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Contribution to the chemical composition of the tetrahedrite group minerals from the Jeleniarka (Hirschkohlung) deposit near Dobšiná, Spišsko-gemerské rudohorie Mts., Slovakia: First occurrence of bismuth-rich members in Gemeric unit

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Abstract

A preliminary EPMA-WDS study of two samples of minerals of the tetrahedrite group from the Jeleniarka (Hirschkohlung) deposit near Dobšiná revealed their surprisingly complex chemical composition. Tetrahedrite-(Fe), tetrahedrite-(Zn) as well as tetrahedrite-(Hg) were identified at the deposit. Especially interesting are high concentrations of Bi (up to 1.23 *apfu*, 14.75 wt. %) which were detected in tetrahedrite-(Zn) directly associated with the bismuth sulfosalts. This phase could probably represent a younger generation of minerals of the tetrahedrite group. The Bi-enriched members of the tetrahedrite group are generally very rare within all types of ore mineralization in the Western Carpathians.

Key words: *tetrahedrite-(Fe), tetrahedrite-(Zn), tetrahedrite-(Hg), annivite series, chemical composition, Jeleniarka deposit, Dobšiná, Gemeric Unit, Spišsko-gemerské rudohorie Mts., Slovakia*

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Introduction

The Spišsko-gemerské rudohorie Mts. area is representing one of the most important accumulations of ore deposits in the Carpathians. There are more than 1200 hydrothermal ore veins known within this relatively small region, with two major types of ore mineralization: siderite-type carbonate-quartz veins with sulfides and sulfosalts (extensively exploited especially for iron and copper as well as minor amounts of mercury, silver, nickel and cobalt in Dobšiná, Rožňava, Drnava, Rudňany, Novoveská Huta, Hnilčík, Švedlár, Gelnica, Slovinky, Medzev etc.) and quartz-stibnite veins (e.g. Betliar, Čučma, Bystrý potok, Štofova dolina, Helcmanovce or Poproč) (Varček 1962; Chovan et al. 1994; Grecula et al. 1995).

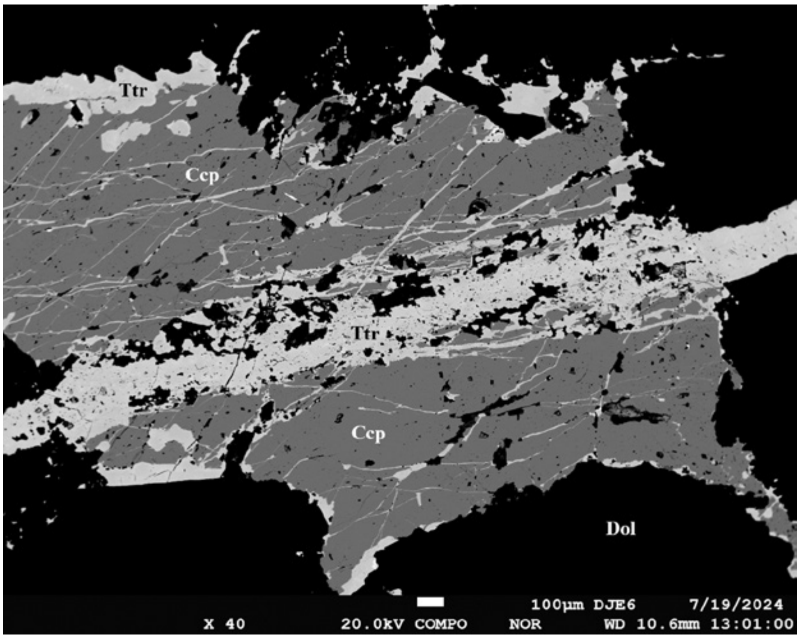
Abundant presence of minerals of tetrahedrite-tennantite series (especially Fe or Zn, locally Hg and rarely also Cu^{2+} dominant members) is very typical feature of the hydrothermal siderite-type veins in the Spišsko-gemerské rudohorie Mts. They often contain also minor amounts of Ag, but despite the fact that Bi sulfosalts are common accessory minerals at the most of the siderite-type veins, no Bi-rich members or Bi-enriched compositions (with over 4 wt. % of Bi) were reported so far (e.g. Bernard 1958, 1961; Varček 1957, 1959, 1960; Novák 1959, 1967; Trdlička 1967; Rojkovič, Krištín 1978; Háber 1980; Cambel et al. 1985; Peterec 1990; Miškovic 1991; Háber et al. 1991, 1993; Grecula et al. 1995; Antal 2002a, b; Pršek, Biroň 2007; Pršek 2008; Pršek, Lauko 2009; Števko et al. 2015; Mikuš et al. 2018; Peterec 2019; Števko, Sejkora 2020; Kyrc, Losos 2021; Števko et al. 2022, 2024).

