Original paper

Bismuth, lead–bismuth and lead–antimony sulfosalts from the granite-hosted hydrothermal quartz veins at the Elisabeth mine, Gemerská Poloma, Spišsko-gemerské rudohorie Mts., Slovakia

Martin ŠTEVKO1,2*, Jiří SEJKORA2

1 Earth Science Institute, Slovak Academy of Sciences, Dúbravská cesta 9, 840 05 Bratislava, Slovak Republic; martin.stevko@savba.sk
2 Department of Mineralogy and Petrology, National Museum, Cirkusová 1740, 193 00 Prague 9, Czech Republic

* Corresponding author

An interesting assemblage of bismuth and complex lead–bismuth and lead–antimony sulfosalts have been identified in samples from hydrothermal quartz veins hosted in S-type granitic rocks at the Elisabeth mine near Gemerská Poloma, Slovakia. We provide the first detailed study of the chemical composition of sulfosalts from the hydrothermal veins directly related to the specialized (Sn–W–F enriched) Gemeric granites. Bismuthinite derivates (bismuthinite and phases with $n_{\text{aik}}$ ranging from 21.3 to 23.7 and 30.3), minerals of the kobellite–tintinaite series (with Sb/(Sb + Bi) atomic ratio ranging considerably between 0.13 and 0.71), giessenite–izoklakeite series (with Sb/(Sb + Bi) from 0.26 to 0.33) as well as Pb–Sb sulfosalts (mainly jamesonite, boulangerite, robinsonite and their Bi-rich varieties) are common. Rare Bi-enriched rouxelite, bournonite and minerals of the tetrahedrite group were also observed. The two distinct types of sulfosalts associations were distinguished, each related to the different type of host rock and with variable Bi/Sb ratio. The first is represented predominantly by Bi-rich sulfosalts (bismuthinite derivates, kobellite, giessenite–izoklakeite) and occurs in the quartz veins hosted in P-enriched leucogranite. The second association is developed only in hydrothermal quartz veins hosted in porphyric granites and except of Bi (bismuthinite derivates) also significant amounts of Sb-rich sulfosalts (tintinaite, boulangerite, robinsonite, jamesonite, rouxelite, bournonite and tetrahedrite-(Zn) to tetrahedrite-(Fe)) are present.

Keywords: sulfosalts, bismuthinite derivates, kobellite homologous series, rouxelite, S-type granite, Gemerská Poloma

Received: 26 May 2021; accepted: 1 October 2021; handling editor: J. Zachariáš

The online version of this article (doi: 10.3190/jgeosci.328) contains supplementary electronic material.

1. Introduction

The greisens, albitites and hydrothermal quartz veins related to specialized S-type Gemeric granites were intensively explored for Sn, W, Mo, Nb, Ta and Li. Even though several interesting mineral associations were discovered (e.g., Malachovský et al. 1997, 2000; Petrík et al. 2011; Števko et al. 2015, 2018; Radvanec and Gonda 2019), the sulfidic ore mineralization and especially sulfosalts were never studied in detail. There are only scattered reports about occurrence of bismuthinite, cosalite, jamesonite, emplectite, tetrahedrite and garavellite from greisens and related hydrothermal quartz veins at the Medvedí potok Sn–W–Mo deposit near Hnílec (Drnzíková and Mandáková 1982; Radvanec and Gonda 2019). Malachovský (1983) described the occurrence of bismuthinite, kobellite, Bi-rich jamesonite and Bi-rich boulangerite from greisens and hydrothermal quartz veins hosted in granite from Dlhá dolina near Gemerská Poloma.

This paper is focused on the detailed mineralogical characterization of recently discovered association of bismuth, lead–bismuth and lead–antimony sulfosalts from the hydrothermal quartz veins hosted in a hidden intrusion of S-type Gemeric granites at the Elisabeth mine near Gemerská Poloma. New data on the chemical composition of minerals of the bismuthinite–aikinite series, kobellite homologous series, Pb–Sb sulfosalts and rouxelite as well as their paragenetic relations are presented.

2. Geological setting

The hydrothermal quartz veins with sulfosalts, sulfides, carbonates and phosphates are hosted in the hidden intrusion of specialized Gemeric granites, which was recently uncovered during the excavation of Elisabeth adit at the Gemerská Poloma talc deposit, located about 10 km northwest of Rožňava town, Spišsko-gemerské rudohorie Mts., Slovak Republic [GPS 48°45’4.07”N and 20°29’39.32”E].

The granitic rocks of the Gemeric Unit represent a distinct type of specialized (Sn–W–F), highly evolved suite with S-type affinity that differs from other granitoids occurring in the Veporic and Tatric Units of the Western Carpathian crystalline basement. Besides fluorine, they
are enriched in phosphorus and rare lithophile elements, such as Li, Rb, Cs, B, Ga, Sn, W, Nb, Ta, U and depleted in REE, Zr, Ti, Sr, Ba (e.g., Uher and Broska 1996; Petrik and Kohút 1997; Broska and Uher 2001; Kubiš and Broska 2005, 2010; Broska and Kubiš 2018; Villaseñor et al. 2021). Recent zircon U–Pb and molybdenite Re–Os isotopic dating indicate emplacement of the Gemenic granites and related post-magmatic mineralization during Late Permian (~260 to 230 Ma; Poller et al. 2002; Kohút and Stein 2005; Radvanec et al. 2009; Villaseñor et al. 2021). Younger, Alpine (Cretaceous) fluid-driven low-temperature tectono-metamorphic overprint affected the granitic rocks along mylonite zones (Breiter et al. 2015).

The Gemenic granitic rocks form several small plutons intruding the intensively folded Lower Paleozoic (mainly Ordovician to Devonian) volcano-sedimentary complex of the Gelnica Group metamorphosed under greenschist-facies metamorphic conditions (Bajaník et al. 1984; Petrasová et al. 2007). In the studied area, the metamorphic rocks are represented mainly by phyllites, metapyroclastic rocks of rhyolitic to dacitic composition, locally with bodies and lenses of metadolomite and strongly steatitized magnesite. The latter has been recently exploited by Elisabeth mine as a talc deposit near Gemenšká Poloma (Kilík 1997; Radvanec et al. 2004; Petrasová et al. 2007). Several types of granites were distinguished in the studied area (Fig. 1): (a) coarse-grained porphyric granite to granite porphyry, (b) medium-grained Li-annite–topaz–tourmaline bearing granite, (c) P-enriched topaz–zinnwaldite leucogranite and (d) albitite (Dianiška et al. 2002, 2007; Breiter et al. 2015). Except for the albitites, all listed types of granitic rocks were recently found in the Elisabeth adit (Števko et al. 2015, 2018).

The hydrothermal quartz veins with sulfosalts were observed in all types of granitic rocks but are especially common in porphyric granites and P-enriched leucogranite. They are generally up to 15 cm thick and up to 3 m long. Besides sulfosalts, they contain variable amounts of albite, muscovite, Li-bearing micas, chlorites, rutile, fluorite, polyrase-(Y) to uranopolyrase, bastnäsite-(Ce), carbonates (Mn-rich siderite, rhodochrosite, calcite and dolomite), phosphates (fluorapatite, triplite, fluorarroyalite-(BaNa), fluorarroyalite-(BaFe), fluordickinsonite-(BaNa) and viitaniemiite) and sulfides like pyrite, arsenopyrite, sphalerite, chalcopyrite and minor galena (Uher et al. 2009; Števko et al. 2015, 2018, 2020).

