BILIBINSKITE, $(Au_{5-6}Cu_{3-2})_8(Te,Pb,Sb)_5$, FROM THE CEMENTATION ZONE OF THE AGINSKOE, KAMCHATKA AND PIONERSKOE, SAYAN MOUNTAINS GOLD–TELLURIDE DEPOSITS

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The mineral assemblages and conditions of formation of bilibinskite are reported. The color photos, without which this unique Au-rich mineral is difficult to be determined, are shown for the first time. The photos illustrate extremely strong bireflectance and anisotropy of bilibinskite. The chemical composition of bilibinskite from the cementation zone of the Aginskoe and Ozernovskoe, Kamchatka, and Pionerskoe, Sayan Mountains gold-telluride deposits is refined. The chemical composition of the bilibinskite from the Aginskoe and Ozernovskoe deposits is close to $Au_5Cu_3(Te,Pb)_5$; while that of Pionerskoe is close to $Au_6Cu_2(Te,Pb,Sb)_5$; generalized formula $(Au_{5-6}Cu_{3-2})_8(Te,Pb,Sb)_5$. Bilibinskite in the oxidation zone is the direct prospecting guide to rich endogenic gold-telluride mineralization.
Figures 4, references 16.
Keywords: bilibinskite, gold-telluride mineralization, Aginskoe deposit, Ozernovskoe deposit, Pionerskoe deposit.

Rickardite, Cu_7Te_5B and weissite, Cu_2Te as pseudomorphs after gold tellurides were reported from the oxidation zone of the Kalgoorlie, Australia (Stillwell, 1931; Markham, 1960), Pervomaiskoe, Northern Kazakhstan (Borishanskaya, 1946), Pionerskoe, Sayan Mountains (Gromova, 1959; Sindeeva, 1959), and Aginskoe, Kamchatka (Andrusenko and Shchepot'ev, 1974) hydrothermal gold deposits. In reflected light, rickardite and weissite are characterized by the extremely wide range of colors, strong bireflectance and anisotropy. Therefore, the optical parameters were considered to be adequate for qualitative determination of these minerals. Hypogenic gold tellurides were unlike to be replaced by supergene copper tellurides elsewhere. The study of gold ores for the cementation zone of the Aginskoe, Pervomaiskoe, and Pionerskoe deposits did not support the presence of copper tellurides. It was established that these are Au-dominated intermetallic compounds (Spiridonov *et al.*, 1978; Spiridonov, Chvileva, 1979, 1982; Chvileva *et al.*, 1988; Spiridonov, 1991, 2010). The most abundant mineral among these compounds is bilibinskite named in memory of Yurii Alexandrovich Bilibin (1901-1952), the outstanding Russian geologist, who investigated geology of gold deposits.

In addition to the listed deposits, bilibinskite and related minerals were described form the Ozernovskoe (Kamchatka), Zod (Armenia), Zhana-Tyube, Zholymbet, Solnyshko, and Almaly (Kazakhstan), and Manka (Altai) deposits. In some places of the cementation zone of the Aginskoe and Zod deposits, bilibinskite and related minerals contain up to 10% of gold in the ores. Bilibinskite occurs as partial or complete pseudomorphs after krennerite $Au_3(Ag,Au)Te_8$, sylvanite $Au(Ag,Au)Te_4$, kostovite $Au(Cu,Ag,Au)Te_4$, calaverite $AuTe_2$, altaite PbTe, and nagyagite $AuPb_5(Te,Sb,Bi)_4S_6$, and rim hypogenic gold. It is associated with Cu-Pb and Fe-Cu-Pb tellurites. The pockets of bilibinskite are up to a few millimeters in size; radiated aggregated of the mineral are frequent. Megascopally, bilibinskite is dark brown and brown, similar to bornite. This mineral is well polished. The cleavage is absent. Conduction is metallic. The relative relief is higher than gold. $VHN_{20} = 380$ $(330-420)$ kg/mm^2 (n = 6). In reflected light, this mineral is looks like bornite in one sections, whereas in the other sections, it is unique due to color changed from grey-violet to beige-cream and blood red that results in strong color bireflectance (Fig. 1). Extremely strong colored anisotropy ranges from grey and dove-color to canary yellow and fiery-red (Fig. 2). The reflectance spectra are unique, complex, and crossed (Fig. 3). According to optical parameters, the symmetry of bilibinskite is low, not high that orthorhombic.

