

## New Mineral Names\*†

FERNANDO CÁMARA<sup>1</sup>, OLIVIER C. GAGNE<sup>2</sup>, AND DMITRIY I. BELAKOVSKIY<sup>3</sup><sup>1</sup>Dipartimento di Scienze della Terra “Ardito Desio”, Università di degli Studi di Milano, Via Mangiagalli, 34, 20133 Milano, Italy<sup>2</sup>Department of Geological Sciences, University of Manitoba, Winnipeg, Manitoba R3T 2N2, Canada<sup>3</sup>Fersman Mineralogical Museum, Russian Academy of Sciences, Leninskiy Prospekt 18 korp. 2, Moscow 119071, Russia

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This New Mineral Names has entries for 10 new minerals, including bulgakite, dynaesite-(La), eleonorite, gatewayite, joanneumite, mendeleevite-(Nd), morrisonite, nolzeite, packratite, vanarsite and a new data on nalivkinite.

## BULGAKITE\* AND NEW DATA ON NALIVKINITE

A.A. Agakhanov, L.A. Pautov, E. Sokolova, Y.A. Abdu and V.Y. Karpenko (2016) Two astrophyllite-supergroup minerals: bulgakite, a new mineral from the Darai-Pioz alkaline massif, Tajikistan and revision of the crystal structure and chemical formula of nalivkinite. Canadian Mineralogist, 54(1), 33–48.

Bulgakite, (IMA 2014-041), ideally  $\text{Li}_2(\text{Ca},\text{Na})\text{Fe}_7^{2+}\text{Ti}_2(\text{Si}_4\text{O}_{12})_2\text{O}_2(\text{OH})_4(\text{O},\text{F})(\text{H}_2\text{O})_2$ , is a new astrophyllite-supergroup mineral. It occurs in the moraine of the Darai-Pioz glacier (39°30'N 70°40'E) in the upper Darai-Pioz alkaline massif in the upper reaches of the Darai-Pioz river, in the area of the joint Turkestan, Zeravshan, and Alay Ranges, Tajikistan. The Darai-Pioz massif is a multiphase intrusion and occupies the core of a large synclinal fold of Carboniferous (Pennsylvanian series) slates. Rocks of the massif have been intruded by fine-grained dikes of biotite tourmaline granites and veins of calcite carbonatites and fenites. Bulgakite was found in a naturally tumbled amphibole–quartz–feldspar boulder of spotty texture, as individual crystals and intergrowths in small cavities (up to 0.5 cm) and as intergrowths (up to 1 cm) of platy crystals and aggregates of poorly crystallized grains. Associated minerals are alkali amphibole, quartz, microcline, bafertisite, aegirine, *calcybeborosilite*-(Y), thorite, fluorite, and later crystallized brannockite and sodgianite. Bulgakite is brownish orange with a pale brown streak and a vitreous luster. Cleavage is perfect parallel to {001} and moderate parallel to {010}. The indentation hardness of bulgakite is  $\text{VHN}_{50} = 204$  (165–221) kg/mm<sup>2</sup>, corresponding to Mohs hardness of ~3.  $D_{\text{meas}} = 3.30(2)$  g/cm<sup>3</sup> (by flotation in Clerici liquid),  $D_{\text{calc}} = 3.326$  g/cm<sup>3</sup>. Bulgakite does not fluoresce under ultraviolet light. It is optically biaxial (+),  $\alpha = 1.695(3)$ ,  $\beta = 1.711(2)$ ,  $\gamma = 1.750(3)$ ,  $2V_{\text{meas}} = 70(5)^\circ$ ,  $2V_{\text{calc}} = 67^\circ$  ( $\lambda = 589$  nm). Dispersion of optical axes is strong  $r < v$ . Pleochroism is: X – intensive reddish brown, Y – light brown, Z – greenish light brown;  $X < Z < Y$ . The FTIR spectra show sharp absorption peaks characteristic of stretching vibrations of OH groups at ~3639 cm<sup>-1</sup> (with a shoulder at ~3655 cm<sup>-1</sup>) and 3589 cm<sup>-1</sup> (with a shoulder at ~3600 cm<sup>-1</sup>). The H<sub>2</sub>O bend peak is observed at 1622 cm<sup>-1</sup>, while Si–O stretches present as a strong band at ~1041 cm<sup>-1</sup>, a broad band centered at ~940 cm<sup>-1</sup>, and a small peak at 695 cm<sup>-1</sup>. The same peaks are observed in the Raman spectrum (532 nm laser source) at 910 cm<sup>-1</sup>, 733 (with a shoulder at ~785 cm<sup>-1</sup>), and 1041 cm<sup>-1</sup>. In addition, peaks at 660, 569, 420, 395, and 367 may be assigned to bending vibrations of the silicate groups,

and those at 258, 233, 170, and 133 cm<sup>-1</sup> are assigned to lattice modes. The electron probe EDS (Na, Zn, and F by WDS) analysis [wt% (ranges not provided)] is: SiO<sub>2</sub> 35.63, Al<sub>2</sub>O<sub>3</sub> 0.95, Na<sub>2</sub>O 1.04, K<sub>2</sub>O 3.27, Cs<sub>2</sub>O 0.31, CaO 2.56, MgO 0.16, ZnO 0.15, FeO 29.24, MnO 7.14, TiO<sub>2</sub> 11.07, Nb<sub>2</sub>O<sub>5</sub> 0.49, ZrO<sub>2</sub> 0.37, SnO<sub>2</sub> 1.18, F 1.01, Li<sub>2</sub>O 1.36 (AAS), Rb<sub>2</sub>O 0.85 (AAS), –F=O<sub>2</sub> 0.43, H<sub>2</sub>O 4.04 (calculated from crystal-structure analysis), total 100.38. The empirical formula based on 31.94 (O+OH+F+H<sub>2</sub>O) pfu, is  $(\text{Li}_{0.94}\text{K}_{0.91}\text{Rb}_{0.12}\text{Cs}_{0.03})_{\Sigma 2.00}(\text{Ca}_{0.60}\text{Na}_{0.40})_{\Sigma 1.00}(\text{Fe}_{5.34}\text{Mn}_{1.32}\text{Li}_{0.25}\text{Mg}_{0.05}\text{Na}_{0.04}\text{Zn}_{0.02})_{\Sigma 7.02}(\text{Ti}_{1.82}\text{Sn}_{0.10}\text{Nb}_{0.05}\text{Zr}_{0.04})_{\Sigma 2.01}[(\text{Si}_{7.78}\text{Al}_{0.24})_{\Sigma 8.02}\text{O}_{24}]\text{O}_2(\text{OH})_4(\text{F}_{0.70}\text{O}_{0.30})[(\text{H}_2\text{O})_{0.94}\square_{1.06}]_{\Sigma 2.00}$ ,  $Z = 1$ . The strongest lines in the X-ray powder diffraction pattern are [*d* Å (%; *hkl*)]: 10.54 (100; 001), 3.50 (100; 003), 2.578 (100; 130), 2.783 (90; 142), 1.576 (68; 351, 322), 2.647 (55; 211). The unit-cell parameters refined from the powder data are:  $a = 5.3729(8)$ ,  $b = 11.926(2)$ ,  $c = 11.638(2)$  Å,  $\alpha = 113.284(4)$ ,  $\beta = 94.560(4)$ ,  $\gamma = 103.085(4)^\circ$ ,  $V = 657.5$  Å<sup>3</sup>. The mineral is triclinic, space group *P1*,  $Z = 1$ . A single-crystal X-ray data was obtained on a crystal of 0.12 × 0.10 × 0.004 mm. The single crystal unit-cell parameters are:  $a = 5.347(1)$ ,  $b = 11.965(2)$ ,  $c = 11.65(3)$  Å,  $\alpha = 113.457(8)$ ,  $\beta = 94.533(8)$ ,  $\gamma = 103.08(1)^\circ$ ,  $V = 657.5$  Å<sup>3</sup>. The crystal structure was refined to  $R_1 = 0.0287$  for 3592 observed [ $F_o > 4\sigma F_o$ ] reflections. In the crystal structure of bulgakite, there are four <sup>4f</sup>T sites, occupied by Si with minor Al, which constitute the T<sub>4</sub>O<sub>12</sub> astrophyllite ribbon. A <sup>16</sup>D site occupied mainly by Ti, along with the T<sub>4</sub>O<sub>12</sub> astrophyllite ribbons constitute the heteropolyhedral (H) sheet. In the octahedral (O) sheet, there are four Fe<sup>2+</sup>-dominant <sup>16</sup>M(1–4) sites. Two H and the central O sheets form the HOH block, and adjacent HOH blocks link via a common anion (X<sub>D</sub><sup>p</sup>) of two D octahedra. In the I (Intermediate) block between adjacent HOH blocks, there are two interstitial cation sites, A and B, and a W site, partly occupied by H<sub>2</sub>O. The aggregate content of the A site is  $(\text{Li}_{0.94}\text{K}_{0.91}\text{Rb}_{0.12}\text{Cs}_{0.03})_{\Sigma 2}$ , ideally Li<sub>2</sub> apfu. The <sup>10</sup>B site is occupied by  $(\text{Ca}_{0.60}\text{Na}_{0.40})$ . The W site is occupied by  $[(\text{H}_2\text{O})_{0.94}\square_{1.06}]_{\Sigma 2}$  pfu. The mineral is named bulgakite after Lev Vasil'evich Bulgak (born 1938), Russian mineralogist, gemologist, translator of geological literature, and discoverer of several new minerals who used to work from 1975 to 2003 at the A.E. Fersman Mineralogical Museum Russian Academy of Sciences, Moscow, Russia. The holotype specimen is deposited in that museum.

