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New data on sulphosalts from the hydrothermal siderite-type veins in the Spišsko-gemerské rudohorie Mts. (eastern Slovakia): 2. Jaskólskiite and associated sulphosalts from the Aurélia II vein near Rožňava

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Abstract

New samples of jaskólskiite were recently collected at the Aurélia II siderite-type hydrothermal vein with sulphides near Rožňava, Spišsko-gemerské rudohorie Mts., Rožňava Co., Košice Region, Slovakia. It forms lead-gray, irregular aggregates up to 1.5 × 1 cm in size, which are enclosed in quartz-siderite gangue. Aggregates of jaskólskiite are consisting of individual, subhedral acicular crystals to 2 mm long, strongly replaced by younger bournonite and associated with Bi-rich jamesonite, tetrahedrite-(Fe), tintinaite, native bismuth and ullmannite. Significant variation of Cu (from 0.04 to 0.23 *apfu*) and Bi contents (from 0.32 to 0.77 *apfu*) was observed in studied sample. The average (n = 69 analyses) empirical formula of jaskólskiite from Rožňava-Aurélia vein based on Pb+Bi+Sb = 4 *apfu* is corresponding to $Pb_{2.11}Cu_{0.13}(Sb_{1.42}Bi_{0.47})_{1.89}S_{5.14}$. Bi-rich jamesonite is the most common sulphosalt at the studied locality and it forms prismatic crystals up to 2 cm or irregular aggregates to 3 cm in size. The Bi content in jamesonite is ranging between 0.49 to 1.69 *apfu*. Bournonite is also common and two compositional types were distinguished. The first, dominant type is represented by Bi-rich bournonite (containing up to 0.14 *apfu Bi*). The second type of bournonite, represented by thin ribbons shows significant enrichment in As (reaching up to 0.49 *apfu*), but has only minor content of Bi (up to 0.08 *apfu*). Tintinaite is rare and its average (n = 9) empirical formula based on sum of all atoms = 63 *apfu* is corresponding to $(Pb_{9.67}Ag_{0.06})_{9.73}(Cu_{2.55}Fe_{0.40}Zn_{0.07})_{3.02}(Sb_{10.19}Bi_{5.37})_{15.56}S_{34.59}Cl_{0.10}$.

Key words: *jaskólskiite, jamesonite, bournonite-seligmannite series, tintinaite, sulphosalts, chemical composition, Aurélia vein, Rožňava, Spišsko-gemerské rudohorie Mts., Slovak Republic*

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Introduction

The Spišsko-gemerské rudohorie Mts. represent one of the most important accumulations of ore deposits in the whole Carpathian mountain range. There are more than 1200 hydrothermal ore veins known within this relatively small area, with two major types of mineralization: siderite-type carbonate-quartz veins with sulphides (extensively exploited in Dobšiná, Štítnik, Rákoš, Rožňava, Drnava, Rudňany, Novoveská Huta, Hnilčík, Henclová, Prakovce, Gelnica, Slovinky, Medzev etc.) and quartz-stibnite veins (Betliar, Čučma, Štofova dolina, Helcmanovce, Poproč or Zlatá Idka). Furthermore, Sn-Mo-W bearing greisens or granite-related hydrothermal quartz veins, hydrothermal veins with U-REE mineralization as well as strata-bound VMS pyrite-Cu-Pb-Zn ore mineralization and hydrothermal-metasomatic bodies of siderite and magnesite±talc are present (Varček 1962; Chovan et al. 1994; Grecula et al. 1995; Rojkovič 1997).

All of the above mentioned types of ore mineralization contain various sulphosalts mostly as accessory ore minerals. Abundant presence of minerals of tetrahedrite-tennantite series (especially Fe, Zn and locally also Hg dominant members) is very typical feature of the siderite-type veins (e.g. Bernard 1958, 1961; Varček 1957, 1959, 1960; Novák 1959, 1967; Trdlička 1967; Háber 1980; Cambel et al. 1985; Peterec 1990; Miškovic 1991; Háber et al. 1993; Grecula et al. 1995; Antal 2002a, b; Pršek 2008; Pršek, Biroň 2007; Pršek, Lauko 2009; Števko et al. 2015; Mikuš et al. 2018; Peterec 2019; Števko, Sejkora 2020). Bi sulphosalts are also quite common, especially minerals of the bismuthinite-aikinite series (e.g. Paděra et al. 1955; Kupčík et al. 1969; Hurný, Krištín 1978; Mumme, Žák 1983; Antal 1991; Beňka, Siman 1994; Pršek 2008; Števko et al. 2015; Mikuš et al. 2018, 2019; Števko et al. 2021) and kobellite homologous series (e.g. Trdlička, Kupka 1957; Hak, Kupka 1958; Novák 1961; Trdlička et al. 1962; Václav 1964; Zábranský, Radzo 1966; Háber, Streško 1969; Háber 1980; Jeleň 1991; Pršek 2008; Pršek, Peterec 2008; Mikuš et al. 2018, 2019). Other Bi sulphosalts like cosalite (Bernard 1964; Háber 1980), galenobismutite (Antal 1991; Pršek 2008), jaskólskiite (Pršek, Biroň 2007), nuffieldite (Pršek et al. 2006; Števko et al. 2021) or wittichenite (Háber 1978; Kozub et al. 2011) are rare. Chalcostibite is infrequent too (Sejkora et al. 2011; Mikuš et al. 2018). Unusual assemblage of Ag-Bi sulphosalts (matildite, gustavite and benjaminite) was recently described from the Kobaltová vein near Medzev by Mikuš et al. (2019). The most common Pb sulphosalts at the siderite-type veins are bournonite, jamesonite (often Bi-rich) and boulangerite (e.g. Zimányi 1914; Novák 1962; Trdlička 1967; Kupčík et al. 1969; Háber 1980; Miškovic 1990; Pršek, Biroň 2007; Pršek, Peterec 2008; Sejkora et al. 2011; Mikuš et al. 2018, 2019), whereas berthierite and garavellite (Mikuš et al. 2018), meneghinite (Beňka, Siman 1994) or zinkenite and scainiite (Sejkora et al. 2011) are scarce. Rare Hg sulphosalts, marrucciite (Sejkora et al. 2011) and grumiplucite (Števko et al. 2015) were also recently identified. As-rich sulphosalts, seligmannite and jordanite were described from the Zenderling deposit near Gelnica by Sejkora et al. (2011).

The occurrence of jaskólskiite at the Aurélia II vein, associated with Bi-rich jamesonite, bournonite and boulangerite was first described by Pršek, Biroň (2007). This paper is presenting new compositional data on jaskólskiite as well as associated sulphosalts from newly collected samples.

