

RARE MINERALS OF In, Cd, Mo, AND W IN GOLD-BASE METAL VEINS OF THE BUGDAYA Au-Mo(W)-PORPHYRY DEPOSIT, EASTERN TRANSBAIKALIA, RUSSIA

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New data on a number of rare minerals of In, Cd, Mo, and W, which have been obtained using modern analytical techniques, are described in this article. These minerals have been identified in gold-rich polymetallic ore superimposed on Mo(W) stockwork porphyry mineralization. Indium mineralization presents extremely rare dzhalindite $\text{In}(\text{OH})_3$ that was previously described in Russia only from deposits Dzhallinda, Amur region and Verkhnee, Primorsky krai as supergene mineral. Tungsten and molybdenum are concentrated in rare intermediate phase of the wulfenite-stolzite series $\text{Pb}(\text{W}_{0.74}\text{Mo}_{0.26})\text{O}_4$, and Cd, in greenockite CdS. Occurrence of well-shaped cubic crystals of dzhalindite exclusively in quartz and association of the mineral with sphalerite, native silver, and electrum allow suggesting its hypogene origin (in contrast to previous findings as supergene pseudomorphs after indium sulfide). However, additional investigation is required to establish formation conditions of dzhalindite.

4 figures, 22 references.

Keywords: dzhalindite, Mo-bearing stolzite sphalerite, greenockite, Bugdaya porphyry deposit, Eastern Transbaikalia, polymetallic veins, gold mineralization.

Geological structure, ore mineralogy, and stages of mineralization

The Bugdaya Au-Mo(W) porphyry deposit, eastern Transbaikalia located 18 km SW of the Shakhtama mine in the interfluvium of the Gazimur and Unda rivers is hosted in the central volcanic dome of concentric-radial structure. This dome is located in the southeastern large Variscan granitoid pluton that was intruded by the Late Jurassic subvolcanic granite-porphyry and rhyolite-porphyry.

Mo-W ore is hosted in a stockwork that is column-shaped in vertical section and oval, in plan of 1100 x 800 m in size. This stockwork comprises variably oriented quartz-molybdenite veins and veinlets (few to tens cm thick) with local scheelite, which arrange around stock of silicified rhyolite (granite) porphyry. Gold (1–2 to 100–150 g/t, less frequent higher) is hosted in steep quartz-sulfide veins (250–300 m long and from few to 3–4 cm thick), which also contain the main resources of Pb and Zn (Kharitonov *et al.*, 2003).

Our investigations indicated that ore of the Bugdaya deposit where about 70 minerals were identified is characterized by more variable and complex mineralogy that previously reported. Pyrite, galena, sphalerite, molybdenite, chalcocopyrite, and scheelite are the most abundant. Arsenopyrite, fahlores, As-rich pyrite, magnetite, and hematite are less abundant. Small amounts of various bismuth (aikinite series, matildite-galena series, and Cu-Ag-Pb-Bi-S system) and antimony (polybasite, pearceite, and their Te-bearing analogues; boulangerite; and bourmonite) minerals are frequently observed. Rare minerals are native silver, kustelite, tellurides and sulfotellurides, wurtzite, dzhalindite, and greenockite. Two latter minerals are described below. Gold-silver alloy with fineness ranging from 962 to 223 were found to be associated with minerals from base metal veins and veinlets.

Quartz is dominant gangue mineral; chalcedony, carbonates, muscovite (sericite), phlogopite, tourmaline, potassi-

um feldspar, kaolinite, smectites, and fluorite are minor. Covellite, chalcocite, bornite, ferrimolybdenite; rare ilsemanite and stolzite; cerussite, barite, and anglesite were described from supergene zone.

Four major stages of hydrothermal mineralization are recognized: (1) pre-ore; (2) quartz-molybdenite; (3) gold-base metal; and (4) post-ore (Kovalenker *et al.*, 2007). Pre-ore K-feldspatization and strong silicification occurred after emplacement of sub-volcanic rhyolite-(granite)-porphyry stock. Then, Mo-W stockwork of the quartz-molybdenite stage was formed. Gold-base metal veins accompanied with sericitization and pyritization of wall rocks are located in the structures cutting Mo-W mineralization. Precipitation of late stage chalcedony, quartz, and carbonates as veins and veinlets accompanied with argillization and insignificant redeposition of earlier minerals complete the hydrothermal mineral-forming process.

