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Tellurides and native elements in copper-zinc ores of manifestations «Zapadnoe» (Subpolar Urals, Russia)

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ABSTRACT

Background: Previously conducted mineralogical and geochemical studies of copper-zinc ores manifestations «Zapadnoe» showed that the feature of pyrrhotite, pyrite, chalcopyrite and sphalerite is an increased content of Ag and industrially significant Au content, as well as the appearance of silver-containing sphalerite. The purpose of this study is to establish the mineralogical form of noble metals in ores. **Methods**: Mineralogical studies were conducted using an electronic scanning microscope JSM-6510LV (Jeol Ltd). 13 samples taken from the core of the wells were studied: 954 determinations of the ore-forming minerals were made, 140 of them recorded the presence of precious metals. **Results**: Precious metals – gold and silver – tellurides are mainly: hessite, stutzite, volynskite, matildite, cervelleite, petzite and sylvanite; rarely native gold. The host mineral matrix is most often sulfides: sphalerite, pyrrhotite, chalcopyrite, pyrite; rarely – galena. **Conclusion**: The angular, xenomorphic form of separation of aggregates and the consistency of the mineral composition of telluride mineralization can be the result of crystallization of a relatively low-temperature melt among thermally more stable silicate and sulfide phases

KEYWORDS: Subpolar Urals, copper-zinc ores, tellurides, native elements

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Telururos y elementos nativos en minerales de cobre-zinc de manifestaciones «Zapadnoe» (Urales subpolares, Rusia)

RESUMEN

Antecedentes: estudios mineralógicos y geoquímicos realizados previamente sobre manifestaciones de minerales de cobre y zinc «Zapadnoe» mostraron que la característica de pirrotita, pirita, calcopirita y esfalerita es un mayor contenido de Ag y contenido de Au industrialmente significativo, así como la aparición de plata que contiene Esfalerita. El propósito de este estudio es establecer la forma mineralógica de los metales nobles en los minerales. Métodos: se realizaron estudios mineralógicos utilizando un microscopio electrónico de barrido JSM-6510LV (Jeol Ltd). Se estudiaron 13 muestras tomadas del núcleo de los pozos: se hicieron 954 determinaciones de los minerales formadores de mineral, 140 de ellas registraron la presencia de metales preciosos. Resultados: Los metales preciosos - oro y plata - telururos son principalmente: hessita, stutzita, volynskita, matildita, cervelleita, petzita y silvanita; raramente oro nativo. La matriz mineral del huésped suele ser sulfuros: esfalerita, pirrotita, calcopirita, pirita; raramente - galena. Conclusión: La forma angular y xenomórfica de separación de agregados y la consistencia de la composición mineral de la mineralización de telururo pueden ser el resultado de la cristalización de una masa fundida de temperatura relativamente baja entre las fases de silicato y sulfuro térmicamente más estables.
PALABRA CLAVE: Urales subpolares, minerales de cobre-zinc, telururos, elementos nativos.

Introduction

The manifestation «Zapadnoe» was revealed during the prospecting for iron ore in 1988 in the south-eastern exocontact zone of the Khorasur massif (Fig. 1) on the Eastern slope of the Subpolar Urals (Komaritsky S.I. «Preparation of geophysical bases for searches (forward operation) iron ore skarn-magnetite formation on Usininskyarea in 1988-90», JSC «Sosvapromgeologiya», 2001). Assay analysis of copper-zinc ores showed a constant presence of a significant impurity of gold (up to 3.19 g/t, average – 0.36-0.46 g/t) and silver (up to 19.95 g/t, average – 4.39 g/t). The author's resources (the sum of categories P_2 and P_3) were: gold – 8.9 t, silver – 361.1 t.