**Nalivkinite (new data).** The description of bulgakite brought a new development in the crystal chemistry of the astrophyllite-supergroup minerals, the location of an H<sub>2</sub>O group in the intermediate (I) block of bulgakite, which required reinvestigation of the crystal structure of nalivkinite, ideally  $\text{Li}_2\text{NaFe}_7^{2+}\text{Ti}_2(\text{Si}_4\text{O}_{12})_2\text{O}_2(\text{OH})_4\text{F}$  (Agakhanov et al. 2008; Uvarova et al. 2008). This H<sub>2</sub>O group is a ligand of the Li atom at the [6]-coordinated A(2) site. Uvarova et al. (2008) reported [5]-coordinated Li at the A(2) site. In the proposal on bulgakite (IMA 2014-041), the issue of the [6]-coordinated A(2) site in bulgakite was outlined and it

\* All minerals marked with an asterisk have been approved by the IMA CNMNC.  
† For a complete listing of all IMA-validated unnamed minerals and their codes, see <http://pubsites.uws.edu.au/ima-cnmmc/>.

was suggested a revision of the crystal structure of nalivkinite that would result in the following ideal formula:  $\text{Li}_2\text{NaFe}_3^{2+}\text{Ti}_2(\text{Si}_4\text{O}_{12})_2\text{O}_2(\text{OH})_4\text{F}(\text{H}_2\text{O})_2$ . The proposal was approved by the CNMNC (Agakhanov et al. 2014). An amount of 1.14  $\text{H}_2\text{O}$  pfu (at the W site) was calculated to achieve the [6]-coordinated environment of Li [A(2)] and thus recalculated the amount of  $\text{H}_2\text{O}$  as 4.32 wt%. The presence of  $\text{H}_2\text{O}$  groups in the nalivkinite structure was confirmed by infrared spectroscopy. FTIR spectra show sharp absorption peaks that are characteristic of stretching vibrations of OH groups: peaks occur at  $\sim 3639\text{ cm}^{-1}$  (with a shoulder at  $\sim 3630\text{ cm}^{-1}$  (with a shoulder at  $\sim 3650\text{ cm}^{-1}$ ) and  $3590\text{ cm}^{-1}$  (with a shoulder at  $\sim 3600\text{ cm}^{-1}$ ). A broad band at  $\sim 3490\text{ cm}^{-1}$  is attributed to  $\text{H}_2\text{O}$  stretches. The  $\text{H}_2\text{O}$  bend peak is observed at  $1622\text{ cm}^{-1}$ . The amount of 4.32 wt% of  $\text{H}_2\text{O}$  calculated from crystal-structure analysis was added to the analysis published by Uvarova et al. (2008):  $\text{SiO}_2$  36.11,  $\text{Al}_2\text{O}_3$  0.58,  $\text{Na}_2\text{O}$  1.88,  $\text{K}_2\text{O}$  2.68,  $\text{Cs}_2\text{O}$  0.93,  $\text{CaO}$  1.24,  $\text{MgO}$  0.11,  $\text{ZnO}$  0.23,  $\text{FeO}$  30.84,  $\text{MnO}$  4.86,  $\text{PbO}$  0.39,  $\text{TiO}_2$  9.48,  $\text{Nb}_2\text{O}_5$  2.40,  $\text{Ta}_2\text{O}_5$  0.61,  $\text{ZrO}_2$  1.47,  $\text{SnO}_2$  0.89,  $\text{F}$  1.45,  $\text{Li}_2\text{O}$  1.30 (ICP-OES),  $\text{Rb}_2\text{O}$  n.d.,  $-\text{F}=\text{O}_2$  0.61, total 101.16 wt%. The revised empirical formula of nalivkinite is based on 32.14 (O+OH+F+H<sub>2</sub>O) pfu:  $(\text{Li}_{1.14}\text{K}_{0.75}\text{Cs}_{0.09}\text{Pb}_{0.02})_{\Sigma 2.00}(\text{Na}_{0.71}\text{Ca}_{0.29})_{\Sigma 1}(\text{Fe}_{2.72}^{2+}\text{Mn}_{0.90}\text{Zr}_{0.08}\text{Na}_{0.08}\text{Mg}_{0.04}\text{Zn}_{0.04})_{\Sigma 6.76}(\text{Ti}_{1.56}\text{Nb}_{0.24}\text{Sn}_{0.09}\text{Zr}_{0.08}\text{Ta}_{0.04})_{\Sigma 2}[(\text{Si}_{1.86}\text{Al}_{0.15})_{\Sigma 2.01}\text{O}_2](\text{OH})_4\text{F}(\text{H}_2\text{O})_{1.14}\square_{0.86}\text{I}_{2.00}$ .  $D_{\text{meas}} = \text{g/cm}^3$  3.32(2) (by flotation in Clerici liquid),  $D_{\text{calc}} = 3.347\text{ g/cm}^3$ . New single-crystal X-ray diffraction data was collected on a crystal of twinned nalivkinite. Lattice parameters are  $a = 5.374(3)$ ,  $b = 11.948(5)$ ,  $c = 11.676(5)$  Å,  $\alpha = 113.360(6)$ ,  $\beta = 94.538(8)$ ,  $\gamma = 103.01(1)$ ,  $V = 658.7$  Å<sup>3</sup>, space group  $P\bar{1}$ ,  $Z = 1$ . The crystal structure was refined to  $R_1 = 0.0452$  for 3546 observed [ $F_o > 4\sigma F_o$ ] reflections.

Bulgakite is a Ca-analog of nalivkinite. Bulgakite and nalivkinite are related by the following substitution:  $0.3\text{ }^8\text{Ca}^{2+} + 0.3\text{ }^3\text{O}^{2-} \leftrightarrow 0.3\text{ }^8\text{Na}^{+} + 0.3\text{ }^3\text{F}^-$ . **F.C.**