3. Analytical methods

The samples with sulfosalts were systematically (period of 2009–2018) collected at the dumps of Elisabeth mine from the hydrothermal quartz veins hosted in various types of granitic rocks.

Quantitative chemical analyses of sulfosalts were performed on a Cameca SX100 electron microprobe (Department of Mineralogy and Petrology, National Museum, Prague, Czech Republic), operating in the wavelength-dispersive (WDS) mode (25 kV, 20 nA and 2 to 5 μm wide beam). The following standards and X-ray lines were used (DL – detection limit, in wt. %):
Tab. 1 Representative chemical analyses of bismuthinite derivates from Gemerská Poloma (in wt. %)

| h.r. | GPE02 | GPE03 | GPE07 | GPX1 | GPA2 | GPA8 |
|------|-------|-------|-------|------|------|------|
| Pb   | 12.50 | 10.22 | 5.76  | 1.94 | 4.19 | 2.91 |
| Cu   | 3.60  | 2.89  | 1.79  | 0.33 | 1.22 | 0.83 |
| Sb   | 5.37  | 3.61  | 3.65  | 4.25 | 3.55 | 9.11 |
| Bi   | 62.17 | 64.22 | 69.79 | 73.47| 71.83 | 67.47|
| S    | 18.62 | 18.85 | 18.82 | 19.02| 18.97 | 19.96|
| Se   | 0.18  | 0.18  | 0.22  | 0.20 | 0.22 | 0.00 |
| Cl   | 0.00  | 0.00  | 0.00  | 0.00 | 0.00 | 0.00 |
| total| 100.44| 99.97 | 100.03| 99.21| 99.97 | 100.28|

| h.r. | GPE02 | GPE03 | GPE07 | GPX1 | GPA2 | GPA8 |
|------|-------|-------|-------|------|------|------|
| Cu   | 1.181 | 0.947 | 0.575 | 0.106| 0.392 | 0.254|
| Pb   | 1.258 | 1.027 | 0.567 | 0.190| 0.412 | 0.273|
| Bi   | 6.203 | 6.396 | 6.817 | 7.143| 7.005 | 6.280|
| Sb   | 0.577 | 0.617 | 0.612 | 0.709| 0.594 | 1.456|
| S    | 6.780 | 7.013 | 7.429 | 7.852| 7.598 | 7.736|
| Se   | 12.108| 12.236| 11.980| 12.051| 12.053| 12.110|
| Cl   | 0.048 | 0.047 | 0.057 | 0.051| 0.056 | 0.000|
| total| 12.156| 12.283| 12.037| 12.103| 12.109| 12.110|

\[ \text{calculated empirical formulae are based on } (\text{Cu} + \text{Pb})/2 + (\text{Sb} + \text{Bi}) = 8 \text{ appu} \]

h.r. – host rock; LG – leucogranite; PG – porphyric granite
fluorapatite, triplite, polycrase-(Y), Li-bearing micas or siderite.

Representative WDS analyses of minerals of the bismuthinite-aikinite series are given in Tab. 1 (all 131 analyses and corresponding calculated empirical formulae are available in the supplementary data). Makovicky and Makovicky (1978) proposed to characterize members of the bismuthinite-aikinite series by $n_{\text{aik}}$, which corresponds to the percentage of CuPbBiS$_3$ end-member in the Bi$_2$S$_3$–CuPbBiS$_3$ series. Based on this approach, the vast majority of samples from Gemerská Poloma correspond to bismuthinite (Fig. 3a), with the calculated value of $n_{\text{aik}}$ ranging between 1.0 to 14.3 (containing up to 0.58 apfu of Cu and 0.57 apfu of Pb). In one sample, exsolved lamellae, and ribbons hosted in bismuthinite were observed (Fig. 2a, 2b). These phases with $n_{\text{aik}}$ ranging from 21.3 to 23.7 and 30.3 (Fig. 3a) are fitting to the compositional gap between pekoite (with $n_{\text{aik}} = 16.7$) and gladite ($n_{\text{aik}} = 33.3$) and may represent new members of the bismuthinite-aikinite series. Similar exsolved phases with $n_{\text{aik}} = 21–22$ and $n_{\text{aik}} = 25–27$ were described by Topa et al. (2002) from Felbertal scheelite deposit (Austria), as well as by Cook (1997) from epithermal veins near Baia Borşa (Romania), Ciobanu and Cook (2000) and Cook and Ciobanu (2003) from Ocna de Fier skarn deposit (Romania), Xiang-Ping et al. (2001) from Funishan skarn deposit (China), Pršek and Mikuš (2006) from Kolba deposit near Lúbietová (Slovakia) or Voudouris et al. (2013) from Stanos deposit in Chalkidiki (Greece). The amount of Sb substituting for Bi (Fig. 3b) varies in the studied samples considerably from 0.55 up to

![Diagram](image-url)
4.2. Kobellite homologous series

4.2.1. Kobellite–tintinaite series

Minerals of the kobellite–tintinaite series are the most common sulfosalts and occur as individual acicular to prismatic crystals up to 1.5 cm or radial groups and irregular aggregates up to $3 \times 3$ cm in size embedded in quartz. They occur both in porphyric as well as in P-enriched leucogranites and are associated with bismuthinite (Fig. 2a, 2b), minerals of the giessenite–izoklakeite series (Fig. 5a), tiny inclusions of native bismuth and locally also with jamesonite (Fig. 5b), galena or bournonite. Other minerals frequently associated with minerals of the kobellite–tintinaite series are pyrite, fluorite, fluorapatite, siderite and albite.

Representative chemical analyses of minerals of the kobellite–tintinaite series from Gemerská Poloma and the corresponding empirical formulae are shown in Tab. 2 (all 208 analyses and calculated empirical formulae are available in supplementary data). The calculated value of $N$ (order number of kobellite homolog, see Zakrzewski and Makovicky 1986 for details) ranges from 1.85 to 3.63 $apfu$, locally causing weak, irregular chemical zoning (Fig. 4). The samples from quartz veins hosted in porphyric granite tend to be more Sb enriched than those from P-enriched leucogranite. Besides, minor concentrations of Se (up to 0.09 $apfu$) were also detected in some samples.

Fig. 4 Irregular chemical zoning of bismuthinite caused by variation of Bi and Sb contents. Sample GPA2, BSE image.

Fig. 5a – Kobellite (Kbl) associated with tiny inclusions of minerals of the giessenite–izoklakeite series (Iz) and galena (white). Sample GPES4, BSE image. b – Tintinaite (Tti) associated with jamesonite (Ja). Sample GPES5, BSE image. c – Irregular veinlets of tintinaite (Tti) developed in kobellite (Kbl). Sample GPES4, BSE image.
2.06. The Sb/(Sb + Bi) atomic ratio in samples from Gemerská Poloma (Fig. 6) varies considerably between 0.13 and 0.71, representing a rather wide compositional range between kobellite and lintinaite. However, in individual samples, the Sb versus Bi variation tends to be relatively small and only weak chemical zoning was rarely observed in one case (Fig. 5c, sample GPES4). In general, samples from the quartz veins hosted in porphyric granite tend to be Sb-dominant (lintinaite), whereas Bi-dominant compositions (kobellite) prevail in quartz veins hosted in P-enriched leucogranite. All studied samples contain significant concentrations of Cu (1.44 up to 2.05 apfu), but variable amounts of Fe (0.00 up to 0.61 apfu). Variation of Cu and Fe contents in minerals of the kobellite-lintinaite series from Gemerská Poloma is shown in Fig. 7a. The overall Cu + Fe content ranges from

![Variation of Sb/(Sb + Bi) ratio and calculated value of N for minerals of the kobellite homologous series from Gemerská Poloma.](image-url)
1.65 to 2.10 \( \text{apfu} \), with an average of 1.95 \( \text{apfu} \), close to the ideal value of 2 \( \text{apfu} \) (e.g., Zakrzewski and Makovicky 1986; Moëlo et al. 1995; Wagner and Johnsson 2001; Pršek et al. 2008; Mikuš et al. 2018). The maximum content of Ag substituting for Pb (Fig. 7b) is 0.26 \( \text{apfu} \). In addition, minor amounts of Zn (up to 0.09 \( \text{apfu} \)), Se (up to 0.26 \( \text{apfu} \)) and Cl (up to 0.40 \( \text{apfu} \)) were also locally detected.

