DISCOVERY OF METEORITIC BAGHDADITE, $Ca_3(Zr,Ti)Si_2O_9$, IN ALLENDE: THE FIRST SOLAR SILICATE WITH STRUCTURALLY ESSENTIAL ZIRCONIUM?

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Introduction: During an ongoing nanomineralogy investigation of the Allende CV3 carbonaceous chondrite, baghdadite, $Ca_3(Zr,Ti)Si_2O_9$, has been identified in a V-rich, fluffy Type A Ca-Al-rich refractory inclusion (CAI), *A-WP1*, in USNM 7617. Reported here is the first meteoritic occurrence of baghdadite, as an ultra-refractory silicate mineral in a CAI from a primitive meteorite, among the first solid materials formed in the solar system. Field-emission scanning electron microscope (SEM), energy-dispersive X-ray spectroscopy (EDS), electron back-scatter diffraction (EBSD) and electron probe microanalyzer (EPMA) were used to characterize baghdadite and associated phases. Three new minerals burnettite (IMA 2013-054; $CaV^{3+}AlSiO_6$), paqueite (IMA 2013-053; $Ca_3TiSi_2(Al_2Ti)O_{14}$) and beckettite (IMA 2015-001; $Ca_2V^{3+}{}_6Al_6O_{20}$), were also discovered in *A-WP1* [1-4].

Occurrence, Chemistry, and Crystallography: Baghdadite occurs as one euhedral grain, 0.8 μm in size, within aluminous melilite in *A-WP1* (Fig. 1). The V-rich Type A CAI (0.6 × 1 mm in size) also contain primary spinel, perovskite, paqueite, burnettite, grossmanite-davisite, hibonite, and refractory metal grains in melilite [3]. The CAI is highly altered, containing secondary grossular, anorthite, coulsonite, hercynite, corundum, and beckettite [4].

The chemical composition of baghdadite by low-voltage SEM-EDS is (wt%) CaO 40.02, SiO_2 29.29, ZrO_2 17.41, TiO_2 7.24, Al_2O_3 4.56, MgO 0.84, Nb_2O_5 0.63, sum 100.00, showing an empirical formula of $(Ca_{2.77}Mg_{0.08})(Zr_{0.55}Ti_{0.35}Nb_{0.02})(Si_{1.89}Al_{0.35})O_9$. The composition is slightly contaminated by host melilite due to its small size. The simplified formula is $Ca_3(Zr,Ti)Si_2O_9$. EBSD analysis reveals that this Zr-rich silicate is baghdadite with a $P2_1/a$ monoclinic structure.

Origin and Significance: Baghdadite is an ultra-refractory silicate, joining other Zr-rich refractory oxide minerals from carbonaceous chondrites including allendeite, tazheranite, lakargiite, zirconolite, kangite, panguite, zirkelite, and baddeleyite. Baghdadite is probably the first solar silicate with structurally essential Zr, condensed from solar nebula gas or crystallized from a refractory melt.

References: [1] Ma C. 2013. *Mineralogical Magazine* 77:3002. [2] Ma C. et al. 2015. *Mineralogical Magazine* 79:531. [3] Ma C. and Beckett J.R. 2016. *LPSC* 47:A1595. [4] Ma C. et al. 2016. *LPSC* 47:A1704.

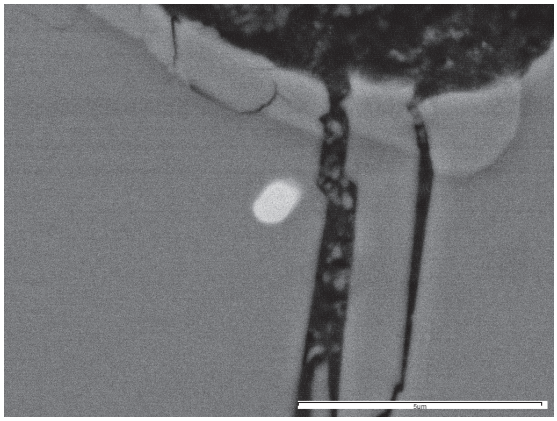

Fig. 1. Back-scatter electron image showing baghdadite (white phase) within melilite in the Allende CAI *A-WP1*.