**PARTIALLY SHOCK-TRANSFORMED OLIVINE IN THE S6 CHONDRITE TENHAM: MECHANISMS OF SOLID-STATE TRANSFORMATION.** Z. Xie, T. G. Sharp[1], and P. S. Decarli[2], [1]School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85287, U.S.A. zhidong.xie@asu.edu, tom.sharp@asu.edu, [2]SRI International, 333 Ravenwood Ave., Menlo Park, CA 94025, paul.decarli@sri.com

## 1. Introduction

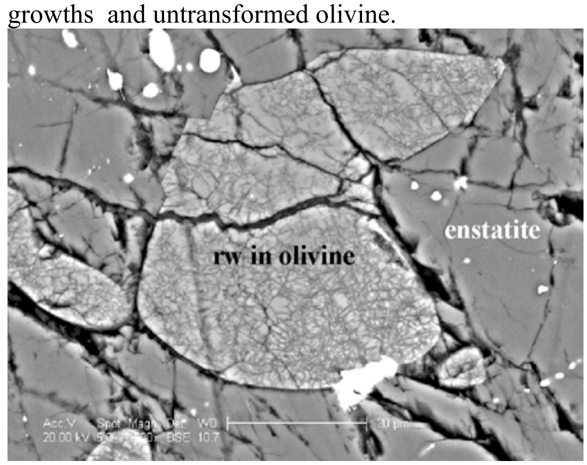
High-pressure minerals, produced by shock metamorphism, are common in and around melt veins in highly shocked chondrites. These minerals either crystallized from silicate melt in the shock-vein or solid-state transformed from host-rock fragments entrained in the melt or along shock-vein margins. Olivine-ringwoodite transformation kinetics can be used to constrain shock duration if one knows P-T conditions and transformation mechanisms. Here we examine the solid-state transformation of olivine to ringwoodite and the formation of ringwoodite lamellae in Tenham.

Ringwoodite lamellae have been reported in partially transformed olivine in or near shock-induced melt veins in heavily shocked (S6) chondrites, Sixiangkou, Yamato791384, and Tenham [1-4]. The lamellar features in Sixiangkou were interpreted to have formed by a coherent intracrystalline transformation mechanism [1], like that observed in experimentally transformed samples by Kerschhofer et al. [5-7]. The kinetic data of Kerschhofer et al. [5-7] were used to infer a shock duration from about several seconds (at 1500°C-1700°C) up to several hours (at 1100°C) [1]. In 2006, Chen et al. [8] reinterpreted the mechanism as incoherent growth, and used Fe-Mg interdiffusion data to infer a shock duration of about several minutes (at 1100 °C). While, based on grain size about 1 μm of polycrystalline ringwoodite (non-lamellae) in Tenham and kinetic data for incoherent growth, we calculate the growth rate at temperature of 1600 K, and infer the shock duration great than 0.1 seconds [4].

One problem with using transformation kinetics to constrain shock duration is that rates depend on the details of the transformation mechanism. For example, growth of topotaxial ringwoodite lamellae in olivine with coherent interfaces is slower than growth of inclusions with incoherent interfaces [5-7]. 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 [9]. Therefore, the detailed mechanisms for forming the lamellae need further microtexture clarification. Here we report new SEM and TEM results to elucidate the lamellar olivine-ringwoodite transformation mechanism in Tenham.

## 2. Results

Tenham has a dense network of black veins which enclose abundant host-rock fragments. Most of the enclosed olivine has been completely transformed to polycrystalline ringwoodite, the spinel-structured high-pressure polymorph of olivine. Relatively few of the entrained olivine grains are partially transformed or contain ringwoodite lamellae. These are commonly intergrown with enstatite in multi-phase fragments in the melt vein or pocket (Fig.1_Top). Some large grains contain totally transformed material, lamellar intergrowths and untransformed olivine.



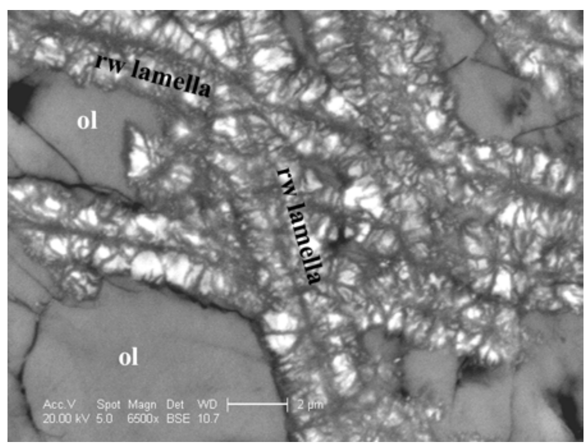




Fig. 1 (Top) BSE SEM image of mostly transformed olivine, with a granular texture. (Low) SEM image showing paired ringwoodite lamellae in olivine.