### 4.2.2. Giessenite–izoklakeite series

Minerals of the giessenite–izoklakeite series are rare and were identified only in two samples, both from the quartz veins hosted in P-enriched leucogranite. They form subhedral grains and aggregates reaching up to 100 \( \mu \text{m} \) in size intimately intergrown with kobellite (Fig. 5a, 8). Representative chemical analyses of minerals of the giessenite–izoklakeite series from Gemerská Poloma and the corresponding empirical formulae are given in Tab. 3 (all 45 analyses and calculated empirical formulae are available in supplementary data). The calculated values of \( N \) range from 3.80 to 4.03. The values of \( \text{Sb}/(\text{Sb} + \text{Bi}) \) ratio in studied samples vary from 0.26 to 0.33 (Fig. 6) and slightly differ between the two studied samples (0.26 to 0.27 in sample GPA4 and 0.31 to 0.33 in sample GPA7).

There is only a quasi-continuous solid solution between giessenite and izoklakeite with increasing Sb/Bi ratio (Moëlo et al. 2008) since, according to the published data, the symmetry of giessenite is monoclinic (Graser and Harris 1986; Makovicky and Karup-Moller 1986) and that of Bi-rich izoklakeite is orthorhombic (Harris et al. 1986; Makovicky and Mumme 1986; Armbruster and Hummel 1987). The exact Sb/Bi ratio at which the symmetry changes is unknown, but according to Moëlo et al. (1995, 2008), the name izoklakeite is applied to all phases with Sb/Bi atomic ratio close to 1 (i.e., \( \text{Sb}/(\text{Sb} + \text{Bi}) \) close to 0.50), even for samples with Bi > Sb. Pažout et al. (2017) estimated that the symmetry change between giessenite and izoklakeite takes place somewhere in the range of \( \text{Sb}/(\text{Sb} + \text{Bi}) \) values of 0.20 to 0.30. Ozawa et al. (1998) described so far the most Bi-enriched izoklakeite from Otome mine in Japan with \( \text{Sb}/(\text{Sb} + \text{Bi}) \) ratio ranging from 0.31 to 0.33. Thus, it is possible that both giessenite and Bi-rich izoklakeite are present at Gemerská Poloma, but all attempts to extract suitable single-crystals to confirm this hypothesis by single-crystal XRD were unsuccessful. Both studied samples of minerals of the giessenite–izoklakeite series contain substantial amounts of Cu (1.81 to 2.15 \( \text{apfu} \)), but surprisingly no Fe (Fig. 7a). Furthermore, the

---

**Fig. 7a** – \( \text{Cu} \) vs. \( \text{Fe} \) (apfu) plot for members of the kobellite homologous series from Gemerská Poloma. **Fig. 7b** – \( \text{Ag} \) vs. \( \text{Pb} \) (apfu) plot for members of the kobellite homologous series from Gemerská Poloma.
The presence of Ag (ranging from 0.46 to 1.01 apfu) substituting for Pb (Fig. 7b) according to lillianite type substitution \( \text{Ag} + \text{Bi} = 2\text{Pb} \) is typical.

### 4.3. Pb–Sb sulfosalts

Pb–Sb sulfosalts, especially jamesonite and robinsonite, as well as minor amounts of boulangerite are common minerals in quartz veins hosted in porphyric granite, but they are absent in hydrothermal quartz veins hosted in P-enriched leucogranite.

#### 4.3.1. Boulangerite

Boulangerite is infrequent. It occurs as acicular crystals up to 7 mm long, developed together with jamesonite in

![Fig. 9a](image)

**Fig. 9a** – Boulangerite (Bou) in contact with galena (Gn). Sample GPN4, BSE image.

**Fig. 9b** – Boulangerite (Bou) associated with jamesonite (Ja) and galena (white). Sample GPN7, BSE image.

| GPES4 | GPA7 |
|-------|------|
| \( \text{Pb} \) | 45.11 | 44.76 | 44.42 | 44.31 | 44.82 | 45.86 | 46.51 | 46.65 | 46.76 | 46.23 | 46.59 | 47.01 | 46.77 | 45.98 |
| \( \text{Ag} \) | 0.93 | 0.86 | 0.91 | 0.82 | 0.99 | 0.85 | 0.89 | 0.53 | 0.49 | 0.46 | 0.66 | 0.60 | 0.54 | 0.64 | 0.74 |
| \( \text{Cu} \) | 1.19 | 1.19 | 1.14 | 1.19 | 1.12 | 1.26 | 1.24 | 1.06 | 1.07 | 1.11 | 1.08 | 1.09 | 1.09 | 1.10 |
| \( \text{Sb} \) | 6.43 | 6.02 | 6.10 | 6.04 | 6.33 | 6.25 | 6.08 | 7.34 | 7.33 | 7.41 | 7.38 | 7.13 | 7.45 | 7.41 | 7.58 |
| \( \text{Bi} \) | 29.40 | 30.00 | 29.79 | 29.72 | 29.67 | 29.41 | 27.56 | 27.72 | 27.43 | 28.12 | 27.90 | 27.27 | 27.54 | 27.72 |
| \( \text{S} \) | 16.97 | 16.65 | 16.92 | 17.20 | 16.63 | 16.89 | 16.69 | 17.02 | 17.21 | 17.12 | 17.05 | 16.94 | 17.15 | 17.27 |
| \( \text{Cl} \) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **total** | 100.03 | 99.48 | 99.28 | 99.27 | 99.04 | 99.80 | 100.17 | 100.02 | 100.47 | 100.29 | 100.52 | 100.24 | 100.26 | 100.10 | 100.39 |

| GPES4 | GPA7 |
|-------|------|
| \( \text{Pb} \) | 23.623 | 23.752 | 23.422 | 23.188 | 23.861 | 23.516 | 24.200 | 24.323 | 24.220 | 24.343 | 24.075 | 24.396 | 24.616 | 24.077 |
| \( \text{Ag} \) | 0.933 | 0.877 | 0.922 | 0.825 | 0.902 | 0.858 | 0.902 | 0.532 | 0.489 | 0.460 | 0.660 | 0.603 | 0.543 | 0.640 | 0.735 |
| \( \text{Cu} \) | 2.039 | 2.059 | 1.960 | 2.022 | 2.129 | 2.151 | 2.140 | 1.808 | 1.811 | 1.884 | 1.844 | 1.861 | 1.849 | 1.856 |
| \( \text{Sb} \) | 5.726 | 5.436 | 5.473 | 5.377 | 5.719 | 5.577 | 5.456 | 6.532 | 6.476 | 6.565 | 6.548 | 6.353 | 6.639 | 6.561 | 6.673 |
| \( \text{Bi} \) | 15.262 | 15.784 | 15.574 | 15.422 | 15.045 | 15.387 | 14.290 | 14.269 | 14.269 | 14.215 | 15.485 | 14.158 | 14.208 | 14.218 |
| \( \text{S} \) | 57.416 | 57.092 | 57.649 | 58.166 | 57.056 | 57.275 | 56.915 | 57.515 | 57.735 | 57.590 | 57.373 | 57.318 | 57.183 | 57.664 | 57.731 |
| \( \text{Cl} \) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **N** | 3.89 | 3.83 | 3.84 | 3.80 | 3.99 | 3.83 | 4.01 | 3.82 | 3.80 | 3.81 | 3.80 | 3.87 | 3.89 | 3.85 | 3.82 |