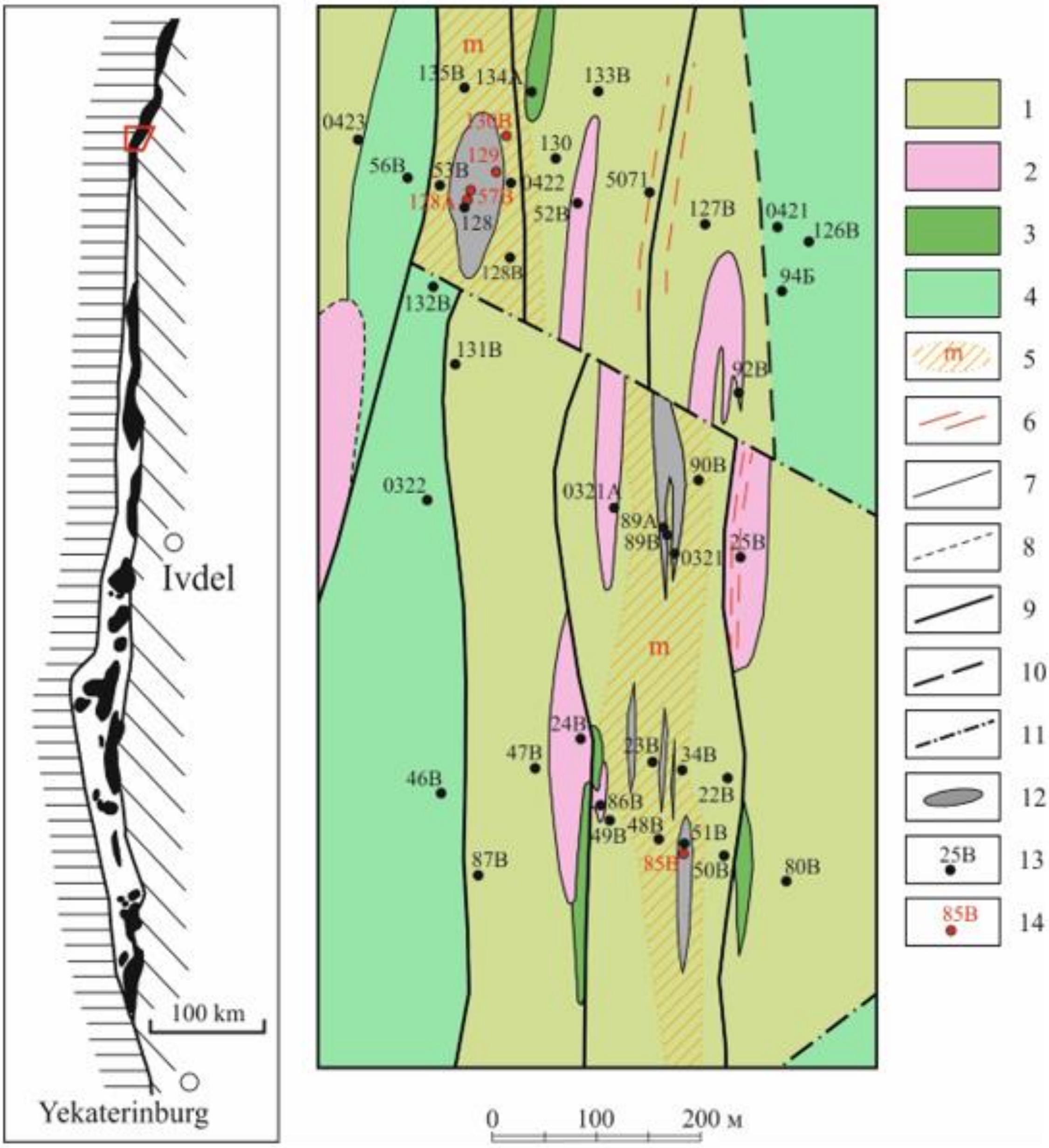

Fig. 1. Schematic geological map of the Zapadnaya area
(byBaturin S.Y., JSC «UGSE», 2009)

1 – tectonic-injection-metasomatic ore-hosting complex. Hornfels on the gabbroids, dike rocks and presumably volcanogenic-sedimentary formations of Shemur suite (O_3-S_1šm), metasomatic rocks undifferentiated; 2 – quartz diorite of the second phase Severorudnichniy complex ($q\delta S_2s_2$); 3 – microgabbro of the second phase of tagilokitlimskiy complex ($\mu\upsilon\delta S_1t_2$); 4 – amphibole and amphibolization gabbro of the second phase of tagilokitlimskiy complex (υS_1t_2); 5 – metasomaticalbite-quartz-chlorite, quartz-epidote-chlorite, epidote-prenite undifferentiated; 6 – blastokataclasite and blastomylonite; 7-8 – geological boundaries: 7 – established; 8 – alleged; 9-11 – tectonic disturbances: 9 – established; 10 – alleged; 11 – by geophysical data; 12 – contours of ore bodies; 13 – exploration wells and their numbers; 14 – exploration wells, the core of which studied noble metal mineralization.

In 2006-2009 on the area «Zapadnaya» was made prospecting for copper (JSC «Ural geological surveying expedition», Yekaterinburg, Baturin S.Y.): there are two complex-structured ore deposits (Zapadnaya and Novaya) (Fig. 1); author's resources of gold of categories P_1+P_2 amounted to 26 tons, silver resources were not estimated. The gold content reaches 24.1 g/t (the average in the ore deposit «Zapadnaya» 0.53 g/t, in the ore deposit «Novaya» – 0.73 g/t); the silver content – up to 69.6 g/t.

