

FEATURES OF ARSENOSULVANITE FROM THE LEBEDINOE DEPOSIT, CENTRAL ALDAN

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The results of examination of arsenosulvanite from the Lebedinoe deposit are discussed. The comparison with available published data of arsenosulvanite and colusite indicated that arsenosulvanite studied here is significantly different from colusite in both content of species-forming minerals and set of admixtures. Based on the electron microprobe data, X-ray diffraction study, and taking into account data by Frank-Kamenetskaya (2002) that arsenosulvanite and colusite are two structural modifications of compound $V_2Cu_{24}As_6S_{32}$, we conclude arsenosulvanite as independent and incorrectly discredited mineral species (Burke, 2006).

2 figures, 4 tables, 25 references.

Keywords: arsenosulvanite, sulvanite, colusite, Lebedinoe deposit.

Introduction

A.G. Betekhtin (1941) described arsenosulvanite, $Cu_3(As,V)S_4$, for the first time from the ore of unknown deposit in Mongolia. The specimens placed at Betekhtin's disposal were "bronze-yellow; the Mohs hardness 3.5; density 4.01; megascopally and microscopically, they were not different from sulvanite and were isotropic". According to two bulk analyses, a new mineral contained Cu, S, As, and V; the content of latter is significantly lesser (4.16, 5.20 wt.%) than in sulvanite, Cu_3VS_4 (11.8–13.7 wt.%). Concentration of As in the new mineral was 11.67 and 12.8 wt.%. Betekhtin measured As in arsenosulvanite few times to resolve a problem of probable $As \rightarrow V$ substitution and revealed oscillating As concentration with the least concentration of 5.1 wt.%. Microscopically, inclusions of other minerals in the samples studied were not observable. Despite this, physical properties of arsenosulvanite were not significantly variable. This fact provided the basis for the conclusion of isomorphic substitution of As for V in the structure of this mineral. In addition, Betekhtin (1941) discussed chemical similarity of arsenosulvanite and enargite and luzonite, which are polymorphous modifications (orthorhombic and monoclinic, respectively) of Cu_3AsS_4 , and similar physical properties and crystal structure of arsenosulvanite, $Cu_3(As,V)S_4$ (cubic), and sulvanite. It turns out that there is probably isomorphic substitution in the Cu_3AsS_4 - $Cu_3(As,V)S_4$ series, i.e., isomorphic substitution between orthorhombic or monoclinic enargite or luzonite and cubic sulvanite occurs. This con-

tradition could be resolved that arsenosulvanite is not cubic or Cu_3AsS_4 compound should have cubic modification, or admixture of V stabilizes high-temperature cubic Cu_3AsS_4 allowing retention of arsenosulvanite, $Cu_3(As,V)S_4$, at low temperature.

Later, arsenosulvanite was found at the Lebedinoe deposit in Russia, as well as at deposits in Bulgaria, Bolivia, Hungary, Canada, Serbia, and USA.

Kachalovskaya *et al.* (1975) suggested that in reflected light, colusite, arsenosulvanite, and sulvanite are hardly different. Pink-beige colusite, beige-yellowish-greenish arsenosulvanite, and grayish-greenish sulvanite are difficult to be distinguished in intimate intergrowths. "Arsenosulvanite is extremely weakly anisotropic in yellowish brown color. Due to anisotropy, fine-grained and local unclear lattice structure of arsenosulvanite grains is exhibited". These authors reported that relief of arsenosulvanite and colusite is notably higher than that of sulvanite.

Mikheev (1941) performed the first X-ray structural study of the mineral. The structure of arsenosulvanite is similar to "the structure of sphalerite, ZnS , with Zn atoms being substituted by As and V atoms in apices of cube and Cu atoms being substituted for Zn atoms in center of faces". The cubic structure obtained is close to the structure of sulvanite, but differs from the latter in atom arrangement in the unit cell. According to Mikheev (1941), it is caused by the admixture of As. Space group is $P\bar{4}3m$; the unit-cell parameter $a = 5.257 \text{ \AA}$.

Later, Orlandi *et al.* (1981), Khoroshilova (1987, 2002), and Frank-Kamenetskaya *et al.*

(2002) who studied the structure of arsenosulvanite compared structures and chemical compositions of arsenosulvanite, sylvanite, and colusite. As a result, the crystal chemical conception of arsenosulvanite was changed. Previously, the simplified chemical formula $\text{Cu}_3(\text{As},\text{V})\text{S}_4$ and cubic structure of the sphalerite type with $a = 5.257(3)$ Å derived from X-ray powder diffraction data (Mikheev, 1941) were assigned to sphalerite. Frank-Kamenetskaya *et al.* (2002) revealed cubic cell containing 32 S atoms with double period 10.5–10.6 Å in comparison with sphalerite and sylvanite, i.e., superstructure $C2a2a2a$.

