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by Lea Aho

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ORE MINERALIZATION AT RITOVUORI, PIHTIPUDAS, CENTRAL FINLAND

BY

LEA AHO

WITH 6 FIGURES AND 3 TABLES IN TEXT AND 3 PLATES

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Mineralized zones in the metamorphosed volcanics of the Pihtipudas schist zone are described. Native gold and bismuth, oxides, arsenides, sulphides and sulphosalts are present. The arsenides and sulphides occur as disseminated grains and veins, while the Pb-, Ag-, Bi-, Sb-, and Cu-bearing sulphosalts occur as inclusions within galena. Microprobe and X-ray diffraction data are given for the sulphosalts. The petrogenesis of the deposit is briefly discussed.

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INTRODUCTION

Samples collected by Aleks Komu from a new railroad cutting initiated investigation by the Exploration Department of the Geological Survey in the Pihtipudas area (Figs. 1 a and 1 b) during 1958—59.

Field investigations were led by A. J. Laitakari. The crew found several boulders and outcrops with arsenopyrite, galena and chalcopyrite in the area known as Ritovuori, 1.5 km south of Pihtipudas church. The high content of precious metals justified further exploration in the area. Geophysical measurements revealed one weak anomaly, subsequently investigated by drilling. The drill cores showed minor amounts of pyrite, pyrrhotite and arsenopyrite in the schists. A galena-quartz vein, an arsenopyrite-quartz vein and a chalcopyrite-bearing lime-rich aggregate were drilled to investigate their relationship to the schists.

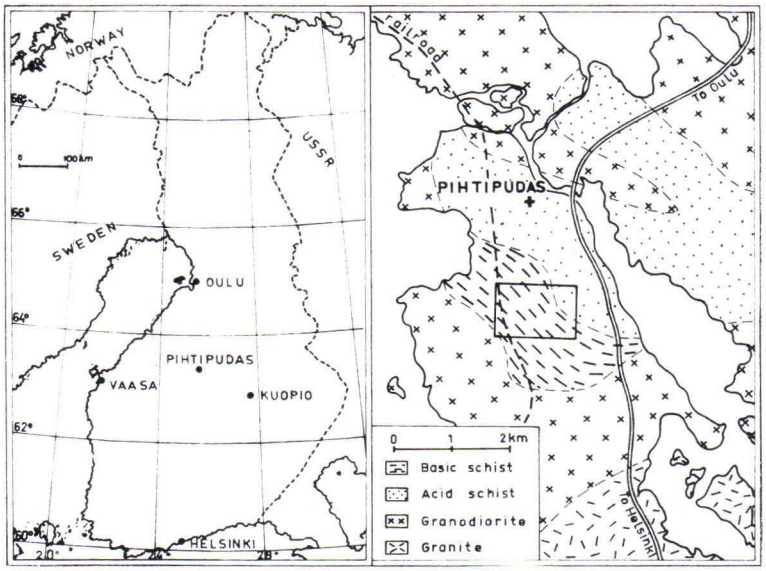

FIG. 1 a. Location and general geological map of the Pihtipudas area. The investigated area is outlined.

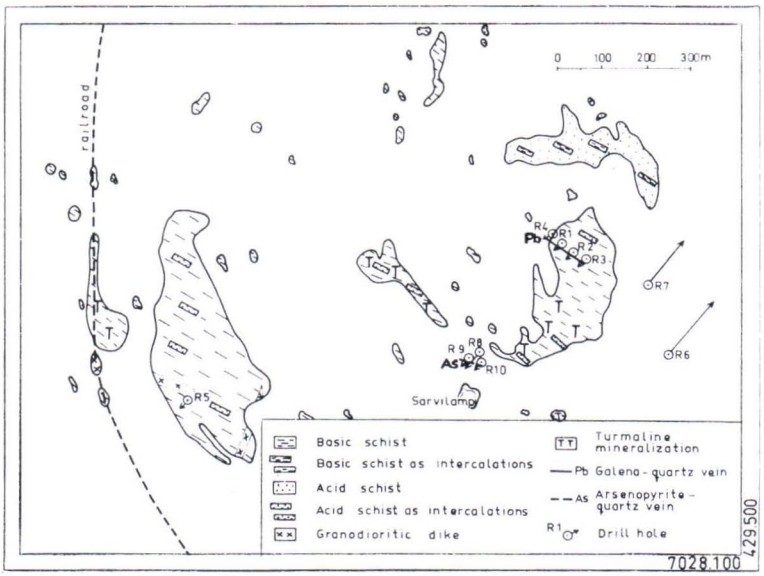

FIG. 1 b. Local geological map with ore mineralized veins.

The mineralized zone lies within a positive aeromagnetic anomaly extending from the Pihtipudas church as an uniform belt eastwards about 15 km. It was decided to undertake detailed geological mapping of the area during 1965—1967 and to investigate the ore mineralization associated with the surrounding rocks. The material was collected and the microscopic determination of the rocks and minerals were made by the author during the years 1967—1972.

The purpose of this study is to report the results of these investigations, special attention being given to the ore mineralization in the Ritovuori area.

GENERAL GEOLOGY

Wilkman (1938) considered the schists in the area as leptites of sedimentary origin, associated with the Bothnian schists belt and post-Bothnian suites of granites and granodiorites. Salli (1971) recognized an east-west schist zone primarily volcanic in origin, and a north-south schist zone of mainly sedimentary origin. Near the northern margin of the east-west schist zone there are epiclastic metasediments; mica schists, graywacke schists and conglomerate schists. The graywacke-like schists may occur also as intercalations in the basic volcanic schists. The investigated area at Ritovuori contains both disseminated ore minerals and ore-bearing quartz-veins. Both basic schists and acid or intermediate quartz-feldspar schists in the area are crossed by granodioritic dikes.

BASIC SCHISTS

The suite is composed of amphibolites, plagioclase- and uralite porphyrites and schists containing hornblende metacrysts. The bulk of the basic schists are fine-grained amphibolites without any trace of the original texture which was obliterated by strong tectonism. The main constituents of the amphibolite are plagioclase (An_{25-35}), green hornblende (2V $\alpha = 72°—76°$, $c \wedge \gamma = 16°—18°$) and dark brown biotite partially replaced by chlorite. Plagioclase is partly replaced by K-feldspar. Quartz is a common accessory mineral, along with epidote, calcite, zircon, tourmaline, apatite and opaque minerals.

