

# A copper-zinc mineralization in Trollaldalen, Lofoten, Northern Norway.

By  
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## Introduction.

During the spring 1963, the Norwegian Geological Survey, NGU, received specimens and a short report on some zinc-copper bearing veins in Lofoten, Northern Norway.

Because of this, the writer paid a short visit to the locality in the following autumn to get an impression of the deposit and to collect some more samples. The mineralized area is situated in the Vågan district on Austvågøy in Lofoten (see key map, fig. 1). It can easily be reached by car from Svolvær. From the fishing village, Kalle, there is only 1½ km' walk up to the Trolldalsvann (lake) 75 m a. s. l., around which the mineralization occur. From the lake the countryside arises steeply on three sides towards the surrounding mountain ridge (see fig. 3). At different altitudes on this slope copper-zinc bearing veins, ranging from a few cm up to 90 cm thick are found.

According to NGU's files the first claim was staked in 1905, but since then nothing has been done until recently.



Fig. 1. Key map.

*Nøkkelkart.*

### General geology.

In former days the Lofoten islands were considered to consist of some rather special rocks of plutonic origin, designated "Lofoten-eruptivene" or the "Plutonic Rocks of Lofoten". Different ages were proposed, from Precambrian up to Devonian as they were correlated with the Permian rocks of the Oslo region then considered Devonian. (Th. Vogt, 1909.)

After more thorough investigations in the recent years (Heier 1960) the "Plutonic Rocks of Lofoten" are partly estimated as high-grade metamorphics of granulite facies. Field and laboratory observations indicate that these metamorphic rocks consist both of the Precambrian basement

LEGEND:  
 FORKLARING:

	LOFOTSYENITE LOFOTSYENITT
	GNEISSIC GRANITE PRESSET GRANITT (Svolværgranite)
	MASSIVE GRANITE UPRESSET GRANITT

	GABBRO GABBRO
	PERIDOTITE PERIDOTITT
	COVERED LØSE AVLEIRINGER
	SULPHIDE MINERALIZATION SULFIDMINERALISERING

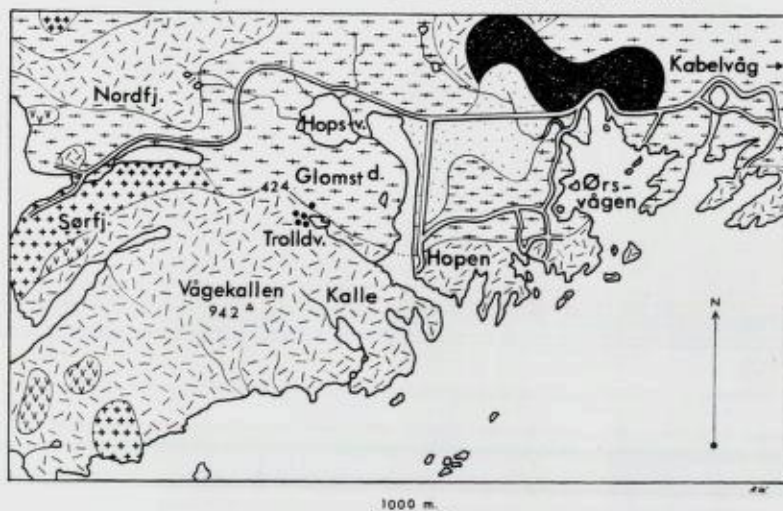


Fig. 2. Geological map after Th. Vogt showing the mineralized area.

*Geologisk kart etter Th. Vogt som viser det mineraliserte området.*

and various Caledonian rocks now intimately interfolded. True plutonics, however, are still considered to exist as syn- or post-orogenic intrusives. The comprehensive designation favoured today is the "Charnocitic Rocks of Lofoten".

From these rocks no sphalerite-chalcopyrite mineralization is earlier described, but a few others are according to N.G.U.'s files reported to occur in the area. On the other hand titaniferous iron ore deposits occur quite frequently, but are either too small or with magnetite-ilmenite too intermixed for any economical use so far. An insignificant deposit of molybdenum is known from Vatterfjord, northeast of Svolvær.

In NGU's files an unpublished field map, scale 1:100.000 by Th.

Vogt, covers the mineralized area here described (see fig. 2). As seen on the map a contact between a syenite (Lofot-syenitt) to the south, and a gneissic granite (Svolvær-granitt) to the north runs along the north-side of the Trolldalen (valley), and according to the writer's observations mineralization occur on both sides of the boundary. But as no explanation follows the map, the accuracy of the boundary is not known, descriptions of the particular rocks are also lacking. Different rocks, however, occur on the north and the south side of Trolldalsvann.

On the northern side of the lake a massive, strongly jointed medium grained granite, grey-brown in colour, was found. It mainly consists of equal amounts of quartz and feldspar with a few pseudomorphs of probable hypersthene, with biotite, opaques, garnet and chlorite as accessories. The quartz shows undulatory extinction and is partly fractured. The feldspar is an antiperthite ranging up to a mesoperthite in some grains. They are made up of albite and microcline. The microcline mostly occurs in irregular patches but also as more regularly orientated lenses. Normal perthite lamellae are rather frequent in the microcline. The pseudomorphs consist, in addition to the probable hypersthene, also of opaques and biotite. The biotite, the most frequent of the accessories, is strongly pleochroic from dark-red-brown to yellow-brown.

On the south side of the lake, adjacent to the copper-zinc bearing veins, a light grey, gneissic rock occurs. It strikes about south  $60^\circ$  east with a dip  $60^\circ$  to the southwest. The rock is finegrained, and its gneissic structure, which is easily seen in the field and specimens, is hardly distinguishable in the microscope. The dominant minerals are quartz and plagioclase  $An_5$  in about equal proportions. In contrast to the granite described above, the quartz here shows no or little undulation. Of dark minerals, both hornblende and pyroxene occur with the latter as the dominating one. They are usually associated with each other and with sphene. The hornblende is strongly pleochroic brownish-green to light green. The pyroxene has oblique extinction, a fairly strong green colour and weak pleochroism. Calcite appears in small amounts evenly distributed throughout the rock. Accessories are sphene, garnet and opaques.