Rare dzhalindite and greenockite were probably precipitated at the end of gold-base metal stage.

Dzhalindite

Indium mineralization was found as dzhalindite $\text{In}(\text{OH})_3$ that had been previously described in Russia only from tin ore of deposits Dzhalinda, Amur region, Khingan Minor (Genkin and Murav'eva, 1963) and Verkhnee, Kavalerovo district Primorsky krai (Gorelikova *et al.*, 2008) as pseudomorphs after indite. Dzhalindite was identified at some tin deposits in the other countries including Zinnwald-Cinovec (border between Czechia and Germany) (Jansa *et al.*, 1998); Mangabeira, Brazil (Moura and Francisquinibotelho, 2000); and Mount Pleasant, Canada (Sutherland, 1971). The mineral was found at the Flambeau Cu-Au-Ag deposit, Wisconsin, USA; Kamazu Au-Ag-Te-Mn deposit, Japan; and Lavrion, Greece nickel (annabergite) deposit. Octa-

hedral crystals of dzhalindite were mentioned, when hydroxides of rare and trace elements at the Tsumeb deposit, Namibia and deposits of Nevada, USA were described (Yakhontova and Zvereva, 2000).

Complete description of dzhalindite from deposits in other countries is available only from the Mount Pleasant deposit (Sutherland, 1971), where this mineral associated with quartz, calcite, and galena was found in veinlet cutting sphalerite.

Mode of occurrence and mineral assemblage. For the present, we identified cubic crystals of dzhalindite $\text{In}(\text{OH})_3$ only in one section of quartz-sulfide vein at 50 m depth below surface. Ore minerals replacing minerals of quartz-molybdenite stage occurred close to dzhalindite are quartz-galena-chalcopyrite-sphalerite segregations with small amount of pyrite and fahlore (predominant tennantite) and enriched in gold (predominant electrum with fineness 698 to 748). Aggregates of base metal sulfides are strongly fractured, healed by tennantite, then brecciated again, and cemented by fine-grained quartz with crystal size ranging from 40 to 70 μm .

Dzhalindite presents square and rectangular well-crystallized grains, and less frequent other sections of cube (triangular, rhombic, trapezoid, and hexagonal) (Fig. 1, 2). Size of crystals varies from 30 to 94 μm , most frequent, from 50 to 70 μm . Locally, intergrowths of several crystals are observed. Frequency of dzhalindite is 70 crystals in section 4 x 2 cm in size.

Dzhalindite occurs only in the areas, where late quartz cements fragments of grains of high-Fe sphalerite-I (4.1–6.54 wt. % Fe). According to spectral analysis, this sphalerite contains, %: 0.03–3 Cu, 0.1–0.2 Cd, 0.03–0.5 Mn, 0.008–0.08 Ag, and 0.002–0.05 In. Fine disseminated chalcopyrite is frequently observed in sphalerite-I. Few 1 mm grains of galena-I intergrown with rare tennantite occur among fragments of sphalerite-I.

