SHOCK EFFECTS IN TISSINT: EVIDENCE AGAINST A LONG DURATION SHOCK AND LARGE IMPACTING BODY. T. G. Sharp[1], E. L. Walton[2,3], and J. Hu[1] [1]School of Earth and Space Exploration, Arizona State University, Tempe AZ 85287-1404 (tom.sharp@asu.edu), [2]Grant 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 Martian meteorites have been modified by shock waves, generated by hypervelocity impact events on Mars. Shock P-T-*t* conditions can be constrained from the high-pressure phases that form by solid-state transformations and by crystallization products of shock melts, and by shock deformation of host rock minerals [1]. Similarly, one can use transformation kinetics and melt-vein cooling rates to constrain durations of the shock pulse and impact parameters such as size and velocity of the impacting body. Baziotis et al. [2] identified a large array of high-pressure minerals in Tissint and used their observations to argue for a long duration shock pulse and a large impacting body. In this study we also investigate shock metamorphism in Tissint to understand shock melt crystallization and olivine phase transformation in order to constrain shock conditions and duration. We use these results to evaluate the interpretation [2] of a long shock pulse and large impact on Mars.

Methods: Two polished thin sections of Tissint were investigated by transmitted and reflected light microscopy. Micro-textures were characterized by BSE images at UAb. Major and minor elemental abundances were measured using EDS. Raman spectra were collected at GMU with a Bruker SENTERRA spectrometer using a 532 nm laser operating at 10 mW. Several areas of interest were excavated with a FEI Nova II FIB-SEM system and these sections were analyzed using FEI CM200FEG and Jeol 2000FX TEM instruments in the LeRoy-Eyring Center for Solid State Science at ASU. Synchrotron micro X-ray diffraction was performed on areas of interest within the Tissint thin sections at GSE-CARS at the Advanced Photon Source, Argonne National Lab.

Results: Tissint is composed of mm-size macrocrysts of zoned olivine and smaller more ferroan olivine embedded in a groundmass of pyroxene and plagioclase (now glass). Both thin sections contain heterogeneously distributed shock melt in the form of veins and pockets. Raman spectroscopy confirmed the presence of several high-pressure phases including; maskelynite, ringwoodite, and jadeite.

Olivine-ringwoodite transformation: As in other highly shocked meteorites, olivines are only transformed in close association with shock melt, where the temperatures during shock are highest. Along several shock veins, olivine macrocrysts have bright rims (Fig. 1a) indicative of transformation. Raman spectra collected on bright rims and lamellae confirm that they are ringwoodite. We observe a transition from a polycrystalline ringwoodite margin (Fig 1a) to a partially transformed olivine with ringwoodite lamellae. TEM analysis shows that these lamellae are that occur sub parallel to $(100)_{ol}$. Nad coherently with the host olivine.

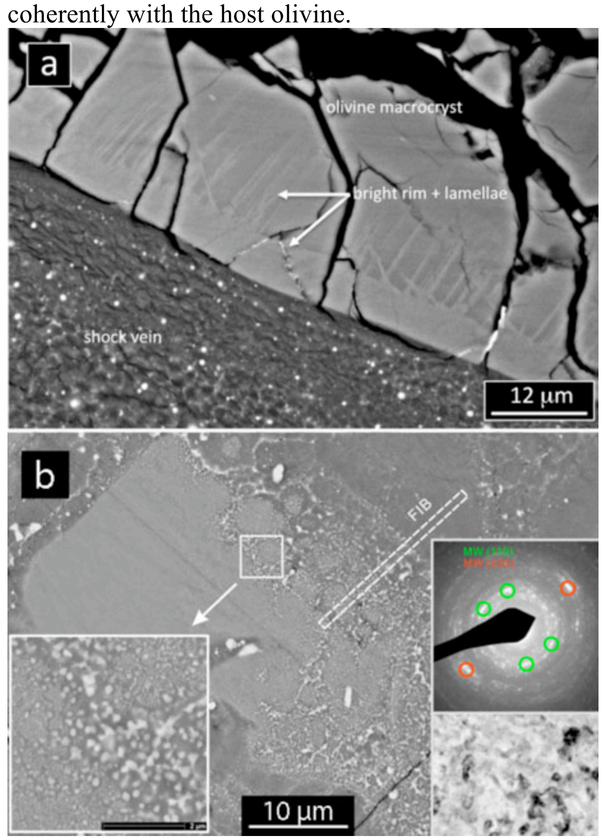

Figure 1. BSE images of transformed olivine. Ringwoodite and ringwoodite lamellae (a) occur in olivine along the contact with the shock vein. Olivine dissociated into nano-crystalline magnesiowüstite and pyroxene in a melt pocket. SAED pattern shows reflections for oriented magnesiowüstite.

Olivine to silicate perovskite plus oxide: Clasts of olivine entrained within a smaller (~300−450 µm) shock-melt pocket show transformation to two distinct phases. The texture of the dissociated olivine clast consists of many tiny blebs of high and low contrast (BSE) material (Fig. 1b). 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. 1b).

