

## ORE MINERALOGY IN THE PROTEROZOIC KALLIOSALO GOLD OCCURRENCE, WESTERN FINLAND, WITH PRELIMINARY DATA ON AN UNSPECIFIED MINERAL, $\text{Ag}_3\text{Au}_3\text{Sb}_{10}\text{S}_{10}$

by  
H. Appelqvist

Geological Survey of Finland, SF-02150 Espoo, Finland

Key words (GeoRef Thesaurus, AGI): gold ores, ore minerals, aurostibite, criddleite, electron probe data, Proterozoic Kalliosalo, Nurmo, Finland

### Introduction

The Seinäjoki area has been known for its antimony potential since 1936, when the Geological Survey of Finland received an antimony-bearing sample found in a quarry used for the extraction of hard rock aggregate (Pääkkönen 1959). Since then, the Seinäjoki area has been the object of systematic prospecting operations from time to time, especially in the 1950s and 1970s. As a result, several antimony mineralizations have been discovered (Kahma 1958, Pääkkönen 1966, Oivanen 1982). Usually hosted by plagioclase porphyrite sills and often occurring in their contacts with the surrounding supracrustal rocks (Fig. 1), these antimony mineralizations are characterized by appreciably high contents of native antimony. In the Kalliosalo antimony mineralization (Fig. 1), for example, slightly more than half of the antimony content is due to native antimony. This is very unusual, as hardly anywhere else in the world does native antimony occur in such large quantities. Moreover, most other antimony mineralizations are Phanerozoic (Mäkitie et al. 1991). Mineralogical investigations of the antimony mineralizations in the Seinäjoki area have led to the discovery of two new mineral species: seinäjokite (Mozgova et al. 1977) and pääkkönenite (Borodaev et al. 1982).

Anomalously high gold abundances have been met with here and there in many of the plagioclase porphyrite sills in the Seinäjoki area. The gold tends to occur in the native form in arsenopyrite-loellingite-gold association and as aurostibite in antimony-bearing occurrences (Aho 1980).

The present study provides a mineralogical interpretation of the high gold contents (25—226 ppm) in several plagioclase porphyrite samples sent to the Geological Survey of Finland by an amateur prospector in December 1991. The samples were taken from a quarry in the Kalliosalo plagioclase porphyrite sill, in which rock is quarried for hard rock aggregate. The same sill also hosts the Kalliosalo antimony mineralization in its contact with the surrounding supracrustal rocks (Fig. 1).

### Geology

The geology of the Seinäjoki area has been described by Neuvonen (1961), Pääkkönen (1966) and Mäkitie et al. (1991). An investigation report of the Kalliosalo gold prospect was drawn up by Kärkkäinen (1991), and the geology and mineralogy of the Kalliosalo antimony mineralization were discussed at length by Lehtiö (1981).

The main rocks in the Seinäjoki area are metapelites and metagreywackes of the Early Proterozoic Svecofennian schist belt (Mäkitie et al. 1991). Several lenticular plagioclase porphyrite and uralite-plagioclase porphyrite bodies of varying size occur south and southeast of the town of Seinäjoki (Fig. 1). They are conform or nearly conform with their wall rocks and are interpreted as hypabyssal sills (Neuvonen 1961, Pääkkönen 1966). Their chemical composition varies from andesitic to rhyodacitic. In the A — F — M diagram they lie in the calc-alkalic field (Kärkkäinen 1991a). U-Pb dating on the zircons in a plagioclase porphyrite sill near Seinäjoki yielded an age of  $1886 \pm$