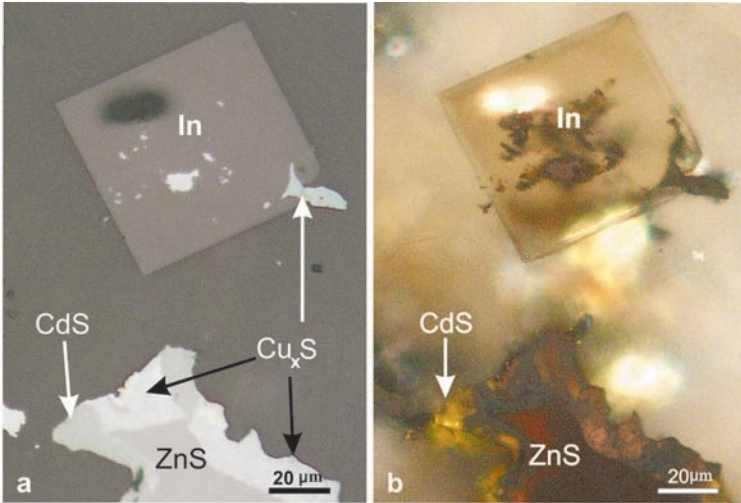


Fig. 1. Dzhaldindite and associated minerals. (a) Photomicrograph of well-shaped crystal of dzhaldindite (In) overgrown by minerals of the CuS-Cu₂S (Cu_xS) system in quartz (dark gray), the same minerals together with greenockite (CdS) overgrow sphalerite (ZnS), thin polished section. (b) Photomicrograph of the same dzhaldindite crystal that is transparent with weak coloration, yellow reflections of greenockite are well seen in sphalerite, cross polars, strong light. (c) BSE image of dzhaldindite (rotated 30°) with pronounced zoning. (d) BSE image of greenockite rim (light gray) with admixture of chalcocite in quartz.

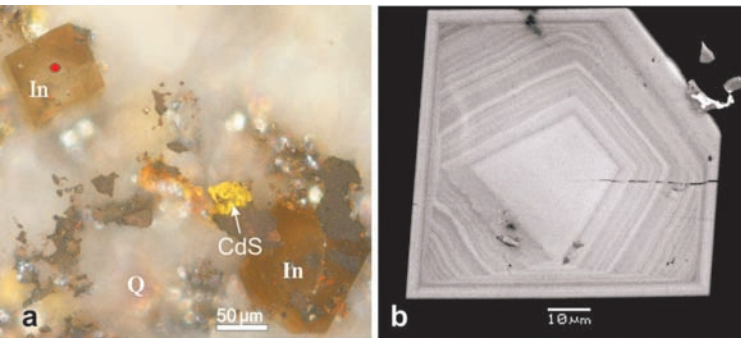
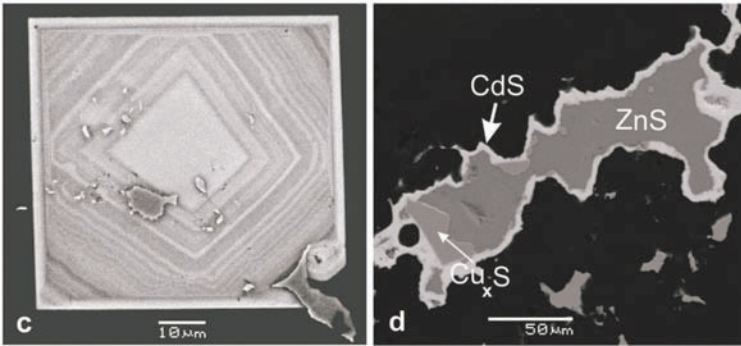
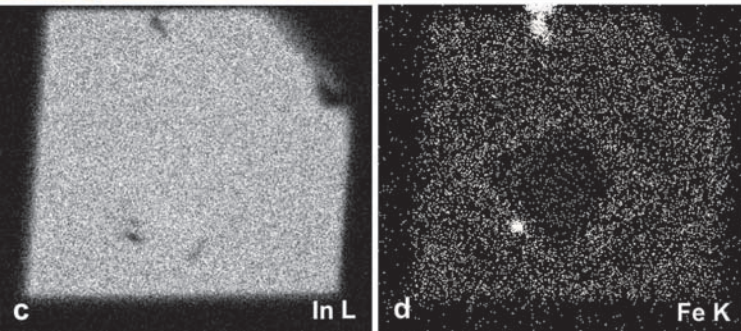


Fig. 2. Fe-rich variety of dzhaldindite and distribution of Fe and In in it. (a) Photomicrograph of brown crystals of dzhaldindite in quartz; one of the crystals (right low) is overgrown by minerals of the CuS-Cu₂S system; yellow mineral is greenockite; thin polished section, cross polars, strong light. (b) BSE image of dzhaldindite crystal (red point in Fig. 2a). (c) X-ray map of In in the crystal; (d) X-ray map of Fe (zoning is remarkable, Fe is lower in the core) in the crystal.



