SHOCK HISTORY OF FOSSIL UNGROUPED ACHONDRITE ÖSTERPLANA 065: RAMAN SPECTROSCOPY AND TEM STUDY OF A RELICT CHROME-SPINEL GRAIN. S. S. Rout[1,2*], P. R. Heck[1,2,3] and B. Schmitz[1,4], [1]Robert A. Pritzker Center for Meteoritics and Polar Studies, The Field Museum of Natural History, 1400 S. Lake Shore Drive, Chicago, IL 60605, USA. [2]Chicago Center for Cosmochemistry, [3]Department of Geophysical Sciences, The University of Chicago, 5734 S. Ellis Avenue, Chicago, IL 60637, USA. [4]Department of Physics, Lund University, Lund, Sweden. *srout@fieldmuseum.org

Introduction: The L-chondrite parent body breakup (LCPB) in the asteroid belt ~466 Ma ago produced ejecta that was discovered as >100 fossil L-chondrite meteorites (1-21 cm in diameter) in Sweden and abundant micrometeorites worldwide within post-LCPB Middle Ordovician sediments [1]. Elemental and oxygen isotope composition of relict chrome-spinel from the fossil meteorites confirm that they are L-chondritic [2-4] except one ungrouped achondrite, Österplana 065 (Öst 065) [5-6]. Whole-rock ε^{54}Cr and Δ^{17}O values and elemental composition of chrome-spinel grains from Öst 065 show that the meteorite is different from any previously known meteorites [6]. The similarity of the cosmic-ray exposure age of Öst 065 [5] and fossil L chondrites [7] most probably suggests that they are related and Öst 065 could be a piece of the impactor that hit the L-chondrite parent body. Additional evidence for this hypothesis could be provided by the study of the shock history of relict chrome- spinel grains from Öst 065. Shock features of two fossil L chondrites were recently studied by comparing nanoscale features between chromite grains in fossil L chondrites as well as in recent L-chondrite falls/finds [8].

Here, we present a study of shock features in chrome spinels from the fossil ungrouped achondrite Öst 065. We present results from Raman spectroscopy and TEM of Öst 065 chrome spinel and compare with the features in chromite from highly shocked recent L chondrites.

Samples & Methods: We studied polished chrome-spinel grain mounts from Öst 065 using a HORIBA LabRAM HR Evolution confocal Raman system at the NUANCE facility, Northwestern University. A 473 nm Ar^+ laser was focused to ~1 µm spot and spectra were accumulated for 120 sec. Raman spectra were obtained from 12 chrome-spinel grains. A TEM lamella was then prepared from one of the chrome-spinel grains using a Zeiss 1540XB FIB-SEM at the Electron Microscopy Center (EMC), Argonne National Laboratory (ANL). The TEM lamella was then studied using a FEI Tecnai F20ST TEM equipped with an EDAX SDD EDS detector also at EMC. Quantitative TEM-EDS analysis was performed by measuring the k-factors for Cr, Fe, Mg and Al on the UWCr-3 chromite standard [3]. For reference, highly shocked L chondrites Tenham (FMNH ME 2617 #4) and Catherwood (FMNH ME 3066 #2) were studied [8].

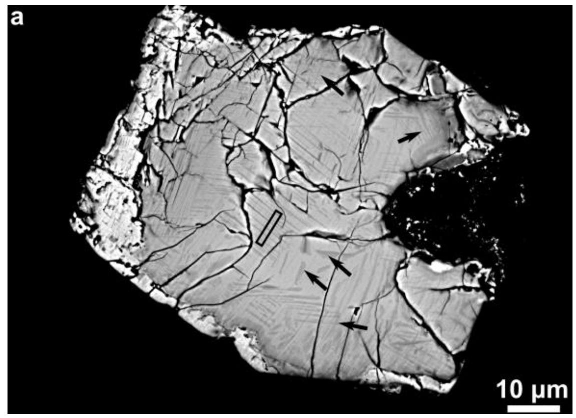

Fig. 1: Backscattered electron (BSE) image of a chrome-spinel grain from Öst 065. The region where the FIB lamella was prepared is shown by an open rectangle. Exsolution-like weathering-enhanced shock features are indicated by arrows.

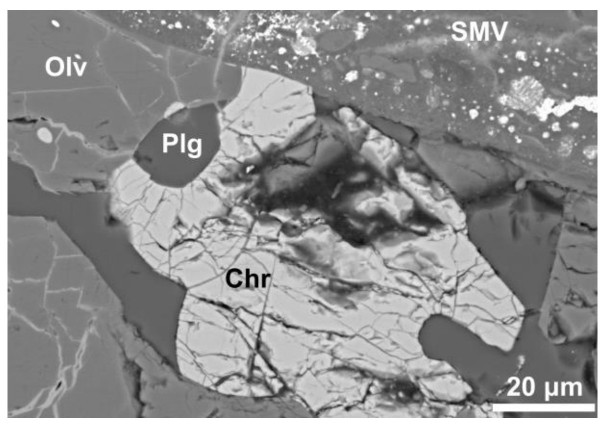

Fig. 2: BSE image of a highly fractured chromite grain from Tenham. Olv = Olivine; Plg = Plagioclase; Chr = Chromite; SMV = Shock melt vein.

