Shock-induced ringwoodite rims around olivine fragments in melt vein of Antarctic chondrite GRV022321 : Transformation Mechanism Zhidong. Xie[1], Xiaochun. Li[1], Thomas. G. Sharp[2], and Paul. S. De Carli[3], [1]Nanjing University, Nanjing, P.R.China, zhidongx@nju.edu.cn, njulxc@163.com; [2]Arizona State University, Tempe, AZ 85287, U.S.A. tom.sharp@asu.edu; [3]SRI International, Menlo Park, CA 94025, paul.decarli@sri.com.

Introduction: High-pressure minerals, produced by shock metamorphism, are common in and around melt veins in highly shocked chondrites. These minerals either crystallized from silicate melt in the shock induced vein or solid-state transformed from host-rock fragments entrained in the melt or along shock-vein margins. The shock duration can be constrained by using cooling rates of melt veins [1-2], growth rates of the high-pressure minerals [3-4], or element diffusion [5].Transformation rates depend on the transformation mechanism. For example, growth of topotaxial ringwoodite in olivine with coherent interfaces is slower than growth of inclusions with incoherent interfaces [4-5]. Similarly, diffusion-controlled growth, where rates are determined by long-range diffusion, is generally much slower than interface - controlled growth, which is only dependent on diffusion across the interface [6-8].

Occurrences of high-pressure mineral rims have been reported in shock-induced melt veins in several highly shocked (S6) chondrites, ALH78003, Peace River and GRV052049 [9-11]. Ringwoodite rims on partially transformed olivines were found in the classification of Chinese Antarctic chondrites. Feng et al., interpreted the ringwoodite as a product of melt crystallization [11]. However, the evidence for melting of the olivine precursor is limited.

The purpose of this study is to elucidate the mechanisms of transformation and Mg-Fe diffusion of the olivine to ringwoodite, and infer the shock duration by using different thermal kinetic calculations.

Sample and Methods: GRV022321 is one Antarctic chondrite with weight of 2.16g, collected by Chinese Antarctic Research Expedition Team in 2003. The sample is curated in China Polar Research Institute Center (PRIC), and were classified as L6 S5 W2 chondrite. Electron microprobe (EMPA), Raman spectroscopy, and Focus ion beam (FIB)-Scanning electron microscopy (SEM), and Transmission electron microscopy (TEM) were used to investigate the ringwoodite rims around olivine cores in shock-induced melt veins of the Antarctic chondrites GRV022321.

Results: GRV022321 has a network of shock veins that enclose abundant host-rock fragments, ranging from 5 μm to 100 μm, with most between 20 and 30 μm. In BSE images, the enclosed olivine fragments have bright ringwoodite rims, up to 20 μm wide, and a dark olivine core (Fig. 1). The bright contrast of the rims suggest that they are richer in fayalite content relative to the dark cores. Grains less then 5 μm are completely transformed to ringwoodite.

Raman spectroscopy was used to identify the minerals in partially transformed olivines. The spectrum from a small grain is that of ringwoodite, with characteristic peaks at 796 and 846. Spectra from the bright rims are dominated by ringwoodite, but some of these spectra show a mixture of ringwoodite and olivine components. Spectra from the dark cores are predominantly olivine. One spectrum from a dark core shows pure olivine whereas some spectra are mixed olivine and ringwoodite. Most of the spectra from dark cores also have small peaks at around 720 and 920 cm-1, which suggests minor amounts of wadsleyite. This may reflect stacking disorder in ringwoodite, which locally results in the wadsleyite signature.

EMPA data confirm that the ringwoodite rims are richer in Fe than the olivine core. The ringwoodite rims have Fe contents equivalent to 45 to 50 mole% Fa. The olivine grain in the core has 23 mole % fayalite, which is the same the untransformed olivine outside the shock veins. The darkest material occurs adjacent to the rims and has the lowest iron content, as low as 10 mole% Fa. The high fayalite content of the rims and the low content of the adjacent olivine, indicates that Fe partitioned into the ringwoodite during the olivine-ringwoodite transformation. This implies that the transformation was diffusion controlled and that long-range Fe-Mg interdiffusion occurred during the shock pulse.