Mineralogical and geochemical studies of copper-zinc ores, performed at the Institute of Mineralogy of UrO RAS (Miass), showed that the feature of pyrrhotite, pyrite, chalcopyrite and sphalerite manifestations «Zapadnoe» is an increased content of Ag and industrially significant Au content, as well as the appearance of silver-containing sphalerite. Sphalerite-silver-galena and chalcopyrite-gold-silver-telluride associations are distinguished, «...obviously represented by thin scattered invisible mineralization in chalcopyrite and sphalerite». According to the results of these studies, the manifestation «Zapadnoe» is presumably attributed to the gold-silver-copper-zinc sulfide scarn type. Analogues of the symptoms of copper-zinc ores «Zapadnoe» proposed Tarnierskoedeposit (chalcopyrite) and Sarbaisky (mineralization occurs in) in the North and Middle Urals: the range of available mineralogical characteristics it is recognized as the intermediate between them (Safina et al., 2010).

Thus, the analysis of the results of previous work on the manifestation «Zapadnoe» shows that the question of the form of gold and silver in copper-zinc ores remains open.

1. Materials and methods

Mineralogical studies were conducted on the electronic scanning microscope JSM-6510LV (Jeol Ltd) with energy-dispersive spectrometer INCAEnergy 350 with the detector X-Max 80 (Oxford Instruments Analytical Ltd) at an accelerating voltage of 20 kV, electron beam current of 0.3-0.5 on the time when the set of 10 spectra with (Novosibirsk, Institute of Geology and Mineralogy SB RAS, analyst Karmanov N.S.). Studied 13 samples taken from the core of wells 85B (ore deposit «Novaya») and 57B, 128A, 129, 130B (ore deposit «Zapadnaya») (Fig. 2). A total of 954 definitions of the composition of ore-forming minerals were performed, of which 140 recorded the presence of precious metals. The nomenclature of noble-metal minerals is determined in accordance with (Zelenov, 1989).

Since the size of the analyzed grains often turned out to be equal to (or slightly less than) the cross section of the analyzer beam, the analysis results also included figures relating to the host mineral matrix. Therefore, when determining the composition of the mineral, an adjustment to the composition of the host mineral was introduced.

1. Results

Gold and silver mineralogy of ores of manifestations «Zapadnoe»

In the composition of manifestations «Zapadnoe» oresthe presence of the following mineral species, in which the noble metals play a major role: hessite, stutzite, volynskite, matildite, cervelleite, petzite and sylvanite; rarely native gold.

Hessite(Ag_2Te) was found in all studied samples in the form of tiny secretions, occasionally reaching 10, extremely rarely – 30 microns. The mineral forms both independent grains and participates in coalescence with other tellurides (rarely with native gold). Most often hessite was observed in sulfides – sphalerite, chalcopyrite, pyrite, pyrrhotite and galena, less often – in silicates (chlorite, biotite, plagioclase, epidote and garnet).

In this regard, it should be noted some features. First, hessite (often together with other tellurides) forms a chain of linearly elongated grains, indicating control of their location by microcracks or intergranular space; this feature is observed only when it is placed in sulfides. Second, the mineral (and intergrowths with other tellurides) occurs, as isometric inclusions does not detect connection with the fracture: in sulfides (with hessite has a rectilinear shape) or silicates (mineral or has wavy and bay border or forms a very thin rash of grains, the nature of the constraint for which an estimate is very difficult).

Willing hessite forms intergrowths (up to gradual mutual transitions) with other tellurides – volynskite, petzite, tellurobismuthite, melonite and altait. Features of the hessite composition according to the results of electron probe studies are given in table 1, the forms of hessite in the ores of the manifestation «Zapadnoe» are shown in figure 3.

