PETROGRAPHY AND SHOCK METAMORPHISM OF HOWARDITE SARIÇIÇEK. R. Saini[1] and C. D. K. Herd[1], [1]Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, Alberta T6G 2E3, Canada, email: rsaini2@ualberta.ca.

Introduction: Howardites are part of the HED group of meteorites, a group that may originate from the asteroid 4 Vesta [1]. Sariçiçek is a howardite that fell in Turkey in 2015 and was subsequently investigated by a large consortium study for details about the meteorite's fall, find, mineralogy, petrology, and geochemistry [2]. The meteorite was classified as a "regolith howardite" based on its high siderophile element content and noble gas abundance [2]. Its petrographic investigation revealed that it is a clast-rich breccia set in a fine-grained matrix of crushed and fragmented material. Fragmentation most likely was caused by impact events. Although there have been some observations reported on the mechanical deformation experienced by pyroxene [1] and plagioclase [2], the shock effects in this meteorite have not yet been extensively studied. This study seeks to fill in this gap, through the characterization of the diversity of material present in Sariçiçek and the shock effects in various clasts and the matrix.

Sample and Methods: One polished thin section from the MacEwan University collection was studied. A ZEISS Sigma 300 FESEM at the University of Alberta was used to acquire BSE images with a 15-20 kV accelerating voltage. Mineral identifications were aided by a Bruker EDX system fitted to the FESEM. Mineral structures were analysed using a Horiba Scientific XPLORA- PLUS Raman spectrometer at MacEwan University. The Raman spectrum was collected in confocal mode using 532 nm laser and 1800 grooves / millimeter grating to achieve a spectral resolution of 1.4 cm^{-1} at FWHM.

Mineralogy and Petrography. Sariçiçek contains a variety of clasts and mineral fragments set in a fine-grained matrix. Clasts include lithic clasts similar to those described in [1], impact melt clasts and breccias, and two impact-induced accretionary lapilli-like clasts that consist of a silica core that is armored by pyroxene rim. Fragments of silicate-metal aggregate were also found in the sample. The matrix consists of broken and crushed fragments of high-Ca pyroxene, low-Ca (ortho)pyroxene, silica, plagioclase, chromite, ilmenite, and troilite. Orthopyroxene clasts sometimes contain chromite mineral inclusions, and high-Ca pyroxene lamella with oriented chromite inclusions in both phases. Silica is present mostly as quartz and cristobalite in the matrix and lithic clasts.

A variety of impact-melt clast textures, compositions, and sizes were identified. The clasts vary in size from ≤100 μm to ~400 μm. An example of an impact melt clast includes a clast that has equant crystals of pyroxene (as large as 45 μm) set in a glassy to fine grained matrix of pyroxene composition. Another impact melt clast has equant crystals of pyroxene (as large as 10 μm) and olivine (as large as ~ 8 μm) set in a cryptocrystalline basaltic matrix. Yet another impact melt clast consists of olivine microlites set in an amorphous matrix of pyroxene and plagioclase composition. In general, a variety of impact melt breccias contain clasts of pyroxene, plagioclase, silica, and olivine set in a vesiculated and glassy to fine-grained crystalline matrix of variable composition (pyroxene, pyroxene + plagioclase or pyroxene + plagioclase + olivine).

Shock metamorphic features. Some melt is observed at small scale (~ 1 μm to 10 μm) in the matrix and along a few lithic and mineral clasts. The melt in the matrix might not be a part of previous impact melt clasts as its contact with the matrix is irregular and not sharp like clast boundaries. The melt is characterized by a quenched texture or flow deformed shape, and Raman peaks from the matrix, crystals, and clasts are consistent with pyroxene crystals and glass.

Some Shock features have been observed in clasts and following are examples of interest:

Clast A is a large orthopyroxene clast with high-Ca pyroxene lamellae and has a shock induced melt vein cutting through the clast; the vein is restricted to the clast boundary (Fig. 1a), indicating the clast had a distinct shock history before being integrated into the Sariçiçek breccia. The vein has a width of 10 μm and is at sharp contact with the host rock. The right margin of the vein consists of poorly crystalline pyroxene, as indicated by the broad peaks in the Raman spectrum at 332 cm^{-1}, 670 cm^{-1}, and 998 cm^{-1}, and grading into a zone of glass + granular crystals in the center and towards the left margin of the vein (Fig. 1b). Crystals in the vein are very fine-grained (≤1 μm in size) and the Raman peaks at 312 cm^{-1}, 363 cm^{-1}, 688 cm^{-1}, 1022 cm^{-1} confirm that pyroxene is the primary phase that has crystalized from the melt in the vein.

