= NEW MINERALS ====

Epifanovite, NaCaCu₅(PO₄)₄[AsO₂(OH)₂] \cdot 7H₂O: a New Mineral from the Kester Deposit, Sakha (Yakutia) Republic, Russia

V. N. Yakovenchuk^{*a*, *}, Ya. A. Pakhomovsky^{*a*}, N. G. Konoplyova^{*a*}, T. L. Panikorovskii^{*a*}, Yu. A. Mikhailova^{*a*}, V. N. Bocharov^{*c*}, S. V. Krivovichev^{*a*, *b*}, and G. Yu. Ivanyuk^{*a*}

^aKola Science Center, Russian Academy of Sciences, Murmansk oblast, Apatity, ul. Fersmana 14, 184209 Russia ^bInstitute of the Earth Sciences, St. Petersburg State University, Universitetskaya nab. 7/9, St. Petersburg, 199034 Russia ^cResearch Center Geomodel, St. Petersburg State University, Ul'yanovskaya ul., 1, St. Petersburg, 198504 Russia

> **e-mail: yakovenchuk@ksc.ru* Received February 17, 2017

Abstract—Epifanovite, NaCaCu₅(PO₄)₄[AsO₂(OH)₂] · 7H₂O, a new natural copper, sodium and calcium arsenate—phosphate, has been found in a quartz—phosphate pocket within greisenized cassiterite-bearing granodiorite of the Kester tin deposit, Sakha (Yakutia) Republic, Russia. The mineral occurs as crusts of tabular pseudotetragonal crystals up to 50 µm across and 10 µm thick. Associated minerals are fluorapatite, pseudomalachite, malachite, a Na-analogue of batagayite, tobermorite, libethenite, arsenolite, native copper and unknown Mg–Zn phosphate. Epifanovite is turquoise-blue with pale blue streak, vitreous luster (dull in crusts), and a Mohs hardness of 3. The mineral is brittle. Cleavage is perfect on (001) and good on (100) and (010). Density measured in the Clerici solution is 3.65(3) g/cm³; the calculated density is 3.73 g/cm³. Epifanovite is optically biaxial (–), $\alpha = 1.708(5)$, $\beta = 1.730(5)$, $\gamma = 1.735(5)$. $2V_{obs} = 40^{\circ}-45^{\circ}$, $2V_{calc} = 50^{\circ}$. Optical orientation: X = a, Y = b. The empirical formula calculated on the basis of P + As = 5 is (Na_{0.94}K_{0.06})_{21.00}(Ca_{0.82}Na_{0.08})_{20.90}(Cu_{5.04}Zn_{0.06})_{25.10}(PO₄)₄[AsO₂(OH)₂] · 7H₂O. The Raman spectrum contains the following bands, cm⁻¹: 293, 359 (v₁₋₂, CuO₅); 455, 556, 594, 640, 921, 962, 1002, 1086, 1153 (v₁₋₄, PO₄), 77, 121, 161, 183, 730, 828, 858 (v₁₋₃, AsO₄), 2900, 3200, 3410 (v₁, OH). The mineral is monoclinic, $P2_1/m$, a = 9.6912(9), b = 9.7440(9), c = 9.9561(9) Å, $\beta = 102.23$ (1)°, V = 918.7(1) Å³, Z = 2. The strongest reflections in the powder X-ray diffraction pattern <u>are</u>, I-dÅ–hkl: 100–9.73–001, 35–6.79–110, 12–4.355–021, 43–3.072–130, 24–3.061–221, 24–3.003–222, 11–2.698–023, 10–1.6775–504. The mineral was named in honor of the Russian geologist Porphyry Prokop'evich Epifanov, who discovered the Ege-Khaya and Kester tin deposits. Epifanovite is structurally close to the lavendulan-group minerals and related species: andyrobertsite, calcioandyrobertsite, mahner

Keywords: epifanovite, new mineral, copper phosphate-arsenate, Kester deposit, Sakha-Yakutia **DOI:** 10.1134/S1075701518070103