The original texture of plagioclase- and uralite porphyrites is somewhat better preserved. Plagioclase and hornblende or hornblende aggregates occur as phenocrysts varying in size from 1 mm to 3 mm. Hornblende in the groundmass is fine-grained (0.05—0.1 mm). The groundmass mineralogy is similar to that of the amphibolite.

Schists containing hornblende metacrysts are present in the amphibolite and the plagioclase- and uralite porphyrites as intercalations. Euhedral metacrysts of hornblende 1—2 cm in length contain as inclusions minerals of the groundmass. The groundmass mineral compositions appear identical to those in the basic schists. These kind of intercalations may have formed by the recrystallization of basic schists.

Locally, the basic schists contain lime-rich aggregates 20—30 cm in diameter. These consist primarily of epidote, calcite and sphene, with accessory quartz, plagioclase, scapolite, K-feldspar, hornblende and hematite. The lime-rich aggregates are usually enriched in ore minerals.

QUARTZ-FELDSPAR SCHISTS

The acid or intermediate schists are grey or reddish-grey in colour. The main constituents are quartz, plagioclase and K-feldspar with the grain size varying between 0.05—0.5 mm. Plagioclase varies from An_{10-15} in acid schists to An_{15-30} in intermediate schists. It is commonly partly replaced by quartz, K-feldspar, calcite or epidote. Biotite and rarely muscovite are present. Accessories are apatite, zircon, sphene, epidote, tourmaline and opaque minerals. Locally, quartz and sometimes plagioclase or K-feldspar occur as phenocrysts 1—3 mm in diameter.

ORE MINERALIZATION

The ore mineralizations at Ritovuori are situated primarily in the brecciated and tourmaline-mineralized zone. Since the zone is diffuse the exact boundary cannot be drawn. The area is about 1 km in length and some 200 m in breadth; it is situated in the contact zone of the basic schists and the quartz-feldspar schists. The contact between the basic and quartz-feldspar schists is sharp, but both schists are found as intercalations within each other.

The breccia occurs only in the basic schists; the basic fragments are 5—10 cm in diameter, and surrounded by a tourmaline rim 2—3 mm in breadth. The breccia matrix is composed of fine-grained quartz, plagioclase, K-feldspar, biotite and sometimes hornblende.

Tourmaline mineralization occurs both in the basic and quartz-feldspar schists with tourmaline forming euhedral grains or aggregates 2—3 cm in diameter.

Plagioclase in the quartz-feldspar schist is slightly sericitized in the contact zone for a width of 10—20 m. The sericitized schists locally contain both biotite and muscovite.

TABLE 1

List of minerals

	Galena-quartz vein	Arsenopyrite-quartz vein	Lime-rich aggregates
Gold		+	
Bismuth	+		+
Rutile		+	
Magnetite			+
Ilmenite			+
Arsenopyrite	+	+++	
Loellingite		+	
Pyrite	++	++	+
Pyrrhotite			+
Marcasite	+	++	+
Sphalerite		+	+++
Chalcopyrite	++	+	+++
Cubanite			+
Covellite			+
Galena	+++		+++
Greenockite	+		
Pb-Bi-Sb-Cu-sulphosalts	+		+
Pb-Bi-Sb-sulphosalts	+		
Ag-Sb-sulphosalts	+		+
Quartz	++	+++	+
Calcite			+++
Scheelite			+
Tourmaline	+	+	+
Sphene	+		++
Epidote			++
Plagioclase			+
K-feldspar			++
Scapolite			+
Amphibole			+
Muscovite			+
Chlorite			+

Abundance:

+ = sparse
++ = moderate
+++ = abundant

The ore mineralization have been divided into the following groups based on their main components:

a) sparsely disseminated arsenopyrite and pyrite grains
b) minor amounts of pyrrhotite, chalcopyrite and pyrite in the basic schists and breccia fragments
c) galena, sphalerite and chalcopyrite in small amounts within the lime-rich aggregates
d) an arsenopyrite-quartz vein
e) a galena-quartz vein.

Minor antimony, bismuth and silver mineralization is present in the lime-rich aggregates (group c) and the galena-quartz vein (group e). Native gold occurs as minute grains in the arsenopyrite-quartz vein (group d).

The disposition of the ore minerals is given in Table 1.

DETAILED ORE MINERALOGY

Native metals

Gold

Native gold most commonly occurs filling fractures in arsenopyrite or the interstices between euhedral arsenopyrite grains in arsenopyrite-quartz vein (Fig. 2.).

FIG. 2. Native gold (white) in fractured arsenopyrite (light grey) with chalcopyrite (grey) in arsenopyrite-quartz vein. Magn. 80 x, one nicol.

A rounded grain was found as an inclusion in pyrite of the galena-quartz vein. The content of gold varies considerably even within the same vein.

Clark (1960) suggests that gold may be present as sub-microscopic inclusions or as solid solution in arsenopyrite and migrates at lower temperatures towards fracture zones. The major part of gold at Ritovuori may have been deposited in this way; lesser amounts of gold occur in the other sulphides.

Bismuth

Native bismuth occurs in the galena-quartz vein as small droplets in galena and as exsolution blebs within the different phases of the altered Pb-Bi-Sb-sulphosalt (cf. Plate II, Figs. a and c). Ramdohr (1969) suggests that native bismuth has formed during the alteration of bismuth compounds, especially in the Pb-Bi-sulphosalts, as a result of decreasing temperature.

Bismuth is more abundant as inclusions within galena of the galena-bearing lime-rich aggregates than in the galena-quartz vein. The larger bismuth grains display twinning (Fig. 3.). Craig (1967) suggested that crystallization stresses are apparently sufficient to produce twinning. Twinning may also result from grinding, but the bent lamellae caused by mechanical deformation has not been observed.

