SHOCK EFFECTS IN TISSINT II: OLIVINE TRANSFORMATION TO SILICATE PEROVSKITE AND OXIDE. J. Hu[1], T. G. Sharp and E. L. Walton[2,3], [1]School of Earth and Space Exploration, Arizona State University, Tempe AZ 85287-1404 (Jinping.hu@asu.edu), [2]MacEwan University, City Centre Campus, Edmonton, AB, Canada (waltone5@macewan.ca), [3]University of Alberta, Department of Earth & Atmospheric Sciences, Edmonton, AB, Canada.

Introduction: All the Martian meteorites experienced strong shock metamorphism from impact on Mars. Tissint, a picritic shergottite fall, has strong shock deformation, high-pressure minerals and extensive shock melt as heterogeneously distributed veins and pockets (Walton et al., LPSC companion abstract). The shock conditions for Tissint can be estimated from the high-pressure solid-state transformation and the mineral assemblages quenched from the shock melt [1]. However, the shock effects in Martian meteorites are distinct from those in well studied ordinary chondrites. This is attributed to compositional differences as well as the distinct impact conditions on their respective parent bodies. Moreover, the complex texture and appearance of the high-pressure assemblages in Martian meteorites make identification of high-pressure phases difficult. In this study, we employ FIB-TEM analysis and synchrotron X-ray micro-diffraction to investigate the mineralogy and crystal structures of the high-pressure phases in Tissint to understand its shock history.

Methods: Petrographic analysis of one Tissint thin section was performed using polarized light microscopy and field-emission SEM (FEI XL30). TEM samples were prepared with a focused ion beam instrument (FEI Nova 200) using Ga ion beam. TEM imaging, electron diffraction and EDS analysis were performed on the FIB sections using a FEI CM200 and a JEOL 2000FX analytical TEM, both operated at 200 kV. All of the electron microscopy was performed in the LeRoy-Eyring Center for Solid State Science at Arizona State University.

Synchrotron micro X-ray diffraction was performed on a thin section at GSE-CARS in the Advanced Photon Source, Argonne National Lab, with the sector 13BMD bending magnet, which has an X-ray beam of 5 x 12μm (focused). X-ray energy of 30keV (λ=0.4137Å) was used for the analysis.

Results:

Olivine to silicate perovskite plus oxide: Fragments of olivine in shock-melt pockets show transformation to two distinct phases. A similar two-phase assemblage was observed in a thin rim on a 20μm-thick melt vein.

The texture of the dissociated olivine fragments consists of many tiny blebs of high-contrast (BSE) material in a matrix of low-contrast material (Fig. 1). This texture is coarsest in contact with shock melt and becomes progressively finer into the transformed olivine fragment. Synchrotron X-ray diffraction patterns from this transformed olivine match clinopyroxene (close to the clinoenstatite end member, space group $P2_1/c$). In situ electron diffraction patterns of a FIB section display strong diffraction from magnesiowüstite (111) and (220) as well as a ring pattern from polycrystalline clinopyroxene (Fig. 1). TEM images show very fine-grained 100-200nm anhedral crystals of magnesiowüstite and clinopyroxene.

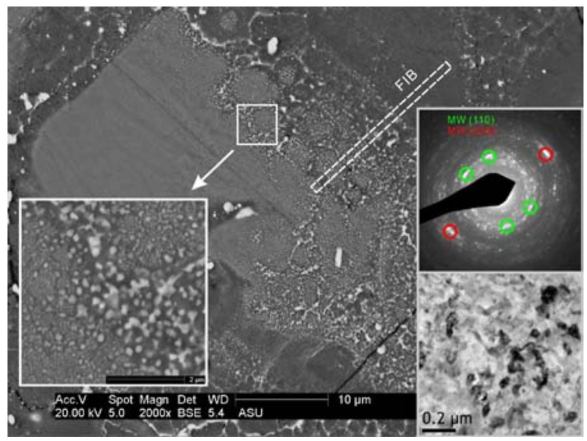

Fig. 1 BSE image of a dissociated olivine clast within a shock melt pocket. The border zone with bright blebs is shown in the white box on the left. A FIB section for TEM was made from the marked region. TEM image (lower-right) of the dissociated border shows fine-grained clinopyroxene and magnesiowüstite. Electron diffraction pattern (upper-right) shows strong spotty diffractions of magnesiowüstite and powder ring patterns from clinopyroxene.