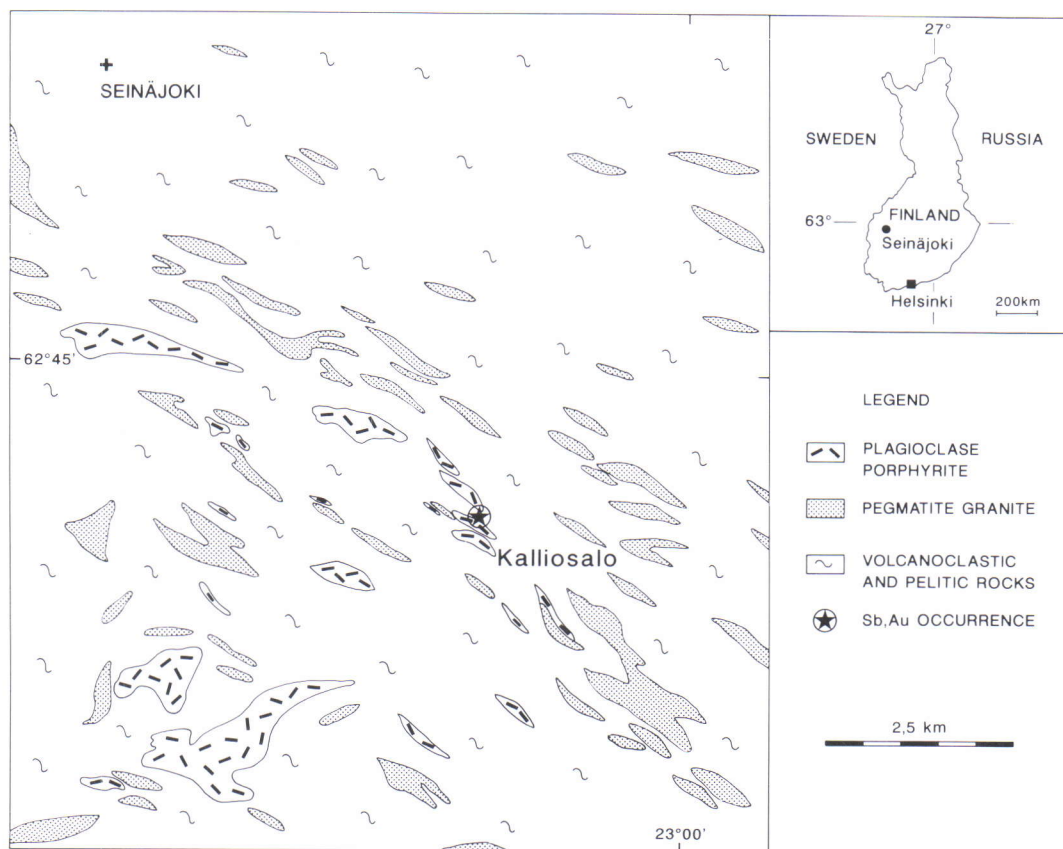


Fig. 1. Generalized geological map of the Seinäjoki area. The map is based on the geological map of Finland 1:100 000 (Mäkitie et al. 1991). The inset shows the location of the area.

3 Ma, which is interpreted as the time of emplacement of the rock (Mäkitie et al. 1991).

The Kalliosalo plagioclase porphyrite sill lies about 8 km southeast of Seinäjoki (Fig. 1). It trends northwest-southeast, is 0.8 km long and has a greatest width of approximately 0.2 km. In its northeast contact with tuffite the sill hosts the Kalliosalo antimony mineralization with an estimated 460 000 tonnes of ore assaying 0.73 % Sb (Oivanen 1982). The Au-bearing samples are from the western part of a 5–15-m-thick silicified shear zone that cuts the general strike of the Kalliosalo plagioclase porphyrite formation and the major axes of the Sb mineralization at a low angle, ending near the northern end of the Sb mineralization. The estimated total length of the shear zone is about 250 m. The zone was sampled with diamond sawing and percussion drilling. The highest Au content was encountered near the place where the first samples were found, assaying 25 ppm Au in a 1-m intersection (Kärkkäinen 1991).

#### Sample selection

Polished thin sections and polished slabs were prepared from the plagioclase porphyrite samples

with 25–226 ppm Au for the mineralogical study. Only one of the two polished sections cut from the sample with 226 ppm Au contained several gold-bearing mineral grains in a quartz vein.

#### Analytical procedures

The polished thin sections and polished slabs were studied under a polarizing microscope mainly in reflected light. Microprobe analyses of the ore minerals were made with a Jeol 733 Superprobe, voltage of 15 kV and probe current of 30 nA. Both semiquantitative EDS analyses and quantitative microprobe analyses were made. The standards and X-ray lines used in the microprobe work are given in Table 1.

#### Ore mineralogy

The ore minerals occur in a quartz vein (width 3–7 mm) with several apophyses consisting of fairly anhedral vein quartz ( $\varnothing$  0.5–3 mm). Almost colourless amphibole and pale green hornblende plus chlorite and minor tourmaline are met with in the contacts of the quartz vein with the

Table 1. The standards and the X-ray lines used for the microprobe analysis.

	X-ray line	Aurostibite	The undefined mineral
S	K $\alpha$	chalcopyrite	chalcopyrite
Cu	K $\alpha$	chalcopyrite	chalcopyrite
Fe	K $\alpha$	chalcopyrite	chalcopyrite
Ni	K $\alpha$	pentlandite	pentlandite
Co	K $\alpha$	cobaltite	cobaltite
As	K $\alpha$	cobaltite	cobaltite
Hg	L $\alpha$	cinnabar	cinnabar
Te	L $\alpha$	Sb <sub>2</sub> Te <sub>3</sub>	Sb <sub>2</sub> Te <sub>3</sub>
Sb	L $\alpha$	Sb <sub>2</sub> Te <sub>3</sub>	Sb <sub>2</sub> Te <sub>3</sub>
Au	L $\alpha$	metal	metal
Ag	L $\alpha$	metal	metal
Bi	L $\alpha$	metal	metal
Tl	L $\alpha$	metal	metal

plagioclase porphyrite. The ore minerals usually occur in the margins of the quartz vein, often intruding the plagioclase porphyrite along grain boundaries. The main ore minerals are arsenopyrite, native antimony, stibnite, aurostibite, pyrrhotite, gudmundite and an undefined mineral. Native gold is usually seen in the margins of altered aurostibite grains together with native antimony.

