

DISCOVERY OF BECKETTITE, $\text{Ca}_2\text{V}_6\text{Al}_6\text{O}_{20}$, A NEW ALTERATION MINERAL IN A V-RICH Ca-AL-RICH INCLUSION FROM ALLENDE. Chi Ma^{1,3}, Julie Paque¹, and Oliver Tschauner²; ¹Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125, USA; ²Department of Geoscience and High Pressure Science and Engineering Center, University of Nevada, Las Vegas, NV 89154, USA; ³chi@gps.caltech.edu.

Introduction: During a nanomineralogy investigation of the Allende CV3 meteorite, we discovered the new mineral beckettite (IMA 2015-001; $\text{Ca}_2\text{V}^{3+}_6\text{Al}_6\text{O}_{20}$) in a V-rich, fluffy Type A Ca-Al-rich inclusion (CAI) *A-WPI* in USNM 7617, which was previously studied by Paque and coworkers [1-3]. Electron probe microanalysis (EPMA), scanning electron microscopy, and electron backscatter diffraction (EBSD) were used to characterize its chemical composition and structure. Beckettite is a new vanadium aluminate mineral and a new member of the sapphirine supergroup. This phase was previously observed in *A-WPI* based on EPMA [1]. Synthetic $\text{Ca}_2\text{V}_6\text{Al}_6\text{O}_{20}$ has not been reported. Here, we describe beckettite as a new alteration mineral in a CAI and consider its origin and implications for alteration processes. Beckettite is named in honor of John R. Beckett, a cosmochemist at California Institute of Technology. The new mineral and name have been approved by the Commission on New Minerals, Nomenclature and Classification of the International Mineralogical Association [4].

Occurrence, chemistry, and crystallography: Beckettite occurs as aggregates of crystals 4 to 8 μm in size within highly altered areas of *A-WPI* (Figs. 1-4), along with secondary grossular, anorthite, coulsonite, hercynite, and corundum. Primary phases in the CAI are melilite, spinel, perovskite, grossmanite-davisite, hibonite, paqueite ($\text{Ca}_3\text{TiSi}_2(\text{Al},\text{Ti},\text{Si})_3\text{O}_{14}$) [5], burnettite (CaVAAlSiO_6) [5], and refractory metal grains.

The mean chemical composition of type crystals by

Table 1. EPMA data for type beckettite.

Constituent	wt% n=5	SD
Al_2O_3	44.14	0.29
V_2O_3	31.6	0.1
CaO	13.58	0.15
TiO_2	5.54	0.07
SiO_2	2.02	0.03
MgO	1.22	0.03
Sc_2O_3	0.7	0.03
FeO	0.35	0.14
Na_2O	0.04	0.01
MnO	0.05	0.06
Total	99.24	

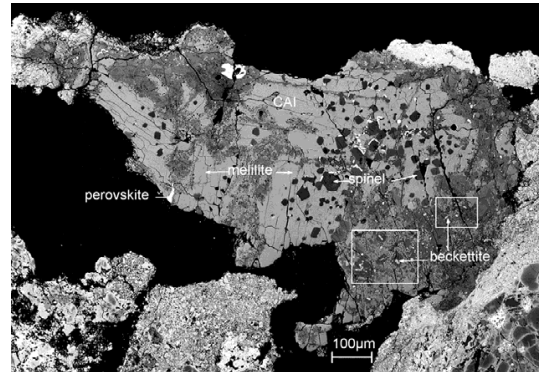


Fig. 1. Backscatter electron (BSE) image showing the Type A CAI *A-WPI* in Allende. The locations of beckettite are enclosed by rectangle.

