A RAMAN STUDY OF CHELYABINSK LL5-6 CHONDRITE BRECCIA: INVESTIGATING THE SIGNATURES OF SHOCK-INDUCED MELTING IN NEAR EARTH ASTEROIDS. J.M. Trigo-Rodríguez[1], C.E. Moyano-Cambero[1], N. Mestres[2], and A. Bischoff[3]. [1]Institute of Space Sciences (CSIC-IEEC). Campus UAB, Fac. Sciences, C5-p2, 08193 Bellaterra (Barcelona), Spain. trigo@ieec.uab.es [2] Institut Ciència de Materials de Barcelona (ICMAB/CSIC), Campus UAB, 08193 Bellaterra (Barcelona), Spain. [3]Institut für Planetologie, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany. E-mail: bischoa@uni-muenster.de.

Introduction: The Chelyabinsk superbolide occurred on Feb. 15th, 2013 entering in the atmosphere at a velocity of ~19 km/s and delivering an energy of ~500 kT of TNT [1,2]. The superbolide exploded in the atmosphere and produced thousands of specimens with a currently Total Known Weight (TKW) of >>600 kg of meteorites that provide an unique opportunity to study the physico-chemical properties of a Near Earth Asteroid (NEA). It is well-known that most NEAs are S- (or Q-) class asteroids associated with ordinary chondrites [3]. A significant number of chondritic meteorites have been found to be breccias exhibiting unequivocal features of shock metamorphism [4-7]. Obviously, shock is accompanied by brecciation due to the transport of comminuted rock fragments often available at the surfaces of asteroids. Small NEAs probably have intense collisional histories due to the cascade sequence of events occurring during their dynamic transport until they reach the near-Earth region. Then, NEAs like Chelyabinsk having a few tens of meters in diameter are expected to have experienced a significant degree of shock and brecciation. These processes make them to be weak bodies disrupting preferentially in Earth's atmosphere, but still capable to deliver significant shock wave energy and meteorites to the ground, being a significant source of hazard to humans [2,8].

Technical procedure: Two thin sections of Chelyabinsk were studied. High-resolution mosaics of the sections were created from separate 50X images taken with a Zeiss Scope petrographic microscope. The mosaics allowed to establish target features to be characterized by micro-Raman, SEM, and EDS techniques.

SEM-EDS techniques. We used a FEI Quanta 650 FEG working in low vacuum BSED mode. The EDS detector used to perform elemental analyses is an Inca 250 SSD XMax20 with Peltier cooling with an active area of 20 mm^2. Some selected areas were explored at different magnification, and SEM elemental mapping together with EDS spectra were obtained.

Micro-Raman study. Several micro-Raman spectra were taken in backscattering geometry at room temperature using 5145 Å line of Argon-ion laser with a Jobin-Yvon T-64000 Raman spectrometer attached to an Olympus microscope and equipped with a liquid-nitrogen-cooled CCD detector. The lateral spatial resolution was ~1μm and the laser power onto the sample was kept below 0.5 mW to avoid degradation due to sample overheating. The Raman spectrometer provided spectra in a working range between 100 and 1,400 cm^{-1}

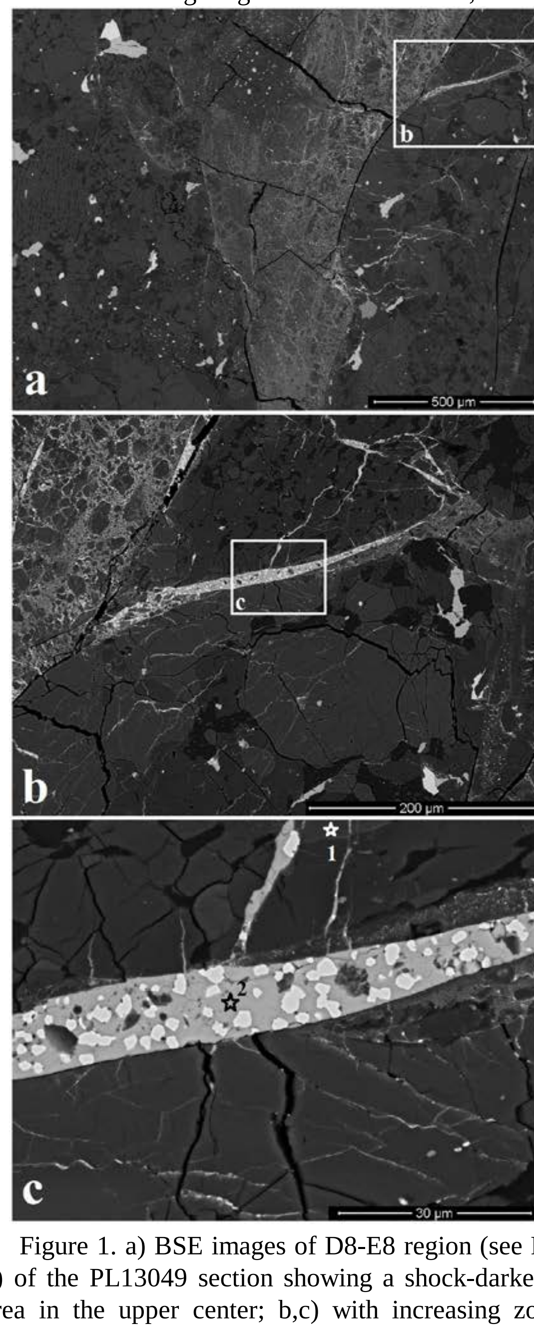

Figure 1. a) BSE images of D8-E8 region (see Fig. 2) of the PL13049 section showing a shock-darkened area in the upper center; b,c) with increasing zoom (insets) details of a shock vein (with the two points analyzed by Raman; compare Fig. 3) are shown.

