Mem. S.A.It. Vol. 87, 121

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High pressure phases in NWA 8711, a shock melted L6 chondrite from Northwest Africa: a combined Raman and EMPA study

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Abstract. We report the occurrence of two coexisting high-pressure assemblages in shock-induced black veins of NWA 8711, an L6 chondrite recently found in Northwest Africa. The main phases of the host rock are olivine, enstatite, diopside, plagioclase, iron-nickel alloy and troilite. The presence of typical shock metamorphic features both in olivine and pyroxene, as well as of maskelynite and melt veins point to a shock stage S6. Two coexisting distinct assemblages were observed in the shock-melted areas: (1) a very fine-grained intergrowth of silicate phases sprinkled with fine-grained metal and troilite blebs and (2) a coarser-grained polycrystalline aggregate consisting of ringwoodite crystals. EMPA analyses were performed on both the chondritic matrix and on individual grains of the shock-melted area to characterize their mineralogical composition. EMPA analyses on the coarse-grained area suggested the presence of shock-generated ringwoodite and low-Ca majorite. These data are confirmed by Micro-Raman point analyses. The analyses performed on the fine-grained portion of the veins allowed to determine the presence of a majorite-pyrope solid solution. According to literature data the majorite-pyrope solid solution suggests a crystallization from a shock-melted chondritic matrix under high pressures and temperatures. Ringwoodite and low-Ca majorite were instead formed by solid state transformation of olivine and low-Ca pyroxene originally present in the meteorite.

1. Introduction

Phase transitions and dissociation reactions within the Earth's mantle are extremely important for the comprehension of the evolution and the dynamic nature of the Earth. Mineral assemblages in shock-melt veins of meteorites may reproduce at the microscopic scale the pressure and temperature conditions that lead to phase transformations in the mantle. In the Earth's transition zone (Ringwood et al., 1970), Mg-Fe olivine transforms to wadsleyite and ringwoodite (both with spinel structure). At higher pressures, and temperatures ($P>23$ GPa and $T>1600^oC$), typical of the lower mantle, ringwoodite dissociates to bridgmanite (Tschauner et al., 2014) a perovskite-type structure (Kato & Kumazawa, 1985) and magnesiowustite (Ito et al., 1984; Chen & El Goresy, 1994).

The garnet majorite is believed to be a significant component of the transition zone, stable in the pressure range 19-24 GPa and at

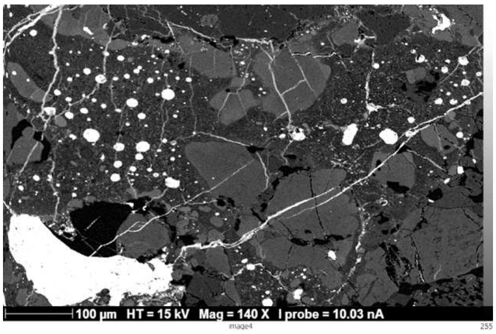

Fig. 1. SEM-BSE image of the general appearance of the shock melted area of the L6 melt breccia chondrite NWA 8711: pale grey large crystals are ringwoodite, white spots are Fe,Ni alloys and troilite

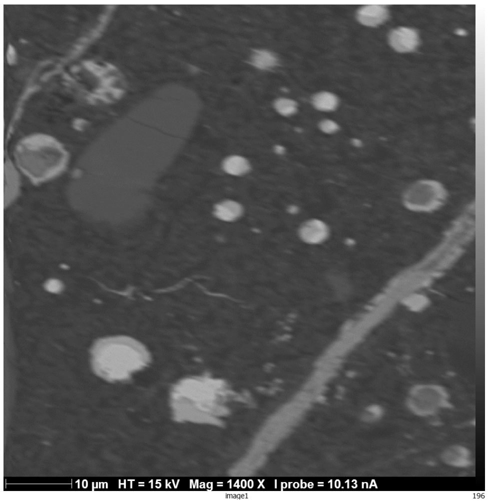

Fig. 2. SEM-BSE blow-up of fig. 1 displaying the fine-grained area of NWA 8711; the dark-pale grey mix is the majorite-garnet solid solution (gran size <1 micron); pale grey rounded spots are kamacite and troilite blebs