Oxide ore minerals

Minor amounts of oxide ore minerals are present; some rutile is found as inclusions within the arsenopyrite of the arsenopyrite-quartz vein and is considered to have crystallized before the arsenopyrite. The lime-rich aggregates contain some magnetite; ilmenite occurs in the basic schists.

Sulphides and arsenides

Arsenopyrite

Arsenopyrite is a major mineral in the mineralized zone occurring as grains and aggregates 2—3 cm in diameter in both the basic and acid schists. It is also a main mineral in the arsenopyrite-quartz vein as euhedral grains. Arsenopyrite does not occur in the basic fragments of breccia which may indicate that ore mineralization occurred after brecciation. Chalcopyrite and pyrrhotite fill the fractures in arsenopyrite and the interstices between arsenopyrite grains. Arsenopyrite appears to have remained, for the most part, stable during the deposition of later ore minerals. Mimetic twinning of arsenopyrite is common, especially in the arsenopyrite-quartz vein. Twinning has been observed in gangue-filled fractures, perhaps reflecting the influence of stress on the symmetry and twinning (Clark, 1965).

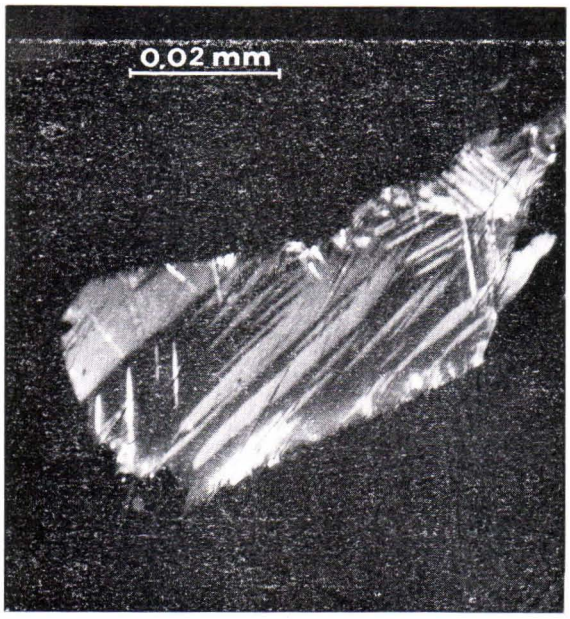

FIG. 3. Twinning in native bismuth within galena of a lime-rich aggregate. Galena black, bismuth grey and twinned. Crossed nicols, oil imm., photo E. Halme.

Loellingite

Minor amounts of loellingite are present. Loellingite occurs as small grains within the arsenopyrite-quartz vein. It was distinguished from arsenopyrite by etching with concentrated $FeCl_3$.

Pyrite

Pyrite, as arsenopyrite, is abundant in the mineralized zone. It occurs as euhedral grains, and with marcasite in fine-grained intergrowths replacing pyrrhotite. The euhedral pyrite grains have a skeletal form. In the galena-quartz vein the skeletal pyrite grains contain inclusions of galena. This is interpreted as evidence that pyrite has also formed during the later stages of crystallization.

Pyrrhotite

Disseminated pyrrhotite grains occur in the basic schists, breccia fragments and lime-rich aggregates. Pyrrhotite is replaced by pyrite and marcasite intergrowths in both the galena-quartz and the arsenopyrite-quartz veins. The replacement of pyrrhotite is not similar in the two veins.

In the arsenopyrite-quartz vein the altered extremely fine-grained substance has an oval and concentric form (»birds eye»); this material is commonly called marcasite although pyrite may co-exist or frequently be the only mineral (Ramdohr, 1969).

In the galena-quartz vein pyrrhotite is replaced by marcasite or pyrite-marcasite aggregates. They often form lamellar aggregates, // (0001) of pyrrhotite. Marcasite remains while the pyrrhotite is leached away resulting in cellular pseudomorphs of pyrrhotite (Ramdohr, 1969). The small marcasite grains are clearly anisotropic; gangue minerals fill the interstices of the lamellae.

Sphalerite

Sphalerite occurs as disseminated grains with galena and chalcopyrite in the lime-rich aggregates. It was not observed in the galena-quartz vein and only occasionally in the arsenopyrite-quartz vein. Sphalerite contains exsolution blebs of chalcopyrite.

Chalcopyrite

Minor amounts of chalcopyrite occur as disseminated, small grains in the basic schists and the tourmaline-bearing breccia. It occurs as rare grains in the arsenopyrite-quartz and galena-quartz veins. Chalcopyrite is a principal ore mineral in the lime-rich aggregates, associated with sphalerite and galena. This chalcopyrite is apparently of later age than that in the basic schists. Chalcopyrite may contain unmixed cubanite lamellae which may be replaced by covellite. These secondary copper sulphides occur in very small amounts.

Galena

Galena is a primary constituent of the galena-quartz vein and occur as disseminated grains in the lime-rich aggregates. Pb-Bi-Sb-bearing sulphosalts, Ag-Sb-sulphosalts and native bismuth are present as irregular inclusions in galena. In addition greenockite blebs occur in the galena of the galena-quartz vein.

Greenockite

Greenockite has been observed as small anhedral grains (0.01—0.03 mm) in galena only in the galena-quartz vein. It is bluish grey with internal reflections varying from light yellow to brown (cf. Plate II, Figs. a and e).

Sulphosalts

The sulphosalt minerals are divided into three groups:

1. Pb-Bi-Sb-Cu-sulphosalts
2. Pb-Bi-Sb-sulphosalts (several different phases)
3. Ag-Sb-sulphosalts

FIG. 4. Pb-Bi-Sb-Cu-sulphosalt (white-grey) within galena (darker grey) of the galena-quartz vein. In vertical direction lies a scratch trace which was produced by grinding. The scratch goes over galena and sulphosalt. Sulphosalt remains almost unmarked. Magn. 80 x, crossed nicols.

All three sulphosalt groups occur as inclusion within the galena of the galena-quartz vein. In the lime-rich aggregates only Pb-Bi-Sb-Cu-sulphosalts (1.) and Ag-Sb-sulphosalts (3.) are present.