The chemical composition of bilibinskite (determined with a Camebax electron microprobe) from the Aginskoe, Ozernovskoe, and Pionerskoe deposits is as follows, wt.%: 49.6, 50.8, 58.1 Au; 1.57, 0.99, 2.81 Ag; 9.35; 9.29, 4.53 Cu; 0.21, 0.02, 0.17 Fe; 24.6, 24.0, 23.6 Te; 12.8, 13.9, 6.35 Pb; 0.18, 0, 1.53 Bi; 0.23, 0, 3.53 Sb; and 0.34, 0, 0.13 Se, respectively; total is 98.88, 99.00, and 98.75 (n = 13, 5, 6), respectively. The electron microprobe data, high color strength (color purity) (close to native gold and three times more than that of rickardite), and metallic conduction

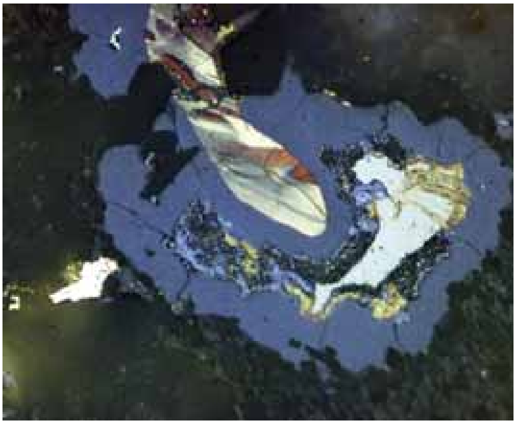

Fig. 1. Photomicrograph of bilibinskite with bright colored bireflectance intergrown with Fe-Cu-Pb tellurite. Cementation zone, Aginskoe deposit, Kamchatka. Reflected light. Width of image 120 microns.

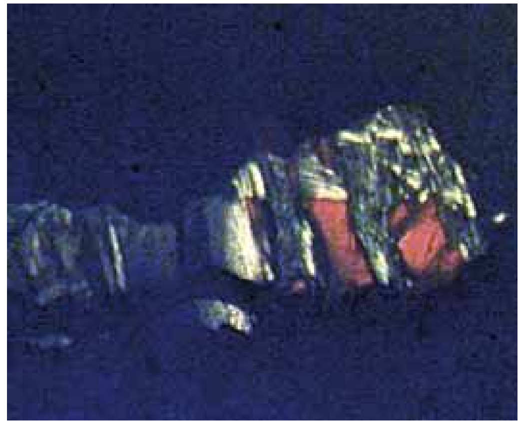

Fig.2. Photomicrograph of bilibinskite with bright color anisotropy. Cementation zone, Aginskoe deposit, Kamchatka. Reflected light, crossed polars. Width of image 80 microns.

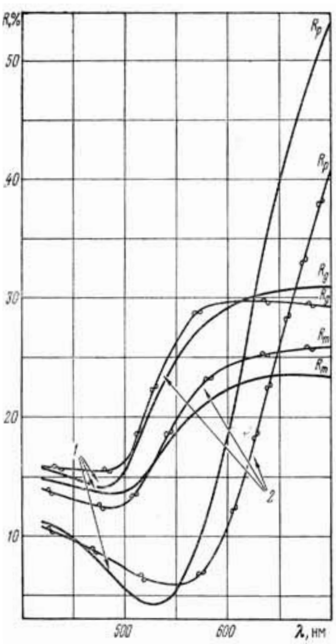

Fig.3. Reflectance spectra of bilibinskite and Sb-rich bilibinskite in the range of 400 to 700 nm from (1) Aginskoe deposit, Kamchatka, and (2) Pionerskoe deposit, Sayan Mountains, respectively.