TEM images show 100−200 nm magnesiowüstite plus crystalline clinopyroxene. Synchrotron X-ray diffraction patterns from this material match clinopyroxene and magnesiowüstite. We infer that the pyroxene represents silicate perovskite that formed from olivine at high pressure and subsequently transformed to pyroxene after pressure release.

Shock-vein crystallization: Clinopyroxene occurs throughout the quenched shock melt in this sample. Ringwoodite also occurs in the melt around the dissociated olivine clasts as well as in the thin melt vein. TEM imaging and diffraction of a glassy thin vein identify clinopyroxene, ringwoodite and stishovite in a glassy matrix.

A thicker, irregularly-shaped shock vein, exhibits several features that set it apart from the thin vein. The shock-melt contact with the host rock is gradational. At its thickest (1.4 mm) the shock vein matrix consists of glass + vesicles + Fe-sulfide spheres. The glasses range from schlieren-rich to homogeneous. The abundance of crystals increases toward the host-rock margin. A zone ~100 μm at the vein margin is largely crystalline, as are areas of the vein where it is thinner (~450 μm). BSE images reveal the presence of many sub-rounded fragments near the vein margin and EDS analyses confirm that the fragments are (compositionally): olivine + pyroxene + chromite + plagioclase.

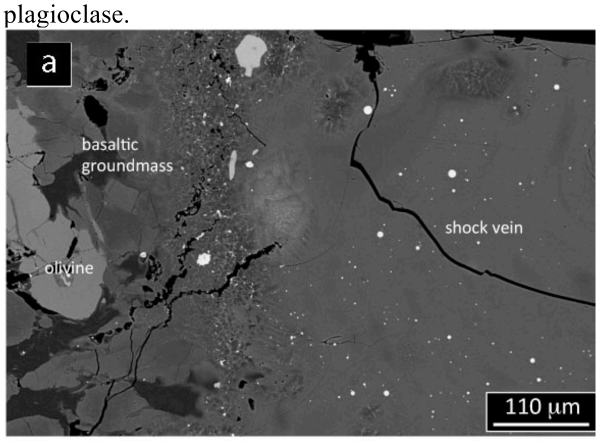

Figure 2. BSE image of the largest melt vein showing a glassy interior and dendritic olivine crystals

No evidence for high-pressure polymorphs were identified in the thickest part of this vein. Crystals with pyroxene composition yield spectra with sharp characteristic Raman peaks. Likewise spectra from host-rock olivine in direct contact with the vein exhibit a strong olivine doublet at 818 and 847 cm^{-1}. Entrained host rock pyroxene and olivine fragments show no signs of transformation. The glassy vein center yields weak Raman signals consistent with pyroxene-rich glasses. Jadeite, with peaks near 375 cm^{-1}, 520 cm^{-1}, 700 cm^{-1} and a doublet at 990 cm^{-1} and 1000 cm^{-1} has been identified in entrained grains that were originally plagioclase and along the walls of former plagioclase in contact with the vein.

Discussion:

Shock conditions & P-T history: The extensive shock melt and the presence of high-pressure phases indicate that Tissint was highly shocked. The melt in the thinnest vein (20 μm) and adjacent to the transformed olivine in a thicker vein (~300−450 μm) consist of clinopyroxene, ringwoodite and stishovite, suggesting crystallization at moderate pressures (~15 GPa). The lack of a majoritic garnet, commonly found in L chondrite shock veins, may reflect the higher SiO_2 content of the Tissint shock melt. In contrast, the dissociation of the olivine to silicate perovskite suggests that Tissint was shocked to a pressure greater than ~ 25 GPa. This inconsistency between transformation and crystallization pressure (~15 GPa versus ~25 GPa) suggests that crystallization of the melt occurred during pressure release.

The duration of the shock is more difficult to constrain. Baziotis et al [1] used ringwoodite crystal sizes, combined with ringwoodite growth-rate data and melt-pocket cooling rates to argue for a long duration (~ 1s) shock pulse and therefore a large (10km) impacting body. Our analysis of melt veins and pockets in Tissint shows that shock-melt quenched during and after the shock pulse, indicating that the time required for shock melt to quench exceeded the shock pulse. Thin shock veins (~100 μm) cool on the order of 10−20 ms while larger pockets cool (>1 mm) in seconds [3]. The melt-vein quench features and assemblages we observe in Tissint are consistent with a shock pulse on the order of 10s of ms, and therefore a impacting body only 100s of m in size. This implies that the impact on Mars that shocked and ejected Tissint was not exceptionally large.

References: [1] Sharp T. G. and De Carli P. S. (2006) MESS II 1, 653-677. [2] Baziotis I. P. et al. (2013). *Nature Commun*. doi: 10.1038/natcomm2414. [3] Shaw C.S.J., Walton E.L. (2013) *MAPS* doi: 1011/MAPS12100.