

SVERIGES GEOLOGISKA UNDERSÖKNING

SER. C.

Avhandlingar och uppsatser.

N:o 470.

ÅRSBOK 39 (1945) N:o 3.

A NICKEL-COBALT-SILVER-
MINERALIZATION IN THE LAVER
COPPER MINE, N. SWEDEN

BY

OLOF H. ÖDMAN

Pris 0,50 kr.

STOCKHOLM 1945

KUNGL. BOKTRYCKERIET. P. A. NORSTEDT & SÖNER

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Descriptive Part.

When a cross-cut was driven for prospecting purposes to the south on the 130 m level in the Laver Mine there was struck a fault-zone which carried a number of interesting minerals, among them an unusually large amount of native silver. Thin plates of the metal covered surfaces on the fault-planes to a size of some cm² and shining growths of moss silver appeared in narrow calcite seams. Among other ore minerals observed were safflorite, argentite, polybasite(?), and pyrrargyrite, and among gangue minerals calcite, apophyllite, and zeolites. This paragenesis shows the occurrence to belong to the nickel-cobalt-silver-bearing veins so well known from a great many mining camps all over the world.

The silver-bearing fault strikes about E—W and dips vertically. It cuts chloritized liparite and a greenstone dyke (for a description of these rocks compare Ödman 1943 and Du Rietz 1945) in a part of the mine which is about 100 m distant from the area of the main ore bodies.

The fault-zone is not very conspicuous, being only 5—15 cm wide, and it would have been passed without notice but for the shiny silver plates attracting the attention of the miners. The fault is not a clean break but rather a breccia which occasionally contains broken pieces of the surrounding chloritized rock, either healed by the various gangue minerals or contained in a soft chloritic gouge. Minor and often discontinuous slips penetrate the fault-zone. Along some parts of the fault-zone one observes short and narrow veinlets filled with gangue minerals such as calcite, apophyllite, zeolites, and quartz. Some of these veinlets are vuggy.

Turning now to the paragenesis the account will be opened with a description of the *native silver*. In its most conspicuous form the silver occurs as plates, sometimes attaining a thickness of 1—2 mm, on slips in the main fault-zone. They may also be contained in the chloritic gouge. The colour of the silver in this instance is generally pinkish or yellowish, more seldom »silver white». The surface is rugged or somewhat slicken-sided because of sliding and polishing in the fault. In order to test the purity of the metal a chemical analysis was carried out at the Laboratories of the Boliden Co. by Miss Th. Berggren:

Table 1.

Ag	94.27
Cu	<0.01
Hg	0.05
S	0.10
	<hr style="width: 50%; margin-left: auto; margin-right: 0;"/>
	94.43
Gangue minerals, mainly calcite	5.57

According to a spectrographic test by Funke the content of gold does not exceed 0.01 %.

Silver is also found in intergrowths with calcite or apophyllite and it then appears in a filiform or dendritic shape which may be described as moss silver. The colour is normal »silver white». The texture of the intergrowth is either simple as in Fig. 1 or more complex as in Fig. 2. In Fig. 1 one can trace an octahedral development of the individual grains building up the dendrites.

Silver is further noticed as inclusions in argentite and pyrargyrite. In one case a wire of pinkish silver, a couple of mm long, was observed in a vug lined with apophyllite crystals. It is identical in shape with the wire silver from the Kongsberg Mines, Norway (Neumann 1944).

Argentite has been observed filling vugs in apophyllite or zeolite (Fig. 3). It is here associated with silver which in part lines the walls of the vug and in part occurs as irregular grains in the argentite. The texture here implies a replacement of argentite by silver. Argentite has further been noticed in small, separate grains in many of the silver-bearing polished sections. Some small slips within the fault-zone are covered with a smeared-out, shining black and metallic substance which is believed to be argentite.