INTRODUCTION

Arsenates and phosphates are some of the most abundant natural species of divalent copper, and the discovery of new minerals constantly spurs interest in them. In particular, some new anhydrous copper arsenates were recently discovered from exhalations of the Great Fissure Tolbachik Eruption, Kamchatka, Russia (Pekov et al., 2014, 2015a, b, 2016). Assemblages of secondary copper phosphates and arsenates in the oxidation zone of ore deposits where several new copper mineral species have been discovered are more productive in this regard (Plášil et al., 2014a,b; Ma et al., 2014; Sarp et al., 2014). This study describes epifanovite (NaCaCu₅(PO₄)₄[AsO₂(OH)₂] · 7H₂O), a new mineral from the Kester deposit, Sakha (Yakutia) Republic, Russia. The Kester tin-tantalum deposit was discovered in 1937 by Russian geologist Porphyry Prokop'evich Epifanov, head of the Kirgilyakh geological crew of the Yakutia Branch of Souyuzolovonickelrazvedka in northeastern Yakutia, Russia. More than 130 minerals have been found at this tin-greisen deposit (Pavlovsky et al., 2015). The phosphate assemblage, includes augelite, amblygonite, pseudomalachite, libethenite, turquoise, and other. The studies of mineral paragenetic assemblages of this unique deposit was completed in the 1940–1950s, and this gap should be filled (Kokunin, 2011).

In the 1980s, the first three authors of this paper collected material, which includes at least three unidentified phosphates. However, these phases could not be fully described using the available instruments then due to the small size and bad quality of the crys-



Fig. 1. P.P. Epifanov in 1940, after (Kazaryan, 1989).

tals. Developing X-ray diffraction methods and modern diffractometers equipped with highly sensitive Xray plate detectors have made it possible to determine the new Kester phases and submit proposals of new mineral species to the Commission on New Minerals, Nomenclature, and Classification of Minerals, International Mineralogical Association (CNMNCM IMA).

The first of these minerals described in this paper is epifanovite (NaCaCu₅(PO₄)₄[AsO₂(OH)₂] · 7H₂O), approved by the CNMNCM IMA in 2016 (IMA no. 2016-063). The mineral was named in Epifanov's honor¹ (Fig. 1), who discovered the Ege-Khaya (1936) and Ulakhan-Engelyakh tin deposits in Verkhoyansk krai (Smirnov et al., 1941), in addition to the Kester deposit. The holotype specimen of epifanovite was deposited at the Mineralogical Museum of St. Petersburg State University (no. 19658/1). Epifanovite is the second mineral after kesterite (Cu₂ZnSnS₄) (Ivanov and Pytenko, 1959) discovered at the Kester deposit.

OCCURENCE

Epifanovite was found in an isometric quartz– phosphate pocket approximately 5 m in diameter (Fig. 2) in greisenized cassiterite-bearing granodiorite. This pocket is predominantly filled by "sinter" aggregates (up to 30 cm in diameter) of light gray carbonate-rich fluorapatite (staffelite) and porous milky white quartz (up to 10 cm in diameter). These aggregates are broken by mineralized fractures. Walls of the fractures and cavities in quartz and especially fluorapatite aggregates are coated by dark green crystals (up to 4 mm in length) and spheres (up to 5 mm in diameter) of Asbearing pseudomalachite, druzes of pale green prismatic crystals of libethenite (up to 7 mm in length), and isolated grains of native copper (up to 3 mm in diameter). All of the listed minerals are overgrown by radial aggregates (up to 3 mm in diameter) of filiform Na-analogue of batagayite individuals, colorless arsenolite cuboctahedra (up to 1 mm in diameter), colorless square tobermorite plates (up to 1 mm in size), ice-gray flattened prismatic crystals (up to 2 mm) of potentially new Mg and Zn phosphate mineral, and turquoise-blue crusts of tabular pseudotetragonal epifanovite crystals (up to 50 µm across and 10 µm in thickness, Fig. 3). Pinacoidal faces {100}, {010}, and {001} on these crystals were identified with an electron microscope.

PHYSICAL PROPERTIES AND OPTICAL PARAMETERS

Epifanovite is turquoise-blue with pale blue streak. The luster of individual plates and crusts is vitreous and dull, respectively. The mineral is non-luminescent under UV light. The Mohs hardness is 3. Epifanovite is brittle. The cleavage is perfect parallel to (001) and good parallel to (100) and (010); no separation is observed. The fracture is stepwise. The density measured in Clerici solution is 3.65(3) g/cm³, the density calculated from the structure data and empirical formula is 3.73 g/cm³. Epifanovite is optically biaxial, negative. The refractive indices at $\lambda = 589$ nm are $\alpha =$ 1.708(5), $\beta = 1.730(5)$, $\gamma = 1.735(5)$. $2V_{obs} = 40^{\circ}-45^{\circ}$, $2V_{calc} = 50^{\circ}$. The optical orientation is X = a, Y = b. Microscopically, the mineral is green, nonpleochroic and dispersion-free.

