Sorosite, Cu(Sn,Sb), a new mineral from the Baimka placer deposit, western Chukotka, Russian Far East

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ABSTRACT

Sorosite, ideally Cu(Sn,Sb), is a new mineral species from the Baimka gold-platinum-group mineral placer deposit, Chukotka, Russian Far East. It occurs as large subhedral to euhedral crystals (0.1–0.4 mm in length), hexagonal in cross section, minute crystals (< 15 μm, also hexagonal), and anhedral grains. Sorosite forms inclusions in Sn-bearing native tin, is often intergrown with stistaite (Sn1.12-1.13 Sb0.87-0.88) and occurs with herzenbergite (SnS), native lead, and trace cassiterite. Sorosite is brittle with a microhardness VHN40.50 = 443.7 kg/mm2 (n = 3). No cleavage is observed. In reflected light, the large crystals are nearly white with a pinkish tint, whereas the microcrystals show a pronounced pinkish tint. Birefringence is variable. The average of nine electron microprobe analyses gave Cu35.33, Fe1.18, Sn58.18, and Sb4.77, sum 99.46 wt%, corresponding to (Cu1.00 Fe0.04)Sn1.04(Sn0.89 Sb0.07)S0.96. The powder pattern is close to those of natural Cu(Sn,Sb) and synthetic η-CuSn; it was indexed for a hexagonal cell, with a = 4.217(4) Å, c = 5.120(6) Å, and V = 78.85 Å3. For Z = 2, the calculated density is 7.6 g/cm3. The strongest lines in the pattern are at 2.970 (011), 2.112 (110), and 2.094 Å (012). The sorosite-bearing mineral assemblage apparently formed under low fO2 and fS2 conditions.

INTRODUCTION

The Baimka gold placer deposit, western Chukotka, Russian Far East, is situated in the River Bolshoy Anyuy area, near the Baimka River (Fig. 1). Various platinum-group minerals, PGM, (but principally Pt-Fe alloys) occur in close spatial association with Au in the placer (Gornostaev 1994; Gornostaev et al. 1994). During examinations by reflected light microscopy, an unusual composite grain (3 mm in the longest dimension) was encountered. Electron microprobe analyses of several fragments from this grain showed it to consist of an unnamed Cu-(Fe)-Sn-Sb mineral, in close association with Sb-bearing native tin and stistaite (ideally SnSb). Characteristics of this mineral are reported here. We have named it sorosite after George Soros (born in 1930), well-known American financier, in recognition of his important support to science (the ISF, established by G. Soros, has been a great help to scientists in republics of the former Soviet Union during the current financial crisis) and efforts to promote open societies throughout the world. We have named it sorosite after George Soros (born in 1930), well-known American financier, in recognition of his important support to science (the ISF, established by G. Soros, has been a great help to scientists in republics of the former Soviet Union during the current financial crisis) and efforts to promote open societies throughout the world.

GEOLOGICAL BACKGROUND

The remote Baimka area is characterized by very complicated geology and by various ore deposits. The Baimka gold-PGM placer is located in the Aluchin horst, which contains widespread ophiolitic rocks (Dovgal 1964). In the vicinity of the placer, two principal complexes are recognized. First, the Aluchin complex is a large ultramafic ophiolitic complex of a Permian (or Triassic) age. It occurs as three separate (north to northwest trending) bodies that are controlled by a regional fault system (Fig. 1). The largest body (~250 km2) extends along strike for about 40 km. The complex consists mainly of peridotite (harzburgite), subordinate dunite, and pyroxenite. The ultramafic rocks are serpentinized to various degrees. Abundant dikes of olivine dolerite, trachydolerite, diorite porphyrite, aplite, and numerous quartz veins are observed at the contact (Aksenova et al. 1970; Lychagin 1985; Surnin and Okrugin 1989). The second complex, the Yegdegkychsky gabbro-syenite-(monzonite) complex (Jurassic to Cretaceous?) is the product of two (or three) major intrusive phases: an early gabbro and gabbro-diorite phase; a later phase of various syenites (some quartz-bearing and some of alkaline affinity); and quartz-bearing diorites (Berlimble and Gorodinskii 1978; Gorodinskii et al. 1982; Volchkov et al. 1982). Of particular interest are clinopyroxenite-gabbro intrusions (up to ~4.5 km in diameter; V.P. Fomin, unpublished data), which are attribu-
**Figure 1.** Schematic geological map showing principal complexes in the Baimka area (western Chukotka, Russian Far East). 1 = Yelegkgychsky complex; 2 = Aluchin complex; 3 = faults; 4 = Baimka placer; 5 = location (shown in the insert) of the Baimka deposit in Russia.