Pb-Bi-Sb-Cu-sulphosalts

Pb-Bi-Sb-Cu-sulphosalts occur as lath-shaped or tabular grains up to 0.4 mm in width within galena (Fig. 4.). While the optical properties are best observed in oil, a weak pleochroism and strong anisotropy is evident in air. In a diagonal orientation, the grains are easily distinguished from galena by their slightly greenish grey colour.

Standard etch tests (one minute) gave the following results: (a) 1: 1 HCl, 20 % KCN and 40 % KOH negative; (b) 1: 1 HNO_3 stains iridescent to brown; (c) 20 % $FeCl_3$ gave a faint tarnish.

The polished hardness of the sulphosalts is nearly the same as that of galena. The scratch hardness is higher than that of galena (Fig. 4.). The microhardness was determined with a Vickers hardness tester. The indentation load was 50 g. The Vickers hardness was 160 kg/mm^2 obtained on a tabular grain and 127 kg/mm^2 obtained on a lath-shaped grain. The lath-shaped grain fractured along the cleavage direction.

The reflectivity of the sulphosalts is presented in Table 2. The difference in reflectivity of the sulphosalt I and II is not great, but still detectable. Electron micro-

TABLE 2

The reflectivity,[1]) microprobe analyses and atomic proportions of the Pb-Bi-Sb-Cu-sulphosalts.

	$R_{546\ nm}$ %	Wt. %						atomic proportions
		Pb	Bi	Sb	Cu	S	Sum	
Sulphosalt I	39.3—42.6	46.3	19.7	13	2	15.7	96.7	$Pb_{7.1}Bi_{3.0}Sb_{3.4}CuS_{15.5}$
Sulphosalt II	37.7—42.1	50.2	24.9	6	2	15.3	98.4	$Pb_{7.7}Bi_{3.8}Sb_{1.6}CuS_{15.2}$

Sulphosalt I, taken from the galena-quartz vein
Sulphosalt II, taken from a lime-rich aggregate

[1]) The reflectivity of the sulphosalts was measured in air using a Leitz MPV microscope photometer. Monochromatic light was obtained with interference filter (546nm). SiC was used as a standard, the reflectivity of which is R = 20.6 % in air. Three different grains were measured from sulphosalt I and sulphosalt II. Since only a few grains were suitable for measurements, the results are not completely reliable.

probe analyses were made of the same sulphosalts; these data suggest that the reflectivity increases with the content of antimony.

Nowacki (1969), in his study of the structural classification of the sulphosalts noted the following minerals which have similar chemical composition to the Pb-Bi-Sb-Cu-sulphosalts at Ritovuori (cf. Table 2).

Kobellite ..... $Pb_5(Bi, Sb)_8S_{17}$, Bi: Sb = (0—1.6): 1
Giessenite ..... $Pb_9Bi_6Sb_{1.5}CuS_{30}$
Bismuth-Robinsonite ..... $Pb_{8.2}(Bi, Sb)_{12}S_{25}$, Sb: Bi = 100: 69
Rézbanyite-Type ..... $Pb_4(Bi, Sb)_{10}S_{19}$

In addition, some Pb-Bi-sulphosalts (e.g. lillianite) contain antimony. Schot and Otteman (1969) note that antimony-rich lillianite is similar to kobellite. Vaasjoki and Kaitaro (1951) have examined a »lillianite» from Iilijärvi which contains antimony, but is not homogeneous and is identical with seleniferous cosalite coexisting with a mixture of galena. Sakharova and Krivitskava (1972) concluded from their study of lead-antimony-bismuth-sulphosalts that kobellite and cosalite belong to the same sulphosalt group, with the general formula $R_2^{2+} R_2^{3+} S_5$. Stibial lillianite belongs in a different sulphosalt group, the general formula of which is $R_3^{2+} R_2^{3+} S_6$. In both groups the bismuth-antimony ratio is variable while the atomic sums of bismuth and antimony are practically constant. Giessenite, $Pb_9Bi_6Sb_{1.5}CuS_{30}$ (Graeser, 1963) is, in chemical composition closely related to the Pb-Bi-Sb-Cu-sulphosalts at Ritovuori. Copper forms obviously an essential constituent of these minerals. In many sulphosalt studies the copper content is overlooked as an impurity. According to Karup-Møller (1973) antimony is necessary for the formation of giessenite. Sb-free giessenite has not been found.

The X-ray powder diffraction data for Pb-Bi-Sb-Cu-sulphosalts I and II, stibial lillianite and kobellite are given in Table 3. The data show some similarities with

TABLE 3

X-ray powder diffraction data for Pb-Bi-Sb-Cu-sulphosalts.

1.		2.		3.		4.	
d(Å)	I	d(Å)	I	d(Å)	I	d(Å)	I
						4.76	1/2
						4.54	1/2
		4.31	w			4.34	1/2
4.17	mw					4.27	1/2
				3.86	2	3.98	4
3.75	mw	3.73	s	3.73	1	3.75	1/2
3.57	mw	3.60	m			3.57	1
				3.50	10	3.54	10
						3.44	1
3.39	vs	3.43	m	3.42	7	3.41	9
3.29	ms	3.33	mw	3.31	3	3.27	4
		3.169	m	3.18	2		
3.13	m			3.07	2	3.12	1
3.01	m			3.01	7		
		2.964	s	2.95	9	2.98	1
						2.90	1/2
2.88	s	2.85	*w	2.84	2	2.85	2
2.81	m						
2.74	w	2.755	ms	2.76	2	2.72	5
2.60	vw					2.60	1/2
						2.57	1/2
		2.532	w	2.52	2	2.523	1
2.43	vw			2.49	2		
						2.355	1/2
2.31	w			2.29	2	2.305	1
		2.265	mw			2.253	1/2
		2.199	mw	2.17	7	2.185	1/2
2.14	ms					2.150	2
2.11	w					2.129	2
		2.094	mw			2.092	1/2
				2.06	8		
2.04	ms	2.045	mw			2.039	1
						2.011	1
1.95	w	1.975	*w	1.960	3	1.976	1/2
		1.899	mw				
1.88	w			1.875	1		
				1.850	4		
1.81	w			1.805	1		
		1.787	mw	1.766	6		
1.73	ms			1.751	6		
		1.716	mw				
1.70	w						

Line intensity:

vs = very strong, s = strong, ms = medium strong, m = medium, mw = medium weak, w = weak.

