

Nuwaite (Ni₆GeS₂) and butianite (Ni₆SnS₂), two new minerals from the Allende meteorite: Alteration products in the early solar system

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ABSTRACT

Nuwaite (Ni₆GeS₂, IMA 2013-018) and butianite (Ni₆SnS₂, IMA 2016-028) are two new chalcogenide minerals, occurring as micrometer-sized crystals with grossular, Na-bearing melilite, heazlewoodite, and Ge-bearing Ni-Fe alloys in veins and as mono-mineralic crack-filling material in igneous diopside in the Type B1 Ca-Al-rich inclusion (CAI) *ACM-2* from the Allende CV3 carbonaceous chondrite. The chemical composition of type nuwaite is (wt%) Ni 65.3, S 10.3, Ge 8.2, Te 7.9, Sn 5.1, and Fe 1.7, with a sum of 98.5 and an empirical formula of (Ni_{5.95}Fe_{0.16})(Ge_{0.60}Sn_{0.23})(S_{1.72}Te_{0.33}). The simplified formula is Ni₆(Ge,Sn)(S,Te)₂, leading to an end-member of Ni₆GeS₂. The chemical composition of type butianite is (wt%) Ni 62.1, Sn 8.9, Te 10.3, S 8.9, Ge 5.3, Fe 1.3, sum 99.1, giving rise to an empirical formula of (Ni_{5.93}Fe_{0.13})(Sn_{0.52}Ge_{0.41})(S_{1.56}Te_{0.45}). Butianite's simplified formula is Ni₆(Sn,Ge)(S,Te)₂ and the end-member formula is Ni₆SnS₂. Both nuwaite and butianite have an *I4/mmm* intergrowth structure with *a* = 3.65 Å, *c* = 18.14 Å, *V* = 241.7 Å³, and *Z* = 2. Their calculated densities are 7.24 and 7.62 g/cm³, respectively. Nuwaite and butianite are the first known meteoritic minerals with high Ge and Sn concentrations.

Nuwaite and butianite are very late-stage, vapor-deposited, alteration products, filling in pores within preexisting grossular-rich alteration veins and cracks in igneous Al,Ti-diopside. These phases and associated heazlewoodite and Ge-bearing alloys are observed only within the Ca-,Al-rich inclusion (CAI) and not outside it or at the inclusion-matrix interface. As only sections in one half of *ACM-2* contain nuwaite/butianite, they were probably derived through a relatively low *f*_{O₂}*f*_{S₂} sulfidation process, in which a highly localized, low-temperature Ge-, Sn-bearing fluid interacted with a portion of the host CAI. It is likely that the fluid became relatively more Sn- and Te-enriched with time and that crack fillings post-date vein fillings, possibly due to a late remobilization of vein sulfides.

Keywords: Nuwaite, Ni₆GeS₂, butianite, Ni₆SnS₂, new minerals, Allende meteorite, CV3 carbonaceous chondrite, Ca-Al-rich inclusions