Pyrargyrite may occasionally be recognized in hand specimens, attracting notice — in spite of the small size of the grains (which seldom attain 2 mm in length) — because of its red colour. A spectrographic test kindly undertaken by Dr. Gabrielsson showed the ratio $Sb : As = 95 : 5$. Under the microscope pyrargyrite has sometimes been seen in association with argentite and native silver. The latter is probably replacing pyrargyrite.

The occurrence of *Co-Ni-arsenide* is of particular interest. It is found as crusts around dendritic or tooth-shaped formations of native silver in calcite or, more rarely, as individual crystals, aggregates of crystals, or star-shaped twins in the gangue. A chemical analysis (Table 2) of the dendrites (the arsenide could not be separated from the silver) shows a predominance of Co over Ni ($Co : Ni = 2 : 1$), and the mineral may thus be regarded as safflorite, although with an appreciable content of Fe and Ni.

Table 2.

	Ag + arsenide	Arsenide	Arsenide, recalculated	Arsenide Mol. prop.
Ag	68.9	—	—	—
Co	2.8	2.8	10.3	175
Ni	1.3	1.3	4.8	82
Fe	2.8	2.6	9.5	170
Cu	0.2	—	—	—
Bi	0.01	—	—	—
As	17.3	17.3	63.6	876
Sb	3.2	3.2	11.8	97
S	0.33	—	—	—
	96.84 %	27.2 %	100.0 %	
Gangue minerals	3.16.			

In the calculation of the approximate composition of the arsenide, silver and chalcopyrite were first deducted from the analysis. The position of the antimony is somewhat dubious: no Sb-mineral has been observed and the element may enter in the arsenide or, possibly, in the form of dyscrasite as solid solution in silver. The former alternative has been considered the most likely one in this case and Sb is allotted to the safflorite. From the figures of the recalculated arsenide composition the ratio $(\text{Co} + \text{Ni} + \text{Fe}) : (\text{As} + \text{Sb}) = 1 : 2.27$ is then obtained, giving a fairly good agreement with the composition of safflorite.

Under the microscope the safflorite has a considerably lower power of reflexion than the silver and a somewhat grayish white colour. Pleochroism is hardly perceptible and the anisotropism is of medium strength. The outer borders of the safflorite crusts are quite irregular and show isometric individuals of safflorite protruding into the calcite (Figs. 4 and 5). Occasionally also separate crystals of it are seen enclosed in the calcite at some distance from the crust. The interior borders of the crust, facing the silver, are on the whole smooth, although spear-shaped grains of safflorite may protrude into the silver and replace it. The outlines of the silver kernels sometimes give the impression that the silver formed isometric crystals grown into a kind of crystal skeleton, the later replacement by the arsenide, however, having partly destroyed the idiomorphism. The experience from other occurrences shows that in these associations an idiomorphic growth of the silver is quite common, e.g. at the deposits at Cobalt, Ontario (Keil 1933, Figs. 6 and 8—10), and in the Erzgebirge, Germany. The dendrites of silver-safflorite ramify and when freed from the enclosing calcite they have the appearance of root-fibres. In another intergrowth between silver and safflorite the former appeared in rounded, almost circular grains interlocking and overlapping so as to resemble clods of roe (Fig. 6). The silver is surrounded by crusts of safflorite which on their surfaces show a good crystal development. Occasionally native silver also fills the interstices between the intergrowths or the teeth of the safflorite, thus indicating a later phase of silver deposition than the one inside the safflorite crusts. In still another case the dendrites are sometimes tubercle-shaped in cross-section, their interior being filled with silver, polybasite(?), chalcopyrite, and (or) calcite. The tubercles are surrounded by bushy halos of needle-shaped safflorite crystals.

The structure and behaviour of the silver-safflorite intergrowths now described are typical of the Ni-Co-Ag-type of ore deposits as represented by the occurrences at Batopilas and Sabinal, Mexico, Cobalt, Ontario, Kongsberg, Norway, Sarrabus, Sardinia, the Erzgebirge, Germany, and others.

