NEW EVIDENCE FOR THE COLOURATION AND FORMATION OF RINGWOODITE IN SEVERELY SHOCKED CHONDRITES. C. M. Lingemann[1] and D. Stöffler[2], [1]Institut für Planetologie, Westfälische Wilhelms-Universität Münster, D-48149 Münster, Germany, email: LINGEMA@NWZ.UNI-MUENSTER.DE, [2]Museum für Naturkunde, Institut für Mineralogie, Humboldt-Universität zu Berlin, D-10115 Berlin, Germany.

Introduction. As part of a long-term research project on shock metamorphism of chondrites [1-4] we examined ringwoodite, a high-pressure polymorph of olivine. G. Moreland noted an unknown mineral in the meteorite Coorara with an eye-catching purple colour unlike anything he had observed before [5,6]. The same mineral was found by Binns et al. in the meteorite Tenham, identified as the γ-phase high-pressure-polymorph of olivine and named ringwoodite after A. E. Ringwood [7].

18 L5 and L6 chondrites have been studied to better understand the colouration and formation of ringwoodite aggregates, some of them in more detail: Acfer 040, Acfer 044, Catherwood, Coorara, Johnson City, Tenham. They have been analyzed by optical microscopy, SEM, EPMA and ATEM.

Results. Ringwoodite occurs as isotropic polycrystalline aggregates of submicroscopic crystals (100 nm - 2 µm diameter). They replace olivine grains in the fragments inside fine-grained crystallized melt veins or melt pockets or at the contact of the melt veins to the host chondrite. Ringwoodite may coexist with wadsleyite, the β-phase high-pressure polymorph of olivine, which has a pale fawn colouration [2-3,8-9]. The colour of ringwoodite varies between the meteorites, between different ringwoodite bearing aggregates and even in one single aggregate. The ringwoodite aggregates can show every shade of blue, purple, grey and green, or they have no colour at all. A closer look at coloured aggregates shows that the colour is not homogeneous, but seems to originate from something with a size similar to the ringwoodite crystallites (Fig. 1). In some grains the colour only occurs along thin planes within the aggregates.

EDS-analyses with the SEM and the ATEM and microprobe analyses reveal that the average composition of the polycrystalline ringwoodite aggregates is near to the composition of the olivine in the host chondrite (Fa_{24-25}, MnO 0.50 wt.%) although there is a tendency to higher FeO- and lower MnO-contents in the ringwoodite aggregates. The individual analyses show a wide range of scatter. In Johnson City for example, ringwoodite compositions vary between Fa_{12} and Fa_{35} and from values below the detection limit up to 0.7 mol% MnO indicating the coexistence of ringwoodite and wadsleyite. No significant chemical differences have been found between colourless and coloured ringwoodite aggregates or the differently coloured aggregates (Fig. 2).

TEM imaging of coloured ringwoodite aggregates shows an amorphous phase around the single crystals (Fig.3 and 4). Electron diffraction patterns of this phase show the typical halo of amorphous materials. The thickness of this phase lies between 6 and 30 nm. We observed no such phase in colourless ringwoodite aggregates.

Discussion. The results confirm the interpretation that ringwoodite was formed at locations where localized melting of the meteorite produced melt veins or melt pockets due to localized shock-pressure and temperature excursions [1-4].

Binns et al. reported purple and grey ringwoodite in Tenham [7]. Price et al. described the colour of ringwoodite in Tenham as varying from cobalt blue, through pale blue to colourless in different examples [10]. This matches with our observations that the colour of ringwoodite can be quite variable in one single meteorite. Binns [11] found that the purple ringwoodite within the melt veins in Tenham is not as Fe-rich as that which is grey and adjacent to the melt veins. Coleman [12] noted minor differences between analyses of different ringwoodite grains in Catherwood, but he found no systematic difference of the type noted by Binns. Our observations support Coleman's results. The individual analyses of ringwoodite aggregates scatter in a wide range, but there is no correlation between colouration and chemical composition of ringwoodite aggregates.

Price et al. analysed blue ringwoodite in Tenham and observed ringwoodite grains, coated with a thin film of glass [10]. They suggested that during the shock event the olivine structure became unstable and formed a glass, from which ringwoodite crystallized. The amorphous material along the ringwoodite grain boundaries probably represents the remains of a prograde olivine glass. The existence of such a prograde glass has been reported by Jeanloz et al. [13]. They suggested that glass forms incipiently in olivine shocked to about 50 to 55 GPa.

