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Ore minerals of the Panarechka epithermal low-sulphide Au-Ag deposit

A.V. Chernyavsky[1], Yu.L. Voytekhovsky[1], A.V. Voloshin[1,2], E.E. Savchenko[1]

[1] *Geological Institute, KSC RAS, Apatity*

[2] *Apatity Branch of MSTU, Geology and Minerals Department*

Abstract. On the territory of the Panarehka volcanic-tectonic structure the NW and SE blocks have been defined according to the mineralogical data. The former relates to the Au-Te deposit type novel for the Kola Peninsula, the latter is of the gold-quartz type. The NW block reveals a great variety of ore minerals of the Au-Ag-Te and Bi-Te-(S+Se) systems, sulphides and sulphosalts.

Аннотация. На территории Панареченской вулкано-тектонической структуры по минералогическим данным выделены СЗ и ЮВ блоки. Первый относится к новому для Кольского п-ова Au-Te типу месторождений, второй – к золото-кварцевому типу. В СЗ блоке отмечено большое разнообразие рудных минералов из Au-Ag-Te и Bi-Te-(S+Se) систем, а также сульфидов и сульфосолей.

Key words: mineralogy, tellurides, gold, silver, tetradimite group, aleksite group, Kola Peninsula

Ключевые слова: минералогия, теллуриды, золото, серебро, группа тетрадимита, группа алексита, Кольский полуостров

1. Introduction

On the territory of the Kola Peninsula and Northern Karelia there are Au occurrences relating to the Proterozoic volcanogenic complexes: 1) in the Pechenga-Imandra-Varzuga Belt – the South Pechenga Structural Zone (SPSZ) with 9 occurrences, and the Panarechka volcanic-tectonic structure (PRVTS), where the North-Western and South-Eastern blocks (NWB and SEB) are defined; 2) in the Pana-Kuolayarvi structure – the Mayskoye deposit and Kayraly occurrence. Dotted on the map there are the outcrops, where Au is identified, according to some published data (Fig. 1). The ore occurrences are joint in space with volcanites and refer to the epithermal type.

Table 1 reflects the mineralogical study of PRVTS, SPSZ, Kayraly and Mayskoye. 13 minerals with the species-forming role of Au-Ag have been defined here, in PRVTS mostly. This structure is located in the central block of the Imandra-Varzuga zone of the Pechenga-Varzuga Greenstone Belt. It is a brachyform ellipsoid-like structure with 18-km-long NW elongation and 6-km-long width. The Pana-Varzuga deep fault breaks the middle part of the structure dividing it into two blocks with different mineralization, i.e. NWB and SEB shifted on 4 km regarding each other (Fig. 2) (*Chernyavsky et al*., 2009). On the PRVTS there are 4 types of ore-bearing rocks to follow: carbonaceous and sulphide-carbonaceous schists, cericite-carbonate-albite-quartz metasomatites, chlorite-carbonate metasomatites and massif pyrite ores. The ore mineralization is connected with the zones, which suffered an intensive metasomatism (silicification, sericitization).

Studying the ore mineralization, JSC "Central Kola Expedition" has revealed 16 ore minerals in ore-promising rocks. Along with sulphides, Au, tellurides and oxides of Fe and Ti have been defined. Examining the polished sections of JSC "CKE" and a new drill core material, the authors have analyzed an earlier determined mineralization and defined new ore minerals. The total amount of the PRVTS minerals has considerably increased. The possibility to divide them into three groups to follow has occurred: the minerals with the species-forming role of Ag and Au (12 minerals), the ones of the Bi-Te-S system (18 minerals) and 27 minerals representing sulphides and sulphosalts.

2. Description and chemical composition of ore minerals

Tellurides are the most numerous among minerals with the Ag and Au species-forming role (Table 2): the simple ones – empressite, hessite, stützite, volynskite and petzite, the compound ones (sulphotellurides) – nagiagite and benleonarite (Russia-first finds). The pentlandite variety, argentotennantite, has been noted. Native Au and Ag have been discovered. The very Au minerals are represented by petzite and nagiagite. Minerals of Ag minerals and its associations with Te, i.e. phases MPh-1, MPh-2 and MPh-3 dominate among Au-Ag minerals. The last two phases may be silver analogues of kalaverite. Minerals with the Ag and Au species-forming role and the Te anion role have been defined in NWB; in SEB only Au and Ag have been found.

