DISCOVERY OF NEW MINERAL JIANMUITE, $ZrTi^{4+}Ti^{3+}{}_5Al_3O_{16}$, IN THE ALLENDE METEORITE: AN ULTRAREFRACTORY PHASE FROM THE SOLAR NEBULA

Chi Ma[1], Roberto Borriello[2,3], Fahui Xiong[4], Sofia Lorenzon[2], Enrico Mugnaioli[2], Jingsui Yang[5], Xiangzhen Xu[4], Edward S. Grew[6]; [1]California Institute of Technology, USA (chima@caltech.edu); [2]University of Pisa, Italy; [3]Ca' Foscari University of Venice, Italy; [4]Institute of Geology, Chinese Academy of Geological Sciences, China; [5]Nanjing University, China; [6]University of Maine, USA.

Introduction: Jianmuite ($ZrTi^{4+}Ti^{3+}{}_5Al_3O_{16}$; IMA 2023-057) is a new Ti,Al,Zr-oxide mineral identified as inclusion in corundum from chromitites in the Luobusa ophiolite (Tibet, China) and in the Allende meteorite [1].

The Allende CV3 carbonaceous chondrite, fell in Mexico on February 8, 1969, is the best-studied meteorite in history. More than fifty years after it fell, this space rock continues to be source of new discoveries. An ongoing nanomineralogy investigation has revealed 20 IMA-approved new minerals in Allende since 2007 [e.g., 2-7], including 13 refractory phases and 5 late-stage alteration phases, providing new puzzle pieces toward the big picture and our understanding of nebular and parent body processes in the early solar system. Presented here is jianmuite in Allende, an ultrarefractory phase from the solar nebula – the latest new mineral from Allende. Field-emission scanning electron microscope (SEM), electron back-scatter diffraction (EBSD) and electron probe microanalyzer (EPMA) were used to characterize jianmuite and associated phases in the Allende meteorite. Jianmuite from Luobusa was studied using Energy-dispersive X-ray spectroscopy and 3-dimensional electron diffraction to give the crystal structure: space group $I\text{-}4$, a = 10.3675(10) Å, c = 9.8125(10) Å, V = 1054.70(18) Å^3, and Z = 4 [1].

Occurrence, Chemistry, and Crystallography: Jianmuite in Allende occurs as several anhedral to euhedral crystals, 3 × 6 µm to 8 µm × 12 µm in size, along with corundum, mullite, tistarite and kaitianite grains in the matrix in section USNM 3510-5 [7]. The matrix mainly consists of olivine with minor troilite and pentlandite. These grains are likely from the cluster of refractory phases identified in a chondrule in USNM 3510-6, where Ti^{3+}-bearing corundum grains and the type tistarite (Ti_2O_3) were first identified [2,8]. USNM 3510-5 and USNM 3510-6 are series thin sections, prepared by the Smithsonian Institution's National Museum of Natural History. The O-isotope analyses of two corundum grains in the cluster in USNM 3510-6 reveal that the grains have compositions well above the terrestrial fractionation line but on the Carbonaceous Chondrite Anhydrous Mineral (CCAM) line (see Fig. 3 in [8]). It is evident that those refractory grains are extraterrestrial materials.

The chemical composition of one jianmuite grain in Allende by EPMA (WDS) is (wt%) Ti_2O_3 44.68, TiO_2 12.62, Al_2O_3 26.82, ZrO_2 13.95, SiO_2 2.32, FeO 0.52, MgO 0.19, CaO 0.17, Sc_2O_3 0.12, sum 101.4, giving $^{VIII}(Zr_{0.768}Ti^{4+}{}_{0.232})^{VII}(Ti^{3+}{}_{3.160}Ti^{4+}{}_{0.840})_{\Sigma 4.000}{}^{VI}(Al_{2.830}Ti^{3+}{}_{1.056}Fe_{0.049}Mg_{0.032}Ca_{0.021}Sc_{0.012})_{\Sigma 4.000}{}^{IV}(Al_{0.738}Si_{0.262})_{\Sigma 1.000}O_{16}$, based on 16 atoms of O. The simplified formula is $(Zr,Ti^{4+})(Ti^{3+},Ti^{4+})_4(Ti^{3+},Al)_4(Al,Si)O_{16}$. The ideal formula is $Zr(Ti^{3+}{}_3Ti^{4+})(Ti^{3+}{}_2Al_2)AlO_{16}$. The EBSD patterns of the Allende jianmuite can be indexed only by the tetragonal $I\text{-}4$ structure of the Luobusa jianmuite, with a mean angular deviation of 0.7º.

Origin and Significance: The Allende jianmuite is an ultrarefractory phase, probably formed by condensation or crystallized from a refractory melt under reduced conditions in the solar nebula. Jianmuite is among first solid materials formed in the solar system, joining other 50+ refractory minerals identified in carbonaceous chondrites [9]. These refractory minerals mark the very beginning of mineral evolution in the solar system.

The Allende corundum grains, in association with tistarite (Ti_2O_3) [2], kaitianite (Ti_3O_5) [7] and jianmuite, are Ti-rich with 0.43~3.21 wt% Ti_2O_3, suggesting a reducing environment. The preliminary O-isotope analyses of two corundum grains reveal that the grains have compositions on the CCAM line, consistent with formation or alteration in an O^{16}-depleted reservoir within the solar system; such an oxygen reservoir predated or was contemporaneous with chondrule formation [8]. The isotope measurements suggest that the corundum is not presolar but may have formed in a ^{16}O-depleted reservoir during the earliest stages of the solar system. This is consistent with even more extreme isotopic compositions of nano magnetite particles that interpreted to be the product of low temperature oxidation of alloys in an ^{16}O-depleted nebular or asteroidal reservoir [10]. The corundum, tistarite, kaitianite and jianmuite grains in Allende are most likely early condensing phases in a cooling gas of solar composition but a more complex origin is also possible.

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