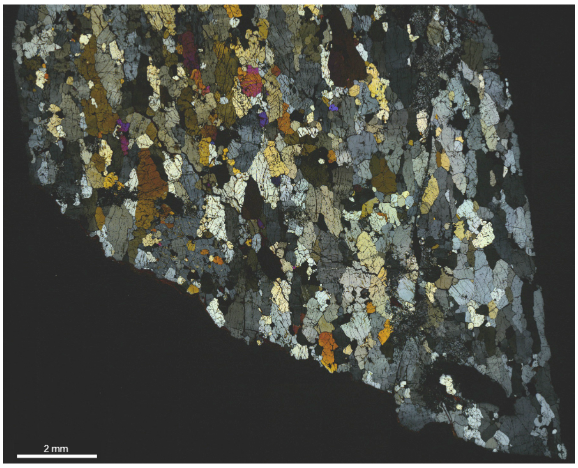

Fig. 1. Photomicrograph of a thin section of Divnoe (#11) (crossed polarized light), showing obvious preferred orientation of constituent olivine crystals.

Results:

The studied Divnoe sections are mostly composed of olivine with small amounts of pyroxenes. The average olivine size is 1 mm long and 0.5 mm wide and pyroxene is a little bigger than olivine. The size of pyroxene reaches 1 mm x 2 mm. Shock metamorphism is weak to moderate as seen from undulatory extinction of olivine. The optical microscopy shows an obvious preferred orientation of olivine crystal in both sections (Fig. 1) and inverted pigeonite is also observed. The presence of inverted pigeonite indicates that this meteorite experienced a slow cooling event. EPMA elemental maps show that the chemical composition of olivine is fairly homogeneous (Fo_{80-72}) (Fig. 2). These observations are consistent with [2].

We collected a crystal orientation map (5.0 x 6.5 mm) in one of the Divnoe sections (#11) by EBSD. Almost all points were well indexed by the olivine structure and matching with the distribution of olivine as obtained by elemental mapping (Fig. 2). The results of EBSD analyses are plotted as stereographic projections of upper-hemisphere, equal-area plots according to the main olivine crystallographic axes [100], [010] and [001], respectively. The representative pattern of the CPO of olivine is pronounced with the [001] axis (Fig. 3).

Bulk chemical analysis of Divnoe shows that light rare earth elements (LREE) are strongly depleted (e.g., La <0.01 x CI), implying crystallization of a fractionated melt [2]. Siderophile elements are slightly depleted compared to chondirtes (e.g., Ir, Pt ~ 0.5 x CI).

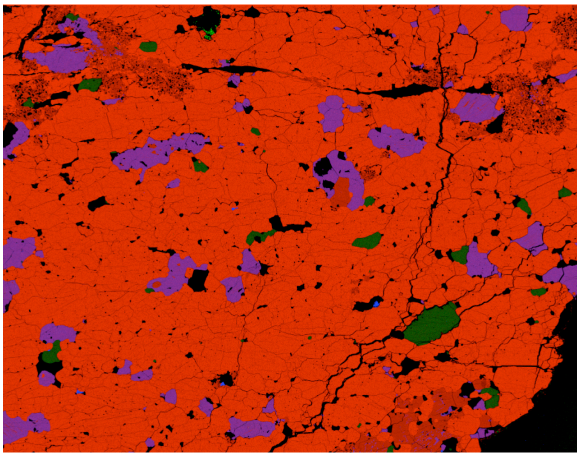

Fig. 2. Mg (red), Al (green) and Ca (blue) distribution map (9 x 7 mm) of Divnoe, showing that the sample is mostly composed of homogeneous olivine.

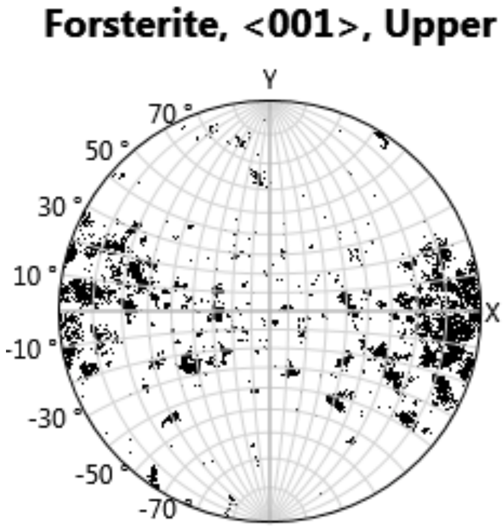

Fig. 3. Stereographic projection of the crystal orientation of [001] (*c* axis) of olivine grains in Divnoe (PTS #11).

Discussion and Conclusion:

Our EBSD study of Divnoe olivine confirms the presence of CPO parallel to [001] axis (elongated dimension), as reported by [4]. The interpretation of CPO in Divnoe olivine is possible by comparing it with known CPO of olivine in terrestrial rocks and those generated by experimentally deformed olivine. In the study of CPO of olivine in terrestrial rocks, it is known that there are representative patterns of CPO determined by the slip system which formed the pattern (e.g., A-, B-, C-, D- and E-type fabrics in [7]). The CPO of Divnoe olivine is similar to the B- or C-type fabric patterns, both of which are considered to be formed under low temperature condition (<1000 ^{o}C) [9]. This may imply a low temperature igneous differentiation in the parent body related to the segregation of Fe-FeS melt.

We consider that the most likely scenario is that Divnoe olivine was formed by accumulation of olivine crystals in magma as suggested by its petrofabrics and lithophile contents. This is consistent with [4]. Probably, cumulus olivine settled down in convecting magma with their longer dimensions ([001] axis) parallel to a flowing direction at the bottom of the magma chamber. Similar cumulate texture is found in pyroxenes of Zagami Martian meteorite [e.g., 10]. However, Divnoe contains high abundance of siderophile elements especially platinum group elements (PGEs) as for a cumulate rock. This may suggest that Divnoe is a residue of partial melting.

Thus, the petrographic texture and LREE composition imply that Divnoe is a cumulate rock, but siderophile elements composition indicates that the Divnoe meteorite is a residue of partial melting. Probably, Divnoe experienced more complex history than previously thought, for example involving addition of Fe metal by impact. More detailed study should be needed to clarify the formation process of the Divnoe meteorite on its parent body.

References:

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