LAMELLAR OLIVINE IN THE DIVNOE ACHONDRITE: EVIDENCE FOR HIGH-PRESSURE EXSOLUTION? M.I. Petaev, Harvard-Smithsonian Center for Astrophysics, Cambridge, MA, USA

The olivine-rich Divnoe achondrite contains numerous large olivine grains which have a lamellar or banded appearance in back-scattered electron images, caused by minor compositional differences. One such grain, viewed in transmitted light, displays a system of lamellae with the same orientation and scale as the compositional banding. The only process known to produce such structure and chemical variability in olivine grains is high-pressure transformations between α-, β- and γ-olivines, but in other meteorites and in experimental products the structure is ~100 times finer than the Divnoe lamella.

INTRODUCTION The meteorite Divnoe is an olivine-rich achondrite with subchondritic chemistry and mineralogy [1-4]. It has a coarse-grained granoblastic olivine groundmass with relatively large poikilitic patches of pyroxene and, rarely, plagioclase. The groundmass also contains areas of troilite- and/or metal-rich ol-px fine-grained lithology, having reactionary boundaries with the groundmass and different mineral chemistry [5]. Numerous μm- to mm-thick veins of troilite and, rarely, metal cross all the lithologies found in the meteorite.

The major silicate minerals display evidence of weak to moderate shock metamorphism: wavy to blocky extinction in olivine, pyroxenes, and to a lesser degree, plagioclase; irregular, and, rarely, planar fractures in olivine and low-Ca pyroxene, often filled by troilite; strong planar fractures in high-Ca pyroxene. Some plagioclase grains display well-developed twinning, sometimes with diffuse boundaries between twinned crystals. No evidence of shock has been found in metal and troilite.

Olivine and pyroxenes display minor intergrain variations in composition [5] and complex zoning patterns.

OLIVINE STRUCTURE AND CHEMISTRY The most unexpected and intriguing result of this study was the discovery of fine μm-scale chemical variability in olivine grains in the rock whose textural and mineralogical characteristics suggest extensive recrystallization and slow cooling in the temperature range from ~1000°C to ~500°C and lower. In spite of this, in back-scattered electron images many if not all of olivine grains show a lamellar appearance, which seems to be crystallographically controlled (Fig. 1a), caused by minor chemical variations (Fig. 1b). The points on the graph are microprobe analyses made at the dark rounded spots seen in Fig. 1a. In some cases these fine-scale variations are superimposed on large-scale compositional zoning in olivine grains where they are in contact with pyroxene (Fig. 2). In all grains studied so far, the BSE variability is caused by differences in Fe/Mg ratio between lighter (Fe-rich) and darker (Fe-poor) lamellae. The range of variations in most of the microprobe scans done is less than 3 mol.% Fe; however, these points were equally spaced in the scans, not placed according to tones in the BSE images. To define more precisely compositional variability, the lightest, darkest, and some intermediate lamellae were analyzed in three olivine grains. Differences of 2.7, 3.0 and 3.2 mol.% Fe were found (Fig. 3), as well as a strong positive correlation between Fe and Mn, which was only detectable (>0.05 wt.%) minor element. Among several lamellar olivine grains studied by transmitted light, one was found to have 5 - 12 μm-thick lamellae (Fig. 4a) with the same orientation and thickness as the lamellae seen in back-scattered electron images (Fig. 4b). Several other grains with similar structure have been found in thin sections.

DISCUSSION The scale of structural and compositional variations found in Divnoe olivines has not been observed in terrestrial and other extraterrestrial olivines. Ferromagnesian olivines are generally understood to form an almost ideal solid solution between end members, and there is no reason to expect any exsolution to occur. Detailed structural studies of natural olivines has shown some preferred occupation of M1 sites by Fe at high temperatures [6 and references therein], but this would not promote exsolution.

Coexisting minerals with olivine stoichiometry and slightly different Fe/Mg ratios have been found in several highly shocked ordinary chondrites [7-11]. These grains are composed of isotropic polycrystalline aggregates of high-pressure olivine polymorphs—wadsleyite (β) and ringwoodite (γ) — and are characterized by compositional differences up to 8 mol.% Fe between coexisting phases. Some grains display ultratine (up to 0.1 μm) lamellar structure (e.g. Fig. 2c in [11]), qualitatively similar to the structure of Divnoe olivine grains. Experimental [12 and references therein] and thermochemical [13] studies of the high-pressure transformations in olivine have shown that transformations at pressures of 100 - 160 kbar and temperatures of 800 - 1600 K result in substantial difference in Fe/Mg ratios between coexisting polymorphs. Lamellar structure was not found by [12] in their experimentally produced olivine polymorphs, but experimental studies of transformations between α, β and γ phases of Mg2SiO4 at 150 kbars [14] did produce ultratine (up to 0.01 μm) straited microstructure in β and γ phases similar to the structure observed in Divnoe olivine by transmitted light. This structure was interpreted by [14] to be a system of stacking faults that arises during the phase transformation. [14] also found lamellar intergrowths of β and γ phase, but the scale of the lamellae is even finer (~0.001 μm).

Thus, only process known to produce exsolution in olivine is high-pressure transformation between its polymorphs. The structural and compositional similarity between Divnoe olivine grains and the occurrences discussed above indicates that this could explain the Divnoe olivines. But what process was responsible for the transformations? Such high static pressures seem to be unrealistic for meteorites, and the presence of plagioclase in Divnoe limits the static pressure to less than ~30 kbars. The shock features recorded in Divnoe are characteristic of shock pressure of 200 - 300 kbars, enough to produce transformations between α,
β and γ polymorphs in olivine. The chemical variations between lamellae in Divnoe olivine are also comparable to those between olivine polymorphs in highly-shocked chondrites. However, the scale of exsolution is extremely coarse in Divnoe. In addition, lamellae with different compositions in Divnoe are composed only of the anisotropic α-polymorph of olivine. This discrepancy could be explained by low-temperature post-shock annealing which has erased shock features in metal and troilite, and transformed β and/or γ polymorphs to α without changing their compositions.

REFERENCES

Fig. 1. Lamellae in Ol (top) and compositional variations between them (bottom).

Fig. 2. Fine- and large-scale chemical variations in Ol.

Fig. 3. Fe-Mn correlation in lamellar Ol. Data on separate grains are shown by different symbols.

Fig. 4. Lamellar structure in Ol. Width of view 170 µm. A - transmitted light, b - BSE image.