AN EXPERIMENTAL SIMULATION OF SHOCK-VEIN CRYSTALLIZATION USING THE MULTI-ANVIL APPARATUS T. G. Sharp[1], Z. Xie[1], Emmanuel Soignard[2] and P. DeCarli[2], [1]School of Earth and Space Exploration and [2]Department of Chemistry and Biochemistry, Arizona State University, Tempe, AZ 85287, U.S.A. tom.sharp@asu.edu, Emmanuel.Soignard@asu.edu, zhidong.xie@asu.edu [3]SRI International, 333 Ravenwood Ave., Menlo Park, CA 94025, paul.decarli@sri.com

1. Introduction

Shock metamorphism of planetary materials is a fundamental process in the solar system. Shock recovery experiments have been used to generate the shock effects seen in nature and calibrate the pressure required to produce these metamorphic effects [1]. One problem with this approach is that shock-recovery experiments generally use a shock reverberation technique where multiple-shock loading results in a low internal energy and temperature relative to natural single-shock events [2]. Also, the duration of experimental shock pulses can be more than six orders of magnitude shorter than natural shock events. Although shock-recovery experiments have provided useful information about shock effects and processes, they overestimate the pressures required shock-induced mineral transformations [3-4].

As an alternative, one can use the minerals that crystallize at high-pressure in shock-veins to estimate crystallization pressures and thereby constrain shock pressures [5-6]. This approach also provides information about pressure changes during the quench of the veins. However, interpretations of assemblages rely on limited phase equilibrium data from difficult high-pressure experiments. High-pressure melting data are available for KLB-1 peridotite [7], Allende CV3 [8-9] and Mbale L6 chondite [10].

Silicate melts in shock veins of highly shocked L chondrites generally have high-pressure mineral assemblages [5]. The quench of melt veins is primarily driven by thermal conduction to the surrounding host rock [3]. One-dimensional heat-flow calculations for a 580-μm shock vein in Tenham suggest that thermal quench of the melt-vein center from 2700 K to ~ 2300 K required about 40 ms at 25 GPa [3]. This is comparable to the quench of superliquidus melts in multi-anvil experiments. In this study, we are conducting L-chondrite melting experiments in the multi-anvil apparatus to investigate the mineralogy and mineral textures produced by rapid quench from superliquidus conditions at pressure from 17 to 22 GPa to see if they match the mineral assemblages and textures in natural melt veins.

2. Experimental Methods

Experiments were conducted using a split-sphere multi-anvil apparatus at the Australian National University (ANU) and a Walker-style multi-anvil apparatus at Arizona State University (ASU). To attain pressures up to 23 GPa, we used the COMPRES 8/3 cell assembly, which consists of an 8-mm MgO-Al_2O_3 octahedral pressure medium, a Re-foil furnace, a $LaCrO_3$ insulating sleeve and a type-C thermocouple. Pyrophyllite gaskets were use on 28-mm (ANU) and 1-inch (ASU) WC cubes, both with 3-mm truncation edge lengths. The samples consisted of crushed Mbale L chondrite contained in either Fe-Ir capsules (97 wt% Ir) at ANU and graphite capsules at ASU. Quench was achieved by either cutting the power to the furnace (fast quench) or by quickly ramping the power down (slow quench). However, as a result of furnace failures, quench rates were not well controlled in the ANU experiments.

Pressures were calibrated for the COMPRES 8/3 assemblies using phase transitions at 1600 °C (ANU data) and by *in situ* X-ray diffraction (ASU) at the GSECars beam line at the Advanced Photon Source. The *in situ* calibration demonstrates that for this assembly, the pressure decreases significantly at temperatures above the L-chondrite liquidus. The pressures for ASU experiments are based on *in situ* temperature-dependent calibration and the pressures of ANU experiments have been recalibrated, using the *in situ* temperature-dependent calibration.

3. Results

Analysis of experimentally quenched samples: A summary of the experiments, run conditions and products is presented in Table 1. Majorite-bearing assemblages were produced in all but two runs, with majorite textures ranging from course equant grains to dendritic. Most of these samples also contain ringwoodite, but two have wadsleyite and some show evidence of magnesiowüstite. In sample MA 860, which had a

Table 1. Multi-anvil run conditions and products

Run	P (GPa)	T (°C)	Quench	Assemblage
MA860	21.0	2440	slow	Mj+Rw+Mw
MA862	19.1	2330	fast	Ak + gls
MA865	18.0	2020	slow	Mj+Rw+Mw?
MA866	17.9	2300	slow	Mj + Rw?
MA871	19.3	2350	fast	Mj + Wds
BB345	21.6	2200	Fast	Pv + Rw
BB358	18.6	2500	Fast	Mj+Rw+Wds?
BB366	21.2	1950	Fast	Mj + Rw
BB377	20.5	2250	Fast	Mj + Rw

relatively slow quench during furnace failure, equant majoritic garnets occur up to 100 µm in size. In sample MA 871, which experienced rapid quench from 19.3 GPa and 2350 °C, majoritic garnets occur as relatively coarse-grained dendrites along with wadsleyite. Sample 862, quenched quickly from 19.1 GPa and 2330 °C, contains long acicular crystals of akimotoite.

