The occurrence of ringwoodite in shock veins of the Elephant Moraine A79001 shergottite. E. L. Walton-Hauck[1,2], [1]Grant MacEwan University, City Centre Campus, Edmonton, AB, T5J 4S2, Canada, (waltone5@macewan.ca). [2]University of Alberta, Department of Earth & Atmospheric Sciences, Edmonton, T6G 2E3, AB, Canada.

Introduction: Elephant Moraine (EET) A79001 was recovered from the 1979 ANSMET expedition as a single stone weighing 7942 grams [1]. EETA79001 contains two different igneous lithologies (A and B), joined along an igneous contact. Lithology A is basalt containing many megacrysts of highly magnesian olivine and low-Ca pyroxene (up to 3 mm diameter), with common inclusions of smaller euhedral chromites. Lithology B is a sub-ophitic ferroan basaltic rock. Both lithologies are cut across by thin (~1 - 110 μm), black, glassy veins and larger (mm- to cm-size) pockets of glass + crystals. These veins and pockets are loosely referred to as 'lithology C' or shock veins and shock melt pockets to clarify their impact origin.

Purple grains tentatively identified as ringwoodite, the high pressure polymorph of olivine, were reported from EETA79001 Lithology A shock veins during the original meteorite processing [2]; however, the nature of these grains has not yet been confirmed. In this study, shock veins in EETA79001 lithology A have been investigated using optical microscopy, scanning electron microscopy, the electron microprobe and micro-raman spectroscopy. The presence of ringwoodite is confirmed. The occurrence of this phase can be used to locate ringwoodite in other olivine-bearing Martian meteorites.

Overview of Shock Features: All precursor igneous plagioclase grains have been converted to optically isotropic maskelynite throughout the host rock or normal glass within a zone ~200 μm distant from the cm-size shock melt pocket. The latter phase is distinguished by the presence of conspicuous flow lines and vesicles. Olivine and pyroxene show pervasive fracturing (irregular and planar) and strong mosaicism. Pyroxene exhibits polysynthetic mechanical twinning associated with shock. Olivine megacrysts are strongly colored yellow-brown and weakly pleochroic.

Thin section EETA79001,73 is approximately half shock melt pocket and half lithology A by area. Lithology A is cut across by a dense network of black and amber colored shock veins that vary in thickness from ~1 μm to 109 μm, as measured in the two dimensions of the section. The veins appear to have a random distribution throughout the sample and they connect to the larger shock melt pocket. The contacts between shock veins and host rock are sharp, cutting cleanly across mineral grain boundaries. Offsets along the vein are observed as an apparent displacement of igneous minerals along its margin.

This study focuses on one area where the shock vein cuts across an olivine megacryst and locally widens (67 - 109 μm). Numerous fragments of host rock olivine are entrained within the vein (Fig. 1)

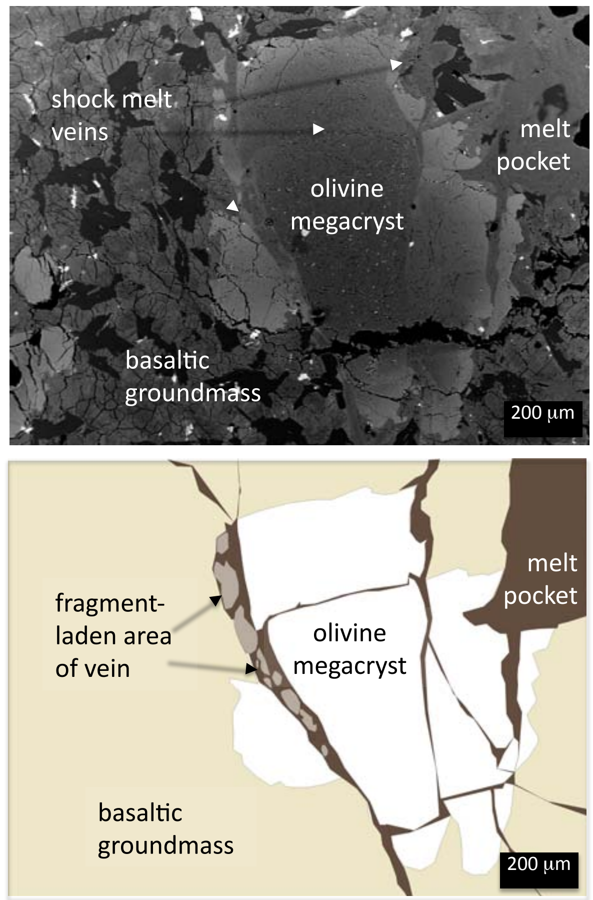

Figure 1. (top) BSE image of zoned olivine megracryst cut across by an interlocking network of shock veins. A sketch of the corresponding area (bottom), shows the relationship between shock melts (brown), basaltic groundmass (yellow) and the olivine megacryst (white).

Analytical Methods: Polished thin section EETA79001,73 was initially investigated by transmitted light microscopy. Detailed microtextures were characterized by backscattered electron (BSE) images at the University of Alberta (UAb) using a Zeiss EVO MA LaB_6 filament scanning electron microscope (SEM). BSE images were acquired using a Si diode detector under conditions of 20 kV (accelerating voltage) and 5.0 mm (working distance). SEM BSE images imported into the image analysis software ImageJ were used to measure grain sizes and vein thicknesses.