Tetrahedrite was observed in one section only and is one of the rarer components in the paragenesis. In the cases mentioned it replaced calcite gangue, assuming tubercle-shaped forms as shown in Fig. 7. Pyrrargyrite replaced the tetrahedrite.

Polybasite(?). A mineral thought to be polybasite was noticed in two sections. The qualities of the mineral as seen under the microscope agree fairly well with those given by Schneiderhöhn-Ramdohr (1931). The shade of colour is different from that of pyrrargyrite and the internal reflections are not so strong.

Chalcopyrite is noticed on many occasions as small grains without any direct relationship to the silver paragenesis. Only seldom is it seen in association with the silver minerals. In one case chalcopyrite in a calcite veinlet was replaced

by the calcite and by native silver and a mineral that is either pyrargyrite or polybasite. In another case a small grain of chalcopyrite contained a couple of insignificant veinlets of covellite.

Finally there can be mentioned the rare occurrence of *pyrite* and *sphalerite*.

The most important gangue mineral is *calcite*. Most of the veins are filled with it and it often forms the matrix of the silver dendrites and of other ore minerals as well. Calcite may also fill druses of apophyllite.

Quartz is also noticed in separate veinlets in the fault-zone, but it does not seem to be mineralized in the same degree as the aforementioned mineral and it may even be questioned if it really belongs to the silver paragenesis.

Next to calcite in importance comes *apophyllite* which shows various modes of appearance. Generally it occurs in repeated, subparallel veinlets intercalated with thin remnants of the wall-rock or veinlets of calcite. Sometimes the apophyllite veinlets are symmetrical with prismatic individuals of the mineral growing out at right angles from the walls, but most often the filling is quite irregular. Narrow veinlets of apophyllite have been seen to traverse the vein-zone and cut calcite veinlets and intercalated sections of the wall-rock (Fig. 8). Fig. 9, on the other hand, demonstrates a case in which narrow seams of apophyllite frame a veinlet of sulphide-bearing calcite. Now and again the apophyllite veinlets contain vugs, their walls clad with small but well developed crystals of apophyllite. In one of these vugs the tiny silver wire mentioned above was found. Some vugs are filled with calcite as shown in Fig. 8. The apophyllite crystals in the vugs have an icy gray colour. Apophyllite sometimes replaces calcite and in one such instance it was seen how dendrites of silver together with some other metallic minerals were deposited in the newly formed apophyllite. In order to check the microscopic determination of the apophyllite Dr E. Ygberg kindly determined its mean index of refraction and obtained the figure 1.536 (Na-light), which well agrees with the established index for this mineral.

In a few thin sections two colour-less minerals with very low refringence have been observed. One of them occurs as small prismatic or quadrangular grains, with two distinct cleavages, arranged in rows in the apophyllite veinlets. The refringence is lower than that of apophyllite and the birefringence is weak. It is alternatively uniaxial and biaxial with a changing optic sign. The other mineral occurs in the chloritized wall-rock as disseminated grains or as small druses, sometimes filled with calcite. The birefringence is very low and the optic angle and the character vary. In both cases it is evident that the minerals belong to the *zeolite* group. No further endeavour was made to identify the minerals.

The vein-forming process was probably quite extended in time, and various surges of solution ascended the fault-zone. Overlapping occurred in the deposition of some minerals and no uniform crystallization sequence can be established. Only the main features can be given.

The crystallization probably began with the deposition of calcite in the

veinlets. Among the ore minerals, tetrahedrite, chalcopyrite, sphalerite, and pyrite may suitably be made to form one group of minerals, probably crystallizing fairly early. At least chalcopyrite is, however, replaced by calcite, and the deposition of this mineral shows overlapping and very likely embraced a long period.