Various researchers suggested the following formulas of arsenosulvanite: $\text{Cu}_3(\text{As},\text{V})\text{S}_4$ (Mikheev, 1941); $\text{Cu}_{26}\text{V}_2(\text{As}, \text{Sb}, \text{Sn}, \text{Ge})_6\text{S}_{32}$ (Orlandi *et al.*, 1981); $\text{Cu}_{24}\text{V}_2\text{As}_6\text{S}_{32}$ (Khoroshilova *et al.*, 1984); $\text{Cu}_{24+x}\text{V}_2(\text{As}, \text{Sb})_{6-x}\text{S}_{32}$, where $x = 0-2$ (Spry *et al.*, 1994). Frank-Kamenetskaya *et al.* (2002) reported the bulk composition of colusite, arsenosulvanite, and V-As-bearing germanite as $\text{Cu}_{24+x}^+\text{V}_{2+2y}^{3+}(\text{As}, \text{Sb})_{6-x-y}^{5+}(\text{Sn}, \text{Ge})_x^4\text{V}_y^{3+}\text{S}_{32}$, where $0 \leq x \leq 2$, $0.5 \geq y \geq 0$. According to Frank-Kamenetskaya *et al.* (2002), the arrangement of cations in the structures of arsenosulvanite and colusite results in the generalized crystal chemical formula $\text{Cu}_{2-x}^{\text{M}}\text{V}_2^{\text{M}}\text{Cu}_{26-y}(\text{As}, \text{Ge}, \text{Sn}, \text{Sb}, \text{V})_6\text{S}_{32}$, where $\text{Cu}^{\text{M}}, \text{V}^{\text{M}}$ are cations at the interstitial sites ($0.2 \leq x \leq 2.0$, $2.7 \geq y \geq 0$, respectively). Variable composition of the structures studied is caused by heterovalent isomorphic substitution at the sphalerite site 6c (space group $P\bar{4}3n$). Charge imbalance arising as a result of substitution of the As pentavalent cations by cations of lower valence is compensated by additional Cu^+ cations. Non-stoichiometric compositions are due to vacancies at interstices and sphalerite sites partly occupied by Cu (T'1, T2, T4) and V (T'2) cations. The cited paper clearly indicates that colusite and arsenosulvanite in strict sense are different minerals. Their structures consist of framework of CuS_4 and $(\text{As}, \text{Ge}, \text{Sb})\text{S}_4$ apex-shared tetrahedrons. The main difference is occupation of interstitial sites of tetrahedral framework, where differently ordered V and Cu atoms are arranged (Frank-Kamenetskaya *et al.*, 2002): in colusite, the interstices are occupied by V but in arsenosulvanite, by Cu.

Thus, the contradiction noted by Betekhtin (1941) that consisted in similar chemical composition of arsenosulvanite, and of enargite and luzonite, which are polymorphous modifications of Cu_3AsS_4 (orthorhombic and monoclinic, respectively) as well as in similar physical properties and crystal structure of arsenosulvanite, $\text{Cu}_3(\text{As},\text{V})\text{S}_4$ (cubic), and of sylvanite is not yet solved. Moreover, Burke (2006) discredited arsenosulvanite as mineral species on the basis of Spry *et al.* (1994). These authors studied the structure of colusite and taking into account data by Riedel and Paterno (1976) who examined the Cu_3VS_4 - Cu_3AsS_4 system and revealed intermediate cubic compound $\text{Cu}_{12}\text{VAs}_3\text{S}_{16}$ with X-ray diffraction pattern similar to that of colusite and arsenosulvanite, interpreted an intermediate compound $\text{Cu}_{12}\text{VAs}_3\text{S}_{16}$ or $(\text{Cu}_{24}\text{V}_2\text{As}_6\text{S}_{32})$ (that is arsenosulvanite) as Sn-free colusite. However, Spry *et al.* (1994) referred to previous studies rather than gave own data of arsenosulvanite. Nevertheless, they concluded the identity of arsenosulvanite and colusite that provided the basis for discreditation of the former (Burke, 2006). In this case, Burke (2006) did not refer to Frank-Kamenetskaya *et al.* (2002) although this could prevent the discreditation of arsenosulvanite. The aim of this study is to bring out the actual problem of arsenosulvanite as independent mineral species.

Analytical techniques

The thin polished sections were studied with an OPTON microscope. Magnification from $\times 60$ to $\times 1250$ was used; the main operating magnification was $\times 200$. The chemical composition was determined with a Cam-Scan-4D scanning electron microscope equipped with a Link ISIS EDS operating at accelerated voltage 20 kV and beam current of 4 nA. Back-scattered electron images of the objects studied here were obtained. X-ray powder patterns were obtained by photomethod with an URS-50 diffractometer in RKD-57.3 mm camera, $\text{FeK}\alpha$ radiation, Mn filter.

Analytical techniques

Mode of occurrence, physical properties, and chemical composition

M.I. Novgorodova placed at our disposal the specimens from the Lebedinoe mine (Orochon deposit, dump of prospecting pit No 7) collected by A.I. Fastalovich in 1941 and stored in the collection by N.V. Petrovskaya.

Mode of occurrence, physical properties, and chemical composition

Petrovskaya (1973) reported the Lebedinoe ore field in her book "Native Gold":

"Some fields of Late Cambrian gold mineralization, including Lebedinoe are located on the margins of epicratonic troughs in the area of tectonic activation of the ancient Aldan shield".

"The rocks of ancient sequences are highly dislocated and altered as a result of intrusion of large synorogenic granitic plutons. The nearly horizontal sequence of the Cambrian weakly metamorphosed dolomite of 200 m thick overlaps eroded surface of the ancient sequences. Both structural units are intruded by numerous small plutons of the Upper Jurassic-Lower Cretaceous age". These are predominantly stocks, laccoliths, and dykes of intermediate rocks of elevated alkalinity. The mineralization is hosted mainly in the upper structural unit. Altered wall-rocks are ankeritized dolomite and sericitized and silicified igneous rocks.

"The intrusive bodies and crystalline rocks of basement are cut by steep veins composed of quartz (80–90%); metasomatic sulfide-carbonate bodies (occasionally as vein apophyses) are hosted in dolomite along horizontal faults". The metasomatic bodies consist of ankerite (30%) firstly formed as a result of acting of ore-bearing fluids on the Cambrian dolomite sequence. Ore minerals are dominated by pyrite; significant chalcopyrite was identified; and substantial hematite in some veins was observable. Fastalovich and Petrovskaya (1940), and Petrovskaya (1973) reported abundant galena, sphalerite, pyrrotite, galenobismutite, and tennantite-tetrahedrite and extremely rare vanadium sulfide, sulvanite. Supergene minerals are varied iron hydroxides, jarosite, copper oxides (cuprite), copper sulfides (chalcocite and covellite), copper and lead carbonates (malachite, azurite, and cerussite), sulfates (gypsum and melanterite), and manganese minerals (Fastalovich and Petrovskaya, 1940).