4. Discussion

Comparison to Natural samples: The most common melt-vein assemblage in highly shocked chondrites such as Tenham, Sixiangkou and RC106, is a mixture of majoritic garnets, magnesiowüstite and minor residual glass intermixed with droplets of quenched Fe-Ni-sulfide melt. Commonly, the magnesiowüstite is transformed to magnetite and ferropericlase. The majoritic garnets are generally equant and occur from a few µm in Tenham and Sixiangkou, to up to 20 µm in RC106. The majorites in RC 106 grade from coarse into dendritic, which become increasingly fine grained toward the melt-vein margins (Fig. 1 bottom). Majoritic garnet also occurs with ringwoodite in samples such as Roy. Although our experiments produced ringwoodite as the dominant Fe-rich phase rather than magnesiowüstite, the garnet textures, including dendrites, seen in natural samples were reproduced (Fig. 1).

Akimotoite ((Mg,Fe)SiO_3-ilmenite) and vitrified silicate (Mg,Fe)SiO_3-perovskite occur with ringwoodite in melt veins of Acfer 040 [11] and along melt-vein margins in Tenham [3]. Akimotoite also occurs along with ringwoodite and clinopyroxene in Umbarger [12]. Based on experimentally determined phase relations, akimotoite is a subsolidus phase that is not stable with silicate liquid. In one of our quenched samples, relatively large plates of akimotoite crystallized from the melt during rapid quench. This experiment suggests that high-pressure minerals can crystallize metastably in rapidly quenched melts and that such phases should be expected in the rapidly quenched melt veins and especially at melt-vein margins.

Crystallization pressure: It should be noted that our pressures are significantly lower than those of previous phase-equilibrium studies [6-8]. The primary reason for this is that previous studies may not have taken into account the loss of pressure at very high temperatures in small assemblies. Our results suggest that some previous phase equilibrium studies overestimated the pressure at their highest P-T conditions by several GPa and that the actual crystallization pressures of natural shock veins in S6 chondrites are less than our previous estimate ~ 25 GPa.

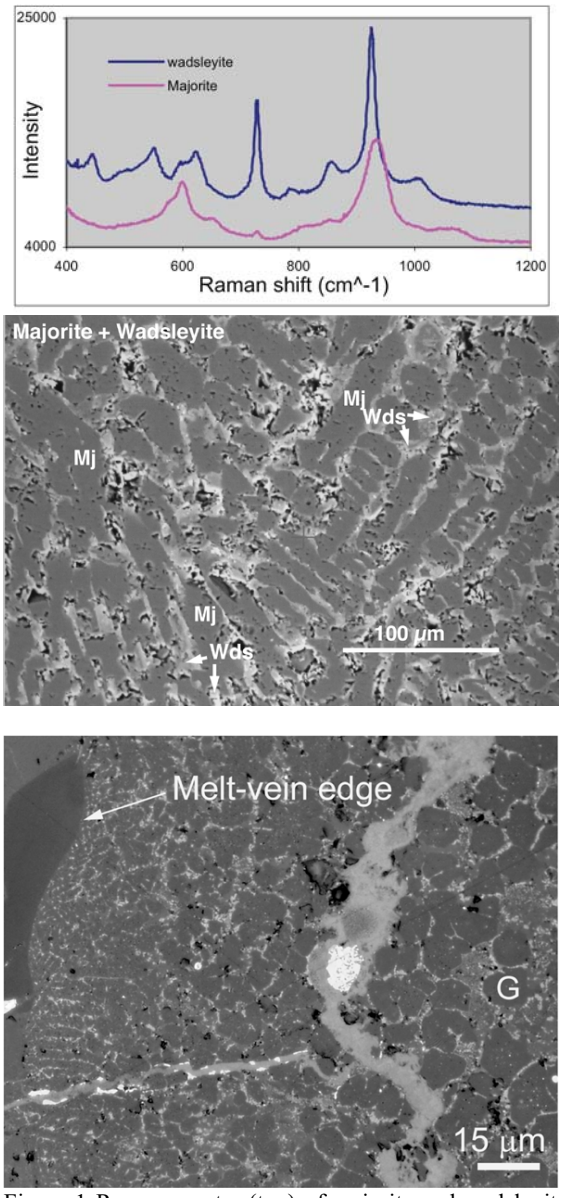

Figure 1 Raman spectra (top) of majorite and wadsleyite in experimental charge MA871. SEM image (center) of dendritic majorite + wadsleyite in MA871. SEM image (bottom) of a shock vein in RC 106, showing majorite that ranges from equant toward the center of the vein (right) to dendritic at the melt-vein edge (left).

References:

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