The formation of the silver-safflorite intergrowths then followed. The microscopic study of the intergrowths decidedly indicates that silver was the first mineral deposited and that safflorite is later. This question has been discussed in the literature dealing with deposits of this type and some students have advocated the opinion that silver is later and that it replaced the arsenide from the interior. In a few recent papers the discussion has been reopened and much evidence in favour of silver being an early precipitant has been produced (Keil 1933, Bastin 1939, and Neumann 1944). At Laver, however, some silver was deposited also after the formation of the arsenide (p. 5).

The other silver minerals are difficult to place in the sequence. They are more or less replaced by native silver and thus come in somewhere close to this mineral in the deposition.

Contemporary with the silver, at least in some cases, is apophyllite, as it replaces calcite together with silver. On the other hand apophyllite is also a late mineral, as veinlets of it are found to cut the vein-zone. The zeolites are contemporaneous with the apophyllite and the mineralization probably ended with the crystallization of these minerals.

Discussion.

A question of primary importance is whether the silver and possibly some of the other silver minerals can be interpreted as being of supergene origin. This question may be answered in the negative and that for several reasons. First of all may be emphasized the depth at which the silver minerals occur and the practically general absence of secondary, supergene minerals in the Laver deposit as a whole (Ödman 1943). Among other circumstances supporting the conception of the hypogene deposition of the silver minerals may be mentioned their appearance in apophyllite,¹ the association of silver with arsenide, which surrounds the former in the dendrites, and its intimate association with chalcopyrite and tetrahedrite. The presence of covellite in a couple of insignificant grains would, however, point to some supergene enrichment having taken place, but considering the weight of evidence speaking against a supergene origin, these small grains of covellite do not amount to much. A supergene origin might be expected in the case of the thin coatings of native silver on some of the minor slips in the fault-zone. A spectrographic test on a silver sheet of the kind mentioned, kindly undertaken by Dr S. Landergren at the request of the author, showed, however, only a slight increase in the contents of copper and antimony as compared with primary moss silver from a calcite veinlet, and

¹ Also the occurrence of silver minerals in calcite may be advanced as the latter certainly is primary, sometimes being replaced by apophyllite.

there is accordingly hardly any reason for considering the former kind of silver to be supergene.

If we may now look upon the hypogene origin of the paragenesis as settled, the next questions are what was the source and origin of the ore-bearing solutions and what was their character. As regards the first question, it seems natural to turn to the Laver copper ore for the source of the silver-bearing solution and to consider it the final, low-hydrothermal surge of the ore-depositing medium in the mine. Very little actual support can be presented. The silver paragenesis appears on a fault-zone striking practically at right angles to the ore-bearing faults of the mine, which faults probably acted as ducts for the ore solutions (Ödman 1943, p. 31), and, what is more, the copper ore at Laver is altogether very poor in silver, and as to Ni and Co, they are only present in very insignificant quantities.¹ No other possible source of the ore solution can, however, be suggested.

As to the character of the ore-forming medium it would seem clear — considering the paragenesis — that it was a low-hydrothermal solution of the mesothermal type. It ascended the bed-rock along the fault-zone and crystallized here in available fissures and open spaces.

The cobalt-nickel-silver paragenesis now described belongs to a wide-spread type of ore deposits on which there already exists a voluminous literature. The occurrence at Laver, although without any economic significance, adds a new name to the long list of deposits belonging to this type. The paragenesis at Laver is poor as compared with many other deposits of the same general type. A study of the paragenetic table compiled by Bastin (1939) shows that besides a general similarity between Laver and the deposits in Ontario and those in the Erzgebirge in Germany there exists a particular resemblance to the occurrences at Sarrabus, Sardinia (Piepoli 1933), Bullard's Peak, New Mexico, and Batopilas, Mexico (Krieger 1935 b), Sabinal, Mexico (Krieger 1935 a), and Wickenburg, Arizona (Bastin 1923). At Laver the arsenide group is particularly poorly developed as compared with what is the case at other occurrences, and barite and bismuth, generally common constituents in these veins, are completely lacking. Apophyllite and zeolites are on the other hand present, minerals which on the whole seem to be poorly developed in this type of deposits.