Most fragments of sphalerite-I are rimmed by thin (from portions to first tens μm ; less frequent more) aggregates of the $\text{CuS-Cu}_2\text{S}$ system minerals (Fig. 1). Microscopically and chemically, covellite and phases $\text{Cu}_{1.79}\text{S}$ $\text{Cu}_{1.82}\text{S}$, which are optically and compositionally close to chalcocite were identified among these minerals. Non-stoichiometric composition is probably caused by fine admixture of covellite in chalcocite but other minerals of the $\text{CuS-Cu}_2\text{S}$ system such as djurleite and anilite are also possible. Elevated Ag (1.1–1.7 wt. %) is a feature of these minerals. Silver substitutes univalent copper or is related to fine inclusions of Ag-bearing minerals. In addition to these minerals, greenockite (Fig. 1a, b, d) and galena-II are frequently observable in the rims. Development of galena-II after covellite and its few tens μm thick veinlets filled interstices between grains of greenockite and chalcocite are remarkable.

Sphalerite-II, greenockite, pyrite, native silver, and electrum were identified in dzhalindite-bearing quartz. Few sphalerite-II is observed adjacent to fragments of sphalerite-I as euhedral isometric or slightly elongated and rounded crystals of several tens μm in size. In contrast to sphalerite-I, it is characterized by strong brownish yellow reflections and does not contain inclusions of chalcopyrite; rims of the other minerals are extremely rare.

Pyrite was observed in small amount as trails of tiny (4–5 μm) well-shaped cubic crystals. Such trails can overgrow crystals of dzhalindite.

Relatively small amount of native silver is hosted only in dzhalindite-bearing quartz as intergrowths of curved 80 μm long wire-shaped crystals and less frequent, as clotted segregations with uneven lobe-shaped outlines of few to first tens μm in size. Native silver (8 point analyses) is distinguished by insignificant (tenths wt. %) Zn, Cu, and S; 0.04–0.3 wt. % Te and 0.2–0.43 wt. % Au.

Electrum is present in quartz in slightly less amount than native silver and occurs as small clotted segregations and isometric grains (2–70 μm) with imperfect faces. Much larger (up to 176 μm) segregations of electrum in sphalerite-I are isometric or slightly elongated and have smooth and more frequently rounded outlines. Fineness of electrum (about 700) from this assemblage (mean of 40 point analyses) is usual for rich ore and slightly lower than average value (about 730) at the deposit.

All these minerals spatially associated with dzhalindite are not intergrown with it and occur not more than tens microns of the mineral. In single instance, 4 μm inclusion of electrum with approximately equal weight portions of Au and Ag was observed in dzhalindite.

Optical parameters and physical properties. Dzhalindite was identified on the basis of composition, optical parameters, and symmetry similar to synthetic phase $\text{In}(\text{OH})_3$ produced by reaction of alkalis and salts of indium during boiling (Fricke, Seitz, 1947) and natural dzhalindite, that was described as new mineral in (Genkin and Murav'eva, 1963). Due to small sizes of the dzhalindite segregations, X-ray diffraction study of the mineral was failed.

Dzhalindite is dark gray under reflected light and significantly brighter than quartz but darker than scheelite. Reflectance of dzhalindite is about 8–9% that is consistent with measurements at $\lambda = 589 \text{ nm}$ (yellow light) 8.2% (Genkin and Murav'eva, 1963). Internal reflections are weak, whitish or yellowish, with slight translucence on crystal margins.

Cross polars microscopic observation at maximum lighting shows that sections of the dzhalindite cubes are transparent and semitransparent, locally pinkish-yellowish or practically colorless, with yellowish amber (to light brown) tint (Fig. 2a). Between these varieties, there are all intermediate varieties dominated by practically col-

orless transparent crystals (Fig. 1b). Relief is substantially lower than that of quartz and slightly lower than sphalerite. Dzhalindite is well polished; surface of crystals is smooth and flaw-free.

All crystals of dzhalindite are zoned with alternated darker and lighter zones. It is clearly seen in back scattered electron (BSE) images (Figs. 1c, 2b) made with JSM-5610 and JSM-5300 analytical scanning electron microscopes (ASEM). ASEM study of the crystal surface shows that zoning is also displayed in relief probably indicating different density and hardness of zones. The revealed zoning is caused by different composition of the zones (Fig. 2 d).

Thickness of the zones decreases outward from 4 μm to portions of microns. Intermediate zones have smoothed tops (edges) with smoothing increasing to the margin that can testify to certain dissolution of the growing crystals. Same faces of the intermediate zones are curved. Outer zone of the crystal is compared with core and nearly elsewhere is cubic. In many cases, these outer zones (as crystal faces) are oriented at approximately 45° to the earlier intermediate zones. The normal rhythmic zoning without crystallographic reorientation of the outer zone and final faces occurs in the smaller crystals. In such crystals, no features of dissolution (smoothed apices, inclusions of other minerals, roughness of faces of intermediate zones etc.) during growth are observed.