**Arsenopyrite** is the dominant ore mineral. It occurs as euhedral, sometimes amoeba-like, grains either separately or as aggregates containing other ore minerals (Fig. 2). Its grain size ranges from 0.05 mm to 2.5 mm.

**Native antimony** is met with as separate anhedral grains with distinct cleavage fractures. Its grain size is 0.2 mm — 2 mm, and it is weakly but distinctly anisotropic. Most grains show a lamellar texture, a few with thin lamellae clearly visible in two directions. Native antimony also exists as inclusions in arsenopyrite.

**Stibnite** is usually needle shaped or lamellar (length 0.01—0.3 mm) with typical undulatory extinction between crossed polarizers. It often forms aggregates with pyrrhotite, which has partly changed to lamellar marcasite along 0001 planes (Ramdohr 1980, p. 842). Only once was stibnite observed to form a tabular grain in contact with an arsenopyrite grain.

### Aurostibite

Aurostibite occurs as anhedral grains both separately and intergrown with arsenopyrite, gudmundite and the undefined mineral (Fig. 2). The grain size of aurostibite varies from about 10  $\mu$ m to 1 mm, and all grains show an alteration to a red-brown or violet-brown secondary material. The alteration, which has begun along microcracks and grain boundaries (Figs. 2 and 4), may have changed the whole grain into a secondary material

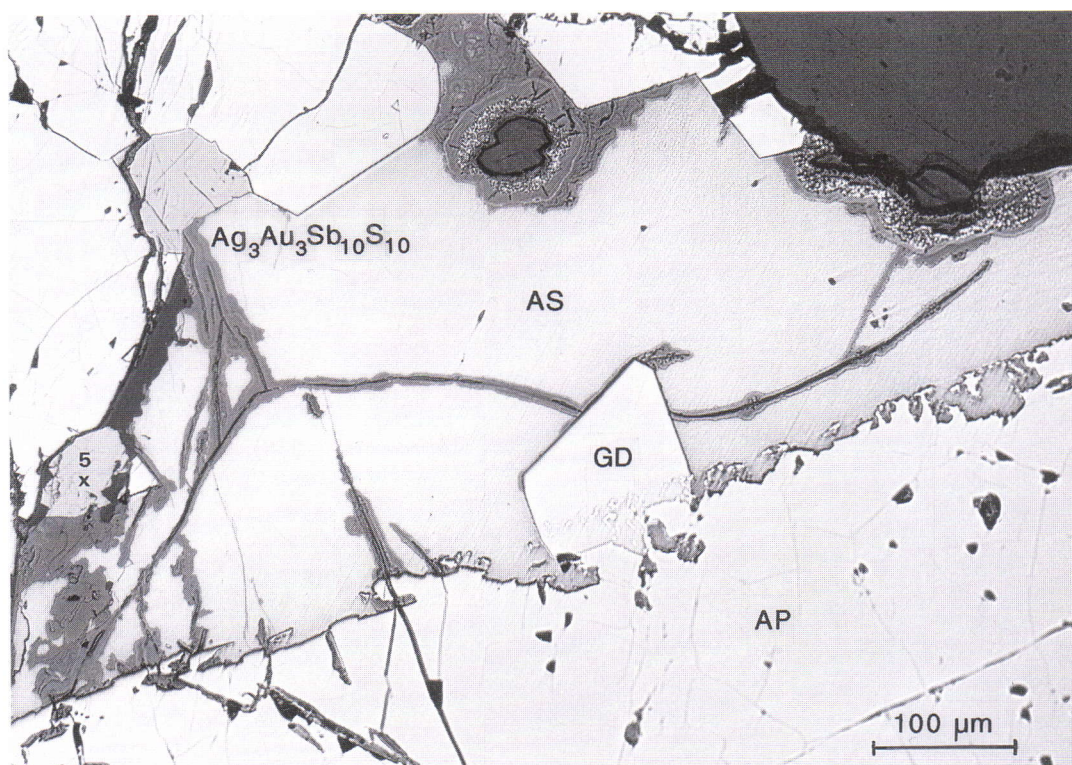


Fig. 2. An ore mineral aggregate of arsenopyrite (AP), aurostibite (AS), gudmundite (GD) and the undefined  $Ag_3Au_3Sb_{10}S_{10}$ . The microprobe analysis point is marked with (5) (see Table 4). Note the incipient alteration of aurostibite along microcracks. The reflectivity of aurostibite is clearly lowered due to tarnishing in air. Reflected light, 1 polarizer. All micrographs taken by the author.