### **The copper-zinc bearing veins.**

The vein, which has called attention to this mineralization occurs in the light gneiss on the south side of the lake, about 35 m up the steep slope. It is exposed over a distance of about 10 m, more or less following



the gneiss structure. It wedges out to the northwest and disappear underneath the rockfall on the other end.

Apophyses 30–40 cm long, 3–4 cm thick are seen to extend into the adjacent gneiss as well as a poor impregnation mainly of chalcopyrite, which appear as stringers a few mm long close to the vein. The other minerals detectable are pyrrhotite, mainly dominating, chalcopyrite and sphalerite in about equal proportions, and at last small amounts of arsenopyrite. Gangue minerals are quartz, pyroxene and a few grains of calcite (see fig. 4). The vein as a whole is very dark in colour due to a smoky appearance of the gangue quartz.

About a 100 m higher up along the mountains side a new vein, but of a rather different appearance is found. Due to bad weather it could not be visited during the writers short trip to the locality, but according to local people it can be followed for about a 100 m, lying almost flat with a maximum thickness of about 70 cm. From the many samples received from this vein, it appears as almost massive pyrrhotite with a few irregular patches of chalcopyrite. Sphalerite can hardly be distinguished



Fig. 3. Looking NW up Trolldalen. The mineralization occurs along mountain wall in the background.

*Bilde tatt mot NV opp Trolldalen.  
Mineraliseringen forekommer i fjellsiden i bakgrunnen.*

macroscopically. Gangue minerals are also here quartz and pyroxene, a few grains of antiperthite are also observed.

On the north side of Trolldalsvann a vein, only a few meters long, has an approximate vertical position determined by fractures in the host-rock. This mineralization which never exceeds 20 cm in thickness consists almost entirely of pyrrhotite with a little chalcopyrite and sphalerite. Also a few other similar mineralizations are reported to occur in the area.

### Paragenesis.

The minerals observed macroscopically are mentioned above. A few more, however, were identified in the microscope, and they are all listed below.

Main constituents of the ore	Minor constituents of the ore	
Pyrrhotite	Valleriite	
Chalcopyrite	Galena ?	
Cubanite	Marcasite	} Alteration of pyrrhotite.
Sphalerite	Pyrite	
Arsenopyrite	Limonite	

Arsenopyrite, and probably galena, which only occur as inclusions in the former, are only observed in the lower vein. Cubanite with one exception is also only connected to this, while valleriite occurs on both the upper and the lower mineralization south of the lake. The fracture-filling north of the lake contains no minerals other than those seen macroscopically, except for ubiquitous alteration products.

### Pyrrhotite.

As mentioned, this is the most frequent sulphide mineral in the Troll-dalen deposit. Especially in the upper, flatlying massive vein and in the thin vein north of the lake it is by far the dominant ore mineral. Two distinct mode of occurrence are clearly seen in the polished sections.

1. In the massive variety no grain boundaries are distinguished and optical continuity seems to occur throughout the whole section, with exceptions of grains totally enclosed in silicate. A slight undulatory effect, however, and a few cases of probable twinning appear. The latter

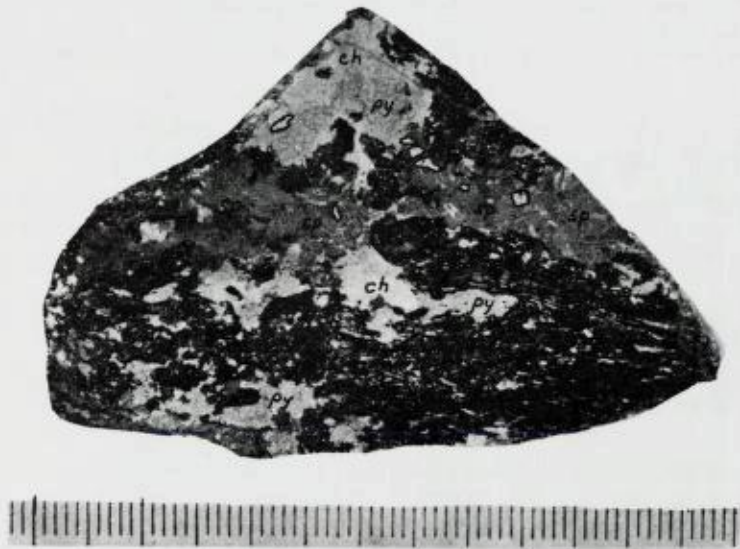


Fig. 4. Hand specimen of the ore showing the distribution of the different minerals (sp) sphalerite, (ch) chalcopyrite, (py) pyrrhotite, encircled arsenopyrite, black gangue minerals.

*Håndstykke som viser fordelingen av de forskjellige mineraler, (sp) sinkblende, (ch) kobberkis, (py) magnetkis, innsirklet arsenkis, sort gangmineraler.*

phenomena occurs as straight cut wedges with different extinction from the surrounding mass, or as straight lines fading out in both ends. The most prominent feature, however, is the appearance of closely spaced internal lamellae forming sinuous lenses always parallel or subparallel (see fig. 5). Their maximum size is about 0.01–0.015 mm thick and 0.3–0.4 mm long. They are rather difficult to distinguish without crossed nichols but by rotating the stage they will in one position stand out due to darker colour than the matrix.

Ramdohr (1955) states that pyrrhotite usually shows this structure. The lamellae generally develops parallel (0001) but may also have uneven distribution. In Trolldalen lamellae only in the (0001) direction are developed as they always run parallel with the cleavage. Both Ramdohr and Uyténbogaardt (1951) mention that lamellae with a lighter appearance than the matrix are the most common, but while Uyténbogaardt has found that the matrix is usually the harder, Ramdohr mention this quality for the lamellae. However, Ramdohr also mention localities, among them Råna and Sulitjelma where the opposite is the case, both as far as the



colour and hardness are concerned. Vokes (1957) also in his investigation of the Birtavarre ore has found the lamellae to be darker than the matrix. Concerning the colour this is also the case in Trollaldalen, but the Becke line test points towards an equal hardness. The anisotropism is seen to be stronger in the lamellae than in the matrix, but the two components show simultaneous extinction, which according to Uytendogaardt always is the case.