1. Sulphosalt I, Ritovuori, Pihtipudas, Ni-filter, Cu-radiation, camera diameter 57,54 mm (P. Kallio).

2. Sulphosalt II, Ritovuori, Pihtipudas, Ni-filter, Cu-radiation, camera diameter 114.83 mm, * masked by NaCl (P. Kallio).

3. Stibial lillianite (1854), Darasun, U.S.S.R. (Sakharova and Krivitskava, 1972).

4. Kobellite, Hvena, Sweden (Harris et al., 1968).

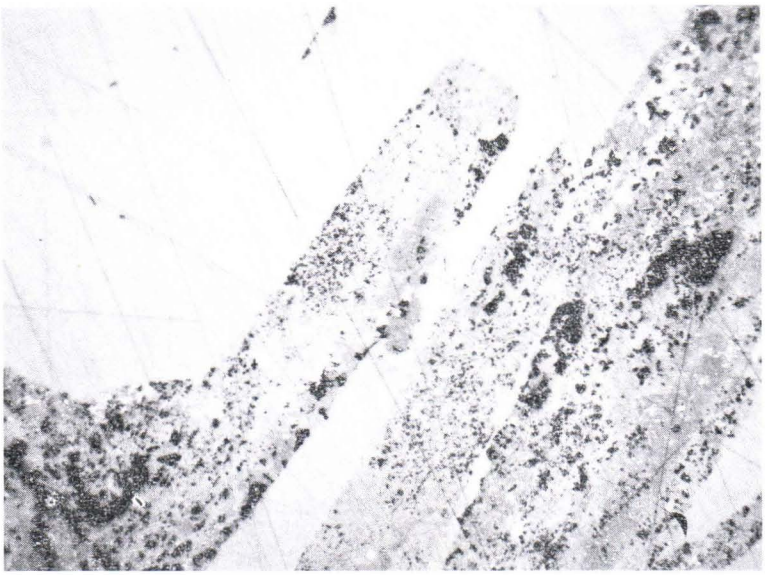

FIG. 5. Lath-shaped Pb-Bi-Sb-sulphosalts within galena of the galena-quartz vein. White points are native bismuth. Magn. 80 x, one nicol, oil imm., photo E. Halme.

each other, but the results are not identical even between the sulphosalt compounds I and II. Identification by X-ray diffraction analyses is difficult because of the close similarities in crystal structure for different lead sulphosalts. Equivalent sulphosalts could not be found among the known Pb-Bi-Sb-Cu-sulphosalts. Both sulphosalts may be new members of a sulphosalt series. A study of the crystal structure could give the answer to this problem.

Pb-Bi-Sb-sulphosalts

Pb-Bi-Sb-sulphosalts altered to different phases occur as inclusions in galena of the galena-quartz vein. The grains are tabular or lath-shaped, between 0.4—0.6 mm in length. The similarity in form of these grains suggests that they originated from the same mineral which became unstable and altered into several different phases plus abundant native bismuth (Fig. 5.). The greyish parts composed of small lath-shaped grains may be distinguished in the sulphosalt grains. These have a slight reflection pleocroism and a distinct anisotropy. They form bent and radial aggregates resulting from the breakdown of the original mineral (Fig. 6.).

Three different phases have been observed based on the distribution of antimony (cf. Plate I, Fig. c.). The content of antimony varies from nil in phase I, to medium in phase II and to abundant in phase III. The relationship of lead to antimony is seen in Fig. b. The content of lead is abundant in phase I, when antimony is nil.

FIG. 6. Pb-Bi-Sb-sulphosalts showing bent and radial growth aggregates. Crossed nicols, photo E. Halme.

In phase II the antimony and lead content are medium. The lead content in phase III sparse when antimony is abundant. The $BiL\alpha_1$ scanning image shows the distribution of bismuth. The bismuth content is sparse in phase I, medium in phases II and III. The $CuK\alpha_1$ scanning image shows copper occurring as small dots around the sulphosalt grain.

Alteration of the Pb-Bi-Sb-sulphosalt to the different phases and native bismuth has occurred only in the galena-quartz vein. The galena-quartz vein also contains Pb-Bi-Sb-Cu-bearing sulphosalt I showing no sign of alteration.

Ag-Sb-sulphosalts

Grains of Ag-Sb-sulphosalts occur as inclusions in galena and within the Pb-Bi-Sb-sulphosalts. The largest grain measures up to 0.2 mm, but normally the grain size is < 0.1 mm. The colour of the Ag-Sb-sulphosalts is grey or bluish grey against galena, but much lighter than greenockite and sphalerite.

There are two types of Ag-Sb-sulphosalts. One is macroscopically deep-red. This sulphosalt is pleochroic with red internal reflections, and distinctly anisotropic. The second is a lighter grey than the former and slightly pinkish. Reflection pleochroism and anisotropy have not been observed. This could be due to the orientation of the grains. Because of the small grain size more accurate microscopic studies could not be performed.

Microprobe analyses were made to determine the composition of the Ag-Sb-sulphosalts (cf. Plate II). On the right side of the studied section is the Pb-Bi-Sb-sulphosalt altered to different phases, the boundaries of which are clearly visibly against the galena on the left side (Fig. b.). The lower side of the X-ray scanning images ($SbL\alpha_1$ and $AgL\alpha_1$) shows the antimony and silver bearing sulphosalts. The $SbL\alpha_1$ image clearly shows the distribution of antimony between the Ag-Sb-sulphosalt and the Pb-Bi-Sb-sulphosalt. The points of native bismuth in galena and in the Pb-Bi-Sb-sulphosalt are seen in the $BiL\alpha_1$ image.

Plate III presents a photomicrograph, concentration profiles and X-ray scanning images of the Ag-Sb-sulphosalts. In the middle of the photomicrograph both Ag-Sb-sulphosalts can be seen as a greyish area in galena. A splinter of light-coloured chalcopyrite divides the greyish grain. On the left side of this grain lies a hole with several grains of marcasite. On the right side of the photomicrograph is the Pb-Bi-Sb-sulphosalt, slightly more greyish than galena. The distribution of lead, bismuth and antimony in the sulphosalts is shown by the corresponding X-ray scanning images.

