BACK-TRANSFORMATION OF RINGWOODITE IN L5-6 CHONDRITE MBALE: IMPLICATIONS FOR THE PRESERVATION OF SHOCK EFFECTS IN HIGHLY SHOCKED METEORITES

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Introduction: High-pressure minerals in shock-induced melt are the most important signature of shock stage S6 in chondrites [1]. The quenched melt portion provides information on high-pressure mineral assemblage and shock condition in the S6 chondrites. However, the total volume of the melt is only a small proportion of the whole rock in most S6 samples [2]. Many shock-blackened chondrites and impact melt breccias, which include a significantly larger proportion of melt, are commonly identified as shock stage S4 or less because no obvious high-pressure minerals are observed in these samples. The large volume of shock melt in chondrites, as an indication of strong shock, is apparently inconsistent with the lack of high-pressure phases.

Mbale is a L5-6 chondrite containing ~1mm shock veins. Chen et al. (1995) investigated olivine fragments in the shock melt of Mbale and found iron-rich lamellae. They inferred that these features were related to high-pressure transformation to ringwoodite and wadsleyite. In this study, we report on the back transformation of high-pressure minerals in Mbale. This sample illustrates how high-pressure phases and other shock signatures can be erased by high post-shock temperatures.

Sample and Methods: Two thin sections of Mbale were characterized by optical microscopy, Raman spectroscopy, field emission scanning electron microscopy (FESEM) with energy dispersive X-ray spectroscopy (EDS) in Leroy Eyring Center for Solid State Science, at Arizona State University. Synchrotron X-ray diffraction was performed at GSE-CARS, Advanced Photon Source, Argonne National Lab.

Results: The groundmass of Mbale is highly deformed. Both olivine and pyroxene fragments in the shock melt were transformed during shock. The quenched melt is dominated by high-pressure minerals.

Host rock petrology. Poorly defined chondrules and recrystallized secondary feldspar indicate that Mbale is petrologic type 5-6. However, unlike the completely recrystallized L6 chondrites, the groundmass contains chondrules that can be delineated and fine-grained mesostasis. Feldspar grains larger than 50µm are rare. The host rock is highly fractured and deformed. The olivine and pyroxene grains outside the melt vein are full of fractures and show strong mosaicism. The feldspar near the melt are optically isotropic and have flow features and poorly-defined grain shapes, suggesting they are normal glass quenched from melt. The feldspars far from the melt are transformed to maskelynite.

Solid state transformation. All the olivine composition fragments have the olivine structure with no evidence for ringwoodite or wadsleyite. However, synchrotron XRD data, taken from a 5 x 10 µm area in the olivine, produce high-quality powder patterns, indicating that the olivine fragments are completely recrystallized to a nanocrystalline aggregate. Back scattered electron (BSE) images show strong contrast in the olivine, corresponding to heterogeneity in iron concentration. The shape of iron-rich domains varies from granular blocks, to rims and lamellae. The blocks are commonly smaller than 1 micron with no orientation preference. In several big fragments, the iron-rich domain can be a few microns in size. Rims only occur in fragments smaller than 20 microns. Rim width does not exceed 2-3 microns. Lamellae are thin and rare. They are observed in limited area in the fragments with complicated texture.

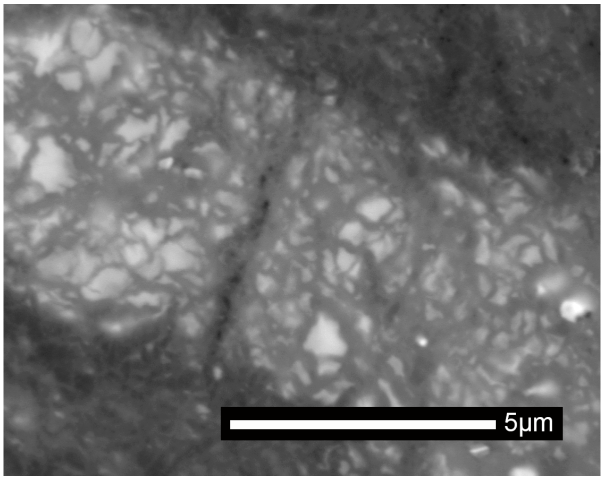

Figure 1. BSE image of the olivine fragment in shock melt showing strong iron heterogeneity. The iron rich domains are variable in shape and size.

