



179. **Burckhardtite** crystals (Bkd) at the contact of **malachite** (Mlc) and **cerussite** (Cer) in association with **mimetite** (Mim), **phosphohedyphane** (Phdy) and **bismutite** (Bit). **Zone 3**, level +235 m. SEM/BSE image: Anatoly V. Kasatkin.

This is the first time this mineral has been identified in the territory of the Russian Federation, but it is interesting to note that just a month after this finding, chenevixite was observed by us in samples from the dumps of the tin open pit at the Sherlovaya Gora deposit in the Transbaikal Region. There it forms mustard-yellow crusts on limonite and is associated with olivenite and scorodite.

Silicates

The silicate minerals comprise a minor component of the oxidized ores of the Phosphatno-Arsenatnaya vein and do not form any significant clusters.

Burckhardtite, $\text{Pb}_2(\text{Fe}^{3+}\text{Te}^{6+})(\text{AlSi}_3\text{O}_8)\text{O}_6$, was observed in one specimen from **Zone 3** (level +235 m) as rosettes and intergrowths (up to 0.5 mm in size) consisting of yellow-brown lamellae (up to 50 μm thick) at the contact of malachite and cerussite in association with mimetite, phosphohedyphane, and bismutite (Fig. 179). Chemically, the Murzinskoe burckhardtite is close to ideal (Table 10, anal. 13). In the territory of our country, burckhardtite was previously described in the oxidation zone of the Aginskoe deposit in Kamchatka (Kasatkin, 2019) and Priozernoe deposit in the Northern Urals (Kasatkin *et al.*, 2023). This finding of burckhardtite is probably the third in Russia.

Illite, $(\text{K},\text{H}_3\text{O})(\text{Al},\text{Mg},\text{Fe})_2[(\text{Si},\text{Al})_4\text{O}_{10}][(\text{OH})_2,\text{H}_2\text{O}]$, is rare and found at level +235 m forming light gray to light blue pods (reaching 1 cm in size) on the surface of quartz-limonite aggregates in association with vauquelinite–fornacite series minerals, mottramite, and "cuprocoronadite". It appears that illite is a relict primary mineral here. Its empirical formula is $(\text{K}_{0.45}\text{Na}_{0.13})_{\Sigma 0.58}(\text{Al}_{2.00}\text{Mg}_{0.09}\text{Fe}_{0.04})_{\Sigma 2.13}[\text{Al}_{0.85}\text{Si}_{3.15}\text{O}_{10}](\text{OH})_2$. The mineral identification is supported by the IR spectrum (wave numbers of bands maxima at: 3640, 3327, 1016, 825, 804, 536, 475, 410 cm^{-1}).

Nontronite, $\text{Na}_{0.3}\text{Fe}^{3+}_2(\text{Si},\text{Al})_4\text{O}_{10}(\text{OH})_2 \cdot n\text{H}_2\text{O}$, forms rich clusters that are locally distributed in the Murzinskoe deposit, but in the oxidation ores of the Phosphatno-Arsenatnaya vein, it was observed only in **Zone 3** (level +235 m) as canary yellow earthy segregations (up to 3 x 2 in size) in quartz-limonite aggregates in association with segnitite and malachite. This ferric smectite was identified by its chemical composition and PXRD pattern.

Titanite, $\text{CaTi}(\text{SiO}_4)\text{O}$, and **zircon**, ZrSiO_4 , are rare accessory minerals that were identified during EMPA of samples from **Zone 2**. They occur as small (up to 10 μm in size) grains in quartz in association with various arsenates, phosphates, azurite, malachite, and other minerals.

Tosudite, $\text{Na}_{0.5}(\text{Al},\text{Mg})_6(\text{Si},\text{Al})_8\text{O}_{18}(\text{OH})_{12} \cdot 5\text{H}_2\text{O}$, a very rare dioctahedral mixed-layer clay mineral with ordered smectite and chlorite layers, was identified in specimens from level +245 m. It forms pale blue clay aggregates (up to 0.5 mm in size) on quartz that are associated with azurite, bayldonite, segnitite, and

limonite. The mineral was identified using a complex series of methods and, according to Nikita V. Chukanov, is partly a hydrated variety. Its empirical formula is $\text{Ca}_{0.14}(\text{Al}_{5.37}\text{Mg}_{0.36}\text{Fe}_{0.17})_{\Sigma 5.90}[\text{Si}_{6.55}\text{Al}_{1.45}\text{O}_{18}](\text{OH})_{12} \cdot n\text{H}_2\text{O}$. The strong reflections in the PXRD pattern ($d = 27.4, 14.2, 4.47, 2.57, 2.51, 1.50 \text{ \AA}$) and wave numbers of bands maxima in the IR spectrum (3649, 3625, 3544, 1054, 1006, 985 (shoulder), 950 (shoulder), 740, 535, 476 cm^{-1}) support the mineral identification.

Chrysocolla, $(\text{Cu}_{2-x}\text{Al}_x)\text{H}_{2-x}\text{Si}_2\text{O}_5(\text{OH})_4 \cdot n\text{H}_2\text{O}$, is typical in the oxidized ores of the Phosphatno-Arsenatnaya vein, but is more common in the other levels of the Murzinskoe deposit, where it forms extremely rich segregations and is one of the major supergene minerals. Chrysocolla occurs as massive light blue and light green veinlets and pods (up to 4–5 cm in size) in quartz. Nearly white Al-rich varieties are also observed. Chrysocolla is one of the latest minerals and often overgrows crusts composed of arsenates and phosphates.

Conclusions

The Phosphatno-Arsenatnaya vein is significantly different than most hydrothermal mineralized veins of the Murzinskoe deposit in terms of both thickness (up to 8 m in the thickest part compared to thicknesses of 0.5–3 m for other veins) and the mineralogy of primary sulfides and sulfosalts such as chalcopyrite, galena, As-dominant tetrahedrite group minerals, and arsenopyrite. The coexistence of these minerals in the ores and the abundant fluorapatite in the host rocks resulted in unique phosphate-arsenate mineralization. While supergene phosphates and phosphate-chromates (pseudomalachite, pyromorphite, phosphohedyphane, and vauquelinite) are observed also at the upper levels of the Murzinskoe deposit (+275 to +250 m), arsenates are uncommon there and are primarily associated with variations in the chemical compositions of As-bearing phosphates where separate zones show $\text{As} > \text{P}$. At these levels pseudomalachite-cornwallite, pyromorphite-mimetite and vauquelinite-fornacite form solid solution series, where the vast majority of compositions fall into the field of P-dominant minerals. The only exception is the remarkable collection-quality samples of philipsburgite, an As-P-ordered phosphate-arsenate of Cu and Zn, discovered for the first time in Russia at level +255 m of this deposit, while kipushite, a P-dominant member of the series, was not found (for details, see: Kasatkin *et al.*, 2024). Instead, in the Phosphatno-Arsenatnaya vein arsenates dominate phosphates in terms of both the number of mineral species and their abundance. In addition, many arsenates are totally P-free. Here, the abundance of arsenates is attributed to widespread arsenopyrite and tennantite, which became an important hypogene source of arsenic. At the upper levels of the open pit, arsenopyrite was not found, even as relics, and the chemical composition of tetrahedrite group minerals is highly variable where both As- and Sb-dominant members are observed. The study of specimens collected in autumn of 2024 at the lower levels (+220 to +200 m), i.e. below the Phosphatno-Arsenatnaya vein, allowed to enlarge the list of minerals found at the deposit (Table 1) by numerous rare arsenates, both new for the deposit (arsenosiderite, bariopharmacosiderite, cobaltlotharmeyerite, preisingerite,