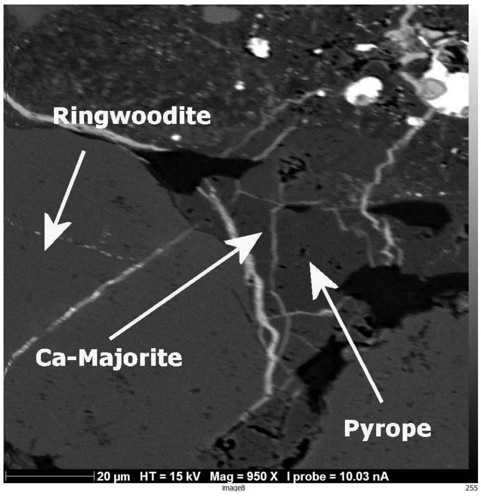

Fig. 3. SEM-BSE image of the coarse-grained portion of the melted area; dark grey crystals are Ca-majorite and pyrope, pale grey is ringwoodite

temperatures between 1700-2600^{o}C (Kato & Kumazawa, 1985), while at higher pressures it transforms to bridgmanite. In this communication we report the occurrence of two coexisting high-pressure assemblages in shock-induced black veins of NWA 8711, an L6 chondrite recently found in Northwest Africa. This meteorite was bought by Nicola Castellano at the Genova mineral fair in May 2014. The main mass, weighing 140g, is partially covered by a black fusion crust. The polished thin section analyzed displays a chondritic texture, with a matrix consisting of a homogeneous intergrowth of olivine and low-Ca pyroxene crystals.

The main phases of the host rock are olivine ($Fo_{74,9}$; Fe/Mn = 48,27), enstatite ($Eni_{76,4}Wo_{1,4}$; Fe/Mn = 27,55), diopside ($En_9Fs_{47}Wo_{44}$; 0,40 TiO2, 0,50 Al2O3, 0,88 Cr2O3, 0,29 MnO, 0,54 Na_2O, all in wt. %), plagioclase, metallic iron-nickel, and troilite. Typical shock metamorphic features, such as undulatory extinction, irregular fractures, and sets of planar fractures can be observed both in olivine and pyroxene. Plagioclase has been transformed to maskelynite, a shock-induced diaplectic glass. The shock features observed point to a shock stage S6. The section shows large areas of shock melt veins 100 to 700 μm wide intersecting the chondritic matrix (Fig.1). Two coexisting distinct assemblages were observed in these shock-melted areas: (1) a very fine-grained intergrowth of silicate phases, dark green in plane polars, which is sprinkled with fine-grained metal and troilite blebs (Fig. 2) and (2) a coarser-grained polycrystalline aggregate consisting of unfractured

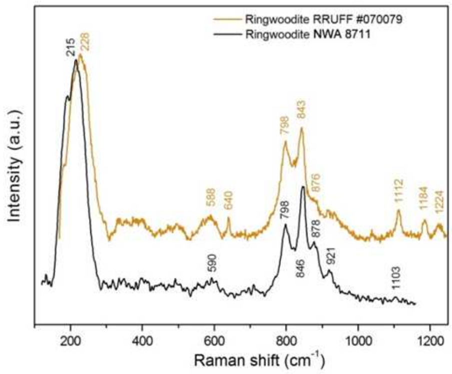

Fig. 4. Micro-Raman spectrum of a ringwoodite crystal of NWA 8711 compared with the reference spectrum

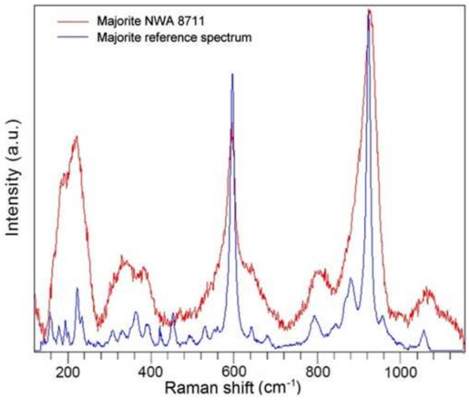

Fig. 5. Micro-Raman spectrum of a majorite crystal of NWA 8711 compared with the reference spectrum

rounded large ringwoodite crystals 15–300 μm in diameter, most of which appear blue in plane polars, with rare pale brown or transparent crystals at grain boundaries (Fig. 3). Maskelinite and metal-troilite intergrowths up to 300 μm in size can be occasionally found.

