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# Discovery of Al-rich and Ti-bearing rhönite-type mineral, $Ca_2(Mg_4Ti_2)(Al_4Si_2)O_{20}$, in NWA 4964 CK carbonaceous chondrite: A refractory phase from the solar nebula

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During a nanomineralogy investigation of the NWA 4964 CK3 carbonaceous chondrite, a refractory Al-rich and Ti-bearing rhönite-type mineral, $Ca_2(Mg_4Ti_2)(Al_4Si_2)O_{20}$ with the *P*-1 aenigmatite structure, was identified in a Ca-Al-rich inclusion (CAI), using field-emission scanning electron microscope (SEM), electron back-scatter diffraction (EBSD) and electron probe microanalyzer (EPMA). This new mineral has been submitted to the IMA-CNMNC for approval. Such Al-rich and Ti-bearing rhönite was previously observed in Allende CAIs [1,2].

The mineral occurs with fine-grained rutile and titanite, as irregular grains at 1 to 8 ɛm in size, in three areas within the CAI in NWA 4964. Its chemical composition by EPMA shows an empirical formula (based on 20 oxygen *apfu*) of $Ca_{2.00}(Mg_{3.44}Ti^{4+}_{1.49}Fe_{0.36}Ti^{3+}_{0.34}Al_{0.24}V^{3+}_{0.07}Ca_{0.06}Cr_{0.01})_{\Sigma 6.01}(Al_{3.63}$ The simplified formula is $Ca_2(Mg,Ti^{4+},Fe,Ti^{3+},Al)_6(Al,Si)_6O_{20}$. The ideal formula is $Ca_2(Mg_4Ti^{4+}_2)(Al_4Si_2)O_{20}$. EBSD analysis revealed that it has a triclinic *P*-1 aenigmatite structure, identical to that of the Allende rhönite [2].

This rhönite-group mineral crystallized from a refractory melt under reduced conditions in the solar nebula, joining other 50+ refractory minerals identified in carbonaceous chondrites. Those primary minerals mark the very beginning of mineral evolution in the solar system.

[1] Fuchs (1971), *American Mineralogist* 56, 2053-2068.

[2] Bonaccorsi et al. (1990), *European Journal of Mineralogy* 2, 203-218.