DISCOVERY OF WARKITE, $Ca_2Sc_6Al_6O_{20}$, A NEW Sc-RICH ULTRA-REFRACTORY MINERAL IN MURCHISON AND VIGARANO.

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Introduction: Scandium has an inherent but underutilized potential for constraining environments and processes in the early solar system because it occurs at modest to high concentrations in a wide variety of refractory and ultra-refractory phases in chondritic meteorites. As a first step towards realizing some of Sc's potential, we have been conducting nanomineralogy investigations of carbonaceous chondrites to characterize Sc-rich phases and their petrographic context. Here, we describe a new scandium aluminate mineral, $Ca_2Sc_6Al_6O_{20}$ with a *P-1* aenigmatite-type structure, in ultra-refractory inclusions from the Murchison CM2 and Vigarano CV3 chondrites [1]. Based on EPMA, a previously reported phase in the CH chondrite Acfer 182 [2] provides another example. The Commission on New Minerals, Nomenclature and Classification of the International Mineralogical Association has approved this mineral (IMA 2013-129) [3], the name, warkite, in honor of David Wark (1939-2005) for his many contributions to research on Ca-Al-rich inclusions.

Occurrence, Chemistry, and Crystallography: The Murchison and Vigarano warkites occur as 4–12 μm aggregates of 1–4 μm crystals and are both associated with perovskite. In Murchison section Me2642, it occurs with perovskite in a cluster of ultra-refractory inclusions surrounded by a Wark-Lovering rim consisting of Sc-bearing diopside and spinel. In Vigarano section USNM 7618, warkite occurs with perovskite, gehlenitic melilite, and davisite. Warkite and perovskite (and melilite) are texturally early relative to the davisite. The Sc-Al phase of [2] contacts mostly perovskite but also grossite and a Sc-, Zr-rich phase, probably allendeite.

The general formula of warkite is $Ca_2(Sc,Ti,Al,Mg,Zr)_6Al_6O_{20}$ with an endmember of $Ca_2Sc_6Al_6O_{20}$. EBSD reveals that warkite has the *P-1* aenigmatite structure with a best fit using cell parameters for Allende rhönite from [4]. Based on stoichiometry, 63% of Ti in the Murchison warkite and all of the Ti in the Vigarano warkite is trivalent. As noted by [1], warkite and perovskite in the Murchison inclusion are ^{16}O-rich ($\Delta^{17}O \sim -24\pm3$‰ and -21 ± 3‰, respectively) and consistent with CCAM line.

Origin and Significance: Warkite is a new ultra-refractory mineral, joining the other recently described Sc-rich phases allendeite, davisite, eringaite, kangite, panguite, tazheranite, and thortveitite. The oxygen-isotope compositions imply formation in an ^{16}O-rich gaseous reservoir, consistent with those of normal CAIs prior to alteration. The Sc-rich nature, association with REE-rich perovskite, and growth prior to davisite suggest that warkite is a very-early player in the final assembling of solid materials from this reservoir. The environment in which this took place was likely highly reducing because warkite is Ti^{3+}-rich.

References: [1] Ma C. et al. 2014. *LPSC* 45, #1196. [2] Weber D. and Bischoff A. 1994. *GCA* 58, 3855–3877. [3] Ma C. et al. 2014. *Miner. Mag.* 78, 552. [4] Bonaccorsi E. et al. 1990. *Eur. J. Mineral.* 2, 203–218.