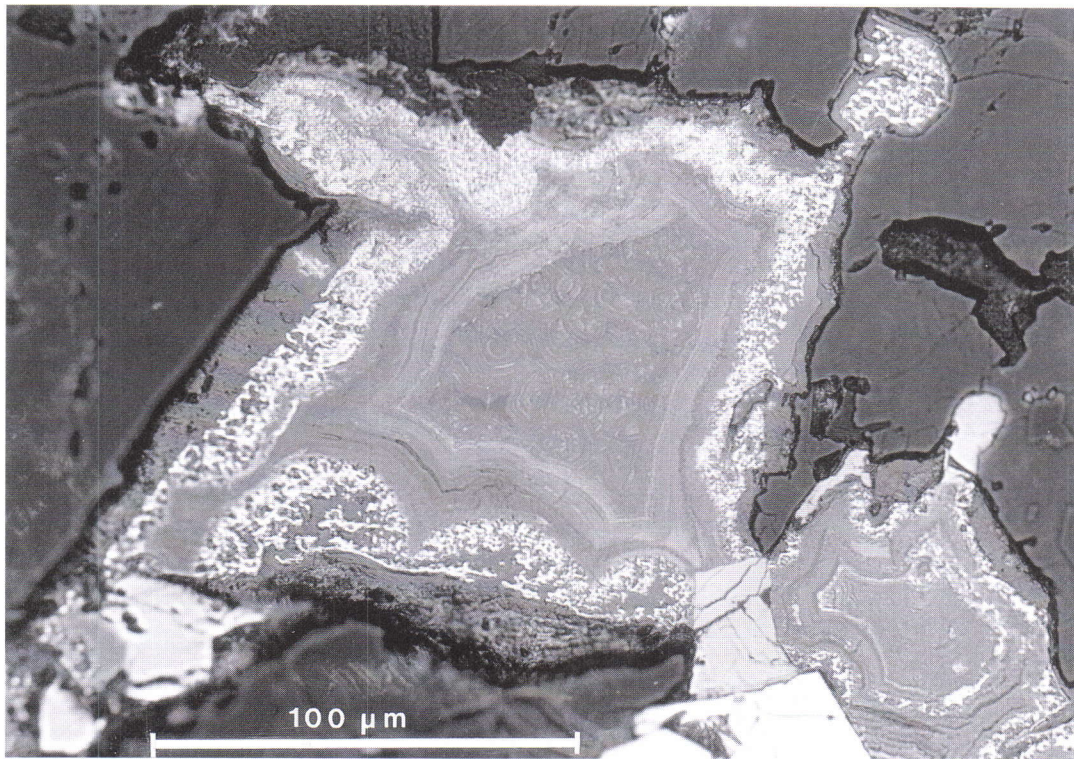


Fig. 3. A totally altered aurostibite grain with colloform texture. The grain is surrounded by a corona-like rim consisting of native gold and antimony. Reflected light, 1 polarizer.