**Appearance and Associated Minerals**

Native tin is the chief ore mineral in all the polished mounts examined, followed by sorosite and stitaite. A tin sulfide (herzenbergite), cassiterite and native lead are the only minor constituents. Sorosite occurs as inclusions in native tin. Large crystals (LC) are up to 0.4 mm in length, well-developed, and commonly broken (in polished mount) crystals with hexagonal crystal outlines (e.g., Figs. 2a and 2b). Minute crystals (MC) are \( \leq 15 \) \( \mu \)m subhedral to euhedral (hexagonal) crystals and elongate anhedral grains (Fig. 2b). Skeletal appearance and cavities (filled by Sn), characteristic of the MC, are rarely observed in the LC (Fig. 2b). No cleavage is observed.

Stitaite appears as lath-shaped crystals (up to 0.3 mm long), closely associated with the Sn and sorosite. It was also observed as an inclusion in sorosite. The presence of the sorosite-stitaite intergrowths is noteworthy (e.g., Fig. 2a). Rare herzenbergite typically occurs relatively close to the contact of native tin as small (up to 25 \( \mu \)m) subhedral to euhedral crystals and anhedral grains, which are isolated within native tin (Fig. 2d) and, more rarely, within sorosite (Fig. 2c). A fine-grained cassiterite that is locally in contact with herzenbergite (Fig. 2d) occurs sporadically in trace quantities, and its aggregates are typically less than 0.06 mm in the longest dimension. Experimental data indicate that cassiterite can coexist with SnS (herzenbergite) in the whole range of geologically probable temperatures (Drábek and Štěmplok 1974), and these minerals occur together (in opposite textural relationships) in several mineralized zones (Smets 1993 and references therein). Native lead is present as minute inclusions in native tin and veinlets (up to 15 \( \mu \)m), which may partly replace the sorosite MC.

**Microhardness and Optical Properties**

Sorosite is very brittle and fractures easily during micro-indentation under loads \( \approx 50 \) g. This property is presumably responsible for the appearance of the broken sorosite crystals in polished mount. Two measurements carried out with a Neophot-2 tester (Kola Science Center) gave VHN\(_{40}\) = 452 and 498 kg/mm\(^2\). An additional measurement (made for another LC at the University of Hamburg) gave VHN\(_{50}\) = 381 kg/mm\(^2\) (M. Tarkian, written communication). The average is 443.7 kg/mm\(^2\).

Owing to a high reflectance, the LC seem to be nearly white in reflected light. However, a pinkish tint is observable under high magnification. The MC show a pronounced pinkish tint. Typically, birefringence is not observed in air, although weakly to distinctly birefringent grains are present. Anisotropy is distinct to moderate, from brownish gray to bluish gray.

Reflectance data show a strong birefringence for one LC grain and weak for another (Table 1a and 1b). Measurements were carried out with a Neophot-2 tester (Kola Science Center) in air; MSFP-2 microphotometer, Si standard; R\(_{\text{air}}\) = 35.7% and the University of Hamburg (in air and oil; Zeiss MPM microphotometer, WTIC standard; R\(_{\text{oil}}\) = 44.3%.)
Figure 2. (a) A large (broken) crystal of sorosite (So), associated with stistaite (St = lath-shaped crystals) and native tin (Tn); black = epoxy. (b) Large sorosite crystal (So = partly skeletal) adjacent to stistaite (St). Tn = native tin. Note abundant microcrystals of sorosite isolated within native tin. (c) Subhedral sorosite (So) containing a subhedral inclusion of herzenbergite (He). Note that crystal faces of the inclusion are sub-parallel to those of the host sorosite. Tn = native tin. (d) Subhedral herzenbergite (He), enclosed within native tin (Tn). Cst = fine-grained cassiterite. Back-scattered electron images. Scale bar is equivalent to 100 µm in a and b, and 10 µm in c and d.

= 49.5, R_{\text{avg}} in oil = 35.5%), respectively. Sorosite has an exceptionally high reflectance, e.g., R(max)_{\text{avg}} in air = 78%. The dependence of the reflectance on wavelength and the maximum reflectance values obtained for the two grains are very similar to each other. However, the first grain displays lower minimum values (Table 1), implying that sorosite is optically negative, but more measurements are required.

