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Sammendrag

Tegnforklaring tilstede, men kartet mangler

Report on microscopy of thin- and ore sections of the precambrian rocks in the Tømmerås window and the GRONG OLDEN CULMINATION with special reference to the Lead-Zinc-mineralization of Roktdal, Haervola and Gressamoen, TRØNDELAG, NORWAY.

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1. Introduction

The aims of the following report are as follows:

i) A qualitative and semiquantitative determination of 90 thin- and polished sections. (See mineral tables) from the Tømmerås window and the Grong Olden culmination in Trøndelag, Norway.

ii) A petrological classification and assignment of the rocks studied under the microscope with special emphasis on the rock composition (reflected in the mineral assemblage Chapter 3.1.1. - 3.1.5.) and the metamorphic fabric.

A comparison of macroscopical rock descriptions and results can be found in Chapter 2.

iii) A microscopic determination of the mineralizations from Roktdal, Gressamoen and Haervola, with special descriptions of the fabric and paragenesis of host rock and mineralization to formulate probable genetic models.

iv) A comparison of the mineralizations in Roktdalen, Gressamoen and Haervola in order to determine whether or not these occurrences can be considered to lie at a similar tectonostratigraphic position.

2. Summary

Based upon the study of mineral assemblages qualitative and semiquantitative, grain sizes, textures and metamorphic facies, the rocks are divided in metabasites, metasediments, leptites and Haervola granites. Their mineralogical composition are to be found in Chapter 3.1.1. - 3.1.5.

The Haervola granites are not only closely associated with the leptites in the field but are also hardly distinguishable in mineralogical composition.
The granites typically showed higher contents of microcline-perthite, homogeneous grain distribution and were lacking augentextures which are formed in the leptites by plagioclasephenocrysts in a fine-grained groundmass. Especially tectonized leptites show strong similarities with the granites.

The microscopic homogeneity of the leptites in the field is not apparent under the microscope although the leptites from the Tømmerås window and the Grong Olden culmination show certain similarities.
The apparent overall uniform compositions of the leptites could be subdivided according to variations in the mineralogical composition i.e. garnet content, and more obviously by differing textures e.g. feldspar phenocrysts, blastesis and ophitic textures.
In the authors opinion the leptites originate from a heterogeneous series of sediments and volcanic tuffs, metamorphosed to the upper greenschist-amphibolite facies.
Primary mineralogical compositions influence the post metamorphic mineralogy of the leptites.

The leptites are intruded by metabasites. These are magmatites of a basic composition which were metamorphosed without destruction of primary magmatic textures. The mineral alteration has led to the formation of hornblende, chlorite, epidote and clinozoisite. This alteration is not believed to be caused by regional metamorphism but rather by syn- or postcinematic autometasomatic processes.
The secondary alteration products, sericite, titanite, calcite, epidote, clinozoisite and leucoxene have been collectively crystallized. Secondary growth of garnets hints towards postcinematic metamorphism.

The metasediments are represented by biotite-hornblende gneisses, carbonates and quartzites.

In the following, a comparison between the petrographic classifications in the field and those under the microscope is given. Discrepancies occur mostly with metabasites where typical magmatic textures were not recorded in the field and green hornblende and chlorites not clearly recognized.
Due to the fine-grained nature of the leptites field descriptions were not always correct, especially the presence of garnet bands were rarely recorded.

Tab. I: Comparative rock descriptions

Sample No.	Field description	Description of Slabed Specimen	Petrographical Microscopy
8 0 1 0 0 2	k-feldspar-chlorite -gneiss	altered leptite	altered leptite
8 0 1 0 1 2	altered leptite	altered leptite	acid volcanic
8 0 1 0 1 4	"Augen" leptite	leptite	leptite
8 0 1 0 1 7	leptite	leptite	leptite
8 0 1 0 1 8	granulated leptite	banded leptite	acid volcanic
8 0 1 0 1 9	granulated leptite	banded leptite	acid volcanic
8 0 1 0 2 0	granulated leptite	banded leptite	acid volcanic
8 0 1 0 2 5	granitic gneiss	granitic gneiss	granitic gneiss
8 0 1 0 3 4	granite	granite	granite
8 0 1 0 3 7	biotite-chlorite-schist	mica-schist	banded leptite
8 0 1 0 3 6	qtz-fs-pegmatite	granite	granite
8 0 1 0 4 0	granitic gneiss	altered leptite	altered leptite
8 0 1 0 5 1	kf-qtz-bio-granite	leptite	banded leptite
8 0 1 0 5 2	granitic gneiss	leptite	banded leptite
8 0 1 0 5 4	altered leptite	leptite	leptite
8 0 1 0 5 5	altered leptite	leptite	leptite
8 0 1 0 5 7	altered leptite	banded leptite	banded leptite
8 0 1 0 5 8	qtz-fs-bio-gneiss	leptite	banded leptite
8 0 1 0 7 5	qtz-fs-bio-gneiss	leptite	acid volcanic

Sample No.	Field description	Description of Slabed Specimen	Petrological Microscopy
8 4 0 1 0 2	altered leptite	altered leptite	leptite
8 4 0 1 0 3	amphibolite	altered leptite	garnetbearing amphibolite
8 4 0 1 0 4	banded carbonate	banded carbonate	banded carbonate
8 4 0 1 0 5	amphibolite	amphibolite	mica schist
8 4 0 1 0 6	banded carbonate	banded carbonate	banded carbonate
8 4 0 1 0 7	amphibolite	banded leptite	biotite-hornblende-schist
8 4 0 1 0 9	altered leptite	altered leptite	altered leptite
8 4 0 1 1 0	qtz-vein	quartzite	quartzite
8 4 0 1 1 1	altered leptite	altered leptite	altered leptite
8 4 0 1 1 2	altered leptite	altered leptite	altered leptite
8 4 0 1 1 3	amphibolite	mica-schist	mica-schist
8 4 0 1 1 4	leptite	leptite	banded leptite
8 0 0 1 0 4	banded carbonate	banded carbonate	banded carbonate
8 0 0 1 0 8	brecciated leptite	brecciated leptite	brecciated leptite
8 0 0 1 0 9	amphibolite	metabasite	metabasite
8 0 0 1 1 2	muscovite mica-schist	phyllite	quartzitic phyllite
8 0 0 1 1 3	brecciated leptite	brecciated leptite	brecciated leptite
8 0 0 1 1 4	chlorite-hornblende-schist	amphibolite	hornblende-epidote-gneiss
8 0 0 1 1 7	"Augen" leptite	banded carbonate	acid volcanic
8 0 0 1 1 8	leptite	leptite	acid volcanic
8 0 0 1 1 9	amphibolite	leptite	hornblende gneiss
8 0 0 1 2 1	banded leptite	banded leptite	acid volcanic
8 0 0 1 2 5	"Augen" leptite	altered leptite	acid volcanic
8 0 0 1 2 6	greenschist	metabasite	metabasite
8 0 0 1 2 7	greenschist	metabasite	metabasite
8 0 0 1 3 0	amphibolite	mica-schist	hornblende-biotite-gneiss
8 0 0 1 3 1	marble	carbonate	carbonate
8 0 0 1 3 5 A/B	quartzite	quartzitic mica-schist	quartzitic mica-schist
8 1 1 0 6 5	quartzite	quartzitic mica-schist	acid volcanic
8 0 1 1 1 3	quartzite	quartzitic mica-schist	acid volcanic