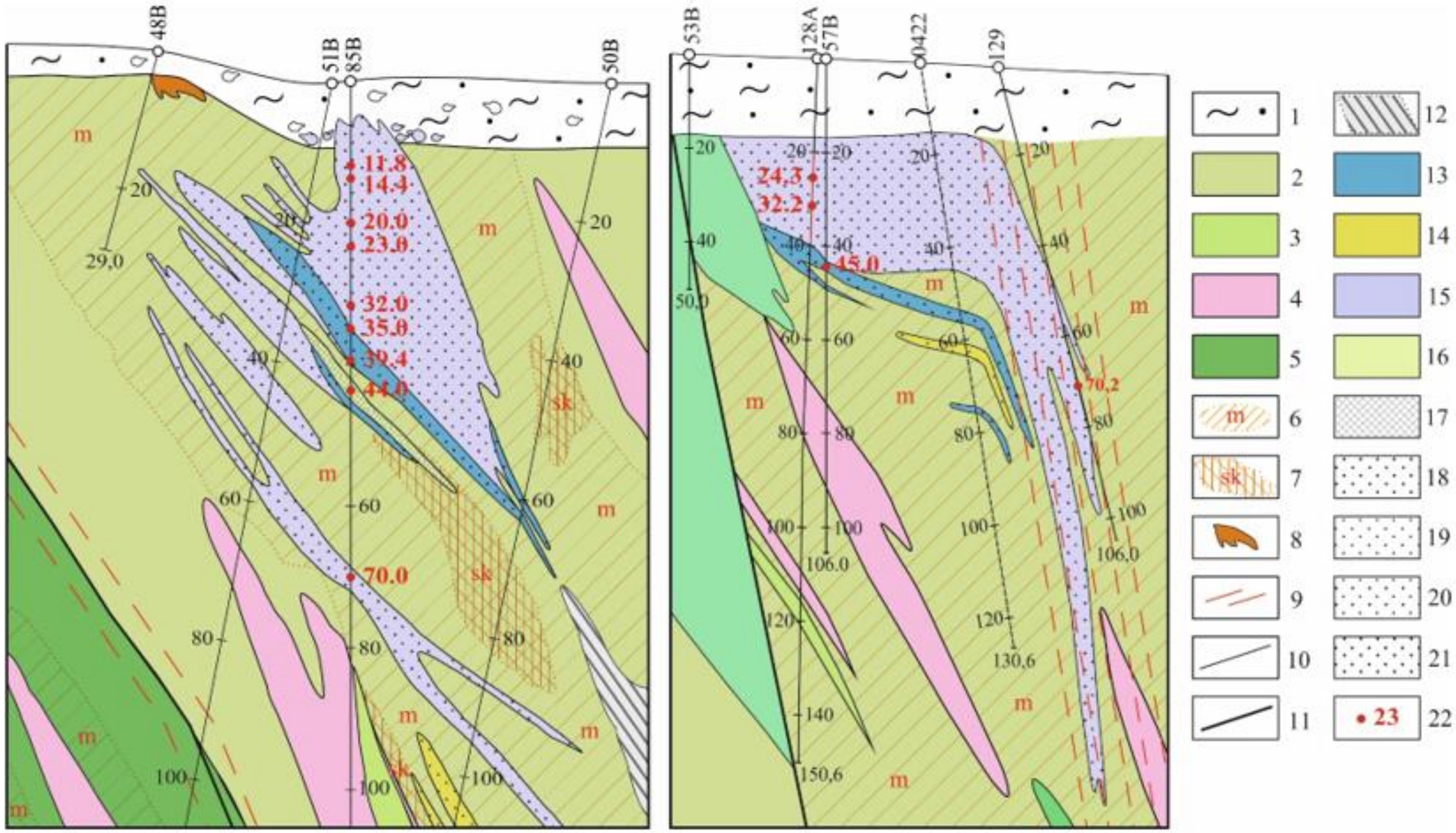

Fig. 2.The manifestation «Zapadnoe». Ore deposit «Novaya» (left) and ore deposit «Zapadnaya» (right) Geological sections (by Baturin S.Y., JSC «UGSE», 2009) and sampling scheme for mineralogical studies 1 – unconsolidated Quaternary sediments; 2 – dykes of spessartites; 3 – tectonic-injection-metasomatic ore-bearing complex; 4 – quartz diorites of the second phase Severorudnichniy complex ($q\delta S_{2}s_{2}$); 5 – microgabbro of second phase Tagilokitlimskiy complex ($\mu\upsilon\delta S_{1}t_{2}$); 6 – metasomatites; 7 – skarns; 8 – iron hat; 9 – blastomylonite and blastokataclasite; 10 – geological boundary; 11 – tectonic faults; 12 – prospective ore body; 13-16 – pyrite ores: 13 – copper (Cu>0,7%); 14 – zinc (Zn>1%); 15 – copper-zinc (Cu>0,7%; Zn>1%); 16 – sulfur (S>35%); 17-21 – grades of ores (krap by the corresponding color): 17 – solid massive; 18 – impregnated copper; 19 – impregnated zinc; 20 – impregnated copper-zinc; 21 – substandard (Cu<0.7%; Zn<1%; S<35%); 22 – points of material selection for electron probe studies.

Native gold (Fig. 4) recorded in six samples, in all mineralogical types of ore deposits «Novaya» and «Zapadnaya» throughout the vertical scale of mineralization; forms a fine selection, occasionally reaching 12 microns. Usually found alone, rarely observed intergrowths with hessite and petzite. The features of propagation – forms of separation or cracks in the intergranular space of sulphides (sphalerite, chalcopyrite, galena); in the development of secondary minerals (chlorite, epidote, amphibole) have wavy contacts and califoornia. In the composition (table 2) there is always a significant admixture of silver until the appearance of electrum (only in copper-zinc ores). With the depth of the probity of native gold increases.

