BRADACZEKITE, NaCu₄(AsO₄)₃, A NEW MINERAL SPECIES 
FROM THE TOLBACHIK VOLCANO, KAMCHATKA PENINSULA, RUSSIA

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ABSTRACT

Bradaczekite, NaCu₄(AsO₄)₃, was discovered in a fumarole in the North Breach of the Great fissure Tolbachik eruption (GFTE) in 1975–1976, Kamchatka Peninsula, Russia. Bradaczekite forms aggregates of dark blue plates elongate along [102]. The well-developed forms are {010}, {111} and {112}. The forms {310}, {210}, {021} and {110}, {111} and {341} are common. Associated minerals are hematite, tenorite, lammerite, urusovite, orthoclase and johillerite. The mineral has an adamantine luster and a light blue to white streak. No cleavage has been observed. The mineral is transparent, biaxial, optically negative, /H9251 1.76(1), /H9252 1.92(1), /H9253 1.96(1), 2Vcalc. 50.0°. The optical orientation is Z = b, X \(\gamma\) c = 23° in the obtuse \(\beta\) angle. Bradaczekite shows strong pleochroism: X violet-red, Y green, Z greenish blue. The mineral is monoclinic, space group C\(\text{2}/c\), a 12.051(1), b 12.434(1), c 7.2662(7) Å, \(\beta\) 117.942(1)°, V 961.8(2) Å\(^3\), Z = 4, Dcalc. = 4.77(1) g/cm\(^3\) (for the empirical formula). The strongest eight lines of the X-ray powder-diffraction pattern \[d \text{(Å)} (I) (hkl)\] are: 6.22(13)(020), 3.60(21)(202, 131), 3.43(100)(112, 310), 3.21(35)(002), 2.791(24)(202), 2.696(18)(330), 2.683(30)(240), and 2.665(17)(400). Electron-microprobe analyses yielded: Na 2 O 5.17 (4.37–5.78), K 2 O 0.35 (0.14–0.80), CuO 43.13 (41.31–45.22), ZnO 0.79 (0.19–1.18), Fe 3 O 3 0.38 (0.03–1.05), As 2 O 5 49.62 (48.61–50.66), V 2 O 5 0.13 (0–0.90), total 99.55 (97.69–101.56) wt.%. The empirical formula, normalized to O = 12 \text{apfu} (atoms per formula unit), is (Na\(\text{1.16}\), K\(\text{0.05}\))\(\text{1.21}\) (Cu\(\text{3.74}\), Zn\(\text{0.07}\), Fe\(\text{3+}\)\(\text{0.03}\))\(\text{3.84}\) (As\(\text{3.00}\), V\(\text{0.01}\))\(\text{3.01}\) O\(\text{12}\), close to the ideal NaCu₂(AsO₄)₃ confirmed by crystal-structure analysis. The mineral is named in honor of Hans Bradaczek, crystallographer at the Free University of Berlin.

Keywords: bradaczekite, new mineral species, arsenate, Tolbachik volcano, Kamchatka Peninsula, Russia.

Nous avons découvert la bradaczekite, NaCu₄(AsO₄)₃, dans une fumerole de la brèche du nord du volcan fissural de Tolbachik, en éruption en 1975–1976, dans la péninsule de Kamchatka, en Russie. La bradaczekite se présente en plaquettes bleu foncé allongées selon [102]. Les formes {010}, {111} et {112} sont bien développées. Les formes {301}, {001}, {321}, {101}, {100}, {021}, {110}, {311} et {341} sont courantes. Lui sont associées hématite, ténorite, lammerite, urusovite, orthoclase et johillerite. La nouvelle espèce possède un éclat adamantine et une rayure bleu pâle ou blanche. Aucun clivage n’est apparent. C’est un minéral transparent, biaxé négatif, \(\alpha\) 1.76(1), \(\beta\) 1.92(1), \(\gamma\) 1.96(1), 2Vcalc. 50.0°. L’orientation optique est Z = b, X \(\gamma\) c = 23° dans l’angle \(\beta\) obtus. La bradaczekite fait preuve d’un fort pleochroïsme: X violette à rouge, Y vert, Z bleu verdâtre. Elle est

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Bradaczekite is a sodium copper arsenate, NaCu₄(AsO₄)₃, recently discovered within a fumarole in the North Breach of the Great fissure Tolbachik eruption (GFTE) in the Kamchatka Peninsula, Russia. The mineral is named in honor of Hans Bradaczek (b. 1940), crystallographer at the Free University of Berlin. The type specimen is deposited in the Mining Museum, Mining Institute, St. Petersburg, Russia. The mineral and mineral name have been approved by the Commission on New Minerals and Mineral Names, IMA (case 2000–002). Bradaczekite has a synthetic analogue (Pertlik 1987). Our purpose is to document the physical and chemical attributes of this new species.

The GFTE is the largest basaltic eruption in more than 200 years (Fedotov 1984). It was active in 1975–1976 and consisted of two Breaches (North and South) and seven cones. Beginning in the late 1970s, fumarolic activity of the GFTE resulted in a unique assemblage of minerals, with two dozen new species discovered to date. Bradaczekite was found in 1980, 1983 and 1990 among the products of fumarolic activity on the second cinder cone of the North Breach. The mineral is found closely associated with hematite, tenorite, lammerite, urusovite, orthoclase and johillerite. Exhalative lammerite, Cu₃(AsO₄)₂, was detected in GFTE fumaroles by Filatov et al. (1984) and Popova & Popov.
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Glavatskikh & Bykova (1998) described johillerite, Na(Mg,Zn)₃Cu(AsO₄)₃, from the products of fumarolic activity of the second cinder cone of the North Break. Bradaczekite forms aggregates of elongate plates (Fig. 1), and intergrowths with urusovite and johillerite are common. The size of individual grains is about 0.2 mm in length and about 0.1–0.2 mm across.