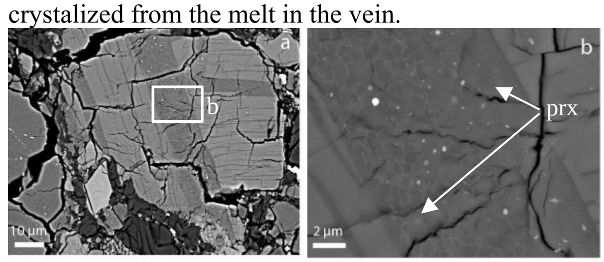

Fig. 1: BSE images of Clast A and the shock melt vein with the granular phase on the left and towards the

centre of the vein, and amorphous pyroxene on the right. Prx = pyroxene.

Clast B is composed of pyroxene and plagioclase and contains melt on its left margin (Fig. 2a). The melt zone is characterized by flow lines and is generally of pyroxene composition (Fig. 2b). The Raman spectra obtained from two different regions within the melt contains two broad humps and slightly sharper peaks at ~670 cm^{-1} and ~1000 cm^{-1}, revealing the presence of both glass and poorly crystalline pyroxene phases within the melt. No crystals were observed within the melt region as no phase seems to have crystalized from the it.

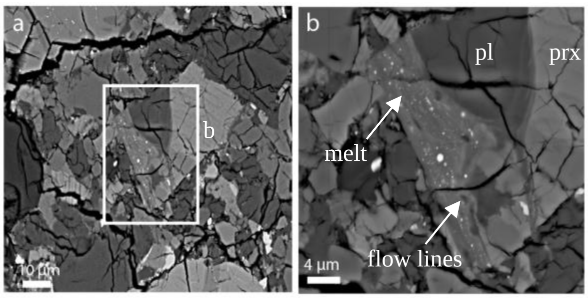

Fig. 2: BSE images of melt constricted to the left margin of clast B . Pl = plagioclase.

Clast C is an angular impact melt clast (~100 μm in size) and composed of fine-grained pyroxene and some quartz unevenly distributed throughout (Fig. 3a). There are zones within the clasts where phases have crystalized from the melt with a globular texture (Fig. 3b). Peaks in the Raman spectra acquired from these globules at 336 cm^{-1}, 673 cm^{-1}, and 1004 cm^{-1} are consistent with pyroxene and a distinct peak at 916 cm^{-1} present in the same Raman spectrum is consistent with garnet [4]. Future electron microprobe data will test whether garnet is of high-pressure origin [e.g., 5].

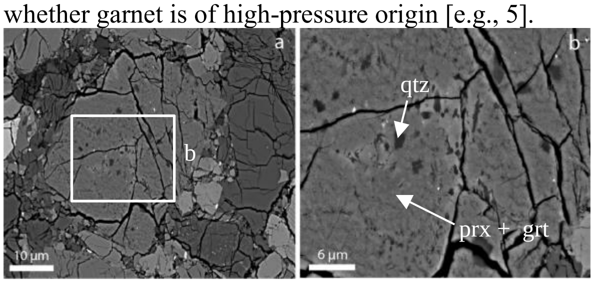

Fig. 3: BSE image of Clast C, an angular impact melt clast with pyroxene and garnet present in a globular texture. Grt = garnet, qtz = quartz.

Discussion and Conclusion:

No high-pressure polymorph of pyroxene is present in the shock vein observed in clast A; however, the presence of a shock vein itself indicates a shock stage of 3 or above [6, 7]. No high-pressure mineral is present in clast B, but incipient melting of pyroxene is indicative of localized shock pressures of ~> 70 [8]. Future optical microscopy and electron microprobe data will aid in confining the shock conditions experienced by the garnet bearing impact-melt clast. Different shock features are present in diverse clasts in Sariçiçek, highlighting the distinct shock histories of the investigated clasts.

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