Table 1. Composition of hessite(%) and characteristics of the host mineral matrix

n	Composition				Host mineral matrix
	Ag		Te		
	min	max	min	max	
Well 85B, depth 11.8 m					
18	54,51	63,52	36,48	42,44	Sphalerite, pyrrhotite
Well 85B, depth 14.4 m					
5	58,23	62,87	37,13	41,77	Sphalerite, plagioclase, chlorite
Well 85B, depth 20.0 m					
10	61,70	63,33	36,67	38,30	Chalcopyrite, chlorite, pyrite, sphalerite, epidote
Well 85B, depth 23.0 m					
5	59,27	62,44	37,56	40,73	Sphalerite, chalcopyrite, pyrite
Well 85B, depth 32.0 m					
1		62,84		37,16	Sphalerite
Well 85B, depth 35.0 m					
7	60,86	63,36	36,64	39,14	Sphalerite, altaite, pyrite, pyrrhotite, chlorite, plagioclase
Well 85B, depth 39.4 m					
5	57,86	64,34	35,66	42,14	Chalcopyrite, chlorite, pyrite, garnet
Well 85B, depth 44.0 m					
15	55,94	63,84	33,15	44,06	Chlorite
Well 85B, depth 70.0 m					
11	61,36	63,70	36,30	38,64	Pyrite, sphalerite, chlorite
Well 57B, depth 45.0 m					
5	62,28	65,06	34,94	37,72	
Well 128A, depth 24.3 m					
1		62,42		37,58	Chalcopyrite
Well 130B, depth 64.6 m					
5	62,44	63,22	36,78	37,56	Sphalerite, pyrrhotite, pyrite

Note: n – number of tests

Petzite (Au_3AgTe_2) rare material recorded in three samples taken from core wells 85B (the deposit «Novaya»), dedicated to the sphalerite (as a rule, the cleavage cracks), is always present together with the other precious-metal tellurides (hessite, cervelleite), forming small inclusions of irregular shape with size less than 5 microns in all mineralogical types of ores. Features of petzite the results of electron-probe studies is shown in table 3, forms of petzite in ores of «Zapadnoe» manifestations is presented in figure 4.