The general explanation for these textures are exsolution. Looking at (fig. 5), we see that the lamellae are slightly bent where they cross the twin planes. A similar feature is illustrated by Vokes from Birtavarre and has been attributed to "stress acting on the ore after the solidification and exsolution of the pyrrhotite", as twinning in pyrrhotite is regarded as a result of stress (Ramdohr 1955). Mikkola (1963) from his studies of the Vihanti deposit, Finland, suggest that the lamellae texture is associated with deformation after crystallization.

2. The pyrrhotite from the two other localities has a totally different appearance. The mineral occur in close relationship with other sulphides and more intermixed with the silicates as seen on (fig. 4). This pyrrhotite appears as anhedral grains, mainly ranging from 0.4–2 mm across.

The lamellae texture is here observed in only one section from the zinc-copper ore, and even in this, only in a part of the section. The lamellae seem to be absent in the pyrrhotite replacing the chalcopyrite. As far as colour and anisotropism are concerned no obvious difference are distinguished between the two varieties.

A fact, which can be mentioned about the pyrrhotite from Trollaldalen is the differences in magnetic properties. The various specimens have been tested with an ordinary field compass, and except one specimen, all those from the massive flatlying pyrrhotite vein, had no effect on the compass needle. All the other specimens proved to be magnetic. This is probably due to variation in the Fe/S ratio, as earlier investigations have pointed towards increasing magnetic properties with increasing sulphide content (Grønvold and Haraldsen 1952), (Vokes 1957).

### **Chalcopyrite.**

The chalcopyrite occurs as insignificant grains and aggregates adjacent to the silicates in the massive pyrrhotite, and in the fracturefilling on the north side of the valley. In the massive pyrrhotite it is also seen locally to form irregular grains along cracks or form needles parallel to the internal



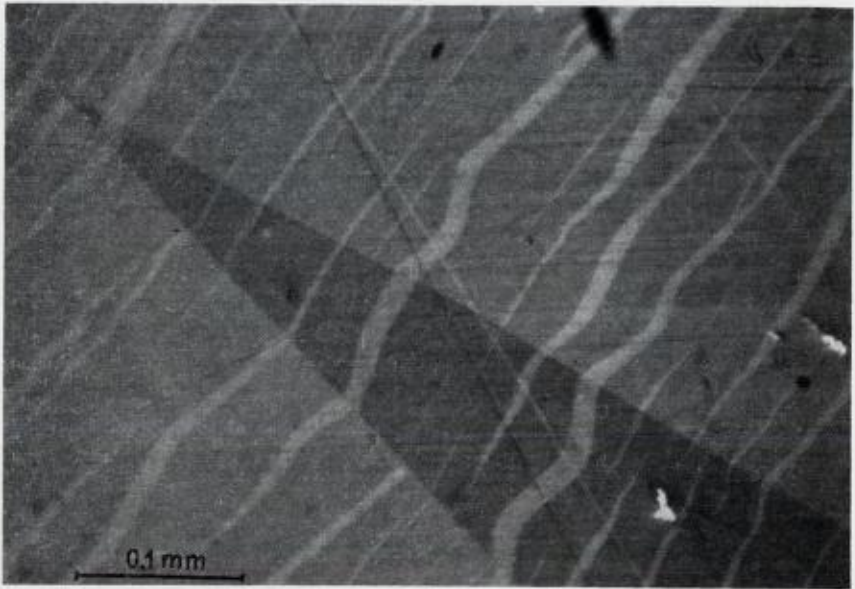


Fig. 5. Lamellae and twinning in pyrrhotite. + N.

*Lameller og tvillingdannelse i magnetkis. + N.*

lamellae. This latter case is most probably a result of exsolution. At the third locality it is much more prominent and occurs in aggregates up to a few cm wide, although mainly smaller, and nearly always associated with pyrrhotite (see fig. 4). When investigated in polished sections it turns out that what here was regarded as pure chalcopyrite contain at an estimated average as much as 30–40 % cubanite.

The chalcopyrite grains are anhedral, pleochroism is not observed and the anisotropism is rather weak. Between crossed nichols an irregular lamellar-twinning occurs in most of the grains. Its relation to pyrrhotite varies, but in most cases it is found to be corroded along the contacts to the pyrrhotite. This corrosion gives the chalcopyrite an irregular, ragged outline with the original grainboundary often still visible (see fig. 7). This is quite different from where replacement has occurred, which is apparent in some places (see fig. 8). The pyrrhotite here embays the chalcopyrite and envelopes fragments which together still show the outline of the original grains. But here the contact pyrrhotite – chalcopyrite itself generally is smooth.

The chalcopyrite is, as mentioned, almost always associated with

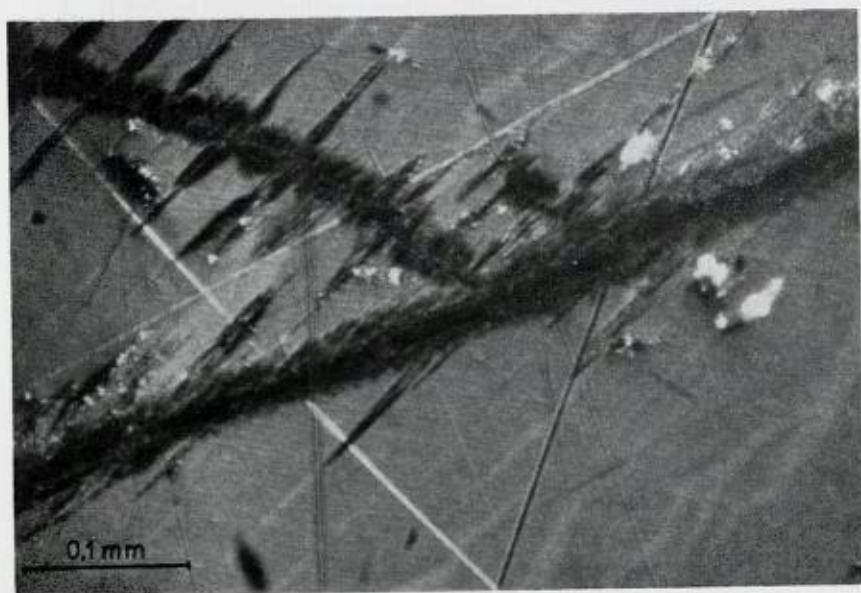


Fig. 6. Marcasite (black) along cracks in pyrrhotite (grey). + N.