The following ore mineral assemblages were found
in the polished sections:

Tab. II: Paragenesis of ore minerals

Structure of the Mineralization	Rock Type	Paragenesis
impregnation	altered leptite	il, mt, py, cp, ZnS, (lim)
massive	Haervola granite	PbS, ZnS, py, cp, mt, he, (lim, cov)
impregnation	granitic gneiss Haervola	mt, py, PbS, ZnS, (lim, leu)
impregnation	metabasite	mt, il, py, cp, po
stratiform	quartzite (Gressamoen)	Pbs, po, py, (leu lim)
impregnation	amphibolite (Roktdalen)	il, mt, po, cp, PbS
massive	carbonate (Roktdalen)	PbS, po, cp, ZnS, Cu, mt, py, masc, (lim)
stratiform	carbonate	PbS, ZnS, py, cp
vein-type	pegmatite (Roktdalen)	il, PbS, py, cp
massive	amphibolite (Roktdalen)	il, mt, PbS, py, po
massive	massive ore (Roktdalen)	cp, py, po, PbS, ZnS, masc, mt, py
massive	massive ore (Roktdalen)	Pbs, ZnS, py, cp, po, masc, mt, py

In parentheses: alteration products

Following the inspection under the microscope, four different base-metal mineralizations were classified:

1) stratabound galena-sphalerite mineralization in:
   i) leptites (Roktdal)
   ii) fluorite-bearing carbonates (Roktdal)
   iii) fluorite-bearing quartzites (Gressamoen)

2) base-metal impregnation in:
   i) biotite schists (Roktdal)
   ii) granitic gneisses (Haervola)

3) vein type galena-sphalerite mineralization with quartz and fluorite as gangue in:
   i) fluorite-bearing carbonates (after Hossack, Roktdal)
   ii) biotite schists, hanging wall of metabasites (after Hossack, Roktdal)
   iii) leptites (Roktdal)

4) Massive, remobilized galena-sphalerite mineralization in:
   i) fluorite-bearing carbonates (Roktdal)
   ii) Haervola granite

Type 1 and 2 are believed to be of primary sedimentary origin, whereas type 3 and 4 represent remobilized mineralization.
The paragenesis of the remobilized ore hints towards a mobilization of metals from the underlying, concordant leptite, carbonate biotite schist sequences.
Sphalerite is strongely correlated to fluorite-bearing carbonates, whereas galena concentrates in the quartz rich leptite-biotite schist sequence.
Pyrite and chalcopyrite was typically found to be associated with the leucocratic members of the rock sequence. Pyrrhotite is confined to melanocratic members.
J. R. Hossack presented a model, where the Pb-Zn mineralization in Roktdal was remobilized from the underlying BJØRNTJERN schists, which contains elevated Pb, Zn, Cu, U, Th concentrations.
During the microscopic investigation these schists were found to be considerably more strongly deformed but of lower metamorphic grade than the impure leptites.
The biotites in the metasediments are red-brown coloured by their Fe-Ti content, whereas the biotites in the leptites and their conformable biotite schists are colourless. Presumably the Fe-Ti content was liberated during metamorphism.
The partial mobilization of rocks can be attributed to, the following processes, causing increased heat flow:

1) volcanogenic exhalative
2) plutogenic (Mobilization and assimilation of host rocks by basic intrusives for example)
3) metamorphogenic (Mobilization during amphibolite-grade metamorphism)
4) sedimentary (Chemical reaction of groundwater with impure sediments

A comparison between the Haervola and Roktdal mineralizations reveals two common features:

1) The massive ore types are confined to ore minerals, which were detected in the surrounding hosts.

2) Remobilization of base metals is confined to areas of increased heat flow of magmatogenic origin.

Furthermore it was found:

- Haervola and Roktdal belong to the same geological unit.
- both occurrences have similar paragenesis
- the alteration products are similar
- both occurences have an equal degree of weathering

However, their chalcopyrite-pyrrhotite content was found to differ. The increased pyrrhotite content of the Roktdal mineralization is believed to be more evidence in favour of the hypothesis that the sulfides were mobilized by the intrusion of basic magnatites.

The mineralization in Gressamoen cannot be connected with magmatic processes. It consists of a stratabound galena - impregnation in fluorite-bearing quartzites within the leptites.

This occurrence is characterized by:

- predominantly galena, minor pyrite and pyrrhotite.
- an intimate association between quartz and galena.
- weak mobilization. The galena is only mobilized over short distances and recrystallized at the intersection between foliation and sedimentary layering.

Given a -similar geological history for the Tømmerås window and the Grong-Olden culmination, which is likely the mineralization in Roktdal, is clearly strongly influenced by magmatogenic remobilization, whereas the occurrence in Gressamoen shows only little mobilization of the ore. Here the primary sedimentary base-metal mineralization appears to be well preserved and only weakly affected by regional metamorphism.

3. Petrography of the Tømmerås window and the Grong Olden culmination

The petrology of the Grong-Olden culmination is comparable to that of the Tømmerås window. The macroscopical rock descriptions are to be seen in the BP report '81. The rock classification based on the work of CHR. OFTEDAL and J. S. PEACEY (1964). The sequences include leptites, acid volcanics, metasediments and metabasites. The following microscopical investigation of the rocks maintains this subdivision.

