

Mineralogical comparison of Northwest Africa 6112 and Divnoe ungrouped achondrites.

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Introduction:

Primitive achondrites have textures suggesting that they were either (partially) molten, partial melt residues or extensively recrystallized, but at the same time have petrologic characteristics, whole-rock chemical compositions or oxygen isotopic compositions that indicate a close affinity to chondrites [e.g., 1]. Thus, primitive achondrites provide information about the early differentiation processes involved in the transition from chondritic materials to achondrites [e.g., 2]. In our previous studies, we paid particular attention to olivine-rich primitive achondrites, because rocks dominantly composed of olivine are generally thought to be formed in the earliest stages of differentiation. Therefore, we consider that studying primitive achondrites mainly composed of olivine contributes to an understanding of the processes involved in planetary differentiation and provides valuable information about the earliest stages of igneous evolution of planetesimals in our Solar System.

In this study we analyzed Northwest Africa (NWA) 6112 and Divnoe. Both of these meteorites are mostly composed of olivine and Divnoe has a characteristic texture of olivine similar to shape preferred orientations (SPO) and crystallographic preferred orientation (CPO) [e.g., 3,4] (Fig. 1). Since such a petrofabric texture generally develops during the transformation caused by the dislocation creep and/or crystal accumulation, analyzing such petrofabric textures will help to improve our understanding of the formation processes of these meteorites [e.g., 5].

Samples and methods:

We prepared three polished thin sections (PTSs) of NWA 6112 and Divnoe (#11 and #16). The PTSs were studied using optical and scanning electron microscopy. Mineral compositions and elemental mapping were obtained by electron microprobes (JEOL JXA 8900L and JXA 8530F at Univ. of Tokyo). To analyze CPO, we used FEG-SEM (JEOL, JSM 7100F at NIPR) equipped with EBSD (electron backscatter diffraction) detector (Oxford AzTec Energy) and obtained crystal orientation stereographic nets using HKL's CHANNEL 5 software. We measured one point per one olivine grain of each PTS. The oxygen isotope composition of NWA 6112 was measured by infrared laser-assisted fluorination at the Open University.

Results:

The thin section of NWA 6112 shows a dark

appearance similar to ureilites [e.g., 6] and is mainly composed of olivine (~70%; Fo_{73.2}; CaO=0.1 wt.% and Cr₂O₃=0.04 wt. %) with minor amounts of clinopyroxene (~5%; En_{46.1}Wo_{43.3}) and plagioclase (~5%; An_{20.8}) (Fig. 2). All of these minerals are coarse-grained and the largest clinopyroxene grain is 8 x 14 mm in size. These major minerals are homogeneous and do not show chemical zoning. At the boundaries and edges of these major mineral grains or along their cracks, fine-grained orthopyroxene (En_{75.5}Wo_{1.7}; ~30 μm in size), iron sulfide (Fe=~60 wt.%, S=~37 wt.%; ~100 μm in size), chromite (Cr₂O₃=57 wt.%, FeO=28 wt.%; ~30 μm in size) and Fe-Ni metal (Ni=~3.5 wt.%; ~20-30 μm in size) are present. The shock degree of NWA 6112 should be very low because only few olivine grains show wavy extinction.

Divnoe mainly contains ~70% olivine (Fo_{~74}) with a smaller abundance of clinopyroxene (En_{~47}Wo_{~43}) (Fig. 1). In our PTSs, plagioclase was not found though previous studies reported plagioclase [e.g., 7]. Minor phases are orthopyroxene (En_{~74}Wo_{~2}), chromite (Cr₂O₃=~56 wt.%, FeO=~27

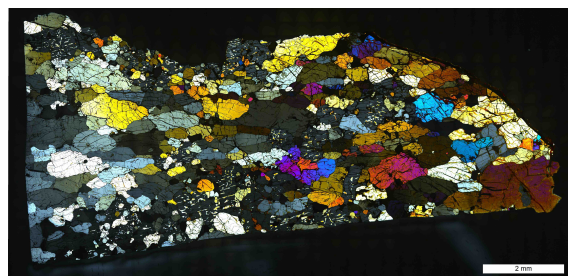


Fig. 1. Optical photomicrograph of a thin section of Divnoe (#16) (crossed polarized light), showing obvious preferred orientation of constituent olivine crystals. The white scale bar is 2 mm.

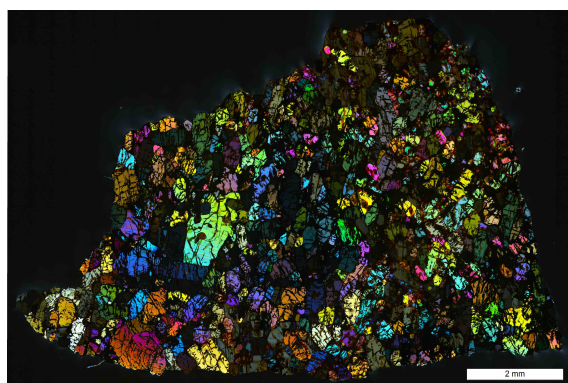


Fig. 2. Optical photomicrograph of a thin section of NWA 6112 (crossed polarized light). The white scale bar is 2 mm.

wt.%) and Fe-Ni metal (Ni \approx 8 wt.%). X-ray elemental maps show that the chemical composition of olivine is fairly homogeneous. The degree of shock metamorphism is weak to moderate as seen from undulatory extinction of olivine. The optical microscopy shows an obvious SPO of olivine crystals in both sections and inverted pigeonite is also observed (Fig. 1). These observations are consistent with earlier studies [3,4,7].