calculated empirical formulae are based on sum of all atoms = 105 apfu
cavities of quartz, subhedral to anhedral grains and aggregates replacing galena (Fig. 9a, GPN4) or individual subhedral crystals up to 100 µm in size associated with jamesonite (Fig. 9b, GPN7). Other accompanying minerals are sphalerite, pyrite, fluorite, siderite, dolomite and albite. Representative chemical analyses of boulangerite are shown in Tab. 4 (all 61 analyses and calculated empirical formulae are available in supplementary data).

Elevated contents of Bi (up to 0.32 apfu) substituting for Sb are typical (Fig. 10). Minor amounts of other elements such as Fe, As or Cl (all reaching up to 0.04 apfu) were also detected.

4.3.2. Robinsonite

Robinsonite is a common sulfosalts in quartz veins hosted in porphyric granite. It forms irregular or radial aggregates up to 3 × 3 cm in size, consisting of individual acicular crystals up to 1.5 cm long. Groups and aggregates of acicular crystals of robinsonite included in fluorite were also observed. Robinsonite is frequently associated mainly with jamesonite (Fig. 11), galena or sphalerite.

Quantitative chemical analyses and the corresponding calculated empirical formulae of robinsonite from Gemerská Poloma are given in Tab. 5 (all 107 analyses and calculated empirical formulae are available in supplementary data). Significant incorporation of Bi (ranging from 0.13 up to 2.08 apfu) is characteristic for robinsonite from Gemerská Poloma (Fig. 10). Similar elevated contents of Bi in robinsonite were so far described only by Jambor and Lachance (1968) from the Dodger tungsten mine in British Columbia (Canada), or by Števko and Sejkora (2017) from Čížko baňa occurrence near Ochtiná (Slovakia). Furthermore, minor concentrations of Fe (up to 0.07 apfu), Cu (up to 0.03 apfu) as well as Cl (up to 0.04 apfu) are present in robinsonite.

![Tab. 4 Representative chemical analyses of boulangerite from Gemerská Poloma (in wt. %)](image)

|     | GPX3 | GPN1 | GPN2 | GPN3 | GPN5 | GPN6 |
|-----|------|------|------|------|------|------|
| Pb  | 38.59| 38.33| 39.68| 39.98| 38.93| 39.71|
| Cu  | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Fe  | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Sb  | 25.37| 25.31| 30.22| 31.27| 28.48| 30.81|
| Bi  | 15.90| 16.05| 9.48 | 8.45 | 12.66| 9.29 |
| S   | 20.12| 20.11| 20.70| 20.99| 20.84| 20.81|
| Cl  | 0.00 | 0.00 | 0.05 | 0.00 | 0.00 | 0.00 |
| total| 99.98| 99.79| 100.13| 100.69| 100.88| 100.77|

are based on sum of all atoms = 23 apfu

![Fig. 10 Variation of Sb and Bi contents (at. %) in Pb–Sb sulfosalts and bournonite from Gemerská Poloma](image)
4.3.3. Jamesonite

Jamesonite is an abundant mineral and it occurs as radial or irregular aggregates up to 3 cm embedded in quartz, which consists of individual acicular crystals up to 1 cm long. It is predominantly associated with other Pb–Sb sulfosalts (robinsonite, boulangerite; Fig. 9b, 11) as well as sphalerite, galena, pyrite, arsenopyrite, fluorite, siderite and dolomite. In two cases, minerals of the kobellite–tintinaite series (tintinaite; Fig. 12) were also found in direct association with jamesonite.

Representative chemical analyses of jamesonite from Gemerská Poloma and the corresponding empirical formulae are given in Tab. 6 (all 128 analyses and calculated empirical formulae are available in supplementary data). Jamesonite is characterized especially by an elevated content of Bi (ranging from 0.11 up to 1.22 apfu) substi-

Tab. 5 Representative chemical analyses of robinsonite from Gemerská Poloma (in wt. %)

|           | GPX3 | GPX1 | GPX2 | GPX3 | GPX1 | GPX2 | GPX3 | GPX1 | GPX2 | GPX3 | GPX1 | GPX2 | GPX3 | GPX1 | GPX2 |
|-----------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Pb        | 38.59| 38.33| 39.68| 39.98| 39.83| 39.71| 39.88| 39.73| 39.88| 39.75| 39.54| 39.36| 39.88| 39.74| 39.88|
| Cu        | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Fe        | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Sb        | 25.37| 25.31| 30.22| 31.27| 28.48| 30.81| 31.83| 22.14| 30.05| 25.98| 33.43| 32.39| 36.75| 35.56| 34.36|
| Bi        | 15.90| 16.05| 9.48 | 8.45 | 12.66| 7.77 | 7.77 | 22.14| 30.05| 25.98| 33.43| 32.39| 36.75| 35.56| 34.36|
| S         | 20.12| 20.11| 20.70| 20.99| 20.81| 20.96| 20.63| 19.72| 20.30| 19.92| 20.24| 20.47| 20.46| 20.13| 20.47|
| Cl        | 0.00 | 0.00 | 0.05 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| total     | 99.98| 99.79| 100.13|100.69|100.88|100.77|100.12|99.72|100.64|99.63|100.07|100.09|99.83|100.20|99.66|
| Pb        | 3.901| 3.879| 3.892| 3.877| 3.820| 3.857| 3.902| 3.874| 3.909| 3.889| 3.928| 3.953| 4.000| 4.046| 3.961|
| Cu        | 0.000| 0.000| 0.000| 0.000| 0.000| 0.000| 0.000| 0.023| 0.000| 0.000| 0.000| 0.031| 0.000| 0.000| 0.000|
| Fe        | 0.000| 0.000| 0.000| 0.000| 0.000| 0.000| 0.000| 0.000| 0.000| 0.000| 0.000| 0.000| 0.000| 0.000| 0.000|
| Sb        | 4.364| 4.359| 5.042| 5.160| 4.755| 5.093| 5.530| 3.890| 5.055| 4.482| 5.591| 5.400| 6.060| 5.913| 5.710|
| Bi        | 1.594| 1.611| 0.922| 0.812| 1.232| 0.895| 0.754| 2.081| 1.047| 1.538| 0.573| 0.657| 0.129| 0.291| 0.413|
| S         | 13.141|13.151|13.116|13.151|13.194|13.155|13.043|13.155|12.967|13.049|12.854|12.958|12.811|12.711|12.916|
| Cl        | 0.000| 0.000| 0.028| 0.000| 0.000| 0.000| 0.000| 0.041| 0.000| 0.000| 0.000| 0.000| 0.000| 0.000| 0.000|

calculated empirical formulae are based on sum of all atoms = 23 apfu
### 4.4. Rouxelite