3.1. Microscopy of the thin sections

3.1.1. Metabasites

The metabasites consist of blue-green medium-fine grained hornblende with lesser amounts of apatite, sphene, zircon, ore and plagioclase. They are medium-fine grained black-green heterogenous rocks with partly developed aplitic structure.

hornblende: The crystal shape is euhedral-prismatic with well developed basal faces showing the typical amphibole-cleavage (appx. 120^{0}). The particular colour changes caused by strong pleochroism from yellowish-green to bluish-green. The crystals are partically cataclastic. Inclusions of rutile, leucoxene, ore, zircon and apatite are common. Limonite layers and rims associated with very thin "flourore" are relicts of formerly existing hornblende. Inclusions of fluid cavities and gas bubbles are situated along former ruptures, inclusions of radioactive zircon form circular pleochroic rims in the hornblende. Included apatite crystals are prismatic to long-columnar with euhedral crystal shapes. Hornblende is altered to chlorite with secondary quartz and calcite. Calcite is very fine grained and crystals highly dispersed in the hornblende, whereas the quartz inclusions having lensoid-ovoid outlines.

biotite: Biotite crystals are xenomorphic-hypidiomorphic, with no obvious contacts with hornblende. They are Ti-rich showing strong pleochroism from brown-red (Trøger 1969). Biotite has replaced hornblende totally or at least partly secondary developed by alteration of hornblende. These biotites form myrmekitic intergrowths with quartz.

sphene: The larger crystals display idiomorphic crystal shapes. They are formed by recrystallization of small wedgelike crystals. Sphene crystals are intergrown with hornblende in a granophyric structure, often including apatites.

opaques: The ore minerals are altered to leucoxene and limonite. Larger grains of rutile and sphene are developed by a later stage of crystallization. Rutile is associated with large skeletal sulfides. Iron-ore, magnetite, ilmenite and titanomagnetite usually are always present and altered into leucoxene. Ramdohr 1956 describes this alteration in the following way:

$$\text{Ilmenite} \xrightarrow{+\,Ca\,+\,H_2O} \text{sphene} + \text{pyrite}$$

plagioclase: Plagioclase is the main leucocratic constituent of the metabasites. The crystals are altered to sericite and are albite twinned. Plagioclase is replaced by hornblende. Exk-feldspar: K-feldspar crystals are always xenomorphic and interstitial to plagioclase closely associated with quartz. K-feldspar and quartz are common in traces.

quartz: a) In sharply defined interstitial areas between silicates.
b) In irregular grains closely associated with secondary minerals.
Alteration products such as calcite and clinozoisite of plagioclase and chlorite of hornblende are common.

calcite: a) See alteration of hornblende and saussuiritization of plagioclase.
b) Discontinuous veins of quartz + k.-feldspar and plagioclase, showing postmagmatically deformation.

Whereas primary structures still exist, no primary constituents remain. The combination of (less basic?) plagioclase, hornblende and various secondary minerals resembles the mineral sequence observed following metamorphism of a gabbroic rock (microgabbro or dolerite). Alteration of the iron ore, epidotization ,saussuritization, chloritization of the primary mineral content of the basic intrusions is attributable to the metamorphic influence and alteration of the whole Tømmerås rock sequence.

8 0 0 1 0 9: Coarse-grained, heterogenous metabasites. The constituents are hornblende, plagioclase, sphene, ore and traces of dark mica, zircon, and apatite. Secondary minerals are chlorite, sericite, leucoxene, rutile, limonite, calcite and quartz. Mm-thick veins of quartz, feldspar and calcite crosscut the primary mineral assemblage. Elongated green chlorite-crystals occur between vein and host rock.

8 0 0 1 2 6: Fine grained metabasite in contact with banded leptite. (fig. 1).

8 0 0 1 2 7: Fine grained metabasite, development of coarse-grained hornblende.

8 0 0 1 1 6: Garnetbearing amphibolite. The main constituents are garnet, hornblende and calcite with smaller quantities of rutile, plagioclase, apatite, ore and others. A particular texture due to metamorphism/recrystallization is most characteristic. Ore minerals show graphic intergrowths with the silicates.

hornblende: The crystals are as usual greenish-blue coloured and hypidiomorphically shaped. They are closely associated with rutile.

garnet: In the section the crystals reach a faint reddish-yellow tint. The growth of garnet granoblasts includes all other constituents, forming coronas of quartz against hornblende. Calcite fills thin ruptures and joints. It replaces hornblende (fig. 2), which is altered to radial-shaped chlorite clusters. This hornblende is partly surrounded by fine-grained biotite. Minor ore alteration products of hornblende and ore crystals associated with secondary biotite and chlorite. Titano-magnetite is altered to leucoxene.

fig. 1: 8 0 0 1 2 6, Brannheiklumpen, thin section, X nicols, magnification x 25, metabasite in contact with biotite-rich banded leptite.

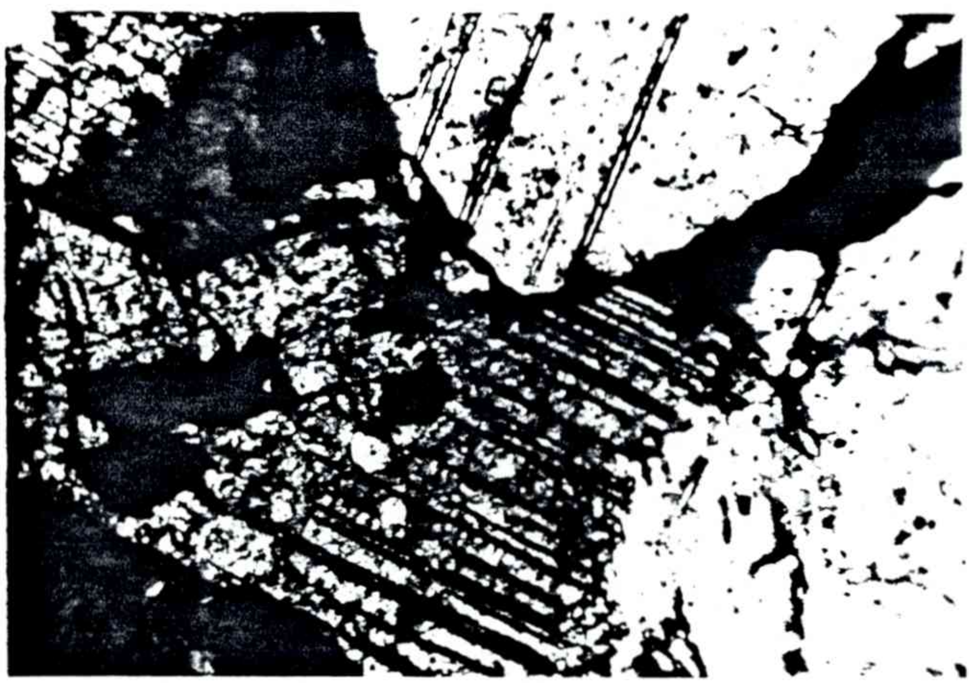


fig. 2: 8 0 0 1 1 6, Snåsavatnet, // nicols, magnification x 73, replacement of hornblende by calcite.

