OXIDATION ZONE

Structure and Composition

The first scanty information on the oxidation zone of the Rubtsovskoe deposit was obtained as a result of drilling in the early 1970s. Three major subzones were distinguished downward: (1) a leached oxidized ore zone largely composed of iron hydroxides and kaolinite; (2) a secondary oxide enrichment subzone with cuprite, native copper, malachite, azurite, cerussite; and (3) a secondary sulfide enrichment subzone (that transitions to an underlying zone of mixed ores) with chalcocite and covellite (Stroitelev *et al.*, 1996).

As a result of our observation in underground workings, the structure, mineralogy, and genetic features of the oxidation zone of the deposit were specified substantially.

The top of the orebody is supergene altered to the highest degree at the WSW flank, where it is located higher in altitude. The upper boundary of the orebody gently plunges ENE and the oxidation zone (we do not discuss the mixed ores) gradually pinches out; the oxidation zone extends along the strike of the orebody for approximately 300 m. In the WSW part of the orebody, the oxidized ores occur in the altitude interval from +137–138 to +163 m. The lower boundary of the oxidized ores rise toward the ESE and the main part of the oxidation zone occurs in the range of +144–145 to +153–157 m. The oxidized part of the orebody varies from 2 to 8 m in thickness, reaching 15–17 m in swells and occasionally more than 20 m. Both underlying and overlapping rocks are dominated by clayey minerals; these are wall-rock argillaceous alterations, frequently altered as a result of ore oxidation especially adjacent to the contact of the orebody. According to our data, the major constituent of argillizites is dioctahedral mica of the muscovite-illite series; sporadically kaolinite, dickite, or dickite-kaolinite clay occurs, and quartz and occasional pyrite are subordinate minerals in the clay.

The oxidized part of the orebody is divided into upper and lower subzones in vertical section.

The top of the oxidized orebody especially in the WSW part is a classic gossan; this is “dried crusts” of relict quartz (with leached cavities of sulfides and carbonates) with abundant limonite. Hematite, kaolinite, and dickite are minor minerals. Massive lenses and clusters of nodules of Pb-bearing jarosite and Pb-bearing alunite occur at the contact between the orebody and outer contact clay. In this subzone, carbonates and Cu and Zn minerals are few. The gossan, or subzone of leached oxidized ores, extends to a height of +156–155 m.

MINERALS

This chapter is based on our observations during 2009 in the operating Rubtsovsky mine and on the results of laboratory studies using the electron microprobe, optical and scanning electron microscopy, powder and single-crystal X-ray diffraction methods, infrared spectroscopy, and goniometry. Earlier-published data on the supergene minerals of the deposit, that are scanty and do not contain any quantitative analytical data, are also included. Taking into account the character of this publication, we give only representative chemical data and unit cell dimensions of most minerals rather than complete chemical analyses, X-ray diffraction patterns, and infrared spectra; but these data are given if they are considered important. At the same time, we have tried to characterize the mode of occurrence, the character of associations and morphology of the minerals thereby emphasizing the features which present the Rubtsovskoe deposit as a unique mineralogical locality. Illustrations, providing sometimes more information than even detailed descriptions, are a very important part of this work.

Fig. 24. Dendrite of native **copper** formed by twins on (111), 7.5 cm. Specimen: *Russian Minerals* Company. Photo: Michael B. Leybov.

More than two thirds of the 64 minerals described from the Rubtsovskoe deposit are supergene (Table. 1). All are mentioned in this part, but only the minerals of the oxidized ores are characterized, whereas the mixed ores and cementation subzone are beyond the scope of this study. The minerals are described by chemical classes.

Native elements *formed in the supergene zone are copper and silver.*

Native copper is abundant over all the area of the subzone of the rich oxidized ores in varied mineral assemblages. It extends vertically from +137 m (WSW flank of the orebody) to +155 m (centre and ENE flank). According to drilling at the initial stage of prospecting the deposit, it was found that native copper is one of the major economic minerals of the oxidized ores (Doronin *et al.*, 1974). It was confirmed by mining operations; sporadically, native copper composes up to 40–60% of the bulk ore. Such numbers appear very spectacular, but these areas are very difficult for drifting and mining due to the extreme viscosity of the native metal that reinforces the rock.
Copper is confined most frequently to significant to goethite (limonite) ores with clay minerals, cerussite, relict quartz, occasional alunite, osarizawaite, and marshite. Sometimes it was very typical to find abundant native copper intimately associated with fine-grained chalcocite (including its pods) occurring within the limonitized zone. Significant native copper is

Fig. 44. Initial stage of replacement of cuprite by native copper: intergrowth of newly formed **copper** crystals in the dissolution cavity in the interior of **cuprite** crystal, 2.5 cm. Specimen: *Russian Minerals* Company. Photo: Michael B. Leybov.