The Gladstone–Dale compatibility index (Mandarino, 1981) calculated from the empirical formula and calculated density is $1 - (K_p/K_C) = 0.035$; i.e., it is excellent.

CHEMICAL COMPOSITION

The chemical composition of epifanovite was determined on a Cameca SX-46 electron microprobe at the Geological Institute, Kola Science Center, Russian Academy of Sciences, under conditions ensuring minimum sample decomposition under an electron beam. The operating conditions were: beam diameter 20 μ m, current intensity 20–30 nA, accelerating voltage 20 kV, and beam movement during analysis. Table 1

¹ We were unable to find Epifanov's birth and death dates.



Fig. 2. Type locality of epifanovite with indication of pocket where mineral was found; map after (Kokunin, 2011).



Fig. 3. (a) Epifanovite crusts (1) and Na-analogue of batagayite bunches (2) overgrowing fluorapatite (3), As-bearing pseudomalachite (4), and native copper (5); (b) Backscattered electron image of section of pseudomalachite sphere coated by epifanovite; (c) secondary electron image of individual epifanovite crystal on crust.

lists the used standards and average contents in three different epifanovite aggregates.

The water content in the mineral was determined by thermogravimetric analysis on a NETZSCH STA 449 F3 thermoanalyzer at St. Petersburg State University in an argon atmosphere at temperatures ranging from room to 1000°C (heating rate 10°C/min; Al₂O₃ was the standard; sample weight 6.2 mg). Weight loss in vacuum before heating was attributed to absorbed water identical to LOI at bulk chemical analysis. The CO₂ content was not measured because of missing C– O vibrations in the Raman spectrum (see below).

The empirical formula calculated on the basis of P + As = 5 is $(Na_{0.94}K_{0.06})_{\Sigma 1.00}(Ca_{0.82}Na_{0.08})_{\Sigma 0.90}$ $(Cu_{5.04}Zn_{0.06})_{\Sigma 5.10}(PO_4)_4[(As_{0.81}P_{0.19})_{\Sigma 1.00}(O_{1.92}OH_{2.06}Cl_{0.02})_{\Sigma 4.00}] \cdot 7.37H_2O$. The idealized formula $NaCaCu_5(PO_4)_4[AsO_2(OH)_2] \cdot 7H_2O$ is consistent with the X-ray structure analysis data taking into account absorbed (?) water (Panikorovskii et al., 2017).

Epifanovite is highly soluble in cold 10% HCl. In vacuum, it rapidly loses approximately 5% H_2O and fractures (Fig. 4).

RAMAN SPECTROSCOPY

The Raman spectrum of epifanovite was measured with a Horiba Jobin-Yvon LabRam HR 800 spectrometer at $\lambda = 514$ nm at St. Petersburg State University. The spectrum obtained (Fig. 5) is close to that of sampleite (NaCaCu₅(PO₄)₄Cl · 5H₂O) from the Chuquicamata deposit in Chile given in the RRUFF database (Lafuente et al., 2015), identification number RR050572.2.

The bands in the spectrum are assigned in analogy with the lavendulan-group minerals (Frost et al., 2007). The bands with maxima at 921, 962, 1002,

Component		Standard				
Component	average	standard deviation	min	max		
H ₂ O	9.60					
H ₂ O*	5.00					
Na ₂ O	3.04	2.44	0.83	5.67	Lorenzenite	
P_2O_5	28.72	4.22	25.79	33.56	Fluorapatite	
Cl	0.05	0.08	0.00	0.14	Atacamite	
K ₂ O	0.31	0.32	0.00	0.64	Wadeite	
CaO	4.42	0.73	3.77	5.21	Wollastonite	
CuO	38.66	2.70	37.10	41.77	Copper metallic	
ZnO	0.49	0.63	0.00	1.20	Sphalerite	
As ₂ O ₅	8.95	1.35	7.48	10.14	Arsenopyrite	
-O=Cl ₂	-0.01					
Total	99.23					

Table 1. Chemical composition of epifanovite

 H_2O^* is water loss in vacuum.