8 4 0 1 0 3: Garnetbearing amphibolite.
Main constituent are greenish-blue coloured hornblende and light brown garnet with lesser amount of plagioclase, quartz, sphene and apatite. "Corona structures" around ore are finely developed. The coronas consist of sphene with sharp boundaries against hornblende.

METABASITES

mineral	800109	800116	800126	800127	840103
quartz	o sec.	+ sec.	o	o	+ sec.
plagioclase	+	+	++	++	+
albite	-	-	-	-	-
k-feldspar	-	-	o	o	-
biotite	-	+ sec.	-	-	-
muscovite	+	-	-	-	-
sericite	+	+ sec.	-	-	+
chlorite	-	+ sec.	+	+	-
calcite	++ sec.	+	-	-	+ sec.
fluorite	-	-	-	-	-
sphalerite	-	-	-	-	-
hornblende	++	++	++	++	++
garnet	++ pink	-	-	+	++ light brown
epidote	+	-	++	++	+
clinozoisite	-	-	-	-	+
zircon	+	+ rad.	+	+	-
sphene	-	++	-	-	+
apatite	+	+	+	+	+
opaques	+	++	+	+	++
rutile	++	+	-	-	-
galena	-	-	-	-	-
leucoxene	-	o	+	+	-
limonite	-	+	-	-	-

++ = main constituent
+ = minor constituent
o = traces

sec = secondary
rad = radioactive

3.1.2. Metasediments

3.1.2.1. Quartzites

Five thin sections of the Gressamoen-Lurudalen area were analysed under the microscope. The rocks can be described either as impure quartzites or typical leptite (See chapt. 3.1.3.3.). The following description complies with the quartzites.

The rocks are marked by a foliation in an angle of approximately 20-30^{o} to the bedding (fig. 3). Where the foliation planes intersect the bedding planes, most of the sulfides occur in larger aggregates, thus giving the impression that the mobilization of the sulfides took place along the bedding planes over only short distances. Besides this course-grained sulfide mineralization there exists a "primary" mineralization of very fine-grained flour-ore parallel to the bedding. The crystals are often enclosed in quartz probably resembling organic material in form of graphite. The flour-ore occurs in fine undulating layers and rims between the quartz often associated with light micas (fig. 4) and elongated larger sulfide crystals showing a fluid structure. The quartz grains are recrystallized without cataclastic textures. Inclusions of xenomorphic fluorite are common. Course-grained fluorite is also found associated with sulfides in places where bedding planes intersect foliation planes. Fluorite crystals are predominantly colourless with violett margins. Connected with the sulfides there frequently occurs redish-brown, iron-rich sphalerite. Traces of biotite, apatite and zircon were also to be found in the quartzites.

Gre 2: Medium-grained, foliated flaser quartzite

Gre 3: Medium-grained, foliated flaser quartzite

Gre 4: Medium-grained, foliated flaser quartzite

Gre 5: Medium-grained, foliated flaser quartzite

8 1 1 8 5 7: Fine-grained quartzite
Thin layers of micas alternate with pure quartzitic layers. The light mica is faint greenish coloured muscovite. The rock contains accessory amounts of opaque phases and zircon. Quartz crystals are xenomorphic fine-grained and very closely intergrown with each other.

8 1 1 0 6 4: Fine-medium grained quartzite.
A typical banding is caused by layers of quartz. Varying in grain size and alternating with thin layers of light mica. The phyllosilicate layers vary in thickness and host larger quartz crystals. The opaque plases occur associated to the quartz or as inclusions in the quartz.

8 0 0 1 1 2: Quartz-muscovite-schist

8 0 0 1 3 5 A/B: See Gre 5, medium-grained foliated quartzite.

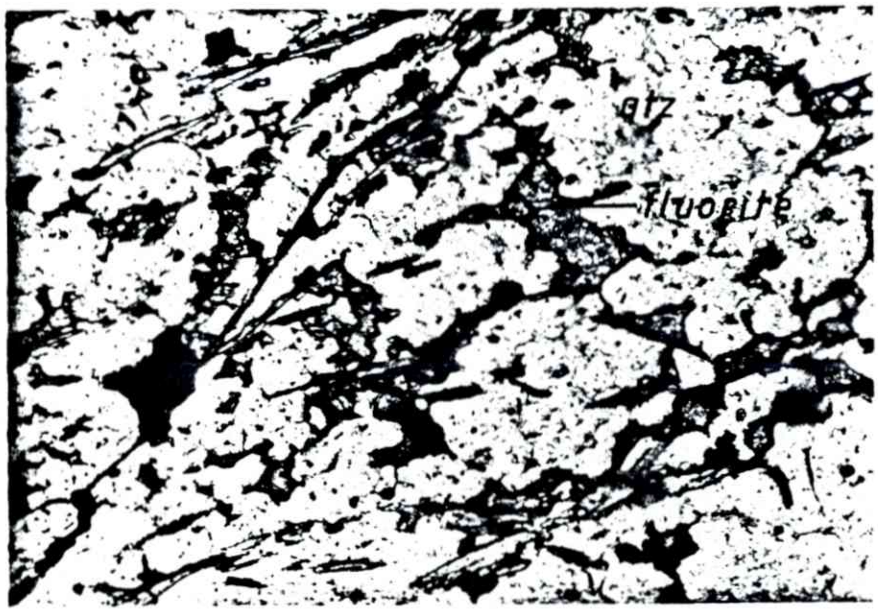


fig. 3: Gre 2, thin section, // nicols, magification x 63, impure quartzite, remobilized quartz includes fluorite, muscovite and ore. Ore minerals are situated along foliation-planes.

