IN SITU TRANSMISSION ELECTRON MICROSCOPY OF OXYGEN-RICH PRESOLAR GRAINS IN THE PARIS METEORITE

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Introduction: The Paris (CM) meteorite is considered the least aqueously-altered CM chondrite [1], both at the thin-section scale and at the transmission electron microscopy (TEM) scale [2]. Bulk and thin section measurements indicate a range of alteration grades from ~2.7 to 2.9, whereas the dominant mineralogy of the matrix at the TEM scale ranges from (most altered) Fe-rich serpentines intermixed with tochilinite and pentlandite to (least altered) amorphous silicate, metal and sulfide assemblages reminiscent of the GEMS grains common to chondritic porous interplanetary dust particles (CP-IDPs).

The abundance of preserved presolar stardust grains provides a sensitive test of the degree of aqueous alteration of primitive materials, due to the high susceptibility of the nanoscale silicates to alteration. The abundance of O-rich (silicate and oxide) stardust found in CP-IDPs can be as high as a few percent; typical CP-IDPs and the most primitive meteorites show a few hundred ppm; and typical CM2 chondrites <30 ppm. Prior reports [3] of the O-rich presolar grain abundance in Paris indicated an abundance consistent on par with typical CM2s. New NanoSIMS measurements reported at this meeting [4] confirm that in the least-altered lithologies, the O-rich presolar grain abundance of Paris at 49 ppm is the highest observed for any CM. Here we report the first results from a coordinated TEM study of the presolar grains in Paris, with a goal of elucidating the mineralogy, mechanisms for preservation and initial stages of alteration.

Methods: Scanning electron microscope (SEM) energy dispersive spectroscopy (EDS) was used to map the composition of two polished thin sections of the Paris CM, provided by the Museum National d'Histoire Naturelle de Paris. Optical microscopy, and SEM-EDS elemental maps were used to distinguish between non oxidized metal-rich regions and more altered regions lacking matrix or trapped in chondrule metal. Oxygen isotope measurements with the NanoSIMS 50L at the Carnegie Institution were used to locate presolar grains. Details of these measurements are reported in Verdier-Paoletti et al. [4]. Focused ion beam sections of two presolar silicate grains were prepared with the FEI Helios G3 FIB-SEM at the Naval Research Lab. The positions of grains were marked with electron-beam deposited carbon and Pt fiducials, and then a protective C strap covering the full section width was deposited with the ion beam. Thinning was performed with a 30kV Ga^+ beam. Transmission electron microscopy data were collected with the NRL JEOL 2200FS field emission scanning TEM, equipped with an Oxford Aztec SDD EDS system, and a Gatan Oneview CMOS camera.

Results and Discussion: The first two grains from [4] targeted for TEM study are both group 1 grains, consistent with formation in AGB stars of 1 -2 $M_\odot$ (Table 1). Both grains were located in a metal-rich lithology (Fig. 1), one in a fine-grained rim (FGR) around a chondrule (R1), and one in an inter-chondrule matrix (ICM) region (R4).

Table 1. Summary of Presolar Grain Analysis

Grain	$^{17}O/^{16}O$	$^{18}O/^{16}O$	Composition /Structure
R4-13C	7.94E-04	1.98E-03	$Mg_{18.7}Fe_{0.9}Si_{18.9}O_{62.3}$ Enstatite
R1C1_3	1.65E-03	1.61E-03	$Mg_{2.89}Fe_{30.2}Si_{9.20}Al_{2.07}O_{55.35}$ Cronstedtite

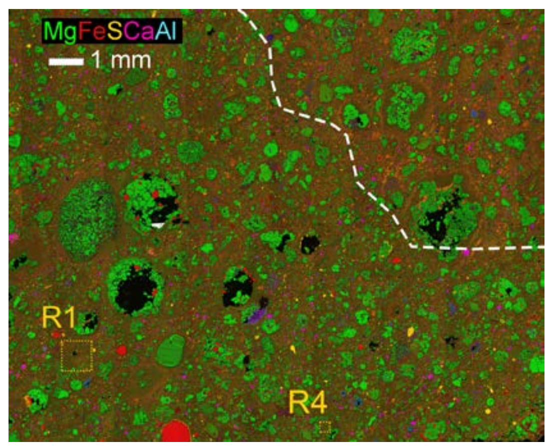

Figure 1. SEM-EDS composite map of the Paris CM revealing metal-poor (upper right) and metal-rich (lower left) lithologies. FIB sections were extracted from areas R1 and R4.

Dark field STEM images of the two extracted sections (Fig. 2) reveal significant differences in the mineralogy. The ICM R4 section is composed primarily of small (100-500 nm) domains of amorphous silicate interspersed with nanoscale metal and sulfide grains. This is very similar to the regions of least alteration described by Leroux et al. [2], albeit with less visible porosity. The FGR R1 section consists primarily of µm to sub-µm Fe-rich phyllosilicates, intermixed with organic matter, and pentlandite. This is consistent with the moderately altered and platy cronstedtite textures reported in [2]. STEM-EDS mapping of these sections also yields elemental compositions that are consistent with the prior reported ranges for the different amorphous silicate –sulfide and cronstedite-rich regions.