## References cited

- Agakhanov, A.A., Pautov, L.A., Uvarova, Y.A., Sokolova, E., Hawthorne, F.C., and Karpenko, V.Yu. (2008) Nalivkinite,  $\text{Li}_2\text{NaFe}_3^{2+}\text{Ti}_2(\text{Si}_4\text{O}_{12})_2\text{O}_2(\text{OH})_4\text{F}$ , a new mineral of the astrophyllite group from the Darai-Pioz massif, Tadjikistan. *New Data on Minerals*, 43, 5–12.
- Agakhanov, A.A., Pautov, L.A., Sokolova, E., Hawthorne, F.C., and Karpenko, V.Y. (2014) Bulgakite, IMA 2014-041. *Mineralogical Magazine* 78, 1241–1248.
- Uvarova, Y.A., Sokolova, E., Hawthorne, F.C., Agakhanov, A.A., and Pautov, L.A. (2008) The crystal structure of nalivkinite, a new lithium member of the astrophyllite group. *Canadian Mineralogist* 46, 651–659.
- DYRNAESITE-(LA)\***
- J.G. Rønso, T. Balić-Žunić and O.V. Petersen (2017) Dyrnaesite-(La) a new hyperagpaite mineral from the Ilmaussaq alkaline complex, South Greenland. *Mineralogical Magazine*, 81(1), 103–111.
- T. Balić-Žunić (2017) The crystal structure of the new mineral dyrnaesite-(La),  $\text{Na}_8\text{Ce}^{\text{IV}}\text{REE}_2(\text{PO}_4)_6$ . *Mineralogical Magazine*, 81(1), 199–208.
- Dyrnaesite-(La) (IMA 2014-070), with simplified formula  $\text{Na}_8\text{Ce}^{\text{IV}}\text{REE}_2(\text{PO}_4)_6$ , is a new mineral found in the Ilmaussaq alkaline complex, South Greenland. Dyrnaesite-(La) occurs in a hyperagpaite arfvedsonite-lujavrite as a primary late magmatic mineral in association with arfvedsonite, albite, microcline, nepheline, sodalite, aegirine, and analcime. It forms 0.2–0.7 mm subhedral grains that show twinning on {210} and {230}. The new mineral is pale yellowish green with white streak and vitreous luster. It is brittle with no cleavage and with an irregular fracture. Mohs hardness was not determined.  $D_{\text{meas}} = 3.68(2)$  and  $D_{\text{calc}} = 3.682\text{ g/cm}^3$ . Dyrnaesite-(La) does not fluoresce in UV light. The mineral is optically biaxial (–),  $\alpha = 1.623$ ,  $\beta = 1.685$ ,  $\gamma = 1.698$ ;  $2V_{\text{meas}} = 47(1)^\circ$  and  $2V_{\text{calc}} = 47.5$ ;  $X = \text{c}$ ,  $Y = \text{a}$ ,  $Z = \text{b}$ . It is pleochroic in pale yellowish green tones;  $X > Y$  and  $Z$ . The average of 63 electron probe analyses on 9 grains (not specified EDS or WDS mode) is [wt% (St.dev.)]:  $\text{P}_2\text{O}_5$  37.17 (0.28),  $\text{SiO}_2$  0.15 (0.04),  $\text{CaO}$  0.90 (0.17),  $\text{Na}_2\text{O}$  20.06 (0.60),  $\text{La}_2\text{O}_3$  16.44 (0.34),  $\text{CeO}_2$  20.23 (0.36) (valence based on structure refinement and charge balance),  $\text{Pr}_2\text{O}_3$  1.40 (0.21),  $\text{Nd}_2\text{O}_3$  3.47 (0.15),  $\text{Sm}_2\text{O}_3$  0.24 (0.13),  $\text{Dy}_2\text{O}_3$  0.06 (0.08),  $\text{Y}_2\text{O}_3$  0.06 (0.04), total 100.18. This gives the empirical formula  $\text{Na}_{7.44}\text{Ca}_{0.19}\text{Ce}_{1.35}\text{La}_{1.16}\text{Nd}_{0.24}\text{Pr}_{0.10}\text{Sm}_{0.02}\text{Y}_{0.01}(\text{P}_{6.02}\text{Si}_{0.03})\text{O}_{24}$  based on 24 O apfu. The strongest lines in the X-ray powder-diffraction pattern [ $d$  Å (%  $hkl$ )] are: 6.57 (100; 101), 4.62 (40; 301,230,400), 3.50 (40; 331), 2.80 (86; 232,402), 2.67 (54; 060,630). Single-crystal X-ray diffraction data collected on a crystal fragment of 0.002 mm<sup>3</sup> refined to  $R_1 = 0.037$  and shows dyrnaesite-(La) is orthorhombic,  $Pnma$ ;  $a = 18.4662(7)$  Å,  $b = 16.0106(5)$  Å,  $c = 7.0274(2)$  Å,  $V = 2077.7$  Å<sup>3</sup>,  $Z = 4$ . The structural formula calculated from the diffraction data and microprobe analysis is  $\text{Na}_{7.89}(\text{Ce}_{0.94}\text{Ca}_{0.06})_{\Sigma 2.00}(\text{Ca}_{0.12}\text{La}_{1.14}\text{Ce}_{0.40}\text{Pr}_{0.10}\text{Nd}_{0.24})_{\Sigma 2.00}(\text{PO}_4)_6$ . The structure of dyrnaesite-(La) is based on the apthitalite/glaserite structure type and is related to the group of  $\text{Na}_3\text{REE}(\text{XO}_4)_2$  compounds (with X = P, V, As). The structure consists of phosphate tetrahedra arranged in a hexagonal pattern. Both the Ce and La sites share edges with three phosphate groups and vertices with three more. Na is observed in 6 sites, found in coordination numbers 6–9 with  $\text{PO}_4$  tetrahedra. Dyrnaesite-(La) is named after the base camp area, Dyrnæs (animal headland), north of the town of Narsaq, Kujalleq Kommune, South Greenland, with the suffix (La) describing the dominance of La as the REE component. The type material is preserved in the Natural History Museum, University of Copenhagen, Denmark. **O.C.G.**
- ELEONORITE\***
- N.V. Chukanov, S.M. Aksenov, R.K. Rastsvetaeva, C. Schäfer, I.V. Pekov, D.I. Belakovskiy, R. Scholz, L.C.A. De Oliveira and S.N. Britvin (2017) Eleonorite,  $\text{Fe}_6^{3+}(\text{PO}_4)_4(\text{OH})_4 \cdot 6\text{H}_2\text{O}$ : Validation as a mineral species and new data. *Mineralogical Magazine*, 81(1), 61–76.
- Eleonorite (IMA 2015-003), ideally  $\text{Fe}_6^{3+}(\text{PO}_4)_4(\text{OH})_4 \cdot 6\text{H}_2\text{O}$ , is mineral species first found at the Eleonore Iron mine, Dünsberg, near Gießen, Hesse, Germany and has since been identified in oxidized zones of many other iron deposits where it was considered to be an oxidized variety of beraunite (Nies 1877, 1880; Streng 1881; Palache et al. 1951). The study concerns the formal validation of eleonorite mostly based on material from the Rotläufchen mine, Waldgirmes, Wetzlar, Hesse, Germany, which is considered as a neotype. Eleonorite most probably is a supergene mineral resulted from natural solid-state oxidation of beraunite that formed by the interaction of phosphate-rich solutions related to phosphorite deposits with late Devonian iron ores. The mineral is associated with goethite, rockbridgeite, dufrenite, kidwellite, variscite, matulaite, planerite, caxoxenite, strengite, and wavellite. Eleonorite forms prismatic crystals flattened on {100}, or with a rhombic cross section, up to  $0.2 \times 0.5 \times 3.5$  mm in size and in random or radial aggregates up to 5 mm across encrusting cavities in massive limonite. Major crystal forms observed are {100}, {301}, and {30 $\bar{1}$ }. Crystals are red brown translucent with light red-brown streak and a vitreous luster. The cleavage is perfect on {100}. It is brittle with Mohs hardness of 3.  $D_{\text{meas}} = 2.92(1)$  and  $D_{\text{calc}} = 2.931\text{ g/cm}^3$ . Eleonorite is optically biaxial (+) with  $\alpha = 1.765(4)$ ,  $\beta = 1.780(5)$ ,  $\gamma = 1.812(6)$ ,  $2V_{\text{meas}} = 75(10)^\circ$ . Dispersion of the optical axes is very strong,  $r > v$ . Optical orientation is  $X = \text{b}$ ; the X- and Z-axes lie in the (100) plane at an angle close to  $90^\circ$  with one another. The new mineral is strongly pleochroic, Z (brown red)  $\gg$  Y  $\geq$  X (brownish yellow). The main absorption bands of the IR spectrum ( $\text{cm}^{-1}$ ; s = strong, sh = shoulder) are: 3553, 3506, 3265s, 3205, 3120sh, 2930sh (O–H stretching vibrations of OH<sup>–</sup> anions and H<sub>2</sub>O molecules), 1625, 1560sh (bending vibrations of H<sub>2</sub>O molecules), 1147, 1095sh, 1065sh, 1032s, 988s [ $\nu_3(\text{F}_2)$  – antisymmetric P–O stretching vibrations of  $\text{PO}_4^{3-}$  anions], 962s, 937s [ $\nu_1(\text{A}_1)$  – symmetric P–O stretching vibrations of  $\text{PO}_4^{3-}$  anions], 810sh, 676 (Fe<sup>3+</sup>–O–H bending vibrations), 588s [triply degenerate  $\nu_4(\text{F}_2)$  O–P–O bending mode of  $\text{PO}_4^{3-}$  anions]. Low-frequency bands observed at 500, 482, 443, 422, and 369 correspond to lattice modes involving Fe<sup>3+</sup>–O stretching and  $\nu_2(\text{E})$  O–P–O bending