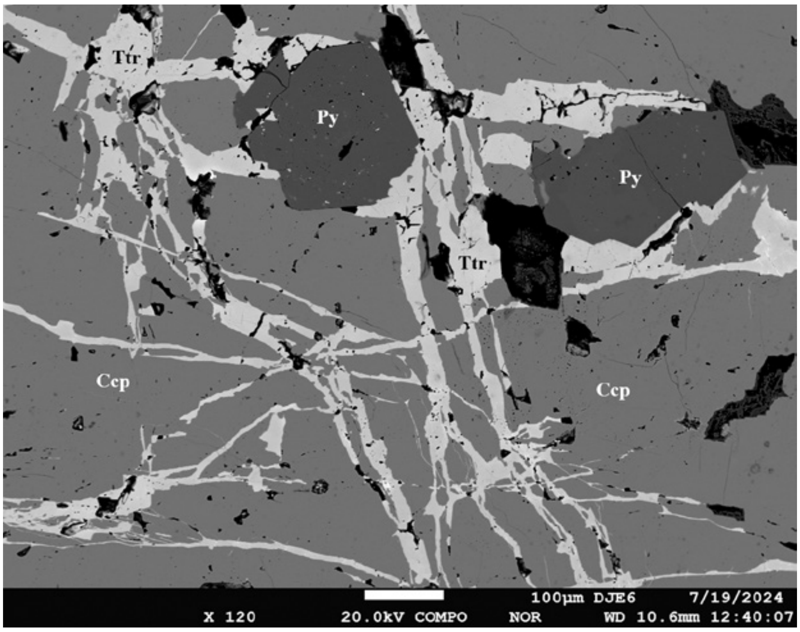
The Jeleniarka deposit (also known as Hirschkohlung or Szarvasbánya) was in the Medieval times one of the most important sources of the copper ores in the area of Dobšiná and also it was the only locality in Slovakia, where bismuth ores were mined in small scale. The most important ore minerals at the deposit are chalcopyrite and minerals of the tetrahedrite group (Rozlozsnik 1935; Halahyjová-Andrusovová 1959; Grecula et al. 1995). Nevertheless, no modern quantitative data on the chemical composition of minerals of the tetrahedrite group are available from this locality.

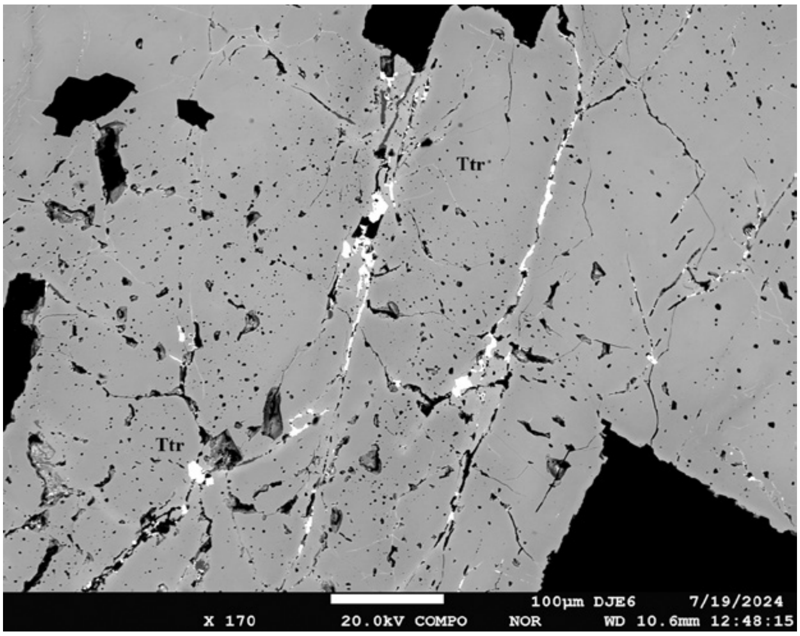
This paper provides preliminary results from a study of two samples of minerals of the tetrahedrite group from the Jeleniarka deposit, which revealed their complex chemistry. Especially notable is presence of Bi-rich compositions, previously unknown in the area of the Spišsko-gemerské rudohorie Mts., and generally very rare within the all types of ore mineralization in the Western Carpathians.

Geological setting and samples

The Jeleniarka (Hirschkohlung) copper deposit is situated around 3.6 km ENE of the Dobšiná town, 1.1 km SW of the Ostrá hill (1013 m a.s.l.) in the Spišsko-gemerské rudohorie Mts., Rožňava Co., Košice Region, Slovakia. The two representative ore samples consisting of dolomite-quartz gangue with macroscopic aggregates of







chalcopyrite, minerals of the tetrahedrite group and minor Bi sulfosalts were collected at the Jeleniarka deposit: sample DJE6 was collected at the dump of the adit at the lower part of the deposit (GPS coordinates (WGS84) of this dump are: 48.823626° N and 20.415188° E, 725 m a.s.l) and sample DJE7 was collected at the dump of the exploration pit at the upper part of the deposit (GPS coordinates (WGS84) of this dump are: 48.825656° N and 20.421075° E, 870 m a.s.l).