We analyzed CPO of olivine crystals in NWA 6112 by EBSD and also collected more data on Divnoe which we reported in our earlier study [4]. Both NWA 6112 and Divnoe clearly show the same CPO patterns (Fig. 3). Olivine grains in both NWA 6112 and Divnoe are preferentially aligned along [001] (*c* axis) whereas [100] (*a* axis) and [010] (*b* axis) are randomly oriented.

Discussion and conclusion:

The dark appearance of NWA 6112 might be taken to indicate a similarity with the ureilites. However, in NWA 6112, there are no reduction rims in either olivine or pyroxene, in contrast to ureilites where they are developed along the boundaries with the carbon-rich matrix. Additionally, CaO and Cr₂O₃ contents in ureilite olivine are characteristically high (CaO: \sim 0.45 wt. %, Cr₂O₃: \sim 0.85 wt.%), but NWA 6112 has lower CaO (0.1 wt.%) and Cr₂O₃ (0.04 wt. %) [e.g., 6]. Furthermore, plagioclase is present

unlike ureilites. Instead, NWA 6112 has very similar mineralogy (chemical compositions of olivine, pyroxene and chromite) and oxygen isotopic compositions ($d^{17}\text{O}=2.336 \pm 0.005\%$, $d^{18}\text{O}=4.893 \pm 0.010\%$) to Divnoe ($d^{17}\text{O}=2.26 \pm 0.01\%$, $d^{18}\text{O}=4.86 \pm 0.00\%$ [8]) which is classified as “ungrouped achondrite” and also shows an affinity to brachinites [e.g., 9, 10]. Brachinites are mostly composed of olivine (\sim 71-96%; Fo₆₄₋₇₃; CaO \approx 0.08-0.3 wt.% and Cr₂O₃=0.01-0.06 wt.%), major clinopyroxene (minor to \sim 15%; En₄₃₋₆₃Wo₃₆₋₄₈), with variable amounts of plagioclase (0-10%; An₁₅₋₃₃), and minor to trace amounts of orthopyroxene (0-20%; En₆₉₋₇₃Wo₂₋₄) [11]. NWA 6112 also has very similar appearance and mineral compositions to MIL 090340 which had been originally classified as “ureilite” and was reclassified to “ungrouped achondrite” [e.g., 9, 10]. Another similar meteorite is RBT 04239 [13].

The same CPO patterns of olivine grains in NWA 6112 and Divnoe suggest that these two meteorites formed by a similar process. Their closely similar oxygen isotope composition suggests that they may have originated from the same parent body possibly related to that of brachinite. The CPO pattern that *c* axis is preferentially oriented has not been reported in the terrestrial rocks [e.g., 5], but is reported in EET 99407 brachinite [12]. Therefore, it is indicated that NWA 6112 (Olivine: Fo_{73.2}) and Divnoe (Olivine: Fo₇₄) experienced a similar formation process to EET 99407 brachinite, but the mineralogy of EET 99407 (Olivine: Fo₆₄) is slightly different [12]. The mechanism to form this CPO is not clear, but we think that melt flow was somehow involved. Probably, NWA 6112 and Divnoe experienced a more complex history than previously thought. More detailed study will be needed to clarify the formation processes of these meteorites on their parent body and we plan to analyze these meteorites by using the same EBSD technique and so investigate further the nature of the CPO in olivine in these brachinite-like samples.

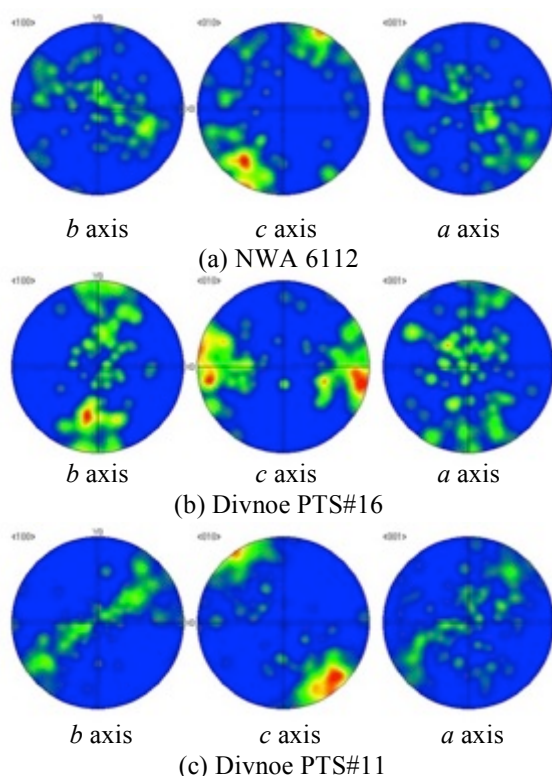


Fig. 3. Stereographic nets of olivine crystals in (a) NWA 6112, (b) Divnoe PTS#16 and (c) Divnoe PTS#11. These were contoured by using HKL’s CHANNEL 5 software. Total measured points were (a) 87 points, (b) 117 points and (c) 172 points, respectively.

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