Fig. 45. Group of **cuprite** crystals partially replaced by native copper, 9.cm. Specimen: *Russian Minerals* Company. Photo: Michael B. Leybov.

Fig. 46. Partial pseudomorph of native **copper** after octahedral crystal of **cuprite**, 6 cm: (*a*) plane view, (*b*) lateral view, where growth of dendritic copper aggregates upward from the basement by which cuprite crystal adhered to copper nugget is well seen. Collection: Anatoly V. Kasatkin. Photo: Michael B. Leybov.

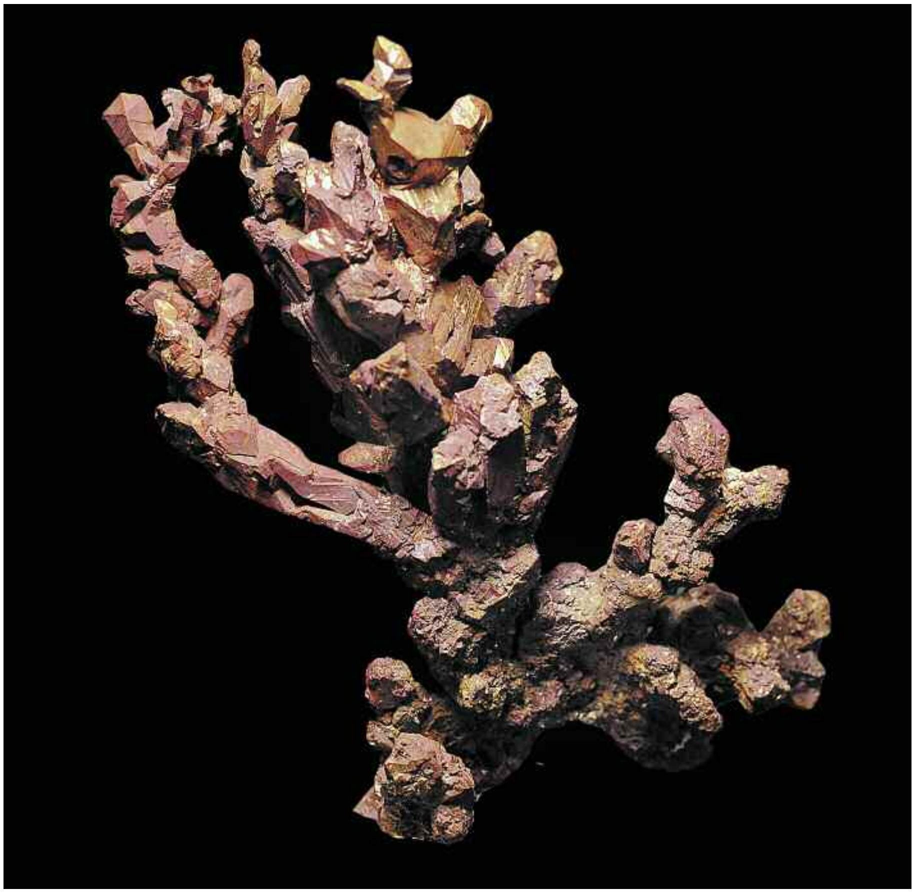

Fig. 47. Dendrite of native **copper** coated by cuprite film, 10 cm. Specimen: *Russian Minerals* Company. Photo: Michael B. Leybov.

crystal clusters overgrown by crystals or crusts of miersite (Fig. 93) were found and in the ENE part, azurite crusts and concretions with this iodide on the surface occurred (Figs. 77, 91).

In the overlapping clayey rocks, marshite is the youngest mineral; it was formed not only after phyllosilicates, but after native copper, azurite, and malachite that are epigenetic minerals in respect to clay silicates. In the oxidized orebody, the marshite-miersite series members were formed after cerussite and oxygen copper minerals. They are later than clay minerals, supergene calcite, sulfates of the alunite-jarosite supergroup, and the major generations of native copper and goethite. However, these iodides are not the latest minerals. In the cavities, marshite is overgrown frequently by the late goethite (Figs. 85, 86, 95), and the latter in turn, by fluorite. In addition, marshite dissolves to form native copper and silver. Occasionally, in the core of large individuals of Ag-free marshite, there is a cavity (up to 5 mm) with typical etching on the walls; complete cubic crystals of native copper or more frequently an intergrowth of such crystals (Fig. 54) dangles in the open space of this cavity. Dendrites of late copper (Fig. 94) or granular aggregates of cuprite (Fig. 16) replace marshite in its pseudomorphs after azurite. As a result of the leaching of crystals of Ag-bearing marshite enclosed in goethite,

Fig. 93. Crystal crusts of yellow **miersite** on a crystal group of cuprite. 6 cm.
Collection: Anatoly V. Kasatkin.
Photo: Michael B. Leybov.