Pyroxene fragments in the melt veins are partially transformed to majorite. XRD results indicate the fragments in the thick vein center are transformed to garnet. Pyroxenes on the vein edge and/or in the thin veins are low pressure polymorphs.

Melt-vein crystallization assemblage. The mineralogical composition of shock melt is consistently dominated by majorite garnet. The BSE image show a typical subhedral garnet texture plus sulfide. The crystal size of majorite varies from sub-micron to 4-5 microns. The sulfides are either round droplets or angular granules. An interstitial oxide phase and a minor silicate phase are also observed in the melt by BSE image (Figure 2) in some areas. XRD suggest the silicate phase is wadsleyite.

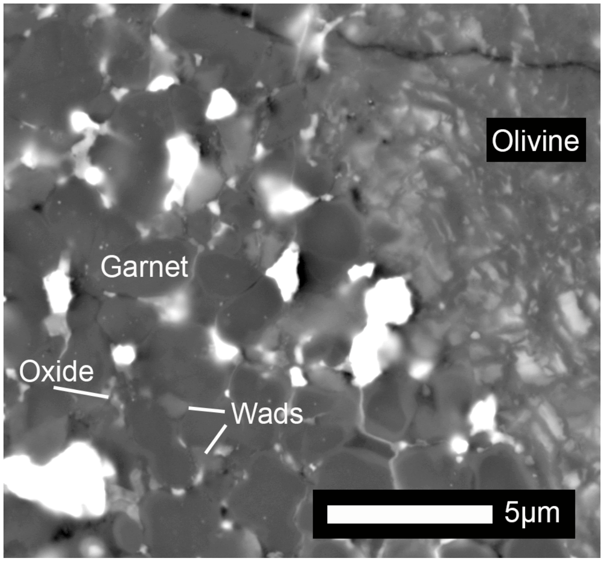

Figure 2. The melt matrix containing majoritic garnet, oxide plus the olivine's polymorph, inferred to be wadsleyite (Wads). Garnet is dominating the texture with the other two phases filling in. The brightest phase is sulfide. An olivine fragment is contacting with the melt.

Discussion:

Crystallization pressure. Crystallization pressure of the melt can provide a good proxy for the shock pressure [3]. The crystallization pressure can be estimated from the melt matrix assemblage using an appropriate liquidus phase diagram [3]. In Mbale, the majorite garnet plus oxide assemblage suggests a quench pressure at about 20-23GPa [4]. Uncertainties are from the lack of chemical equilibration and differences in composition between shock melts and published phase relations. However, this pressure estimate is reasonable for the ordinary chondrites.

Back transformation and post shock annealing. The iron heterogeneity in fine grained polycrystalline olivine fragments is likely a result of partial transformation of olivine to ringwoodite with the iron partitioning into the ringwoodite. The initial high-pressure transformation starts on preferential sites, which become the iron-rich portions of ringwoodite aggregates. The transformation of ringwoodite back to olivine resulted in the fine-grained olivine aggregates present in the sample. This indicates that the post shock temperature was high for a relatively long time after pressure release. During back-transformation, temperature dropped sufficiently to limit olivine grain growth and long-range diffusion and homogenization of the fragments.

The coexistence of high pressure garnet and back transformed olivine is the evidence for the partial degrading of high pressure signature. Annealing starts with the mineral least stable at high temperature and low pressure. The persistence of majoritic garnet in the melt-vein matrix indicates majorite-pyrope garnets are relatively resistant to back-transformation and can be used as an indication of high shock pressure. It is likely that the high-pressure signature of shocked meteorites will be completely erased if the sample is shocked to a very high level such that the post shock temperature is very high.

Background temperature and cooling history. The importance of post-shock temperature for preserving high-pressure phases has been discussed [3]. Generally, the cooling history of the melt veins is controlled by volume of melt and temperature gradient between the melt and host rock. High background temperatures decrease cooling rates significantly. In Mbale (L5-6), the initial rock likely had a higher proportion of mesostasis and porosity than a type 6 L chondrite. This would result in the absorption of shock wave energy and convertion of that energy to heat. This processe would have generated a higher overall temperature in the host rock, leading to slow cooling and therefore partial back transformation after pressure release.

For samples close to an impact site on the parent body, we would expect higher initial porosities and higher shock pressures, resulting in abundant impact-melt and melt-breccia samples. The bulk shock temperature and post-shock temperature in such samples would be higher and the subsequent cooling slower, resulting in extensive back-transformation and annealing of shock features. This can explain why the mostly highly shocked chondrites lack S6 shock characteristics.

References:

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