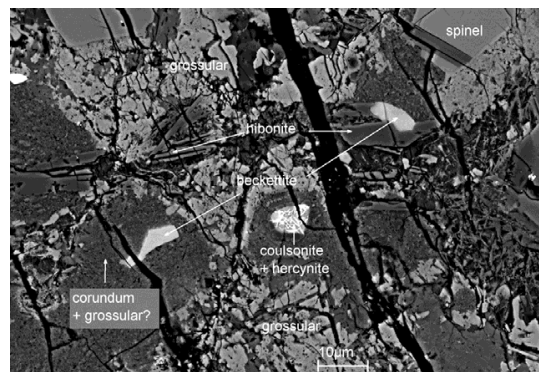


Fig. 2. Enlarged BSE image showing beckettite in one alteration area.

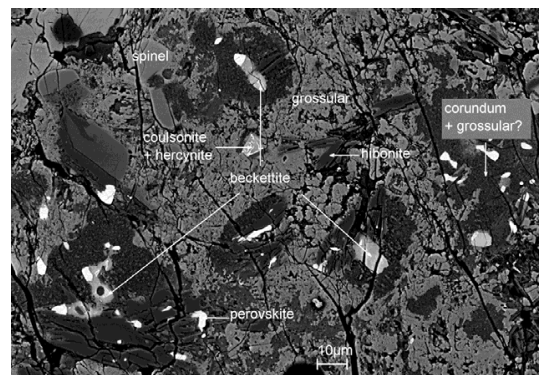


Fig. 3. Enlarged BSE image showing beckettite in another alteration area.

EPMA is given in Table 1. Beckettite shows an empirical formula (based on 20 oxygen atoms per formula unit *apfu*) of $(\text{Ca}_{1.99}\text{Na}_{0.01})(\text{V}^{3+}_{3.47}\text{Al}_{1.40}\text{Ti}^{4+}_{0.57}\text{Mg}_{0.25}\text{Sc}_{0.08}\text{Fe}^{2+}_{0.04}\text{Mn}_{0.01})(\text{Al}_{5.72}\text{Si}_{0.28})\text{O}_{20}$. The general formula is $\text{Ca}_2(\text{V},\text{Al},\text{Ti},\text{Al},\text{Mg})_6\text{Al}_6\text{O}_{20}$ and the end-

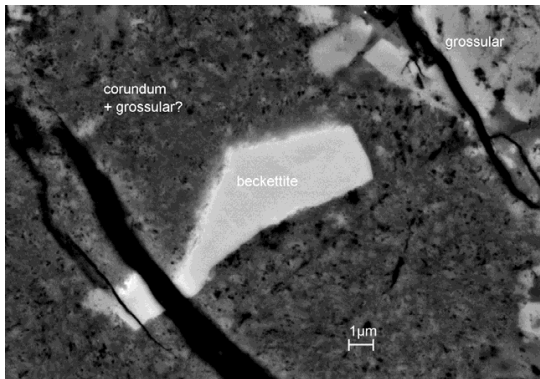


Fig. 4. A further enlarged BSE image revealing type beckettite.

member formula is $\text{Ca}_2\text{V}_6\text{Al}_6\text{O}_{20}$. The EBSD patterns can be indexed by the $P\bar{1}$ aenigmatite structure and give best fits using the Allende rhonite structure from [6] (Fig. 5). Beckettite has Space Group: $P\bar{1}$, showing $a = 10.367 \text{ \AA}$, $b = 10.756 \text{ \AA}$, $c = 8.895 \text{ \AA}$, $\alpha = 106.0^\circ$, $\beta = 96.0^\circ$, $\gamma = 124.7^\circ$, $V = 739.7 \text{ \AA}^3$, and $Z = 2$.