Major and minor elemental abundances were measured on the thin section at UAb using a JEOL 8900 electron microprobe (EMP) equipped with five wavelength dispersive spectrometer. A 1 μm focused beam was employed to analyze minerals and glasses with an accelerating potential of 15 kV and a beam current of 10 nA. Raman spectra were collected with a Bruker SENTERRA instrument at Bruker Optics, Billerica, MA, and with a Renishaw inVia raman microscope at the National Institute of Nanotechnology (NINT), Edmonton, AB. Both instruments used the 50x objective of a microscope to focus the excitation laser beam (514 nm line of Ar+ laser for the SENTERRA and 633 nm line of a HeNe laser for the inVia) to a 3 - 5 micron spot size. To avoid sample deterioration and to achieve good counting statistics, a sequence of ten-20 s exposures were acquired using a laser power of 15 - 30 mW. These multiple exposures were then stacked to achieve the final spectrum. Due to the fine-grained nature of the ringwoodite, the analyses were repeated several times to check reliability. Backgrounds of the spectra were graphically reduced using the LabSpec v. 2.08 software by Dilor SA.

Results: The olivine megacryst is strongly zoned from a magnesian core ($Fo_{76.5}$) to an iron-rich rim ($Fo_{54.3}$). The shock vein cuts across the megacryst where zoning is most pronounced; the Fe-rich rim and Mg-rich core are on adjacent sides of the vein. The shock vein matrix is largely opaque in plane light. SEM imaging of the vein matrix reveals a microcrystalline texture of crystals (≤1 μm), finely intergrown with blebs of bright grains, corresponding to slight enrichments in chromium and sulfur (0.08 - 0.25 Cr_2O_3 and 0.13 - 0.45 SO_3 wt% oxides). This area of the shock vein is laden with rounded to sub-rounded fragments of entrained host rock olivine (10 μm to 95 μm). The outer portions of the fragments (9 - 18 μm) in direct contact with the vein matrix have a distinct purple color, high relief and are optically isotropic. The purple grains are also observed in a zone ~5 μm to 12 μm wide along walls of the olivine megacryst in direct contact with the vein matrix.

BSE imaging reveals that the purple regions are polycrystalline aggregates of crystals 1 to 3.1 μm in diameter (Fig. 2). Raman spectra from these aggregates (olivine fragments entrained within the shock vein and on walls of the olivine megacryst) contains bands from several phases because of the small grain size (1 to 3.1 μm) compared to the laser spot size (3 - 4 μm). Two strong bands at 798 and 844 cm^{-1} correspond to the principal ringwoodite frequency reported by [3]. Bands at 600, 822, 852 and 955 correspond to olivine [3]. EMP analyses of the polycrystalline ringwoodite give a compositional range from $Fo_{67.6}$ to $Fo_{73.9}$.

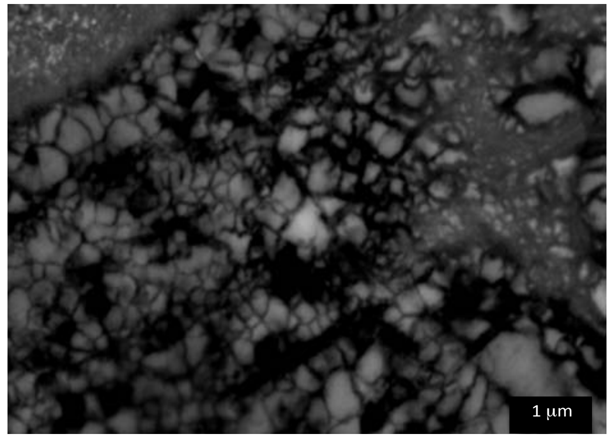

Figure 2. BSE image of polycrystalline ringwoodite aggregates on olivine fragments entrained within the shock vein.

Discussion: Ringwoodite has been confirmed within and adjacent to shock veins in EETA79001 lithology A by raman spectroscopy and optical observations. Within the shock vein, polycrystalline ringwoodite aggregates are found on the margins of host rock olivine entrained as fragments. The fragments have rounded shapes which suggest melting in direct contact with the melt. The composition of ringwoodite ($Fo_{67.6-73.9}$) falls within those compositions obtained from the igneous olivine megacryst ($Fo_{54.3-76.5}$).

The restricted occurrence of ringwoodite, its composition and the rounded shape of fragments are consistent with the consensus view that polycrystalline high-pressure phases in shock-induced melt veins are the result of solid-state transformation rather than crystallization from the melt [4]. The abundance of clasts in the vein (Fig. 1) suggests the vein did not form by injection into a fracture, but rather formed *in situ* by shearing or collapse around cracks and pores. Off-set igneous minerals along vein provide further evidence for displacement and shearing.

A shock pressure of 32 ± 3 GPa has been reported for lithology A by comparing shock effects in rock-forming minerals to the products of shock recory experiments [5]. However, the results of static high-pressure data are increasingly used to interpret the microtextures of shocked meteorites [e.g., 4]. Here, the ringwoodite stability field of [6] is used to estimate a shock pressure of 18 - 23 GPa for EETA79001. Growth rate calculations based on published kinetic data suggest that the time required to grow a 1 μm ringwoodite crystal is ~100 ms [4], suggesting a minimum shock pulse of ≥100 ms for EETA79001.

References: [1] Score R. and Reid A. M. (1981) *Ant. Met. News.* 4, 133-134. [2] Steele I. M and Smith J. V. (1982) *JGR* 87, A375-A384. [3] McMillan P. and Akaogi M. (1987) *Am. Miner.* 72, 361-364. [4] Xie Z. and Sharp T. G. (2007) *EPSL* 254, 433-445. [5] Fritz et al. (2005) *MAPS* 40, 1393-1411. [6] Ohtani E. and Sakai T. (2008) *MAPS* 38, 1451-1460.