The Jeleniarka deposit is represented by a single, E-W trending hydrothermal carbonate-quartz vein, which is around 700 m long and up to 2 m thick. The vein is hosted in Early Paleozoic (Silurian) phyllites and metarhyolites of the Vlachovo Formation, in close proximity to the contact with the rocks of the Rakovec group (Rozlozsnik 1935; Grecula et al. 1995). The dominant gangue minerals are dolomite-ankerite and quartz accompanied by minor siderite. Ore minerals are represented mainly by chalcopyrite, minerals of the tetrahedrite group and pyrite accompanied by subordinate amounts of arsenopyrite, marcasite, several members of the bismuthinite-aikinite series (bismuthinite, krupkaite, aikinite) and native bismuth (Ulrich 1936; Paděra et al. 1955; Halahyjová-Andrusovová 1959; Harris, Chen 1976; Žák, Hybler 1981; Mumme, Žák 1983). Supergene minerals are represented by *limonite*, malachite and erythrite (Halahyjová-Andrusovová 1959).

Fig. 1 *Veinlets and aggregates of minerals of the tetrahedrite group (Ttr) crosscutting aggregate of older chalcopyrite (Ccp) embedded in dolomite (Dol) matrix. Sample DJE6. BSE image by T. Mikuš.*

Fig. 2 *Detail on veinlets of minerals of the tetrahedrite group (Ttr) crosscutting aggregate of older chalcopyrite (Ccp) associated with pyrite (Py). Sample DJE6. BSE image by T. Mikuš.*

Fig. 3 *Slightly chemically zonal aggregate of tetrahedrite-(Fe) (Ttr) with fractures filled by younger cinnabar (white). Sample DJE6. BSE image by T. Mikuš.*

Analytical methods

The quantitative (WDS) chemical analyses of minerals of the tetrahedrite group were performed using a JEOL JXA 8530F electron microprobe (Earth Science Institute of Slovak Academy of Sciences, Banská Bystrica, Slovakia). The following conditions, standards and X-ray lines were used: 20 kV, 15 nA, 1 μm wide beam, Ag_2S (Ag*Lα*), Bi_2S_3 (Bi*Mα*), Bi_2Se_3 (Se*Lβ*), CdTe (Cd*Lα*, Te*Lα*), chalcopyrite (Cu*Kα*), cinnabar (Hg*M*α), GaAs (As*Lβ*), galena (Pb*Mα*), Mn (Mn*Kα*), pyrite (Fe*Kα*, S*Kα*), sphalerite (Zn*Kα*), stibnite (Sb*L*α) and tugtupite (Cl*Kα*). 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).

Results

Sample DJE6 is containing minor subhedral to euhedral grains of pyrite and large anhedral aggregates of chalcopyrite up to 2 cm, which are intersected by network of veinlets and aggregates of younger minerals of the tetrahedrite group (Fig. 1, 2). These veins and aggregates mostly show slight chemical zoning in BSE (Fig. 3) and

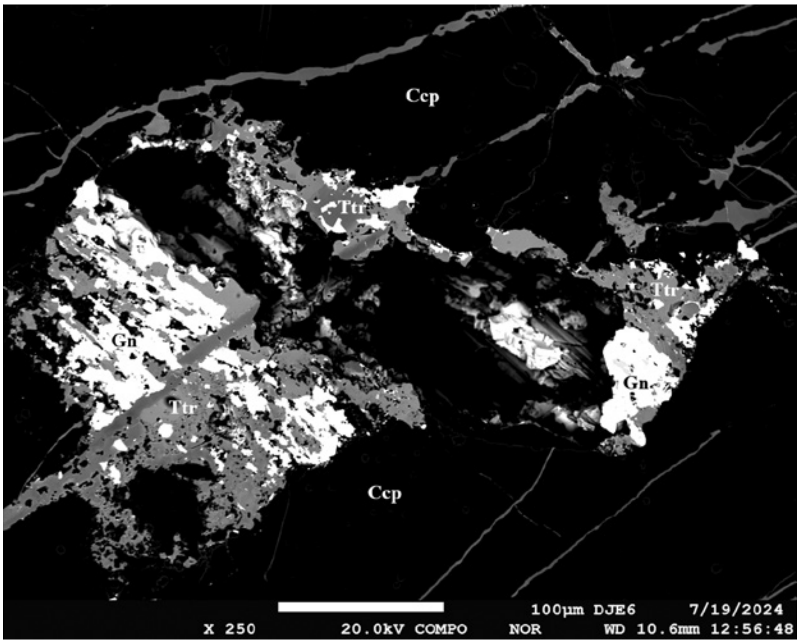


Fig. 4 *Strongly chemically zonal veinlets and aggregates of minerals of the tetrahedrite group (Ttr) associated with galena (Gn), both embedded in chalcopyrite (Ccp). Sample DJE6. BSE image by T. Mikuš.*