Ringwoodite in partially transformed olivine can be recognized by a brighter contrast in back-scatter SEM images. TEM SAED patterns confirmed that these grains are ringwoodite. EDS from SEM and TEM confirm that the ringwoodite is richer in $Fe_2SiO_4$ than the surrounding olivine.

Partially transformed olivines show a variety of ringwoodite textures. Some have granular textures (Fig.1-Top), whereas others have straight or curved ringwoodite lamellae, made up of distinct (1 to 2 μm) crystals. Many of these polycrystalline ringwoodite lamellae occur in pairs (Fig.1-Low). These paired lamellae cross and offset each other.

Electron diffraction also reveals that the ringwoodites in the polycrystalline lamellae occur in roughly the same crystallographic orientation (Fig.2-Top), defining a lattice-preferred orientation. TEM also shows that the remnant olivine in partial transformation region is highly deformed, with high densities of complex dislocations (Fig.2-Low). This olivine has a poorly organized sub-grain structure. The nearby untransformed olivine is also highly deformed, but less than the partially transformed olivine.

**3. Discussion**

The complexity of the transformation textures indicates a variety of transformation mechanism that are a function of pressure and temperature. Because the shock pressure equilibrates in less than a microsecond over mm-sized heterogeneities, we do not attribute the variation in degree of transformation within olivine directly to pressure variations [4]. The variable extent of transformation is likely a result of temperature variations during shock, with the hottest olivine forming non-lamellar polycrystalline ringwoodite. Because reaction mechanisms and kinetics are strongly dependant on temperature, use of kinetics to constrain shock duration should be done with caution and only using rates for appropriate mechanisms and conditions.

The Lamellar textures that we observe in partially transformed olivine in Tenham (Fig.1-Low and Fig.2-Top) are inconsistent with a coherent lamellar transformation mechanism such as that of Kerschhofer et al. (2000) or that proposed by Chen et al. (2004). Instead, the discontinuous lamellar textures indicate distinct ringwoodite crystallites rather than single-crystal lamella. However, the preferred orientation of the ringwoodite crystallites may be the result of coherent nucleation with subsequent loss of coherence during growth. Paired ringwoodite lamellae (Fig.2-Low) suggest the nucleation of ringwoodite on both sides of a planar defect. The offsets observed in crossing lamellae pairs suggest that the defects involve shear.

TEM images of complex dislocation and sub-grain microstructures (Fig.2-Low) suggests that the transformation of olivine to ringwoodite involves extensive deformation. High densities of dislocations provide potential sites for heterogeneous nucleation of ringwoodite. The differential stress at initial stage of the shock results in high strains and local hot zones. The paired ringwoodite lamellae in olivine appear to result from shearing and possibly shear heating, where nucleation occurs on both sides of a shear band. More TEM data is needed to determine the role of deformation in the solid-state transformation of olivine to ringwoodite during shock.

**References:**

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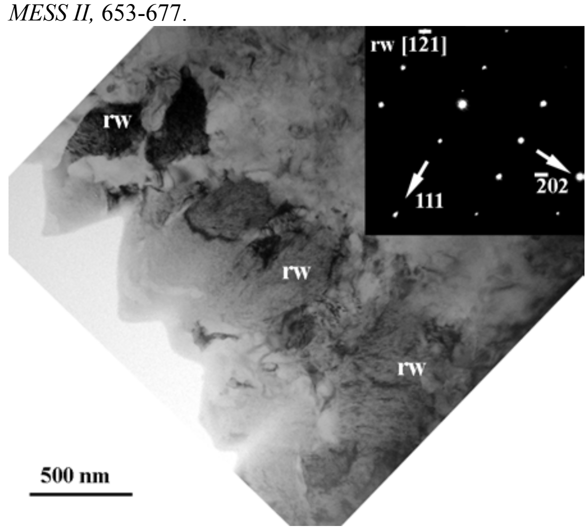


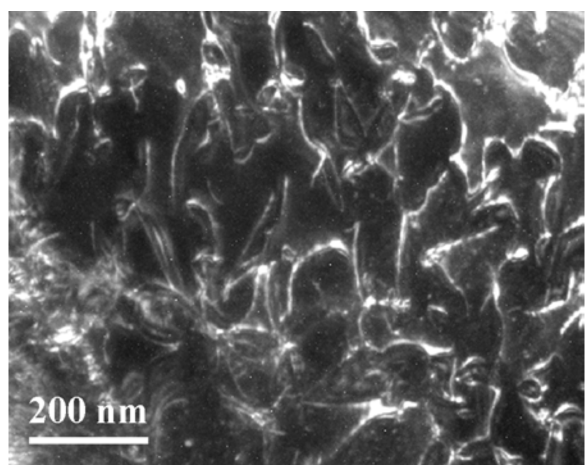


Fig2. (Top) Bright-field TEM image showing a lamellar array of ringwoodite (rw) crystals with similar crystallographic orientations. (Low) Weak-beam dark-field TEM image (g = 004) showing a complex microstructure of c-dislocations (**b** = [001]). A poorly organized sub-grain boundary crosses the low-left corner.