PHOSPHIDE-RICH CLASTS IN THE C2-UNGROUPED TARDA METEORITE

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Introduction: A fireball observed over Morocco on August 25th, 2020 led to the recovery of the C2-ungrouped (C2-ung) carbonaceous chondrite, Tarda. It contains a variety of mineral grains, chondrule fragments, and a few small chondrules set in a fine-grained matrix comprising ~80 vol.% of the sample. Phyllosilicates are the primary phase of the bulk matrix 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. An unusual feature of Tarda's mineralogy is the initial identification of an igneous clast with subophitic texture containing twinned laths of anorthite [1]. The bulk mineralogy of Tarda is consistent with it being of petrologic Type 2. In triple O-isotope space, Tarda lies mostly outside the range of CI chondrites and on this basis Tarda has been classified as C2-ung [1].

In September of 2023, the OSIRIS-REx mission is expected to return samples collected from B-type carbonaceous asteroid (101955) Bennu. Remote sensing by the OSIRIS-REx spacecraft indicates that Bennu may be related to aqueously altered CI, CM and/or C-ung chondrites such as Tarda [2,3]. Due to its rapid recovery, Tarda is a valuable sample for studying genetic relationships between meteorites and asteroids and the secondary processing of meteorite parent bodies, particulary with the upoming return of Bennu sample.

Methods: We conducted coordinated analysis of two thin sections and bulk analysis of a 40 mg aliquot of Tarda. The bulk elemental composition of Tarda was measured using the Thermo Fischer iCap Qc q-ICP-MS at Washington University in St. Louis. We used the Cameca SX-100 Ultra EPMA and Hitachi S4800 SEM in the Kuiper Materials Imaging and Characterization Facility (KMICF) at the University of Arizona (UA) for the initial in-situ mineral and chemical characterization [4]. The FEI Helios NanoLab 660 dual-beam FIB-SEM in the KMICF was used to prepare electron transparent cross-sections (< 100nm thickness). A total of four FIB sections were extracted, one from the matrix, a dolomite grain, and two sections of Tarda's "igneous" clast, including a 50-µm section that was prepared using a procedure based on [5]. Transmission Electron Microscopy (TEM) analyses were carried 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 to obtain information on the nanoscale mineralogy and chemical composition of Tarda.

Results and Discussion: Whole sample X-ray maps of Tarda show that chondrule fragments and carbonates are abundantly dispersed throughout the matrix. Closer inspection of the matrix reveals numerous magnetite framboids, often in clusters, that range in size from ~ 1 to 15 µm. With the exception of two calcite grains, Fe-Mn-dolomite is the predominant carbonate phase and is frequently observed as a partial replacement phase on the rims and within chondrule fragments. Defocused electron probe analyses in the matrix give average analysis totals of 81.4 ± 2.6 wt.% (SE, n=7), which suggests the matrix is hydrated and is consistent with expectations of a petrologic type 2 meteorite.

We identified several clasts in our two thin-sections that resemble the twinned anorthite lath bearing clast described by [1]. Each clast appears to be distinct from the surrounding material, mostly forsterite, with well defined boundaries and no zoning. The laths are highly enriched in P, Cr and Fe relative to the rest of the sample, and are all included in a groundmass of serpentine. With dimensions of about 2 to 10 µm long and less than 1 µm in diameter, individual laths were too small for accurate EPMA analysis. However, detailed TEM analysis of one such clast identified the lathes as the rare phosphide andreyivanovite (FeCrP), first identified in a similar clast within the CR2 chondrite Kaidun [6], and subsequently identified as part of a hydrated microclast in the R chondrite NWA 6828 [7].

In both prior identifications and within Tarda, andreyivanovite is found as inclusions within hydrous phases, suggesting a possible origin from aqueous alteration [7]. However, Zolensky et al. [6] proposed that the laths crystallized from a precursor melt with later aqueous alteration producing the serpentine. Additionally, laboratory synthesis of FeCrP has only been successful in melting experiments with low oxygen fugacity [8,9]. Based on the similarity to the clast in Kaidun and the artificial synthesis of FeCrP occurring only during melting experiments, our data of the andreyivanovite-bearing clast in Tarda support a melt crystallization origin with later aqueous alteration.

Acknowledgment: This work is funded by the University of Arizona Research, Innovation and Impact Office and Arizona Technology and Research Initiative Fund (PI: Haenecour).

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