

**Understanding shock metamorphism based on high-pressure silicate phases in shocked-induced melt veins of chondrite GRV 022115**, Zhidong Xie<sup>1</sup>, Jiaxin Si<sup>1</sup>, Shuhao Zuo<sup>1</sup>, and Yang Li<sup>2</sup>, Zhuang Guo<sup>2</sup>. <sup>1</sup>State Key laboratory for Mineral Deposits Research, School of Earth Sciences and Engineering, Nanjing University, Nanjing, P. R. China, zhidongx@nju.edu.cn. <sup>2</sup>Institute of Geochemistry, Chinese Academy of Sciences, Guiyang, China.

**Introduction:** The shock-induced melt vein in the meteorites is one key piece for us to understand the puzzle of early history of the solar system, which contains high-pressure minerals formed under extreme high shock-pressure and temperature in hypervelocity collision event. The high-pressure silicate phases in meteorites provide valuable insight to the natural impact events in early solar system and useful information about deep mantle mineralogy of the Earth [1-7]. After almost twenty years study of shock-induced melt vein in meteorites, it is well known that the shock induced melt veins contain two basic and distinct silicate assemblages: one is melt-vein matrix which crystallized from the melt, another one is host rock fragments entrained in the melt, experienced solid-state transformation. Both phases record shock conditions. Based on mineral assemblages of high pressure phases, crystallization and transformation pressure and shock-duration can be obtained [1-4]. However, basic questions still remain: how melt vein forms? Can crystallization pressure or transformation pressure represent shock pressure? What are the evolution tracks for the pressure and temperature in melt vein or in single minerals? Is the crystallization pressure for melt-vein matrix consistent with the solid-state transformation pressure for host rock fragments.

Here we use various microanalysis methods, include Raman spectroscopy and electron microscopes (SEM, EMPA, and FIB-TEM), to investigate the microstructure and mineralogy of shock-induced melt veins in one Antarctic GRV 022115 chondrite, which have a full range of shock features, including little phase change to partial phase change, to total transformation, and to dissociation. The goal is to better understand major silicate phases transformations under extreme high-pressure and temperature in a very short shock pulse in one complex situation, to better understand the shock-induced melt vein formation, pressure-time profile and temperature-time profile for single minerals and whole melt vein.

**Results:** GRV 022115 chondrite is one unique highly shocked meteorite with a full range of silicate phase transformations. GRV 022115 chondrite is an Antarctic meteorite collected by Chinese Antarctic Research Expedition Team in Grove (GRV) mountain, were classified as S5 W1 L6 chondrite (Weisberg et al., 2009). The network of black shock-induced melt veins encloses abundant host-rock fragments of olivine, pyroxene and plagioclase which show full range of trans-

formations, from less phase transformation to partial phase transformation, to completed transformation, to dissociation, and to melting or vitrification. Here we mainly focus on the vein matrix crystallization, and solid-state transformation of olivine and pyroxene, which are major minerals in chondrites and in most meteorites.

Melt-vein matrix in GRV 022115 is mainly consisted of euhedral equant majorite ((FeMg)SiO<sub>3</sub>) plus irregular-shaped magnesiowüstite ((FeMg)O) across from one side to another side of the melt vein. This textures is a well known feature in shock-induced melt veins, reported in many previous studies. Euhedral majorite always has rounded-shape with gray contrast in SEM or BSE image, while magnesiowüstite has higher contrast with white color and filling gap between rounded majorite. The width of melt vein in GRV 022115 ranges from tens micrometers to millimeter. Typically, larger veins contain more host-rock fragments than smaller or narrow veins. Some part of vein matrix is consisted of elongated akimotoite crystals. Some part of vein-matrix close to vein edge or big host rock fragments, the rounded majorite features turn into dendritic feathers features which might indicating much rapid cooling rate.

Olivine host rock fragments entrained into melt vein still keep olivine composition with (FeMg)SiO<sub>4</sub>, while the ratio of Fe-Mg changes indicating a diffusion transformation. Some entrained grains or part of big grains still keep olivine structures indicated by Raman spectra, while other parts or whole part of grain show high-pressure phases signatures of ringwoodite and wadsleyite. FIB-TEM work and Raman signatures reveals these grains with olivine structure were transformed into much smaller size, not keep original big single tens micrometer-sized crystals. Far away from the melt vein, olivine grain keep un-deformed, keep sharp extinction with strong and clear Raman peaks. These entrained olivine fragments show rounded edge indicating a melting. Most of them has ringwoodite rim confirmed by Raman and TEM. Small size of olivine grain, like less than 10 micrometer size, were total or completely transformed into ringwoodite. In some case, we see break down of olivine grain into majorite plus magnesiowüstite (FeMg)O, while remain host rock olivine fragments turn into ringwoodite. The dotted spherules of magnesiowüstite (FeMg)O surrounding by vein matrix show a striking image. This is the dissociation of olivine under high pressure and temperature.