TEM was used to confirm the mineralogy of the partially transformed olivines and investigate the microstructures of the olivine polymorphs. Focused Ion Beam (FIB) was used to extract a slice of a partially transformed olivine across the ringwoodite rim. TEM confirm that the rims are ringwoodite and that the cores are predominantly olivine. The ringwoodite rim is polycrystalline, with crystallites up to 500 nm in size. The olivine is also polycrystalline, with crystallites up to 200 nm. The polycrystalline nature of the olivine indicates recrystallization of the once single-crystal olivine either by solid-state transformation or melt crystallization which were discussed next.

Discussion: The occurrence of the rounded grains of partially transformed olivine embedded in the fine matrix of shock veins indicates that they were host-rock fragments entrained into the shock melt. The transformation of the olivine into ringwoodite at the rims occurred by a solid-state transformation, driven by the high temperature of the melt near the rim. This is in contrast to crystallization from a melted olivine grain [10, 11]. Had the olivines melted, we would expect that the first high-pressure polymorph to crystallize would be Mg-rich wadsleyite as a rim. With continued crystallization, the composition of the remaining olivine melt would be enriched in Fe, leading to the crystallization of Fe-rich ringwoodite. In such a high-pressure crystallization scenario, there would be no crystallization of olivine. The Fe-rich ringwoodite rims and olivine cores in our sample are consistent with a solid-state transformation with partitioning of fayalite component to the ringwoodite. This implies diffusion controlled growth of ringwoodite where the rate was limited by long-range interdiffusion in olivine, up to 20 µm distance, during long duration shock pressure.

Diffusion controlled growth implies either a very long shock pulse or very rapid diffusion. Textures seen in BSE images indicate heterogeneous Fe loss loss from the olivine. Using diffusion data of olivine (Farber, et al., 2000, Chakraborty 2010) and simple calculation of x2=D*t, if extrapolated D as 10^{-14} m^2/s at 1500K, 5 µm distance Mg-Fe diffusion needs 2500 s, in another way, 2 second diffusion in 5 µm requires very high $D_{Fe\text{-}Mg}$, as the order of 10^{-11} m2/s in high temperature, close to melt temperature. Grain-boundary diffusion in fine polycrystalline olivine is faster and would require lower temperature. Diffusion rates in the olivine appear to be enhanced by extreme deformation, which transformed single crystal olivine fragments into a nanocrystalline aggregate and locally heated the olivine.

Conclusions: Transformation of olivine to ringwoodite in GRV022321 occurred by a solid-state mechanism with diffusion controlled growth. The transformation is predominantly controlled by temperature where only the hottest olivine transforms. Extreme deformation of the olivine fragments in the melt veins enhances diffusion rates and allows Fe-Mg partitioning in the transformation of olivine to ringwoodite.

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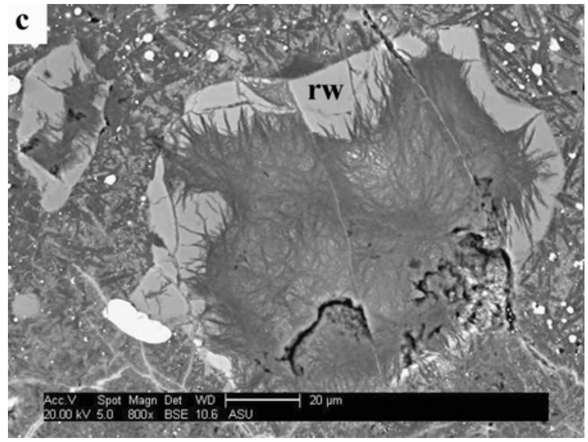

Fig. 1 BSE image of brighter ringwoodite rims around darker olivine core