Geological setting

The Aurélia II vein is located on NE slopes of the Tri vrchy hill (581 m a.s.l.), around 2.5 km NNE of the Rožňava town in the Spišsko-gemerské rudohorie Mts., Rožňava Co., Košice Region, Slovakia. Samples of ore mineralization with jaskólskiite were collected at the dump of old exploration pit (Fig. 1) located in the NE part of the Aurélia II vein. GPS coordinates (WGS84) of this dump are:

Fig. 1 *View of old exploration pit where samples with jaskólskiite were collected. Photo by M. Števko, March 2021.*

Fig. 2 *Aggregate of jaskólskiite enclosed in quartz. Field of view is 9 mm. Photo by L. Hrdlovič.*

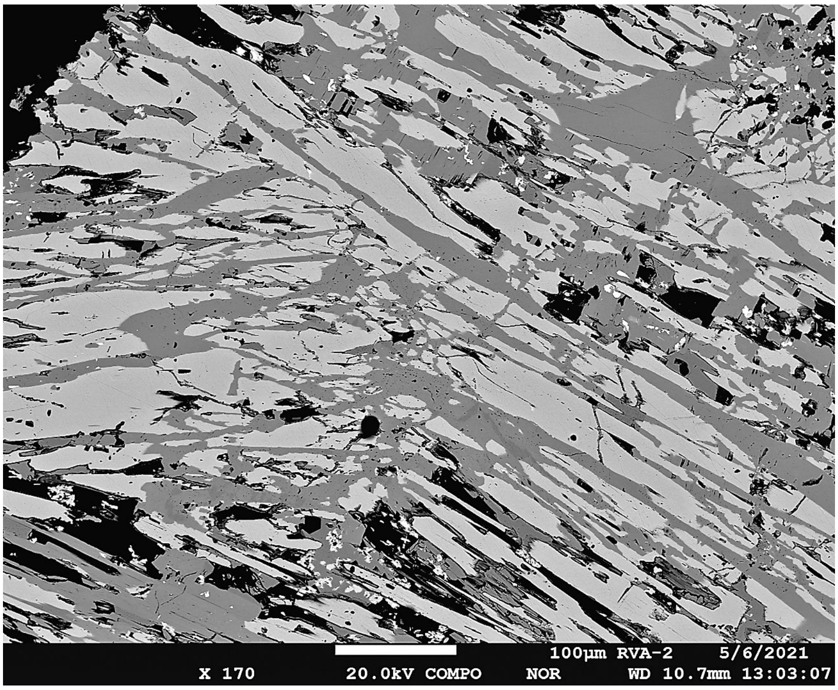

Fig. 3 *Aggregates of jaskólskiite crystals (light grey) replaced by bournonite (dark grey). Tiny white inclusions are native bismuth. BSE image by M. Števko.*

48.682610° N and 20.539870° E, 387 m a.s.l.

The Aurélia II vein is one of the less important siderite-type hydrothermal veins belonging to the Rožňava-Mária-Tri vrchy vein system. This NE - SW trending, 1.2 km long and up to 1.5 m thick hydrothermal vein is hosted in Early Paleozoic rocks of the Gelnica group (the Gemeric Unit), represented by metasandstones and metarhyolites of the Drnava Formation (Furiel 1958; Bajaník et al. 1984; Grecula et al. 1995). The dominant gangue minerals are quartz and siderite accompanied by minor amounts of albite, ankerite, apatite, chlorite, muscovite, tourmaline and rutile. Minerals of the tetrahedrite subgroup are the most frequent ore minerals associated with less abundant arsenopyrite, chalcopyrite, pyrite and pyrrhotite as well as minor boulangerite, bournonite, cobaltite, galena, gersdorffite, hematite, izoklakeite, jamesonite, jaskólskiite, kobellite, magnetite, marcasite, native bismuth, native antimony, sphalerite and ullmannite (Novák 1960; Kupčík et al. 1961; Biroň 1989; Grecula et al. 1995; Pršek 2004; Pršek, Biroň 2007). Kupčík et al. (1961) described also phase related to lillianite, which later turned to be Bi-rich jamesonite (Kupčík et al. 1969; Pršek 2004).

Analytical methods

Paragenetic and textural relationships as well as chemical zoning of ore minerals were studied in BSE mode using a JEOL JXA-8530FE electron microprobe (Earth Science Institute, Slovak Academy of Sciences, Banská Bystrica, Slovak Republic).

The quantitative chemical analyses of sulphosalts were performed using a Cameca SX100 electron microprobe (National Museum, Prague, Czech Republic) operating in the

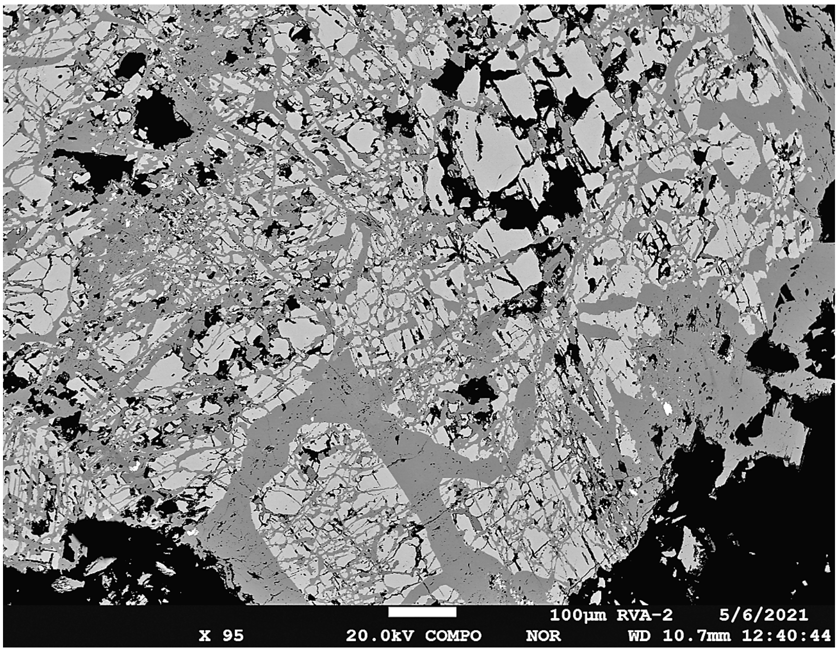

Fig. 4 *Aggregates of jaskólskiite crystals (light grey) replaced by bournonite (dark grey). Tiny white inclusions are native bismuth. BSE image by M. Števko.*

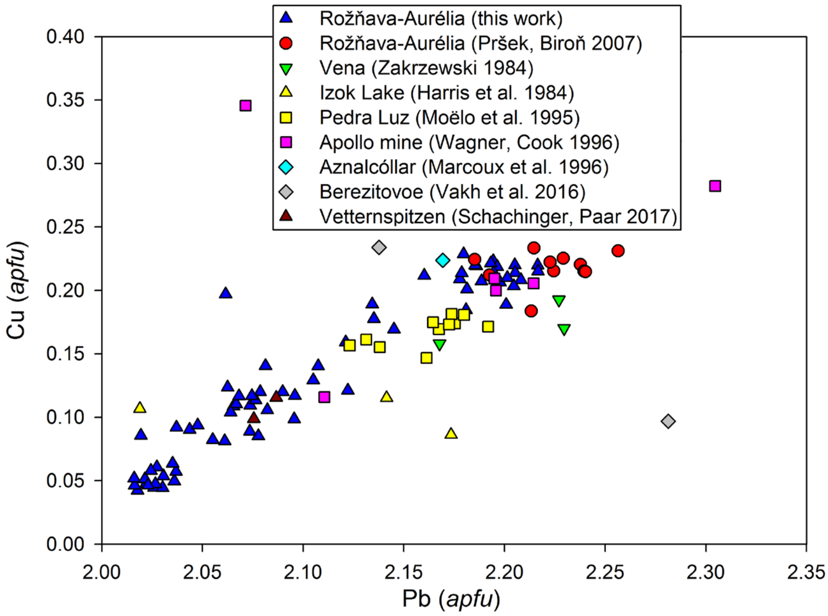

Fig. 5 *Variation of Pb vs. Cu contents (apfu) in jaskólskiite from the Aurélia II vein and other woldwide occurrences.*