The chemical composition of the mineral was determined with a JSM-5300 analytical scanning electron microscope equipped with energy dispersion system. The near colorless transparent variety of dzhalindite contains, wt. %: 63.27 In, 34.68 O, and insignificant Fe. In this case, Fe is minimal (0.61 wt. %) in homogeneous core and reoriented outer zone of the crystals. Slightly more Fe (1.08 wt. %) is detected in one of the darker (in back-scattered electrons) intermediate zones. The light brown semitrans-

parent variety of dzhalindite was analyzed for comparison (Fig. 2). Like the transparent variety, Fe content in the core is low but slightly higher (0.9 wt. %). Concentration of iron in one of the darkest zones is four times higher (3.6 wt. %). Thus, the observable zoning in dzhalindite results from oscillated Fe content in the crystals. It should be noted, the iron concentration in dzhalindite from type locality is much higher ($\text{In}/\text{Fe} = 4$) that is caused different mode of its formation, pseudomorphous replacement of indite, which contains Fe.

Species of iron in dzhalindite are not yet established. Light brown tint of the mineral can indicate three-valence iron and in this case, Fe is probably present as fine compounds rather than substitutes In in the mineral structure because of sufficiently great difference in ionic radii (nm, coordination number is 6): 0.076 Fe^{3+} and 0.094 In^{3+} . Presence of iron as fine compounds of Fe^{3+} is confirmed by variable mineral color that is probably caused by local enrichment of mineralizing fluids in Fe^{3+} .

According to (Roy and Shafer, 1954), just $\text{In}(\text{OH})_3$ is stable phase at 245°C and below (pressure 703 kg/cm^2). At temperature higher than 245° (the same pressure), $\text{In}(\text{OH})_3$ transformed into InOOH . Over 435°C , only phase In_2O_3 is stable. The temperature of formation of studied dzhalindite can be estimated only indirectly, because there are no fluid inclusion data for host quartz and dzhalindite itself. However, homogenization temperature of fluid inclusions in gold-bearing quartz from similar quartz-base metal veins at the Bugdaya deposit ranges from 225 to 205°C (Kovalenker *et al.*, 2007); inclusions in cleiophane homogenize at $217 - 140^\circ\text{C}$. Fluids are sulfate-hydrocarbonate with high degree of oxidation ($\text{CO}_2/\text{CH}_4 > 100$). The results obtained combined with spatial association of dzhalindite with low-temperature minerals (gold-silver mineralization, sphalerite-II, greenockite, and galena-II) most probably testify to the

formation temperature of the minerals no higher than 225°C. All these data can indirectly indicate that in contrast to supergene dzhalindite from the Dzhalinda and Verkhnee deposits, this mineral found at Bugdaya is probably formed under hypogene conditions. However, additional study is required to infer certain conditions of its formation. Yakhontova and Zvereva (2000) emphasized ambiguous formation conditions of dzhalindite; Sutherland (1971) just states a fact that dzhalindite cuts sphalerite.

Greenockite

Mode of occurrence and mineral assemblage. Greenockite is constantly associated with dzhalindite and is observed only in sections with dzhalindite. It is more abundant than sphalerite-II. The mineral occurs as irregular and more frequent, elongated rounded clusters up to 50 µm in size hosted in late quartz usually adjacent to dzhalindite. Traces of the mineral are observed some distance of dzhalindite. Greenockite as few to 10 µm thick rims around sphalerite-I (Fig. 1d) is extremely characteristic. Locally, chalcocite invading to both minerals occurs along contact between sphalerite-I and greenockite. Locally, late galena emplaced as fine inlets into intergrain space of sphalerite-I and greenockite fills interstices between these minerals. No intergrowths of greenockite with other minerals were established.

Optical parameters and physical properties. Under reflected light, greenockite is gray with weak greenish tint. Its reflection is slightly higher than that of sphalerite. Cross polars microscopic observation at maximum lighting shows that greenockite is bright lemon or yellow, transparent or semitransparent (Figs. 1b, 2a). Strong internal reflections hide anisotropy. Relief is lower than that of sphalerite. Greenockite is well polished; surface of crystals is smooth and flawless.