### Chemical Composition

Chemical analytical data for bradaczekite were acquired with a Camebax electron microprobe utilizing an operating voltage of 15 kV and a beam current of 20 nA for all elements. The following standards were used: sanidine (Na, K), CuO (Cu), ZnO (Zn), shcherbinaite (V), lammerite (As) and Fe₂O₃ (Fe). No elements other than those mentioned above were detected. The results of the analyses are summarized in Table 1. The empirical formula of bradaczekite, \( \left( \text{Na}_{1.16}\text{K}_{0.05} \right)_{\text{H9018}} \left( \text{Cu}_{3.74} \text{Zn}_{0.07} \text{Fe}_{3.03} \right)_{\text{H9018}} \left( \text{As}_{3.00} \text{V}_{0.01} \right)_{\text{H9018}} \text{O}_{12} \), calculated on the basis of O = 12 atoms per formula units (apfu), is close to the ideal NaCu₄(AsO₄)₃. The chemical formula of bradaczekite is confirmed by a crystal-structure analysis.

### Crystal Morphology and Physical Properties

Crystals of bradaczekite are elongate along \[ \{102\} \]. The morphology of bradaczekite crystals is rather complex (Fig. 2). The well-developed forms are \{010\}, \{311\}, \{111\} and \{112\}. The forms \{301\}, \{001\}, \{321\}, \{101\}, \{100\}, \{021\}, \{110\}, \{111\} and \{311\} are common. The \( a : b : c \) proportions calculated from morphological data (0.960 : 1 : 0.593) are in good agreement with the proportions based on unit-cell parameters (0.969 : 1 : 0.585). The mineral is dark blue in color with an adamantine luster and a light blue to white streak. No cleavage was observed. The density calculated on the basis of the empirical formula is 4.77(1) g/cm³. Bradaczekite is stable at room temperature and pressure, and is practically insoluble in water and alcohol. The mineral does not fluoresce in either short- or long-wave ultraviolet radiation.

### Optical Properties

The mineral is transparent in transmitted light. Bradaczekite is biaxial and optically negative. The indices of refraction were measured in immersion liquids: \( \alpha = 1.76(1), \beta = 1.92(1), \gamma = 1.96(1) \). \( V_{\text{calc}} = 50.0^\circ \). Optical orientation is \( Z = b, X \cap c = 23^\circ \) in obtuse \( \beta \) angle. Bradaczekite shows strong pleochroism: \( X \) violet-red, \( Y \) green, \( Z \) greenish blue.

### X-Ray Crystallography

Unit-cell parameters of bradaczekite were initially determined using a Weissenberg camera and were further refined by crystal-structure analysis. The mineral is monoclinic, space group \( C2/c \), \( a = 12.051(1) \), \( b = 12.434(1) \), \( c = 7.2662(7) \) Å, \( \beta = 117.942(1) \). \( V = 117.942(1) \) Å³, and \( Z = 4 \). X-ray powder-diffraction data were obtained using CuKα radiation (DRON–2 diffractometer, Ge internal standard). The powder pattern, together with intensities calculated from the crystal structure, are given in Table 2. The crystal-structure refinement of bradaczekite and its detailed description will be given elsewhere.
RELATIONSHIPS TO OTHER MINERALS AND INORGANIC COMPOUNDS

It is apparent that bradaczekite belongs to the alluaudite group of phosphate and arsenate minerals. Minerals of this group are monoclinic, space group \( C2/c \) (Moore 1971, Moore & Ito 1979, Hatert et al. 2000). The alluaudite structure-type is based upon a framework of octahedra and tetrahedra with several interstitial cation sites. Among arsenate minerals that belong to the alluaudite group, johillerite (Keller & Hess 1988) is the closest to bradaczekite, as it contains the same set of interstitial cation positions.

As was mentioned above, bradaczekite is a natural analogue of \( \text{NaCu}_4(\text{AsO}_4)_3 \), a synthetic compound that was synthesized by Pertlik (1987) using hydrothermal methods at 490(5) K. There is only one another known sodium copper arsenate, \( \text{Na}_4\text{Cu}(\text{AsO}_4)_2 \), reported by Effenberger (1988). The copper sodium hydrogen arsenate, \( \text{Na}_5\text{Cu}_3\text{H}(\text{AsO}_4)_4 \), was described by Effenberger (1987). Neither of these two compounds belong to the alluaudite structure-type. However, \( \text{KCu}_4(\text{AsO}_4)_3 \) (Effenberger 1988) is isostructural with respect to bradaczekite.

After alarsite, \( \text{AlAsO}_4 \) (Semenova et al. 1994), coparsite, \( \text{Cu}_4\text{O}_2(\text{As,V})_5\text{O}_6\text{Cl} \) (Vergasova et al. 1999), and urusovite, \( \text{Cu}[\text{AlAsO}_5] \) (Vergasova et al. 2000), bradaczekite is the fourth new As-bearing mineral species discovered in the Tolbachik fumaroles. It should be noted that several Tolbachik arsenates demonstrate a broad range of the \( \text{As}^{5+} \)-for-\( \text{V}^{5+} \) substitution (e.g., coparsite), and there are many copper vanadate minerals of fumarolic origin (Birnie & Hughes 1979, Hughes & Birnie 1980, Hughes & Hadidiacos 1985, Robinson et al. 1987, Hughes et al. 1987a, b, 1988, Vergasova et al. 1990, 1998, 1999). However, none of these minerals belongs to the alluaudite structure-type.

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