NANOSCALE ANALYSIS OF A METAL-PEROVSKITE ASSEMBLAGE IN THE NORTHWEST AFRICA 5028 CR2 CHONDRITE. T. J. Zega[1,2] and P. Mane[1], [1]Lunar and Planetary Laboratory, 1629 E. University Blvd, University of Arizona, Tucson AZ 85750 (tzega@lpl.arizona.edu).

Introduction: Calcium-aluminum-rich inclusions (CAIs) are mm- to cm-sized objects within chondritic meteorites. Characterized by refractory minerals that formed at very high temperatures [1] and radiometric age dates that exceed those of all other solar-system materials [2], CAIs represent time zero for our origins. Detailed analysis of CAIs can therefore provide information on chemical processes from the early solar system.

CAIs contain several different types of oxide and silicate materials [3]. Metal, although rare, can occur in different types of CAIs. We have previously reported on the nanoscale structure of perovskite grains within CAIs [4]. Here we expand on that effort and report on the structure and composition of an assemblage containing metal and perovskite. This work is part of a longer-term effort to examine microstructures and crystal chemistry of CAIs at length scales ranging from the micron level down to the atomic, and to use such information to gain insights into their origins.

Samples and Analytical Methods: A petrographic thin section of the Northwest Africa (NWA) 5028 chondrite was examined using an FEI Helios focused-ion-beam scanning electron microscope (FIB-SEM), equipped with an EDAX energy-dispersive spectrometer (EDS), located at the Lunar and Planetary Laboratory, University of Arizona. We acquired backscattered electron images (BSE) and EDS spectrum images of a local part of an inclusion referred to as 'Hedgehog' – see companion abstract submitted by [5].

An assemblage consisting of metal and perovskite, surrounded by spinel and melilite, was sectioned and extracted using the FEI easylift micromanipulator on the Helios and thinned to electron transparency using previously described methods [6]. The FIB section was ion polished down to 5 keV, to remove the amorphous damage layer created by higher-voltage milling, and subsequently analyzed using the newly installed 200 kev Hitach HF50000 transmission electron microscope (TEM) at the Lunar and Planetary Laboratory. The Hitachi HF5000 is aberration corrected in scanning TEM (STEM) mode and is equipped with a cold-field emission gun, STEM-based bright-field (BF) and dark-field (DF) detectors, as well as an Oxford Instruments X-max large solid angle (2 sr) energy-dispersive X-ray spectrometer (EDS) and a Gatan Quantum ER GIF for electron energy-loss spectroscopy (EELS).

Results and Discussion: Hedgehog has been previously characterized as a type-A CAI. The major mineral phases within it include spinel, perovskite, and melilite but it also contains opaque material as minor phases. A Wark-Lovering rim [7] occurs around the CAI and contains an innermost layer of hibonite, perovskite, and spinel followed by a layer of melilite and pyroxene. Hedgehog has been previously dated using the ^{26}Al-^{26}Mg relative chronometer which shows that the WL rim layer containing hibonite formed within ~640,000 years after the host inclusion [8].