*Markasitt (sort) langs sprekker i magnetkis (grå). + N.*

pyrrhotite in the sulphide aggregate, as well as in thin veins intersecting the silicates. In spite of the frequent corrosion they, probably in most cases develop "mutual boundaries". It is therefore assumed that these minerals are contemporaneous and that the corrosion and more local replacement are due to later processes in the ore.

On the north side of the valley a typical example of "mottled texture" occurs as rodshaped and rounded inclusions of chalcopyrite occur in sphalerite. The average size of these is about 0.005 mm. They are often orientated as chains along crystallographic directions, but random distribution also appears.

### Cubanite.

This mineral has most probably crystallized in two generations. First as lamellae in chalcopyrite, probably a product of exsolution, later granular aggregates have been formed chiefly by replacement of chalcopyrite. The mineral appears with a very few exceptions always in the chalcopyrite field.

The lamellae appear one or two together or in bunches of parallel lenses

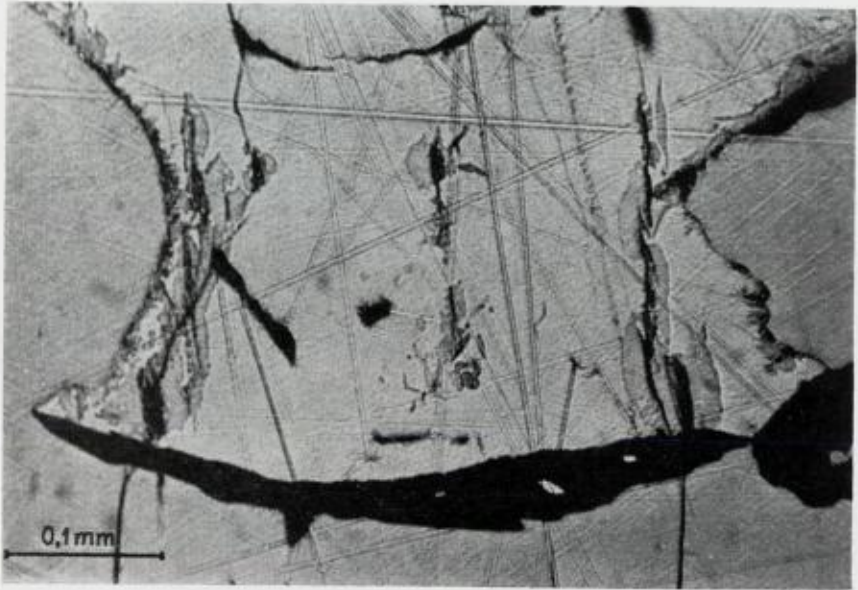


Fig. 7. Photograph which shows corrosion of chalcopyrite (light grey) by pyrrhotite (grey). Black in lower half of fig. is sphalerite.

*Fotografi som viser at magnetkis (grå) korroderer kopperkis (lys grå).  
Sort i nedre del av bildet er sinkblende.*

and laths (see fig. 9). The single ones are normally the largest with a maximum length of 3.5 mm and as much as 0.07 mm thick. This is the typical appearance of this mineral as a normal constituent in high temperature sulphide deposits. It is generally assumed that it has been formed by exsolution from chalcopyrite, with an excess of FeS, and that this exsolution takes place at a temperature around 250–300° C (Ramdohr 1955).

However, quantitatively, the other occurrence of this mineral is by far the most important. It fills up the chalcopyrite fields in almost all proportion and often shows evidence of replacement. Sometimes the replacement seems to have occurred by a growth of the exsolution lamellae leaving chalcopyrite lamellae in a cubanite field (see fig. 10), in more extreme cases there remain minute laths and lenses of chalcopyrite approximately parallel to cubanite lamellae in the adjacent grains of the former mineral. In most cases, however, the replacing cubanite has no relation to the lamellae. On the contrary there seems to be a slight difference in



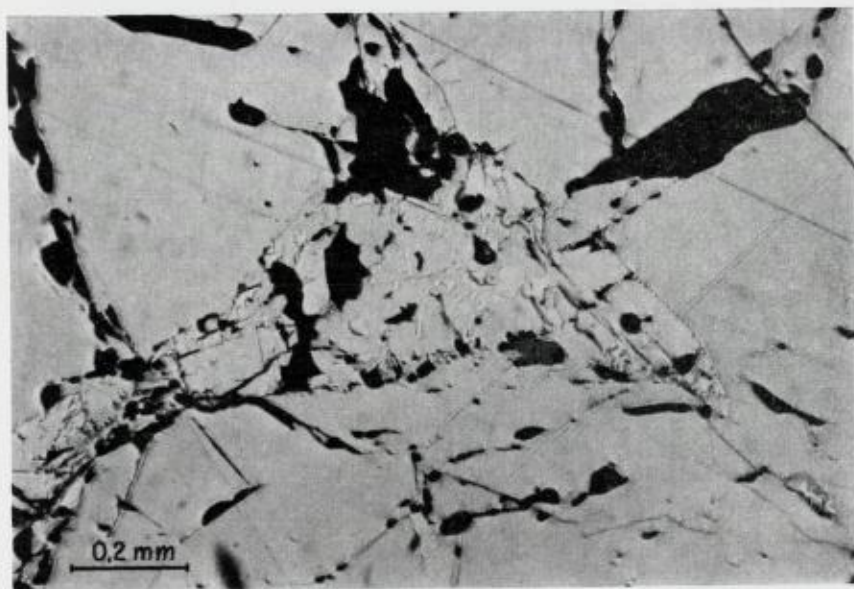


Fig. 8. Remnants of a chalcopyrite grain (relief) replaced and surrounded by pyrrhotite. Black grooves.

*Rester av et kopperkiskorn (relieff) delvis fortrent av omliggende magnetis.  
Sort er groper.*

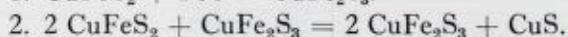
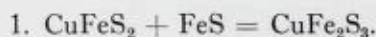
colour and relief between the two, as the lamellae show a pleochroism and a difference in relief from chalcopyrite, which are hardly distinguishable in the other mode of occurrence. The anisotropism is weak but distinct in both generations. However, the colour, which lies between those of chalcopyrite and pyrrhotite, also appears differently in various polished sections, and this difference seems to coincide with the difference in relief, i.e. a dark pyrrhotite like cubanite is seen to have a hardness above chalcopyrite, while the lighter, more yellowish varieties have an almost equal hardness. X-ray powder patterns, however, shows no difference between these varieties.