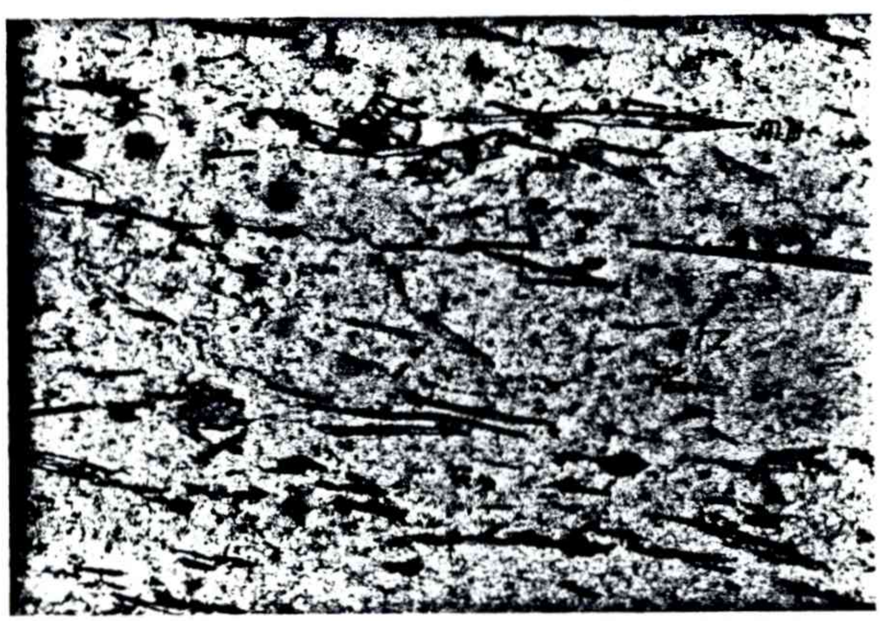


fig. 4: Gre 5, thin section, // nicols, magnification x 50, impure quartzite , faint bedding is shown by the direction of muscovite flakes and fluorite.

METASEDIMENTS(primary quartzites)

mineral	Gres2	Gres3	Gres4	Gres5	800135	800112	811057	801064
quartz	++	++	++	++	++	++	++	++
plagioclase	-	-	-	-	-	-	-	-
albite	-	-	-	-	-	-	-	-
k-feldspar	-	-	-	-	-	-	-	-
biotite	+ sec.	o	-	o sec.	+ sec.	o sec.	-	-
muscovite	++	++	+	++	++	++	-	-
sericite	o	-	-	-	-	-	o	-
chlorite	-	-	-	o	-	-	o	-
calcite	+ sec.	-	-	-	-	-	+	-
fluorite	++	+	-	-	-	-	-	-
sphalerite	-	-	-	-	-	-	-	-
hornblende	-	-	-	-	-	-	-	-
garnet	-	-	-	-	-	-	-	-
epidote	-	-	-	-	o	-	-	-
clinozoisite	-	-	-	-	-	-	-	-
zircon	-	o	o	o	+	+	o	-
sphene	-	-	-	-	-	+ ?	-	-
apatite	-	+	+	+	+	+	-	-
opaques	++	+	+	++	+	+	o	o
rutile	o sec.	o	-	o sec.	-	+	-	-
galena	-	-	-	-	-	?	-	-
leucoxene	-	o	-	-	-	o	-	-
limonite	o	o	-	o	+	+	-	-

3.1.2.2. Others

Seven specimens were analyzed under the microscope. Two, sample No. 800119, 800130, belong to the so called Snåsa Group. This sequence consists of carbonates, conglomerates, quartzites, mica schists, greenschists and amphibolites. The samples were collected south of Snåsavatnet. Another specimen (sample No. 800114) was collected near Oiningen (map sheet 1723 III) where alternating horizons of leptites and metasediments occur. The fourth sample is from a horizon of garnet-bearing hornblende-schist west of Lövsjön (map sheet Norli 1923, IV). The samples 840105/07/13 were collected near the Roktdal mineralization.

8 0 0 1 1 4: Garnet-hornblende-gneiss.
In a very fine-grained matrix of quartz, plagioclase, hornblende, and epidote, garnet and clinozoisite occur in large euhedral porphyroblasts. A proportion of the green hornblende also forms larger idiomorphic crystals. The rock is recrystallized following a strong deformation ("Durchbewegung"). The rotated garnet- and clinozoisite porphyroblasts are poikiloblastic, the inclusions being of quartz (fig. 5). The former mineral assemblage is very similar to that of the leptite, so that the rock probably belongs to a mylonitic zone in the leptite sequence. The plagioclase crystals are heavily altered and the secondary products crystalized in the centre parts of the feldspar crystals. In the section epidote is found besides clinozoisite. Due to the instability of hornblende under deformation, hornblende alters to biotite and clinozoisite (See Tröger 1969).

8 0 0 1 1 9: Fine-grained amphibolite.

<u>hornblende:</u> In the section the hornblende is greenish-blue coloured. Larger euhedral crystals occur in a fine-grained matrix of plagioclase and hornblende. Hornblende is partly altered to biotite. Hornblende and biotite do not occur in contact.

<u>biotite:</u> Biotite crystals are red-brown under the microscope with strong pleochroism. The crystals show partial alteration to chlorite.

<u>opaques:</u> Mostly very fine-grained flour-like as inclusions in hornblende crystals.

<u>quartz:</u> Most of the quartz content in the section is formed by the alteration of hornblende into biotite. Quartz crystals were found interstitially in the matrix.

Apatite and zircon were observed in smaller amounts.

8 0 0 1 3 0: Biotite-hornblende-gneiss.
The rock shows a marked banding due to the mineral content. Strongly folded layers of quartz alternate with biotite-hornblende layers (fig. 6).

<u>opaques:</u> The opaques minerals form large aggregates, they include grains of apatite and quartz and are closely associated with hornblende-biotite layers.

hornblende: The hornblende crystals were found associated with biotite and ore. The crystals are bluish-green coloured and prism-shaped. Larger crystals occur having grown perpendicular to the banding, formed by quartz and biotite-hornblende crystals. These grains are perfectly shaped and characterized by the typical cleavage of amphiboles.

epidote: The epidote crystals are hypidiomorphic, with yellowish-bluish colours under crossed polars and so are difficult to distinguish from clinozoisite. Epidote grains are associated with biotite and hornblende.

titanite: Titanite forms dense aggregates with secondary blue-green coloured chlorite.

biotite: Biotite crystals were found intergrown with hornblende. The flakes are hypidiomorphic and red-brown under ther microscope.

apatite: Apatite crystals are xenomorphic and associated with ore and biotite.