The origin of the colour of ringwoodite has been widely discussed. Steele and Smith speculated that it derives from Mn^{3+} [14]. Jeanloz suggested that the colouration may be due to scattering of light by small particles (radius less than 300 nm) [15]. The observation of an amorphous phase around the ringwoodite crystals by Price et al. [10] supports this suggestion. Scattering of light requires a refractive index difference between the scattering particles and the medium in which they are set. This refractive index difference could be produced by the presence of the glassy material which is found to wet the grain boundaries in coloured ringwoodite aggregates. Our observations of an amorphous phase around the ringwoodite crystals in coloured aggregates and the lack of such a phase in colourless aggregates support the model of Price et al. [10]. Chen et al. observed colourless ringwoodite aggregates in Sixiangkou. They found no amorphous phase at the grain boundaries of the single crystals, whose size of 2-6 µm predicts much more time for their crystallization than for smaller ringwoodite crystallites [16].

The connection between the colour of the ringwoodite aggregates and an amorphous olivine glass, produced by shock, suggests that the coloured ringwoodite aggregates crystallized from olivine that was amorphized by shock and was not molten during the impact event. The colourless ringwoodite aggregates might be crystallized either from a high-pressure olivine melt, produced during an impact

event, or from amorphous olivine like the coloured variety, but with enough time for crystallization, such that no amorphous material remains.

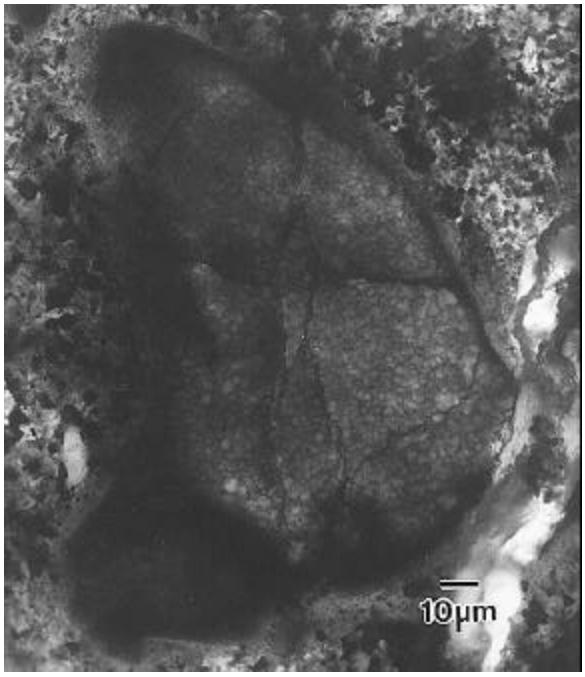

Fig. 1. Blue ringwoodite aggregate embedded in the fine-grained matrix of a melt vein. This aggregate of the meteorite Coorara is traversed by cracks filled with Fe-oxides due to weathering. The colour of the aggregate is not homogeneous, but seems to originate from something with a size similar to the ringwoodite crystallites in the polycrystalline aggregate. Transmitted light.

Fig. 4. Bright-field TEM image of ringwoodite grains in a blue aggregate of the meteorite Coorara. They are surrounded by an amorphous phase.

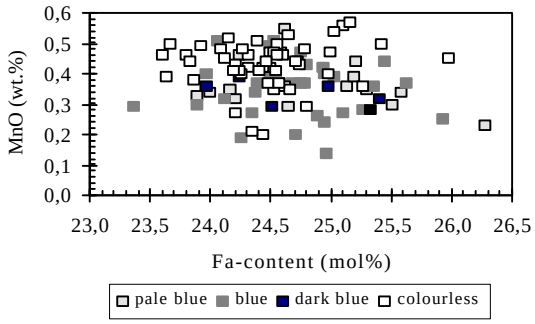

Fig. 2. Composition of ringwoodite aggregates in the meteorite Catherwood with different shades of blue.

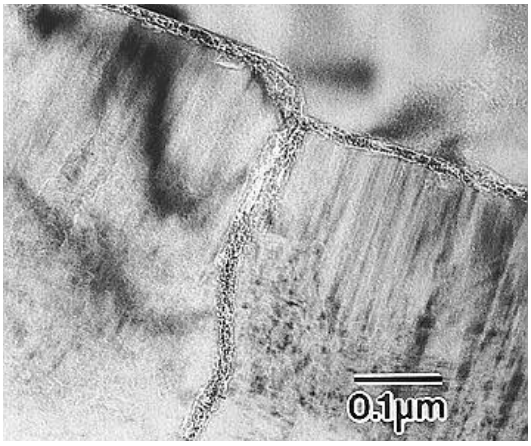

Fig. 3. Bright-field TEM image of an amorphous phase between three ringwoodite grains in a blue and green ringwoodite aggregate of the meteorite Acfer 044. The amorphous phase has an average thickness of 20 nm.

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