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Cryptic silver mineralization in the magnetite-sulfide ore of Sågmurgruvan, Central Sweden

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Abstract

The ores of Sågmurgruvan consist of nearly massive magnetite with locally important concentrations of sulfides: pyrite, pyrrhotite, iron-rich sphalerite, galena, very minor chalcopyrite and accessorial cobaltite, linnaeite and Ag minerals. The Ag minerals are native Ag, acanthite, stephanite and pyrargyrite. However, the majority of the Ag is present as minute, nearly submicroscopic, inclusions of native Ag in porous pyrite. Younger granite, in contact with the massive magnetite-sulfide ores, locally contains small amounts of sulfides (pyrite, galena and nearly iron-free sphalerite) and rather large grains of native Ag. The magnetite-sulfide ores are interpreted as the metamorphic equivalent of siliceous exhalative-sedimentary ores. Occasional spherical pyrite grains are thought to form relicts of the primary sedimentary texture. The mineralization in the granite is thought to originate from local selective remobilization of the magnetite-sulfide ore, caused by the hydrothermal activity accompanying the granite intrusion. The deposition of native Ag in the porous pyrite is probably a low temperature event, during retrogressive metamorphism.

Introduction

Sågmurgruvan is located in the northeastern part of the Bergslagen ore province, approximately 10 km south of the town of Sandviken. It is an abandoned iron mine, exploited from 1892 to 1908. Some thousand tons of magnetite ore, containing abundant local sulfide concentrations, are left on the dumps.

The regional geology is poorly known because of a lack of outcrops, but could be summarized as in Fig. 1 with the intrusive Hedesunda granite in the southeast, Proterozoic gneisses with intercalations of acid and basic metavolcanic rocks in the central part, and a Subjotnian sandstone near Lake Storsjön to the north.

Reconnaissance drilling intersected magnetite ores several tens of metres thick, some parts of which were rich in sulfides. These sulphide ores contain up to 5.9 wt.% Zn, up to 15 wt.% Pb and locally very high Ag contents (200–800 g/tonne). The ores contain very little Cu (0.05–0.3 wt.%), but are relatively rich in Co (0.1 wt.%). The richest iron ores contain 50–60 wt.% Fe. Although pyrite and pyrrhotite are locally rather abundant, the major part of the iron is present as magnetite.

The host rocks consist of rather highly metamorphosed biotite- and garnet-bearing quartzites and minor amphibolites. The magnetite-rich ores in particular show very characteristic granoblastic