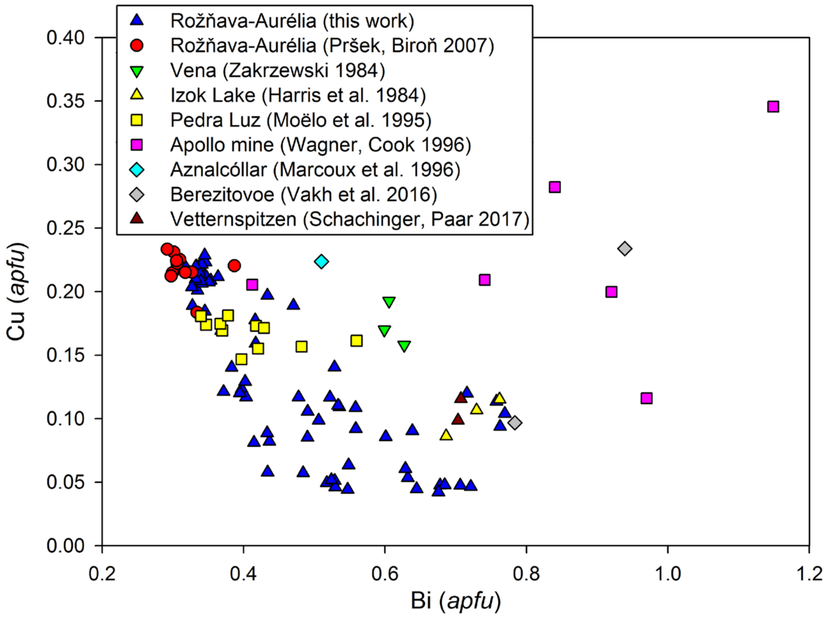

Fig. 6 *Variation of Bi vs. Cu contents (apfu) in jaskólskiite from the Aurélia II vein and other woldwide occurrences.*

wave-dispersive (WDS) mode (25 kV, 20 nA and 0.7 μm wide beam). The following standards and X-ray lines were used to minimize line overlaps: Ag (Ag*L*α), Bi_2Se_3 (Bi*M*β), CdTe (Cd*L*α), Co (Co*K*α), $CuFeS_2$ (Cu*K*α, S*K*α), FeS_2 (Fe*K*α), GaAs (Ga*L*α), Ge (Ge*L*α), HgTe (Hg*L*α), InAs (In*L*α), Mn (Mn*K*α), NaCl (Cl*K*α), NiAs (As*L*β), Ni (Ni*K*α), PbS (Pb*M*α), PbSe (Se*L*β), PbTe (Te*L*α), Sb_2S_3 (Sb*L*α), Sn (Sn*L*α), Tl(Br,I) (Tl*L*α), and ZnS (Zn*K*α). Contents of the above-listed elements, which are not included in the tables, were analysed quantitatively, but their contents were consistently below the detection limit (ca. 0.03 - 0.05 wt. % for individual elements). Raw intensities were converted to the concentrations of elements using automatic "PAP" matrix-correction procedure (Pouchou, Pichoir 1985). The order number of meneghinite homologue *N* for jaskólskiite was calculated according to the procedure proposed by Makovicky (1989) and the order number of kobellite homologue *N* for tintinaite was calculated according to the procedure proposed by Zakrzewski, Makovicky (1986).

Results and discussion

Jaskólskiite is rare mineral at the studied locality. It forms lead-grey, irregular aggregates up to 1.5 × 1 cm in size with metallic lustre (Fig. 2), enclosed in quartz-siderite gangue. Aggregates of jaskólskiite are consisting of individual, subhedral acicular crystals to 2 mm long (Fig. 3, 4), strongly replaced by younger bournonite. Other associated minerals are jamesonite, tetrahedrite-(Fe) and microscopic inclusions of native bismuth.

Representative chemical analyses of jaskólskiite from the Aurélia II vein and the corresponding empirical formulae are shown in Table 1 (all 69

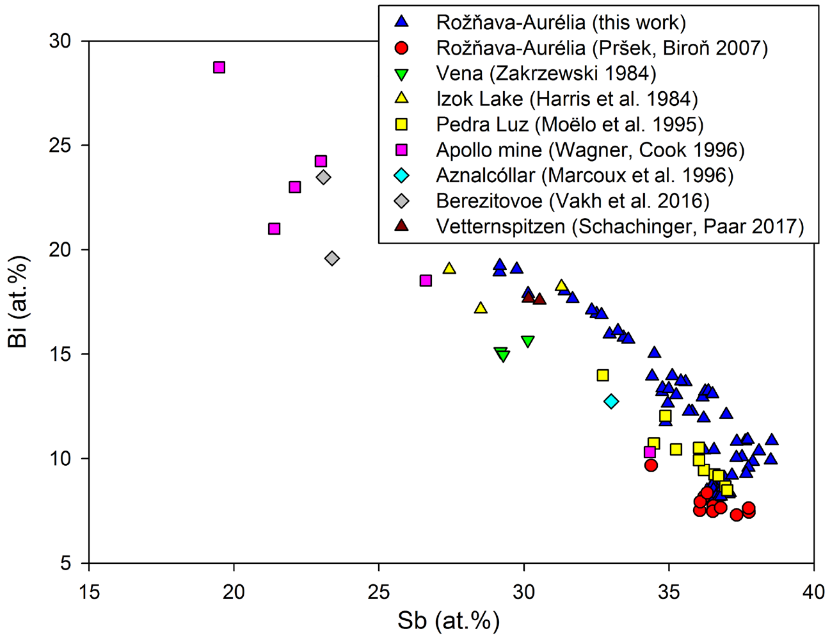

Fig. 7 *Variation of Sb vs. Bi contents (apfu) in jaskólskiite from the Aurélia II vein and other woldwide occurrences.*

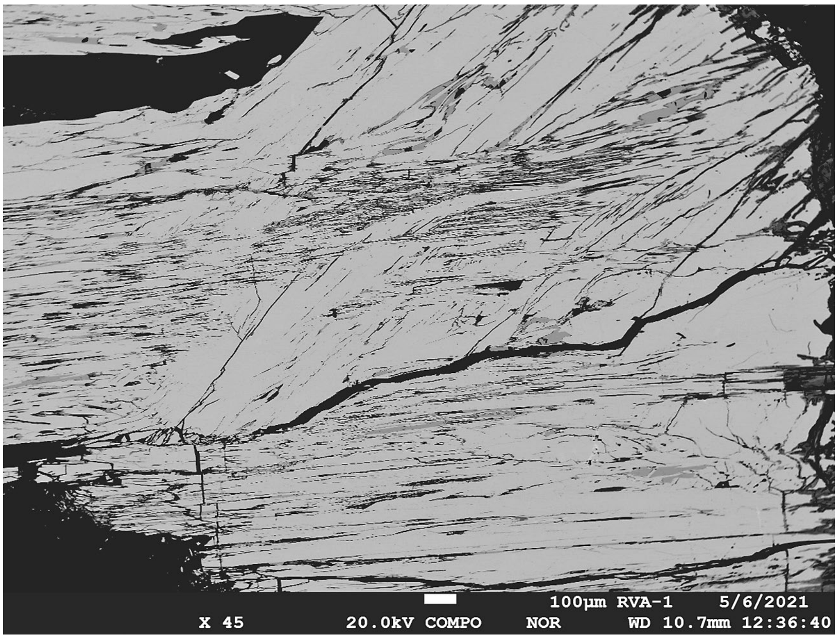

Fig. 8 *Homogenous aggregate of Bi-rich jamesonite (grey) with minor anglesite (dark grey) from the Aurélia vein. BSE image by M. Števko.*