vibrations, possibly combined with libration modes of H<sub>2</sub>O molecules. The average of 5 electron probe EDS analyses is [wt% (range)]: Al<sub>2</sub>O<sub>3</sub> 1.03 (0.81–1.36), Mn<sub>2</sub>O<sub>3</sub> 0.82 (0.60–0.97), Fe<sub>2</sub>O<sub>3</sub> 51.34 (50.60–52.08) (Mössbauer), P<sub>2</sub>O<sub>5</sub> 31.06 (30.57–3.49), H<sub>2</sub>O 16.4 (by chromatography of ignition products at 1200 °C), total 99.58. The empirical formula based on 27 apfu and structural refinement data is (Fe<sub>37.76</sub>Al<sub>10.18</sub>Mn<sub>0.09</sub>)<sub>Σ6.03</sub>(PO<sub>4</sub>)<sub>3.92</sub>O(OH)<sub>4.34</sub>·5.98H<sub>2</sub>O. The strongest lines in the X-ray powder-diffraction pattern [*d* Å (*P*%; *hkl*)] are: 10.41 (100; 200), 9.67 (38; 002), 7.30 (29; 20 $\bar{2}$ ), 4.816 (31; 111,004), 3.432 (18; 600,114,404,313), 3.197 (18; 510,51 $\bar{1}$ ,006,314,602), 3.071 (34; 314,11 $\bar{5}$ ). The unit-cell parameters refined from powder-diffraction data are: *a* = 20.694(6), *b* = 5.143(1), *c* = 19.236(7) Å, β = 93.52(2)°, *V* = 2044 Å<sup>3</sup>. Single-crystal X-ray diffraction data collected on a crystal of size 0.13 × 0.15 × 0.18 mm refined to *R*<sub>1</sub> = 0.068 for 2230 unique *I* ≥ 2σ(*I*) reflections shows eleonorite is monoclinic, space group *C2/c*, *a* = 20.679(10), *b* = 5.148(2), *c* = 19.223(9) Å, β = 93.574(9)°, *V* = 2042.5 Å<sup>3</sup>, and *Z* = 4. Eleonorite is the analog of beraunite following heterovalent substitution of one Fe<sup>3+</sup> ion as Fe<sup>3+</sup> + O<sup>2-</sup> ↔ Fe<sup>2+</sup> + OH<sup>-</sup>. The structure of eleonorite is based on a heteropolyhedral framework formed by *M*(1–4)O<sub>6</sub>-octahedra (where *M* = Fe<sup>3+</sup>; O = O<sup>2-</sup>, OH<sup>-</sup>, or H<sub>2</sub>O) and isolated PO<sub>4</sub> tetrahedra, with a wide channel occupied by H<sub>2</sub>O molecules. Eleonorite is named after the Eleonore Iron mine. The neotype from the Rotläufchen mine and a specimen from the Gutglück mine, Braunfels, Wetzlar, Hesse, German are deposited in the Fersman Mineralogical Museum of Russian Academy of Sciences, Moscow, Russia. **O.C.G.**

## References cited

- Nies, A. (1877) Strengit, ein neues Mineral. Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, 8–16.  
 ——— (1880) Vorläufiger Bericht über zwei neue Mineralien von der Grube Eleonore am Dünsberg bei Gießen. Berichte der Oberhessischen Gesellschaft für Natur- und Heilkunde, 19, 111–113.  
 Palache, C., Berman, H., and Frondel, C. (1951) The System of Mineralogy of James Dwight Dana and Edward Salisbury Dana. Volume II. Wiley, New York.  
 Streng, A. (1881) Ueber die Phosphate von Waldgirmes. Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, 101–119.

## GATEWAYITE\*, MORRISONITE\*, PACKKRATITE\*, VANARSITE\*

A.R. Kampf, J.M. Hughes, B.P. Nash and J. Marty (2016) Vanarsite, packkratite, morrisonite, and gatewayite: four new minerals containing the [As<sup>3+</sup>V<sup>4+</sup>As<sup>5+</sup>As<sup>5+</sup>O<sub>51</sub>]<sup>12-</sup> heteropolyanion, a novel polyoxometalate cluster. Canadian Mineralogist, 54, 145–162.

Secondary mineralization at the Packrat mine in the Gateway district, Mesa County, Colorado, U.S.A. (38°38'51.28"N 109°02'49.77"W), has yielded four new minerals containing the novel polyoxometalate-like heteropolyanion, [As<sup>3+</sup>V<sup>4+</sup>As<sup>5+</sup>As<sup>5+</sup>O<sub>51</sub>]<sup>12-</sup>, which is new to science. The four new minerals are gatewayite, morrisonite, packkratite, and vanarsite and should be referred to as the vanarsite mineral family because vanarsite was the first of them to be approved. The four are found together on montroseite- and corvusite-bearing sandstone and are also closely associated with pharmacolite and a potentially new vanadate mineral. The new minerals formation resulted from the oxidation of montroseite-corvusite assemblages in a moist environment. The structures of the vanarsite family minerals consist of two distinct parts, a structural unit and an interstitial unit: the structural unit in all four vanarsite family minerals is the novel [As<sup>3+</sup>V<sup>4+</sup>As<sup>5+</sup>As<sup>5+</sup>O<sub>51</sub>]<sup>12-</sup> heteropolyanion composed of twelve distorted V<sup>4+</sup>As<sup>5+</sup>O<sub>6</sub> octahedra surrounding a central As<sup>3+</sup>O<sub>3</sub> (arsenite) pyramid and decorated by peripheral As<sup>5+</sup>O<sub>4</sub> (arsenate) tetrahedra, each of which shares three of its four vertices with VO<sub>6</sub> octahedra (a mixture of V<sup>4+</sup> and V<sup>5+</sup>); the stoichiometry and charge of the heteropolyanion varies from [As<sup>3+</sup>V<sup>4+</sup>V<sup>5+</sup>As<sup>5+</sup>O<sub>51</sub>]<sup>11-</sup> to [As<sup>3+</sup>V<sup>4+</sup>V<sup>5+</sup>V<sup>5+</sup>As<sup>5+</sup>O<sub>51</sub>]<sup>12.5-</sup> and serves to balance the charge of the interstitial unit, which differs in each of the four minerals. The vanarsite family minerals are the only known minerals that contain both mixed-valence As and mixed-valence V. The

holotype and/or cotype specimens of all those new species are deposited in the Natural History Museum of Los Angeles County, Los Angeles, California, U.S.A.

**Gatewayite** (IMA 2014-096), ideally Ca<sub>6</sub>(As<sup>3+</sup>V<sup>4+</sup>V<sup>5+</sup>As<sup>5+</sup>O<sub>51</sub>)·31H<sub>2</sub>O, occurs as very dark greenish-blue blades are more or less flattened on {101} and elongated on [010], which are up to 0.5 mm long and form divergent intergrowths. It also occurs as crude prisms, up to 1 mm long, with rounded faces and as composite crystals consisting of subparallel intergrowths of narrow prisms up to 2 mm long. Streak is grayish blue and luster is vitreous. Mohs hardness is ~2, fracture is curved, tenacity is brittle and cleavage is fair on {010} and {101}. *D*<sub>meas</sub> = 2.34(2) g/cm<sup>3</sup> (by floatation in mixtures of methylene iodide and toluene) *D*<sub>calc</sub> = 2.337 g/cm<sup>3</sup>. The mineral is insoluble in H<sub>2</sub>O at room *T* and easily soluble in diluted HCl at room *T*. Optically, gatewayite is biaxial (–), *a* = 1.621(1), β = 1.654(5), γ = 1.668(5) (light not reported), 2*V*<sub>meas</sub> = 66(1)°, 2*V*<sub>calc</sub> = 65.0°. Dispersion is extreme (sense not determined). *Y* = **b**, *X* ∧ **a** ≈ 30° in obtuse β. It is pleochroic: *X* = pale olive green, *Y* = medium greenish blue, *Z* = dark greenish blue; *X* << *Y* < *Z*. The average of electron probe WDS analysis (9 points in 7 crystals) [wt% (ranges)] is: Na<sub>2</sub>O 0.21 (0.09–0.37), CaO 12.31 (11.90–12.79), SrO 0.41 (0.20–0.66), As<sub>2</sub>O<sub>5</sub> 32.18 (29.62–34.43), V<sub>2</sub>O<sub>5</sub> 42.97 (41.95–44.32), total 88.08. The H<sub>2</sub>O loss results in higher concentrations for the remaining constituents than is to be expected for the fully hydrated phases; the analyzed constituents normalized to provide a total of 100% when combined with the calculated H<sub>2</sub>O are: Na<sub>2</sub>O 0.19, CaO 11.31, SrO 0.31, As<sub>2</sub>O<sub>5</sub> 3.60, As<sub>2</sub>O<sub>3</sub> 25.40, VO<sub>2</sub> 7.40, V<sub>2</sub>O<sub>5</sub> 31.39, H<sub>2</sub>O (on the basis of crystal structure) 20.33, total 100.00. The empirical formula based on V+As = 19 and 82 O apfu is: (Ca<sub>5.54</sub>Na<sub>0.17</sub>Sr<sub>0.10</sub>)<sub>Σ5.81</sub>(As<sup>3+</sup>V<sup>4+</sup>V<sup>5+</sup>As<sup>5+</sup>O<sub>51</sub>)·31H<sub>2</sub>O. The strongest lines of the X-ray powder diffraction pattern [*d* Å (*P*%; *hkl* not reported by the authors)] are: 13.2 (47), 11.1 (8), 9.7 (100), 3.246 (9), 2.953 (9), 2.866 (14), 2.810 (17), and 2.758 (9). The single-crystal unit-cell parameters are: *a* = 11.1850(4), *b* = 16.8528(4), *c* = 20.7146(15) Å, β = 91.166(6)°, and *V* = 3903.9 Å<sup>3</sup>, *Z* = 2, space group *P2*<sub>1</sub>. The structure was refined to *R*<sub>1</sub> = 0.053 for 9088 unique, observed [*F*<sub>o</sub> > 4σ(*F*<sub>o</sub>)] reflections. In the structure of gatewayite, the interstitial unit consists of nine isolated H<sub>2</sub>O groups, four of which are partially occupied, and six Ca–O polyhedra that are sixfold- or sevenfold-coordinated. The Ca–O polyhedra share one, two, or three of their vertices with O atoms of the VO<sub>6</sub> octahedra and/or AsO<sub>4</sub> tetrahedra of the structural unit. The remaining vertices of the Ca polyhedra are H<sub>2</sub>O groups. The structural units are linked via the Ca–O polyhedra into a sheet parallel to {101}. The Ca polyhedra do not link to one another. The only linkage between these sheets is via hydrogen bonds. The interstitial unit, [Ca<sub>6</sub>(H<sub>2</sub>O)<sub>23</sub>·8H<sub>2</sub>O]<sup>12+</sup>, combines with the [As<sup>3+</sup>V<sup>4+</sup>V<sup>5+</sup>As<sup>5+</sup>O<sub>51</sub>]<sup>12-</sup> polyanion structural unit in the formula unit. Gatewayite is named for the Gateway mining district in which the Packrat mine is located. Gateway is also the nearest town to the Packrat mine.