Quartz, plagioclase, k-feldspar and albite are the predominant leucocratic minerals. The main constituents are fine-grained plagioclase and quartz occurring in the matrix. K-feldspar occurs interstitially to hornblende crystals.

8 4 0 1 0 5: Coarse-grained amphibolite.
There was no fluorite to be seen in the section as described from the hand-specimen. The mineral content, (See mineral table), has been remobilized. Blue-green hornblende crystals show poikiloblastic textures, the inclusions being of quartz (fig. 7). Under the microscope a small quartz vein with sharp contacts cross cuts the mineral assemblage.

8 4 0 1 0 7: Fine-grained amphibolite.

8 4 0 1 0 3: See 840105, coarse-grained amphibolite with small quartz-vein.

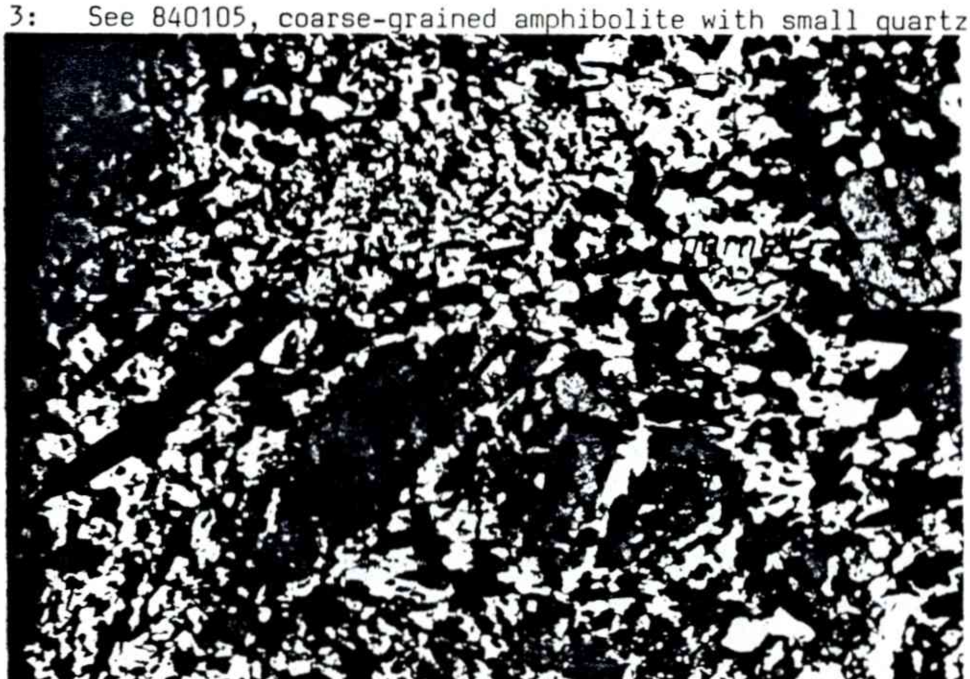


fig.- 5: 8 0 0 1 1 4, thin section, // nicols, magnification x 25, garnet-hornblende-gneiss, porhyroblasts of idiomorphic garnet, clinozoisite and hornblende in fine-grained matrix.

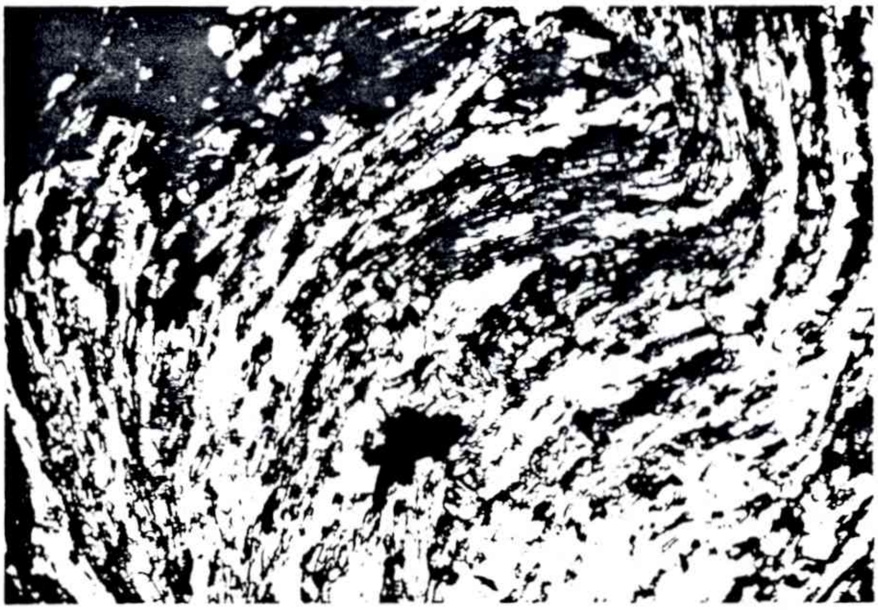


fig. 6: 8 0 0 1 3 0, thin section, // nicols, magnification x 25, folded biotite-hornblende-schist.

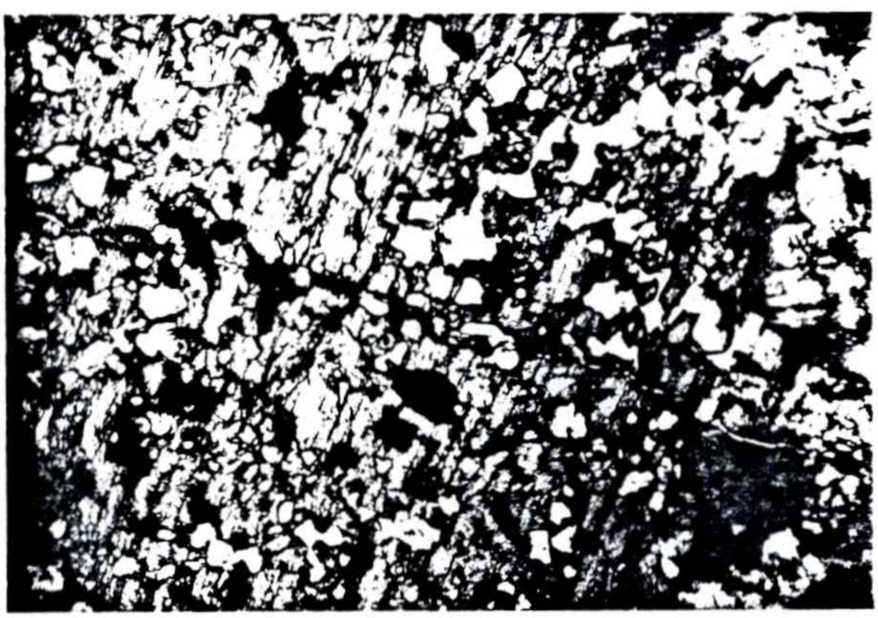


fig. 7: 8 4 0 1 1 3, coarse-grained amphibolite, thin section, // nicols, magnification x 25, poiciloblastic hornblende crystals with inclusions being of quartz.