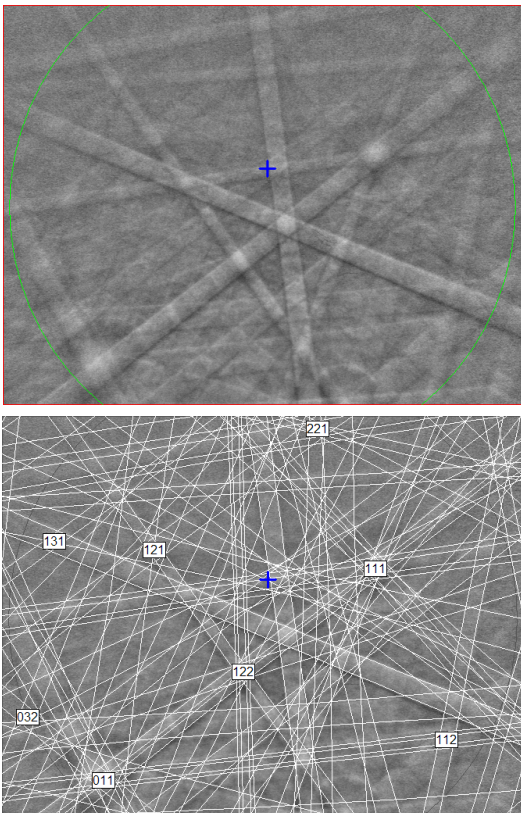


Fig. 5. (top) EBSD pattern of one beckettite crystal; (bottom) the pattern indexed with the the $P\bar{1}$ rhonite structure.

Beckettite grains are invariably in the central portions of alteration regions composed of fine-grained secondary corundum and grossular(?), often in contact with primary V-bearing hibonite and/or perovskite (Figs. 2-4). Similar regions of corundum + grossular(?) are centered by coulsonite $(\text{Fe}_{0.88}\text{Mg}_{0.12})(\text{V}_{1.18}\text{Al}_{0.82})\text{O}_4$ and hercynite $(\text{Fe}_{0.61}\text{Mg}_{0.41})(\text{Al}_{1.84}\text{V}_{0.15})\text{O}_4$. Coulsonite is exsolution in hercynite (Fig. 2). Spinel inclusions in melilite are relatively V-rich (~2 wt%) but the most V-rich refractory phase in this CAI is burnettite (a new V-clinopyroxene with 9.35 wt% V_2O_3 and 6.89 wt% Sc_2O_3), occurring as one micro-crystal in melilite [7].

Origin and significance: Beckettite, $\text{Ca}_2\text{V}_6\text{Al}_6\text{O}_{20}$, is not only a new mineral, but also a new material. It is a new member of the sapphirine supergroup and the V^{3+} -dominant analog of the recently described ultra-refractory phase warkite [8], $\text{Ca}_2\text{Sc}_6\text{Al}_6\text{O}_{20}$.

Beckettite is apparently a secondary alteration phase, as indicated by its petrographic texture, probably formed in the parent body. Beckettite is likely formed by late-stage metasomatic reactions in which grossular, corundum, coulsonite and hercynite, replace primary phases such as melilite, hibonite, MgAl_2O_4 spinel, perovskite and burnettite.

V from primary phases like burnettite should have contributed to the formation of beckettite, coulsonite and hercynite. It seems that beckettite is in the middle of alteration and survives because it is a product of the destruction of what was a V-rich inclusion in melilite in that same spot. The V gets dumped out into beckettite or coulsonite because the V isn't very volatile. Alternative, a simple scenario may also be breakdown of primary hibonite in a hot V-rich fluid to produce beckettite and corundum.

References: [1] Paque J.M. 1985. *Lunar & Planetary Science* 16:651. [2] Paque J.M. 1989. *Lunar & Planetary Science* 20:822. [3] Paque J.M. et al. 2008. *LPSC* 39:A1841. [4] Ma C. et al. 2015. *Mineralogical Magazine* 79:531. [5] Ma C. 2013. *Mineralogical Magazine* 77:3002. [6] Bonaccorsi E. et al. 1990. *European Journal of Mineralogy* 2:203. [7] Ma C. and Beckett J.R. 2016. *LPSC* 47:A1595. [8] Ma C. et al. 2015. *MAPS* 50(S1):A5025.