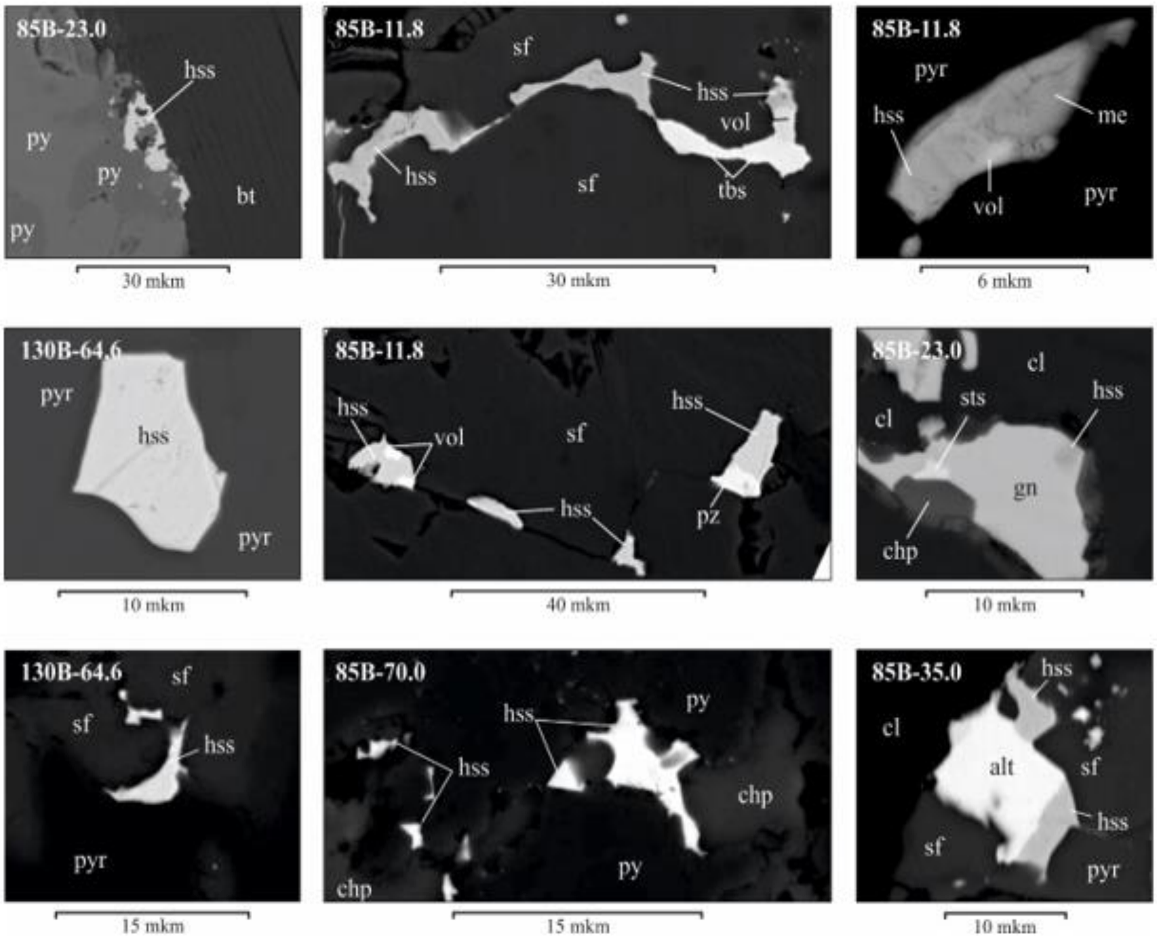

Fig. 3. Forms of hessite in ores of manifestations «Zapadnoe» hss – hessite; me – melonite; pz – petzite; vol – volynskite; tbs – tellurobismuthite; sts – stutzite; alt – altait; py – pyrite; pyr – pyrrhotite; sf – sphalerite; chp – chalcopyrite; gn –galena; bt – biotite; cl – chlorite. In the upper left corner – well number and sampling depth.

Volynskite ($AgBiTe_2$) was observed in two samples of disseminated copper-zinc ores that have been taken from the core bore 85B (the deposit «Novaya»), dated for sphalerite and pyrrhotite, is typically present in the form of intergrowths with hessite, meloniteand tellurobismuthite, rarely forms pure grain, sometimes having hypidiomorphicsubprismaticshape, reaching up to 15 µm. On contact with chlorite volynskite acquires shapeless lumpy shape. The features of the composition of volynskite according to the results of electron probe studies are given in table 3, the forms of volynskite in the ores of the «Zapadnoe» manifestation are shown in figure 4.

Stutzite (Ag_5Te_3) was observed in three samples of disseminated copper-zinc ores that have been taken from the core bore 85B (the deposit «Novaya»), timed to coincide with pyrrhotite and galena and silicate minerals (epidote and andradite), forming independent grains of isometric shape with a size of up to 7 microns and has a clear sharp limits. Features of stutzitethe results of electron-probe studies is shown in table 3, forms of stutzitein the ore of manifestations «Zapadnoe» shown in figures 3 and 4.

Table 2. Composition of native gold (%) and characteristics of the host mineral matrix

n	Composition				Host mineral matrix
	Au		Ag		
	min	max	min	max	
Well 85B, depth 20.0 m					
4	61,62	65,94	34,06	38,38	Chlorite, plagioclase, sphalerite, chalcopyrite
Well 85B, depth 35.0 m					
1		70,74		15,48	Sphalerite
Well 85B, depth 44.0 m					
2	69,51	69,87	30,13	30,49	Chlorite
Well 85B, depth 39.4 m					
7	67,77	76,23	23,77	32,23	Amphibole, chlorite, chalcopyrite, galena, petzite, plagioclase
Well 85B, depth 70.0 m					
5	60,27	78,02	21,98	39,73	Sphalerite, hessite
Well 128A, depth 24.3 m					
2	47,54	48,93	51,07	52,46	Chalcopyrite