The left part of the Ag-Sb-sulphosalt is slightly pleochroic, the grain is anisotropic with abundant red internal reflections. The right part of the grain is gray, internal reflections are absent and the anisotropy is slight. The profiles show the distribution of antimony and silver in the Ag-Sb-sulphosalt as marked in the photomicrograph. The pronounced minimum points of the antimony and silver concentration curves indicate chalcopyrite. The profiles clearly show that the right part of the Ag-Sb-sulphosalt is richer in silver than the left part.

One microprobe analysis was made of the Ag-Sb-sulphosalt with red internal reflections. The results are similar to analyses of pyrargyrite from Lengenbach (Nowacki, 1969). The optical properties of the silver-poor grain are also identical with those of pyrargyrite.

The silver-rich part may be Sb-billingsleyite (Ag_7SbS_6) with weak or absent anisotropy, since the properties (Keighin and Honea, 1969) are very similar to those of this mineral and of stephanite. Stephanite is strongly anisotropic, with no internal reflections. Stephanite decomposes at 197°C ± 5 with an excess of sulfur to form Sb-billingsleyite and pyrargyrite. Keighin and Honea (1969) suggest that Sb-billingsleyite does exist, but may be misidentified as stephanite.

CHARACTERISTICS OF ORE GENESIS

The following main events may be recognized: (1) early stage of rock alteration (sericitization), (2) brecciation and tourmaline mineralization and (3) principal ore stage with development of the veins.

The principal ore stage (3) at Ritovuori consists of two different groups: 1. disseminated grains of ore minerals in the basic schists and in the quartz-feldspar schists, and 2. ore minerals in quartz veins and in lime-rich aggregates.

Arsenopyrite and pyrite occur as disseminated euhedral grains in both the basic schists and the quartz-feldspar schists (group 1.). This assemblage represents relatively high P-T conditions during mineralization. The rutile and tourmaline inclusions in arsenopyrite show that they crystallized before arsenopyrite. The skeletal pyrite grains indicate in this arsenopyrite-pyrite assemblage that pyrite crystallized at early stage. Pyrite was deposited also during the later stages, since galena inclusions have been found within pyrite grains. Disseminated grains of pyrrhotite, chalcopyrite and pyrite occur in the basic schists and in the breccia fragments. This assemblage follows the arsenopyrite-pyrite assemblage. The amount of disseminated pyrrhotite, chalcopyrite and pyrite is variable and sparse, but increases considerably in the mineralized zone of the basic schists.

The mineralized quartz veins and lime-rich aggregates in the basic schists (group 2.) are divided into three distinctive assemblages: (A) arsenopyrite-quartz vein, (B) lime-rich aggregates and (C) galena-quartz vein.

Assemblage (A) consists of arsenopyrite, loellingite, pyrite, marcasite, chalcopyrite and native gold. This assemblage suggests that ore forming fluid was enriched mostly in As, Fe, Cu and Au. The bismuth and antimony-bearing minerals are lacking. Arsenic was deposited as arsenopyrite and loellingite. The abundance of arsenopyrite/loellingite and lack of pyrrhotite may suggest a relatively high As/S ratio in the ore fluids. Arsenic-bearing minerals do not occur in the assemblages (B) and (C).

Ore minerals in assemblage (B) are chalcopyrite, sphalerite, galena, pyrite, pyrrhotite, marcasite, Pb-Bi-Sb-Cu-sulphosalt II, Ag-Sb-sulphosalts and native bismuth. Assemblage (B) indicates a solution rich in Zn, Cu, Fe and Pb, but also containing some Sb, Ag and Bi. The Pb-Bi-Sb-Cu-sulphosalt II in assemblage (B) is less antimony-rich than the corresponding sulphosalt in assemblage (C). This may indicate that the antimony-content in ore forming fluid was increasing during the course of crystallization.

Galena is the main mineral in assemblage (C). The other ore minerals are pyrite, chalcopyrite, marcasite, Pb-Bi-Sb-Cu-sulphosalt I, Pb-Bi-Sb-sulphosalts, Ag-Sb-sulphosalts, greenockite and native bismuth. The solution was rich in Pb with some Cu, Fe, Sb, Ag and Bi. Lack of Zn in the mineralizing solution of this assemblage, resulted in an element such as Cd could not enter the sphalerite structure, thus it deposited as greenockite.

The presence of several mineral assemblages indicates that the ore was deposited from different ore forming fluids or from one ore forming fluid with continuously changing composition.

AGE OF THE MINERALIZATIONS

The radiometric isotope ages of zircon and sphene were determined from the granodiorites and porphyritic granites surrounding the Pihtipudas schist belt. The ages for zircon from the intrusive rocks are about 1900 Ma and for sphene 1800 Ma. Many intrusive rocks of Finland belong to the same lower age group 1800—1850 Ma.

The isotopic composition of lead in the galena of the galena-quartz vein at Ritovuori has been analyzed in several connections (Kouvo and Kulp, 1961; Geological Survey of Finland, Annual report 1965). The latest determination was carried out in the laboratories of the U.S. Geological Survey, Denver, (Geological Survey of Finland, Annual report 1973) with following results:

$$\frac{^{206}Pb}{^{204}Pb} = 15.577 \qquad \frac{^{207}Pb}{^{204}Pb} = 15.287 \qquad \frac{^{208}Pb}{^{204}Pb} = 35.164$$

The model lead age for the Pihtipudas galena is 1800—1850 Ma.

The calculated model age based on the isotopic composition of lead from the Pihtipudas galena differs from the model lead age for the massive sulphide ores in the neighborhood of Pihtipudas, e.g. Vihanti (Rouhunkoski, 1968), Pyhäsalmi (Geological Survey of Finland, Annual report 1973) and Säviä (*op. cit.*, 1966), which is about 2050 Ma.

Genetically, it is noteable that the isotopic composition of lead in the Pihtipudas galena differs from that of the SW-Finland occurrences, which, however, show nearly the same age as the Pihtipudas lead.