Pyrite, chalcopyrite, fahlores, famatinite, bornite, pyrrotite, covellite, digenite, anilite, sulvanite, and two phases with the higher relief were found in thin polished sections along with quartz and carbonate. Sulvanite was found only in one of 18 samples studied here as four irregular-shaped grains of ~150×80, ~100×80, ~40×30, and ~40×20 microns in size among arsenosulvanite (Fig. 1). In reflected light, sulvanite is light yellow, isotropic. Two phases with higher relief than that of sulvanite are similar to arsenosulvanite, but they are highly anisotropic. Accord-

ing to chemical study, they are arsenosulvanite. Their light yellow color is slightly lighter than sulvanite (Fig. 1), but darker than that of fahlores (Fig. 2); bireflectance is weak; the anisotropy of one of these phases varies from light gray with greenish tint to pale lilac; the color of the second phase varies from light grey with weak lilac tint to deep pink. Polysynthetic twins are characteristic of the second phase. In addition, secondary minerals formed after ore minerals are planned to study in the future.

Twenty seven electron microprobe point analyses of sulvanite and arsenosulvanite and calculated formulas are given in Table 1 and Table 2, respectively. According to the idealized formula of arsenosulvanite, $\text{Cu}_{24}\text{V}_2\text{As}_6\text{S}_{32}$, suggested by Frank-Kamenetskaya *et al.* (2002), the compositions were calculated on the basis of 64 atoms.

The first three analyses in the Tables correspond to that of sulvanite containing low As, Sb, and Pb. It is nearly pure sulvanite. The other compositions correspond to sufficiently pure arsenosulvanite. In arsenosulvanite, 0.0–2.9 wt.% Sb that is up to 0.76 *apfu* (an. 24) were detected. Iron content is lower: up to 0.18 *apfu* (an. 18). Two grains of sulvanite which are different in intensity of anisotropy in reflected light are approximately identical in chemical composition. The grain with stronger anisotropy is low-Fe, whereas another grain is Fe-free. Different anisotropy is caused most likely by different sections of the grains. Polysynthetic twins are well observable in sample 242/5 from location 1 (Tables 1, 2, an. 25–27). Only 0.50–1.71 wt.% Sb corresponding to 0.2–0.44 *apfu* were detected in them.

The compositions of sulvanite from the other deposits are given in Tables 1 and 2 (an. 28–36).

The sample for the X-ray diffraction study was prepared by the following way: the grains previously measured with electron microprobe were extracted from polished sections and placed into resin ball. The comparison of the X-ray diffraction pattern of arsenosulvanite obtained in this study with those reported by Mikheev (1941) and Kachalovskaya *et al.* (1975) indicated that the former is closer to the X-ray diffraction pattern given by Mikheev (1941) (Table 3). The X-ray diffraction pattern given in this study shows additional weak reflections with intensities $I = 1 - 2$ (2.52, 1.934, 1.405, 1.365, 1.164) indexed in

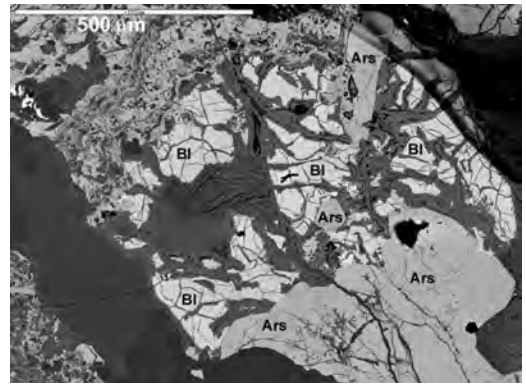
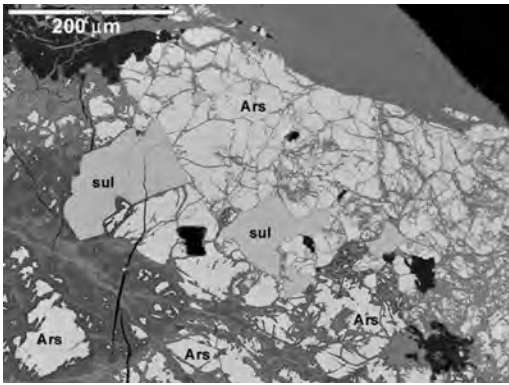


Fig. 1. An assemblage of arsenosulvanite (Ars) (light grey, fractured) and sulvanite (sul) (with pronounced boundaries, darker than arsenosulvanite) enclosed in segregation of secondary minerals (arsenates, sulfates, copper carbonates) and quartz. Sample 242/3 (location 2). BSE image.

Fig. 2. An assemblage of arsenosulvanite (Ars) (light grey, fractured) and tennantite-tetrahedrite (Bl) (light grey) enclosed in segregation of secondary minerals. Sample 242/6 (location 1). BSE image.

space group $P\bar{4}3n$ and are absent in the X-ray diffraction patterns by Mikheev (1941) and Kachalovskaya *et al.* (1975). The strong reflections of sulvanite (5.42, 2.41, 1.910, 1.796, 1.626) are also absent testifying the absence of this mineral in our sample. In the X-ray diffraction pattern obtained by Kachalovskaya *et al.* (1975), there are strong reflections of sulvanite indicating the impurity of this mineral.