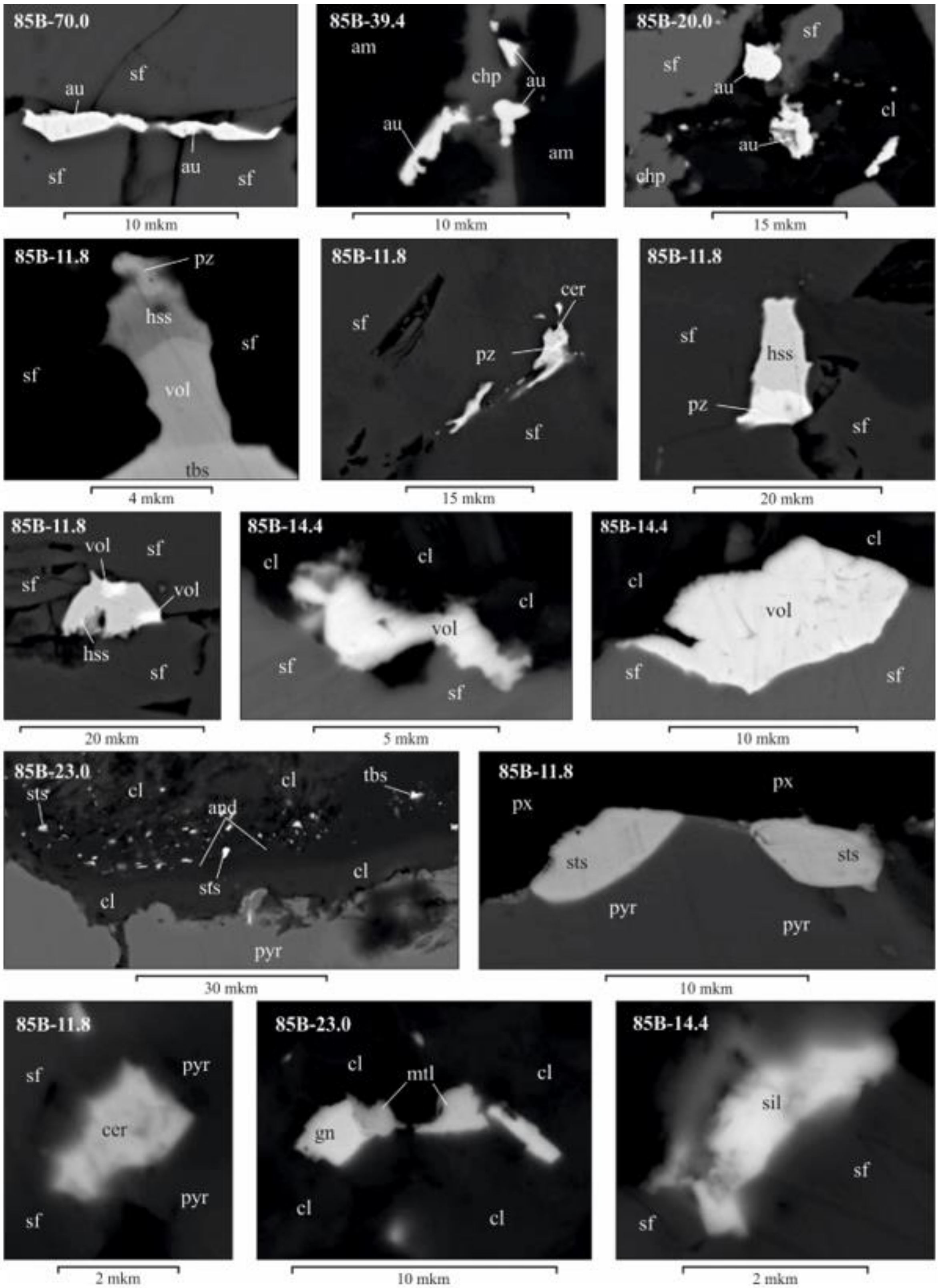

Fig. 4. Forms of native gold (top row), petzite (second row), volynskite (third row), stutzite(fourth row), matildite, cervelleiteand sylvanite(bottom row) in the ores of manifestations «Zapadnoe» au – native gold; am – amphibole; cer – cervelleite; pl – plagioclase; and – andradite; px – pyroxene; mtd – matildite; sil – sylvanite; other abbreviations and symbols see Fig. 3

Table 3. Composition of (%)petzite, volynskite, stutzite, cervelleite, sylvanite andmatildite and characteristics of the host mineral matrix

n	Composition										Host mineral matrix
	Au		Ag		Bi		S		Te		
	min	max	min	max	min	max	min	max	min	max	
Petzite											
Well 85B, depth 11.8 m											
4	23,2	41,7	38,2	44,0					20,1	34,0	Sphalerite
Well 85B, depth 39.4 m											
1		34,6		41,9						23,6	Amphibole, chlorite
Well 85B, depth 44.0 m											
1		24,8		51,0						24,3	Chlorite
Volynskite											
Well 85B, depth 11.8 m											
3			18,2	22,8	35,6	35,9			41,3	46,1	Sphalerite, hessite
Well 85B, depth 14.4 m											
3			18,5	18,7	35,7	36,6			44,6	45,9	Chlorite, sphalerite
Stutzite											
Well 85B, depth 11.8 m											
2			57,7	58,0					42,0	42,3	Pyrrhotite
Well 85B, depth 20.0 m											
1				53,4						40,2	Epidote
Well 85B, depth 23.0 m											
3			59,0	62,6					37,4	41,0	Garnet, galena
Cervelleite											
Well 85B, depth 11.8 m											
3	2,87	4,43	55,6	59,9			2,14	4,88	32,0	39,2	Sphalerite, pyrrhotite
Well 128A, глубина 24.3 m											
1				58,81				5,98		35,2	Sphalerite
Sylvanite											
Well 85B, depth 14.4 m											
1		21,07		23,31						55,6	Sphalerite
Matildite											
Well 85B, depth 23.0 m											
2			21,8	23,0	56,6	58,5	18,4	18,6			Galena, chlorite

Cervelleite (Ag_4TeS), **matildite** ($AgBiS_2$) and **sylvanite** ($(Au,Ag)_2Te_4$) as single grains were found in four samples taken from the core of interspersed copper-zinc ores in wells 85B (deposit «Novaya») and 128A (deposit «Zapadnaya»). Find a close association with pyrrhotite, sphalerite (cervelleiteand sylvanite) and chlorite (matildite) (Fig. 4). Mineral compositions are given in table 3.