Table 1 *Representative WDS analyses of tetrahedrite-(Fe) from the Jeleniarka deposit (wt.%)*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
sample	**DJE6**	**DJE6**	**DJE6**	**DJE6**	**DJE6**	**DJE6**	**DJE6**	**DJE6**	**DJE6**	**DJE6**	**DJE6**	**DJE6**	**DJE6**	**DJE6**	**DJE6**
Pb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.16	0.00
Cu	39.23	39.46	40.19	38.92	39.69	38.34	38.77	36.15	38.79	38.75	36.86	37.60	37.99	39.23	38.25
Fe	5.93	5.37	5.30	4.49	5.86	3.57	3.61	1.84	3.13	3.70	2.31	2.46	4.06	4.23	3.94
Zn	0.93	1.30	1.27	2.59	1.66	2.05	2.10	1.91	3.50	3.25	2.69	2.64	2.27	2.11	2.19
Cd	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.08	0.00	0.00
Mn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00
Hg	0.80	1.12	1.14	1.44	0.36	2.58	2.95	9.57	1.41	0.43	6.19	5.65	2.00	1.49	1.57
Sb	25.38	23.77	22.51	24.14	23.89	27.50	27.35	25.76	27.94	27.89	26.91	26.00	27.31	25.56	27.86
As	2.07	3.35	4.14	2.75	2.73	0.26	0.27	0.49	0.25	0.28	0.30	0.86	0.54	1.74	0.28
S	25.84	25.77	26.05	25.90	25.85	25.82	25.74	24.88	25.88	25.77	25.27	25.63	25.63	25.82	26.06
Se	0.00	0.00	0.00	0.00	0.00	0.06	0.08	0.00	0.05	0.00	0.00	0.00	0.08	0.00	0.06
total	100.19	100.14	100.58	100.21	100.05	100.18	100.87	100.60	100.94	100.12	100.64	100.84	100.01	100.35	100.22
Cu *A+B* site	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000
Pb	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.009	0.000	0.000	0.013	0.000
Σ *A+B* site	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.009	10.000	10.000	10.013	10.000
Fe	1.738	1.565	1.529	1.320	1.698	1.086	1.090	0.587	0.934	1.103	0.721	0.758	1.227	1.255	1.192
Zn	0.233	0.324	0.313	0.650	0.411	0.533	0.541	0.521	0.891	0.827	0.716	0.695	0.586	0.535	0.566
Hg	0.065	0.091	0.092	0.118	0.029	0.219	0.248	0.851	0.117	0.036	0.537	0.485	0.168	0.123	0.132
Cu	0.101	0.112	0.196	0.056	0.098	0.261	0.278	0.150	0.176	0.151	0.098	0.187	0.087	0.217	0.177
Cd	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.000	0.000	0.012	0.000	0.000
Mn	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.015	0.000	0.000
Σ *C* site	2.138	2.092	2.130	2.143	2.237	2.100	2.156	2.109	2.119	2.125	2.072	2.126	2.095	2.129	2.067
Sb	3.411	3.179	2.980	3.255	3.173	3.842	3.784	3.774	3.826	3.814	3.848	3.677	3.784	3.474	3.869
As	0.452	0.729	0.890	0.602	0.590	0.059	0.060	0.117	0.056	0.061	0.070	0.197	0.121	0.384	0.064
Σ *D* site	3.862	3.908	3.870	3.857	3.763	3.900	3.844	3.891	3.881	3.875	3.919	3.874	3.905	3.858	3.933
S	13.183	13.085	13.096	13.262	13.034	13.695	13.519	13.844	13.454	13.382	13.720	13.761	13.488	13.325	13.741
Se	0.000	0.000	0.000	0.000	0.000	0.013	0.017	0.000	0.010	0.000	0.000	0.000	0.018	0.000	0.014