**Morrisonite** (IMA 2014-088), ideally Ca<sub>11</sub>(As<sup>3+</sup>V<sup>4+</sup>V<sup>5+</sup>As<sup>5+</sup>O<sub>51</sub>)<sub>2</sub>·78H<sub>2</sub>O, occurs as very dark blue blades are flattened on {010} and elongated on [100]. They are up to about 1 mm long, striated lengthwise, and grow in sub-parallel and divergent intergrowths. Streak is grayish blue and luster is vitreous. Mohs hardness is ~2½, fracture is curved, tenacity is brittle, and cleavage is perfect on {010} and good on {100}. *D*<sub>meas</sub> = 2.29(2) g/cm<sup>3</sup> (by floatation in mixtures of methylene iodide and toluene) *D*<sub>calc</sub> = 2.221 g/cm<sup>3</sup>. The mineral is insoluble in H<sub>2</sub>O at room *T* and easily soluble in diluted HCl at room *T*. Optically, morrisonite is biaxial (–), *a* = 1.611(2), β<sub>calc</sub> = 1.631, γ = 1.637(2) (light not reported), 2*V*<sub>meas</sub> = 58(1)°. Dispersion is not observable. *Y* = **b**, *X* ≈ **a**, *Z* ≈ **c**. It is pleochroic: *X* = blue, *Y* = dark blue, *Z* = dark blue; *X* << *Y* ≈ *Z*. The average of electron probe WDS analysis (33 points in 13 crystals) [wt% (ranges)] is: Na<sub>2</sub>O 0.21 (0.01–0.57), CaO 11.82 (10.98–12.30), As<sub>2</sub>O<sub>5</sub> 32.71 (30.59–34.58), V<sub>2</sub>O<sub>5</sub> 42.79 (41.43–44.73), total 87.53. The H<sub>2</sub>O loss results in higher concentrations for the remaining constituents than is to be expected for the fully hydrated phases; the analyzed constituents normalized to provide a total of 100% when combined with the calculated H<sub>2</sub>O are: Na<sub>2</sub>O 0.18, CaO

10.36, As<sub>2</sub>O<sub>3</sub> 3.44, As<sub>2</sub>O<sub>5</sub> 24.63, VO<sub>2</sub> 5.14, V<sub>2</sub>O<sub>5</sub> 31.82, H<sub>2</sub>O (on the basis of crystal structure) 24.44, total 100.00. The empirical formula based on V+As = 38 and 180 O apfu is: (Ca<sub>10.61</sub>Na<sub>0.34</sub>)<sub>Σ10.95</sub>(As<sup>3+</sup><sub>1.00</sub>V<sup>4+</sup><sub>1.78</sub>V<sup>5+</sup><sub>0.06</sub>As<sup>5+</sup><sub>16</sub>O<sub>51</sub>)<sub>2</sub>·78H<sub>2</sub>O. The strongest lines of the X-ray powder diffraction pattern [*d* Å (*I*%); *hkl* not reported by the authors] are: 12.2 (69), 11.4 (100), 9.9 (16), 9.2 (23), 6.81 (12), 6.10 (11), 2.936 (16), and 2.839 (12). The single-crystal unit-cell parameters are: *a* = 14.9566(18), *b* = 48.208(6), *c* = 23.838(3) Å, β = 90.034(6)°, and *V* = 17187 Å<sup>3</sup>, *Z* = 4, space group *P*2<sub>1</sub>/*c*. The structure was refined to *R*<sub>1</sub> = 0.075 for 4194 unique, observed [*F*<sub>o</sub> > 4σ*F*<sub>o</sub>] reflections. In the structure of morrisonite the interstitial unit consists of 10 well-defined Ca–O polyhedra in all of which the Ca atom is sevenfold coordinated. These Ca–O polyhedra share one, two, or three of their vertices with O atoms of the VO<sub>6</sub> octahedra and/or AsO<sub>4</sub> tetrahedra of the structural unit. The remaining vertices of these Ca–O polyhedra are H<sub>2</sub>O groups. A further 11th Ca site could not be well defined in the refinement. The structural units are linked via the Ca–O polyhedra, as well as by an extensive system of hydrogen bonds. The interstitial unit, [Ca<sub>11</sub>(H<sub>2</sub>O)<sub>78</sub>]<sup>22+</sup>, combines with two [As<sup>3+</sup>V<sup>2+</sup>V<sup>5+</sup>As<sup>5+</sup>O<sub>51</sub>]<sup>11-</sup> polyanion structural units in the formula unit. Morrisonite is named for the Morrison Formation, in which the Packrat mine and other U–V mines of the Uravan mineral belt occur.

**Packratite** (IMA 2014-059), ideally Ca<sub>11</sub>(As<sup>3+</sup>V<sup>2+</sup>V<sup>5+</sup>As<sup>5+</sup>O<sub>51</sub>)<sub>2</sub>·83H<sub>2</sub>O, occurs as very dark greenish-blue blades flattened on {110} and elongated on {001}. They are up to about 1 mm long, striated lengthwise, and grow in sub-parallel and divergent intergrowths. It also occurs as pearly green, botryoidal aggregates. Streak is grayish blue and luster is vitreous. Mohs hardness is ~2, fracture is curved, tenacity is brittle and cleavage is fair on {001}, {110}, and {110}. *D*<sub>meas</sub> = 2.36(2) g/cm<sup>3</sup> (by floatation in mixtures of methylene iodide and toluene) *D*<sub>calc</sub> = 2.351 g/cm<sup>3</sup>. The mineral is insoluble in H<sub>2</sub>O at room *T* and easily soluble in diluted HCl at room *T*. Optically, packratite is biaxial (–), *α*<sub>calc</sub> = 1.625, β = 1.628(2), γ = 1.629(2) (light not reported), 2*V*<sub>meas</sub> = 60.7(4)°. Dispersion is moderate *r* < *v*. *X* ≈ ± {110}, *Z* ^ *c* ≈ 20°. It is non-pleochroic. The average of electron probe WDS analysis (4 points in 2 crystals) [wt% (ranges)] is: Na<sub>2</sub>O 0.30 (0.25–0.38), CaO 11.29 (10.69–11.79), As<sub>2</sub>O<sub>5</sub> 31.28 (29.33–34.22), V<sub>2</sub>O<sub>5</sub> 40.23 (38.53–41.76), total 83.22. The H<sub>2</sub>O loss results in higher concentrations for the remaining constituents than is to be expected for the fully hydrated phases; the analyzed constituents normalized to provide a total of 100% when combined with the calculated H<sub>2</sub>O are: Na<sub>2</sub>O 0.27, CaO 10.27, As<sub>2</sub>O<sub>5</sub> 3.38, As<sub>2</sub>O<sub>3</sub> 24.29, VO<sub>2</sub> 5.57, V<sub>2</sub>O<sub>5</sub> 30.46, H<sub>2</sub>O (on the basis of crystal structure) 25.56, total 100.00. The empirical formula based on V+As = 38 and 185 O apfu is: (Ca<sub>10.72</sub>Na<sub>0.51</sub>)<sub>Σ11.23</sub>(As<sup>3+</sup><sub>1.00</sub>V<sup>4+</sup><sub>1.97</sub>V<sup>5+</sup><sub>9.80</sub>As<sup>5+</sup><sub>23</sub>O<sub>51</sub>)<sub>2</sub>·83H<sub>2</sub>O. The strongest lines of the X-ray powder diffraction pattern [*d* Å (*I*%); *hkl* not reported by the authors] are: 14.5 (49), 12.1 (49), 10.5 (100), 7.45 (20), 6.61 (16), 2.939 (22), 2.846 (19), and 2.732 (22). The single-crystal unit-cell parameters are: *a* = 18.0572(4), *b* = 19.4126(4), *c* = 24.0586(17) Å, α = 87.364(6), β = 86.266(6), γ = 79.267(6)°, and *V* = 8263.4 Å<sup>3</sup>, *Z* = 2, space group *P*1. The structure was refined to *R*<sub>1</sub> = 0.0395 for 14753 unique, observed [*F*<sub>o</sub> > 4σ*F*<sub>o</sub>] reflections. In the structure of packratite, the interstitial unit consists of 24 isolated H<sub>2</sub>O groups and 11 Ca–O polyhedra that are sevenfold, eightfold, or ninefold coordinated. The Ca–O polyhedra share one, two, or three of their vertices with O atoms of the VO<sub>6</sub> octahedra and/or AsO<sub>4</sub> tetrahedra of the structural unit. The remaining vertices of the Ca polyhedra are H<sub>2</sub>O groups. The structural units are linked via the Ca–O polyhedra, as well as by an extensive system of hydrogen bonds. None of the Ca polyhedra links to another. The interstitial unit, [Ca<sub>11</sub>(H<sub>2</sub>O)<sub>99</sub>·24H<sub>2</sub>O]<sup>22+</sup>, combines with two [As<sup>3+</sup>V<sup>2+</sup>V<sup>5+</sup>As<sup>5+</sup>O<sub>51</sub>]<sup>11-</sup> polyanion structural units in the formula unit. Packratite is named for the locality, the Packrat mine.