It is of particular interest that shortly before the silver find was made at Laver, a similar but richer paragenesis was discovered in the Lindsköld copper mine at Kuorbevere, 90 km SW of Laver. An elaborate description of this association is being published by Dr S. Gavelin (1945) contemporaneously with the present paper (same series, No. 469), and in view of the close relationship with the silver mineralization at Laver a few quotations from Gavelin's paper will be given below.

Also from a general geological point of view there exist certain resemblances, as at Lindsköld the main ore minerals are chalcopyrite and pyrrhotite, including some arsenopyrite, and as the copper mineralization occurs in volcanic rocks

¹ Du Rietz (1945, p. 10 and 11) gives the following figures of the Ni- and Co-contents of the breccia ore: Ni — 0.011 and 0.02%, Co — < 0.002%.

in the form of impregnations, breccias, and solid masses. The volcanics have been altered to cordierite-antophyllite-schists. The As-Ag-Co-Ni-mineralization at Lindsköld is associated with calcite-bearing fissures, cutting ore and wall-rocks. Among the ore minerals observed by Gavelin we particularly note native arsenic, native silver, dyscrasite, freibergite, proustite, löllingite, smaltite, and safflorite. Besides calcite, also quartz, fluorite, and zeolites constitute the gangue minerals. Among the zeolites Gavelin has identified laumontite, stellerite, and chabasite. As regards the order of crystallization the reader is referred to the table on p. 13 in Gavelin's paper.

Gavelin arrives at the conclusion that the paragenesis is hypogene. He discusses the source of the mineralizing solutions and assumes, in agreement with the present author in the case of the Ag-mineralization at Laver, that there exists a genetic relationship between the veins and the copper ores.

Gavelin finally emphasizes the general interest and importance of the association of the As-Ag-Co-Ni-paragenesis with a sulphide mineralization of the general and wide-spread type represented by the deposits at Kuorbeväre. The discovery of the similar paragenesis at Laver, with relations to a sulphide ore of the above-mentioned type, lends still more prominence to this point. As far as the present author is aware, there is no other instance known in which an As-Ag-Co-Ni-mineralization is found in association with a high-temperature sulphide ore deposition.

Summary.

A recent find of Ni-Co-Ag-paragenesis in the Laver mine, appearing close to the chalcopyrite ore bodies, is described. The paragenesis occurs on a fault zone and consists of native silver, argentite, pyrargyrite, polybasite(?), safflorite, tetrahedrite, chalcopyrite, sphalerite, and pyrite in a gangue of calcite, quartz, apophyllite, and zeolites. The minerals form veinlets in the fault breccia or, in some cases, occur in the chloritic gouge. The paragenesis is undoubtedly of hypogene origin. Although no definite proof can be presented, it seems highly probable that the mineralization is closely related to the general copper-iron-sulphide mineralization in the mine and that the veins were formed by low-hydrothermal rest-solutions.

The paragenesis is compared with some recently discovered veins in the Lindsköld copper mine, situated 90 km SW of Laver, and containing in part similar minerals, as native silver, native arsenic, dyscrasite, proustite, Co-Ni-arsenides, calcite, quartz, zeolites, and others (S. Gavelin 1945). Both occurrences are closely connected to high-temperature copper-iron-sulphide mineralizations and probably constitute the low-temperature final phase of the latter.

The author finally wishes to express his gratitude to Mr E. Bengtson, Director of the Boliden Mining Co., for his kind permission to publish this paper.