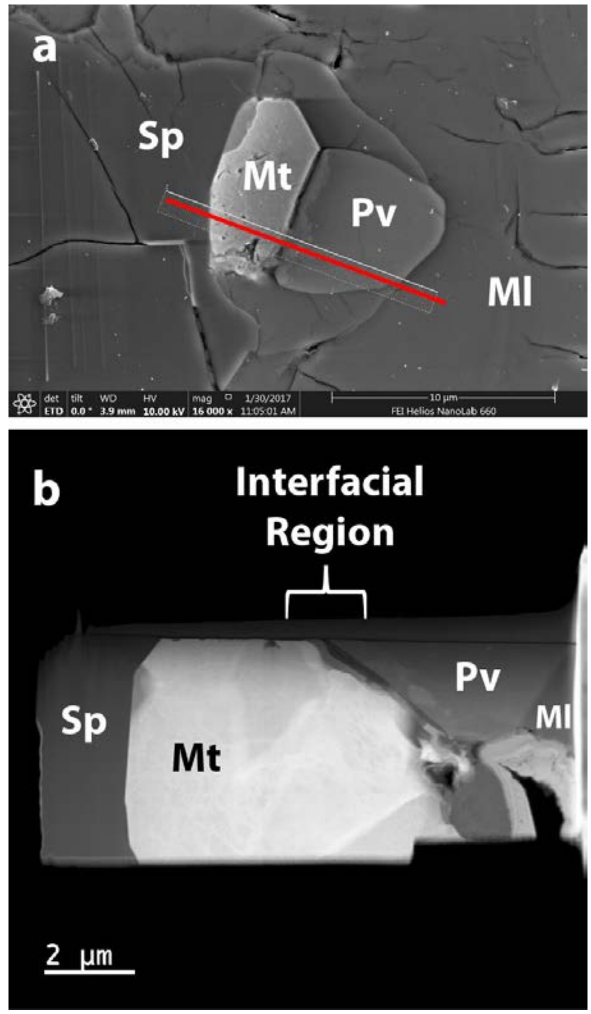

Fig. 1. FIB and TEM data on the metal-perovskite assemblage from NWA 5028. (a) BSE image acquired in FIB. Red line indicates FIB transect. (b) HAADF image acquired in the TEM. Sp=spinel; Mt=metal; Pv=perovskite; and Ml = melilite.

The metal-perovskite assemblage is shown in Figure 1. It is characterized by a euhedral metal grain (~5 µm

× 7.5 μm, orthogonal dimensions) and a subhedral perovskite grain (~6 μm × 6.25 μm). The metal grain is surrounded by spinel and the perovskite is surrounded by melilite [5]. The interface between the metal and spinel is linear, and the BSE images show previously unidentified sub-μm domains of material both at the interface and within the two grains. A FIB section was created along a line transecting the spinel, metal, perovskite, and part of the melilite (Fig. 1a).

STEM-based BF and DF imaging and EDS mapping provide an overview of the mineralogy of the section and reveal the character of the assemblage at depth (Fig. 1b). Selected-area electron-diffraction (SAED) patterns reveal phase identification and grain orientation. The spinel and metal grains extend through the depth of the section. The spinel exhibits uniform atomic-number (Z) contrast in the high-angle annular dark-field (HAADF) image and EDS mapping confirms it is homogeneous Mg-Al spinel. SAED patterns show that the spinel is a single crystal. The metal grain contains a subhedral morphology at depth and its upper interface with spinel contains a triple junction. DF imaging of the metal grain reveals non-uniform atomic-number (Z) contrast, which EDS mapping shows is due to a Ni-poor and Ni-rich domains. SAED patterns of the Ni-rich domain are consistent with taenite, whereas those so far acquired from the Ni-poor domain index to Fe metal. The perovskite grain terminates about halfway to the base of the section where it is bounded by a lower-Z material in the DF image. The interface between the perovskite and the metal contains several bands of material with varied Z-contrast. EDS mapping shows that these bands consist of (a) and Fe, Mg, O phase; (b) a Ca, P, and O phase, and (c) an Fe, Mg, Ti, and O phase. SAED patterns reveal all three bands are crystalline and indexing is consistent with spinel for band 'a'. Neither 'b' nor 'c' have thus far been identified.

Compact type-A CAIs are one of the major types of refractory inclusions in chondritic meteorites. They are believed to have been partially heated and some may have crystallized from a melt [9]. The data here do not preclude such processing, and indeed, our companion study [5] indicates that parts of the inclusion show evidence for deformation, most likely by nebular shocks that could have also heated and melted part(s) of the inclusion. However, the interfacial region between the metal and the perovskite grains contains clear evidence for secondary alteration. Although we have not yet clearly indexed the SAED pattern from the Ca-P-O phase, we suspect that it is a phosphate that could be characteristic of aqueous alteration. If confirmed, it would suggest that Hedgehog experienced secondary processing some time after accretion of its parent body. Whether the spinel and the Fe-Mg-Ti-O material formed during such processing is unclear, but seems likely based on its spatial relationship with the surrounding metal and perovskite grains. Additional measurements, which we plan to do, should help determine the phases in the interfacial region and provide insight into the chemical pathway of the alteration.

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