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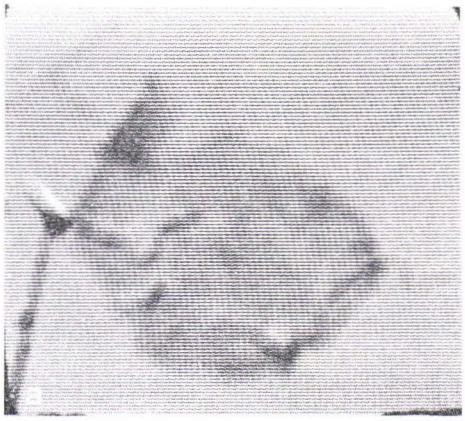
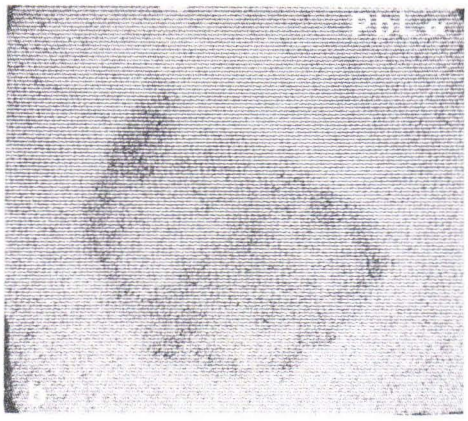
PLATE I

FIG. a. BSE image of Pb-Bi-Sb-sulphosalts within galena of the galena-quartz vein. FIGS. b—e. Scanning images showing the distribution of Pb, Sb, Bi and Cu in the grain shown in Fig. a. Magn. 250 x.


a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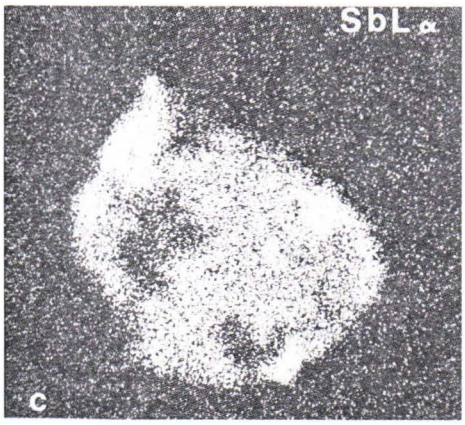
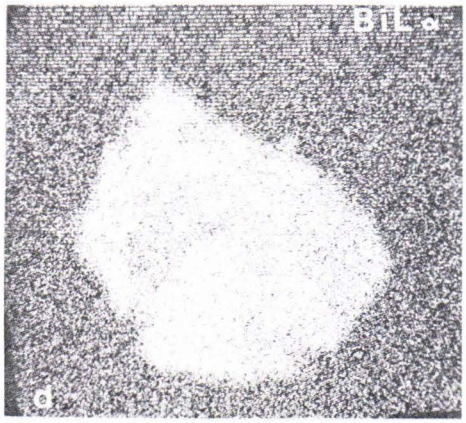

SbLα
c


BiLα
d

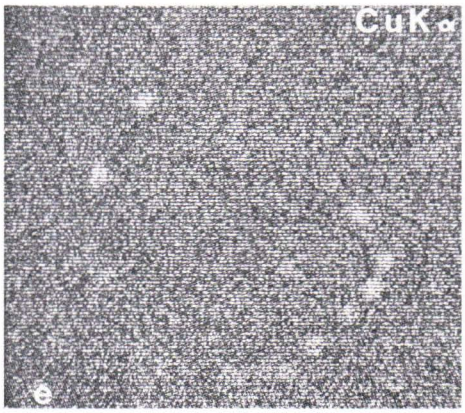
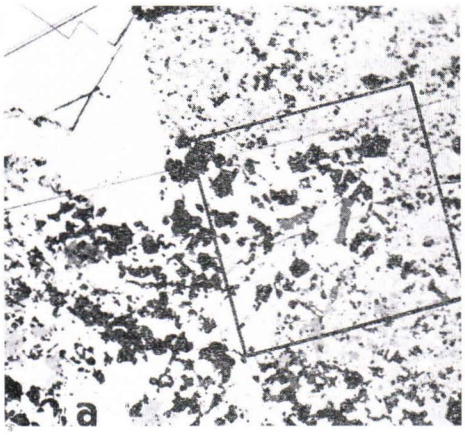

CuKα
e

PLATE II

FIG. a. Ag-Sb-sulphosalts (grey), Pb-Bi-Sb-sulphosalt (light grey), native bismuth (white) and greenockite (dark grey) within galena of the galena-quartz vein. Magn. 180 x, one nicol. FIGS. b—e. Scanning images, showing the distribution of Sb, Bi, Ag and Cd, were taken from the area indicated on the photomicrograph. Magn. 290 x.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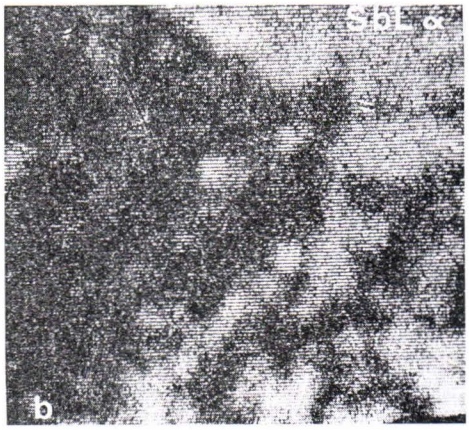
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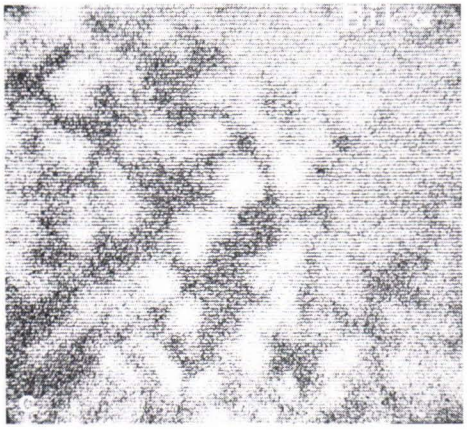
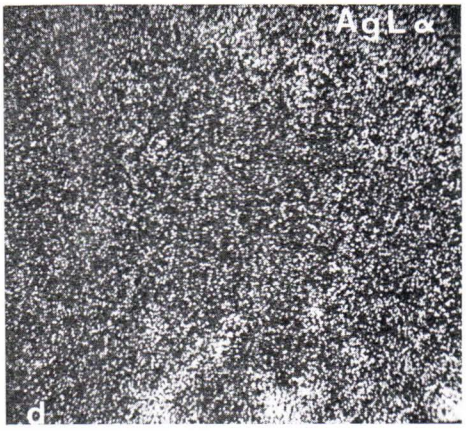