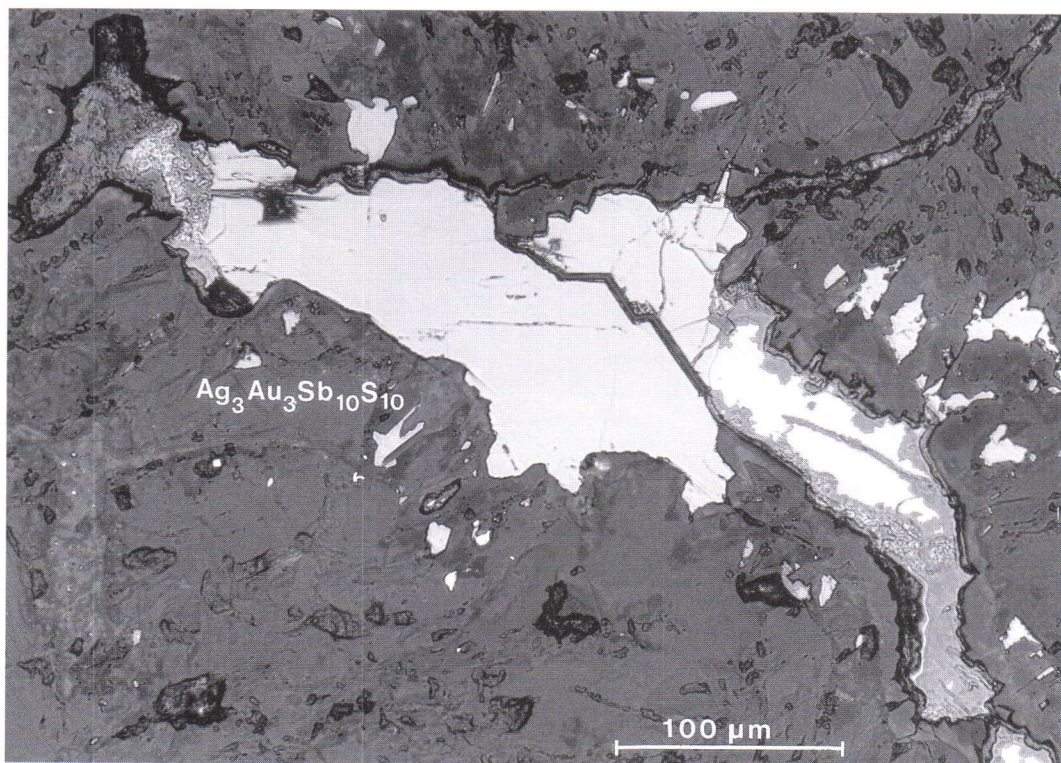


Fig. 4. The undefined  $Ag_3Au_3Sb_{10}S_{10}$  in contact with one completely altered (to the left) and one partly altered (to the right) aurostibite grain. The mineral aggregate is divided by a microcrack. Most of the small mineral grains surrounding the mineral aggregate consist of the undefined mineral. Reflected light, 1 polarizer.

Table 2. Microprobe analyses of altered aurostibite from the Kalliosalo gold occurrence.

	1	2	3	4	5
S	0.02	2.42	1.09	0.64	0.02
Cu	0.07	0.00	0.05	0.03	0.02
Fe	0.00	1.16	1.71	0.01	0.04
Sb	55.08	29.17	25.26	35.24	42.02
As	0.37	0.03	0.61	0.07	0.96
Au	45.23	50.99	54.28	50.16	47.54
Ag	0.03	0.04	0.00	0.01	0.00
Bi	0.31	0.06	0.24	0.21	0.00
Total	101.15	84.15	83.24	86.51	90.67

1. Intact aurostibite.  
 2—4. Altered aurostibite, violet-brown layers.  
 4. Altered aurostibite, red-brown layer.  
 Microprobe analyses by B. Johanson and L. Pakkanen.

(Fig. 3). In many cases the altered grain is partly or completely surrounded by a corona-like rim composed of native gold and native antimony (Figs. 2, 3 and 4) (cf. Ramdohr 1980, p. 824). A beautiful colloform texture with concentric red-brown and violet-brown layers has developed in many of the altered aurostibite grains (Fig. 3). Inspected in reflected light with nearly crossed polarizers and with high light intensity the concentric layers reveal very narrow hematitic layers. Hematitic material also exists among the intergrown gold and antimony as fine-grained dissemination. Table 2 gives the results of a set of microanalyses across an alteration zone in an aurostibite grain. The set begins at the intact aurostibite and ends near the Au-Sb corona. Outside the aurostibite contact, the Sb content drops sharply and the Au content correspondingly increases (analyses 1—3). Towards the Au-Sb corona the Sb content increases and the Au content decreases (analyses 4—5). Because the sum of the analysed elements in the altered aurostibite is considerably less than 100 %, and no heavier elements are lacking according to the EDS analysis, the inference is that it is hydrous.

**Pyrrhotite** is anhedral and is partly altered to marcasite from the margins and along 0001 planes. Its grain size is 0.1—0.5 mm. As stated above, lamellar marcasite often forms aggregates with stibnite.

**Gudmundite** occurs as idiomorphic grains in connection with aurostibite and arsenopyrite (Fig. 2).

**An undefined ore mineral** is met with as anhedral grains in association with aurostibite, arsenopyrite and gudmundite (Figs. 2, 4, 5 and 6). Its grain size ranges from few  $\mu\text{m}$  to about 200  $\mu\text{m}$ . It is grey, resembles fahlerz and is distinctly anisotropic between crossed polarizers. It shows neither reflection pleochroism nor anisotropy colours. Thin lamellae oriented in two direc-

tions were clearly visible in two grains (Fig. 6). Provisional reflectance values for four wavelengths are given in Table 3. According to microprobe analyses (Table 4), the mineral contains Ag, Au, Sb and S. A chemically similar mineral, criddleite, is known from the Hemlo gold mine (Harris et al. 1988). Comparison with the microprobe analyses of criddleite (Harris et al. 1988, p. 693) reveals that the contents of Au, Sb and S are nearly the same in both minerals, but that the content of Ag is twice as high in the undefined mineral, and that Tl is lacking altogether. Criddleite has also been reported from the gold district of Vigès, France (Gatellier et al. 1990). The Au/Tl ratio of the Vigès criddleite is higher than that of the Hemlo criddleite. Assuming that in the unknown mineral Ag replaces the Tl in the same structure of criddleite, the idealized formula of the unknown mineral is  $\text{Ag}_{3.6}\text{Au}_{2.6}\text{Sb}_{9.0}\text{S}_{10.7}$ .