In addition to chalcopyrite cubanite is also in a small scale found to replace the gangue minerals, small grains around 0.15 mm including numerous relics are seen to extend into the silicates.

When part of corroded chalcopyrite grains have been replaced by cubanite, the corroded grain boundary changes abruptly to smooth, i. e. although replaced the cubanite is never corroded by pyrrhotite. It is

therefore assumed that the formation of granular cubanite is later than the corrosion of chalcopyrite and perhaps a result of this, after equation no. 1. This equation is used by Ødman (1933) when he assumes that cubanite is formed when chalcopyrite in solution "Kupfer (kies) führenden Lösungen" reacts with pyrrhotite. J. E. Hawley (1962) ascribes the development of much of the granular cubanite from the Frood mine, Sudbury, to absorption of magnetite, pyrrhotite and pentlandite by copper-rich sulphide liquid. The difference between these localities and Trolldalen is that in the latter the opposite seems to have taken place.

As the amount of chalcopyrite corroded by pyrrhotite is rather small compared to the cubanite present, the writer suggests that a further replacement of chalcopyrite by cubanite takes place according to equations no. 2 and no. 3. At certain conditions replacement stops and as a last reaction we find the replacement of both cubanite and chalcopyrite by pyrrhotite.



It must be mentioned that quite a few of the cubanite grains show wormlike intergrowths of pyrrhotite. These very much resemble texture in chalcopyrite, illustrated by Vokes (1957) from Birtavarre and ascribed to probable corrosion as they almost only appear along the boundary between the two minerals. In the cubanite, however, they appear throughout the whole grain 0.1–0.2 mm long up to 0.01 mm thick, mainly following two distinct directions in cubanite. These directions coincide with the direction, which along sphalerite stars are found to develop (see fig. 11). It is assumed that this pyrrhotite has unmixed from the surrounding cubanite. Pyrrhotite similar in texture is also described from cubanite lamellae in the Frood ore by Newhouse (1931) and attributed to exsolution.

### Valleriite.

Until later years this mineral was only described from one locality in Norway, namely Jakobsbakken, Sulitjelma, (Ramdohr 1938). Since it has been identified and described from the Håfjellstuva copper prospects (S. Foslie 1950), the Birtavarre ore (Vokes 1957), the Bleikvassli Mine

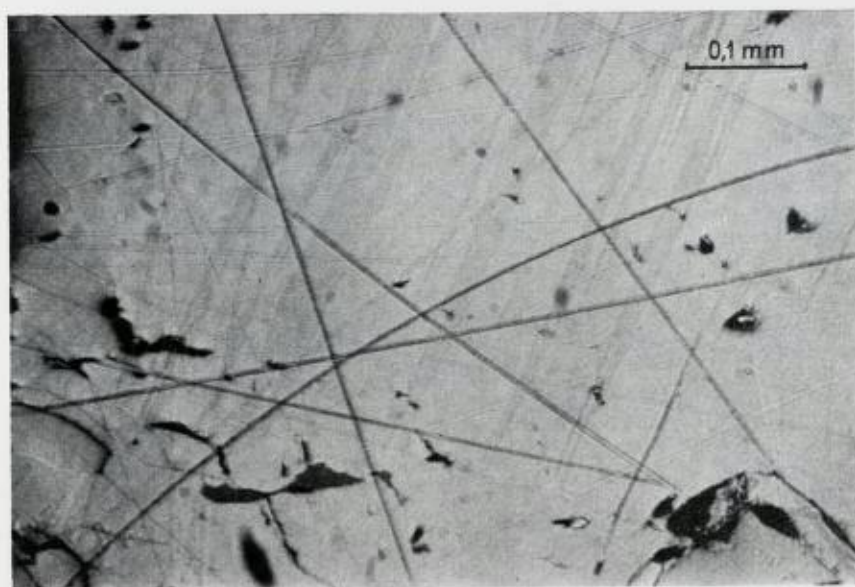


Fig. 9. Cubanite lamellae in chalcopyrite.  
*Cubanittlameller i koppekis.*

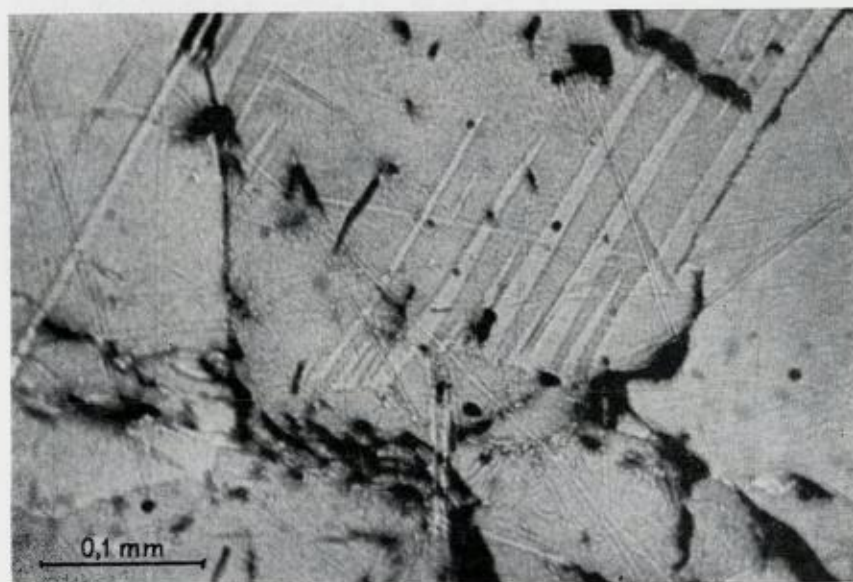


Fig. 10. Chalcopyrite (white) partly replaced by cubanite grey.  
*Koppekis (hvit) delvis fortrent av cubanitt (grå).*