**Vanarsite** (IMA 2014-031), ideally NaCa<sub>12</sub>(As<sup>3+</sup>V<sup>2+</sup>V<sup>5+</sup>As<sup>5+</sup>O<sub>51</sub>)<sub>2</sub>·78H<sub>2</sub>O, occurs as very dark blue blades flattened on {100} and elongated on {010}, which occur in subparallel intergrowths and form fan-like or finger-like aggregates up to about 5 mm in length. Streak is grayish blue

and luster is vitreous. Mohs hardness is ~2, fracture is curved, tenacity is brittle and cleavage is fair on {100}. *D*<sub>meas</sub> = 2.48(2) g/cm<sup>3</sup> (by floatation in mixtures of methylene iodide and toluene), *D*<sub>calc</sub> = 2.460 g/cm<sup>3</sup>. The mineral is insoluble in H<sub>2</sub>O at room *T* and easily soluble in diluted HCl at room *T*. Optically, vanarsite is biaxial (–), α = 1.645(5), due to the dark color in the *Y* and *Z* optical directions β and γ calculated based upon the independently measured retardation (α – γ = 0.04) and 2*V* value: β<sub>calc</sub> = 1.677, γ<sub>calc</sub> = 1.681 (light not reported), 2*V*<sub>meas</sub> = 37(2)°. Dispersion not observable. *Y* = **b**, *X* ^ **a** ≈ 12° in obtuse β. It is pleochroic: *X* = cornflower blue, *Y* = dark blue, *Z* = dark blue; *X* << *Z* < *Y*. The average of electron probe WDS analysis (16 points in 8 crystals) [wt% (ranges)] is: Na<sub>2</sub>O 0.63 (0.43–1.22), CaO 13.08 (12.65–13.46), SrO 0.21 (0.10–0.35), FeO 0.04 (0.00–0.08), As<sub>2</sub>O<sub>5</sub> 31.61 (28.55–34.24), V<sub>2</sub>O<sub>5</sub> 43.89 (41.41–45.33), total 89.47. The H<sub>2</sub>O loss results in higher concentrations for the remaining constituents than is to be expected for the fully hydrated phases; the analyzed constituents normalized to provide a total of 100% when combined with the calculated H<sub>2</sub>O are: Na<sub>2</sub>O 0.54, CaO 11.30, SrO 0.19, FeO 0.03, As<sub>2</sub>O<sub>3</sub> 3.41, As<sub>2</sub>O<sub>5</sub> 23.34, VO<sub>2</sub> 9.55, V<sub>2</sub>O<sub>5</sub> 27.44, H<sub>2</sub>O (on the basis of crystal structure) 24.20, total 100.00. The empirical formula based on V+As = 38 and 180 O apfu is: (Ca<sub>11.70</sub>Na<sub>1.01</sub>Sr<sub>0.11</sub>Fe<sub>0.02</sub>)<sub>Σ12.84</sub>(As<sup>3+</sup><sub>1.00</sub>V<sup>4+</sup><sub>3.34</sub>V<sup>5+</sup><sub>8.76</sub>As<sup>5+</sup><sub>30</sub>O<sub>51</sub>)<sub>2</sub>·78H<sub>2</sub>O. The strongest lines of the X-ray powder diffraction pattern [*d* Å (*I*%); *hkl* not reported by the authors] are: 13.1 (100), 10.0 (98), 9.3 (63), 7.87 (56), 4.67 (35), 4.44 (31), 3.339 (33), and 2.962 (32). The single-crystal unit-cell parameters are: *a* = 25.8515(5), *b* = 10.9416(2), *c* = 28.2861(6) Å, β = 102.215(1)° and *V* = 7828.9 Å<sup>3</sup>, *Z* = 2, space group *P*2<sub>1</sub>/*c*. The structure was refined to *R*<sub>1</sub> = 0.048 for 14592 unique, observed [*F*<sub>o</sub> > 4σ*F*<sub>o</sub>] reflections. In the structure of vanarsite, the interstitial unit consists of seven isolated H<sub>2</sub>O groups, one insular Na(H<sub>2</sub>O)<sub>6</sub> octahedron, and six Ca–O polyhedra that are either sevenfold or eightfold coordinated. The Ca–O polyhedra share two, three, or four of their vertices with O atoms of the VO<sub>6</sub> octahedra and/or AsO<sub>4</sub> tetrahedra of the structural unit. The remaining vertices of the Ca polyhedra are H<sub>2</sub>O groups. The interstitial unit, [Na(H<sub>2</sub>O)<sub>6</sub>Ca<sub>12</sub>(H<sub>2</sub>O)<sub>58</sub>·14H<sub>2</sub>O]<sup>25+</sup>, combines with two [As<sup>3+</sup>V<sup>5+</sup>V<sup>4+</sup>As<sup>5+</sup>O<sub>51</sub>]<sup>12.5-</sup> polyanion structural units in the formula unit. The name vanarsite is based on the composition of the mineral and specifically the fact that it contains vanadate, arsenite, and arsenate groups. **F.C.**

### JOANNEUMITE\*

H.-P. Bojar, F. Walter and J. Baumgartner (2017) Joanneumite, Cu(C<sub>3</sub>N<sub>3</sub>O<sub>3</sub>H<sub>2</sub>)<sub>2</sub>(NH<sub>3</sub>)<sub>2</sub>, a new mineral from Pabellón de Pica, Chile and the crystal structure of its synthetic analogue. *Mineralogical Magazine*, 81(1), 155–166.

The new mineral joanneumite (IMA 2012-001) ideally Cu(C<sub>3</sub>N<sub>3</sub>O<sub>3</sub>H<sub>2</sub>)<sub>2</sub>(NH<sub>3</sub>)<sub>2</sub>, triclinic, is the first mineral containing the isocyanurate anion, (C<sub>3</sub>N<sub>3</sub>O<sub>3</sub>H<sub>2</sub>). It was discovered in the guano deposit at Pabellón de Pica Mountain, Iquique Province, Tarapacá Region, Chile (20°54'50"S, 70°08'25"W). A convergence of a small disseminated Cu mineralization in the hosting gabbro with the nitrogen-rich guano sites on its top led to formation of unique mineralization. Three minerals containing NH<sub>3</sub> (ammine) group (ammineite, shilovite, chanabayaite) were discovered here along with an alkali-ammonia-copper-sulfate möhinite and alkali-copper-oxalate antipinitite. Joanneumite is closely associated with salammoniac, dittmarite, möhinite, and gypsum filling small cracks in gabbroic rocks. It forms violet microcrystalline aggregates up to 2 mm showing sometimes well-shaped cubic crystals which are pseudomorphs after unidentified mineral. The new mineral is transparent, vitreous with a pale violet streak and is non-fluorescent. Mohs hardness is 1. The density was not measured due to the lack of the suitable material; *D*<sub>calc</sub> = 2.020 g/cm<sup>3</sup> for an ideal chemical formula. The optical properties were not obtained. The FTIR spectrum of joanneumite is identical to its synthetic analog *trans*-[Cu(cyan-kN)<sub>2</sub>(NH<sub>3</sub>)<sub>2</sub>]. The main absorption bands of the IR spectrum (cm<sup>-1</sup>; s = strong, m = medium, w = weak) are: 3331s,