## Discussion

The Kalliosalo gold occurrence is interpreted as a hydrothermal gold mineralization in which gold principally occurs as aurostibite and native gold. In the Sb-rich part of the binary system Au-Sb, the crystallization from the melt begins with native Sb below 631°C. The only intermetallic phase in that system,  $\text{AuSb}_2$ , begins to crystallize at 460°C, which is the first eutectic point. If the gold content is high enough, native gold starts to crystallize together with  $\text{AuSb}_2$  in the second eutecticum at 360°C (Elliot 1965, p. 231). According to microthermometric measurements on fluid inclusions in quartz in the gold antimony deposit of Vigès, the maximum temperature of formation of the association criddleite-aurostibite-gold is estimated to be  $220 \pm 20^\circ\text{C}$  (Gatellier et al. 1990). The alteration of aurostibite is probably of late

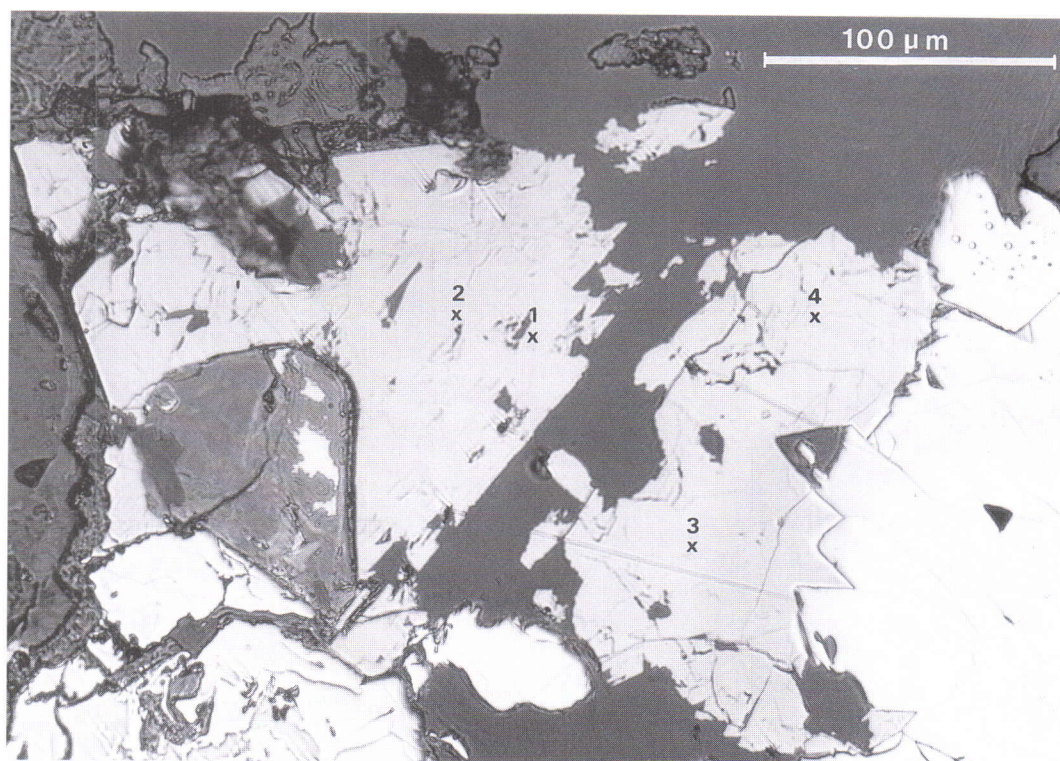


Fig. 5. Two grains of the undefined  $\text{Ag}_3\text{Au}_3\text{Sb}_{10}\text{S}_{10}$ . The grain to the left contains a nearly altered aurostibite grain as an inclusion. The grain to the right is in contact with arsenopyrite. The microprobe analysis points are marked with (1), (2), (3) and (4) (see Table 4). Reflected light, 1 polarizer.