Rouxelite is very rare. It forms subhedral to anhedral grains up to 80 µm (Fig. 13) directly associated with Bi-rich robinsonite, Bi-rich jamesonite and galena in quartz veins hosted in porphyric granite. Quantitative chemical analyses and the corresponding calculated empirical formulae of rouxelite from Gemerská Poloma

#### Tab. 7 Chemical composition of rouxelite from Gemerská Poloma (in wt. %)

|      | GPN5   | GPN6   | GPN7 | GPN8 | GPA3 | GPA4 |
|------|--------|--------|------|------|------|------|
| Pb   | 0.14   | 0.19   | 0.20 | 0.17 | 0.17 | 0.17 |
| Ag   | 1.11   | 1.37   | 1.48 | 1.29 | 1.29 | 1.29 |
| Hg   | 1.16   | 1.77   | 1.77 | 1.15 | 1.15 | 1.15 |
| Cu   | 0.06   | 0.00   | 0.00 | 0.00 | 0.00 | 0.00 |
| Sb   | 27.67  | 27.83  | 27.64 | 28.31 | 28.31 | 28.31 |
| Bi   | 16.13  | 6.27   | 6.30 | 6.33 | 5.97 | 5.37 |
| S    | 19.79  | 19.56  | 19.65 | 19.71 | 19.81 | 19.81 |
| total| 99.55  | 100.33 | 99.88 | 100.20 | 100.18 | 99.64 |

calculated empirical formulae are based on sum of all atoms = 53 $\text{apfu}$
are shown in Tab. 7. Elevated contents of Ag (up to 0.22 \textit{apfu}), which substitutes for Hg (Fig. 14a) as well as minor amounts of Fe (up to 0.12 \textit{apfu}) were detected. The presence of significant contents of Bi (ranging from 2.66 to 3.24 \textit{apfu}) substituting for Sb (Fig. 14b) is a characteristic feature of rouxelite from Gemerská Poloma, whereas no Bi was detected in rouxelite from Buca della Vena and Magurka (Orlandi et al. 2005) or Kľačianka (Sejkora et al. 2021) and rouxelite from Monte Arsicio (Biagioni et al. 2014) shows only minor bismuth enrichment (up to 0.03 \textit{apfu}). The mean \((n = 12)\) empirical formula of studied rouxelite based on \(\Sigma Me = 53 \text{ \textit{apfu}}\) is \((\text{Cu}_{1.95}\text{Fe}_{0.04}\text{Hg}_{0.70}\text{Ag}_{0.17})_{20.87}\text{Pb}_{22.58}(\text{Sb}_{24.59}\text{Bi}_{0.97})_{27.56}\text{S}_{65.28}\). 

\[ \text{Pb}_{0.97}\text{Cu}_{0.95}(\text{Sb}_{1.02}\text{Bi}_{0.02})_{1.99}\text{S}_{65.28} \]

4.5. Bournonite

Bournonite was rarely found as anhedral grains and aggregates up to 40 µm in size associated with tintinaite and galena (Fig. 15) in quartz veins hosted in porphyric granite. WDS analyses of bournonite from Gemerská Poloma are shown in Tab. 8. Besides of dominant contents of Pb, Cu, Sb and S only minor amounts of Bi (up to 0.03 \textit{apfu}) were observed (Fig. 10). The mean \((n = 7)\) empirical formula of studied bournonite based on the sum of all atoms = 6 is \(\text{Pb}_{0.97}\text{Cu}_{0.95}(\text{Sb}_{1.02}\text{Bi}_{0.02})_{1.99}\text{S}_{3.04}\).

4.6. Tetrahedrite group minerals (tetrahedrite-(Zn), tetrahedrite-(Fe))

Minerals of the tetrahedrite group are very rare and occur only in quartz veins hosted in porphyric granite. They form anhedral grains and aggregates up to 7 mm in size embedded in quartz, closely associated with chalcopyrite and pyrite. Quantitative chemical analyses and the corresponding calculated empirical formulae of minerals of the tetrahedrite group from Gemerská Poloma are shown in Tab. 9. The trigonal position is predominantly occupied by Cu and only mi-

Fig. 14a – Variation of Ag vs. Hg contents (\textit{apfu}) in rouxelite from Gemerská Poloma and other worldwide occurrences. b – Variation of Sb versus Bi contents (\textit{apfu}) in rouxelite from Gemerská Poloma.
nor amounts of Ag (up to 0.10 apfu) are present. Zinc is a dominant element in the tetrahedral site (reaching up to 1.18 apfu), but Fe (reaching up to 1.16 apfu) is locally prevailing over Zn (Fig. 16), accompanied by only minor amounts of Hg (up to 0.05 apfu). Antimony is considerably prevailing (3.55–4.08 apfu) over As (0.03–0.58 apfu), so according to the recently published nomenclature scheme of minerals of the tetrahedrite group (Biagioni et al. 2020), the studied phases from Gemerská Poloma correspond to tetrahedrite-(Zn) and tetrahedrite-(Fe).

4.7. Origin and metallogenic setting of the studied mineralization

Bismuth (especially bismuthinite derivates and kobellite homologs) and lead–antimony sulfosalts (especially jamesonite, boulangerite or bouroninite) are relatively common ore minerals at the siderite-type hydrothermal carbonate–quartz veins with sulfides hosted in Paleozoic (mostly Carboniferous) rocks in the Spišsko-gemerské rudohorie Mts. (e.g., Vacţ 1957; Kupčík et al. 1969; Grecura et al. 1995; Pršek 2008; Mikuš et al. 2018,

---

**Tab. 8** Chemical composition of bouroninite from Gemerská Poloma (in wt. %)

|          | Pb   | 14.38 | 14.74 | 14.71 | 14.15 | 14.29 | 40.82 | 41.62 |
|----------|------|-------|-------|-------|-------|-------|-------|-------|
|          | Cu   | 12.47 | 12.39 | 12.07 | 12.45 | 12.46 | 12.22 | 12.43 |
|          | Sb   | 20.88 | 20.59 | 20.28 | 20.91 | 20.62 | 24.80 | 25.80 |
|          | Bi   | 0.06  | 0.98  | 1.19  | 0.25  | 0.53  | 1.14  | 0.71  |
|          | S    | 19.96 | 20.10 | 20.10 | 19.90 | 19.88 | 19.82 | 20.36 |
| total    |      | 99.75 | 100.80 | 100.28 | 99.66 | 99.78 | 98.81 | 100.91 |