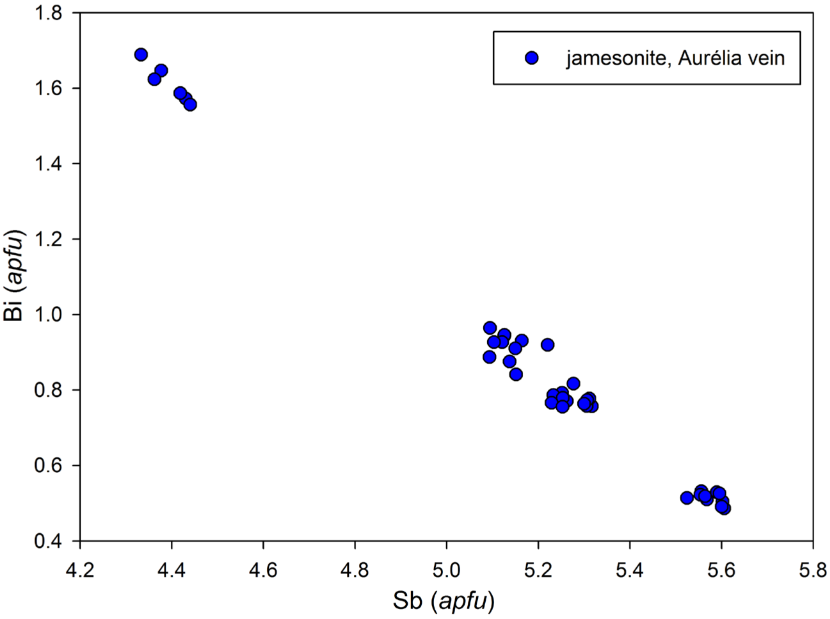

Fig. 9 *Variation of Sb vs. Bi contents (apfu) in jamesonite from the Aurélia II vein.*

analyses are available in supplementary file). The calculated value of *N* (order number of meneghinite homologue, see Makovicky 1989 for details) for jaskólskiite from the Aurélia II vein ranges from 3.75 to 4.02 (with average of 3.94), which is close to the theoretical value *N* = 4 (e.g. Makovicky, Nørrestam 1985; Berlepsch et al. 2001; Moëlo et al. 2008). Zakrzewski (1984) and Makovicky, Nørrestam (1985) defined ideal empirical formula of jaskólskiite as $\mathrm{Cu}_x\mathrm{Pb}_{2+x}(\mathrm{Sb,Bi})_{2-x}\mathrm{S}_5$, where Sb exceeds Bi and value of *x* is about 0.2 *apfu*. Later, Moëlo et al. (1995) slightly redefined it to $\mathrm{Cu}_x\mathrm{Pb}_{2+x}(\mathrm{Sb}_{1-y}\mathrm{Bi}_y)_{2-x}\mathrm{S}_5$, with value of *x* ranging between 0.10 to 0.22 and *y* vary from 0.19 to 0.41. Significant variation of Cu content (from 0.04 to 0.23 *apfu*, Fig. 5) was observed in studied jaskólskiite from the Aurélia II vein, with obvious positive correlation between Pb and Cu contents (Fig. 5) and negative trend

Table 1 *Representative WDS analyses of jaskólskiite from Rožňava-Aurélia II vein (wt.%)*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Pb	49.63	48.75	47.53	46.95	47.90	48.76	49.71	48.15	47.33	50.94	50.89	50.52	52.77	50.95	51.77
Cu	1.35	1.01	0.62	0.30	0.41	0.60	0.94	0.42	0.73	1.64	1.50	1.22	1.60	0.89	1.34
Sb	19.07	19.14	19.09	17.87	20.44	21.03	20.72	21.55	15.72	20.26	19.88	20.57	20.51	21.25	20.56
Bi	11.03	12.48	14.27	15.85	11.48	10.44	9.58	10.41	17.79	8.13	8.13	8.74	7.62	9.00	8.26
S	18.84	18.90	19.01	19.18	19.13	19.18	19.39	19.42	18.44	18.95	19.02	18.93	17.81	18.08	17.91
total	99.91	100.28	100.52	100.14	99.35	100.01	100.33	99.95	100.02	99.93	99.43	99.98	100.32	100.18	99.86
Pb	2.134	2.081	2.019	2.018	2.037	2.055	2.105	2.024	2.064	2.180	2.194	2.145	2.216	2.122	2.181
Cu	0.189	0.141	0.086	0.042	0.057	0.082	0.129	0.058	0.104	0.229	0.211	0.169	0.220	0.121	0.185
Sb	1.395	1.390	1.380	1.307	1.479	1.508	1.493	1.542	1.167	1.475	1.458	1.487	1.466	1.506	1.474
Bi	0.470	0.528	0.601	0.675	0.484	0.436	0.402	0.434	0.769	0.345	0.347	0.368	0.317	0.372	0.345
S	5.235	5.214	5.219	5.326	5.256	5.223	5.304	5.274	5.197	5.240	5.300	5.194	4.835	4.867	4.876
N	3.893	3.885	3.872	3.952	3.960	3.947	3.952	3.934	3.922	3.904	3.966	3.952	3.993	4.002	3.993

calculated empirical formulae are based on (Cu+Pb)/2+(Sb+Bi) = 8 *apfu*

Table 2 *Representative WDS analyses of jamesonite from Rožňava-Aurélia II vein (wt.%)*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Pb	36.54	36.87	36.71	37.83	38.22	38.78	38.80	38.50	38.31	38.90	38.22	38.02	38.52	38.37	38.61
Fe	2.30	2.42	2.43	2.36	2.50	2.52	2.48	2.43	2.43	2.48	2.40	2.45	2.47	2.40	2.44
Sb	24.41	24.82	24.08	29.33	29.66	32.45	32.28	32.09	31.95	32.12	30.51	30.27	30.19	30.39	30.00
Bi	15.76	14.93	16.11	9.26	8.31	4.83	5.08	4.96	5.25	5.14	7.45	7.61	8.02	7.63	7.77
S	20.89	20.88	20.71	21.32	21.47	21.38	21.47	21.15	21.32	21.31	21.31	21.45	21.11	21.18	21.14
total	99.90	99.92	100.03	100.09	100.16	99.96	100.10	99.13	99.26	99.95	99.89	99.81	100.31	99.97	99.96
Pb	3.851	3.876	3.881	3.885	3.901	3.936	3.932	3.949	3.915	3.961	3.914	3.884	3.956	3.941	3.972
Fe	0.900	0.944	0.952	0.900	0.947	0.950	0.933	0.925	0.921	0.936	0.912	0.930	0.941	0.915	0.931
Sb	4.377	4.440	4.333	5.125	5.151	5.605	5.568	5.602	5.556	5.564	5.317	5.262	5.276	5.311	5.252
Bi	1.647	1.556	1.688	0.942	0.841	0.486	0.510	0.504	0.532	0.519	0.757	0.771	0.817	0.777	0.793
S	14.226	14.184	14.146	14.148	14.160	14.023	14.057	14.019	14.077	14.021	14.101	14.154	14.010	14.056	14.052

calculated empirical formulae are based on sum of all atoms = 25 *apfu*

Table 3 *Representative WDS analyses of bournonite (Bnn) and As-rich bournonite (As-Bnn) from Rožňava-Aurélia II vein (wt.%)*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Bnn	Bnn	Bnn	Bnn	Bnn	Bnn	Bnn	As-Bnn	As-Bnn	As-Bnn	As-Bnn	As-Bnn	As-Bnn	As-Bnn	As-Bnn
Pb	38.94	41.15	40.31	41.21	40.77	40.86	41.34	41.02	40.71	41.18	41.28	40.32	42.48	41.41	42.44
Cu	12.77	13.19	13.00	13.24	13.06	12.95	13.06	13.05	13.72	13.40	13.17	13.56	13.28	13.01	12.59
Fe	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.11	0.00	0.10	0.00	0.00	0.00
Sb	22.41	24.96	22.80	24.87	23.45	24.38	24.89	19.44	15.15	13.68	19.38	14.32	12.93	21.13	16.19
Bi	5.90	0.00	3.69	0.36	2.55	1.56	0.03	1.70	2.55	3.03	1.45	3.53	2.08	1.27	1.96
As	0.00	0.01	0.00	0.00	0.00	0.00	0.00	4.24	6.72	7.29	3.84	6.94	7.93	2.49	6.00
S	19.92	20.39	20.14	20.24	20.09	20.25	20.69	20.51	21.03	21.27	20.68	21.14	21.27	20.81	20.75
total	99.96	99.71	99.95	99.92	99.93	100.01	100.01	99.96	100.03	99.97	99.80	99.91	99.97	100.11	99.92
Pb	0.922	0.955	0.947	0.959	0.957	0.954	0.954	0.937	0.909	0.918	0.942	0.901	0.947	0.947	0.966
Cu	0.986	0.999	0.996	1.005	0.999	0.986	0.983	0.972	0.999	0.974	0.980	0.988	0.965	0.970	0.934
Fe	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.013	0.009	0.000	0.009	0.000	0.000	0.000
Sb	0.903	0.986	0.912	0.985	0.937	0.969	0.977	0.756	0.575	0.519	0.753	0.545	0.490	0.822	0.627
Bi	0.139	0.000	0.086	0.008	0.059	0.036	0.001	0.038	0.056	0.067	0.033	0.078	0.046	0.029	0.044
As	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.268	0.415	0.449	0.243	0.429	0.489	0.157	0.378
S	3.049	3.059	3.059	3.044	3.047	3.056	3.085	3.028	3.034	3.064	3.050	3.051	3.063	3.075	3.051