Discussion

As aforementioned, the samples of arsenosulvanite studied here are characterized by nearly constant composition (Table 2, an. 1–27). Insignificant Fe and Sb were detected. Content of V in these samples exceptionally analysis 26 (where it is 2.01 *apfu*) and in the samples from Japan deposits (Table 2, an. 35, 36) does not exceed 2 *apfu*. The concentration of V reaches 2.26 *apfu* in previously published compositions of sulvanite from the Lebedinoe deposit (Table 2, an. 28–30). Arsenosulvanite from Mongolia is the Fe-richest (2.54–3.30 *apfu*) (Table 2, an. 31, 32). It should be noted that the compositions were determined by bulk chemical analysis rather than electron microprobe. In addition, only these samples are isotropic. Taking into account this two remarks, elevated vanadium concentration in the compositions of sulvanite from Mongolia are explained by the following reasons: (1) the analyzed samples are cubic colusite rather than arsenosulvanite and therefore they are isotropic and contain more than 2 *apfu* V, and (2) the selection of homogeneous material for bulk analysis is

very difficult, therefore mechanical impurity of any V-bearing mineral is possible, for example, mentioned by Petrovskaya (1941) vanadium-mica that fills fractures in sulvanite together with malachite, azurite, and brown iron hydroxides. A.G. Betekhtin who discovered arsenosulvanite noted that "bright green powder films as oxidizing products are extremely characteristic of weathered surface of arsenosulvanite grains". He suggested that it is certain intermediate variety between copper vanadates, turanite, $\text{Cu}_5(\text{VO}_4)_2(\text{OH})_4$, or volborthite, $(\text{Cu,Zn,Ni})_3\text{V}_2\text{O}_7(\text{OH})_2 \cdot 2\text{H}_2\text{O}$, and copper arsenate, tyrolite, $\text{CaCu}_5^{2+}(\text{AsO}_4)_2(\text{CO}_3)(\text{OH})_4 \cdot 6\text{H}_2\text{O}$, or erythrine, $\text{Co}_3(\text{AsO}_4)_2 \cdot 8\text{H}_2\text{O}$. Taking into account the highest qualification of Betekhtin, our second suggestion is unlikely. However, currently, mineralogists run into phenomenon, when megascopally homogeneous material turns out composed of two phases as revealed by microscopic study with high magnification. Therefore, the second unlike explanation of high content of vanadium (more than 2 *apfu*) is not worth rejection. Consequently, it may be suggested that up to 2 *apfu* V incorporate into arsenosulvanite. Number of As or total As and Sb is close to 6 *apfu* (5.65–6.34 *apfu*), i.e., 6 ± 0.35 *apfu*. Content of S ranges from 31.46 to 32.28 *apfu*. Cu content is the most variable from 23.72 to 24.86 *apfu*.

Electron microprobe data of colusite by Spry *et al.* (1994) are given in Table 4. They are recalculated on the sum of 64 atoms for comparison with data of arsenosulvanite.

According to the electron microprobe data, content of V in 12 samples of colusite

Table 1. Bulk chemical and electron microprobe data of sulvanite and arsenosulvanite

№ an.	Description of phase	Cu	Fe	V	As	Sb	S	Σ
1	Light yellow	52.05	—	13.22	—	0.03	34.22	99.96*
2	isotropic sulvanite	52.64	—	13.14	0.08	—	34.97	100.83
3		52.25	—	13.30	—	0.02	35.29	100.86
Average		52.31	—	13.22	0.03	0.02	34.83	100.55
4	Light yellow slightly	50.20	—	3.09	13.61	0.15	32.87	99.92
5	darker than sulvanite;	51.10	—	3.26	13.75	—	32.66	100.77
6	anisotropy from -	50.99	—	3.24	13.78	0.10	32.57	100.68
7	light grey with greenish	50.34	—	3.25	13.65	0.58	32.65	100.47
8	tint to pale violet; relief	50.42	—	3.20	13.87	0.74	32.98	101.21
9	is higher than that of	50.60	—	3.06	12.55	2.49	32.95	101.65
10	sulvanite	50.85	—	3.14	14.22	0.45	32.24	100.90
11		50.01	—	3.21	13.21	2.06	32.36	100.85
12		50.30	—	3.17	12.04	2.44	32.52	100.47
13		50.83	—	3.05	13.68	1.01	32.68	101.25
14	Light yellow slightly	50.48	—	3.16	14.84	—	34.11	102.59
15	darker than sulvanite;	49.99	—	3.15	14.76	—	34.05	101.95
16	anisotropy from pale light	49.89	0.13	3.21	15.15	—	33.76	102.14
17	violet to deep pink-light	48.99	0.20	3.19	14.78	—	33.63	100.79
18	violet; relief is higher than	48.52	0.33	3.13	13.99	0.18	32.49	98.66
19	that of sulvanite;	48.99	0.09	3.06	15.05	—	33.44	100.63
20	polysynthetic twins are clear	48.97	0.07	3.19	14.51	0.77	33.19	100.70
21		48.95	0.15	3.11	15.14	0.17	33.62	101.14
22		49.15	—	2.94	14.61	—	33.22	99.92
23		49.09	—	3.01	14.94	0.18	33.89	101.11
24		48.34	0.05	3.01	13.35	2.94	32.72	100.41
25		50.20	—	3.19	13.89	1.71	33.07	102.06
26		49.87	—	3.31	13.28	1.68	33.13	101.27
27		49.47	—	3.15	13.94	0.50	33.13	100.19
28	Weakly anisotropic	50.35	—	3.7	13.35	—	32.55	99.95
29	arsenosulvanite	50.40	—	3.69	13.52	—	32.39	100.00
30		50.40	—	3.60	13.49	—	32.50	99.99
31	Isotropic	48.84	—	4.16	12.80	—	33.14	99.95**
32	arsenosulvanite	46.65	—	5.20	11.67	—	31.66	99.00**
33	Weakly anisotropic	48.8	—	3.7	12.4	—	31.7	96.6
34	arsenosulvanite	50.6	—	3.4	13.2	—	32.22	100.04
35	Arsenosulvanite	46.2	3.4	3.1	10.2	3.9	31.8	99.6***
36	Arsenosulvanite	49.4	—	3.2	12.3	—	33.9	98.8