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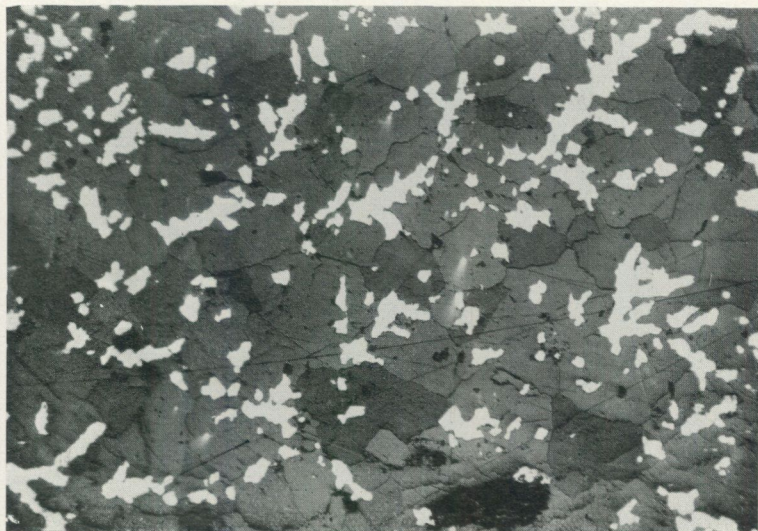


Fig. 1. Dendritic silver, showing traces of an octahedral development.
Polished section, ord. light, 30 \times .

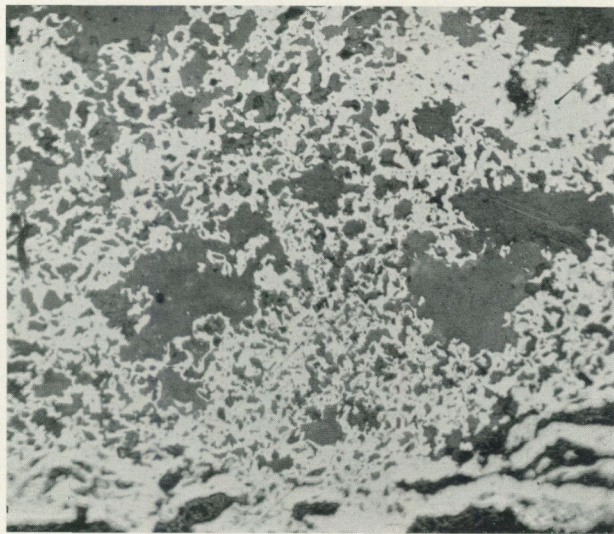


Fig. 2. Moss silver, sometimes showing tubercle-texture, in calcite. Polished section, ord. light, 100 \times .

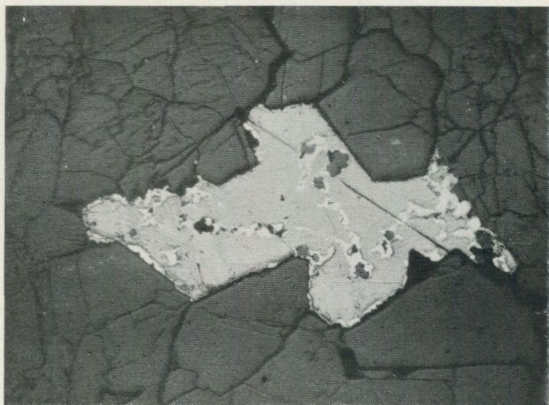


Fig. 3. Argentite, partly replaced by silver, filling vug in apophyllite. Polished section, ord. light, 45 \times .