calculated empirical formulae are based on sum of all atoms = 6 *apfu* between Bi and Cu contents (Fig. 6). On the contrary, in sample studied by Pršek, Biroň (2007), variation of Cu content was rather limited (only 0.18 to 0.23 *apfu*). So far the lowest content of Cu in jaskólskiite (0.09 *apfu*) was reported from Izok Lake in Canada by Harris et al. (1984). Similar low Cu concentrations (0.10 *apfu*) were also observed in jaskólskiite from Vetternspitzen, Austria (Schachinger, Paar 2017). The highest concentrations of Cu (up to 0.35 *apfu*) were detected in samples from the Apollo mine, Siegerland, Germany (Wagner, Cook 1996). Moëlo et al. (1995) noted that Cu stabilizes structure of jaskólskiite towards lower temperatures. Based on published data and our new analyses from the Aurélia II vein the range for the coefficient *x* proposed by Moëlo et al. (1995) for natural jaskólskiite could be redefined as $0.04 \leq x \leq 0.35$. The Bi contents in studied jaskólskiite (Fig. 7) are also highly variable (from 0.32 to 0.77 *apfu*), with value of Bi/(Bi+Sb) atomic ratio ranging between 0.18 to 0.40. Pršek, Biroň (2007) reported so far the lowest concentrations of Bi in natural jaskólskiite (0.29 *apfu*), whereas most Bi-enriched jaskólskiite with up to 1.15 *apfu* of Bi was reported by Wagner, Cook (1996) from the Apollo mine. The average (n = 69 analyses) empirical formula of jaskólskiite from Rožňava-Aurélia vein based on Pb+Bi+Sb = 4 *apfu* is corresponding to $Pb_{2.11}Cu_{0.13}(Sb_{1.42}Bi_{0.47})_{1.89}S_{5.14}$.

Jamesonite is the most common sulphosalt at the studied locality. It occurs as metallic, acicular to prismatic crystals up to 2 cm long, or irregular aggregates to 3 cm enclosed (Fig. 8) in quartz-siderite matrix. Jamesonite is often associated with minerals of the tetrahedrite subgroup, bournonite, jaskólskiite or minor tintinaite, native bismuth and ullmannite.

Representative WDS analyses of jamesonite from the Aurélia II vein are

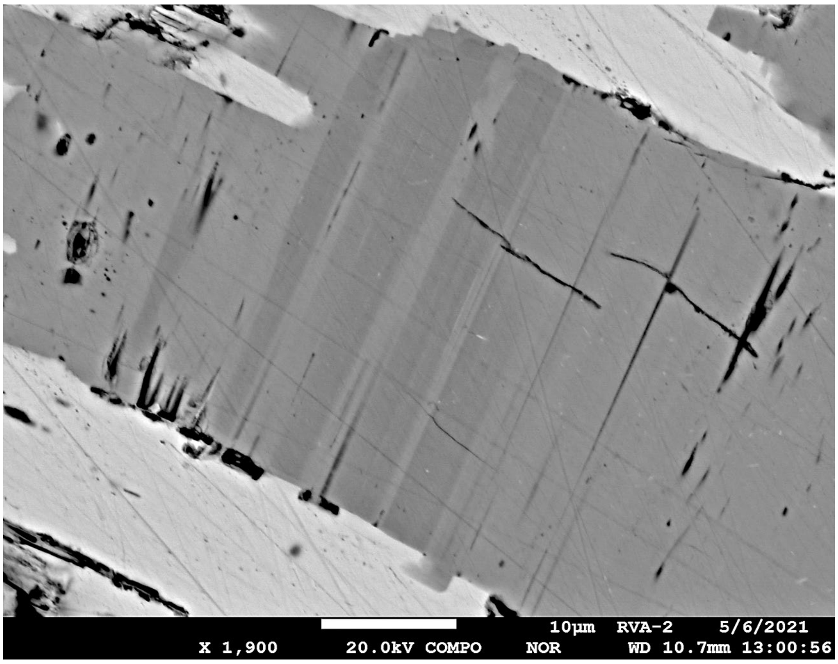

Fig. 10 *Thin ribbons of As-rich bournonite (dark grey) in Bi-rich bournonite (grey). Light grey subhedral grains are jaskólskiite. BSE image by M. Števko.*

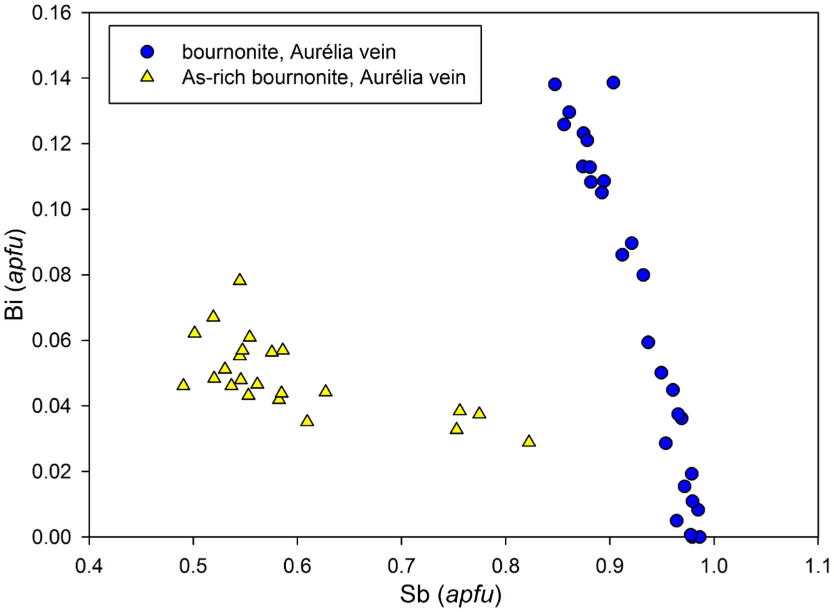

Fig. 11 *Variation of Sb vs. Bi contents (apfu) in bournonite from the Aurélia II vein.*