2. Instruments and methods

Optical microscopy was undertaken at the laboratories of the Museum of Planetary Sciences of Prato, Italy, using an Axioplan-2 polarizing optical microscope equipped with Axiocam-HR camera. SEM-SE images have been performed at the Dipartimento di Chimica, Università degli Studi di Firenze laboratories by means of a Hitachi SEM model S-2300 equipped with EDX analyser and a Noran System Six 300 software. Micro-Raman analyses have been performed at the Museo di Storia Naturale, Università degli Studi di Firenze laboratories with a Horiba/Jobin-Yvon equipped with a 1800 g/mm single holographic grating. The spectrograph was coupled to a He-Ne laser source emitting at 632.8 nm (red-light region). The laser beam was focused on the sample using a x50 objective lens resulting in a laser spot of about 3 μm2. EMPA-WDS analyses have been performed at the Firenze laboratories of the IGG–CNR (National Council of Research) with a Jeol Microbeam microprobe. Both the chondritic portion and the shock-melt veins were investigated by means of optical microscopy, SEM, EMPA and Micro-Raman techniques. EMPA analyses of individual grains were performed on the chondritic portion in order to determine the general minerochemical features of the host matrix and for classification purposes. EMPA and Micro-Raman point analyses were performed on individual grains of the shock-melted veins to characterize their mineralogical composition.

3. Experimental results

The Micro-Raman spectra provided by the optically blue and pale brown grains of the coarse grained assemblage fit well with those of two high pressure polymorphs of olivine and low-Ca pyroxene, namely ringwoodite and low-Ca majorite (Figs.4 and 5). EMPA analyses on these phases ($Fo_{72,2}$, 0,14 wt. % MnO, Fe/Mn = 181,59 for ringwoodite; $En_{77,5}Fs_{21,3}Wo_{1,2}$, 0,18 TiO_2, 0,18 Al_2O_3, 0,13 Cr_2O_3, all in wt. %, Fe/Mn = 27,62 for majorite) provided compositions very similar to those of olivine and low-Ca pyroxene in the matrix, apart from a remarkable difference in the Fe/Mn ratio between olivine and ringwoodite, confirming the hypothesis that these are shock-generated high pressure phases formed from matrix phases. EMPA analyses performed on the fine-grained portion of the veins allowed to determine the presence of a majorite-pyrope solid solution rich in Al, Ca, Na, and Cr (47,59 SiO_2, 27,17

MgO, 2,60 CaO, 0,38 MnO, 16,64 FeO, 0,10 TiO_2, 3,19 Al_2O_3, 0,33 Cr_2O_3, 1,20 Na_2O, 0,13 K_2O, 0,17 NiO, all in wt. %). The occurrence of magnesiowustite, cited in the literature (Chen et al., 1996; Sharp et al., 1996) was not detected. Micro-Raman analysis on these phases does not return clear spectra due to the presence of a marked fluorescence.

4. Discussion and conclusions

Textural and compositional data are consistent with literature data, which report these two different assemblages in other highly shocked chondrites, like Tenham, Coorara, Sah 98222 and YAM 74445 (Ozawa et al., 2009). No evidence for partial transformation as found in experiments was observed (Sharp et al., 1996; Brearley & Rubie, 1994). According to Chen et al. (1996) the majorite-pyrope solid solution crystallized from a melt produced by shock-fusion under high pressures and temperatures, with a composition similar to the bulk of the chondritic matrix. Ringwoodite and low-Ca majorite in the second assemblage were instead formed by solid state transformation of olivine and low-Ca pyroxene originally present in the meteorite. The absence of wadsleyite in the polycrystalline lithology suggest pressures higher than 20 GPa, while the absence of bridgmanite suggest an upper limit of 24 GPa to pressure. Temperatures should range from 2050 to 2300^{o}C.

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