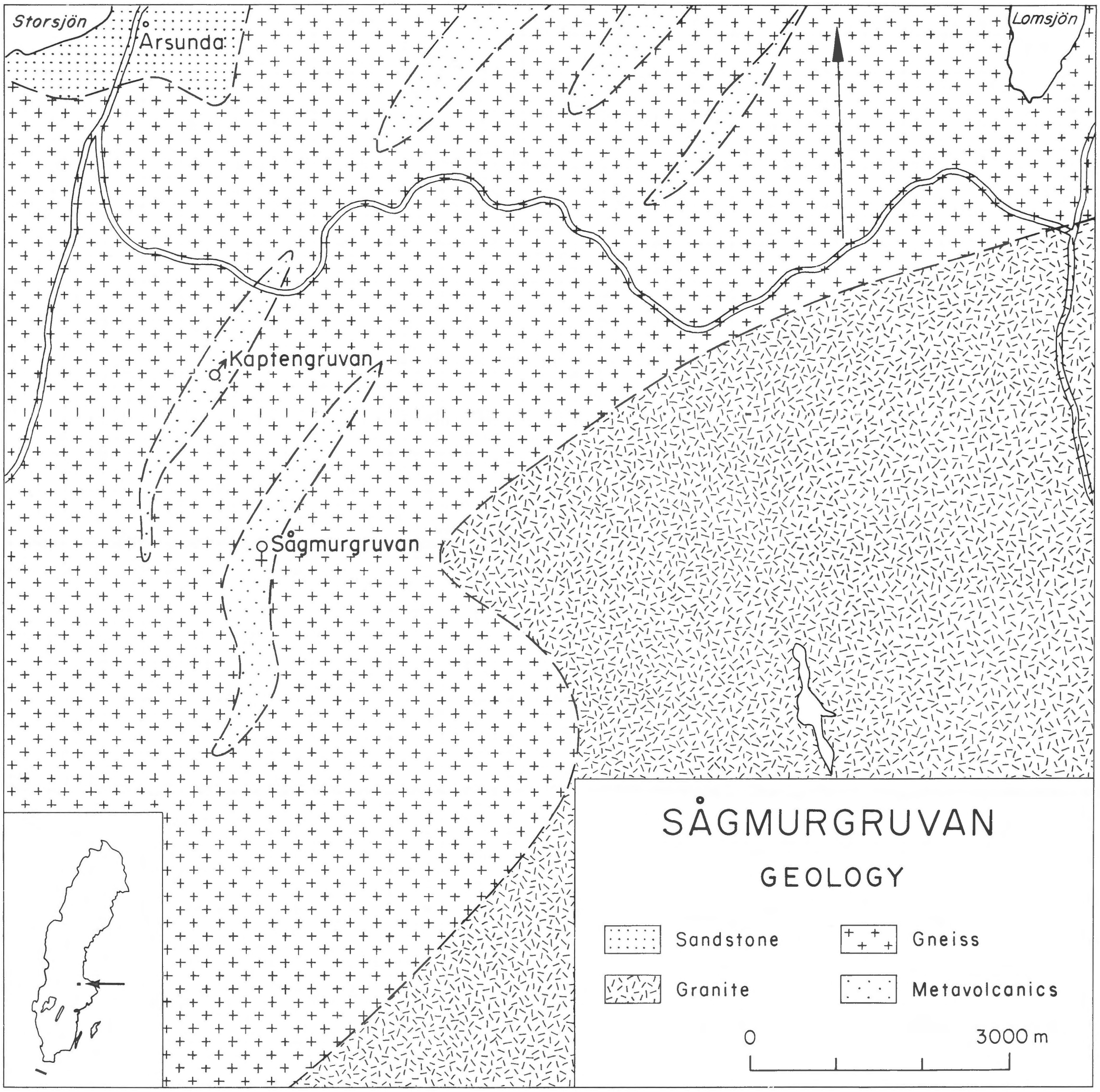


Fig. 1. Geological sketch map of the Sågmurgruvan area.

polygonal textures, with well-formed triple-point junctions. Locally the silicate minerals, especially biotite, penetrate the sulfides. In several places intercalations of reddish granitic rocks and pegmatites occur. In a drill-core section strongly chloritized granite is in contact with the magnetite-sulfide ore. This ore is particularly rich in Ag (812 g/tonne).

In the present study the results of microprobe analyses of 16 drill-core samples of ore are given.

Petrographic and mineralogical descriptions

Host rocks

The main components of the quartzitic rocks are quartz and biotite, locally chloritized, and minor garnet, muscovite, fluorite and hornblende. The garnet in the quartzitic rocks is a spessartine-almandine with the following compositions in mole percentages of end members: almandine 47–57, spessartine 30–37, pyrope 2–4 and grossular 8–20. Biotite, chlorite and hornblende are relatively rich in iron; biotite contains 1–4 wt.% F and hornblende approximately 1 wt.% F. The amphibolites consist of hornblende with minor quartz and biotite.

Granitic rocks

These consist of quartz, sodic plagioclase (albite), minor microline, biotite and accessorial epidote and fluorite. Microcline contains 0.3–1.0 wt.% BaO and approximately 0.1 0.2 wt.% PbO. The feldspars are more or less altered by sericitization and chloritization. The biotite also shows some chloritization. Near the contact with the ores the feldspars in the granite are nearly completely altered to fine grained aggregates of iron-rich chlorite.

Ores

Two types of ores can be distinguished: A – The common, locally massive, magnetite or magnetite-sulfide ores, and B – Sulfide disseminations in granitic rocks, only of very minor importance.

Type A ore

The main ore minerals are magnetite and varying proportions of pyrite, pyrrhotite, sphalerite and galena, with accessorial chalcopyrite, marcasite and gahnite. Pyrite and pyrrhotite are present in varying proportions, and one of these may be present only in very minor amounts. The Ag minerals mostly occur in trace amounts, as do molybdenite, mackinawite and the cobalt minerals linnaeite and cobaltite.

Magnetite may contain small amounts of MnO (<0.1 wt.%), TiO_2 (0.1 wt.%) and Al_2O_3 (0.25–0.3 wt.%). Locally it contains very small, more or less orientated inclusions of probable Mn-rich ilmenite and Zn-bearing spinel, both too small for quantitative analysis. They have been formed by exsolution or possibly by oxidation 'exsolution' (Ramdohr, 1975; Buddington & Lindsley, 1964).