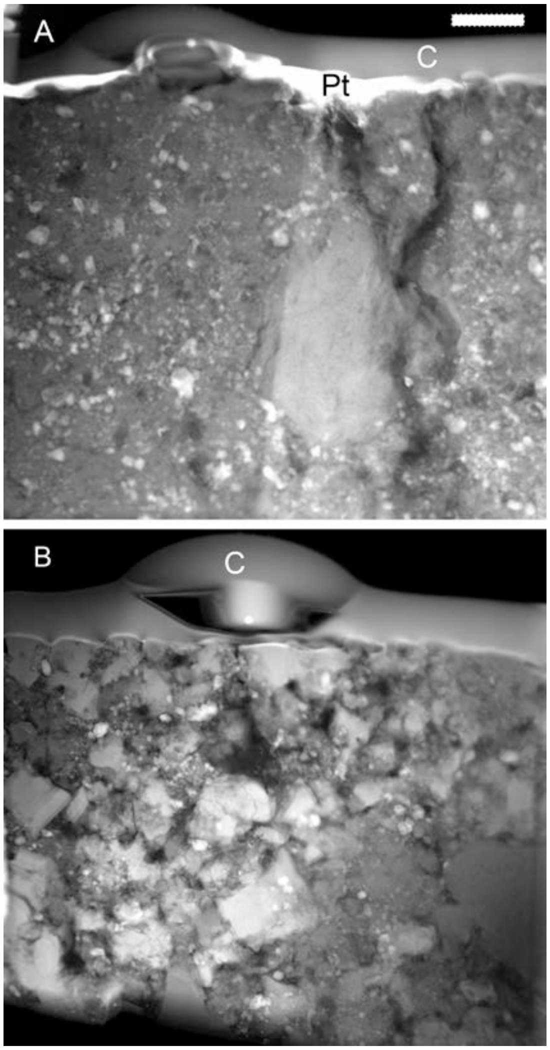

Figure 2. STEM-HAADF images of FIB sections from the Paris meteorite. A) ICM R4 and B) FGR R1. The labels C and Pt refer to FIB-deposited masking materials. The scale bar indicates 1μm for both A and B.

The presolar grains appear at the top of images in Fig. 2, and are shown at higher resolution in Fig. 3. The clear distinction of the grains from the adjacent matrix and location under the fiducial provide strong confirmation that the presolar grains are correctly identified, but this will be confirmed with subsequent NanoSIMS measurements. The mineral identification of the grains is based on selected area diffraction and EDS elemental analysis. It is notable that R1C1_3 is identified as cronstedtite, which is almost certainly a product of parent body alteration. This is the first report of an inherited, though presumably diluted, presolar O isotope signature in a secondary mineral. The magnitude of the $^{17}O/^{16}O$ isotope anomaly in this grain is half that of R4_13C, a nearly Fe-free enstatite, and the most anomalous grain in our isotope study.

Our results confirm that Paris is a very primitive CM, but that aqueous alteration has affected the presolar silicate grain population in all but the very least altered regions, and that there is significant variation in degree of alteration visible at the TEM scale in the most primitive areas identified by SEM-EDS and SIMS.

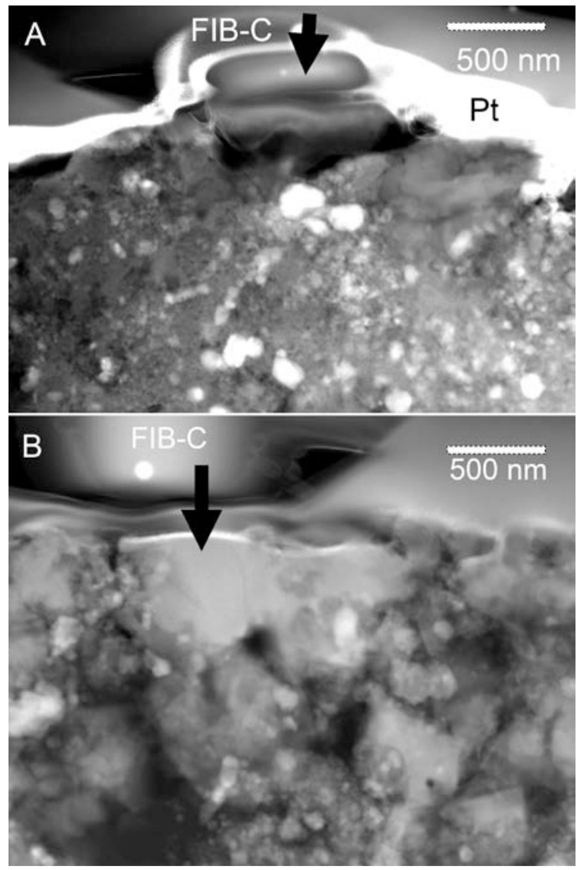

Figure 3. STEM-HAADF of the presolar silicate grains from the ICM R4 (A) and FGR R1 (B) regions. Black arrows indicate the presolar grain locations under the C fiducial mark.

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References:.[1] Hewins R. H. et al. (2014), *GCA*, *124*, 190-222. [2] Leroux et al. (2015), *GCA*, *170*, 247-265 [3] Verdier-Paoletti M. J. et al. (2019), *LPSC L*, #2948. [4] Verdier-Paoletti M. J. et al. (2020), *this meeting*.