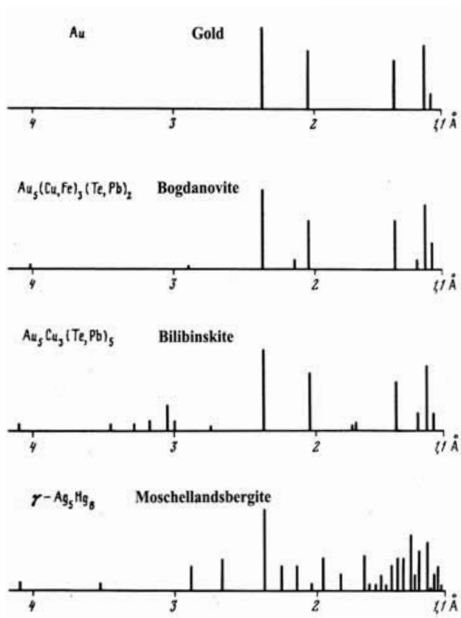

Fig. 4. X-ray diffraction powder patterns of gold, bogdanovite, bilibinskite, and moschellandsbergite.

are not consistent with assumption of a significant oxygen in bilibinskite.

Due to small monoblocks (less than 10–15 microns), the X-ray single crystal study and determination of the structure of the mineral were failed. The X-ray diffraction patterns of bilibinskite and related bogdanovite (Fig. 4) are different from that of gold (Berry, Thompson, 1962) in additional reflections. On the basis of this fact, these minerals are suggested to have superstructures produced from face-centered cubic lattice of gold. The dimension of the primitive pseudocubic subcell of bilibinskite is a'_o = 4.10 Å. The X-ray powder diffraction pattern of bilibinskite shows many additional weak and medium reflections in comparison with gold that permits the similarity to moschellandsbergite Hg_8Ag_5 with the same relation of atoms of different species. The structure of moschellandsbergite is similar to the disordered defect body-centered cubic superlattice of γ-br a ss Zn_8Cu_5 (Pearson, 1972). The X-ray diffraction data, elevated hardness, and insignificant anisotropy of hardness are not consistent with the assumption of the layered structure of the mineral.

According the X-ray diffraction data of bogdanovite, Au, Cu, Fe, and Ag are combined at one structural site Me (core of the face-centered cubic lattice), while Te, Pb, Sb, and Bi occupy another site X (interstitial atoms) (Spiridonov *et al.*, 1991). The chemical composition of bogdanovite corresponds to the formula $Au_5(Cu,Fe)_3$

$(Te,Pb)_2$, in other words Me_4X. Therefore, bilibinskite is considered as plumbotelluride – stibioplumbotelluride of Au and Cu with the composition of Me_8X_5.

The formulae of bilibinskite from the Aginskoe, Ozernovskoe, and Pionerskoe deposits calculated on the basis of 13 atoms are as follows:

$(Au_{4.82}Cu_{2.82}Ag_{0.28}Fe_{0.07})_{7.99}(Te_{3.69}Pb_{1.18}Se_{0.08}Sb_{0.04}Bi_{0.02})_{5.01}$;
$(Au_{5.01}Cu_{2.84}Ag_{0.18}Fe_{0.01})_{8.04}(Te_{3.66}Pb_{1.30})_{4.96}$;
$(Au_{5.91}Cu_{1.43}Ag_{0.52}Fe_{0.06})_{7.92}(Te_{3.71}Pb_{0.61}Sb_{0.58}Bi_{0.15}Se_{0.03})_{5.08}$.
respectively. The composition of bilibinskite from Aginskoe and Ozernovskoe is close to $Au_5Cu_3(Te,Pb)_5$; from Pionerskoe, to $Au_6Cu_2(Te,Pb,Sb)_5$; the generalized formula of the mineral is $(Au_{5-6}Cu_{3-2})_8(Te,Pb,Sb)_5$.

A mineral, $AuTeO_3$, with optical parameters similar to bilibinskite occurs in the cementation zone of the Aginskoe and Ozernovskoe deposits, Kamchatka. The minerals similar to bilibinskite but are different in composition and X-ray diffraction pattern occur at the Ashley deposit, Canada (Harris *et al.*, 1983).

In the oxidation zone bilibinskite (Au-Cu plumbotelluride and stibiplumbotelluride) is unstable. It is replaced by the aggregates of fine-lamellar and sponge gold, balyakinite $CuTeO_3$, plumbotellurite $PbTeO_3$, Cu-Pb oxytellurites, the cupriferous gold group minerals, and iron hydroxides.

The bilibinskite group minerals in the weathering profile are the direct prospecting guide to rich endogenic gold-telluride mineralization.

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