Results and discussion: The Chelyabinsk chondrite (LL5-6) is a genomic breccia formed by LL5 and LL6 lithologies as well as clasts of shock melt and shock-darkened lithologies [6]. The rock has also experienced significant shock that produced severe mineral transformations. Shock veins filled with Fe-Ni and troilite are present all over the meteorite (see e.g. Fig. 1). Shock-darkened lithologies and clasts of impact melt brecias occur as (almost) opaque areas in the transmitted light mosaic (Fig. 2). A high-pressure polymorph of merrillite, $Ca_9MgNa(PO_4)_7$, that has a trigonal structure γ-$Ca_3(PO_4)_2$ has been identified nearby shock veins (see Fig. 1c). We have confirmed this by point-and-shoot Raman analyses that unequivocally identified the high-pressure form of trigonal merrillite within the small veins due to its characteristic intense peaks at 956 and 972 cm^{-1} (Fig. 3). The presence of this high-pressure mineral indicates that the rock experienced peak shock pressures higher than ~25 GPa [9] consistent with the shock stage already proposed (S4).

Conclusions: Two sections of Chelyabinsk chondrite have been studied to reveal the shock-induced features. The meteorite is a chondrite breccia formed by distinctive LL5 and LL6 lithologies [6], but has experienced significant degrees of shock metamorphism. Our Raman analyses identified the high-pressure trigonal merrillite blended with olivine close to shock veins. The mere presence of this mineral indicates that the materials experienced peak shock pressures higher than 25 GPa. The occurrence of shock-darkened minerals and other dark lithologies has an influence on the reflective properties of asteroids: Thus, shock-processing greatly reduces the chance of discovery of these dangerous projectiles in space [10].

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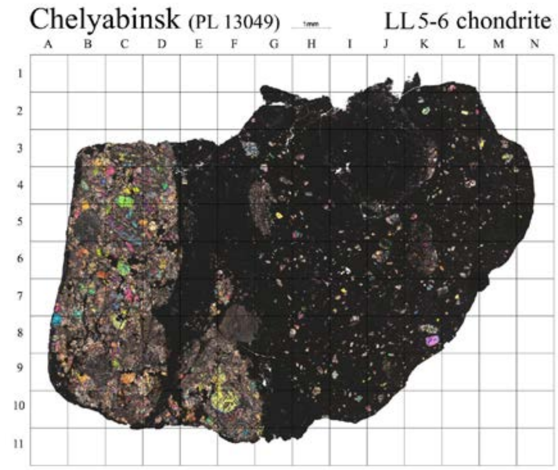

Figure 2. The analyzed section showing the chondritic texture on the left hand side and an impact melt breccia at the right hand side. Both lithologies are separated by a shock-darkened area and shock veins.

References: [1] Borovicka J. et al. (2013) *Nature, 503*, 235–237. [2] Brown P. G. et al. (2013) *Nature, 503*, 238–241. [3] Binzel R.P. et al. (2010) *Nature* 463, 331-334. [4] Bischoff A. et al. (2006) in *Meteorites and the Early Solar System II*, D.S. Lauretta & H.Y. McSween Jr. (eds.), Univ. Arizona Press, Tucson, 679-712. [5] Bischoff A. & Stöffler D. (1992) Eur. J. Mineral. 4, 707-755. [6] Bischoff A. et al. (2013) Meteorit. Planet. Sci. 48, A61. [7] Stöffler D. et al. (1991) Geochim. Cosmochim. Acta 55, 3845–3867. [8] Bland P.A. and Artemieva N.A. (2003) Nature 424, 288-291. [9] Xie X. et al. (2002) Geochim. Cosmochim. Acta 66, 2439-2444. [10] Cloutis E.A. (1990) Icarus 84, 315-333. [11] Walton E. et al. (2013) 45th LPSC, abs.1039

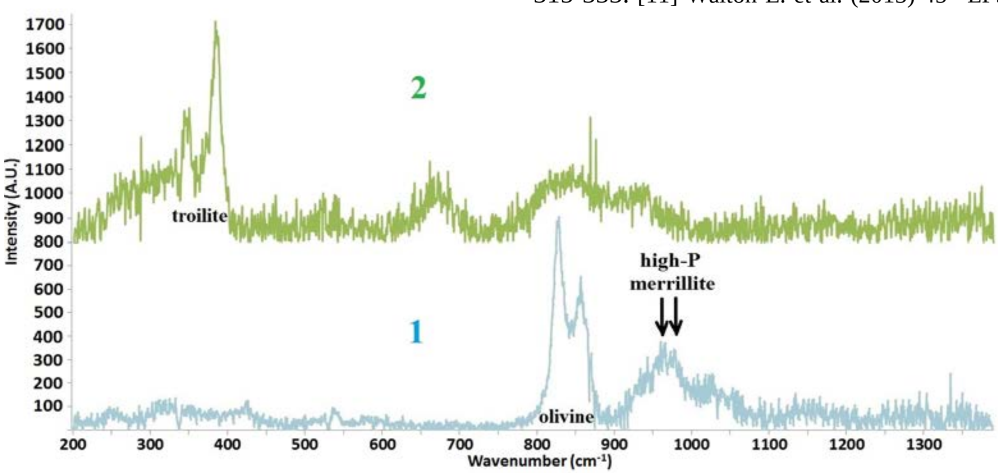

Figure 3. Raman spectra of point 1 and 2 marked in Fig. 1c. Main Raman identifications are given. The other weak peaks in spectrum 2 are temptatively associated with ringwoodite, a high-P polymorph of olivine [11].