TRANSMISSION ELECTRON MICROSCOPE ANALYSIS OF A SPINEL-PEROVSKITE ASSEMBLAGE WITHIN A REFEACTORY INCLUSION FROM THE NORTHWEST AFRICA (NWA) 5028 CR2 CHONDRITE.

T. Ramprasad[1], P. Mane[2], T.J. Zega[1,2] [1]Dept. of Material Science and Engineering, University of Arizona, Tucson, AZ 86719, USA. [2]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 86721, USA. (tarunika@lpl.arizona.edu)

Introduction: Calcium-aluminum rich inclusions, (CAIs) are mm to cm-sized objects found in chondritic meteorites [1]. They are composed of high-temperature mineral phases that are thermodynamically predicted to be among the first-formed solids during condensation from the protosolar nebula. [2-4]. These inclusions record the processes during early stages of solar system formation, and their analysis can further our understanding of those processes.

CAIs are mainly composed of oxides and silicates, and have also been observed to contain assemblages of refractory metal, sulfides and phosphates [1]. Most CAIs are surrounded by a rim sequence composed of similar oxide and silicate minerals. Type-A CAIs are known to have more refractory phases than type-B CAIs [1]. Analysis of the oxide phases in type-A CAIs can help us understand the temperature, pressure and oxygen fugacity conditions prevelant during their formation. Spinel, $MgAl_2O_4$ and perovskite, $CaTiO_3$ occur in both the interiors as well as the rims [1]. In this work, we analyzed spinel and perovskite grain assemblages from a CAI in the Northwest Africa (NWA) 5028 CR2 chondrite.

Sample and Analytical Techniques: A section of the meteorite NWA 5028 (Center for Meteorite Studies, Arizona State University collection #1845-5) containing a type-A CAI (named as TR01) was analyzed using a Cameca SX-100 electron microprobe and a FEI Helios NanoLAB 660 focused-ion-beam (FIB) scanning electron microscope (SEM) [equipped with EDAX energy-dispersive spectroscopy (EDS)], located at the Lunar and Planetary Laboratory (LPL), University of Arizona. EDS maps and backscattered electron images (BSE) of the complete CAI were acquired. The two selected spinel-perovskite assemblages were extracted and thinned to electron transparency (less than 100nm) using previously described methods [5] with the FEI Helios FIB-SEM. The section from the interior of the inclusion was analyzed using a 200 keV spherical-aberration-corrected Hitachi HF5000 tranmission electron microsope (TEM), located at LPL. The HF5000 is equipped with a Gatan 965 post-column electron energy-loss spectrometer (EELS) and Oxford Instruments X-max dual, side-entry EDS with (large) solid angle of 2.0 sr. Electron diffraction patterns were acquired on the perovskite and spinel grains using selected-area electron-diffraction (SAED) analysis.

Results and Discussion: The minerology of this CAI is consistent with Type A CAIs (80-85 % melilite, 15-20 % spine1 and l-2 % perovskite), as defined by Grossman [6] and its rounded morphology suggests that it is a compact type A (CTA) inclusion. It has been suggested that during the formation of CTAs, the condensate assemblages underwent partial melting and crystallization, resulting in rounded inclusion [7].

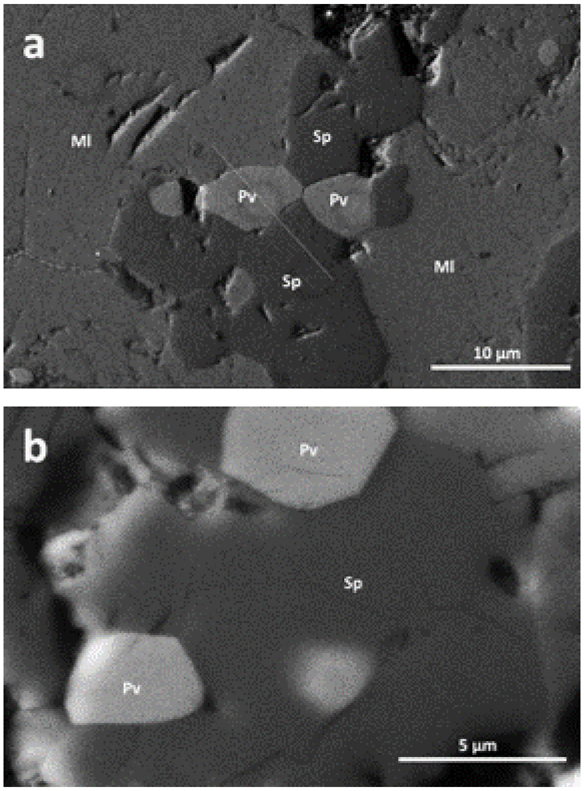

Fig 1 BSE images of Spinel - Perovskite assemblages (a) Interior - WDS and EDS analysis revealed that the grains from the interior are surrounded by melilite (b) Rim. High - contrast regions are perovskite grains.
Pv = perovskite; Sp = spinel; Ml = melilite.