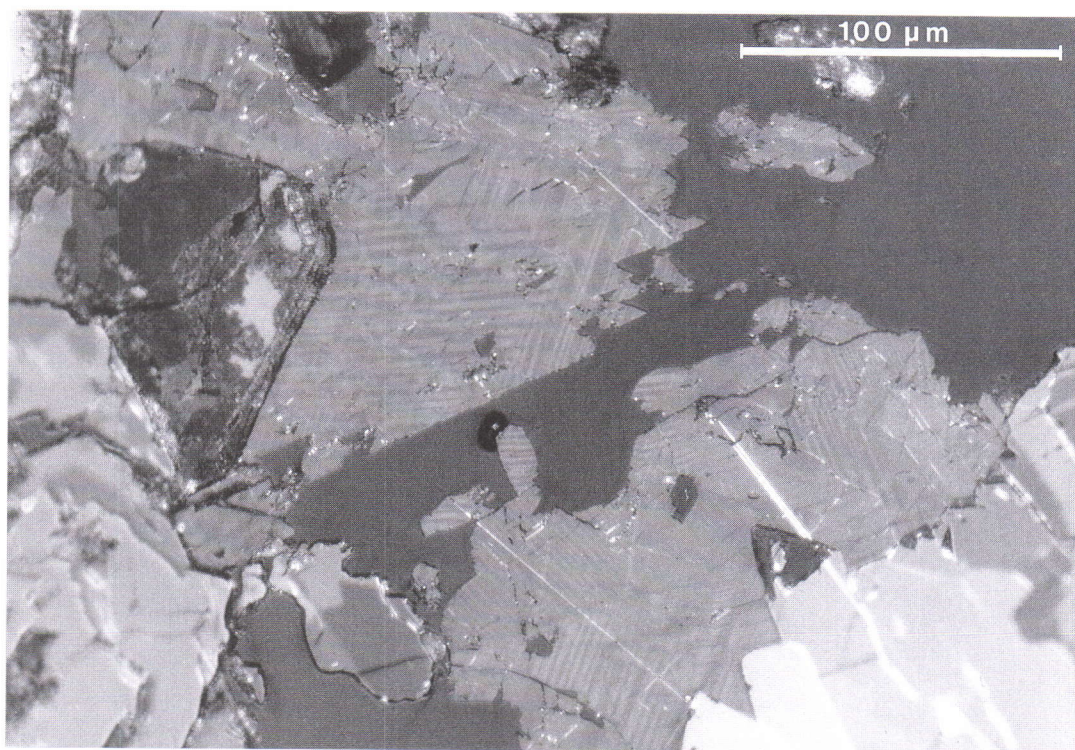


Fig. 6. Lamellar texture in the undefined mineral. The mineral grains are the same as in Fig. 5. Reflected light, polarizers nearly crossed.

hydrothermal or, according to the delicate microtextures observed, even of supergene origin. Iron, which exists as interstitial hematitic material in altered aurostibite and intergrown with gold and antimony, may have participated in the process of formation of native gold and antimony.

The undefined mineral,  $\text{Ag}_3\text{Au}_3\text{Sb}_{10}\text{S}_{10}$ , currently a subject of detailed study, may be a new species or it may represent the silver end member of the criddleite-''silver criddleite'' isomorphic series. The discovery of criddleite with a lower thallium content than that in the original criddleite from Hemlo (Gatellier et. al 1990) suggests the latter alternative.

Table 3. Reflectance data in air (objective N Plan 20x/0.45) and oil (objective N Plan 50x/0.85 Oil) for the undefined mineral  $\text{Ag}_3\text{Au}_3\text{Sb}_{10}\text{S}_{10}$ .

$\lambda$ nm	Air		Oil	
	R1	R2	R1	R2
470	37.0	45.1	25.2	29.6
546	34.7	42.3	23.4	26.7
589	34.2	41.5	23.4	27.2
650	33.0	40.4	22.2	25.7

Final polishing of the sample made with 1/4  $\mu\text{m}$  diamond paste. Standard: WTiC 166. Immersion oil DIN 58884. Reflectance measurements made with Leitz MPV SP photometer system by K. Kojonen and D. Kristen (in preparation). R1 and R2 are the minimum and maximum reflectance values (cf. Harris et al. 1988).

Table 4. Microprobe analyses of the undefined mineral  $\text{Ag}_3\text{Au}_3\text{Sb}_{10}\text{S}_{10}$  from the Kalliosalo gold occurrence.

	1	2	3	4	5	6
Tl	0.00	0.00	0.00	0.00	0.00	0.00
Ag	16.47	16.22	16.70	15.92	16.09	16.57
Au	21.66	21.45	21.73	22.00	22.39	21.76
Sb	45.55	46.96	47.50	46.15	47.67	46.76
S	14.54	13.72	13.38	14.72	14.22	14.60
Hg	0.00	0.63	0.00	0.40	0.09	0.19
As	0.00	0.09	0.00	0.16	0.17	0.18
Total	98.37	99.21	99.47	99.38	100.57	100.11

1—4. Refer to analysis points in Fig. 5.  
5. Refers to analysis point in Fig. 2.  
6. Mean of six analyses of the grain in Fig. 4.  
Microprobe analyses by B. Johanson and L. Pakkanen.