calculated empirical formulae are based on ΣMe = 16 *apfu*

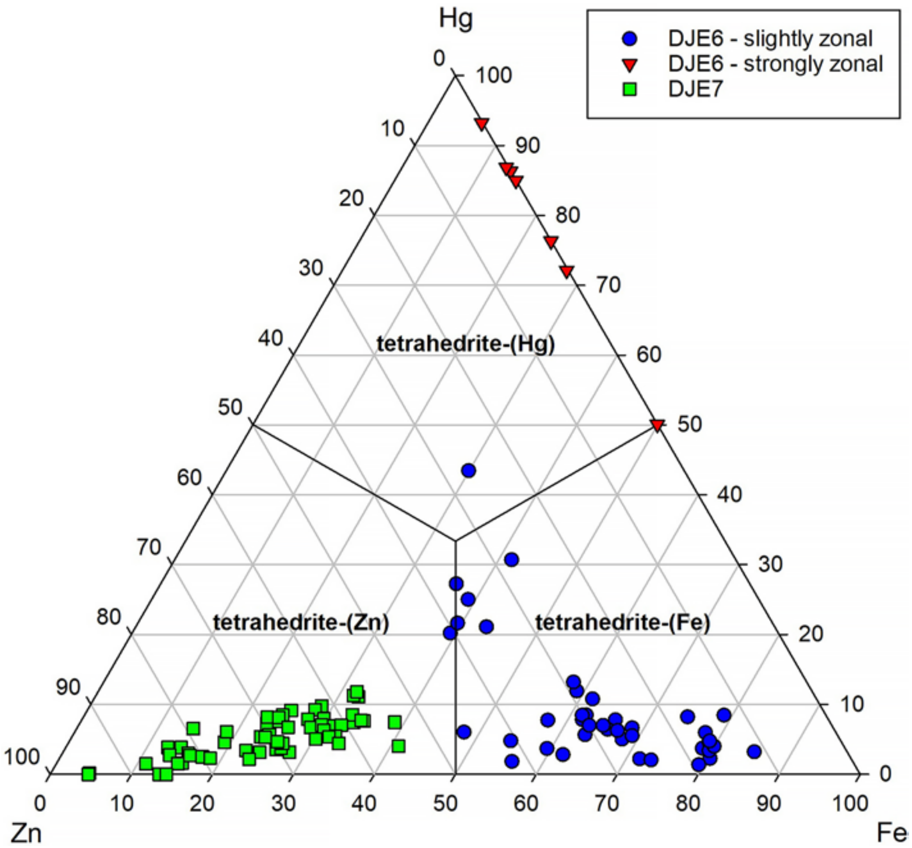


Fig. 5 *Ternary Fe-Hg-Zn diagram for minerals of the tetrahedrite group from the Jeleniarka deposit.*

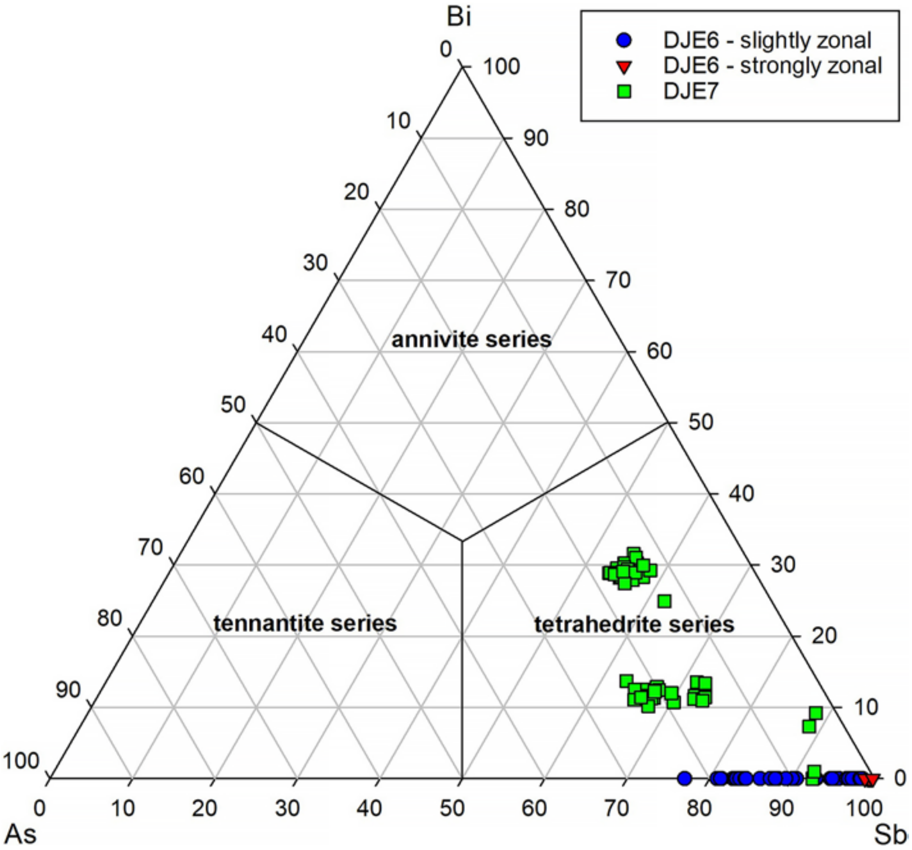


Fig. 6 *Ternary Sb-Bi-As diagram for minerals of the tetrahedrite group from the Jeleniarka deposit.*

their fractures are locally filled by younger cinnabar. More rarely, strongly zonal, irregular aggregates and veinlets of minerals of the tetrahedrite group (Fig. 4), closely associated with galena, were observed in chalcopyrite.