Results: All chrome spinels from Öst 065 are heavily fractured and show planar features (Fig. 1). The fracturing is similar to the one in chromite in Tenham (Fig. 2) and Catherwood. In backscattered electron images of Öst 065 chrome-spinel features resembling mineral exsolution lamellae along planar fractures are apparent (Fig. 1). Chrome-spinel grains from

Öst 065 have distinct Raman spectra peaks at ~717 cm^{-1} and ~605 cm^{-1}. In comparison, the chromite grains from Tenham and Catherwood have a distinct peak between 686-688 cm^{-1} and secondary peaks at ~600 cm^{-1} and 496-500 cm^{-1} (Fig. 3). This is expected as the elemental compositions of chrome spinel from Öst 065 and chromite from L chondrites are different. There is no difference between the Raman spectra from the host chrome spinel and the mineral exsolution-like features along the planar fractures in Öst 065 (Fig. 3). No xieite, a high-pressure phase of chromite, was detected within the 12 studied chrome-spinel grains from Öst 065. The TEM sample from the Öst 065 chrome-spinel grain shows planar fractures and many dislocations and defects throughout the lamella (Fig. 4). The dislocation density ($1x10^{13}$ m^{-2}) is a factor of two lower than in a chromite from Tenham ($2x10^{13}$ m^{-2}) outside a shock-melt vein (SMV) [Fig. 2; 8]. In the Öst 065 chrome-spinel grain the planar fractures are along (311) compared to (011) in Tenham chromite. In the TEM images, the mineral exsolution-like features along the planar fractures have a very irregular boundary (Fig. 4). These features are most probably due to terrestrial weathering which is indicated by higher concentrations of ZnO (~0.7 wt%) and MnO (~1 wt%) measured with TEM-EDS. The composition of the unweathered volume of the chrome spinel and the weathered features also differ in the Cr/Fe ratios: ~1.5 and ~1.8, respectively. The studied chrome-spinel grain is a single crystal with a diffraction pattern consistent with cubic spinel (Fd3m) structure. There is no difference in the diffraction pattern between the unweathered and weathered part. No polycrystallinity, like in chromites from SMV of highly shocked Tenham and Catherwood meteorite was observed.

Discussion: The high density of fractures in Öst 065 chrome spinel confirms that it is highly shocked. Similar abundant planar features are not visible in SEM images of chromite from highly shocked L chondrites Tenham and Catherwood. The planar features in Öst 065 chrome spinel are most likely shock-produced and were enhanced by weathering and leaching processes during terrestrial residence in the marine sediment. The similarity of the planar fractures and dislocation density between Öst 065 and Tenham chrome spinel suggests that Öst 065 was also heavily shocked possibly up to shock stage S6. The chrome-spinel grain is certainly not from a SMV within Öst 065. Typically only about ~2% of all chromite or chrome spinel in a highly shocked meteorite are high-pressure polymorphs from a SMV [8]. Thus more than 100 chrome-spinel grains from Öst 065 would need to be studied to find one. However, chrome spinel from SMVs may also have been preferentially destroyed during sediment diagenesis due to their inherent polycrystalline nature and presence of high density of dislocations [8].

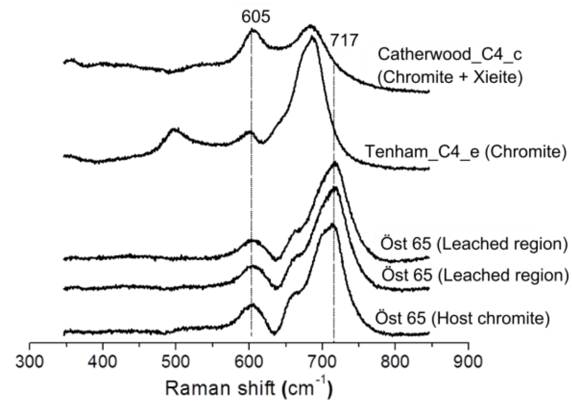

Fig. 3: Stacked Raman spectra of chrome spinel from Öst 065 and chromites from highly shocked L6 chondrites Tenham and Catherwood.

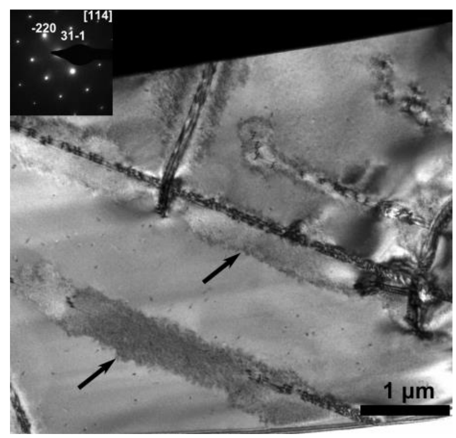

Fig. 4: BF-TEM image of Öst 065 chrome spinel. Arrows point to the weathering-enhanced shock features along the planar fractures. Inset: Selected area electron diffraction pattern.

Conclusion: We conclude that the presence of abundant weathering-enhanced planar shock features along with a high density of planar fractures and dislocations such as observed in Öst 065 chrome spinel (Fig. 1,4) is good indicator of high shock state (up to S6) of fossil meteorites. Thus, our conclusion is consistent with the hypothesis that Öst 065 was possibly a piece of the impactor causing the LCPB.

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