1086, and 1153 cm⁻¹ correspond to different bond vibrations in PO₄ tetrahedra. The bands at 828 and 858 cm⁻¹ correspond to stretching vibrations in AsO₄ tetrahedra; the bands at 2900, 3200, and 3410 cm⁻¹ are assigned to O–H stretching vibrations. A number of bands corresponding to P–O and As⁵⁺–O bending vibrations, Cu²⁺–O stretching vibration, and lattice modes are in the low-frequency part of the spectrum ($<700 \text{ cm}^{-1}$). The complex composition of the minerals hampers proper assignment of bands to specific vibrations. In contrast to the spectrum of sampleite, the bands at 828 and 858 cm⁻¹ caused by the As⁵⁺–O bonds in AsO₄ tetrahedra are present in the spectrum of epifanovite.



Fig. 4. Secondary electron image of epifanovite crystals fractured in vacuum.



Fig. 5. Raman spectra of epifanovite (this study) and sampleite (Frost et al., 2007).



Fig. 6. TG and DSC curves of epifanovite.

HEATING BEHAVIOR

The heating behavior of epifanovite was studied by thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC). Three stages of weight loss, 7.3, 2.3, and 2.7%, are recorded on the corresponding curves (Fig. 6). In addition, 5% of weight was loss owing to released adsorbed molecular water in vacuum before heating (see above).

The 7.3% weight loss and the endothermic peak at 486°C, caused by loosing of crystallization molecular water, while the 2.3% weight loss relates to the dehydroxylation process. The endothermic peak at 849°C and corresponding 2.7% weight loss were caused by

GEOLOGY OF ORE DEPOSITS Vol. 60 No. 7 2018

the decomposition of epifanovite, forming CuO and an unidentified amorphous compound.

X-RAY POWDER DIFFRACTION

The powder X-ray diffraction pattern of epifanovite (Table 2) was collected with a Rigaku R-AXIS RAPID II diffractometer ($Co_{K_{\alpha}}$ radiation, $\lambda = 1.7892$ Å) equipped with a semicylindrical X-ray sensitive plate with optical storage (Debye–Scherrer geometry, diameter 127.4 mm). The experimental data were processed using a program created by S.N. Britvin, St. Petersburg State University (Britvin et al. 2017). According to the X-ray structure data (Panikorovskii et al., 2017), the new mineral is monoclinic, space

I _{obs}	$d_{\rm obs}$, Å	Icalc	$d_{\text{calc}}, \text{\AA}$	hkl	I _{obs}	$d_{\rm obs}$, Å	I _{calc}	$d_{\text{calc}}, \text{\AA}$	hkl
100	9.73	26	9.73	001	5	2.430	2	2.433	004
35	6.79	100	6.79	110	10	2.405	1	2.409	114
1	4.787	5	4.756	102	3	2.325	1	2.321	141
12	4.355	28	4.356	021	4	2.248	1	2.244	104
5	3.944	25	3.942	201	5	2.211	2	2.215	124
9	3.827	17	3.822	$\overline{2}02$	7	2.166	4	2.166	240
2	3.569	10	3.558	$\overline{212}$	4	2.104	2	2.104	$\overline{422}$
5	3.448	1	3.442	022	3	1.9741	1	1.9743	134
2	3.395	2	3.396	220	3	1.9321	1	1.9319	412
2	3.299	14	3.289	103	6	1.9048	1	1.9071	502
1	3.236	2	3.243	003	1	1.7992	1	1.7981	$\overline{251}$
3	3.168	5	3.157	300	2	1.7462	1	1.7469	251
43	3.072	22	3.072	130	7	1.7171	2	1.7171	413
24	3.061	49	3.064	221	10	1.6775	2	1.6766	$\overline{5}04$
24	3.003	40	3.007	$\overline{2}\overline{2}2$	2	1.5689	1	1.5674	531
8	2.935	6	2.939	212	2	1.5207	1	1.5204	045
3	2.880	13	2.887	103	4	1.5137	0	1.5166	$\overline{5}\overline{4}1$
11	2.698	22	2.700	023	6	1.4985	0	1.4986	4 35
3	2.670	1	2.665	$\overline{231}$	2	1.4442	0	1.4433	206
2	2.483	1	2.483	123	10	1.3736	2	1.3741	$\overline{5}\overline{5}1$
6	2.450	2	2.448	321					

 Table 2. Powder X-ray diffraction pattern for epifanovite

group $P2_1/m$. The unit cell parameters refined from the powder X-ray diffraction data are: a = 9.6912(9), b = 9.7440(9), c = 9.9561(9) Å, $\beta = 102.23$ (1)°, V = 918.7(1) Å³, Z = 2. The strongest eight reflections in the X-ray diffraction pattern are: I-dÅ-hkl: 100– 9.73-001, 35–6.79–110, 12–4.355–021, 43–3.072– 130, 24–3.061–221, 24–3.003–222, 11–2.698–023, 10–1.6775–504.