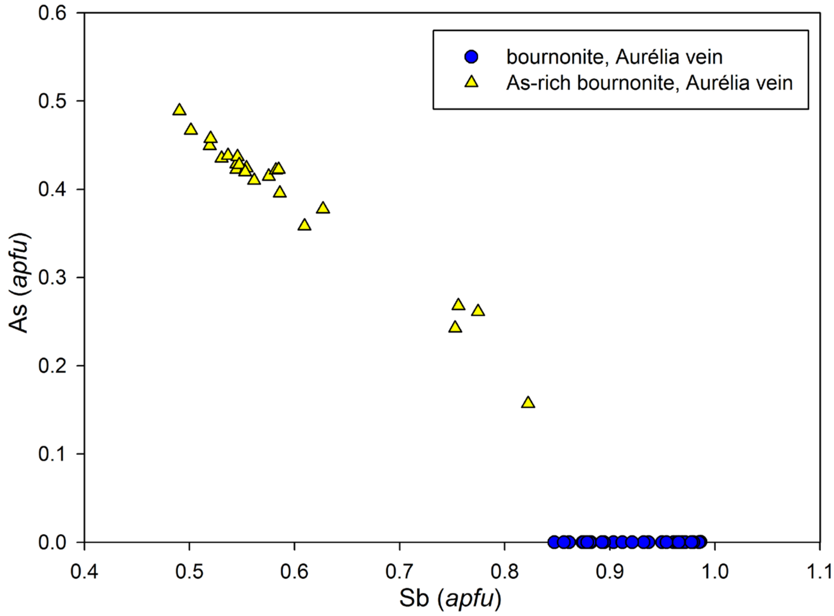

Fig. 12 *Variation of Sb vs. As contents (apfu) in bournonite from the Aurélia II vein.*

shown in Table 2 (all 41 analyses are available in supplementary file). The presence of significant contents of Bi (ranging from 0.49 to 1.69 *apfu*) substituting for Sb (Fig. 9) is the characteristic feature of the studied jamesonite.

Bournonite forms microscopic, anhedral aggregates (Fig. 3, 4), which are replacing jaskólskiite. It is mostly homogenous in BSE, but thin lamellae and ribbons of As-rich bournonite (Fig. 10) were locally observed.

Representative WDS analyses and corresponding calculated empirical formulae of bournonite from the Aurélia II vein are shown in Table 3 (all 51 analyses are available in supplementary file). The two distinct compositional types of bournonite were distinguished. The first, dominant type is represented by bournonite containing variable concentrations of Bi (reaching up to 0.14 *apfu*, Fig. 11) and with average (n = 28) empirical formula corresponding to $Pb_{0.95}Cu_{0.99}(Sb_{0.93}Bi_{0.07})_{1.00}S_{3.06}$. The second type, represented by thin ribbons, shows significant enrichment in As (reaching up to 0.49 *apfu*, Fig. 12), but has only minor contents of Bi (up to 0.08 *apfu*, Fig. 11). The average (n = 23) empirical formula of As-rich bournonite based on sum of all atoms = 6 *apfu* is $Pb_{0.94}Cu_{0.97}(Sb_{0.59}As_{0.39}Bi_{0.05})_{1.03}S_{3.06}$.

Tintinaite was rarely found as aggregates of thin, acicular crystals up to 300 µm long (Fig. 13) enclosed in tetrahedrite-(Fe). Other associated ore minerals are jamesonite, bournonite and native bismuth.

Representative chemical analyses of tintinaite are shown in Table 4. The calculated value of *N* (order number of kobellite homologue, see Zakrzewski, Makovicky 1986 for details) is ranging from 1.83 to 2.01. The Sb/(Sb+Bi) atomic ratio in sample from the Aurélia II vein varies only slightly between 0.63 and 0.68. The overall Cu+Fe content ranges from 2.65 to 3.34 *apfu*, which is exceeding the ideal value of 2 *apfu* (Zakrzewski and Makovicky 1986; Moëlo et al. 1995). Furthermore, the presence of Ag (reaching up to 0.14 *apfu*) sub-

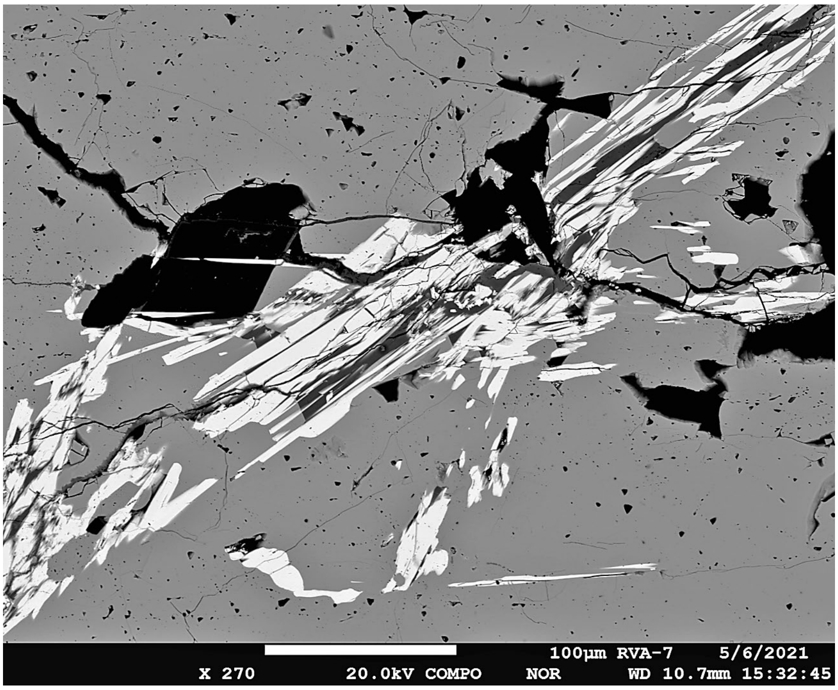

Fig. 13 *Aggregate of thin acicular crystals of tintinaite (white) enclosed in tetrahedrite-(Fe). BSE image by M. Števko.*

Table 4 *WDS analyses of tintinaite from Rožňava-Aurélia II vein (wt.%)*

	1	2	3	4	5	6	7	8	9
Pb	33.25	35.90	35.30	35.65	35.97	35.95	35.60	34.79	35.72
Ag	0.26	0.09	0.12	0.11	0.13	0.11	0.00	0.06	0.12
Cu	2.75	2.57	2.87	2.58	2.55	2.67	3.26	3.29	3.21
Fe	0.41	0.40	0.37	0.33	0.37	0.36	0.42	0.42	0.48
Zn	0.08	0.09	0.09	0.00	0.00	0.00	0.15	0.15	0.19
Sb	22.17	21.56	21.51	22.26	21.74	21.69	20.96	22.71	22.24
Bi	22.22	19.58	19.82	19.49	19.65	19.70	20.35	19.02	18.27
S	18.89	19.78	19.83	19.48	19.66	19.51	19.72	19.43	19.69
Cl	0.07	0.07	0.00	0.07	0.08	0.08	0.00	0.10	0.07
total	100.09	100.05	99.92	99.98	100.15	100.08	100.46	99.97	99.99
Pb	9.240	9.807	9.628	9.807	9.857	9.880	9.687	9.474	9.683
Ag	0.136	0.047	0.064	0.058	0.068	0.058	0.000	0.031	0.062
Σ	9.376	9.855	9.692	9.865	9.926	9.938	9.687	9.506	9.746
Cu	2.488	2.292	2.550	2.312	2.279	2.393	2.892	2.919	2.837
Fe	0.421	0.408	0.373	0.338	0.376	0.369	0.424	0.425	0.483
Zn	0.072	0.078	0.080	0.000	0.000	0.000	0.129	0.130	0.163
Σ	2.980	2.778	3.003	2.649	2.655	2.761	3.446	3.474	3.483
Sb	10.483	10.025	9.986	10.421	10.138	10.146	9.705	10.525	10.259
Bi	6.122	5.304	5.361	5.317	5.339	5.370	5.490	5.137	4.911
Σ	16.605	15.329	15.347	15.738	15.477	15.515	15.195	15.662	15.170
S	33.922	34.925	34.958	34.634	34.814	34.656	34.672	34.199	34.490
Cl	0.116	0.112	0.000	0.113	0.128	0.129	0.000	0.160	0.111
N	1.832	1.993	1.982	1.957	1.987	1.986	1.987	1.924	2.012

calculated empirical formulae are based on sum of all atoms = 63 *apfu* stituting for Pb as well as minor amounts of Zn and Cl (both up to 0.16 *apfu*) were detected in studied sample. The average (n = 9) empirical formula of tintinaite based on sum of all atoms = 63 *apfu* is $(Pb_{9.67}Ag_{0.06})_{9.73}(Cu_{2.55}Fe_{0.40}Zn_{0.07})_{3.02}(Sb_{10.19}Bi_{5.37})_{15.56}S_{34.59}Cl_{0.10}$.