The chemical composition of greenockite (2 point analyses) determined using a JSM-5300 analytical scanning electron microscope equipped with energy dispersion system is close to stoichiometric, wt. %: 74.08 – 76.5 Cd, 21.93 – 23.5 S. Theoretical composition is as follows, wt. %: 77.81 Cd and 22.19 S. Deficiency of Cd is caused by admixture of Zn (up to 2.19 wt. %) and Cu (up to 1.71 wt. %).

Conditions of formation. According to most publications, natural greenockite is formed exclusively under low-temperature conditions. In this case, it can be both supergene and hypogene. Often, the exact determination of the origin is difficult. It is caused by similar morphology of supergene and hypogene grains (for example, in our case, a presence of the mineral as rims) and associated minerals whose precipitation is possible in both settings. Recently, papers, where greenockite is attributed with high validity to hypogene minerals, were published. For example, Pletnev (1998) assigned greenockite to hypogene minerals. Greenockite is present in sublimates of the lowest temperature (300 – 600°C) fumarole field of the Kudryavy volcano (Chaplygin, 2008). According to fluid inclusion study (Tombros *et al.*, 2005), deposition temperature of the Ag-Au-Te epithermal mineralization associated with greenockite is 215°C that is within range of precipitation of late quartz and cleiophane 225 – 140°C given when dzhalindite was described.

Impurities of Cd in sphalerite (up to tenths wt. %) and tetrahedrite containing up to 2.97 – 3.64 wt. % Cd in rich ore were probable source of cadmium to form greenockite. Cadmium appears to release during dissolution and recrystallization of these minerals at late stage of hydrothermal process.

Mo-bearing stolzite ("chillagite")

Name of rare mineral "chillagite" existed for almost whole last century starting

¹ – The mineral that we identified should be apparently called Mo-rich stolzite due to strong predominance of W over Mo.

* – mineral was discredited by the Commission on New Minerals and Mineral Names, International Mineralogical Association (CNMNMN) IMA.

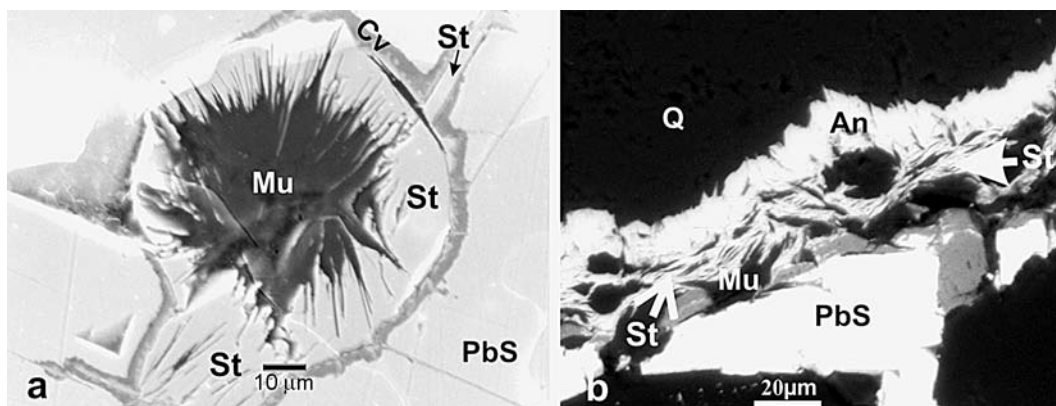


Fig. 3. BSE images of the stolzite-wulfenite series mineral. (a) Rosette-shaped Mo-rich stolzite (St) in galena (PbS); the mineral fills fracture in galena and is rimmed by covellite (Cv) (upper part); muscovite (Mu) in the core of Mo-rich stolzite; white spot in the upper part is sputtering defect. (b) Veinlet-shaped Mo-rich stolzite intergrown with anglesite (An) at the contact between galena and quartz (Q); laths of muscovite (Mu) are observed in Mo-bearing stolzite.

from the first original description of this mineral in 1912 from Christmas Gift Mine, Chillagoe, Queensland, Australia (Ullman, 1912). The mineral turned out intermediate member of the $PbWO_4$ (stolzite) - $PbMoO_4$ (wulfenite) solid solution series, where stolzite and wulfenite have the same space group $I4_1/a$. Later investigation of the mineral from the same deposit showed that it should be considered as W-rich wulfenite, which, in contrast to its pure variety, crystallizes in space group $I4$ due to W-Mo ordering (Jury *et al.*, 2001).