DISCUSSION

As mentioned above, epifanovite is the second mineral after kesterite and the first phosphate discovered at the Kester tin deposit. In addition, according to (Panikorovskii et al., 2017), epifanovite is the second after machatschkiite ($Ca_6(AsO_4)(AsO_3OH)_3PO_4$ · 15H₂O) (Walenta, 1977; Effenberger et al., 1982) natural phosphate with ordered phosphate and arsenate groups. In the chemical composition and crystallographic parameters, epifanovite is very close to the lavendulan-group minerals and minerals structurally related to them: andyrobertsite, calcioandyrobertsite, mahnertite, and richelsdorfite. Panikorovskii et al. (2017) described the structure of epifanovite.

Epifanovite obviously resulted from low-temperature (apparently supergene) alteration of primary ore minerals at the Kester deposit [chalcopyrite, bornite, chalcocite, covellite, cubanite, cuprite, tetrahedrite, enargite, stannite, sphalerite, löllingite, and realgar (Kokunin, 2011)] by oxidizing hydrothermal fluids and their interaction with staffelite. The crystallization sequence of low-temperature minerals (copper \rightarrow pseudomalachite \rightarrow libethenite \rightarrow epifanovite \rightarrow slavkovite \rightarrow arsenolite) points to a regularly evolved chemical composition of mineral-forming fluids as they interacted with fluorapatite and precipitated newly formed phases: Cu \rightarrow CuP \rightarrow CaCuPAs \rightarrow CuAs \rightarrow As.

ACKNOWLEDGMENTS

The study was supported by the Russian Science Foundation (project no. 14-17-00071). The equipment of the Research Centers for X-ray diffraction studies and Geomodel at St. Petersburg State University was used.

REFERENCES

Britvin, S.N., Dolivo-Dobrovolsky, D.V., and Krzhizhanovskaya, M.G., Software for processing of X-ray powder diffraction data obtained from the curved image plate detector of Rigaku RAXIS Rapid II diffractometer, *Zap. Ross. Mineral. O-va*, 2017, vol. 146, no. 3, pp. 104–107.

GEOLOGY OF ORE DEPOSITS Vol. 60 No. 7 2018

Effenberger, H., Mereiter, K., Pimminger, M., and Zemann, J., Machatschkiite: crystal structure and revision of the chemical formula, *Tschermaks Mineral. Petrog. Mitt.*, 1982, vol. 30, pp. 145–155.

Frost, R.L., Weier, M.L., Williams, P.A., Leverett, P., and Kloprogge, J.T., Raman spectroscopy of the sampleite group of minerals, *J. Raman Spectroscop.*, 2007, vol. 38, pp. 574–583.

Ivanov, V.V. and Pyatenko, Yu.A., On so-called kesterite, *Zapiski Ross. Mineral. O-va*, 1959, vol. 88, no. 2, pp. 165–168.

Kazaryan, P.L., *Pod severnym siyaniem. K 50-letiyu osnovaniya Batagaya* (Under Northern Lights. To the 50th anniversary of Batagay, Yakutsk, RIO Goskomizdat, 1989. Kokunin, M.V., Rare minerals of the forgotten deposit, *Otechestvennaya Geol.*, 2011, no. 1, pp. 72–82.

Lafuente, B., Downs, R.T., Yang, H., and Stone, N., The power of databases: the RRUFF project, in *Highlights in Mineralogical Crystallography*, Armbruster, T. and Danisi, R.M., Eds., Berlin: W. De Gruyter, 2015, pp. 1–30.

Ma, Z., Li, G., Chukanov, N.V., Poirier, G., and Shi, N., Tangdanite, a new mineral species from the Yunnan Province, China and the discreditation of "clinotyrolite", *Mineral. Mag.*, 2014, vol. 78, pp. 559–569.

Mandarino, J.A., The Gladstone-Dale relationship. Part IV: The compatibility concept and its application, *Can. Mineral.*, 1981, vol. 19, pp. 441–450.