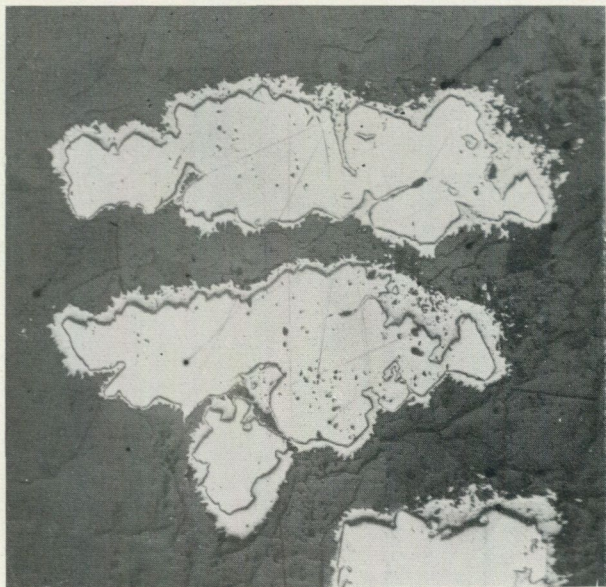


Fig. 4. Dendrites of silver (kernels, with traces of octahedral development) and rammelsbergite (crusts) in calcite. Polished section, ord. light, 45 \times .

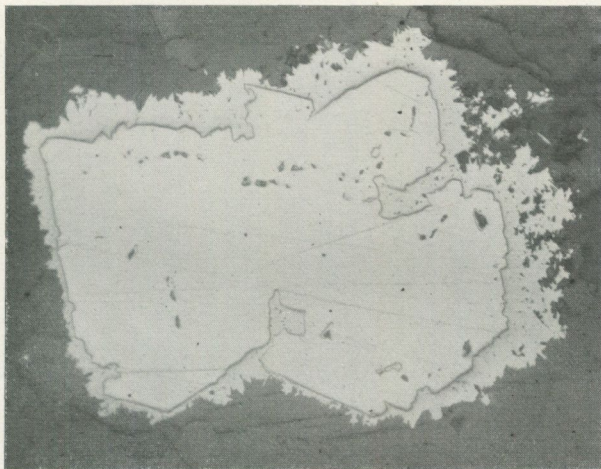


Fig. 5. Same as Fig. 4. Note replacement of silver by rammelsbergite and the star-shaped twins of the latter to the right. Polished section, ord. light, 100 \times .

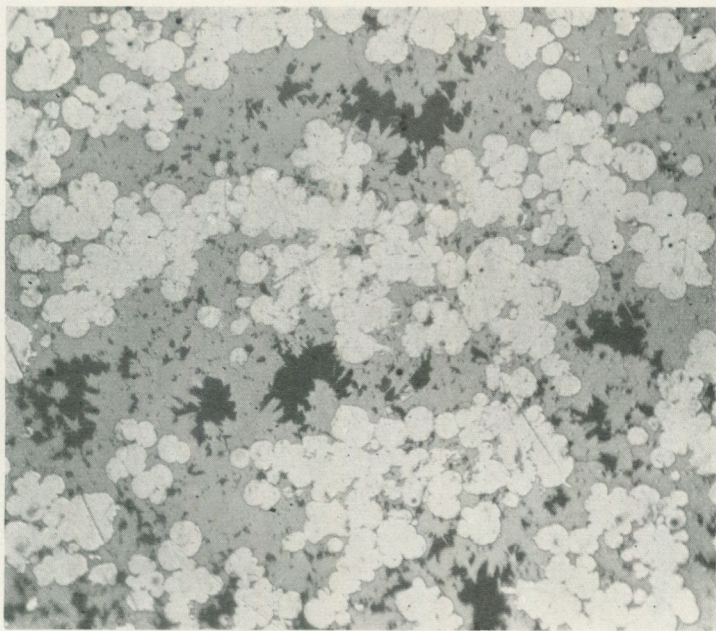


Fig. 6. Roe-shaped formations of native silver (light gray) surrounded by rammelsbergite (gray). Polished section, ord. light, 180 \times .