The slightly zonal aggregates and veinlets are compositionally corresponding (Fig. 5) mostly to **tetrahedrite-(Fe)** with stable presence of Zn (from 0.23 to 0.89 *apfu*) and variable content of Hg (from 0.03 to 0.85 *apfu*). Minor concentrations of Cd (up to 0.02 *apfu*) were also observed. Content of As is also variable (0.06 to 0.89, Fig. 6), Bi was not detected and Se is reaching up to 0.02 *apfu*. Representative quantitative chemical analyses of tetrahedrite-(Fe) from the Jeleniarka deposit are shown in Table 1. The average (n = 48) empirical formula based on sum of Me = 16 *apfu* is $Cu_{6.00}[Cu_{4.00}(Fe_{1.23}Zn_{0.53}Hg_{0.18}Cu_{0.17})_{\Sigma 2.12}](Sb_{3.52}As_{0.36})_{\Sigma 3.88}S_{13.45}Se_{0.01}$.

The strongly zonal ones (Fig. 5) are represented by **tetrahedrite-(Hg)** with variable concentrations of Fe (from 0.13 to 1.04 *apfu*). Zinc is totally absent and only minor contents of Mn (up to 0.02 *apfu*) as well as Ag (up to 0.01 *apfu*) were detected. Antimony is the dominant (3.79 - 3.88 *apfu*) element at the *D* site and only very low concentrations of As (up to 0.04 *apfu*, Fig. 6) are present. The Se content is reaching up to 0.03 *apfu*. Quantitative chemical analyses of tetrahedrite-(Hg) are shown in Table 2. Its average (n = 7) empirical formula based on sum of Me = 16 *apfu* is $Cu_{6.00}[Cu_{4.00}(Hg_{1.60}Fe_{0.45}Cu_{0.09})_{\Sigma 2.14}](Sb_{3.83}As_{0.02})_{\Sigma 3.85}S_{14.26}Se_{0.02}$.

Sample DJE7 is represented by quartz-dolomite gangue with abundant chalcopyrite and acicular crystals of Bi sulfosalts (bismuthinite, pekoite, gladite, krupkaite, emplectite) with minor native bismuth, which are overgrown or partly replaced by strongly chemically zonal, anhedral aggregates of minerals of the tetrahedrite group (Fig. 7). This type could probably represent a younger generation of minerals of the tetrahedrite group.

Tetrahedrite group minerals in this sample are corresponding to **tetrahedrite-(Zn)** with Zn contents ranging between 0.99 to 1.87 *apfu* (Fig. 5), stable presence of Fe (0.09 to 0.75 *apfu*) and minor concentrations of Hg (up to 0.23 *apfu*). In addition, trace amounts of Ag and Cd (both up to 0.04 *apfu*) as well as Mn (up to 0.02 *apfu*) were detected. Antimony is the dominant Me^{3+} constituent in the studied sample (2.12 to 3.61 *apfu*) often accompanied by As (0.09 to 0.93 *apfu*). The most interesting feature is the stable presence of Bi content (Fig. 6), reaching up to 1.23 *apfu* (14.75 wt. %, 0.81 *apfu* on average), which is responsible for strong chemical zoning observed in BSE. Such high bismuth contents have not been reported in any minerals of the tetrahedrite group from the Spišsko-gemerské rudohorie Mts. So far, the highest concentrations of Bi in tetrahedrite group minerals (up to 3.57 wt. %) from the Spišsko-gemerské rudohorie Mts. were described by Miškovic (1991) from an unspecified locality in the Dobšiná mining district. The Bi-rich compositions with more than 8 wt. % of Bi are generally rare in the Western Carpathians, and have so far only been reported from the copper ore mineralization hosted in Permian paleobasalts of the Hronic unit near Kvetnica (Ferenc et al. 2025). Minor Se (up to 0.06 *apfu*) is also locally present. Representative quantitative chemical analyses of Bi-rich tetrahedrite-(Zn) from the Jeleniarka deposit are shown in Table 3. An average (n = 57) empirical formula of studied tetrahedrite-(Zn) based on sum of Me = 16 *apfu* is $(Cu_{5.97}Ag_{0.03})_{\Sigma 6.00}[Cu_{4.00}(Zn_{1.35}Fe_{0.46}Hg_{0.10}Cu_{0.10}Cd_{0.02})_{\Sigma 2.04}](Sb_{2.48}Bi_{0.81}As_{0.64})_{\Sigma 3.93}S_{12.87}Se_{0.01}$.

All WDS analyses of minerals of the tetrahedrite group for both studied samples from the Jeleniarka deposit are available in the supplementary file.

