SHOCK FEATURES IN THE CHELYABINSK LL5 CHONDRITE: PRELIMINARY RESULTS.
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Introduction: Shock effects within meteorites are the products of impacts and collisions in the asteroid belt that eventually led to the ejection of the meteorite from its parent body. Although detailed studies of shock effects within various highly shocked (S5-S6) L chondrites have been carried out in order to understand the P and T conditions during the impacts events [e.g., 1,2], very few studies have been done on LL and H chondrites [3,4]. Improved knowledge of shock effects on these other ordinary chondrites is desirable because of their different origin.

Here, we present preliminary results from the Chelyabnisk meteorite that exploded over the Chelabinsk area of Russia on February 15, 2013. Hundreds of fragments were collected subsequent to the airblast and were classified as LL5 ordinary chondrites [5] with impact melt rock clasts and shock-darkened lithologies. The LL5 classification was challenged by [6], who stated that Chelyabinsk is a complex genomict breccia that also contains LL6 lithologies. In this study we search for high pressure mineral phases in impact melt veins, found within a shock-darkened fragment.

Methods: We prepared a polished section from Field Museum Chelyabinsk specimen ME 6050. We used the Field Museum's Zeiss Evo 60 SEM equipped with an Oxford EDS system to image the melt veins and look for characteristic shock features for later Raman and FIB/TEM studies. We also studied the texture of the melt veins and the composition of phases both inside and outside the veins using SEM/EDS. High pressure mineral polymorphs form generally near or within the melt veins. For quantitative SEM/EDS analyses the following standards were used: Enstatite (Mg, Si), diospide (Ca), synthetic forsterite (Mg), olivine from Springwater meteorite (Fe), San Carlos olivine (Mg, Si), anorthite (Ca), microcline (K), rutile (Ti), corundum (Al), chromite (Cr) and Albite (Na).

Results: The studied fragment contains abundant shock melt veins ranging in thickness from ~50 µm to ~1 mm and two melt pools. Most of the melt veins contain abundant silicate clasts surrounded by a matrix of sulfide and metal (Fig. 1). Sometimes the clasts are rounded, indicating that they have been partially resorbed. Some veins have low abundances of opaque phases with most of the opaque phases occurring as rounded or partly irregular blebs. A thin layer is present at the contact between one of the melt veins and the host meteorite (Fig. 1). It contains small (1-10 µm) rounded metal and sulfide blebs and very fine grained crystals. The melt pool contains some large lithic silicate clasts, small euhedral zoned crystals (~2-4 µm), quenched melt, large rounded metal and sulfide blebs and melt matrix (Figs. 2,3). From the presence of planar fractures and undulatory extinction within olivine and pyroxene, mosaicism within the olivine and absence of maskelynite, the fragment has a shock stage of S4, consistent with other studied fragments.

Olivine: The composition of olivine within the matrix is Fa_{29-30} which falls into the LL chondrite range. Olivine within the veins also has a similar composition. The small euhedral olivine grains that crystallized from the melt pools are too small to analyze with SEM/EDS.

Pyroxene: Low-Ca pyroxene within the matrix has an average composition of $Fs_{24.5}Wo_{1.5}$, which is consistent with other meteorites in the LL group. The compositions of Ca-rich pyroxenes within the veins is $Fs_{9-10}Wo_{44.5-45}$. This value is similar to the composition of Ca-rich pyroxene measured by others [5] within the Chelyabinsk matrix.

Feldspar: Composition of feldspar within the matrix and the veins are also similar ($Ab_{82-84}Or_{6-10}$).

Quenched glass: Two occurrences of quenched glass were found within one of the melt pools. The glass is rich in Na, Mg, Al, Ca, a composition that is the result of melting of olivine, feldspar and pyroxene.

Discussion: Our preliminary analysis did not find any signature of high-pressure minerals within the melt veins. High-pressure minerals form either by solid-state transformation of low pressure minerals or by crystallization from melts at high pressure [2]. Those formed by the former process have similar compositions as their host minerals and it is almost impossible to identify them by compositional analysis (SEM/EDS) alone. Therefore, we cannot deny the presence of high-pressure phases within or near the melt veins from our present study. Planned Raman spectroscopic studies will help in identifying any of these phases.The liquidus phases within the melt veins have a different composition to the meteorite matrix and can be identified by SEM/TEM/EDS. These data can help to constrain the pressure and temperature during crystallization. FIB sections will be prepared from the interstitial melt within the veins (e.g. Figs. 2-5) in order to characterize the liquidus phases.