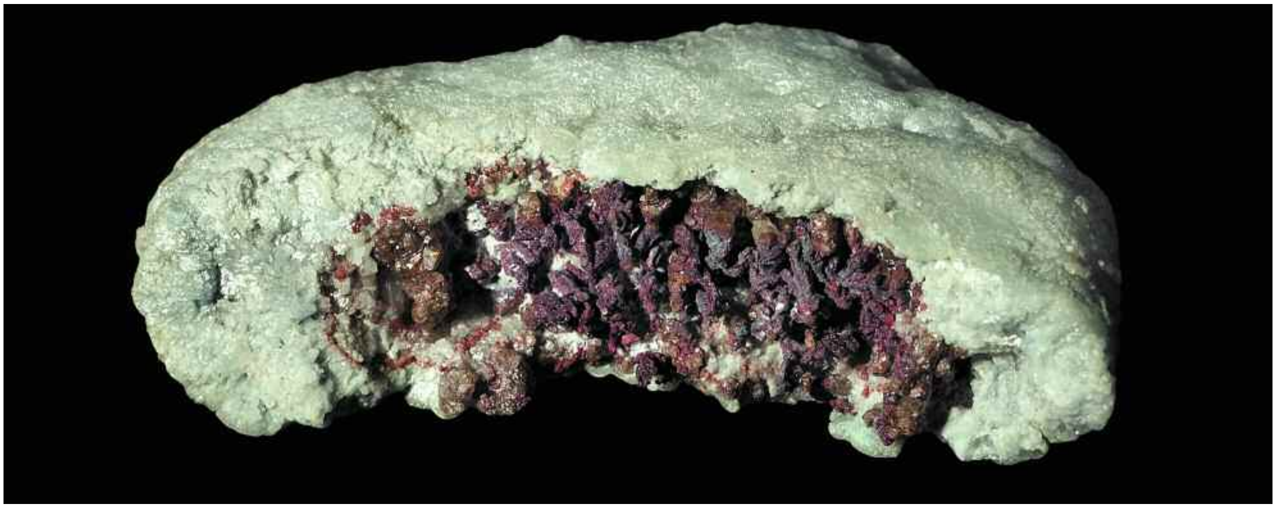

Fig. 94. Pseudomorph of pale bluish **marshite** after flattened concretion of azurite (7 cm); the latest aggregate of native **copper** replacing marshite is in the core. Collection: Victor V. Levitsky. Photo: Stanislav I. Pekov.

the characteristic tetrahedral cavities with clear imprints of faces with a sculpture typical of this iodide arise; thin flakes of newly formed silver occur in these cavities. In one of the locations (level +147 m), such abundant “negative pseudomorphs” with silver were found at 3–4 m from the zone where marshite containing up to 1 wt.% Ag occurs in a similar environment. Occasionally, the dissolution of marshite gives way to the regeneration of this mineral (Fig. 78).

Iodargyrite at the Rubtsovskoe deposit is chemically pure AgI (Table. 1, anal. 23) belonging to polytype 2*H* (Pekov *et al.*, 2010).

This mineral is transparent or semitransparent, with an adamantine luster on faces and a strong greasy luster on fractures. It is lemon yellow or light yellow up to straw or greenish yellow, and the smallest crystals are nearly colorless. Iodargyrite is not fluorescent in UV light. The mineral is very soft, and in contrast to brittle miersite, is flexible, ductile and easily spread with pressing.

Fig. 95. Fine spherulites of **goethite** overgrowing colorless crystals of **marshite** (sample 36). Width of image 3.5 mm. Private collection. Photo: Igor V. Pekov and Anatoly V. Kasatkin.

CONCLUSIONS

Two aspects causing the uniqueness of the oxidation zone of the Rubtsovskoe deposit should be emphasized: a scientific and a general cultural "museum" one. The scientific importance results from its mineralogical and geochemical diversity, most of all its amazingly rich iodide mineralization. The second aspect that the deposit is the source of numerous world class mineral specimens. Without overstatement, their appearance was the most prominent mineralogical and museum event in Russia for the two latest decades, at least.

The oxidation zone of the Rubtsovskoe deposit is deep below the surface and mining conditions here are extremely unfavorable due to abundant clayey wall rocks. Therefore, the preservation in situ of even small parts of this locality as a geological monument is absolutely impossible. The only way to retain a "mineralogical memory" of this and many other deposits is to store ex situ the representative samples in the mineralogical and geological museum and private collections. Therefore, the initiative of the administration of *Siberia-Polymetals* OJSC to organize special collecting of copper nuggets at the Rubtsovsky mine is commendable; in this way, numerous excellent mineralogical specimens were saved from being processed at the deposit.

We hope that the Rubtsovskoe deposit will continue to produce new interesting finds.

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MINERAL INDEX

Italic type marks minerals that are only mentioned.