2. Discussion of results and conclusions

These data suggest that:

1. The greatest mineralogical diversity of tellurides and native elements is typical for ores of the deposit «Novaya», in the ore deposit «Zapadnaya» the set of minerals of the considered types is sharply limited.

2. Silver and gold mineralization is represented mainly by tellurides, much less – sulfides and native elements. Minerals often have complex relationships with each other, and there are no signs of substitution of some minerals with others.

Silver forms 5 independent mineral forms (in descending order of importance): hessite (Ag_2Te), stutzite(Ag_5Te_3), volynskite ($AgBiTe_2$), matildite ($AgBiS_2$), cervelleite(Ag_4TeS). Silver in high concentrations (up to 15%) is present in other tellurides: melonite ($NiTe_2$) and tellurobismuthite (Bi_2Te_3).Hessit is a through mineral – fixed in both ore bodies, in all mineralogical types of ores, at all depths. Gold forms 3 independent mineral forms – petzite (Au_3AgTe_2), electrum and native gold. As a permanent and significant impurities present in gold cervelleite(to 3.6%), occasionally in hessite (up 2.5%).

Angular, xenomorphic form of aggregates and consistency of mineral composition of telluride mineralization can be the result of crystallization of relatively low-temperature melt among thermally more stable silicate and sulfide phases (Ciobanu et al., 2006; Tomkins, 2007).

The presence of noble metal telluride mineralization in copper-zinc ores is fixed in many deposits (Bortnikov et al., 1988; Moloshag et al., 2004). Telluriana form of gold and silver in ores may reflect the upper level of the epithermal mineralization similar to deposits Birgildinsko-Tominskiy ore node (Plotinskaya and Trubkin, 2010).

3. Noble metal mineralization is confined mainly to the main ore-forming minerals – sphalerite and pyrrhotite, rarely – galena. The association of gold-silver mineralization with zinc sulfides (sphalerite) demonstrates the proximity of the

manifestation «Zapadnoe» to the modern pyrite constructions Mir and TAG of the Mid-Atlantic ridge (Mozgova et al., 2000).

There is a close spatial and possibly paragenetic relationship with secondary minerals – epidote and chlorite.

4. The features of the geological position of the manifestation «Zapadnoe» and mineralogy of precious metals practically correspond to the Tarnier copper deposit (Belogub et al., 2010). A distinctive feature is the absence of telluride-bismuth mineralization (Belogub et al., 2010) and the confinement of noble metal mineralization to all types of ores.

Conflict of interest

The author confirms that the submitted data does not contain conflict of interest.

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References

Belogub EV, Moloshag VP, Novoselov KA, Kotlyarov VA (2010) Native bismuth, tsumoite and lead-bearing variety of tsumoite of Tarnierskoye copper-zinc massive sulfide deposit (the North Urals). ZapiskiRossiyskogoMineralogicheskogoObschestva, 6: 108–119.

Belogub EV, Novoselov KA, Moloshag VP, et al. (2010) Mineralogy of precious metals in the ores of the Tarnier copper deposit (North Ural). Native gold: typomorphism of mineral associations, conditions of formation of deposits, problems of applied research, vol. 1, Moscow, IGEM RAS.

Bortnikov NS, Kramer H, Genkin AD, KrapivaLYa, Santa-Krus M. (1988). Parageneses of tellurides of gold and silver in the gold Deposit of Florence (Republic of Cuba). Geology of ore deposits, 2: 49–61.

Ciobanu CL, Cook NJ, Damian F, Damian G (2006). Gold scavenged by bismuth melts: An example from Alpine shear-remobilizates in the Highiş Massif, Romania. Mineralogy and Petrology, 87: 351–384.

Mozgova NN, BorodaevYuS, Stepanova TV, et al (2000) Precious metals in sulfide associations of deep parts of the active construction of the TAG (Mid-Atlantic ridge. 26º08' n.l.). Lithology and mineral resources, 1: 5–24.

Plotinskaya OYu, Trubkin NV (2010) Mineral associations and forms of gold location in the fields of the Birgildinsko-Tominsky ore node (Ural). Native gold: typomorphism of mineral associations, conditions of formation of deposits, problems of applied research, vol. 1, Moscow, IGEM RAS.

Safina N.P, Maslennikov V.V, Maslennikova S.P (2010) Mineralogical and geochemical features of sulfide ore deposits of the manifestation «Zapadnoe», Subpolar Urals. Ways of realization of oil and gas and ore potential of Khanty-Mansiysk Autonomous Okrug–Yugra,Khanty-Mansiysk, Izdatnaukaservis, book 2: 492–500.

Tomkins AG (2007). Three mechanisms of ore re-mobilisation during amphibolitesfacies metamorphism at the Montauban Zn-Pb-Au-Ag deposit. Mineralium Deposita, V. 42: 627–637.

Zelenov VI (1989). Method of research of gold and silver ores, Moscow, Nedra, pp. 302.