METASEDIMENTS (others)

mineral	800114	800119	800130	840113	840107	840105
quartz	++	+o	++	++ sec.	+	++
plagioclase	++	++	++	++	++	++
albite	-	-	-	-	-	-
k-feldspar	o	o	+	+	+	o
biotite	-	++	++	++ ti-rich	++	++ green
muscovite	-	-	-	-	-	++
serizite	+ sec.	+	+	o	+	+
chlorite	-	-	-	o	o	+ sec.
calcite	+	-	-	+ sec.	-	++
fluorite	-	-	-	-	-	-
sphalerite	-	-	-	-	-	-
hornblende	++	++	++	++	++	-
garnet	+	-	-	-	-	-
epidote	+	-	+	-	-	-
clinozoisite	++	-	-	+	-	-
zircon	+	+ rad.	+	+ rad.	+ rad.	+ rad.
sphene	-	-	+	+	-	-
apatite	+	+	+	+	+	+ agg.
opaques	+	++	+	++	+	+
rutile	-	-	-	-	-	o
galena	-	-	-	-	+	-
leucoxene	-	-	-	-	+	-
limonite	+	+	+	-	+	+

3.1.3. Leptites

The metamorphic rock sequence in the Tømmerås window and the Grong-Olden culmination is extensively studied by many authors. The following description of more or less banded granitic gneisses, the most common rock in the Precambrian area, is made by Chr. Oftedal and J. S. Peacey (1964):

"The term 'leptite' is here used to mean a pale grey or pinkish, fine to medium grained, banded or massive rock, consisting principally of feldspar and quartz, with lesser amounts of such minerals as biotite, muscovite, epidote, garnet, sphene, and zircon." The origin of the rocks is under discussion. The composition of possible parents varies from acidic igneous rocks to that of former psammitic impure sandstones with pelitic layers as well as layers of probably acid rhyolitic tuffs. The gneisses are cut by numerous dikes of basic igneous intrusions (Chapt. 3.1.1.).

The striking feature of the 'leptites' is the variety of grain sizes, grain boundary types and grain shapes seen in hand specimens and also in parts of the sections. The leptites are dark-grey to pinkish-orange and the textural heterogeneity caused by slightly rotated plagioclase porphyroclasts and large elongated quartz crystals in a fine grained quartz-feldspar-matrix. The texturally more homogenous or gneissose banding is usually not detectable in hand specimens but is clearly observable under the microscope. The 'leptites' can be described as banded gneisses as well as foliated granites (Chapt. 3.1.4.). For all leptite types, the dark layers consist of biotite, chlorite, muscovite, ore minerals, epidote and sometimes garnet, whereas the light bands are rich in quartz and feldspar. The bands vary in thickness from less than a mm to a meter scale. The obvious possibility that the gneissose banding is a relict of original bedding is supported in some areas by layers of biotite-schists and marbles conformable to the surrounding leptites.

Under the microscope the 'Granulitgefüge' (Scheumann 1932) is well developed. The specimens show a typical mortar structure. The grain boundaries between elongated quartz crystals are often lobate and in many place small crystals of a second quartz generation between quartz and feldspar are developed. In the fine-medium grained quartz-feldspar-matrix, large slightly rotated plagioclase crystals (appx. 1 cm) are a common feature. The plagioclase crystals were marginally fractured and subgrains of the primary plagioclase developed during a later stage of recrystallization. These large plagioclase porphyroclasts (occasionally microclineperthites) result in the typical ophtalmitic structure of strongly granulated leptite varieties, called "Augen-leptite" (Chapt. 3.1.3.3.3.).

<u>plagioclase:</u> Plagioclase crystals occur in two different generations. Primary porphyroclast with bent albite-lamellae are partly altered. Saussuritization and sericitization have caused secondary minerals such as muscovite, calcite and epidote. The alteration products are included in the primary plagioclase porphyroclasts. Smaller crystals in the matrix show the same degree of alteration. It also appears that partly the epidote and occasionally the clinozoisite content in the groundmass originate from the break down and recrystallization of a former plagioclase-rich mineral assemblage.

The evidence of recrystallization in these rocks are the mechanical fragmentation of large strained plagioclase crystals into subgrains without marked strain shadowing of extinction between crossed polars and without strong alteration. The secondary plagioclase crystals are incompletely albite- and pericline-twinned and always fine-medium grained.

<u>k-feldspar:</u> The potash feldspar is a granoblastic microcline-perthite associated with quartz and is irregularly distributed in the matrix. Inclusions of albite are common. The feldspar minerals are cut by fractures which are filled by fine-grained albite. Fragments of altered plagioclase crystals in the microcline are a striking feature. A smaller amount of the potash-feldspar exsolves in plate-shaped inclusions from the plagioclase crystals, forming anitperthitic plagioclase in the leptites. The plagioclases are also partly surrounded by rims of k-feldspar.

<u>quartz:</u> The quartz crystals show marked strain shadowing of extinction between crossed nicols and irregular curved boundaries to the neighbouring minerals. Lobate crystal shapes of large quartz aggregates are common, as well as small recrystallized quartz grains between quartz and feldspar. The second generation is not strained and therefore presents some evidence in favour of mechanical fragmentation of grain boundaries and later recryltallization of larger quartz crystals. Quartz has replaced and includes all other minerals and also forms quartzitic layers in the leptites.

Phyllosilicates always exist in the leptites these being mainly flaky biotite and muscovite preferentially oriented parallel to banding.