Notes: analyses: bulk chemical (31, 32) and electron microprobe (1–30, 33–36); samples: 242/3 (location 2), analysis 1–13; 242/6 (location 1), analysis 14–22; 242/6 (location 3), analysis 23 and 24; 242/5 (location 1), analysis 25–27. *Including 0.44 wt. % Pb. Average of three point analyses of sulvanite is 0.15 wt. % Pb. **Including insoluble residue, wt. %: 1.01 (an. 31) and 3.82 (an. 32). *** Including 1.0 wt. % Sn. In addition, in analysis 34, 0.62 wt. % Ge was detected. Dash denotes that the element was not analyzed. (1–30) Lebedinoe deposit, South Yakutia: (1–27) this study, (28) Novikov et al. (1974), average of two measurements; (29, 30) Khoroshilova (1987); (31, 32) Mongolia (Betekhtin, 1941); (33, 34) Bor, Serbia: (33) Kachalovskaya et al. (1975), (34) Cvetkovi and Karanovi (1993); (35) Hayakawa, Japan (Ishiyama et al., 1990); (36) Osarizawa, Japan (Taguchi and Kizawa, 1974).

Table 2. Formulas of sulvanite and arsenosulvanite given in Table 1 calculated on the sum of 64 atoms

No an.	Formula	Mineral	Valence balance Δ , %
1	$\text{Cu}_{24.40}^+ \text{Pb}_{0.06} \text{V}_{2.00}^{5+} \text{V}_{5.73}^{5+} \text{Sb}_{0.01} \text{S}_{31.79}$	Light yellow isotropic sulvanite	0.6
2	$\text{Cu}_{24.34}^+ \text{V}_{2.00}^{5+} \text{V}_{5.58}^{5+} \text{As}_{0.03}^{5+} \text{S}_{32.04}$		2.6
3	$\text{Cu}_{24.10}^+ \text{V}_{2.00}^{5+} \text{V}_{5.65}^{5+} \text{Sb}_{0.01}^{5+} \text{S}_{32.25}$		3.2
Average	$\text{Cu}_{24.28}^+ \text{Pb}_{0.02} \text{V}_{2.00}^{5+} \text{V}_{5.65}^{5+} \text{As}_{0.01}^{5+} \text{Sb}_{0.01}^{5+} \text{S}_{32.03}$		2.1
4	$\text{Cu}_{24.56}^+ \text{V}_{1.88}^{5+} (\text{As}_{5.65} \text{Sb}_{0.04})_{5.69}^{5+} \text{S}_{31.86}$	Light yellow slightly darker than sulvanite;	2.0
5	$\text{Cu}_{24.86}^+ \text{V}_{1.96}^{5+} (\text{As}_{5.67} \text{S}_{31.49})$	anisotropy from light grey with greenish tint	0.2
6	$\text{Cu}_{24.85}^+ \text{V}_{1.97}^{5+} (\text{As}_{5.70} \text{Sb}_{0.02})_{5.72}^{5+} \text{S}_{31.46}$	to pale violet; relief is higher than that of	0.6
7	$\text{Cu}_{24.60}^+ \text{V}_{1.98}^{5+} (\text{As}_{5.66} \text{Sb}_{0.15})_{5.81}^{5+} \text{S}_{31.62}$	sulvanite	0.5
8	$\text{Cu}_{24.46}^+ \text{V}_{1.94}^{5+} (\text{As}_{5.70} \text{Sb}_{0.18})_{5.88}^{5+} \text{S}_{31.70}$		0.2
9	$\text{Cu}_{24.59}^+ \text{V}_{1.85}^{5+} (\text{As}_{5.18} \text{Sb}_{0.63})_{5.81}^{5+} \text{S}_{31.74}$		0.9
10	$\text{Cu}_{24.85}^+ \text{V}_{1.93}^{5+} (\text{As}_{5.89} \text{Sb}_{0.12})_{6.01}^{5+} \text{S}_{31.22}$		3.2
11	$\text{Cu}_{24.54}^+ \text{V}_{1.96}^{5+} (\text{As}_{5.50} \text{Sb}_{0.52})_{6.02}^{5+} \text{S}_{31.47}$		2.3
12	$\text{Cu}_{24.73}^+ \text{V}_{1.94}^{5+} (\text{As}_{5.02} \text{Sb}_{0.63})_{5.65}^{5+} \text{S}_{31.69}$		1.1
13	$\text{Cu}_{24.73}^+ \text{V}_{1.85}^{5+} (\text{As}_{5.64} \text{Sb}_{0.26})_{5.90}^{5+} \text{S}_{31.51}$		0.7
14	$\text{Cu}_{24.00}^+ \text{V}_{1.88}^{5+} \text{As}_{5.98}^{5+} \text{S}_{32.14}$	Light yellow slightly darker than sulvanite;	1.6