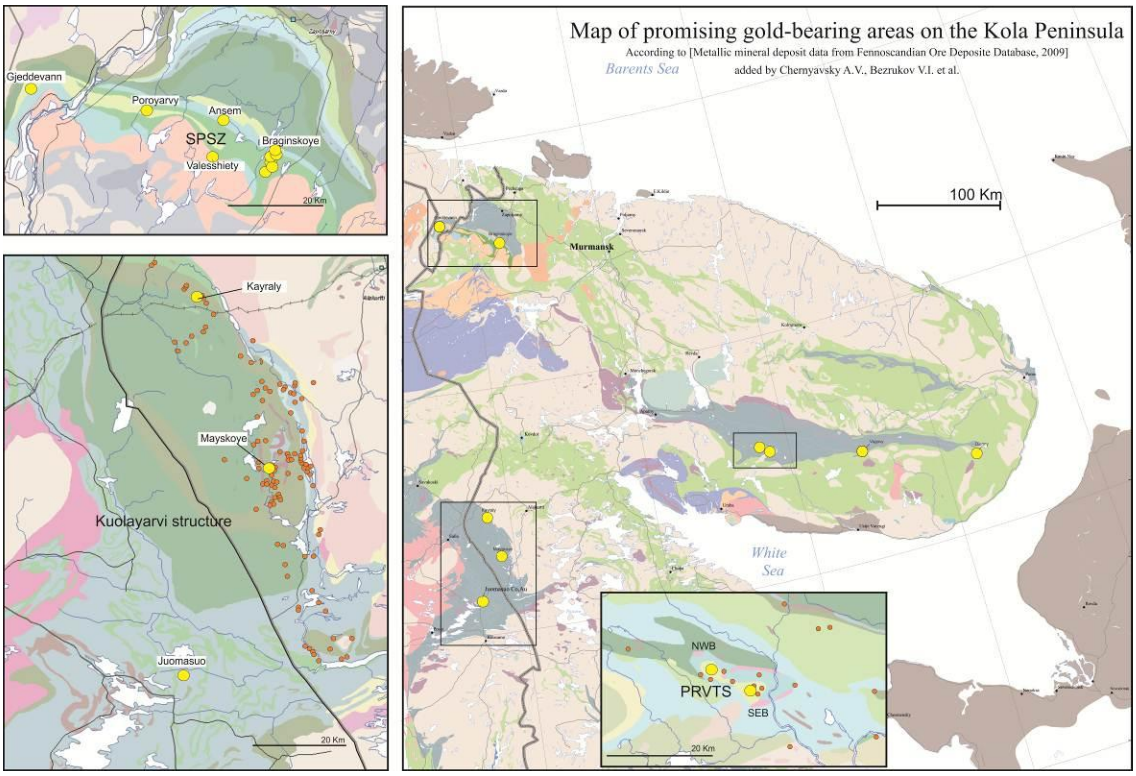

Fig. 1. Scheme of promising gold-bearing areas on the Kola Peninsula. According to metallic mineral deposit data from Fennoscandian Ore Deposite Database 2009, added by Chernyavsky A.V. according to Bezrukov V.I.

Table 1. Au and Ag minerals of various occurrences of the Kola-Karelian region

Mineral	Formula	Occurrences			
		PRVTS (*Gablina*, 2008)	SPSZ (*Akhmedov et al.*, 2004)	Kayraly (*Voytekhovsky et al.*, 2009)	Mayskoye (*Gavrilenko, Rezhenova*, 1987; *Safonov et al.*, 2003)
Gold	Au	7	12	19	7
Silver	Ag	2			
Empressite	AgTe	1			
Argentopentlandite	$Ag(Ni,Fe)_8S_8$	1			
Hessite	Ag_2Te	1	2		
Stützite	$Ag_{5-x}Te_3$	1			
Volynskite	$AgBiTe_2$	5			
Argentotennantite	$(Ag,Cu)_{10}(Zn,Fe)_2As_4S_{13}$	1			
Freieslebenite	$AgPbSbS_3$	5			
Benleonardite	$Ag_8(Sb,As)Te_2S_3$	1			
Kalaverite	$AuTe_2$			2	
Petzite	Ag_3AuTe_2	2	3		
Nagiagite	$Pb_5Au(Te,Sb)_4S_{5-8}$	1			

Note: digits indicate the number of published analyses.