**Tab. 9** Chemical composition of tetrahedrite-(Zn) and tetrahedrite-(Fe) from Gemerská Poloma (in wt. %)

|          | GPS8 |      | Ttr-Fe |      |      | Ttr-Zn |      |
|----------|------|------|-------|------|------|--------|------|
| Ag       | 0.65 | 0.65 | 0.67  |      |      |        |      |
| Cu       | 37.85 | 37.73 | 37.15 |      |      |        |      |
| Fe       | 3.70  | 3.90  | 3.87  |      |      |        |      |
| Zn       | 3.42  | 3.16  | 3.21  |      |      |        |      |
| Hg       | 0.24  | 0.04  | 0.20  |      |      |        |      |
| Sb       | 29.63 | 29.49 | 29.50 |      |      |        |      |
| As       | 0.19  | 0.15  | 0.17  |      |      |        |      |
| S        | 24.55 | 24.47 | 24.32 |      |      |        |      |
| total    | 100.23 | 99.59 | 99.09 |      |      | 99.38  | 99.39 | 99.78 | 98.89 | 99.93 | 100.47 |

|          |      | Cu<sub>0.98</sub> | 6.000 | 6.000 | 6.000 | 6.000 | 6.000 | 6.000 | 6.000 | 6.000 | 6.000 |
|----------|------|------------------|------|------|------|------|------|------|------|------|------|
| Ag       | 0.100 | 0.100 | 0.104 |      |      | 0.096 | 0.096 | 0.090 | 0.082 | 0.064 | 0.065 | 0.068 | 0.059 |
| Sb       | 0.20  | 0.003 | 0.017 |      |      | 0.032 | 0.054 | 0.024 | 0.020 | 0.045 | 0.047 | 0.042 | 0.047 |
| As       | 0.020 | 0.033 | 0.038 |      |      | 0.064 | 0.078 | 0.094 | 0.074 | 0.142 | 0.157 | 0.546 | 0.063 |
| S        | 0.012 | 0.067 | 0.098 |      |      | 0.087 | 0.099 | 0.126 | 0.109 | 0.147 | 0.129 | 0.140 | 0.139 |
| total    | 12.664 | 12.688 | 12.710 | 12.740 | 12.676 | 12.702 | 12.648 | 12.351 | 12.446 | 12.420 | 12.618 |
Although the studied association of sulfosalts from the hydrothermal quartz veins at the Gemerská Poloma has many similarities with the sulfosalt mineralization frequently developed at the siderite-type hydrothermal veins in the Gemeric unit, it represents considerably different and much older type of mineralization. Kohút and Stein (2005) confirmed the Permian (~260 Ma) age of hydrothermal ore mineralization related to the Hnilec granite intrusion by Re/Os dating of molybdenite. In contrast, recent geochronological data from hydrothermal monazite (Hurai et al. 2015) or hydrothermal carbonates and gersdorffite (Kiefer et al. 2020) support the Cretaceous age of the siderite-type hydrothermal veins in the Gemeric unit. Moreover, bismuthinite, kobellite homologs and Bi-rich jamesonite were recently identified at hydrothermal U–Mo mineralization in Majerská valley near Čučma, also directly related to Permian Gemeric granites (Ferenc et al. 2021). Thus, the association of sulfosalts represented by bismuthinite, kobellite homologs and Bi-rich Pb–Sb sulfosalts is not typical only for the siderite-type veins but also for the other, mineralogically different and older types of hydrothermal mineralization in the Gemeric unit.

The origin of the hydrothermal quartz veins with sulfosalts at the Gemerská Poloma is connected to the post-magmatic hydrothermal activity directly related with the intrusion of specialized, P-, F- and Li-enriched S-type Gemeric granites. This is supported by the fact that the studied veins are developed strictly in granitic rocks as well as by significantly different styles of mineralization with an abundant presence of fluorite or phosphates (Števko et al. 2015) and locally also Nb–Ta minerals (Uher et al. 2009) or bastnäsite-(Ce) (Števko et al. 2020) and only minor presence of hydrothermal carbonates (Mn-rich siderite and minor dolomite). Hurai ed. (2007) studied fluid inclusions in quartz and fluorite from the hydrothermal quartz veins with sphalerite, galena and Pb–Sb sulfosalt hosted in granite from the exploration drill hole VDD-14 located in Dlhá dolina near Gemerská Poloma. Homogenization temperatures of primary two-phase \( \text{H}_2\text{O} - \text{CO}_2 \) inclusions in quartz were 115–150 °C and \( \text{H}_2\text{O} - \text{NaCl} - \text{CaCl}_2 \) fluid inclusions in fluorite homogenized at 96–147 °C. The salinities varied substantially (from 3.1 to 35 wt. % NaCl eq.), especially in fluid inclusions in fluorite. It can be assumed that the studied hydrothermal quartz veins with sulfosalts, fluorite and phosphates from Gemerská Poloma represent relatively low thermal, granite-related hydrothermal mineralization.

5. Conclusions

The hydrothermal quartz veins hosted in S-type Gemeric granites at Elisabeth mine near Gemerská Poloma contain an interesting and complex association of Bi, Pb–Bi and Pb–Sb sulfosalts represented by bismuthinite derivates, minerals of kobellite homologous series, boulangerite, robinsonite, jamesonite, rouxelite, bournonite and minerals of the tetrahedrite group.

The two distinct types of sulfosalts associations were distinguished, each related to the different type of host rock and with variable Bi/Sb ratio. The first one is represented predominantly by Bi-rich sulfosalts (bismuthinite...
Sulfosalts from the Elisabeth mine, Gemerská Poloma, Slovakia

This work was financially supported by the VEGA project (2/0028/20) to MS and by the Ministry of Culture of the Czech Republic (DKRVO 2019-2023/1.II.c, 00023272) to JS. Both referees, Juraj Majzlan and Štefan Ferenc, as well as handling editor Jiří Zachariáš and editor-in-chief Jakub Plášil, are highly acknowledged for comments and suggestions that helped immensely to improve the manuscript.

Supplementary file with tables containing chemical analyses of bismuthinite derivates, kobellite-tintinaite series, giessenite-izoklakeite series, boulangerite, robinsonite and jamesonite is available online at the Journal web site (http://dx.doi.org/10.3190/jgeosci.328).

Acknowledgements. This work was financially supported by the VEGA project (2/0028/20) to MS and by the Ministry of Culture of the Czech Republic (DKRVO 2019-2023/1.II.c, 00023272) to JS. Both referees, Juraj Majzlan and Štefan Ferenc, as well as handling editor Jiří Zachariáš and editor-in-chief Jakub Plášil, are highly acknowledged for comments and suggestions that helped immensely to improve the manuscript.

Supplementary file with tables containing chemical analyses of bismuthinite derivates, kobellite-tintinaite series, giessenite-izoklakeite series, boulangerite, robinsonite and jamesonite is available online at the Journal web site (http://dx.doi.org/10.3190/jgeosci.328).