Pyrrhotite with 60.6 ± 0.6 wt.% Fe and 39.25 ± 0.2 wt.% S contains small amounts of Co, on average 0.14 wt.% (0.1–0.2 wt.%). Pyrrhotite may be altered to an intergrowth of pyrite and magnetite, to marcasite, or may show 'bird's-eye' alteration texture.

Pyrite is often present in large aggregates. Different types can be distinguished: (a) clean, without inclusions, locally with euhedral outlines; (b) with numerous inclusions of other sulfides, mainly galena, minor pyrrhotite, chalcopyrite, or silicates and occasionally native Ag; these inclusions indicate locally a zonary texture of the pyrite; (c) porous and 'dirty' pyrite, commonly containing numerous very small inclusions of marcasite, and generally showing a poor polish. For the most part this type of pyrite represents late-stage replacement of pyrrhotite, as can be deduced from transitions to 'bird's-eye' alteration texture of pyrrhotite and other textural evidence. Another type of porous pyrite, occasionally with a typical spherical shape, is very locally present as inclusions in pyrrhotite and chalcopyrite. It may be a relict of the original sedimentary texture; (d) pyrite intergrown with small magnetite grains, forming symplectitic intergrowths, corresponding to altered pyrrhotite. Pyrites of types (a) and (b) (re)crystallised simultaneously with the other ore minerals.

Pyrite contains small amounts of Co, up to 0.4 wt.%, and As, up to 0.2 wt.%. Occasionally a Co-rich pyrite is present with a zoned distribution of Co (1.9 wt.% in the core and 7 wt.% at the borders).

Marcasite mostly occurs as minute inclusions in pyrite. In two samples, however, it forms rather coarse crystalline grains, frequently with inclusions of porous pyrite.

Sphalerite is mostly rich in iron, generally between 5 and 7 wt.%, while the Mn contents are usually <0.1 wt.% and the Cd contents generally vary between 0.4 and 0.5 wt.%. Lower Fe contents occur locally, especially in a transitional zone near the contacts of the magnetite-sulfide ore with the granite. Occasionally a slight discoloration of the brown sphalerite is visible on grain boundaries, caused by a slight Fe-depletion.

Galena contains small local inclusions of native Ag or Ag–Sb-sulfosalts. In some samples galena contains small amounts of Ag and Sb, both up to

0.06 wt.%. In a few samples some Bi is present in galena in amounts up to 0.1 wt.%, in addition to very low contents of Ag (≤0.05 wt.%).

Gahnite, zinc spinel containing 25 wt.% Zn, only occurs very locally as rather large grains, intergrown with magnetite and also containing very small exsolution bodies of magnetite. Gahnite is not found in mutual contact with sphalerite.

Type B ore

In the granitic rocks disseminations of clean, more or less euhedral pyrite (type a), galena, nearly colourless sphalerite and very minor chalcopyrite are locally present. Pyrrhotite and magnetite are typically absent. Sphalerite only contains 1.3–2.3 wt.% Fe, 0.35–0.5 wt.% Cd while Mn was not detected. Silver is present as rather large grains of native Ag.

Description of the Ag minerals

The high contents of Ag (up to 800 g/tonne) suggest an abundant presence of Ag minerals in the magnetite-sulfide ores, but at first sight they are apparently rather rare.

The most common Ag minerals are: *native Ag,* mostly present as small grains (5–10 μm), associated with galena or as inclusions in pyrite; *acanthite* occurs as small irregular grains; *pyrargyrite:* very rare small grains; *stephanite:* some larger grains, but only in one sample. Irregular inclusions of pyrargyrite in stephanite are common.

Furthermore only a small amount of Ag is present in solid solution in galena: ≤0.05 wt.% and chalcopyrite: 0.06 wt.% (n.d. – 0.18).

Table 1. Results of electron microprobe analyses of 'dirty', porous pyrite (wt.%). n.a. = not analysed.

