DISCOVERY OF NEW MINERAL BUTIANITE, Ni_6SnS_2, AN ALTERATION PHASE FROM ALLENDE

Chi Ma
Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125, USA
Email: chi@gps.caltech.edu

Introduction: During an ongoing nanomineralogy investigation of the Allende CV3 meteorite, a new mineral, $Ni_6(Sn,Ge)(S,Te)_2$, was identified in fractures in a Type B1 Ca-Al-rich refractory inclusion (CAI) *ACM-2*, named "butianite". Synthetic Ni_6SnS_2 is well known [1]. Presented here is the first natural occurrence of Ni_6SnS_2, as a new alteration mineral in a CAI from a primitive meteorite. Field-emission SEM, electron back-scatter diffraction (EBSD) and electron probe microanalyzer (EPMA) were used to characterize its composition and structure. The mineral has been approved by the Commission on New Minerals, Nomenclature and Classification of the International Mineralogical Association (IMA 2016-028) [2]. The name is after two Chinese words "Bu Tian", meaning *patching the sky*, from the story of "Nu Wa Bu Tian" in the ancient Chinese mythology. Nu Wa, the goddess, patched the fractured wall of Heaven to save the early World after Pan Gu's creation. Nuwaite (Ni_6GeS_2; IMA 2013-018) [3] was named after "Nu Wa" in allusion to the secondary mineral filling cracks in a primitive refractory inclusion from the early solar system. Butianite (Ni_6SnS_2) is the Sn-analog of nuwaite, a new secondary phase along with nuwaite to fill the cracks in the same CAI in Allende. Butianite and nuwaite are among the eighteen IMA-approved new minerals from Allende since 2007.

Occurrence, Chemistry, and Crystallography: Butianite occurs as irregular grains, 0.5 to 1.4 μm in width, up to 8 μm long in one crack, which is the type material, in Al,Ti-rich diopside in the CAI in USNM 7616 (Fig. 1). Part of the Type B1 CAI (> 1.5 mm in size) is present in a few sections (including USNM 7554, 7555, 7615, 7616). Melilite with spinel, Al,Ti-diopside and anorthite occupies the mantle area with a Wark-Lovering rim consisting mainly of spinel, perovskite and Al,Ti-diopside. A trace of Ni-Fe rich metal assemblies is present in melilite. The CAI *ACM-2* also contains newly-found minerals grossmanite ($CaTi^{3+}AlSiO_6$; USNM 7555) [4], monipite (MoNiP; USNM 7554) [5], majindeite ($Mg_2Mo_3O_8$; USNM 7615) [6], and nuwaite (Ni_6GeS_2; USNM 7616 & 7554) [3].

The mean chemical composition of butianite by low-voltage EPMA is (wt%) Ni 62.12, Sn 11.12, Te 10.31, S 8.91, Ge 5.32, Fe 1.32, sum 99.11, showing an empirical formula of $(Ni_{5.92}Fe_{0.13})(Sn_{0.52}Ge_{0.41})(S_{1.56}Te_{0.45})$ based on 9 atoms *pfu*. The simplified formula is $Ni_6(Sn,Ge)(S,Te)_2$. The end-member formula is Ni_6SnS_2, requires Ni 65.83, Sn 22.18, S 11.99, total 100.00 wt%. EBSD analysis reveals that butianite has a *I*4/*mmm* superstructure, identical to that of synthetic Ni_6SnS_2 [1], showing a = 3.65 Å, c = 18.14 Å, V = 241.7 Å^3, Z=2. The calculated density is 7.62 g cm^{-3} using the empirical formula.

Origin and Significance: Butianite (Ni_6SnS_2) is a new chalcogenide mineral with an intergrowth structure. It is the Sn-analog of nuwaite (Ni_6GeS_2). Nuwaite and butianite may be the first solar minerals with high Ge, Sn and Te concentrations, providing new insights into alteration processes of CAIs in carbonaceous chondrites.

Nuwaite and butianite are apparently a late-stage alteration product, filling some pore and fracture spaces in the Allende CAI. There seems also to a solid solution between nuwaite and butianite. They were probably derived from a sulfidation process, where Ni-Fe metals reacted with a low-temperature fluid enriched in S, Ge, Sn and Te.

References: [1] Baranov A.I. et al. 2003. *Inorganic Chemistry* 42:6667–6672. [2] Ma C. 2016. *Mineralogical Magazine* 80:920. [3] Ma C. 2015. *Meteoritics & Planetary Science* 50(S1):A5151. [4] Ma C. and Rossman G.R. 2009. *American Mineralogist* 94:1491–1494. [5] Ma C. et al. 2014. *American Mineralogist* 99:198–205. [6] Ma C. and Beckett J.R. 2016. *American Mineralogist* 101:1161–1170.

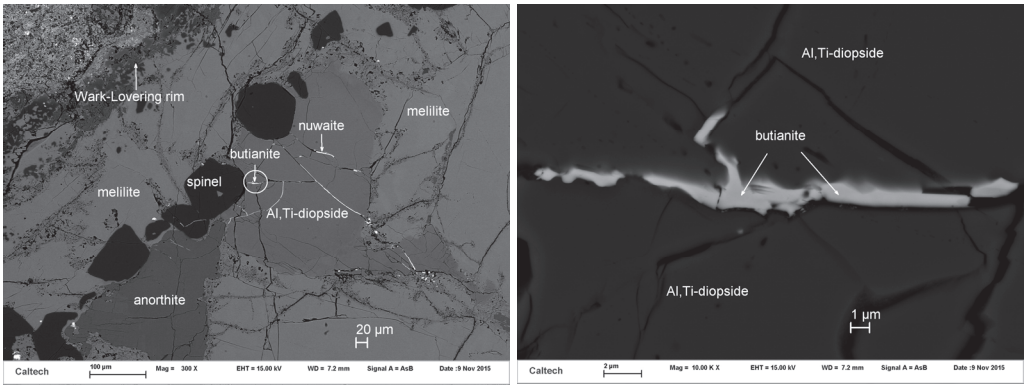

Fig. 1. Back-scatter electron images showing butianite in a crack within Al,Ti-diopside in the CAI *ACM*-2.