Panikorovskii, T.L., Krivovichev, S.V., Yakovenchuk, V.N., and Ivanyuk, G.Yu., *The crystal structure of epifanovite, Zap. Ross. Mineral. O-va*, 2017, no. 3, pp. 39–50.

Pavlovskii, A.B., Pechenkin, A.G., and Lugovskaya, I.G., *Geologo-pomyshlennye tipy mestorozhdenii poleznykh isko-paemykh. Olovo* (Geological-Industrial Types of Ore Deposits. Tin), Moscow: VIMS, 2015.

Pekov, I.V., Zubkova, N.V., Yapaskurt, V.O., Belakovskiy, D.I., Vigasina, M.F., Sidorov, E.G., and Pushcharovsky, D.Yu., *New arsenate minerals from the Arsenatnaya fumarole, Tolbachik volcano, Kamchatka, Russia. II. Ericlaxmanite and kozyrevskite, two natural modifications of Cu₄O(AsO₄)₂, <i>Mineral. Mag.*, 2014, vol. 78, pp. 1553–1569.

Pekov, I.V., Zubkova, N.V., Yapaskurt, V.O., Belakovskiy, D.I., Vigasina, M.F., Sidorov, E.G., and Pushcharovsky, D.Yu., New arsenate minerals from the Arsenatnaya fumarole, Tolba-Kamchatka, volcano. Russia. III. Popovite, chik Cu₅O₂(AsO₄)₂, Mineral. Mag., 2015a, vol. 79, pp. 133–143. Pekov, I.V., Zubkova, N.V., Belakovskiv, D.I., Yapaskurt, V.O., Vigasina, M.F., Sidorov, E.G., and Pushcharovsky, D.Yu., New arsenate minerals from the Arsenatnaya fumarole, Tolbachik volcano, Kamchatka, Russia. IV. Shchurovskyite, $K_2CaCu_6O_2(AsO_4)_4$ and dmisokolovite, $K_3Cu_5AlO_2(AsO_4)_4$, Mineral. Mag., 2015b, vol. 79, pp. 1737-1753.

Pekov, I.V., Zubkova, N.V., Yapaskurt, V.O., Polekhovsky, Y.S., Vigasina, M.F., Belakovskiy, D.I., Britvin, S.N., Sidorov, E.G., and Pushcharovsky, D.Yu., *New arsenate minerals from the Arsenatnaya fumarole, Tolbachik volcano, Kamchatka, Russia. VI. Melanarsite,* $K_3Cu_7Fe^{3+}O_4(AsO_4)_4$, *Mineral. Mag.*, 2016, vol. 80, pp. 855–867.

Plášil, J., Kasatkin, A.V., Škoda, R., and Škácha, P., Klajite, $MnCu_4(AsO_4)_2(AsO_3OH)_2(H_2O)_{10}$, from Jáchymov (Czech Republic): the second world occurrence, *Mineral. Mag.*, 2014a, vol. 78, pp. 119–129.

Plášil, J., Sejkora, J., Škoda, R., Novák, M., Kasatkin, A.V., Škácha, P., Veselovský, F., Fejfarová, K., and Ondruš, P., Hloušekite, $(Ni,Co)Cu_4(AsO_4)_2(AsO_3OH)_2(H_2O)_9$, a new member of the lindackerite supergroup from Jáchymov, Czech Republic, *Mineral. Mag.*, 2014b, vol. 78, pp. 1341– 1353.

Sarp, H., Černý, R., Pushcharovsky, D.Yu., Schouwink, P., Teyssier, J., Williams, P.A., Babalik, H., and Mari, G., La barrotite, $Cu_9Al(HSiO_4)_2[(SO_4)(HAsO_4)_{0.5}](OH)_{12} \cdot 8H_2O$, un nouveau minéral de la mine de Roua (Alpes-Maritimes, France), *Riv. Scient.*, 2014, vol. 98, pp. 3–22.

Smirnov, S.S., Dubovik, M.M., and Epifanov, P.P., Mineralogical description of the Yana–Adychan region, *Mater. Inst. Geol. Sci. USSR Acad. Sci. Mineral.*, 1941, vol. 46, pp. 1–62.

Walenta, K., Machatschkiit, ein neues Arsenatmineral aus der Grube Anton im Heubachtal bei Schiltach (Schwarzwald, Bundesrepublik Deutschland), *Tscherm. Miner. Petrog. Mitt.*, 1977, vol. 24, pp. 125–132.

Translated by I. Baksheev