The phases similar in composition and called as "chillagite" were described from ores of several deposits in the eastern Transbaikalia (Syritso *et al.*, 1964), including the Shakhtama mine group in Gazimur-Zavodsky district (Chureva, 1948) and Dzhida tungsten deposit (Korzinsky *et al.*, 1959). It was found at deposits in other regions (Smol'yaninova *et al.*, 1963; Yushkin *et al.*, 1972).

Mode of occurrence and mineral assemblage. The mineral was identified in the vein gold-base metal mineralization superimposed on the earlier tungsten-molybdenum stockwork. Such superimposition resulted in the complex Au-Ag-Mo-W-Pb-Zn-Bi mineralization. In addition, in consequence

of supergene transformation (sampling depth is 50 m below surface) mineralogy of ore became more complex and along with appearance of ferrimolybdate and less frequent ilsemannite formed after molybdenite, this rare intermediate phase of the lead molybdate-tungstate series fills fractures and cavities in galena and some other minerals of the gold-base metal veins.

The sample containing Mo-rich stolzite is highly sulfidized gold-rich fragment of vein with content of sulfides about 75%. Sulfides are dominated by practically fresh pyrite of two generations, chalcopyrite, and galena with covellite and insignificant chalcocite, which occur as thin films on these minerals or fill microfractures in them. Other minerals, sphalerite, various sulfosalts including tetrahedrite and Cd-bearing tetrahedrite, Te-bearing polybasite (average ~4% Te), matildite, and wittichenite are subordinated. Quartz is predominant gangue mineral. In addition, there are muscovite (no more than 2%) and anglesite (no more than 1%) filling fractures in quartz and galena. In the sample, we observed extremely great amount (for this deposit) of native gold and electrum grains of three generations with fineness ranging from 962 to 504. Gold-silver phases cutting covellite

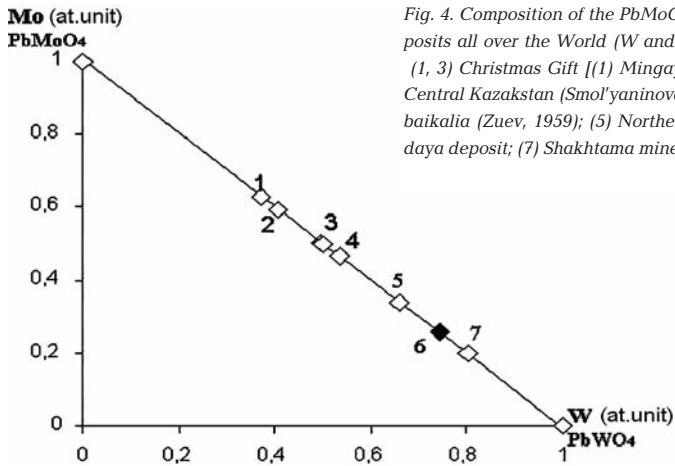


Fig. 4. Composition of the PbMoO_4 - PbWO_4 series minerals from various deposits all over the World (W and Mo concentrations – in atomic percent). (1, 3) Christmas Gift [(1) Mingaye, 1916; (3) Ullman, 1912]; (2) Akchatau, Central Kazakhstan (Smol'yaninova and Senderova, 1963); (4) Eastern Transbaikalia (Zuev, 1959); (5) Northeastern Russia (Gladyshev, 1949); (6) Bugdaya deposit; (7) Shakhtama mines, Eastern Transbaikalia (Chureva, 1948).

as thin (1–3 μm) veinlets have the lowest fineness.

Mo-rich stolzite occurs predominantly in cavities and along cleavage in galena; and less frequent, at the contact of galena with quartz, muscovite and other minerals of the gold-base metal veins (Fig. 3). Therefore, galena and occasionally other sulfides of the Bugdaya deposit are enriched in molybdenum and especially in tungsten (up to 4125 g/t W), with inclusions of primary minerals of these elements being absent in them. Mo-rich stolzite overgrows laths of potassium mica if they occur in galena or at contact with it. Segregations of Mo-rich stolzite are locally rimmed by covellite (Fig. 3a). Mo-rich stolzite is also observed in veinlets as intergrowths with anglesite (Fig. 3b).