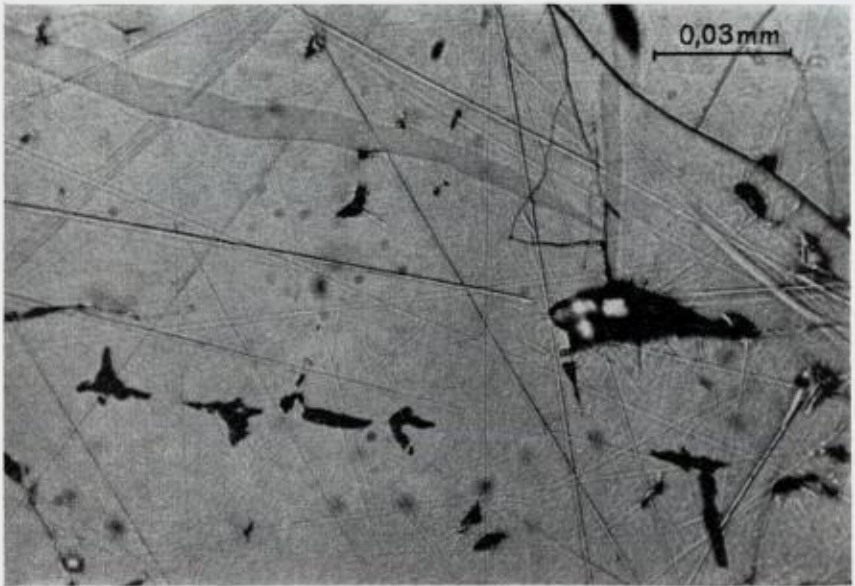


Fig. 11. Dark pyrrhotite lamellae (upper half) and sphalerite stars (lower half) in a cubanite grain.

*Magnetkis-lameller (øvre halvdel) og sinkblendestjerner (nedre halvdel) i et cubanitkorn.*

(Vokes 1963) and Røros (personal communication with O. Jøsang). Most probably most of the Norwegian pyrite deposits would reveal this mineral if closely microscopically investigated.

In the Trolldalen deposit it appears in both the veins south of the lake. It is found as a few single irregular or mainly rodshaped grains 0.04–0.05 mm long, always in chalcopyrite and mainly near the pyrrhotite, (see fig. 12). In a very few cases it is also seen along the chalcopyrite – cubanite boundary. Its pleochroism is strong, pinkish-white to bluish-grey and its anisotropism very distinct.

From the literature it is seen that this mineral almost solely occurs in chalcopyrite, and according to its appearance is interpreted either as a result of exsolution or to have been formed by replacement. The present material, however, is too scarce for any genetic proposal.

### Sphalerite (Marmatite).

As will be seen from (fig. 4) the sphalerite occupies its own field among the gangue mineral, and is only in a smaller scale found associated with the other sulphides. In the latter case it is mainly found along or near the silicate walls or along the boundary between pyrrhotite and cubanite-chalcopyrite, (see fig. 8). It is also seen extending into the sulphides and replacing these, for instance cutting cubanite lamellae in chalcopyrite. Where veins of sphalerite meet with pyrrhotite fields they seem to disappear in the latter like a river drying out in the sand. In the intermediate zone where pyrrhotite is enveloped in sphalerite, the outline of larger pyrrhotite grains can be imagined by optical continuity of smaller grains. The granular aggregates of pure sphalerite contain numerous inclusions of pyrrhotite as separate grains, or chains where the different joints have individual extinction. This indicates that both replacement and exsolution of pyrrhotite have taken place, and probably in the order here presented.

Macroscopically the sphalerite is dark brown, almost black in colour, which indicate a high content of FeS. Two samples of sphalerite were picked under binocular microscope from random specimens belonging to the lower vein south of the lake. With the accuracy of spectrographical analysis, the two samples proved to be identical.

	Wt % FeS	Wt % CdS	Wt % MnS
Sphalerite, Trolldalen	17,3	0,27	0,06

This FeS-value is probably somewhat high due to micro inclusions of pyrrhotite in the sphalerite. But, anyway, it should indicate a high temperature of formation which will be briefly considered later.

Another occurrence of sphalerite is as numerous exsolution intergrowths appearing in all the other sulphides. Most conspicuous are the more or less well developed sphalerite stars in both chalcopyrite and cubanite (see fig. 11). Also the texture by Ramdohr (1955) designated as "zincblende skelett" occur, and is observed along cubanite lamellae partly in these and partly in chalcopyrite, indicating that the sphalerite unmixed before the cubanite.

### **Arsenopyrite (Danaite).**

Although described last, this is probably the first sulphide to have crystallized. It is found in the chalcopyrite – pyrrhotite fields, in the sphalerite, and, although more rare, amongst the gangue minerals. But only in the lower vein south of the lake. The grains, normally subhedral, vary in size from 0,15 mm to as much as 5 mm across. The arsenopyrite always appears in single grains, the smaller ones have complete extinction between crossed nichols, while the larger ones often have irregular fields with a different orientation included. This might be a result of cataclasis, which according to Ramdohr (1955) is often seen in arsenopyrite due to its early formation and brittleness. To a certain extent both pyrrhotite, chalcopyrite and sphalerite have replaced the arsenopyrite, chiefly along a thin outer zone, and in a few cases along cracks. For one reason or another this replacement is most conspicuous where the replacing minerals have attacked along the silicate-arsenopyrite boundary, while the boundaries towards the other sulphides remain mainly idiomorphic. The age of the frequent sphalerite inclusion in the arsenopyrite is somewhat doubtful. They may be ascribed to the general replacement, but looking at (fig. 13) it seems that the sphalerite is here associated with galena?, which is observed no other places but included in some of the arsenopyrite grains. We might therefore assume that the intergrown sphalerite together with galena? are contemporary with the arsenopyrite.

From a spectrographical test of the mineral, the Co-content was estimated as high as 5–6 %.

### **Alteration minerals.**

Before describing the different minerals altered from pyrrhotite, it must be mentioned that all the investigated specimens were sampled on or close to the surface.