A 2-μm thick rim of dissociated olivine on the border of a thin melt vein shows two-phase contrast in BSE images (Fig. 2). Electron diffraction from this rim in a FIB section produced a magnesiowüstite ring pattern with a diffuse ring from an amorphous material. TEM imaging shows magnesiowüstite crystals of ~ 50 nm in size and glass (Fig. 2).

Shock-induced vein crystallization assemblage: Clinopyroxene occurs throughout the quenched shock melt in this sample. Ringwoodite also occurs in the melt pockets around the dissociated olivine clasts as well as in the thin melt vein (Fig. 1&2). TEM analysis of the glassy thin vein matrix identified a few anhedral crystals of clinopyroxenes, ringwoodite and stishovite in a predominantly amorphous material. Ringwoodite occurs in the matrix as well as on the boundary between the matrix and the dissociation rim. The ringwoodite on the boundary is relatively coarse-grained. The quenched melt around the dissociated olivine clasts consist of fine-grained ringwoodite and clinopyroxene.

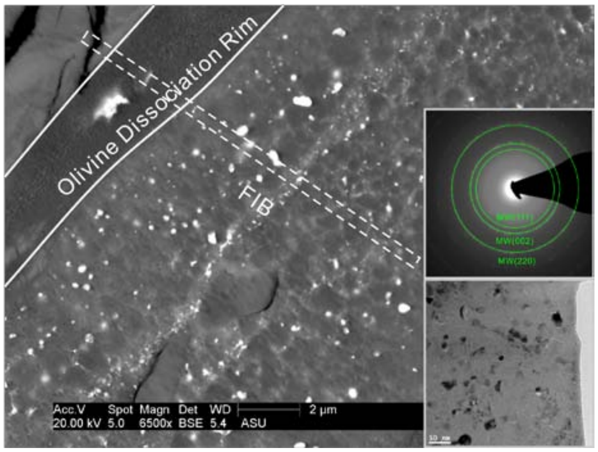

Fig 2 BSE image of the dissociated olivine on the border of a thin melt vein. The vein cuts across a large, strongly zoned olivine macrocryst. TEM image (lower-right) of the rim shows magnesiowüstite plus glass. The distinct ring pattern of magnesiowüstite is shown in electron diffraction (upper-right) as well as a diffuse amorphous ring.

Discussion:

Shock conditions & P-T history: The extensive melt in Tissint indicates that it was highly shocked, similar to S6 L chondrites. The localized melt tends to form thicker veins and pockets compared to those observed in L chondrites. The melt in the thin vein (20μm) and adjacent to the transformed olivine in the thicker pocket (~300-450μm) consists of clinopyroxene, ringwoodite and stishovite, indicating crystallization at moderate pressures (~15GPa) during quench. The thin melt vein is likely to have cooled rapidly compared to the thicker melt pockets, resulting in a higher proportion of amorphous material and coexistence of ringwoodite, stishovite and clinopyroxene. In contrast, the dissociation of the olivine to silicate perovskite suggests that Tissint was shocked to a very high pressure, in excess of 25GPa [2]. This apparent inconsistency in pressure (15GPa versus 25GPa) indicates that the crystallization of melt occurred after the peak pressure release.

The existence of either clinopyroxene or glass rather than silicate perovskite in the dissociated olivine is consistent with the sample remaining hot after pressure release. In the thin vein, which cooled quickly, the silicate-perovskite is vitrified. In the thicker melt vein, which remained hotter longer, the silicate perovskite back-transformed to clinopyroxene after pressure release.

Impact on Mars: Some Martian meteorite falls and finds, including Tissint, are paired by overlapping cosmic-ray exposure ages near 0.72 ± 0.3Ma [3]. Assuming that this flux of Martian meteorites was ejected by a recent impact on Mars, the size of the impactor was likely smaller than that on the L chondrite parent body. In this case, the shock duration of Martian meteorites is much shorter compared to L chondrites [4]. Quench of large veins after pressure release and extensive back transformation of transformed olivine support this model (Walton et al., LPSC companion abstract).

References: [1] Sharp T. G. and De Carli P. S. (2006) MESS II 1, 653-677. [2] Ito E. and Takahashi E. (1989) JGR. 94(B8), 10637-10646. [3] Aoudjehane H. C. et al. (2012) Science 338(6108), 785-788. [4] Beck P. et al. (2005) *Nature*, doi:10.1038/nature03616.