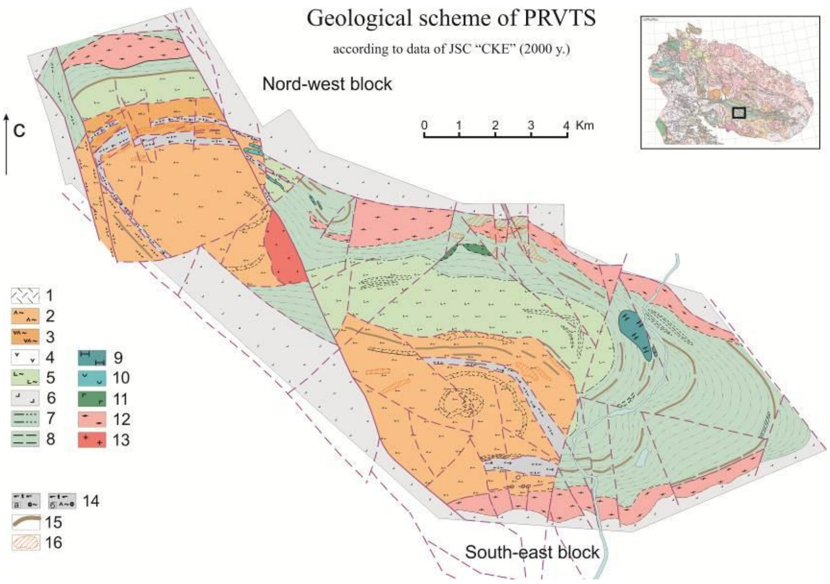

Fig. 2. Geological scheme of PRVTS, according to data of JSC "CKE", 2000.
1 – metariolites; 2 – metadazites; 3 – metadaziandesites; 4 – metaandesites; 5 – basic metatuffs; 6 – metaandelbasalts; 7 – metasandstones; 8 – metapelites; intrusive formations: 9 – metaperidotites; 10 – metapicrites; 11 – diabases, gabbro-diabases; 12 – subalkaline monazites, granodiorites, subalkaline gabbroids, syenites; 13 – leucogranites; 14 – sulphide-carbonaceous schists: a – of carbonaceous material > 50 %; b – of carbonaceous material < 50 %; 15 – sulphide-carbonaceous formations; 16 – metasomatites

New minerals Bi-Te allowed considering the Bi-Te-S system (Table 3). Minerals with the Te anion role (tellurides and sulphotellurides) are represented by native Te and simple and complex associations to follow: the simple ones – associations with a different Bi variation (tsumoite, tellurobismuthite, pilsenite); an association with Hg have been identified – coloradoite (Kola Peninsula-first find); the complex ones – radhakrishnaite having formed after the gallenite-sphalerite association, which includes tellurides. Radhakrishnaite performs no common activity of Cl-rich emanations at final stages of the ore mineralization formation (*Genkin et al*., 1985). Minerals of the Bi-Te-S system are rather widely represented in terms of species and numbers. These are defined in NWB, which is probably caused by its being better studied in comparison with SEB.

Table 2. Chemical composition of minerals with the Ag and Au species-forming role (wt %)

	Empressite	Argentopentlandite	Argentotennatite	Benleonardite	Stützite	Nagiagite
Ag	49.34	10.95	3.62	63.87	59.62	
Au	1.54					9.49
Cu			32.83	0.28		
Zn			1.16			
Pb						57.85
Fe		25.74	11.22	1.90		2.63
Ni		31.61				
S		31.41	28.72	10.76	0.07	6.46
As			0.99			
Sb			21.46	10.65		9.07
Bi					0.93	
Se				1.13		
Te	48.85			11.40	40.07	14.5

	Au		Ag		Petzite		Freieslebenite	
	Range (7 analyses)	Average					Range (5 analyses)	Average
Ag	11.22 – 29.59	21.78	47.99	52.09	50.52	46.09	14.41-24.63	21.35
Au	67.46-87.31	76.52	47.73	44.99	19.23	24.14		
Pb							33.02-46.42	38.62
Fe	0.00-3.82	1.70		2.92			0.84-3.81	2.34
S							12.30-15.85	14.88
Sb							19.37-23.92	22.30
Se							0.00-0.87	0.51
Te					30.25	29.76		
Hg			4.28					