Conclusions

A preliminary study of chemical composition of minerals of the tetrahedrite group from the Jeleniarka (Hirschkohlung) deposit near Dobšiná revealed their surprisingly complex chemistry. Presence of tetrahedrite-(Fe), tetrahedrite-(Hg) as well as tetrahedrite-(Zn) is documenting a strong variation of elements such as Fe, Zn, Hg, Sb, As and Bi in the ore forming fluids. It is likely that more than one generation of minerals of the tetrahedrite group is present at the studied locality. Elevated contents of bismuth documented in tetrahedrite-(Zn) from the Jeleniarka deposit are rather unusual as Bi-bearing members of the tetrahedrite group are generally very rare within the all types of ore mineralization in the Western Carpathians.

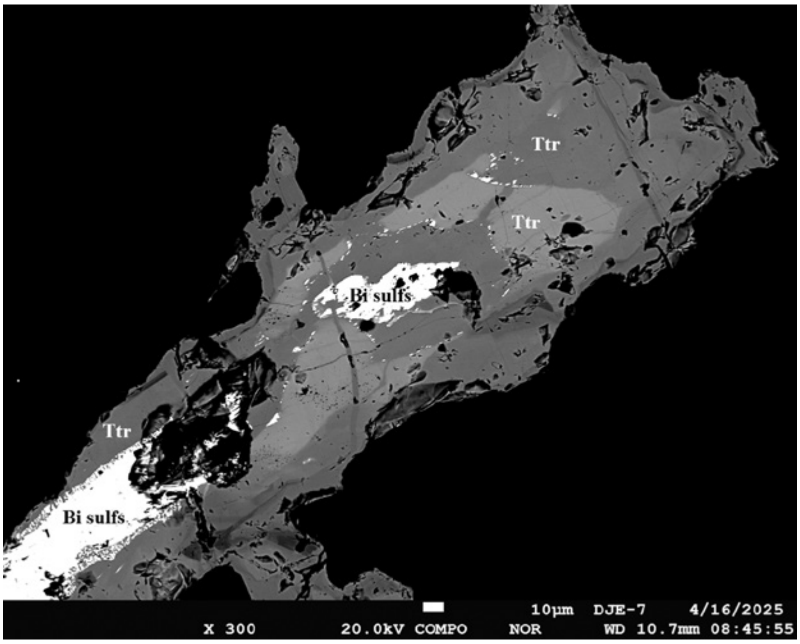


Fig. 7 *Strongly chemically zonal aggregates of minerals of the tetrahedrite group (Ttr) associated with bismuth sulfosalts (Bi sulfs). Sample DJE7. BSE image by T. Mikuš.*

Table 2 *Quantitative WDS analyses of tetrahedrite-(Hg) from the Jeleniarka deposit (wt.%)*

	1	2	3	4	5	6	7
sample	**DJE6**	**DJE6**	**DJE6**	**DJE6**	**DJE6**	**DJE6**	**DJE6**
Ag	0.07	0.00	0.05	0.00	0.06	0.07	0.00
Cu	32.93	32.84	33.71	33.92	35.11	33.28	33.48
Fe	0.81	0.94	1.43	1.73	3.18	0.37	0.73
Mn	0.00	0.00	0.05	0.06	0.00	0.00	0.00
Hg	18.32	19.11	16.56	16.13	11.47	18.75	17.75
Sb	24.39	23.82	24.63	24.70	25.43	23.90	24.21
As	0.06	0.09	0.12	0.09	0.04	0.17	0.03
S	23.53	23.45	23.84	23.84	24.87	24.09	24.24
Se	0.00	0.00	0.12	0.06	0.15	0.11	0.00
total	100.11	100.24	100.51	100.55	100.31	100.75	100.45
Cu *A+B* site	10.000	10.000	10.000	10.000	10.000	10.000	10.000
Ag	0.013	0.000	0.009	0.000	0.010	0.013	0.000
Σ *A+B* site	10.013	10.000	10.009	10.000	10.010	10.013	10.000
Hg	1.769	1.846	1.565	1.513	1.044	1.817	1.710
Fe	0.280	0.326	0.485	0.581	1.041	0.130	0.254
Cu	0.041	0.014	0.058	0.042	0.085	0.179	0.181
Mn	0.000	0.000	0.017	0.020	0.000	0.000	0.000
Σ *C* site	2.090	2.186	2.126	2.156	2.169	2.126	2.145
Sb	3.881	3.791	3.835	3.817	3.812	3.815	3.842
As	0.016	0.024	0.031	0.023	0.009	0.044	0.008
Σ *D* site	3.897	3.814	3.866	3.840	3.821	3.859	3.850
S	14.216	14.175	14.094	13.987	14.156	14.602	14.607
Se	0.000	0.000	0.029	0.015	0.034	0.026	0.000
calculated empirical formulae are based on ΣMe = 16 *apfu*							