Most of the studied veins have dominant silicate fragments from the host meteorite and an interstitial metal and sulfide matrix (Fig. 1). This suggests that these veins did not reach high enough temperatures to facilitate complete melting of silicates and metal-sulfides. However, other parts of the veins and the melt pools show clear signs of complete to partial melting (e.g. rounded to irregularly shaped metal and sulfide blebs) and unmixing of silicate and metal-sulfide melt. The difference in texture within the same melt vein indicates heterogeneous temperature distribution. A similar thin vein as seen at the contact between one of the vein and host meteorite (Fig. 1), was also seen in the Roy L5-6 chondrite [7]. This vein within the Roy meteorite contained majorite and ringwoodite and was suggested to have quenched rapidly over a narrow pressure range. In our Chelyabinsk section the quenched melt seen within a melt pool (Figs. 2,3) are a clear indication of rapid quenching of the veins by conduction of heat to the cold host meteorite matrix. A FIB section will be prepared from the melt in order to look for any crystallizing phase.

Our preliminary study shows that the composition of the phases within the melt veins and the host Chelyabinsk meteorite are similar. Part of the shock induced veins and the melt pools, within the Chelyabinsk meteorite, have been subjected to high pressure and temperature melting and recrystallisation. Micro-Raman and FIB/TEM will be carried out within these veins and melt pools in order to look for any high pressure phases or any crystallizing liquidus minerals. Other shocked LL5-6 meteorites will be studied to make comparisons with the Chelyabinsk meteorite.

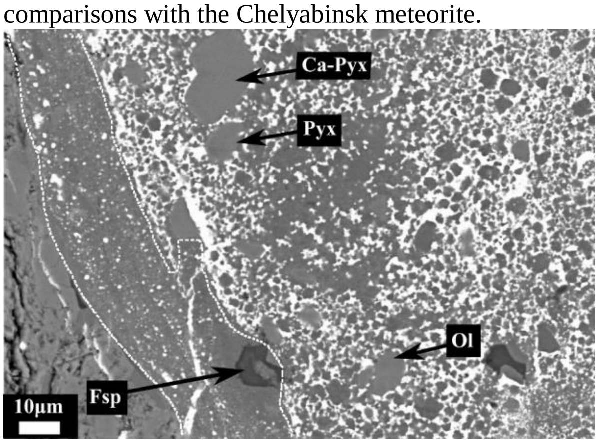

Fig.1: BSE image of melt vein within Chelyabinsk ME6050 with many rounded and irregularly shaped silicate fragments surrounded by bright Fe,Ni-metal and Fe-sulfide. A thin layer is clearly present at the edge of the vein is and marked by dashed lines. Ol = olivine; Ca-Pyx = Ca-rich pyroxene; Pyx = low-Ca pyroxene; Fsp = feldspar.

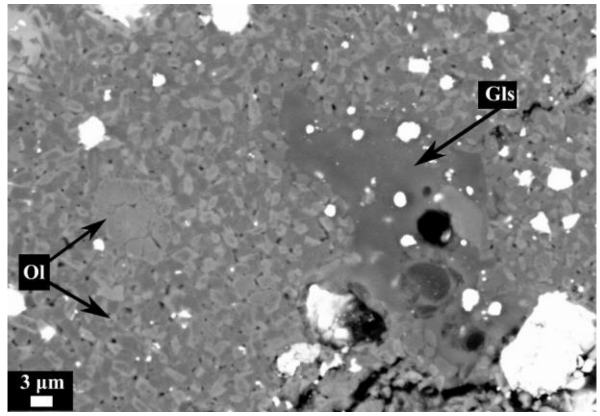

Fig. 2: BSE image of one of the melt pools within the studied Chelyabink meteorite. Small euhedral crystals of Ol and a larger sintered Ol crystal is present within a melt matrix of Pyx-like composition. A large quenched melt (Gls) is also present. White rounded objects are metals and sulfides.

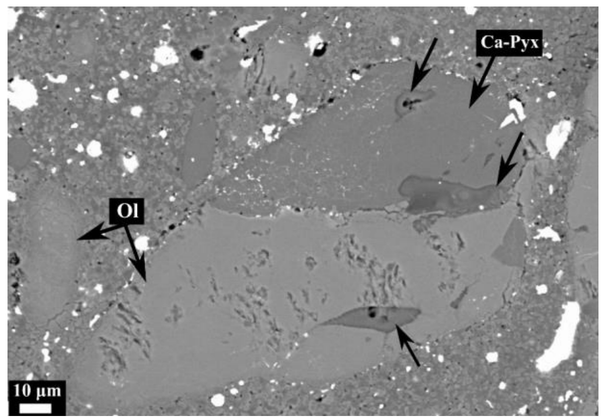

Fig. 3: BSE image of a large silicate clast within the melt pool. Within the clast three Na-,Al-,Mg-rich melt regions are visible (marked by arrows).

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