	Hessite		MPh-1		MPh-2	MPh-3	Volynskite	
	Range (6 analyses)	Average	Range (7 analyses)	Average			Range (5 analyses)	Average
Ag	56.72-66.6	62.98	68.12-69.36	68.80	29.78	23.88	15.73-23.01	19.65
Au	0.00-13.07	2.30			2.00			
Pb							0.00-18.60	3.75
Fe			0.00-1.65	0.30			0.00-2.86	0.89
S							0.00-0.11	0.22
Bi							23.45-37.36	33.11
Te	29.24-38.05	34.5	30.04-32.74	31.29	68.22	76.12	35.93-46.66	42.59

Table 4 highlights major ore minerals (sulphides and sulphosalts). This mineral group has two branches as follows: the pyrite one (pyrite – gersdorffite – cobaltite) and the markazite one (markazite – arsenopyrite – costibite). Simple sulphides and oxides of Fe and Ti are present in all the PRVTS ore zones. Occurring of Cu rare minerals (geerite and digenite) allows distinguishing a mineral group in the Cu-S system. There are two series in it: chalcozine-digenite and geerite-covelline (Table 5). Different temperature and chemical resistence of Cu sulphides allows using them as indicators of thermal and physical-chemical history of the deposits formation (*Gablina*, 2008).

Minerals of the Au-Ag-Te system are no widely distributed, but host concentrations of precious metals. Along with native elements, 9 minerals to follow are known here: calaverite, krennerite, sylvanite, montbraite, mutmanite, petzite, empressite, hessite and stützite (Fig. 3) (*Plotinskaya, Kovalenker*, 2008). In PRVTS 6 minerals (Au, Ag, hessite, petzite, stützite and empressite) and 3 mineral phases (MPh-1, MPh-2, MPh-3) of this system have been defined. Au is low-grade (Fig. 3), which is characteristic of the Au-Ag-Te epithermal systems. The best widespread are hessite and phase MPh-1 close to it, which has been marked to have a high Ag content. It is impossible to analyze the structure of the phase due to its minor amounts. Probably, it is to prove hessite.

Table 3. Ore minerals of the Bi-Te-S system

Mineral	Formula	Mineral	Formula
Bismuth	Bi	Joseite-A	Bi_4TeS_2
Tellur	Te	Baksanite	$Bi_6Te_2S_3$
Altaite	PbTe	Rucklidgeite	$PbBi_2Te_4$
Bismuthine	Bi_2S_3	Aleksite	$PbBi_2Te_2S_2$
Tetradimite	Bi_2Te_2S	Kocharite	$PbBi_4Te_7$
Tsumoite	BiTe	Phase C	$PbBi_4Te_4S_3$
Ingodite	Bi_2TeS	Radhakrishnaite	$PbTe_3(Cl,S)_2$
Tellurobismuthite	Bi_2Te_3	Coloradoite	HgTe
Pilsenite	Bi_4Te_3	MPh-8	$HgBi_2Te_4$
Hedleyite	Bi_7Te_3	MPh-26	$PbBi_2Te_2S_2$

Table 4. Sulphides and sulphosalts

Mineral	Formula	Mineral	Formula
Pyrite	FeS_2	Cubanite	$CuFe_2S_3$
Markazite	FeS_2	Bornite	Cu_5FeS_4
Pyrrhotite	$Fe_{1-x}S$	Wittichenite	Cu_3BiS_3
Pentlandite	$(Fe,Ni)_9S_8$	Famatinite	Cu_3SbS_4
Makinavite	$(Fe,Ni)_9S_8$	Tetrahedrite	$(Cu,Fe)_{12}Sb_4S_{13}$
Violarite	$FeNi_2S_4$	Boulangerite	$Pb_5Sb_4S_{11}$
Galenite	PbS	Arsenopyrite	FeAsS
Sphalerite	ZnS	Cobaltite	CoAsS
Greenockite	CdS	Gersdorffite	NiAsS
Geerite	Cu_8S_5	Costibite	CoSbS
Diginite	Cu_9S_5	Stibnite	Sb_2S_3
Molybdenite	MoS_2	Nickel	Ni
Chalcozine	Cu_2S	MPh-9	PbCuFeSbS
Kovelline	CuS	MPh-10	PbCuFeSbS
Chalcopyrite	$CuFeS_2$		