References

Armbruster T, Hummel W (1987) (Sh,Bi,Pb) ordering in sulfosalts: crystal-structure refinement of a Bi-rich izoklakeite. Amer Miner 72: 821–831
Bajaník Š, Ivaníčka J, Melko J, Pristaš J, Reichwalder P, Snopko L, Vozár J, Vozárová A (1984) Geological map of the Slovenské Rudohorie Mts. – eastern part 1:50 000. Dionýz Štúr Institute of Geology, Bratislava
Biagioni C, Moello Y, Orlandi P (2014) Lead–antimony sulfosalts from Tuscany (Italy). XV. (Tl–Ag)-bearing rouxelite from Monte Arsiccio mine: occurrence and crystal chemistry. Mineral Mag 78: 651–661
Biagioni C, George LL, Cook NJ, Makovicky E, Moello Y, Pasero M, Sejkora J, Stanley CJ, Welch MD, Bosi F (2020) The tetrahedrite group: Nomenclature and classification. Amer Miner 105(1): 109–122
Breiter K, Broska I, Uher P (2015) Intensive low-temperature tectono-hydrothermal overprint of peraluminous rare-metal granite: a case study from the Dlhá dolina valley (Gemicicum, Slovakia). Geol Carpath 66: 19–36
Broska I, Uher P (2001) Whole-rock chemistry and genetic typing of the West-Carpathian Variscan granites. Geol Carpath 52: 79–90
Broska I, Kubíš M (2018) Accessory minerals and evolution of tin-bearing S-type granites in the western segment of the Gemic Unit (Western Carpathians). Geol Carpath 59: 483–497
Ciobanu CL, Cook NJ (2000) Intergrowths of bismuth sulfosalts from the Ocna de Fier Fe-skarn deposit, Banat, Southwest Romania. Eur J Mineral 12: 899–917
Cook NJ (1997) Bismuth and bismuth-antimony sulfosalts from Neogene vein mineralisation, Baia Borşa area, Maramureş, Romania. Mineral Mag 61: 387–409
Cook NJ, Ciobanu CL (2003) Lamellar minerals of the cuprobismutite series and related padérite: A new occurrence and implications. Canad Mineral 41: 441–456
Dianiska I, Breiter K, Broska I, Kubis M, Malachovsky P (2002) First phosphorous-rich Nb-Ta–Sn-specialised granite from the Carpathians – Dlhá dolina valley granite pluton, Gemic Unit superunit. Geol Carpath 53: Special Issue (CD-ROM)
Dianiska I, Uher P, Hurai V, Hurajova M, Frank W, Konecný P, Krací J (2007) Mineralization of rare-metal granites. Pp. 254–330 In: Hurai V, ed. (2007) Sources of fluids and origin of mineralizations in the Gemic Unit. Open file report, Dionyz Štúr Institute of Geology, Bratislava, 1–365 (in Slovak)
Drnzikova L, Mandakova K (1982) Mineralogy of tin and associated mineralizations in Hnilec ore field. Unpublished report, Geofond, 1–90 (in Slovak)
Ferenc Š, Števko M, Mikuš T, Milovská S, Kopačik R, Hoppanova E (2021) Primary minerals and age of the hydrothermal quartz veins containing U–Mo–(Pb, Bi, Te) mineralization in the Majerská valley near Čučma (Gemic Unit, Spišsko-gemerské rudohorie Mts., Slovak Republic). Minerals 11: 629
Graser S, Harris DC (1986) Giessenite from Giessen near Binn, Switzerland: New data. Canad Mineral 24: 19–20
Greecula P, Abonyia A, Abonyiová M, Antaš J, Bartalský B, Bartalský J, Dianiska I, Duda R, Gargulák M, Gazdačko L, Hudaček J, Kobulsky J, Lóringcz L, Macko J, Novotný L, Novotný R, Padeřtová J, Rappl J, Števka M, Vrček C, Zlocha Z (1995) Mineral deposits of the Slovak Ore Mountains. Vol. 1. Geocomplex, Bratislava, 1–834
Harris DC, Roberts AC, Criddle AJ (1986) Izoklakeite, a new mineral species from Izok Lake, Northwest Territories. Canad Mineral 24: 1–5
Hurai V, ed. (2007) Sources of fluids and origin of mineralizations in the Gemic unit. Open file report, Dionyz Štúr Institute of Geology, Bratislava, 1–365 (in Slovak)
Hurai V, Paquette JL, Lexa O, Konecný P, Dianiska I (2015) U–Pb–Th geochronology of monazite and zircon in albite metasomatites of the Rožňava–Nadabula ore field (Western Carpathians, Slovakia): implications for the origin of hydrothermal polymetallic siderite veins. Mineral Petrol 109: 519–530
JAMBOR JL, LACHANCE GR (1968) Bismuthian robinsonite. Canad Mineral 9: 426–428
KEFFER S, ŠTEVKO M, VOJTKO R, OZDÍN D, GERDES A, CREASER RA, SZCZERBA M, MAZZLAN J (2020) Geo-
chronological constraints on the carbonate–sulfarsenide veins in Dobšiná, Slovakia: U/Pb ages of hydrothermal
carbonates, Re/Os age of gersdorffite, and K/Ar ages of fuchsite. J Geosci 65: 229–247
KILÍK J (1997) Geological characteristic of the tale deposit in Gemerská Poloma–Dlhá dolina. Acta Montan Slovaca
2: 71–80 (in Slovak)
KOHÚT M, STEIN H (2005) Re–Os molybdenite dating of granitoid mineralization in the Rožňava ore field (Western
Carpathians, Slovakia). Mineral Petrol 85: 117–129
KUBIŠ M, BROSKA I (2005) The role of boron and fluorine in evolved granitic rock systems (on the example of the
Hnielec area, Western Carpathians). Geol Carpath 56: 193–204
KUBIŠ M, BROSKA I (2010) The granite system near Betliar village (Gemic Superunit, Western Carpathians): evolu-
tion of a composite silicic reservoir. J Geosci 55: 131–148
KUPČÍK V, SCHNEIDER A, VARČEK C (1969) Chemical composi-
tion of some Bi sulfosalts from the Spišsko-gemerské rudohorie Mts. Neu Jb Mineral, Mh 10: 445–454 (in
German)
MAKOVICKÝ E, KARUP-MOLLER S (1986) New data on giessenite from the Björgåsen sulfide deposit at Otoften,
northern Norway. Canad Mineral 24: 21–25
MAKOVICKÝ E, MAKOVICKÝ M (1978) Representation of composition in the bismuthinite–aikinite series. Canad
Mineral 16: 405–409
MAKOVICKÝ E, MUMME WG (1986) The crystal structure of izoklakeite, Pb$_{51.3}$S$_{20.4}$Bi$_{19.5}$Ag$_{3.2}$Cu$_{2.9}$S$_{14}$; the kobellite
homologous series and its derivates. Neu Jb Mineral, Abh 153: 121–145
MALACHOVSKÝ P (1983) Mineralogy and paragenetic condi-
tions of tin, rare metal and hydrothermal mineralization in Dlhá dolina. Unpublished report, Geofond, 1–146 (in
Slovak)
MALACHOVSKÝ P, JILEN S, ĎUĎA R (1997) Minerals of indium from Gemerská Poloma–Dlhá dolina. Natura
Carpat 38: 17–22 (in Slovak)
MALACHOVSKÝ P, UHER P, ĎUĎA R (2000) Nb–W minerals in Dlhá valley rare-element granites, Spiš-Gemer Ore
Mountains, Slovakia. Natura Carpat 41: 17–22 (in Slovak)
MIKOŠ T, KONDAŁA J, JACKO S, MIŁOWSKA S (2018) Garavel-
lite and associated sulfosalts from the Strieborná vein in the Rožňava ore field (Western Carpathians). Geol Carpath
69: 221–236
MIKOŠ T, BAKOS F, HÖNSIG S (2019) Bismuth sulfosalts from the siderite–sulphidic and As–Co mineralization in Medzev area, Slovakia. Ageos 11(2): 91–102
MOELO Y, ROGER G, MAUREL-PALACIN D, MARCOURX 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$_3$S$_2$–Cu$_3$S–Sb$_3$–Bi$_3$S$_3$ system. Mineral Petrol 53: 229–250
MOELO Y, MAKOVICKÝ E, MOZGOVA NN, JAMBOR JL, COOK N, PRING A, PAAR W, NICKEL EH, CREASER S, KARUP-
MOLLER S, BALIC-ZUNIC T, MUMME WG, VURRO F, TOPA D, BENDI L, BENTE K, SHIMIZU M (2008) Sulfosalts
systematics: a review. Report of the sulfosalt subcommit-
tee of the IMA Commission on Ore Mineralogy. Eur J
Mineral 20: 7–46
ORLANDO P, MOELO Y, MEERSCHAUT A, PALVADEAU P, LÉONE P (2005) Lead–antimony sulfosalts from Tuscany (Italy).
VIII. Rouxelite, Cu$_4$HgPb$_2$S$_8$S$_6$ (O,S)$_4$, a new sulfosalt from Buca della Vena mine, Apuan Alps: definition and
crystal structure. Canad Mineral 43: 919–933.
OZAWA T, SAITOW A, HORI H (1998) Chemistry and crystallography of Bi-rich izoklakeite from the Otome
mine, Yamanashi Prefecture, Japan and discussion of the izoklakeite–giessenite series. Mineral J 20: 179–187
PAŽOUT R (2020) Distribution of Bi in the crystal structure of Bi-rich jamesonite, FePb$_{(5.48\pm 0.36)_{3.40}}$Bi$_{(0.52)_{2.9}}$S$_{14}$, J Geosci
65: 261–265
PAŽOUT R, SEJKORA J, ŠREIN V (2017) Bismuth and bismuth-
antimony sulphosalts from Kútňa Hora vein Ag–Pb–Zn
ore district, Czech Republic. J Geosci 62: 59–76
PETRÁSOVÁ K, FARVAD SW, ČERÁK P, ŽÁKOVÁ E (2007) Origin and metamorphic evolution of magnesite–talc and
adjacent rocks near Gemerská Poloma, Slovak Republic. J Geosci 52: 125–132
PETRÍK I, KOHÚT M (1997) The evolution of granitoid magmatism during the Hercynian orogen in the Western
Carpathians. In: GRECULA P, HOVORKA D, PUTIŠ M (eds.) Geological Evolution of the Western Carpathians. Miner
Slov Monogr 235–252
PETRÍK I, KUBIŠ M, KONEČNÝ P, BROSKA I, MALACHOVSKÝ P (2011) Rare phosphates from the Surovec topaz–Li
mica microgranite, Gemeric unit, Western Carpathians, Slovak Republic: Role of F/H$_2$O of the melt. Canad
Mineral 49: 521–540
POLLER U, UHER P, BROSKA I, PLAŠŠENKA D, JANÁK M (2002) First Permian–Early Triassic zircon ages for
tin-bearing granites from the Gemeric unit (Western Carpathians, Slovakia): connection to the post-collisional
extension of the Variscan orogen and S-type granite magmatism. Terra Nova 14: 41–48
POUCHOU JL, PICHOIR F (1985) “PAP” (øPZ) procedure for improved quantitative microanalysis. In: ARMSTRONG JT (ed) Microbeam Analysis. San Francisco Press 104–106
PRŠEK J (2008) Chemical composition and crystal chemistry of Bi sulfosalts from the hydrothermal mineralizations
hosted in crystalline basement of the Western Carpathians. Univerzita Komenského, Bratislava, 1–108 (in Slovak)
Pršek J, Mikuš T (2006) Bi sulphosalts from the Ľubietová-Kolba occurrence. Miner Slov 38: 159–164