15	$\text{Cu}_{23.89}^+ \text{V}_{1.88}^{5+} \text{As}_{5.98}^{5+} \text{S}_{32.25}$	anisotropy from pale light violet to deep	2.0
16	$\text{Cu}_{23.86}^+ \text{V}_{1.92}^{5+} \text{As}_{6.14}^{5+} \text{Fe}_{0.07}^{2+} \text{S}_{32.00}$	pink-light violet; relief is higher than that	0.5
17	$\text{Cu}_{23.69}^+ \text{V}_{1.93}^{5+} \text{As}_{6.06}^{5+} \text{Fe}_{0.10}^{2+} \text{S}_{32.22}$	of sulvanite; polysynthetic twins are clear	0.9
18	$\text{Cu}_{24.04}^+ \text{V}_{1.93}^{5+} (\text{As}_{5.88} \text{Sb}_{0.04})_{5.92}^{5+} \text{Fe}_{0.18} \text{S}_{31.91}$		0.3
19	$\text{Cu}_{23.76}^+ \text{V}_{1.85}^{5+} (\text{As}_{6.20} \text{Fe}_{0.05}^{2+})_{6.20}^{5+} \text{S}_{32.14}$		0.2
20	$\text{Cu}_{23.83}^+ \text{V}_{1.94}^{5+} (\text{As}_{5.99} \text{Sb}_{0.20})_{6.19}^{5+} \text{Fe}_{0.04}^{2+} \text{S}_{32.01}$		0.8
21	$\text{Cu}_{23.64}^+ \text{V}_{1.87}^{5+} (\text{As}_{6.20} \text{Sb}_{0.04})_{6.24}^{5+} \text{Fe}_{0.08}^{2+} \text{S}_{32.17}$		0.02
22	$\text{Cu}_{24.01}^+ \text{V}_{1.79}^{5+} \text{As}_{6.05}^{5+} \text{S}_{32.15}$		1.7
23	$\text{Cu}_{23.66}^+ \text{V}_{1.81}^{5+} (\text{As}_{6.10} \text{Sb}_{0.04})_{6.14}^{5+} \text{S}_{32.38}$		2.1
24	$\text{Cu}_{23.82}^+ \text{V}_{1.85}^{5+} (\text{As}_{5.58} \text{Sb}_{0.76})_{6.34}^{5+} \text{Fe}_{0.05}^{2+} \text{S}_{31.96}$		1.4
25	$\text{Cu}_{24.27}^+ \text{V}_{1.93}^{5+} (\text{As}_{5.69} \text{Sb}_{0.44})_{6.13}^{5+} \text{S}_{31.68}$		1.9
26	$\text{Cu}_{24.21}^+ \text{V}_{2.00}^{5+} (\text{As}_{5.47} \text{Sb}_{0.42})_{5.89}^{5+} \text{V}_{0.01}^{3+} \text{S}_{31.88}$		0.1
27	$\text{Cu}_{24.15}^+ \text{V}_{1.91}^{5+} (\text{As}_{5.77} \text{Sb}_{0.12})_{5.89}^{5+} \text{S}_{32.04}$		1.4
28	$\text{Cu}_{24.64}^+ \text{V}_{2.00}^{5+} (\text{V}_{0.26}^{3+} \text{As}_{5.54})_{5.80}^{5+} \text{S}_{31.56}$	Weakly anisotropic arsenosulvanite	0.0
29	$\text{Cu}_{24.68}^+ \text{V}_{2.00}^{5+} (\text{V}_{0.25}^{3+} \text{As}_{5.62})_{5.87}^{5+} \text{S}_{31.44}$		1.0
30	$\text{Cu}_{24.67}^+ \text{V}_{2.00}^{5+} (\text{V}_{0.20}^{3+} \text{As}_{5.60})_{5.80}^{5+} \text{S}_{31.53}$		0.3
31	$\text{Cu}_{23.94}^+ \text{V}_{2.00}^{5+} (\text{V}_{0.54}^{3+} \text{As}_{5.32})_{5.86}^{5+} \text{S}_{32.19}$	Isotropic arsenosulvanite	3.4
32	$\text{Cu}_{23.74}^+ \text{V}_{2.00}^{5+} (\text{V}_{1.30}^{3+} \text{As}_{5.04})_{6.34}^{5+} \text{S}_{31.93}$		1.6
33	$\text{Cu}_{24.64}^+ \text{V}_{2.00}^{5+} (\text{V}_{0.33}^{3+} \text{As}_{5.31})_{5.64}^{5+} \text{S}_{31.72}$	Weakly anisotropic arsenosulvanite	2.0
34	$\text{Cu}_{24.83}^+ \text{V}_{2.00}^{5+} (\text{V}_{0.08}^{3+} \text{Ge}_{0.27}^{4+} \text{As}_{5.49})_{5.84}^{5+} \text{S}_{31.33}$		1.5
35	$\text{Cu}_{23.07}^+ \text{Fe}_{1.93} \text{V}_{1.93}^{5+} (\text{Sb}_{1.02} \text{As}_{1.32}^{5+} \text{Sn}_{0.27}^{4+})_{5.61} \text{S}_{31.47}$		2.2
36	$\text{Cu}_{24.19}^+ \text{V}_{1.95}^{5+} \text{As}_{5.09}^{5+} \text{S}_{32.77}$		9.4

Notes: Analyses 29, 30, and 34–36 taken from Frank-Kamenetskaya et al., 2002.