In the massive variety the alteration to marcasite is the most conspicuous. It occurs along almost all the cracks and silicate boundaries. When these are parallel to the (0001) direction in the pyrrhotite, i. e. parallel the cleavage and the lamellae, the marcasite forms a fairly regular zone of 0,03–0.17 mm thick along the cracks. However, where the cracks cut this direction, the marcasite extends like flames or needles into the surrounding pyrrhotite, always with their longest extension parallel (0001). It also seems that the lamellae are more easily altered than the matrix



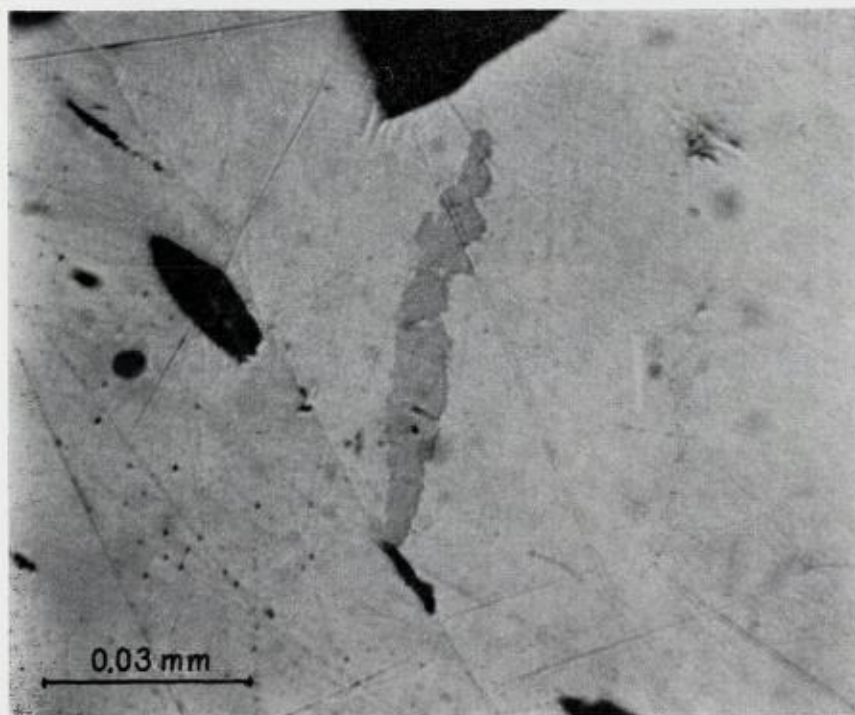


Fig. 12. Valleriite (grey) in chalcopyrite. Pyrrhotite left.

*Valleriitt (grå) i kopperkis. Magnetis til venstre.*

(see fig. 6). The marcasite has a cream-white, slightly bluish colour and a rather weak anisotropism. It has a slightly higher reflectivity than the pyrrhotite, but the difference in relief is almost none. It must be admitted that these features do not point conclusively towards a pure marcasite, but resemble more what is described as a secondary pyrite from the Vihanti deposit (Mikkola 1963). However, what is here regarded as secondary pyrite has a quite different appearance as will be seen below. Foslie (1950) from Håfjellstuva describes a pyrrhotite related mineral, which occurs as an outer marginal zone together with an inner marginal zone (limonite), always bordering marcasite veinlets towards pyrrhotite. This mineral's anisotropism, however, is stronger than both that for pyrrhotite and marcasite. Ramdohr (1955) describes and shows a photograph (Abb 374) of a marcasite-like substance, which he designates a "Zwischen-product". Its anisotropism and pleochroism is somewhat

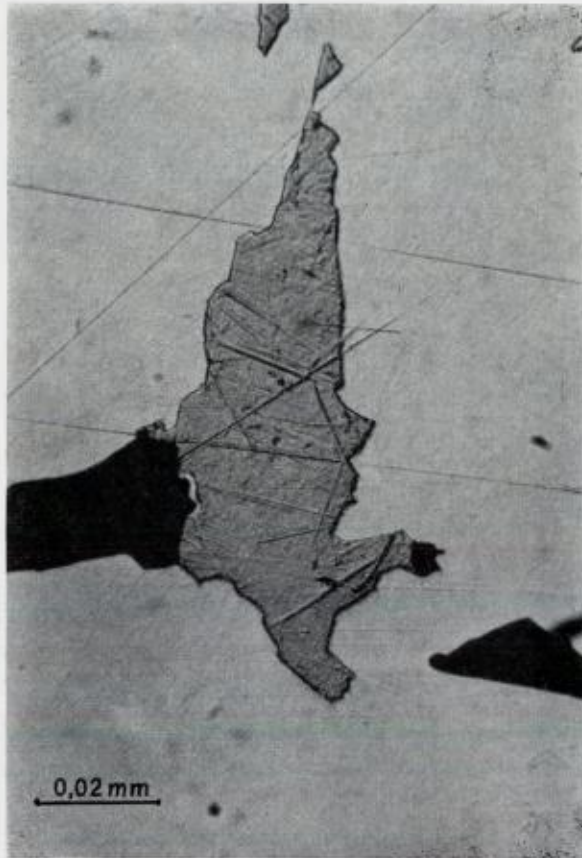


Fig. 13. Galena? (grey) and sphalerite (black) in arsenopyrite.

*Blyglans? (grå) og sinkblende (sort) i arsenkis.*

different from that observed here, but when correlating the figures (see fig. 14), they look very much the same. This "Zwischen-product" is limited to deposits with favourable climatic condition, among which Sulitjelma is mentioned.

The secondary pyrite appears in a few cases as an inner zone between the limonite-filled cracks and the "Zwischen-product" (see fig. 14 and 15). But generally it is most frequent in the second variety of the pyrrhotite and has a more irregular appearance. It occurs as a very finegrained aggregate, white in colour, slightly lighter than the pyrrhotite. Between crossed nichols it appears isotropic or slightly anisotropic. The most con-



Fig. 14. Secondary pyrite (white) and marcasite (light grey) along limonite (black)-filled cracks in pyrrhotite (grey).

*Sekundær svovelkis (hvit) og markasitt (lys grå) langs limonitt (sort)-fylte sprekker i magnetkis (grå).*

spicuous feature, however, is the zonal arrangement along the cracks, as seen under high magnification (see fig. 15). This texture very much resembles the lateral development of "birdeyes" described from Lillefjellklumpen (Sæbø et. al. 1959). Similar alterations of pyrrhotite to marcasite and pyrite are reported by Vokes from Birtavarre. Vokes mentions that the material showing this alteration has been exposed to weathering and is never found in the drill cores.