S	41.8	43.9	33.8	44.0	39.9	41.8
Fe	39.4	38.0	31.7	44.1	35.3	37.4
Co	0.4	0.4	0.3	0.3	0.2	n.a.
Ag	12.1	17.4	26.8	10.0	18.4	12.2
Sb	0.1	>0.1	0.1	0.1	–	–
Pb	6.4	1.5	n.a.	n.a.	n.a.	n.a.
Sum	100.2	101.3	92.7	98.5	93.8	91.4

Note: Pb contents are due to small galena inclusions.

Analyses of 'dirty' porous pyrite, however, show locally high contents of Ag. By analyzing small rectangles (approximately 30 × 35 μm) Ag contents up to 20–30 wt.% were found. Some selected analyses are shown in Table 1. Such Ag-bearing pyrite mostly contains some Co and Sb.

It is obvious that the major part of the Ag is present as very fine to submicroscopic inclusions of native Ag in porous pyrite. This native Ag is usually not visible under the optical microscope, but in some cases, after repeated careful polishing, a multitude of minute inclusions could be observed. Occasionally this Ag-bearing pyrite can be recognized by purplish or bluish tarnishing colours.

The distribution of Ag in a porous spherical pyrite is shown in electronmicroprobe photos (Fig. 2), and the individual grains of native Ag in the same grain of pyrite are visible on a SEM photo (Fig. 3). Somewhat larger grains of native Ag are present in a zoned pyrite grain, of which the outer part is crowded with small inclusions of native Ag (Fig. 4).

The disseminated ores in the granite only contain rather large grains of native Ag, with 1.1 wt.% Sb.

Interpretation of results

The ores of Sågmurgruvan consist of magnetite with important local concentrations of Fe, Zn and Pb sulfides. The ores are located in quartzitic to gneissic rocks and are interpreted as the regional metamorphic equivalents of distal exhalative-sedimentary iron ores. Ag and Co are relatively important minor constituents.

The metamorphic conditions are characterized by the presence of biotite, garnet (spessartine-almandine), hornblende and moreover by a strong recrystallization, indicated by weld-developed granoblastic textures. The local presence of gahnite can be explained by alteration of Fe-bearing sphalerite during metamorphism. Local chloritization is due to retrogressive metamorphism.

Although no exact data on the spatial relations between granite and magnetite-sulfide ores with their host rocks are available,the granites are

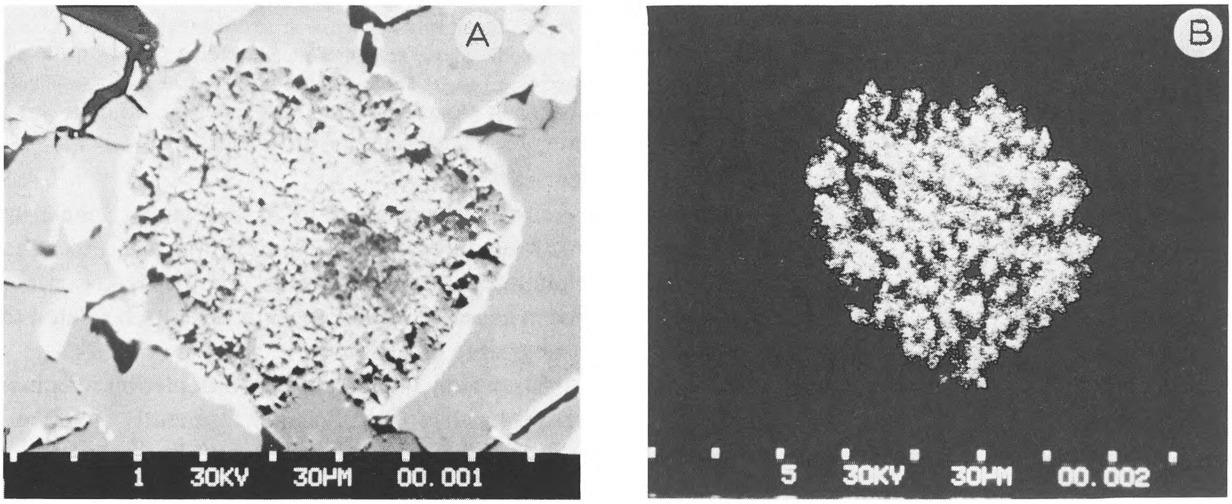


Fig. 2. Porous spherical pyrite grain surrounded by a thin rim of galena (white) in a matrix of pyrrhotite (grey) and galena. A: back-scattered electron image, B: Ag Lα X-ray emission image. The pyrite grain is free of Ag in the outer zone.