Table 3. Comparison of X-ray diffraction patterns of arsenosulvanite, colusite, and sulvanite

№	This study			Arsenosulvanite						Colusite*		Sulvanite	
	<i>I</i>	<i>d/n</i> , Å	<i>hkl</i>	<i>I</i>	<i>d/n</i> , Å	<i>hkl</i>	<i>I</i>	<i>d/n</i> , Å	<i>hkl</i>	<i>I</i>	<i>d/n</i> , Å	<i>I</i>	<i>d/n</i> , Å
1												10	5.42
2													
3	1	4.32	211										
4	4	3.34	310	4	(3.339)	211, 310	5	(3.37)	310β				
5	10	3.01	222	9	3.034	111	10	3.05	222	100	3.066	10	3.12
6	1	2.86	321				1	2.82	321	2	2.839		
7	4	2.62	400	3	2.627	200	4	2.65	400	9	2.656	4	2.69
8	1	2.52	223							2	2.576		
9	2	2.47	411				1	2.47	411				
10							1	2.43	331			8	2.41
11	1	2.35	420				1	2.36	420	1	2.375		
12	1	2.29	332				1	2.25	332	1	2.265		
13	3	2.04	510	5	(2.048)	220β	4	(2.06)	510β, 431β				
14	2	1.934	521							1	1.974		
15							1	1.906	521			10	1.910
16	9	1.849	440	10	1.859	220	9	1.867	440	41	1.878		
17							1	1.810	530, 433	4	1.822	5	1.796
18	2	1.737	610	3	(1.746)	313β	3	(1.757)	600β, 442β				
19	1	1.636											
20							1	1.627	541			6	1.626
21	8	1.573	622	9	1.584	311	8	1.591	622	14	1.601		
22										1	1.533	1	1.552
23	2	1.510	444	1	1.518	222	1	1.521	444				
24	1	1.470					1	1.452	720, 641				
25	1	1.405	642										
26	1	1.365	371, 553, 731										
27				0,5	(1,328)	331β	1	(1,336)	732β, 651β				
28	3	1.308	800	6	1.314	400	4	1.320	800	2	1.328		
29	2	1.254	453										
30	5	1.203	662	7	1.207	331	5	1.210	662	3	1.218		
31							1	1.194	752	1	1.188		
32	1	1.182	840	2	1.180	420	1	1.183	840	3	1.084		
33	1	1.164	833										
34	2	1.121	664				1	1.125	664				
35	2	1.094	931	1	(1,111)	513β	1	1.103	931				
36	7	1.072	844	9	1.074	422	6	1.077	844				
37	4	1.013	10.22	7	1.014	511	3	1.015	10.22	1	1.022		

Notes: * – Butte, Montana, USA.

Table 4. Electron microprobe data of colusite (Spry *et al.*, 1994)

№ an.	Cu	V	Fe	Zn	Ge	Sn	As	Sb	S	Σ
1	50.8	3.2				7.3	8.6	1.1	30.1	100.0
2	49.5	3.0				5.31	8.6	1.1	31.6	99.1
3	50.1	3.3			0.63	0.26	13.6	1.4	31.2	100.49
4	49.5	3.1			1.1	6.6	8.8	0.92	30.2	100.22
5	50.41	3.52	0.58	0.35	2.85	3.17	8.12		29.69	98.69
6	47.98	2.95	1.10	0.07	0.14	8.42	3.61	6.59	29.77	101.06
7	49.40	3.18	0.35	0.33	4.52		8.64	0.34	33.13	101.24
8	48.5	2.7			6.2		10.0		32.3	99.7
9	47.4	2.2	1.8			7.6	7.5	1.4	31.2	99.3
10	49.3	2.7				5.9	12.1		28.2	98.2
11	50.4	3.6				1.3	10.7		31.9	97.9
12	49.5	3.05	1.5			4.65	11.05		30.55	100.30