3266w, 3182m, 3159m, 3012s, 2968w, 2852m, 2805m (N–H stretching vibrations of amine groups); 1786w, 1733s and 1097m, 1089w (C–O stretching vibrations of the isocyanurate complex); 1678m, 1628m, 1602s, 1512w, 1482m, 1453m, 1423m, 1478s (C–N stretching); 1249s (N–H deformation vibrations); 816m (C–N deformation); 773s, 755w, 738s, 712w ( $\pi$ C–O); 689m, 551s, 454s, 427s (C–N–C, C–O, and N–C–O deformation vibrations). The bands related to H<sub>2</sub>O molecules and OH ions were not detected. The average of 10 electron probe EDS analysis (using a rasterized beam and gold-coated samples) is [wt% (range)]: C 20.33 (19.21–21.50), N 31.11 (30.31–32.00), O 28.34 (27.32–27.42), Cu 17.27 (16.72–17.57), Zn 0.24 (0–0.60), H 2.82 (calculated from the structural formula), total 100.11. No other elements with an atomic number >8 were detected. This corresponds to empirical formula Cu<sub>0.96</sub>Zn<sub>0.01</sub>N<sub>7.84</sub>C<sub>5.98</sub>O<sub>6.25</sub>H<sub>9.96</sub> based on 31 atoms pfu. The idealized formula is CuN<sub>8</sub>C<sub>6</sub>O<sub>6</sub>H<sub>10</sub> and the structural formula is Cu(C<sub>3</sub>N<sub>3</sub>O<sub>3</sub>H<sub>2</sub>)<sub>2</sub>(NH<sub>3</sub>)<sub>2</sub>. The strongest lines of the powder X-ray diffraction pattern are [*d* Å (*P*%; *hkl*)] 6.52 (68; 010), 5.15 (47; 011), 4.66 (21; 100, 110), 4.35 (9; 111), 3.29 (6; 120), 3.22 (7; 111), 3.140 (100; 121), 2.074 (7; 132). The unit-cell parameters refined from powder diffraction data of joanneumite at 293 K are: *a* = 5.042(1), *b* = 6.997(1), *c* = 9.099(2) Å,  $\alpha$  = 90.05(3),  $\beta$  = 98.11(2),  $\gamma$  = 110.95(3)°, *V* = 296.3 Å<sup>3</sup>. Joanneumite is triclinic, space group *P*1. The powder diffraction patterns of joanneumite and its synthetic analog are identical. Due to the lack of suitable natural single crystals the synthetic analog of joanneumite was prepared for the single-crystal structure refinement. The crystal structure was solved and refined to *R* = 0.025 based upon 1166 unique *I* > 2σ(*I*) reflections. The unit-cell parameters obtained from single-crystal data at 100 K: *a* = 4.982(1), *b* = 6.896(1), *c* = 9.115(2) Å,  $\alpha$  = 90.53(3),  $\beta$  = 97.85(3),  $\gamma$  = 110.08(3)°, *V* = 290.8 Å<sup>3</sup>, *Z* = 1. The basic structural unit consists of two isocyanurate rings and two ammine ligands each bound through nitrogen atoms to a central Cu atom located at the inversion center, having a distorted square-planar coordination of N atoms. The isocyanurate rings build a topological crenellated ribbon by pairs of hydrogen bonds. The isocyanurate rings are oriented to a layer parallel to (121). The three hydrogens of the ammine groups connect these layers into a three-dimensional network by hydrogen bonds. Practical identity of chemical, powder XRD and FTIR data allows to conclude that the crystal structure of joanneumite is identical with the structure of the synthetic bis(isocyanurate) diamminecopper (II). The basic structural unit in the joanneumite structure is similar to that of ammineite, CuCl<sub>2</sub>(NH<sub>3</sub>)<sub>2</sub>. The two Cl atoms in the ammineite structure are replaced by two isocyanurate groups in the joanneumite structure. Joanneumite is named for the Universalmuseum Joanneum, Graz, Austria which had its bicentennial in 2011 and where the type specimen has been deposited. **D.B.**

### MENDELEEVITE-(ND)\*

A.A. Agakhanov, L.A. Pautov, E. Sokolova, F.C. Hawthorne, V.Yu. Karpenko, O.I. Siidra and V.K. Garanin (2010) Mendeleevite-(Nd), (Cs, □)<sub>6</sub>(□, Cs)<sub>6</sub>(□, K)<sub>6</sub>(REE, Ca)<sub>30</sub>(Si<sub>70</sub>O<sub>175</sub>)(OH, H<sub>2</sub>O, F)<sub>35</sub>, a new mineral from the Darai-Pioz alkaline massif, Tajikistan. *Mineralogical Magazine*, 81(1), 135–141.

Mendeleevite-(Nd) (IMA 2015-031), ideally (Cs, □)<sub>6</sub>(□, Cs)<sub>6</sub>(□, K)<sub>6</sub>(REE, Ca)<sub>30</sub>(Si<sub>70</sub>O<sub>175</sub>)(OH, H<sub>2</sub>O, F)<sub>35</sub>, is a new mineral species coming from the upper Darai-Pioz alkaline massif (located at the juncture of Turkestan, Alay, and Zeravshan Ranges), a ring structure of biotite granites, and aegirine- and quartz-bearing syenites, which occupies the core of a large synclinal fold of terrigenous rocks and schists. The massif has been intruded by alkaline pegmatites, fenites, and carbonatites. Mendeleevite-(Nd) was found in a pectolite aggregate in quartz-rich rocks, which consist mainly of medium-coarse to granular quartz. Brownish-gray nest-like clusters of pectolite aggregate (1 to 30 cm wide) mainly consist of fine to medium pectolite grains, quartz,

aegirine, and fluorite, with minor khvorovite, mendeleevite-(Ce), sokolovaite, hyalotekite, orlovite, kirchhoffite, pekovite, neptunite, zeravshanite, senkevichite, nordite-(Ce), alamosite, pyrochlore-group minerals, and baratovite. Mendeleevite-(Nd) occurs as transparent, colorless, sometimes with a pale brown hue, crystals 10–40 μm in size. It is brittle, with conchoidal fracture. Streak is white, luster is vitreous, while cleavage and parting have not been observed. The indentation hardness VHN<sub>50</sub> = 621 (491–672) kg/mm<sup>2</sup> corresponding to Mohs hardness of 5–5.5. Mendeleevite-(Nd) is not soluble either in water, or in HCl (1:1). It does not luminesce under UV light. *D*<sub>meas</sub> = 3.20(2) g/cm<sup>3</sup> (by flotation), *D*<sub>calc</sub> = 3.155 g/cm<sup>3</sup>. Mendeleevite-(Nd) is optically isotropic, *n* = 1.582(2). IR spectrum shows the following absorption bands 408, 1612, 1011, 980, 695(shoulder), 547(shoulder). The average of 12 electron probe WDS analyses in 2 grains is (wt%, range): SiO<sub>2</sub> 42.30 (41.65–43.22), Gd<sub>2</sub>O<sub>3</sub> 1.69 (1.41–2.07), Eu<sub>2</sub>O<sub>3</sub> 0.47 (0.18–1.06), Sm<sub>2</sub>O<sub>3</sub> 4.19 (3.57–4.56), Nd<sub>2</sub>O<sub>3</sub> 16.19 (15.25–16.85), Pr<sub>2</sub>O<sub>3</sub> 2.79 (2.28–3.53), Ce<sub>2</sub>O<sub>3</sub> 10.12 (9.72–10.78), La<sub>2</sub>O<sub>3</sub> 3.60 (3.23–4.11), SrO 2.99 (2.15–3.60), CaO 2.20 (1.93–2.65), Cs<sub>2</sub>O 8.50 (7.18–9.55), K<sub>2</sub>O 0.85 (0.12–1.73), F 1.25, H<sub>2</sub>O [calculated form charge balance and stoichiometry by analogy with mendeleevite-(Ce)] 3.85, –O=F<sub>2</sub> 0.53, total 100.46. The empirical formula calculated on the basis of 210 (O+F) apfu is: Cs<sub>6</sub>(□<sub>4.20</sub>K<sub>1.80</sub>)<sub>26.00</sub>{[(Nd<sub>9.57</sub>Ce<sub>6.13</sub>Sm<sub>2.39</sub>La<sub>2.20</sub>Pr<sub>1.68</sub>Gd<sub>0.93</sub>Eu<sub>0.27</sub>)<sub>23.17</sub>(Ca<sub>3.90</sub>Sr<sub>2.87</sub>)<sub>26.77</sub>]<sub>29.94</sub>□<sub>0.06</sub>]<sub>23.0</sub>(Si<sub>70.05</sub>O<sub>175</sub>)(OH<sub>14.47</sub>F<sub>6.54</sub>)<sub>22.01</sub>(H<sub>2</sub>O)<sub>14</sub>, *Z* = 2. The strongest lines of the X-ray powder pattern [*d* Å (*P*%; *hkl*)] are: 15.63 (55; 110), 12.73 (40; 111), 11.01 (100; 002), 4.07 (30; 234, 205, 324), 3.56 (30; 116, 325, 235), 3.47 (42; 206, 026), 3.099 (42; 345, 435, 055), 2.192 (42; 0.0.10, 608), 1.819 (41; 3.6.10). The unit-cell parameter refined from the powder data are *a* = 21.9106(4) Å, *V* = 10518.7 Å<sup>3</sup>. The extinction laws in the X-ray powder data are in accord with the space group *Pm* $\bar{3}$ , as in mendeleevite-(Ce) (Sokolova et al. 2011). The same space group has been therefore assigned mendeleevite-(Nd) structure. Mendeleevite-(Nd) is the Nd-analog of mendeleevite-(Ce). Both minerals differ in the dominant REE element, Nd and Ce, with a slight change in amount of REE and Ca(+Sr): REE<sub>23</sub>Ca<sub>7</sub> [mendeleevite-(Nd)] and REE<sub>22</sub>Ca<sub>6</sub> mendeleevite-(Ce) accompanied by change in the OH:H<sub>2</sub>O ratio: 14.46:14.00 [mendeleevite-(Nd)] and 10.17:17.75 [mendeleevite-(Ce)]. Both minerals are named after Dmitri Mendeleev (1834–1907), the great Russian chemist, author of the periodic table of chemical elements, who has had a significant impact on the development of natural sciences and industry, both in Russia and around the world. The holotype specimen has been deposited in the Fersman Mineralogical Museum, Russian Academy of Sciences, Moscow, Russia. **F.C.**