Optical parameters and physical properties. Segregations of Mo-rich stolzite do not exceed hundredths mm in size. It occurs as spear- or lath-shaped crystals elongated along cleavage and locally slightly curved with the length/width ratio ranging from 6 to 10. In cavities, the mineral occurs as rosette radiant intergrowths (Fig. 3a). Under reflected light, it is light gray, with reflection being higher than that of anglesite and close to sphalerite. Mo-rich stolzite is anisotropic with remarkable birefractance that is slightly smoothed by very strong yellowish internal reflections. Under electron

beam, the mineral has bluish-greenish luminescence with intensity close to fluorite and scheelite.

The chemical composition of the mineral determined with a CAMECA MS-46 electron microprobe corresponds to formula $\text{Pb}(\text{W}_{0.74}\text{Mo}_{0.26})\text{O}_4$. Insignificant Fe, Ca, and in one analysis Sr were detected. The W/Mo ratio of previously described "chillagites" widely ranges from 0.59 to 4.03 (Fig. 4). The chemical composition of the examined mineral significantly dominated by W (W/Mo = 2.9) is the closest to "chillagite" from the Shakhtama mines. Small sizes of the grains prevented more detailed study of this mineral, particularly, investigation of its crystal structure. Intimate association of examined Mo-rich stolzite with covellite and anglesite, which are characteristic minerals of the oxidized zone, indicate supergene origin of the mineral.

Conclusions

1. The following factors favored the formation of rare and exotic minerals at the Bugdaya deposit: (1) ore-forming fluids evolved from high-temperature through medium- and low-temperature to supergene; (2) juxtaposition (telescoping) of different stage mineral assemblages in some structures; and (3) multiple brecciation of

ores, corrosion and dissolution of minerals with release of trace elements and their incorporation into new compounds at local geochemical barriers.

2. According to spatial association of Cd and In minerals with early sphalerite, one of the major ore component, they were formed as a result of dissolution and recrystallization of sphalerite.

In-bearing early sphalerite is characteristic of many deposits in the eastern Transbaikalia, though indium content in this mineral rarely reaches tenths percent and intimate correlates with a presence of tin minerals at the deposits implying identification of Sn minerals at the Bugdaya deposit. It is more probable because at the neighboring Shakhtama Mo-porphyry deposit, where indium (up to 50 g/t) was detected in minerals of the base metal ore (bulk analysis), stannite was found (Sotnikov *et al.*, 1995).

Crystallization of dzhalindite and shape and composition of the mineral similar to phase synthesized by the reaction of ammonia with indium salts during boiling and mineral assemblages allow suggesting the formation of dzhalindite at the Bugdaya deposit as a result of neutralization of thermal solutions corroding sphalerite and containing indium released from the latter. The formation temperature of dzhalindite probably was close to that of late cleiophane (about 140°C). Planned study of fluid inclusions from dzhalindite will provide more valid conclusions on the origin of the mineral.

3. Despite greenockite was found at the uranium deposits in the eastern Transbaikalia, it is rare mineral in base metal ores of this region. Lack of local analytical equipment to study minerals probably prevented the findings of greenockite in ores of the base metal deposits in the eastern Transbaikalia, which were investigated in detail mainly in the middle of the last century. It should be added that Cd content in some generations of sphalerite from most de-

posits in the region is comparable to that in sphalerite from the Bugdaya deposit.

Coexisting greenockite and dzhalindite in ore of the Bugdaya deposit can indicate a generality of the processes, which formed these minerals.

4. Spatial combination of late gold-base metal and earlier high-temperature Mo-W mineralizations and ore fracturing favored the formation of rare supergene mineral of the $PbWO_4 - PbMoO_4$ series with formula $Pb(W_{0.74}Mo_{0.26})O_4$ and similar in composition to that at the Shakhtama mines at the near-surface levels of the Bugdaya deposit.

5. Localization of examined minerals in gold-rich areas, which are characterized by elevated jointing and combination of different stage assemblages is important to indicate multiple reworking of these areas of orebodies and unique formation conditions of such rare minerals.

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