Formula calculated on the sum of 64 atoms

	Formula	Valence balance Δ, %
1	$Cu_{25.95}^{+}V_{2.00}^{5+}As_{3.55}^{5+}Sn_{2.00}^{4+}V_{0.04}^{3+}S_{30.47}$ or $Cu_{25.95}^{+}V_{2.00}^{5+}(As_{3.55}^{5+}Sn_{2.00}^{4+}V_{0.04}^{3+})_{5.59}S_{30.47}$	1.1
2	$Cu_{25.03}^{+}V_{1.89}^{5+}(As_{3.69}^{5+}Sb_{0.29}^{5+})_{3.96}^{5+}Sn_{1.44}^{4+}S_{31.66}$ or $Cu_{25.03}^{+}V_{1.89}^{5+}[(As_{3.69}^{5+}Sb_{0.29}^{5+})_{3.96}^{5+}Sn_{1.44}^{4+}]_{5.42}S_{31.66}$	5.0
3	$Cu_{24.85}^{+}V_{2.00}^{5+}(As_{5.72}^{5+}Sb_{0.36}^{5+})_{6.08}^{5+}(Sn_{0.07}^{4+}Ge_{0.27}^{4+})_{0.34}^{4+}V_{0.04}^{3+}S_{30.68}$ or $Cu_{24.85}^{+}V_{2.00}^{5+}[(As_{5.72}^{5+}Sb_{0.36}^{5+})_{6.08}^{5+}(Sn_{0.07}^{4+}Ge_{0.27}^{4+})_{0.34}^{4+}V_{0.04}^{3+}]_{6.46}S_{30.68}$	8.0
4	$Cu_{25.21}^{+}V_{1.97}^{5+}(As_{3.80}^{5+}Sb_{0.24}^{5+})_{4.04}^{5+}(Sn_{1.80}^{4+}Ge_{0.49}^{4+})_{2.29}^{4+}S_{30.48}$ or $Cu_{25.21}^{+}V_{1.97}^{5+}[(As_{3.80}^{5+}Sb_{0.24}^{5+})_{4.04}^{5+}(Sn_{1.80}^{4+}Ge_{0.49}^{4+})_{2.29}^{4+}]_{6.33}S_{30.48}$	5.4
5	$Cu_{25.73}^{+}Fe_{0.34}^{2+}V_{2.00}^{5+}As_{3.51}^{5+}(Sn_{0.87}^{4+}Ge_{1.27}^{4+})_{2.14}^{4+}V_{0.24}^{3+}S_{30.03}$ or $Cu_{25.73}^{+}Fe_{0.34}^{2+}V_{2.00}^{5+}[As_{3.51}^{5+}(Sn_{0.87}^{4+}Ge_{1.27}^{4+})_{2.14}^{4+}V_{0.24}^{3+}]_{5.89}S_{30.03}$	5.0
6	$Cu_{25.03}^{+}Fe_{0.65}^{2+}V_{1.92}^{5+}(As_{1.60}^{5+}Sb_{1.60}^{5+})_{3.20}^{5+}(Sn_{2.35}^{4+}Ge_{0.06}^{4+})_{2.41}^{4+}S_{30.78}$ $Cu_{25.03}^{+}Fe_{0.65}^{2+}V_{1.92}^{5+}[(As_{1.60}^{5+}Sb_{1.60}^{5+})_{3.20}^{5+}(Sn_{2.35}^{4+}Ge_{0.06}^{4+})_{2.41}^{4+}]_{5.65}S_{30.78}$	0.0
7	$Cu_{24.44}^{+}Fe_{0.20}^{2+}V_{1.21}^{5+}(As_{3.62}^{5+}Sb_{0.09}^{5+})_{3.71}^{5+}Ge_{1.96}^{4+}S_{32.48}$ или $Cu_{24.44}^{+}Fe_{0.20}^{2+}V_{1.21}^{5+}[(As_{3.62}^{5+}Sb_{0.09}^{5+})_{3.71}^{5+}Ge_{1.96}^{4+}]_{5.67}S_{32.48}$	11.8
8	$Cu_{23.90}^{+}V_{1.68}^{5+}As_{4.15}^{5+}Ge_{2.67}^{4+}S_{31.60}$ or $Cu_{23.90}^{+}V_{1.68}^{5+}[As_{4.15}^{5+}Ge_{2.67}^{4+}]_{6.82}S_{31.60}$	0.8
9	$Cu_{24.23}^{+}Fe_{1.05}^{2+}V_{1.40}^{5+}(As_{3.25}^{5+}Sb_{0.37}^{5+})_{3.62}^{5+}Sn_{2.08}^{4+}S_{31.61}$ or $Cu_{24.23}^{+}Fe_{1.05}^{2+}V_{1.40}^{5+}[(As_{3.25}^{5+}Sb_{0.37}^{5+})_{3.62}^{5+}Sn_{2.08}^{4+}]_{5.70}S_{31.61}$	5.5
10	$Cu_{25.87}^{+}V_{1.77}^{5+}As_{5.38}^{5+}Sn_{1.66}^{4+}S_{29.32}$ or $Cu_{25.87}^{+}V_{1.77}^{5+}[As_{5.38}^{5+}Sn_{1.66}^{4+}]_{7.04}S_{29.32}$	14.1
11	$Cu_{25.22}^{+}V_{2.00}^{5+}As_{4.54}^{5+}Sn_{0.33}^{4+}V_{0.25}^{3+}S_{31.64}$ or $Cu_{25.22}^{+}V_{2.00}^{5+}[As_{4.54}^{5+}Sn_{0.33}^{4+}V_{0.25}^{3+}]_{5.14}S_{31.64}$	5.1
12	$Cu_{24.86}^{+}Fe_{0.86}^{2+}V_{1.91}^{5+}As_{4.71}^{5+}Sn_{1.25}^{4+}S_{30.41}$ or $Cu_{24.86}^{+}Fe_{0.86}^{2+}V_{1.91}^{5+}[As_{4.71}^{5+}Sn_{1.25}^{4+}]_{5.96}S_{30.41}$	6.0

Notes: 0.35 wt. % Zn (analysis 5); 0.07 wt. % Zn and 0.40 wt. % Mo (analysis 6); 0.04 wt. % Ni and 0.12 wt. % Bi (analysis 7); 0.03 wt. % Mo (analysis 9). (1) Butte, Montana (Levy, 1967); (2) Butte, Montana (Springer, 1969); (3, 4) Lorano, Italy (Orlandi *et al.*, 1981); (5) Gai, Russia (Pshenichnyi *et al.*, 1974); (6) Kairagach, Uzbekistan (Spiridonov *et al.*, 1984); (7) San Fernando, Cuba (Krapiva *et al.*, 1986); (8) unknown deposit, Kazakhstan (Mitryaeva *et al.*, 1968); (9) Chizeuil, France (Delfour *et al.*, 1984); (10, 11) Bor, Serbia (Kachalovskaya *et al.*, 1975); (12) Medet, Bulgaria (Strashimirov, 1982).

from varied deposits ranges from 1.21 to 2.25 *apfu* (San Fernando deposit, Cuba and Bor deposit, Serbia, respectively). Number of As or the sum of As and Sb in colusite varies from 3.20 to 6.08 *apfu* (Kairagach deposit, Uzbekistan and Lorano deposit, Italy). The content of the other elements is as follows, *apfu*: 0–1.60 Sb, 0–2.67 Ge, 0–2.08 Sn, 0–1.05 Fe, 23.90–25.90 Cu, 29.32–32.48 S.

Thus, colusite is characterized by wide ranges of V content and total As and Sb, whereas these values in arsenosulvanite are close to 2 and 6 ± 0.35 *apfu*. Significant Ge and Sn are frequent in colusite, whereas these elements are rare and insignificant in arsenosulvanite. Admixture cations in colusite are resulted from the larger isomorphous capacity of the structure of colusite in contrast to arsenosulvanite. These minerals are significantly different in chemical composition.

Conclusions

(1) Arsenosulvanite and colusite are different mineral species.

(2) Discreditation of arsenosulvanite (Burke, 2006) is incorrect.

(3) Reinvestigation of arsenosulvanite including structural study is required to approve it as mineral species.

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