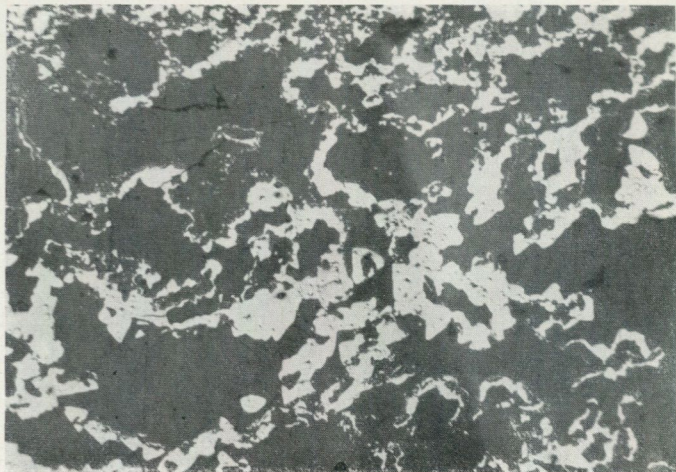


Fig. 7. Tetrahedrite in calcite. Polished section, ord. light, 60 \times .



Fig. 8. Veinlets of apophyllite (light gray), arrows point at a thin seam of zeolite, most of opaque matter to the right is silver. Thin section, ord. light, 8 \times .

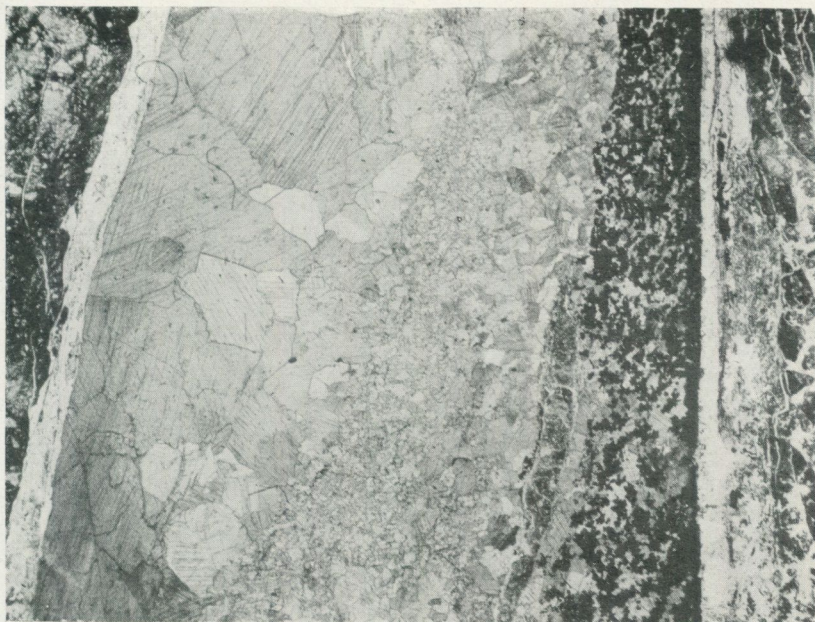


Fig. 9. Cross-section of calcite veinlet. Chloritized wallrock at the margins, wide central portion of calcite with silver dendrites (black) to the right, surrounded by narrow seams of apophyllite. Thin section, ord. light, 7 \times .

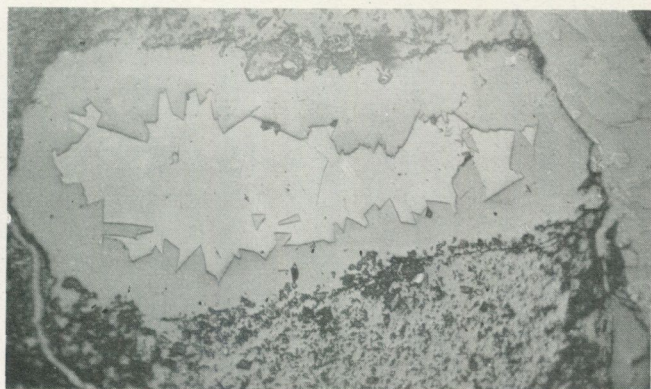


Fig. 10. Vug in apophyllite filled with calcite. Polished section, ord. light, 70 \times .

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