Table 5. Chemical composition of Cu minerals (wt %)

	Chalcopyrite		Chalcozine	Digenite		Geerite		Covelline		
	Range (12 analyses)	Average								
Cu	34.32-34.9	34.57	78.01	76.66	74.45	76.26	75.16	69.63	67.18	72.07
Ag	0.00-0.11	0.01								
Fe	29.86-30.57	30.33	3.07	2.37	3.46		0.79	2.75	3.56	
S	34.36-35.24	34.90	18.92	20.96	22.08	23.74	24.06	27.62	29.26	27.93

	Cubanite	Wittichenite	Famatinite	Tetrahedrite	
				Range (8 analyses)	Average
Cu	25.93	27.84	40.79	24.00-37.3	32.44
Ag		3.42		1.84-11.46	5.28
Fe	34.66	4.37		4.33-18.13	7.72
Zn				0.00-4.62	2.49
S	39.78	9.45	29.7	23.7-33.76	26.63
As			3.31	0.00-1.74	0.86
Sb			26.2	18.76-26.90	24.49
Bi		36.33			
Se		7.54			
Te		11.05			

3. Conclusions

Two trends of the sedimentation sequence of the Au-Ag-Te system minerals have been traced. In one case native Te, sometimes with hessite (stützite) or empressite, is substituted by calaverite and native Au, then petzite and native Au and, finally, hessite with native Au. In this direction the content of Ag in native Au and tellurides increases. The main volume of native Ag is settled until its tellurides form. Such sequence is characteristic of the Kochbula and Kayragach deposits. In another case, the native Te paragenesis is substituted by the association of calaverite with petzite or hessite, then by the association of petzite or hessite with native Au. Native Au is settled after tellurides. Such sequence has been determined on the deposits of C. Bereznyztskoye and Emperior, Fiji (*Plotinskaya*, *Kovalenker*, 2008).

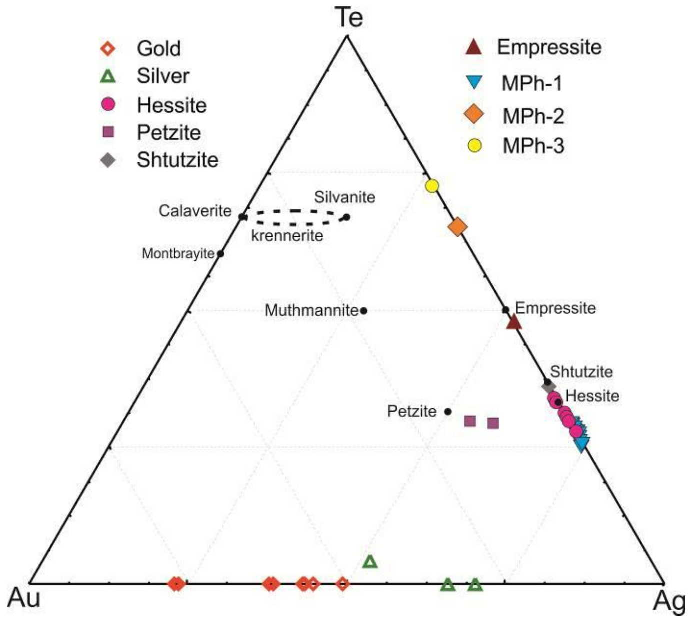

Fig. 3. Minerals of the Au-Ag-Te system. Black dots – ideal composition of the known 9 minerals of the system (*Plotinskaya*, *Kovalenker*, 2008). Colored marks – minerals found in PRVTS

Barite and carbonates in late hessite-bearing associations indicate on the first trend with pH increase. The mineral paragenesis evolution in the Au-Ag-Te system manifests in the transition from native Te through Au detellurides to Au and Ag tellurides, controlled by T decrease, Te fugacity and the solution alkalinity increase.

We conclude the following:

– SWB of PRVTS refers to the epithermal type of low-sulphide Au-Te deposits;

– in the Au-Te deposit of NWB in the Au-Ag-Te system a wide range of mineral parageneses and mineral compositions have been defined;

– minerals of the Au-Ag-Te system are important indicators of physical-chemical conditions of formation, their potential is not still exhausted.

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