thought to be intrusive in the ores. In one drill-core section contacts between granite and magnitite ore have been observed. A sharp contact is obliterated by a thin zone of intensive chloritization. The granite itself locally shows a very strong chloritization; the feldspars at these places are completely altered into fine grained aggregates of chlorite. Chlorite is also present as veinlets in the granite. The ore minerals in the granite (type B ore) consist of pyrite, galena, Fe-poor sphalerite, minor chalcopyrite and native Ag. The main minerals of the type A ores (magnetite and pyrrhotite) are completely absent. The sulfides in the granite show a slight spatial relationship with the chloritisation and sericitisation of the granite and are considered to have been formed by local selective remobilization of the type A ores, due to the hydrothermal activity accompanying the granite intrusion.

The difference in the Fe contents of sphalerite of type A (5–7 wt.%) and type B(1.3–2.3 wt.%) ores is very striking. In type A ores the reddish brown sphalerite locally shows a slight discoloration along

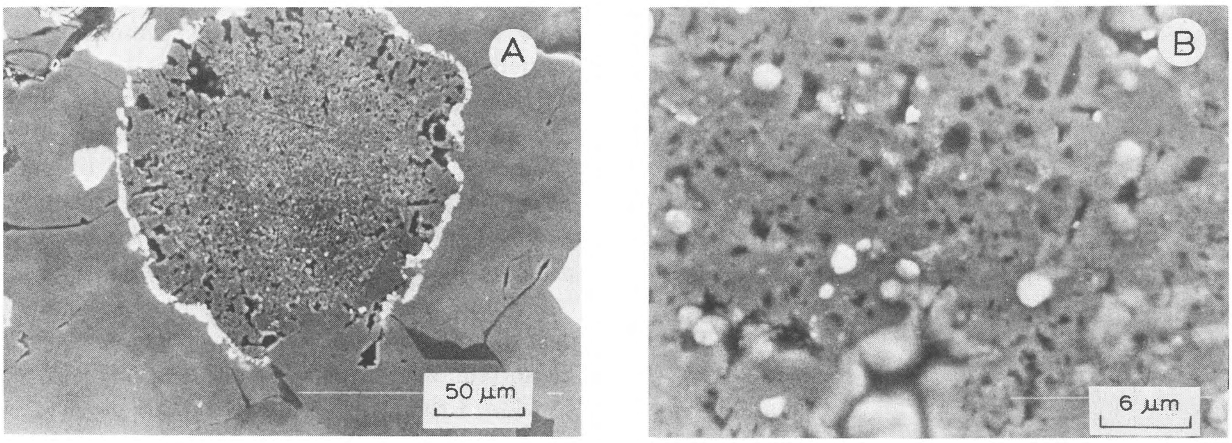
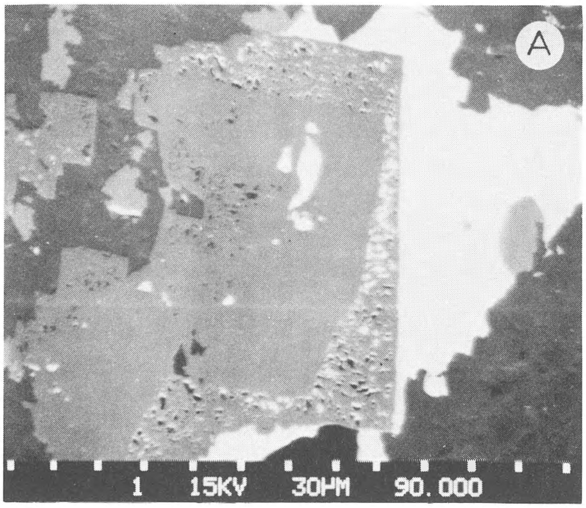
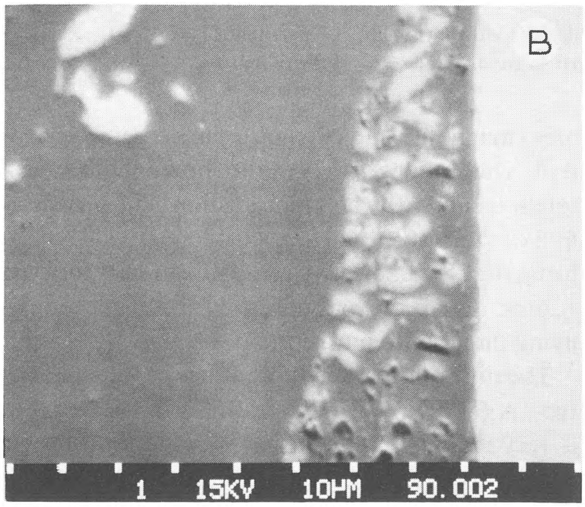


Fig. 3. SEM photos of the same pyrite grain as shown in Fig. 2. The individual grains of native Ag and the porous character of the pyrite are clearly visible at high magnifications (B).