Limonite fill most of the cracks and intersects both primary sulphides





Fig. 15. Secondary pyrite along cracks in pyrrhotite.

*Sekundær svovelkis langs sprekker i magnetkis.*

as well as the adjacent silicates. It is most frequent in the pyrrhotite and its occurrence in other minerals is probably due to migration of solutions from the altered pyrrhotite. It appears as mere cracks and boundary fillings, but also as brainlike extension with remnants of pyrrhotite (see fig. 16).

#### **Summary and conclusion.**

From the previous it is most likely that even separated the various mineralizations in Trolldalen are related and contemporary. Although

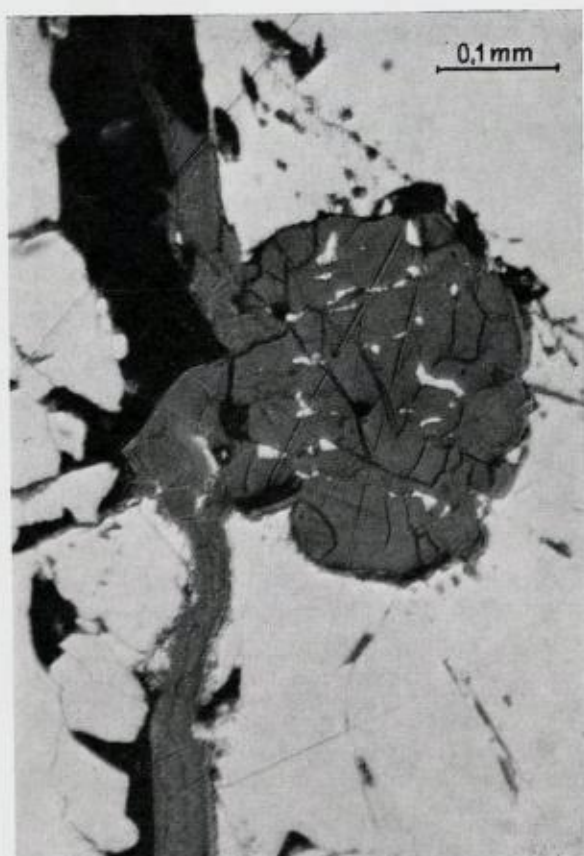


Fig. 16. Limonite (dark grey) in chalcopyrite (white) and pyrrhotite (light grey). Black grooves.

*Limonitt (mørk grå) i kopperkis (hvit) og magnetkis (lys grå).  
Sort er groper.*

different minerals appear in the different veins, pyrrhotite, chalcopyrite and sphalerite are always present. It may also be noted that pyrite, a very common mineral in this paragenesis, is nowhere observed as a primary constituent.

Due to replacement textures the following succession of crystallization is suggested. Appearing as sub. to euhedrale grains, partly replaced by the other sulphides the arsenopyrite seems to be the first mineral in the sequence. It is followed by a simultaneous crystallization of pyrrhotite and chalcopyrite.

The pyrrhotite shows two mode of occurrence, as a massive variety with internal lamellae appear at one locality, while a granular type, but for one occasion without lamellae is seen elsewhere. Also a difference in magnetic properties seems to follow this division. The chalcopyrite contain frequent exsolution lamellae of cubanite, and also shows evidence of being replaced by a second generation of cubanite. The latter appear as granular aggregates in the chalcopyrite fields. It is suggested that the formation of this granular cubanite started from solution formed when the chalcopyrite was corroded by pyrrhotite. Later on both the chalcopyrite and the cubanite have been replaced by pyrrhotite. It therefore seems like the pyrrhotite has been acting in the ore over a longer period, from the simultaneous crystallization with chalcopyrite throughout the formation of the replacement cubanite, and at last during the replacement of the two latter minerals.

Within this period also some few grains of valleriite has crystallized either by replacement or exsolution.

As the last of the primary sulphides sphalerite occurs. It occupies mainly its own fields among the gangue minerals, but when together with the other sulphides to a large extent replaces these. The mineral is dark of colour due to a high content of iron, indicating a high temperature of formation (Kullerud 1953). The writer does not find the present moment opportune for any argument about exact temperatures. Before this, it would be desirable with both further field and laboratory work.<sup>1</sup>

The last minerals to have been formed in the ore are alteration minerals of pyrrhotite. These are described as marcasite, pyrite and limonite, but their identification is somewhat doubtful. Most probably the marcasite can be identified with an intermediate product or "Zwischen-product" between pyrrhotite and true marcasite as described by Foslie (1950) and Ramdohr (1955). Correlated with other Norwegian deposits it is assumed that this alteration is solely due to the weathering mechanism.

From the observation here presented, the writer does not find any

<sup>1</sup> It has also been found by Skinner et al. (1959) that Kullerud's original geothermometer contains uncertainties, especially at high temperatures, and Krause (1961) from his investigation of natural sphalerite, states that these behave different from the synthetic ones used by Kullerud.

Recently a determination of the unit cell edge of 11 sphalerites from Djupvik-Skårnesdalen, Northern Norway, was found to be in agreement with Krause's result. G. Juve: Sink- og blyforekomster i Djupvik-Skårnesdalen, Håfjeldsmulden, Ofoten. Cand. real. thesis, University of Oslo. 1964.



reason to argue about the sulphides pre-orogenic history. Even if any such existed both their position and crystallization now appear to be dependent of the latest orogeny. We have seen as far as two of the veins are concerned, that one follow the gneiss structure of its host rock, while another fills a fracture in massive granite. These are structures which more easily permit metalbearing agents to deposit even during post-orogenic condition. But the paragenesis, as well as the element distribution in the sphalerite are comparable to similar features from other high temperature deposits. Accepting a high temperature of formation combined with typical stress phenomena in the ore, as fracturing and twinning in the different minerals, the mineralization as a whole must have taken place during metamorphism. Heier (1960) from his investigation on Langøy, some 50 km north of Kabelvåg says: "The concept that all metamorphic rocks on Langøy were recrystallized during the Caledonian orogeny is the simplest and most conceivable picture of the geological history".

The writer therefore find it natural to classify the sulphide deposits in Trolldalen as a Caledonian epigenetic mineralization.

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