## References

- Aho, L. 1980.** Seinäjoki-Nurmon Sb-mineralisaatiosta. Central archive of the Geological Survey of Finland. Report M 19/2222/-80/1/10.
- Borodaev, Yu. S. & Mozgova, N. & Ozerova, N. & Oivanen, P. & Yletyinen, V. 1982.** Pääkkönenite,  $\text{Sb}_2\text{AsS}_2$ , a new mineral from Seinäjoki ore region in Finland. Intern. geol. review 24 (10), 1234—1240.
- Elliot, R. P. 1965.** Constitution of binary alloys: first supplement. New York: McGraw-Hill, 230—231.
- Gatellier, J.-P. & Marcoux, E. & Moelo, Y. 1990.** Nouvelle découverte de criddleite dans le district aurifère de Vigès, Massif Central, Creuse, France. Canadian Mineral., v. 28, 739—744.
- Graham, A. R. & Kaiman, S. 1952.** Aurostibite,  $\text{AuSb}_2$ ; a new mineral in the pyrite group. Am. Mineralogist. v. 37, nos. 5—6, 461—469.
- Harris, D. C., Roberts, A. C., Laflamme, J. H. G. & Stanley, C. J. 1988.** Criddleite,  $\text{TlAg}_3\text{Au}_3\text{Sb}_{10}\text{S}_{10}$ , a new gold-bearing mineral from Hemlo, Ontario, Canada. Mineralogical Magazine, December 1988, Vol. 52, 691—697.
- Kahma, A. 1958.** Yhteenveto Geologisen tutkimuslaitoksen tutkimuksista Seinäjoen antimoni-malmiaiheella v. 1954—58. Central Archive of the Geological Survey of Finland. Report M17/Sj-58/2a. 8 p.
- Kärkkäinen, N. 1991a.** Etelä-Pohjanmaan mafisten meta-vulkaniittien petrografia ja kemiallinen koostumus. Unpublished report. Espoo: Geological Survey of Finland.
- Kärkkäinen, N. 1991b.** Nurmon Kallionsalon kulta-aiheen tutkimukset syksyllä 1991. Central Archive of the Geological Survey of Finland. Report M 19/2222/-92/10/1. 5 p.
- Kojonen, K. & Kristen, D.** Reflectivity measurements of some Finnish gold-silver minerals using Leitz MPV SP system. To be published in: Mitteilungen für Wissenschaft und Technik. Leica Mikroskopie und Systeme GmbH, Wetzlar, Germany. (in prep).
- Lashley, W. C. 1985.** Aurostibite and maldonite. California Mining Journal. 55 (1). 28—32.
- Lehtiö, M. 1981.** Kalliosalo antimoniförekomst i Nurmo, Sydösterbotten. Unpublished thesis. Åbo: Åbo Akademi.
- Mäkitie, H. & Lahti, S. I. 1991.** Seinäjoen kartta-alueen kallioperä. Summary: Pre-Quaternary rocks of the Seinäjoki map-sheet area. Geological map of Finland 1:100 000, Explanation to the maps of Pre-Quaternary rocks, Sheet 2222. 60 p.
- Mäkitie, H., Lahti, S. I., Alviola, R. & Huuskonen, M. 1991.** Geological map of Finland 1:100 000. Pre-Quaternary rocks, Sheet 2222, Seinäjoki. Espoo: Geological Survey of Finland.
- Mehlis, A. T. M. 1967.** The Geology of the Indarama Gold-Antimony Mine Sebakwe Area, Que Que, Rhodesia. Symposium on the Rhodesian basement complex. Geol. Soc. Africa, Vol. 71, Annexure, 135—146.
- Morrison, R. J. 1978.** The Blue Spec gold-antimony mine. Geological Survey of Western Australia. Annual Report, 74—79.

- Mozgova, N. N. & Borodaev, Yu. S. & Ozerova, N. A. & Pääkkönen, V. 1977.** New minerals of the group of iron antimonides and arsenides from the Seinäjoki deposits, Finland. *Bull. Geol. Soc. Finland* 49 (1), 47—52.
- Naz'mova, G. N. & Spiridonov, E. M. & Shalayev, Yu.S. 1975.** Aurostibite from Bestyube Deposit, northern Kazakhstan. First find in the USSR. *Acad. Sci. USSR, Dokl., Earth Sci. Sect.* 222. (1—6), 141—143.
- Neuvonen, K., 1961.** Geological map of Finland 1:100 000, Pre-Quaternary rocks, Sheet 2222, Seinäjoki.
- Nysten, P. 1986.** Gold in the volcanogenic mercury-rich sulfide deposit Långsele, Skellefte ore district, northern Sweden. *Mineral. Deposita.* 21 (2), 116—120.
- Oivanen, P. 1982.** Antimonitutkimukset Seinäjoen-Nurmon alueella vuosina 1975—1982. Central Archive of the Geological Survey of Finland. Report M 19/2222/-82/1/10. 3 p.
- Pääkkönen, V 1959.** Tutkimukset Seinäjoella v. 1958. Central Archive of the Geological Survey of Finland. Report M17/Sj-59/1. 1 p.
- Pääkkönen, V. 1966.** On the geology and mineralogy of the occurrence of native antimony at Seinäjoki, Finland. *Bull. Comm. géol. Finlande* 225. 70 p.
- Ramdohr, P. 1980.** The ore minerals and their intergrowths. GDR: Pergamon Press, 1205 p.