Pyroxene host rock fragments entrained in melt vein are not so common compared to abundant olivine host rock fragments. Composition of pyroxene host rock entrained in the vein do not changes too much compared to these host-rock pyroxene far away from the melt-vein. Several small pyroxene-composition grains turn into network-feature grains with a mixture of equant and irregular-shaped grains. FIB-TEM imaging and electron diffraction show that equant grains are amorphous silicate. The morphology and composition are similar to those of the vitrified silicate-perovskite (also called bridgmanite) in other shocked meteorite, which may formed by solid-state transformation from enstatite, which are common in shock-induced vein too.

There is one big multiple-phase chondrule in the melt vein of GRV 022115, consisting of pyroxene, olivine, and plagioclase with very unique transformation features. Plagioclase grains show melting. The edge of pyroxene grain closing to vein matrix turn into majorite plus unknown phases. Most part of pyroxene grains turn into amorphous glass with abundant nano-Fe particles, SiO-rich phases and lots of voids. This is the vitrification of pyroxene or dissociation of enstatite.

**Discussion:** Shock-induced melt veins result from the localized mixing and melting of coexisting minerals, and the subsequent quench of immiscible silicate and metal-sulfide melts. Understanding when a melt vein forms and crystallizes relative to shock loading and pressure release is necessary to relate crystallization pressures to shock pressure. There are several possible mechanisms for melt vein formation. Shock-wave interactions between different shock impedance materials may cause localized melting, which is most pronounced at the interface of metal-troilite and silicates, and the interface of different minerals and pore space. Friction by shear along the contacts of materials of vastly contrasting shock impedance and along fractures may also produce local melting.

The abundance of fragments in shock-induced melt vein of GRV 022115 suggests that this vein did not form by injection into a fracture, but rather formed in situ by shearing or collapsing around cracks and pores. The response of a heterogeneous material to shock compression is extremely complex when viewed on a nanosecond time scale and on a micrometer distance scale. The shock front is chaotic, with order-of-magnitude differences in initial pressure due to shock wave interactions among grains of different shock impedance and to jetting around cracks and pores. After shock wave passing the shocked materials, the whole rock experienced shock, which involve vein shear friction, shock compression, void collapse. The basic physics of shock melt vein is that the kinetic energy transformation into internal energy, transferring kinetic

energy into molecule vibration, hiking temperature resulting the melting, even to break down the bonding of minerals, causing dissociation of minerals. Mineral assemblages of the melt veins studied here show some variations in assemblage, but no clear evidence that crystallization or transformation occurred over a large pressure decrease.

The abundance of shock deformation and phase transformation features near and within melt veins suggest these metamorphic effects are strongly temperature dependent, rather than only pressure dependent. Temperature may be the most important factor for what kind of minerals were formed or crystallized. Temperature is key to form different mineral assemblages for same precursor. Like we see here in GRV 022115 chondrites, we see partial transformation of olivine into ringwoodite, total transformed olivine into ringwoodite, breakdown or dissociation of olivine. These three different transformation may indicate quite different temperature in local area.

Shock physics, phase transformation, and mineral physics are keys to understand the melt vein formation, and the pressure-temperature-time profile for one single host rock fragments or whole melt vein. When we really understand basic physics in mineral physics level, then we can answer basic questions in the beginning. Are these different mineral assemblages really can represent shock pressure, are they record same high pressure.

[1] Xie, et al. (2006) *GCA* **70**, 504-515. [2] Xie and Sharp (2007), *EPSL* **254**, 433-445. [3] Langenhorst and Poirier (2000) *EPSL* **184**, 37-55. [4] Ohtani et al. (2004) *EPSL* **227**(3-4), 505-515. [5] Beck, et al. (2005) *Nature* **435**, 1071-1074. [6] Ohtani et al. (2006) *Shock Waves* **16**:45-52. [7] Miyahara et al. (2008) *Proceedings. NAS* **105**, 8542-8547. [8] Keller et al. (1997) *GCA* **61**, 2331-2341. [9] Noble et al. (2005) *MAPS* **40**, 397-408.