RINGWOODITE IN THE MARTIAN SHERGOTTITE DAR AL GANI 670: THE ROLE OF SHEARING.

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Introduction: Ringwoodite – the spinel-structured high-pressure phase of olivine – has been found in and around melt veins and pockets in several shocked meteorites [e.g., 1, 2, and references therein]. More recently lamellar ringwoodite was described and its formation attributed to either shear-related coherent intracrystalline growth [3], fracture-related incoherent growth [4], or heterogeneous nucleation along specific planes in olivine [5]. However, the formation of lamellar ringwoodite is still a matter of debate.

Here we present the finding of ringwoodite lamellae in sheared olivine of the Martian basalt Dar al Gani 670 shedding new light on its formation

Method: A thin section of Dar al Gani 670 (DaG 670) was studied by optical and scanning electron microscopy. Back-scattered electron images, quantitative mineral analyses, and x-ray elemental maps were acquired with a Jeol JXA 8500F field emission electron microprobe. Raman measurements were performed using a confocal Raman microscope WITec alpha 300 R system operating with a green Nd:YAG laser of 532 nm wavelengths.

Results: DaG 670 is an olivine-phyric shergottite consisting of mm-sized olivine set in a fine-grained groundmass of dominantly pyroxene and plagioclase [6]. Inspection of the DaG 670 section by **optical microscopy** revealed the presence of several cm-sized melt pockets interconnected by melt veins. These veins extend over several cm and – in three cases – crosscut large olivine crystals. In two of these settings parts of the olivine cut by the vein appear to be sheared (Fig. 1) while in the third case no displacement is observed.

Back scattered electron imaging and elemental mapping show significant differences between sheared and non-sheared olivine. In case of the non-sheared olivine the melt vein-olivine interface is characterized by ragged outlines indicating no or only minor melting of the olivine. The vein itself is a highly porous almost structureless melt. Its chemical composition resembles that of the bulk meteorite indicating that the melt initially formed in larger volumes, i.e., melt pockets and was then injected into a preexisting fracture. High-pressure phases of olivine were not found.

In contrast, the textures observed in case of the sheared olivines are quite similar to those found in heavily shocked ordinary chondrites, e.g., gradual contact between host rock and melt vein, quenched vein margins, and numerous FeNi metal and sulfide droplets as well as rounded to sub-rounded mineral fragments entrained in the melt. In the most impressive case (Fig. 1), larger, partially molten and dissolved olivine fragments most likely produced during brittle fracturing are embedded in the melt vein.

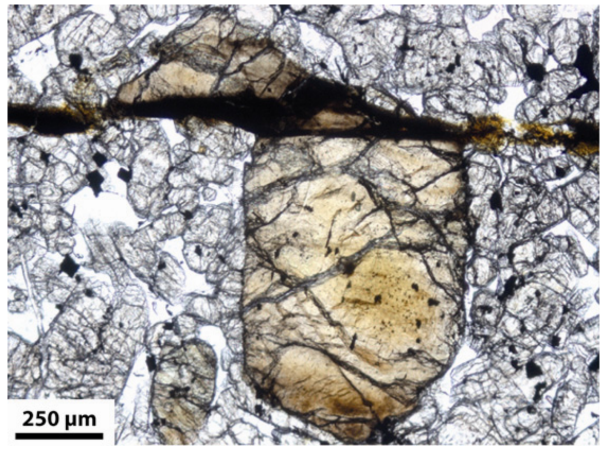

Fig 1. Optical micrograph (parallel polarizers) of a sheared olivine crystal in Dar al Gani 670.

On average, the melt has bulk rock composition except close to the olivine-vein contact where it is more olivine-normative. An only about 0.5-1 µm wide zone of Mg-rich olivine separates the quenched margin of the vein from the sheared olivine host crystal. Composition and texture testify that also this melt formed in larger melt pockets and was injected into preexisting or simultaneously formed fractures.

The most striking features observed in the sheared olivine are thin lamellae extending from the olivine-vein interface into the host olivine (Fig. 2). Similar lamellae are also present in most of the entrained olivine fragments. Elemental mapping shows that the ≤1-3 µm wide lamellae are often more Fe-rich than the host olivine and are separated from each other by thin zones of more Mg-rich olivine (Fig. 2). Lamellae and interstitial zones are both stoichiometrically olivine. The individual lamellae extend up to 20 µm into the host olivines. Close to the vein they consist of aligned sharply defined blocks separated from each other by ultra-thin Mg-rich olivine while further away from the vein the outlines of the lamellae are less clearly defined. Here the lamellae appear to be composed of thin parallel bands orientated along four distinct crystallographic orientations. Lamellae are found all along the melt vein on both sides of the vein even if it narrows to only few µm. The length of the lamellae is positively correlated with the width of the melt vein.