We identified several spinel-perovskite assemblages from EDS maps and wavelength dispersive spectroscopy (WDS) spot analysis using electron microprobe. Two spinel-perovskite assemblages, one from the interior of the CAI and the other from the rim were selected for further analysis (Fig. 1). The assemblages were chosen because they show the presence of transition metal substitutions in the minerals and for their spinel-perovskite interfaces. The nature of the substitutions in the mineral lattice are dictated by environmental conditions such as temperature and oxygen fugacity [8]. The interface between mineral phases provides us with information regarding the processes involved in their formation. The FIB sections were made to transect the interface between the spinel and the perovskite grains. The FIB section of the interior spinel perovskite assemblage shows , smaller (0.1-0.5µm) inclusions of silicates and perovskite hosted in spinel grains. The FIB section of the rims shows inclusions of spinel hosted within perovskite.

The high-angle annular-dark-field image (HAADF) and the EDS maps of the FIB section from the interior of the CAI show that the chemistry of the spinel and perovskite grains are uniform (Fig. 2). The HAADF image of the inclusion within the spinel shows that it has a complex structure. EDS mapping of the inclusion shows that it is composed of a Ca-Al silicate grain with a Ti-rich Ca-Al silcate rim and an adjoining perovskite grain. Higher resolution EDS mapping of the perovskite grain within the spinel reveals a rim containing Mg and Al.

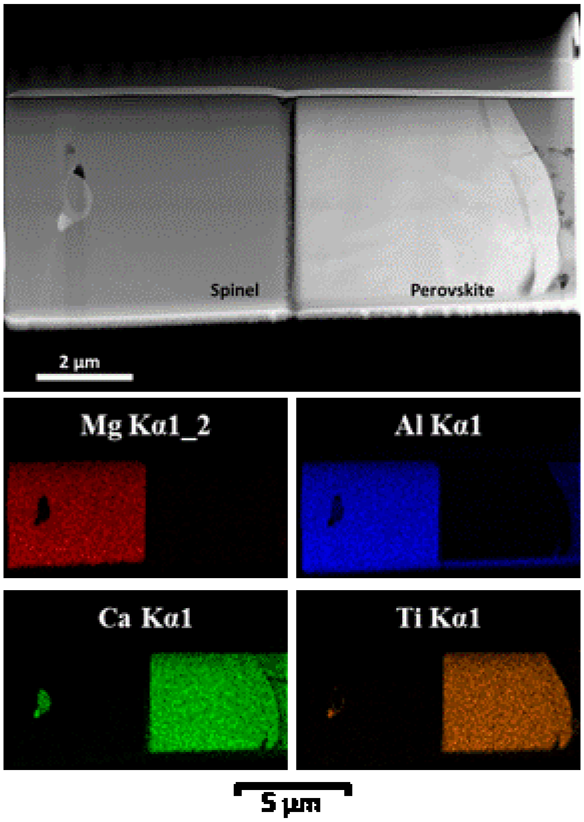

Fig 2 TEM data on the FIB section of the Spinel-perovskite assembly from the interior of the NWA 5028 CAI. (top) High-angle annular-dark-field image (bottom) EDS false-color images.

In the diffraction contrast images, the spinel region appears to be composed of a large grain and multiple smaller grains. SAED patterns acquired at various points show that all sections in the spinel region are similarly oriented, along the [211] direction. The silicate and perovskite grains in the inclusion within the spinel region were found to be oriented close to the zone axis of the surrounding mineral phase (spinel). In the diffraction contrast images, the perovskite region of the section also appeared to be polycrystalline. From the SAED pattern, it was found that the initial grain in the perovskite was oriented in the [211] direction. The diffraction patterns showed that the perovskite was composed of multiple grains similarly oriented with respect to the [211] grain.

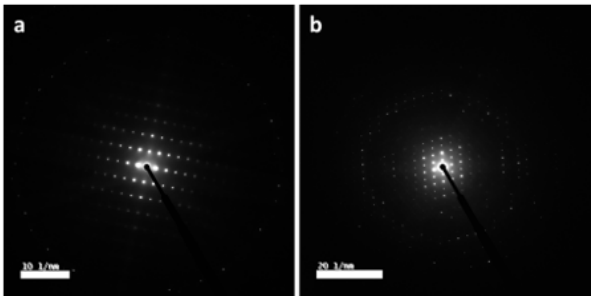

Fig 3 SAED Patterns (a) Spinel (b) Perovskite

The presence of the perovskite grain within the spinel is consistent with the predicted condensation sequence, suggesting that the inclusion formed under equilibrium conditions. The rim around the perovskite grain within the spinel may have formed due to secondary processes.

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