Conclusions

New samples of rare Pb, Cu sulphosalt, jaskólskiite, from the siderite-type hydrothermal carbonate-quartz Aurélia II vein near Rožňava, Spišsko-gemerské rudohorie Mts. were studied in detail. It is associated with bournonite, Bi-rich jamesonite, tetrahedrite-(Fe), tintinaite and native bismuth. Jaskólskiite from the Aurélia II vein has so far the lowest concentrations of Cu (0.04 *apfu*) detected in natural samples.

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References

Antal B (1991) Bi-sulfosoli ložiska Slovinky. Miner Slov 23(4): 368

Antal B (2002a) Tennantite from the vein Mayer, baňa Mária deposit in Rožňava, Spišsko-gemerské rudohorie Mts. Slovak Geol Mag 8(3-4): 195-204

Antal B (2002b) Trends in chemical composition of tetrahedrite from the deposit Jedľovec (Fichtenhübel), Spišsko-gemerské rudohorie Mts. Slovak Geol Mag 8(3-4): 205-217

Bajaník Š, Ivanička J, Mello J, Pristaš J, Reichwalder P, Snopko L, Vozár J, Vozárová A (1984) Geologická mapa Slovenského rudohoria, východná časť 1:50000. ŠGÚDŠ, Bratislava

Beňka J, Siman P (1994) Identifikácia nových minerálov Cu, Pb, Bi, Sb v žilách Brdárky. Geol Práce Spr 99: 23-37

Berlepsch P, Makovicky E, Balić-Žunić T (2001) Crystal chemistry of meneghinite homologues and related sulfosalts. N Jb Miner Mh 3: 115-135

Bernard JH (1958) Chemismus a velikost mřížkových konstant spišsko-gemerských tetraedritů. Rozpr Čs Akad Věd Ř mat přír Věd 68: 1-74

Bernard JH (1961) Mineralogie und Geochemie der Siderit-Schwerspatgänge mit Sulfiden im Gebiet von Rudňany (Tschechoslowakei). Geol Práce Zoš 58: 1-222

Bernard JH (1964) Cosalit ($Pb_2Bi_2S_5$) ze sideritové žíly v Prakovcích ve Spišsko-gemerském rudohoří. Geol Práce Zpr 33: 43-52

Biroň A (1989) Mineralogicko-paragenetické pomery na sideritových žilách severovýchodne od Rožňavy. MS, Diplomová práca, archív KLG PriF UK, Bratislava, 1-91

Cambel B, Jarkovský J, Faith L, Forgáč J, Hovorka D, Hrnčárová M, Hurný J, Ivan P, Karoli A, Kráľ J, Litavec J, Matula I, Mihalov J, Popreňák J, Rényi K, Rojkovič I, Rozložník L, Sasvári T, Savčenková L, Spišiak J, Šmejkal V, Turan J, Turanová L, Varček C, Žabka M, Žukov F (1985) Rudnianské rudné pole. Veda, Bratislava, 1-363

Chovan M, Háber M, Jeleň S, Rojkovič I (1994) Ore textures in the Western Carpathians. Slovak Academic Press, Bratislava, 1-219

Furiel T (1958) Záverečná správa a výpočet zásob Rožňava-okolie Fe, ložisko Sadlovská, ložisko Aurélia, ložisko Szölömal, stav k 1.7.1958. MS, unpublished report, ŠGÚDŠ-Geofond, 1-80 (8688)

Grecula P, Abonyi A, Abonyiová M, Antaš J, Bartalský B, Bartalský J, Dianiška I, Ďuďa R, Gargulák M, Gazdačko Ľ, Hudáček J, Kobulský J, Lörincz L, Macko J, Návesňák D, Németh Z, Novotný L, Radvanec M, Rojkovič I, Rozložník L, Varček C, Zlocha Z (1995) Ložiská nerastných surovín Slovenského rudohoria. Zväzok 1. Geocomplex, Bratislava, 1-834

Háber M (1980) Mineralogische-geochemische und paragenetische Erforschung hydrotermaler Gänge im Gebiet zwischen Prakovce und Kojšov (SGR). Záp Karpaty, Sér Miner Petrogr Geoch Metalog 7: 7-131

Háber M (1978) Mineralogicko-paragenetické pomery na ložisku Novoveská Huta Cu v Spišsko-gemerskom rudohorí. In: Hornická Příbram ve vědě a technice, sek geologie: 411-423

Háber M, Streško V (1969) Ein neues Kobellit-Vorkommen in dem Zips-Gömörer Erzgebirge. Geol Zbor Geol Carpath 20(1): 133-151

Háber M, Krištín J, Rojkovič I (1993) The tennantite-tetrahedrite series in Permian formations of the Western Carpathians. Geol Carpath 45(1) 11-28

Hak J, Kupka F (1958) Identifikace kobellitu z Hummelu ve Spišsko-gemerském Rudohoří. Čas Mineral Geol 3(1): 16-20

Harris DC, Roberts AC, Criddle AJ (1984) Jaskólskiite from Izok Lake, Northwest Territories. Can Mineral 22: 487-491

Hurný J, Krištín J (1978) Aikinite and xenotime from Slovinky (Spišsko-gemerské rudohorie). Geol Zbor Geol Carpath 29(1): 167-171

Jeleň M (1991) Chemické zloženie sulfosolí zo žily Strieborná v Rožňave. Miner Slov 23(4): 369

Kozub G, Budzyń B, Pršek J (2011) Hydrothermal copper-bismuth mineralization from the Joremeny adit, Dobšiná, Slovak Republic-preliminary report. Mineralogia, Spec Pap 38: 123-124

Kupčík V, Matherny M, Varček C (1961) Príspevok k problému štruktúry minerálu “lillianit”. Geol Sbor 12(1): 103-113

Kupčík V, Schneider A, Varček C (1969) Chemismus von einigen Bi-Sulfosalzen aus dem Zips-Gömörer Erzgebirge. N Jb Miner Mh 10: 445-454

Makovicky E (1989) Modular classification of sulphosalts-current status. Definition and application of homologous series. N Jb Miner Abh 160: 269-297

Makovicky E, Nørrestam R (1985) The crystal structure of jaskolskiite, $Cu_xPb_{2+x}(Sb,Bi)_{2-x}S_5$ (x~0.2), a member of the meneghinite homologous series. Z Kristallogr 171: 179-194

Marcoux E, Moëlo Y, Leistel JM (1996) Bismuth and cobalt minerals as indicators of stringer zones to massive sulphide deposits, Iberian Pyrite Belt. Miner Deposita 31: 1-26

Mikuš T, Kondela J, Jacko S, Milovská S (2018) Garavellite and associated sulphosalts from the Strieborná vein in the Rožňava ore field (Western Carpathians). Geol Carpath 69(3): 221-236

Mikuš T, Bakos F, Hönig S (2019) Bismuth sulphosalts from the siderite-sulphidic and As-Co mineralization in Medzev area, Slovakia. Ageos 11(2): 91-102

Miškovic J (1990) Mineralogicko-paragenetické pomery na ortuťovom ložisku Rákoš. Miner Slov 22(1): 68