**Composition**

Wavelength-dispersion (WDS) analyses were carried out with a Cameca MS-46 electron microprobe (Kola Science Center), operated at 20 kV and 20 nA. The X-ray lines used were Kα for Cu and Fe, and Lα for Sn and Sb; synthetic Fe_{10}S_{11} and pure elements were used as standards. Quantitative energy-dispersion analyses (EDS) were carried out at the Institute of Electron Optics, University of Oulu, at 15 kV and 1.2 nA, using a JEOL JSM-6400 scanning-electron microscope equipped with a LINK eXL energy-dispersion spectrometer. The X-ray lines used were K for Cu and Fe, and L for Sn and Sb; pure elements were used as standards. The most finely focused beam was applied (~1 µm in diameter). Counting periods were 100 s. The spectra were processed by LINK ISIS (revision 3.00) on-line program. Owing to the small grain-sizes of sorosite MC, native lead, and cassiterite, these were only analyzed with EDS.

The WDS and EDS electron microprobe analyses of sorosite (Table 2) are in agreement with each other as they are with an average WDS analysis obtained using a JEOL-733 electron microprobe on LC from a newly found placer grain at Baimka (no. 3, Table 2). Copper and Sn are the chief constituents of sorosite, however Fe, Sb, and, to a lesser extent, Ni may also be essential. The three LC, studied in more detail (EDS and WDS), appear to be zoned with respect to Fe; the Fe content is below detection limits (or relatively low) near the edges, whereas the central areas of the crystals yield ≥3 wt% Fe. In
addition to the textural differences, the coexisting MC
and LC are also distinct in composition; the latter appear
to be richer in Sb (Table 2).

The ideal formula is Cu(Sn,Sb) for both types of so-
rosite at Baimka. This formula is corroborated by the
compositional data (Table 2) on related Cu(Sn,Sb) phases,
obvious precursors of sorosite from Uzbekistan (Nikola-
eva et al. 1970) and Colombia (Rose 1981). The τ-CuSn,
phases from Borneo (Stumpfl and Clark 1965) and Por-
tugal (Clark 1972) are also related to sorosite, despite a
relative excess in Cu and the virtual absence of Sb (and
Fe) in their compositions.

Stistaite varies little in composition (nos. 7 and 8, Table
2) with empirical formulae Sn$_{1.12-1.13}$Sb$_{0.87-0.88}$ which are
close to those of stistaite from the type occurrence
(Sn$_{1.15}$Sb$_{0.85}$; Nikolaeva et al. 1970) and from Colombia
(Sn$_{1.12}$Sb$_{0.87}$; Rose 1981). Nikolaeva et al. (1970) hypo-
thesized that the Sb-deficient composition of stistaite
derived (from their electron-microprobe analyses) result-
ed from interference from the associated Sn, and that the
actual composition is close to ideal SnSb. However, this
proposal is rejected by the microprobe data in Rose
(1981) and in the present study, which reveal the Sn-rich
composition of stistaite. The low Sb content (43.3–43.9
at% Sb) in the Baimka stistaite is very close to that of
the Sn-poorest sample of synthetic Sn$_{1.1}$Sb$_{0.9}$ (Hansen
and Anderko 1958).

The Baimka native tin (Table 2) invariably contains
more than 1 wt% Sb in solid solution. Herzenbergite
grains analyzed, including those in Figures 2c and 2d,
gave the ranges: Sn 78.6–81.6 and S 20.6–19.5 wt%, and
average formula Sn$_{1.04}$S$_{0.96}$ (τ atoms = 2). The cassiterite
analysis agrees with the theoretical formula. The native
lead is close to 100 wt% Pb.

### Table 1A. Reflectance data for sorosite

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<tr>
<th>No.</th>
<th>Cu (%)</th>
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<th>Sn (%)</th>
<th>Sb (%)</th>
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<td>97.5</td>
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<tr>
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### Table 1B. Color values: C illuminant

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<th>λₙm</th>
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### Table 2. Representative compositions of sorosite and associated minerals

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<th>No.</th>
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Note: Nos. 1–3 = large sorosite crystals from Baimka; 4–6 = sorosite microcrystals from Baimka; 7 and 8 = stistaite from Baimka; 9 = native tin from Baimka; 10 = unnamed Cu$_{1+x}$Sn$_{1-x}$ from Borneo (Stumpfl and Clark 1965); 11 = unnamed Cu$_{1+y}$Sn$_{1-y}$ from Uzbekistan (Nikolaeva et al. 1970); 12 = unnamed Cu$_{1+z}$Sn$_{1-z}$ from Portugal (Clark 1972); 13 = unnamed Cu$_{1+z}$Sn$_{1-z}$ from Colombia (Rose 1981). No. 1, average of 18 individual analyses; no. 2, n = 9; no. 6, 7, and 11; no. 8, 9, n = 4; and no. 12, n = 2.

* Atomic proportions calculated on the basis: Σ atoms = 2 (sorosite, stistaite, and phases related to sorosite) and Σ atoms = 1 (native tin).

† EDS electron-microprobe analyses.

‡ WDS electron-microprobe analyses.