Table 3 *Representative WDS analyses of tetrahedrite-(Zn) from the Jeleniarka deposit (wt.%)*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
sample	**DJE7**	**DJE7**	**DJE7**	**DJE7**	**DJE7**	**DJE7**	**DJE7**	**DJE7**	**DJE7**	**DJE7**	**DJE7**	**DJE7**	**DJE7**	**DJE7**	**DJE7**
Ag	0.18	0.18	0.18	0.17	0.20	0.11	0.11	0.15	0.10	0.08	0.21	0.11	0.16	0.18	0.18
Cu	36.55	36.76	37.02	37.25	37.21	38.30	38.32	38.36	39.25	39.10	36.78	38.34	37.88	38.45	38.48
Fe	1.97	1.57	1.43	1.80	2.04	0.93	0.93	2.37	0.32	0.31	1.94	2.49	1.17	2.06	1.90
Zn	4.06	4.79	5.13	4.40	4.16	5.99	6.24	3.85	7.47	7.36	4.25	3.92	5.51	4.48	4.76
Cd	0.13	0.09	0.08	0.26	0.17	0.14	0.07	0.16	0.09	0.03	0.14	0.09	0.09	0.08	0.08
Mn	0.00	0.04	0.00	0.06	0.04	0.00	0.00	0.00	0.04	0.00	0.00	0.05	0.00	0.00	0.00
Hg	2.61	2.05	1.18	1.73	1.62	1.52	0.90	1.64	0.03	0.00	1.51	0.87	1.36	0.98	1.14
Sb	15.00	15.27	14.99	15.32	14.89	25.09	18.41	19.01	26.68	26.68	15.22	18.70	24.25	18.98	19.31
Bi	14.07	14.17	14.75	13.50	13.95	3.56	6.87	6.20	0.00	0.50	14.17	5.45	4.36	5.53	6.04
As	2.37	2.29	2.25	2.88	2.79	0.74	4.16	3.88	1.33	1.22	2.64	4.15	0.41	3.73	3.63
S	23.61	23.24	23.44	23.65	23.58	24.31	24.08	24.52	24.60	24.64	23.99	25.36	24.55	24.51	24.83
Se	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.06	0.10	0.16	0.27	0.10
total	100.57	100.47	100.43	101.01	100.64	100.72	100.07	100.13	99.92	99.91	100.90	99.63	99.90	99.24	100.45
Cu $_{A+B\ \mathrm{site}}$	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000
Ag	0.029	0.029	0.029	0.027	0.032	0.018	0.016	0.024	0.016	0.011	0.035	0.017	0.025	0.028	0.028
Σ *A*+*B* site	10.029	10.029	10.029	10.027	10.032	10.018	10.016	10.024	10.016	10.011	10.035	10.017	10.025	10.028	10.028
Zn	1.091	1.278	1.368	1.159	1.101	1.536	1.588	0.988	1.871	1.853	1.133	1.009	1.440	1.153	1.218
Fe	0.620	0.490	0.447	0.556	0.631	0.280	0.276	0.712	0.094	0.092	0.607	0.752	0.359	0.620	0.570
Hg	0.229	0.178	0.102	0.148	0.139	0.127	0.074	0.137	0.003	0.000	0.131	0.073	0.116	0.082	0.095
Cu	0.106	0.091	0.147	0.106	0.140	0.111	0.043	0.129	0.114	0.127	0.096	0.163	0.193	0.194	0.131
Cd	0.021	0.015	0.012	0.039	0.026	0.021	0.010	0.024	0.013	0.004	0.021	0.013	0.013	0.012	0.011
Mn	0.001	0.014	0.000	0.017	0.013	0.000	0.000	0.000	0.012	0.000	0.000	0.014	0.000	0.000	0.000
Σ *C* site	2.067	2.066	2.075	2.026	2.051	2.074	1.992	1.990	2.106	2.076	1.988	2.025	2.119	2.060	2.025
Sb	2.165	2.188	2.145	2.170	2.117	3.456	2.518	2.620	3.588	3.607	2.180	2.587	3.406	2.627	2.653
Bi	1.182	1.183	1.229	1.114	1.156	0.285	0.547	0.498	0.000	0.039	1.183	0.439	0.356	0.446	0.483
As	0.556	0.534	0.522	0.663	0.644	0.166	0.926	0.868	0.290	0.267	0.616	0.932	0.094	0.839	0.810
Σ *D* site	3.904	3.905	3.896	3.946	3.917	3.908	3.991	3.986	3.878	3.913	3.978	3.958	3.856	3.912	3.947
S	12.937	12.645	12.731	12.716	12.734	12.716	12.510	12.833	12.563	12.646	13.046	13.322	13.092	12.879	12.955
Se	0.000	0.000	0.000	0.000	0.000	0.008	0.000	0.000	0.000	0.000	0.013	0.021	0.035	0.057	0.021

calculated empirical formulae are based on ΣMe = 16 *apfu*

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