Pršek J, Ozdín D, Sejkora J (2008) Eclarite and associated Bi sulfosalts from the Brezno-Hviezda occurrence (Nízke Tatry Mts, Slovak Republic). Neu Jb Mineral, Abh 185: 117–130

Radvanec M, Gonda S (2019) Genetic model of Permian hydrothermal mineralization in Generic unit (W. Carpathians) from deep-seated zone of anatetic melting to volcanic-exhalative SedEx mineralization on surface. Miner Slov 52: 109–156

Radvanec M, Kodéra P, Prochaska W (2004) Mg replacement at the Gemerská Poloma talc–magnesite deposit, Western Carpathians, Slovakia. Acta Geol Sin 20: 773–790

Radvanec M, Konečný P, Ondrejka M, Putiš M, Uher P, Németh Z (2009) The Generic granites as an indicator of the crustal extension above the Late-Variscan subduction zone during the early Alpine riftogenesis (Western Carpathians): an interpretation from the monazite and zircon ages dated by CHIME and SHRIMP methods. Miner Slov 41: 381–394

Sejkora J, Števko M, Pršek J, Litochleb J, Hovorič R, Makovicky E, Chovan M (2021) Unique association of sulfosalts from the Kľačianka occurrence, Nízke Tatry Mts., Slovak Republic. Minerals, 11, 1002

Števko M, Sejkora J (2017) Boullangerite and robinsonite from the Ochtiná-Čížko baňa occurrence (Slovak Republic). Bull Mineral Petrolog 25: 273–276 (in Slovak)

Števko M, Uher P, Sejkora J, Malíková R, Škoda R, Václavovič T (2015) Phosphate minerals from the hydrothermal quartz veins in specialized S-type granites, Gennerská Poloma (Western Carpathians, Slovakia). J Geosci 60: 237–249

Števko M, Sejkora J, Uher P, Cámara F, Škoda R, Václavovič T (2018) Fluorattojadite-(BaNa), BaNa2CaFe3+2Al(PO4)3(OH)F2, a new member of the arrojadite group from Gemerská Poloma, Slovakia. Mineral Mag 82: 863–876

Števkov M, Sejkora J, Dolníček Z (2020) Hydrothermal bastnäsite-(Ce) from the Elisabeth adit near Gemerská Poloma (Slovak Republic). Bull Mineral Petrolog 28: 1–8 (in Slovak)

Tumpa D, Makovicky E, Paar WH (2002) Composition ranges and exsolution pairs for the members of the bismuthinite–aikinite series from Felbertal, Austria. Canad Mineral 40: 849–869

Uher P, Broska I (1996) Post-orogenic Permian granitic rocks in the Western Carpathian–Pannonian area: geochemistry, mineralogy and evolution. Geol Carpath 47: 311–321

Uher P, Malachovský P, Bačík P, Chudík P, Števko M (2009) Polyrase-(Y), uranopolyrase a Ti–Nb–Ta–Fe mineral in quartz veins and exocontact zones of the Genners granites, the Slovak Ore Mountains. Bull mineral-petrolog Odd Nár Muz (Praha) 17: 14–24 (in Slovak)

Vanček C (1957) Summary of paragenetic conditions of ore deposits in Genners region. Geol Práce, Zso 46: 107–131 (in Slovak)

Villasenór G, Catlos EJ, Broska I, Kohút M, Hraško L, Aguleraa K, Etzel TM, Kyle R, Stockli DF (2021) Evidence for widespread mid-Permian magmatic activity related to riftting following the Variscan orogeny (Western Carpathians). Lithos (390–391): 106083

Voudouris PC, Spry PG, Mavrogonatos C, Sakellaris GA, Bristol SK, Melfos V, Fornadel AP (2013) Bismuthinite derivate, lillianite homologues, and bismuth sulfotellurides as indicators of gold mineralization in the Stanos shear-zone related deposit, Chalkidiki, northern Greece. Canad Mineral 51: 119–142

Wagner T, Jonsson E (2001) Mineralogy of sulfosalts-rich vein-type ores, Bolden massive sulfide deposit, Skellefte District, Northern Sweden. Canad Mineral 39: 855–872

Xiang-Ping G, Wanatabe M, Ohkawa M, Hoshino K, Shibata Y, Desong C (2001) Felbertalite and related bismuth sulfosalts from the Feniusan copper skarn deposit, Nanjing, China. Canad Mineral 39: 1641–1652

Zakrzewski MA, Makovicky E (1986) Izoklaceite from Vena, Sweden, and the kobellite homologous series. Canad Mineral 24: 7–18