c


AgLα
d

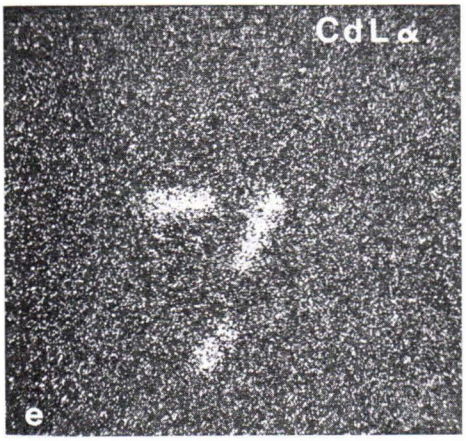
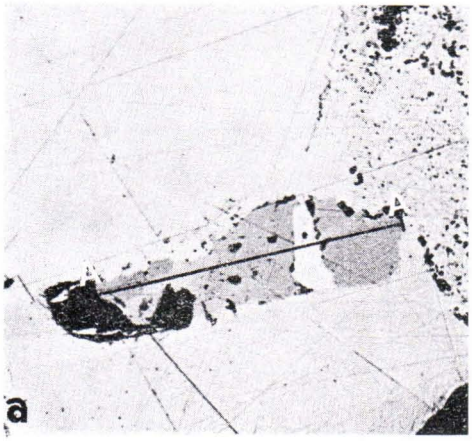

CdLα
e

PLATE III

FIG. a. Ag-Sb-sulphosalts (dark grey) and Pb-Bi-Sb-sulphosalt (light grey) within galena of the galena-quartz vein. FIG. b. A profile of concentration curves of Ag and Sb along the black line A—A'. FIG. c—f. Scanning images showing the distribution of Sb, Ag, Pb and Bi. Magn. 200 x.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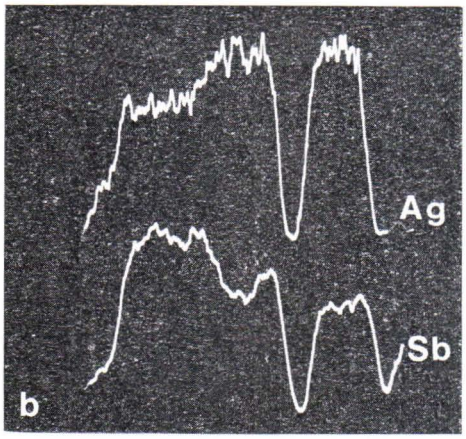
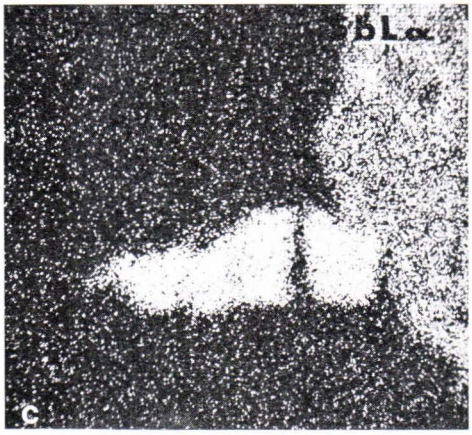
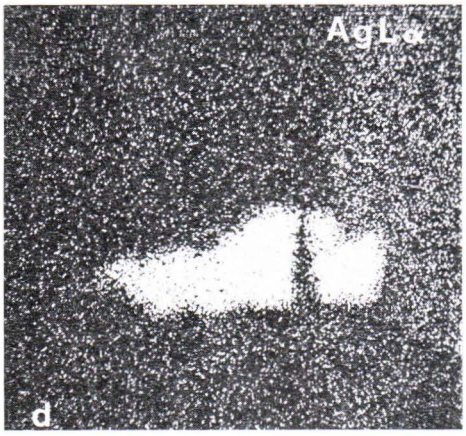
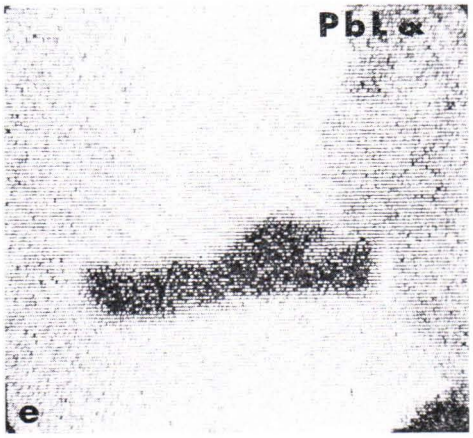
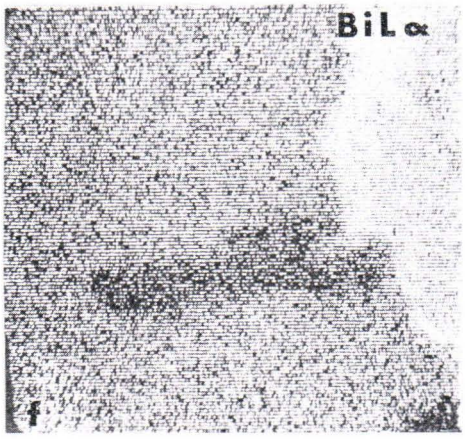

Ag
Sb
b


SbLα
c


AgLα
d


PbLα
e


BiLα
f

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