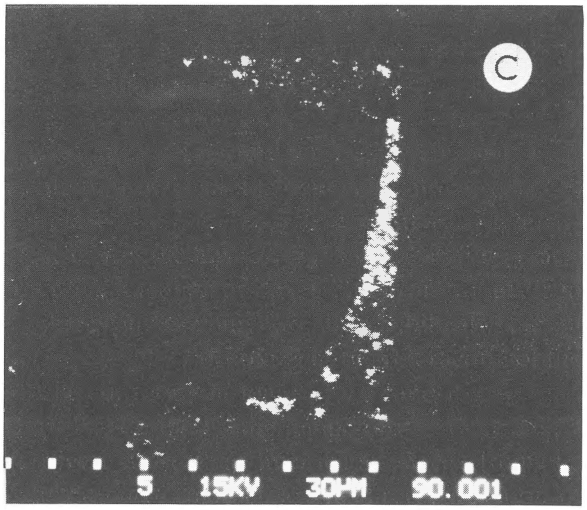


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Fig. 4. Zoned euhedral pyrite grain. A: back-scattered electron image, B: idem, at higher magnifications, C: Ag Lα X-ray emission image. The inner part of the pyrite grain (grey) contains only some inclusions of galena (white); the outer part is crowded with small inclusions of native Ag (white).

grain boundaries due to Fe-depletion. Sphalerite with an intermediate composition has also been found locally in tye A ores. The Fe-depletion has been caused by hydrothermal alteration related to the granite intrusion.

Elsewhere in Bergslagen Fe-depletion in sphalerites has been found rather frequently by the authors. At Vindfall, a small sulfide deposit some 12 km SW of Sågmurgruvan, intensive and large scale Fe-depletion occurs in retrograde skarns in the neighbourhood of a granite (Kieft & Eriksson, 1985).

A minor part of the Ag mineralisation in type A ores consists of Ag sulfosalts: stephanite, minor pyrargyrite and rather small grains of native Ag in pyrite of type (a) and (b). They formed simultaneously with the (re)crystallisation of these types of pyrite and the other sulfides during the peak of metamorphism. The major part of the Ag in type A ores consists of minute inclusions of native Ag in 'dirty' porous pyrite. The porous pyrite is, for the most part, replaced pyrrhotite. Occasionally porous pyrite, with a spherical form, is present as inclusions in pyrrhotite and chalcopyrite. In a few places this spherical texture is accentuated by a thin rim of galena (Figs 2A and 3A). These spherical grains might be interpreted as relict primary pyrite, formed in the exhalative-sedimentary deposit, which escaped recrystallisation. These spherical, and also colloform textures have been described by Rickard & Zweifel (1975) in metamorphic ores of a comparable origin from norhern Sweden.

The finely dispersed native Ag shows a highly irregular distribution but may be present in both types of porous pyrite.

In their study of the Harmsarvet Ag deposit near Falun (central Sweden) Eriksson & Kieft (1980) concluded that Ag is a highly mobile element at rather low temperatures. They found that secondary 'dirty' pyrite-marcasite aggregates, pseudomorphous after pyrrhotite, contained high amounts of Ag. The Ag was finely dispersed and individual Ag minerals were not visible under the microscope. X-ray emission images indicated that the Ag distribution followed the 'bird's-eye' alteration texture of the original pyrrhotite.

The finely distributed Ag in the porous pyrite at Sågmurgruvan is obviously a late-stage phenomenon, possibly also related to the hydrothermal activity accompanying the granite intrusion. If our interpretation of the nature of the spherical porous pyrite is correct, the deposition of Ag is not only related to the alteration of pyrrhotite, but is also favoured by the porous character of the pyrite.

Rather large grains of native Ag in the granite indicate that under the conditions of remobilization native Ag was the most stable phase of Ag mineralization.

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