Raman spectroscopic investigations show that the majority but not all of the lamellae in the sheared olivine host crystals are ringwoodite as proven by the indicative peaks at ~796 and ~844 cm^{-1} (Fig. 3). Some lamellae, however, as well as the interstitial Mg-rich olivine and the lamellae in the entrained fragments are olivine displaying the characteristic double peak at ~826 and at ~853 cm^{-1} in the collected Raman spectra (Fig. 3). No wadsleyite was found.

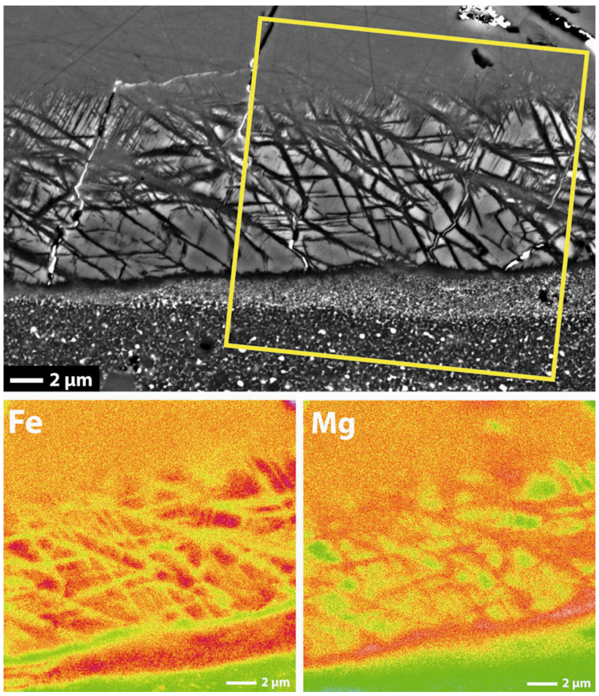

Fig. 2. BSE image and elemental mapping of melt vein and ringwoodite lamellae of the sheared olivine shown in Fig. 1.

Discussion: The textural setting of the lamellae all growing from the olivine-vein interfaces into the crystals proves that the lamellae formed by reconstructive solid-state or martensitic-like transformation rather than by crystallization from the melt.

Such transformation of olivine into ringwoodite occurred only within and directly adjacent to the melt veins as only such regions provided the high temperatures for the rapid transformation kinetics required. The occurrence of ringwoodite is restricted to lamellae in the large olivine host crystals attesting that only those were cold enough to at least partly quench the high-pressure phase in its stability field. Within the veins, olivine fragments show lamellar appearance but the α-olivine structure indicates that they back-reacted from ringwoodite due to prevailing high temperatures after decompression. The compositional differences between most lamellae and the host crystals strongly advocate diffusion controlled nucleation and growth.

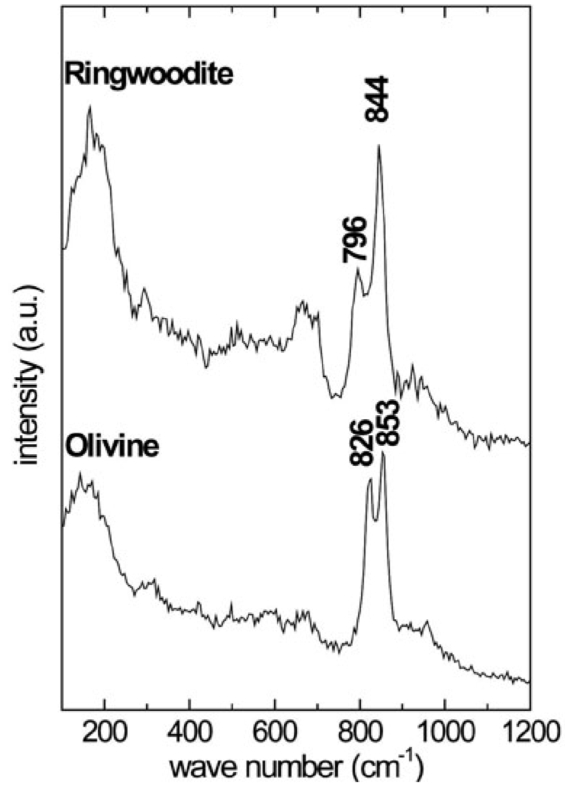

Fig. 3. Raman spectra of ringwoodite lamellae and olivine.

Diffusion was fast enough during ringwoodite formation but too slow to eliminate chemical differences during back-transformation to olivine. As the lamellae are discontinuous and seem to consist of distinct ringwoodite crystallites, they most likely formed by heterogeneous nucleation along defined crystallographic defect planes in olivine. Ringwoodite exclusively occurs in sheared olivine evidencing that high shear stress inducing high densities of lattice defects triggers the formation of olivine high-pressure polymorphs.

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