§ JEOL-733 electron microprobe: n = 151 (Barkov et al., unpublished data). Total includes 0.64 wt% Ni; 0.02 Ni atoms p.f.u. are added to the Cu+Fe value. This analysis and analyses nos. 1 and 2 refer to sorosite from different placer grains at Baimka.
X-RAY STUDY

The material available was insufficient for single-crystal study. The fully indexed X-ray powder diffraction pattern of a ground LC (~0.2 mm) (Table 3) compares well with those for synthetic and natural Cu₆Sn₅ (Westgren and Phragmén 1928; Clark 1972), and natural Cu(Sn,Sb) from Colombia (Rose 1981). The sorosite pattern was indexed for a hexagonal cell with the following unit-cell parameters refined by least-squares from the powder data:

\[ a = 4.217(4) \text{ Å}, \ c = 5.120(6) \text{ Å}, \ V = 78.85 \text{ Å}^3 \]

By analogy with synthetic ψ-FeSb, which is crystallized with NiAs structure type (PDF-34-1053), the space group P6₃/mmc is probable, and sorosite may thus represent a new member of the nickeline group. With \( Z = 2 \), the density calculated for average compositions of LC nos. 1 and 2 in Table 2 is 7.6 g/cm³, close to the calculated density of 7.9 g/cm³ for the Columbian Cu(Sn,Sb) phase (Rose 1981).

DISCUSSION

The sorosite-bearing mineral assemblage at Baimka is closely related to those reported by Nikolaeva et al. (1970) from Uzbekistan and Rose (1981) from a gold-PGM-bearing placer in Colombia. The precursors of sorosite from these localities are also enriched in Sb and are intimately associated with native tin and stibnite. Structurally, sorosite is closely related to unnamed Cu(Sn,Sb) from Colombia (Rose 1981), to synthetic \( \eta \)-Cu₆Sn₅ (Westgren and Phragmén 1928; Carlsson and Hägg 1932), and to natural \( \eta \)-Cu₆Sn₅ from Portugal (Clark 1972). However, microhardness and reflectance values of the latter phase (VHN₉₀ = 61.5; R(max)$_{\text{top}}$ in air = 62.6%) are both reported to be much lower than those of sorosite. The reason for these differences is unknown, but a possibility is that the grain from Portugal, which is found in the oxidized ore, may itself have been oxidized to a certain extent. The \( \eta \)-Cu₆Sn₅ phase is reported from a placer in Borneo (Stumpfl and Clark 1965), where both Au and PGM are present. Copper-tin alloys are also described from Sumatra in spatial association with alluvial gold and PGM; however, no \( \eta \)-Cu₆Sn₅ phase is reported (Bowles et al. 1984).

The composite Sn-Sb-Cu-rich grains, Au, and PGM are concentrated in placers because of their high specific gravities; no genetic relationships appear to exist between them. The primary source for the sorosite-bearing assemblage cannot be unequivocally suggested. However, it is well known that the Siberian (Noril’sk) trap rocks contain widespread Pd-Cu-Sn alloys (Genkin et al. 1981; Cabri 1994), which may reach a few mm across. These occurrences are indicative of conditions favorable for large-scale alloy formation and relative enrichments in Cu, (Pd), and Sn in the trap rocks. Obviously, Pd-free Cu-Sn alloys could occur in similar but Pd-deficient environments, and the Baimka sorosite-bearing assemblage may be derived from rocks (probably sulfide-poor) similar to Siberian traps. A complete analogy is not necessarily implied, and, for instance, a mineralized zone in the Yegdegykhsky complex could be a quite reasonable alternative as the primary source. This suggestion is consistent with the geological features (Fig. 1). However, other possibilities also cannot be excluded; for instance, native tin and lead are known in skarns, formed under granite influence (Damman and Kieft 1990).

The LC and MC appear to have formed by a direct crystallization and by exsolution from the native tin, respectively. The Baimka sorosite may have evolved during crystallization from the Sb-(Fe)-rich LC to the later Sn-rich, Sb-(Fe)-poor MC.

The sorosite-bearing association formed under reduc-
ing conditions; otherwise, abundant cassiterite would have formed. A low sulfur fugacity \( f_{S} \) in the mineral-forming system is implied by the lack of Sn sulfides apart from the rare herzenbergite. The latter is known to crystallize under low \( f_{O_2} \) and relatively low \( f_{S} \) conditions (Smeds 1993 and references therein); the position of Sn/ SnS buffer is close to that of Fe/FeS (Drahek and Stempek 1974). Textural data imply that the Baimka herzenbergite was predominantly formed at a late stage when a higher \( f_{S} \) prevailed in the environment.

**ACKNOWLEDGMENTS**

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**REFERENCES CITED**


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