Miškovic J (1991) Tetraedrity z dobšinského rudného poľa. Miner Slov 23(4): 367-368

Moëlo Y, Roger G, Maurel-Palacin D, Marcoux E, Laroussi A (1995) Chemistry of some Pb-(Cu,Fe)-(Sb,Bi) sulfosalts from France and Portugal. Implications for the crystal chemistry of lead sulfosalts in the Cu-poor part of the Pb_2S_2-Cu_2S-Sb_2S_3-Bi_2S_3 system. Miner Petrol 53: 229-250

Moëlo Y, Makovicky E, Mozgova NN, Jambor JL, Cook N, Pring A, Paar W, Nickel EH, Graeser S, KarupMøller S, Balic-Zunic T, Mumme WG, Vurro F, Topa D, Bindi L, Bente K, Shimizu M (2008) Sulfosalt systematics: a review. Report of the sulfosalt subcommittee of the IMA Commission on Ore Mineralogy. Eur J Mineral 20: 7-46

Mumme W, Žák L (1983) Second occurrence of krupkaite in Czechoslovakia. Čas Mineral Geol 28(1): 61-63

Novák F (1959) Tetraedrit z ložiska Mária u Rožňavy. Geol Práce Zoš 56: 217-246

Novák F (1960) Závěrečná zpráva o geochemicko-mineralogickém výzkumu ložiska Mária baňa a okolí za rok 1958-1959. MS, unpublished report, ŠGÚDŠ-Geofond, 1-120 (7026)

Novák F (1961) Kobellit ze žíly Mária u Rožňavy. Věst Ústř Úst geol 36(2): 97-107

Novák F (1962) Výskyt jamesonitu a bournonitu na sideritových žilách u Rožňavy. Čas Mineral Geol 7(3): 373-281

Novák F (1967) Chemismus tetraedritu ze VII. a X. patra žíly Mária u Rožňavy. Čas Mineral Geol 12(1): 49-57

Paděra K, Bouška V, Pelikán J (1955) Rezbanyit aus Dobšiná in der Ostslowakei, ČSR. Chem Erde 17(4): 329-340

Peterec D (1990) Výskyt rumelky a Hg-tennantitu pri Vyšnom Klátove. Miner Slov 22(2): 189-190

Peterec D (2019) Žilné štruktúry v krásnohorskopodhradskom a drnavskom rudnom poli, chemické zloženie tetraedritov a sukcesné postavenie cinabaritu v sledovanej oblasti. Esemestník 8(1): 12-21

Pouchou JL, Pichoir F (1985) “PAP” (φρZ) procedure for improved quantitative microanalysis. In: Microbeam Analysis (J. T. Armstrong, ed.). San Francisco Press, San Francisco: 104-106

Pršek J (2004) Štruktúra a kryštalochémia sulfosolí zo sulfidických mineralizácií Západných Karpát. MS, Kandidátska dizertačná práca, archív KMP PriF UK, Bratislava, 1-135

Pršek J (2008) Chemické zloženie a kryštalochémia Bi sulfosolí z hydrotermálnych mineralizácií kryštalinika Západných Karpát. Univerzita Komenského, Bratislava, 1-108

Pršek J, Biroň A (2007) Jaskólskiit a sprievodné sulfosoli zo žily Aurélia-Rožňava, Spišsko-gemerské rudohorie. Miner Slov 39(2): 141-146

Pršek J, Lauko Ľ (2009) Hydrotermálna žilná mineralizácia v Zlatej Idke. Miner Slov 41(2): 133-150

Pršek J, Peterec D (2008) Bi-Se-Te mineralization from Úhorná (Spišsko Gemerské Rudohorie Mts., Slovakia): A preliminary report. Mineralogia 39(3-4): 87-103

Pršek J, Makovicky M, Chovan M, Smirnov A (2006) A note on chemical composition of nuffieldite solid-solution from sulphide mineralizations (Western Carpathians, Slovakia) Mineral Polon 37(1): 51-60

Rojkovič I (1997) Uranium Mineralization in Slovakia. Acta geol Univ Comen, Monogr Ser, 1-117

Sejkora J, Ozdín D, Laufek F, Plášil J, Litochleb J (2011) Marrucciite, a rare Hg-sulfosalt from the Gelnica ore deposit (Slovak Republic), and its comparison with the type occurrence at Buca della Vena mine (Italy). J Geosci 56(4): 399-408

Schachinger T, Paar WH (2017): Antimon- und bismuthältige Sulfosalze aus dem Vetternbergbau bei Schladming, Steiermark. Carinthia II, 207/127: 691-698

Števko M, Sejkora J (2020) Sb-enriched association of Ni arsenides and sulfarsenides from the Zemberg-Terézia vein system near Dobšiná (Western Carpathians, Slovak Republic). Bull Mineral Petrolog 28(1): 105-115

Števko M, Sejkora J, Peterec D (2015) Grumiplucite from the Rudňany deposit, Slovakia: a second world-occurrence and new data. J Geosci 60(4): 269-281

Števko M, Sejkora J, Dojčanský Ľ (2021) New data on sulphosalts from hydrothermal siderite-type veins in the Spišsko-gemerské rudohorie Mts. (eastern Slovakia): 1. Nuffieldite and aikinite from Slovinky-Došťavná vein. Bull Mineral Petrolog 29(1): 108-114

Trdlička Z (1967) Mineralogické studium tetraedritu z ložiska Fichtenhübel (Spišsko-gemerské rudohoří). Čas Mineral Geol 12(2): 115-121

Trdlička Z, Kupka F (1959) Kobellit a ryzí vizmut z lokality Fichtenhübel na Slovensku. Sbor Ústř Úst geol (Praha): 453-464

Trdlička Z, Kvaček M, Kupka F (1962) Mineralogicko-chemický výzkum kobellitu ze sideritových žil rudní oblasti Fichtenhübel (Spišsko-gemerské rudohoří). Čas Mineral Geol 7(4): 432-433

Václav J (1964) Identifikácia kobellitu zo žily Dávid pri Henclovej. Geol Práce Zpr 31: 91-94

Vakh AS, Khomich VG, Boriskina NG, Santosh M (2016) The Berezitovoe gold-polymetallic deposit (Upper Amur region, Russia): Structure, mineralogy and genetic aspects. Geosci Front 7: 483-494

Varček C (1957) Prehľad paragenetických pomerov rudných ložísk Gemera. Geol Práce Zoš 46: 107-131

Varček C (1959) Paragenetické pomery žily Mária v Rožňave. Geol Práce Zoš 55: 181-213

Varček C (1960) Paragenetické pomery žily Bernardi pri Rožňave. Acta Geol Geogr Univ Comen, Geol 4: 107-155

Varček C (1962) Vývoj hydrotermálnej mineralizácie Spišsko-gemerského rudohoria v čase a priestore. Geol Práce Zoš 61: 101-112

Wagner T, Cook NJ (1996) Bismuth-antimony sulfosalts from siderite-hosted vein mineralization, Apollo mine, Siegerland, FRG. N Jb Miner Abh 171: 135-153

Zábranský F, Radzo V (1966) Výskyt kobellitu a paragenetické pomery na žile Oriešková, severne od Nižného Medzeva. Sbor Východoslov Múz (Košice) Sér A, 7: 25-37

Zakrzewski MA (1984) Jaskólskiite, a new Pb-Cu-Sb-Bi sulfosalt from the Vena Deposit, Sweden. Can Mineral 22: 481-485

Zakrzewski MA, Makovicky E (1986) Izoklakeite from Vena, Sweden, and the kobellite homologous series. Can Mineral 24: 7-18

Zimányi K (1914) Arsenopyrit und Bournonit von Rozsnyó. Z Kristallogr Mineral 54(4): 578-583