TEM ANALYSIS OF LARGE FIB-SECTIONS FROM PHOSPHIDE-RICH CLASTS IN TARDA

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Introduction: Tarda is a C2-ungrouped (C2-ung) carbonaceous chondrite fall that was recovered following observations of a fireball over Morocco on August 25th, 2020. Initial characterization revealed a variety of mineral grains, chondrule fragments, and a few small chondrules set in a fine-grained matrix comprising ~80 vol.% of the sample [1]. The bulk matrix is dominated by phyllosilicates with lesser components of magnetite, carbonates, olivine, troilite, pyrrhotite, and pentlandite. Chondrule fragments in Tarda often exhibit partial replacement of forsterite by Fe-Mn-dolomite. Tarda's bulk O isotopic composition lies mostly outside the range of CI chondrites and has a bulk mineralogy that is consistent with petrologic Type 2 chondrites, thus leading to the classification of C2-ung [1].

An unusual feature of Tarda's mineralogy is identification of a unique clast during the initial characterization, which was described as having a subophitic texture consisting primarily of twinned laths of anorthite [1]. A separate study reported the identification of clasts containing laths of the rare Fe-Cr-phosphide mineral andreyivanovite (ideally FeCrP) set in a groundmass of serpentine [2], closely resembling FeCrP-bearing clasts identified in the CR2 Kaidun [3]. The origins of FeCrP are not well constrained, with current hypotheses suggesting either crystallization from a precursor melt [3], or formation as a product of aqueous alteration [4]. Here we report TEM analyses on Tarda's FeCrP bearing clasts as part of an effort to better constrain their origins and the alteration history of Tarda's parent body.

Methods: We used the FEI Helios NanoLab 660 dual-beam FIB-SEM in the Kuiper Materials Imaging and Characterization Facility (KMICF) at the University of Arizona to prepare and extract two electron transparent cross-sections (< 100nm thickness) of the lath-bearing clasts in Tarda. One section of ~10 µm in length was extracted from the center of one clast using the standard lift-out methods described in [5]. A second procedure based on the methods described in [6] ultilized Ag nanowires to provide structural support and allowed for the preparation of a 50 µm long section that sampled material from two adjacent clasts and the connective material. In this method, a suspension of 0.5% Ag nanowires (120-160 nm × 20-50 µm, D × L) in isopropyl alcohol from Sigma Aldrich was drop cast onto Cu TEM grids (400 mesh) that were secured to the edge of a 1-inch SEM pin mount with double-sided carbon tape. A wire was then selected and oriented parallel to the tip of the micromanipulator and secured at one end with a small Pt weld. The targeted material for the cross-section was then indicated on the surface of the sample by depositing Pt to form a fiducial marker. The nanowire was aligned with the fiducial marker and the free end was welded to the surface, after which the remainder of the wire was secured and cut free of the micromanipulator. After securing the wire, the lamellae was prepared, extracted, and thinned following standard procedures.

Transmission Electron Microscopy (TEM) analyses were carried out using the 200 keV Hitachi HF5000 STEM/TEM in the KMICF. Our analytical routine included the collection of energy dispersive X-ray spectroscopy (EDS) maps, scanning-TEM (STEM) images, and selected-area electron diffraction (SAED) patterns.

Results and Discussion: Analyses of the 50-µm section revealed a well defined boundary between the two lath-bearing clasts and the connective material, which was identified as forsterite by indexing SAED patterns. The individual laths were found to vary between 2 and 10 µm in length with widths of < 1 µm in all cases. Indexing of SAED patterns identified the laths in all three analyzed clasts as FeCrP, which are set in ground masses of serpentine. Chemical analysis by unstandardized EDS reveals partial replacement of Cr primarily by Fe and Ni, with an average chemical formula of $Fe(Cr_{0.518}Fe_{0.150}V_{0.004}Ti_{0.013}Ni_{0.264}Co_{0.007})P$.

In both prior identifications in the CR2 Kaidun [3] and R chondrite NWA 6828 [4], FeCrP occurs as inclusions within hydrated lithologies, suggesting a likely origin from aqueous alteration. While we cannot rule out the scenario of formation by melt crystallization with subsequent aqueous alteration proposed by [3], the additional identification of FeCrP in hydrated clasts within Tarda provides further evidence for the formation of FeCrP by aqueous alteration.

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