### Reference cited

Sokolova, E., Hawthorne, F.C., Pautov, L.A., Agakhanov, A.A., and Karpenko, V.Yu. (2011) The crystal structure and crystal chemistry of mendeleevite-(Ce), (Cs, □)<sub>6</sub>(□, Cs)<sub>6</sub>(□, K)<sub>6</sub>(REE, Ca, □)<sub>30</sub>(Si<sub>70</sub>O<sub>175</sub>)(H<sub>2</sub>O, OH, F, □)<sub>35</sub>, a potential microporous material. *Mineralogical Magazine*, 75, 2583–2596.

### NOLZEITE\*

M.M.M. Haring and A.M. McDonald (2017) Nolzeite, Na(Mn, □)<sub>2</sub>[Si<sub>3</sub>(B, Si)O<sub>9</sub>(OH)<sub>2</sub>]-2H<sub>2</sub>O, a new pyroxenoid mineral from Mont Saint-Hilaire, Quebec, Canada. *Mineralogical Magazine*, 81(1), 183–187.

Nolzeite (IMA 2014-086), ideally Na(Mn, □)<sub>2</sub>[Si<sub>3</sub>(B, Si)O<sub>9</sub>(OH)<sub>2</sub>]-2H<sub>2</sub>O, is a new mineral found in altered sodalite syenite at the Poudrette quarry, La Vallée-du-Richelieu, Montérégie (formerly Rouville County), Québec, Canada. Nolzeite is a late-stage mineral likely forming under alkaline conditions over a narrow range of low pressures and temperatures. The new mineral was found in ~1 cm diameter vugs in a loose boulder (~1 × 1 m) of sodalite syenite in association with aegirine, nepheline, sodalite, eudialyte-group minerals, analcime, natron, pyrrhotite, catapleite, steedeite, and an unidentified mineral. Crystals are euhedral,

acicular and elongate along [001] with average dimensions of  $5 \times 8 \times 55 \mu\text{m}$  and occur as radiating to loose, randomly oriented groupings within vugs. Pinacoid forms {100}, {010}, and {001} are observed. Crystals are pale green to colorless with a white streak and a vitreous luster. Density and Mohs hardness and full set of an optical data were not measured due to small crystal size. Nolzeite is assumed to be a bi-axial,  $n_{\text{min}} = 1.616(2)$  and  $n_{\text{max}} = 1.636(2)$ . It has positive elongation, and is non-pleochroic. Unlike the closely related species steedeite, nolzeite does not show any fluorescence under short-, medium-, or long-wave UV radiation. Absorption bands of the IR spectrum ( $\text{cm}^{-1}$ ) are observed at  $\sim 2800\text{--}3600$  (O-H stretching), a moderately sharp band is observed at 1631 (H-O-H bending), and strong, sharp bands are observed at  $\sim 650\text{--}700$ ,  $\sim 800\text{--}840$  (symmetric Si-O bending), and  $\sim 900\text{--}1100$  (asymmetric Si-O bending or possibly B-O bending). Absorption bands of the Raman spectrum ( $\text{cm}^{-1}$ ) are observed at  $\sim 3600\text{--}3300$  and  $1600\text{--}1500$  (O-H and H-O-H bending),  $1300\text{--}1200$  (B-OH bending),  $1030\text{--}800$  (Si-O-Si stretching), and  $700\text{--}500$  and  $400\text{--}50$  (Mn-O and Na-O bonding, respectively). The average of 6 electron probe EDS analyses on 4 crystals of nolzeite is [wt% (range)]:  $\text{Na}_2\text{O}$  7.34 (6.30–8.10),  $\text{CaO}$  0.29 (0.21–0.35),  $\text{MnO}$  27.29 (25.99–28.52),  $\text{FeO}$  0.83 (0.76–0.93),  $\text{SiO}_2$  44.17 (43.30–45.35),  $\text{SO}_3$  0.67 (0.35–1.02),  $\text{B}_2\text{O}_3$  (calc. based on charge

balance) 5.45, and  $\text{H}_2\text{O}$  (calc. based on charge balance) 12.16, total 98.20. This gives the empirical formula  $\text{Na}_{1.04}(\text{Mn}_{1.69}\square_{0.24}\text{Fe}_{0.05}\text{Ca}_{0.02})_{\Sigma 2.00}(\text{Si}_{2.96}\text{S}_{0.04})_{\Sigma 3.00}(\text{B}_{0.70}\text{Si}_{0.30})_{\Sigma 1.00}\text{O}_9(\text{OH})_2 \cdot 2\text{H}_2\text{O}$  based on 13 anions pfu. The strongest lines in the X-ray powder-diffraction pattern [ $d \text{ \AA}$  ( $hkl$ )] are: 10.131 (100; 001), 2.808 (50; 211, 220, 113, 123), 6.911 (16; 010), 3.026 (15; 023), 3.593 (13; 013), 2.675 (12; 013). Single-crystal X-ray diffraction data collected on a crystal of size  $7 \times 8 \times 60 \mu\text{m}$  refined to  $R_1 = 0.1281$  for 1361 unique reflections with  $I \geq 4\sigma(I)$  shows nolzeite is triclinic, space group  $P\bar{1}$  with  $a = 6.894(1)$ ,  $b = 7.632(2)$ ,  $c = 11.017(2)$   $\text{\AA}$ ,  $\alpha = 108.39(3)$ ,  $\beta = 99.03$ ,  $\gamma = 103.05(3)^\circ$ ,  $V = 519.27 \text{ \AA}^3$ , and  $Z = 2$ . Nolzeite is a chain silicate closely related to steedeite and members of the sérandite-pectolite series. The structure of nolzeite is based on chains of tetrahedra with a periodicity of three consisting of three symmetrically independent  $\text{SiO}_4$  tetrahedra forming C-shaped clusters closed by  $\text{BO}_2(\text{OH})_2$  tetrahedra, producing single loop-branched dreier borosilicate chains that are in turned linked through shared corners to double chains of edge-sharing  $\text{MnO}_2(\text{OH})$  octahedra. Nolzeite is named after Gert Nolze (b. 1960), a crystallographer at the Federal Institute for Materials Research and Testing (BAM), Berlin, Germany, notably for his part in developing the extensively used program Powdercell. Holotype material is housed in the Canadian Museum of Nature, Gatineau, Quebec, Canada. **O.C.G.**

## Erratum

**Sulfide-silicate textures in magmatic Ni-Cu-PGE sulfide ore deposits: Disseminated and net-textured ores** by Stephen J. Barnes, James E. Mungall, Margaux Le Vaillant, Belinda Godel, C. Michael Leshner, David Holwell, Peter C. Lightfoot, Nadya Krivolutszkaya, and Bo Wei (March, vol. 102, p. 473–506, 2017). Article DOI: <http://dx.doi.org/10.2138/am-2017-5754>. Erratum DOI: <https://doi.org/10.2138/am-2017-E10259>.

The caption on page 493, the second part of Figure 17, should read as follows:

**FIGURE 17.**—*CONTINUED* (e) Photomosaic of polished slabs showing sulfide (Sul) as interstitial network and ellipsoidal globules capped by amygdalae (Amg) filled with very fine-grained serpentine. Olivine pseudomorphs as equant and aligned platy grains (black); orthocumulate (ooc) micro-domains with low sulfide content (gray) separated by sulfide-rich, trapped-liquid poor net-textured micro-domains. (f) Tornado XFM image (S = red, Ca = green, and Al = blue) of same area as e, highlighting distribution of chlorite (Chl) as alteration product of original trapped liquid component. (g) Perspective view of volume-rendered 3D tomography image of same sample shown in a and b, with sulfide network in yellow and large oblate spherical globules in red. Interactive 3DE visualization at <https://data.csiro.au/dap/SupportingAttachment?collectionId=17878&fileId=1235>.