<u>biotite:</u> Biotite crystals are colourless-greenish without the common strong pleochroism, often in subhedral grains without slightly bent cleavage of single flakes. Biotite is always associated with muscovite, chlorite, apatite, ore, zircon, epidote and others forming thin dark bands in the leptites. Colourless biotite crystals are the typical mica in the leptites and best detectable by exsolved limonite rims along the biotite (001)-cleavage. Occasionally the biotite is marginally altered to chlorite. Symplectic intergrowths of quartz and biotite were to be seen in some sections.

<u>muscovite:</u> There is no evidence that the flaky muscovite in the leptites is an alteration product of the feldspathic minerals or the biotite.

<u>chlorite:</u> Chlorite is strongly pleochroic, bluish-green coloured, tabular shaped in close association with hornblende and biotite.

<u>titanite:</u> Sphene crystals are small, mostly colourless-pale-yellowish, irregular-shaped, and part of the leucoxene content having been formed by alteration of the ore minerals.

<u>zircon:</u> Zircon is either fine-grained as inclusions in phyllosilicates or coarse-grained recrystallized, often in close association with apatite and ore. The crystals are colourless and haloes around radioactiv zircon inclusions are very rare.

<u>epidote:</u> The crystals are strong pleochroic, anhedral, green-yellowish-green coloured and recrystallized to larger elongated grains, closely associated with garnet.

<u>apatite:</u> A small proportion of apatite is common in all leptite varieties. Apatite forms either xenomorphic aggregates with ore minerals or prismatic-shaped grains as inclusions in quartz and feldspars.

<u>opaques:</u> Sulfides and iron-ore are the common ore assemblage of the leptites. Small cubic pyrite crystals exist in the matrix, whereas irregular iron ore grains are altered to leucoxene. The alteration of the iron ore minerals are also a striking feature of the leptites.

<u>garnet:</u> Garnet is an important constituent of the banded leptites. The crystals are of comparatively very small size, hardly to be seen in the hand speciments with the naked eye. Usually they are conformable to the bedding and yellowish-pink coloured. Garnets are partly poiciloblastic with inclusions of quartz, feldspar and lesser amounts of ore minerals.

<u>rutile:</u> Rutile is found in altered leptites in small, irregular shaped grains as an alteration product of the iron-ore minerals.

During the microsopy of different leptite sections the following scheme of rock classification assignment was made according to variations in metamorphic textures and mineral assemblages.

3.1.3.1. Brecciated leptites

Three sections of brecciated leptite were analysed under the microscope and all three were different in fragments, matrix, material and secondary mineral phases.

8 1 1 8 1 8: Fine-grained matrix of feldspar, quartz, chlorite, epidote, apatite and opaques with calcite heterogenously scattered pseudomorph after large primary muscovite crystals.

In the groundmass are also fragments of quartz-feldspar-rich leptite to be seen. Cracks are filled with fibrous aggregates of quartz.

8 0 0 1 1 3: Fine-grained matrix of plagioclase, quartz, k-feldspar, biotite, muscovite, traces of opaques, sphene and zircon. The feldspar content is altered to felty zeolithes which occur as fragments in the matrix; cracks being filled with fibrous aggregates of quartz.

8 0 1 1 1 2: Fine-grained matrix of quartz-feldspar-calcite interrupted by vein-type-like mineralization of zeolites and aggregates of piedmontite Ca_2 $(ALFe^{3+})$ AL_2 O/OH/ SiO_4 SiO_7 interstitial an unknown colourless mineral phase, which was microscopically not determinable.

brecciated LEPTITES

mineral	801112	800108	800113
quartz	++	++	++
plagioclas	++	+	+
albite	+	+	+
k-feldspar	++	+	+
biotite	-	-	-
muscovite	-	-	+
sericite	-	-	-
chlorite	-	+ sec.	-
calcite	++	++	-
fluorite	-	-	-
sphalerite	-	-	-
hornblende	-	-	-
garnet	-	-	-
epidote	+ pistacite	+	+
clinozoisite	+	-	-
zircon	-	+ sec.	+
sphene	-	-	+ agg.
apatite	+	+	-
ore	-	+	+
rutile	-	-	o
galena	-	-	-
leucoxene	-	+	+
limonite	-	+	+

++ = main constituent
+ = minor constituent
o = traces

sec = secondary mineral
agg = agglomerate

3.1.3.2. Altered leptite

The alteration of the leptites is shown by zeolitization of the feldspar content and by strongly developed saussuritization of the plagioclase content. Either zeolitization of saussuritization occur in individual thin sections e.g. (zeolitization: section 801040, 800902; Saussuritization: 840109, 840111, 840112).

Zeolitization is well developed in quartz-feldspar-rich leptite specimens with small proportions on phyllosilicates. Saussuritization of leptites is closely associated with the proximity of basic intrusions as for instance in the Roktdal area. Most of these leptites are characterized by increased contents of calcite and fluorite. A high chlorite content is also found, while no epidote occurs in these rocks. Calcite forms small veinlets with green chlorite rims along the contact between the matrix and the veinlets, or it occurs interstitially in the groundmass.

zeolitization:

8 0 1 0 4 0: Fine-grained reddish leptite. The matrix consits of plagioclase, k-feldspar and quartz with a minor proportion of zircon, rutile and apatite. Secondary alteration products are leucoxene (limonite) and zeolites (probably stilbite) which replace the primary pyrite and plagioclase content. Plagioclase is replaced by zeolites.

8 0 0 9 0 2: Fine-grained reddish leptite. The specimen is very cavernous. Structure and mineral content see 801040.

saussuritization:

8 4 0 1 0 2: Fine-grained leptite. Minerals of the groundmass are plagioclase, k-feldspar, quartz, chlorite, muscovite, zircon, apatite, opaques, rutile and secondary leucoxene (limonite). (See also 840109, fig. 8).

8 4 0 1 0 9: Fine-grained leptite with carbonate veinlets. Matrix consists of plagioclase altered to sericite (muscovite), carbonate and secondary chlorite, exsolving albite, quartz and k-feldspar. Accesories are: apatite, zircon, muscovite, chlorite, opaques with secondary chlorite and fluorite interstitial to the matrix. Typical carbonate-veinlets occur with chlorite at the contacts to the host rock same as sulfides and titanite.

8 4 0 1 1 1: Fine-grained leptite with carbonate veinlets. See 840109.

8 4 0 1 1 2: Fine-grained leptite with coarse-grained carbonate in veinlets. (See 840109).

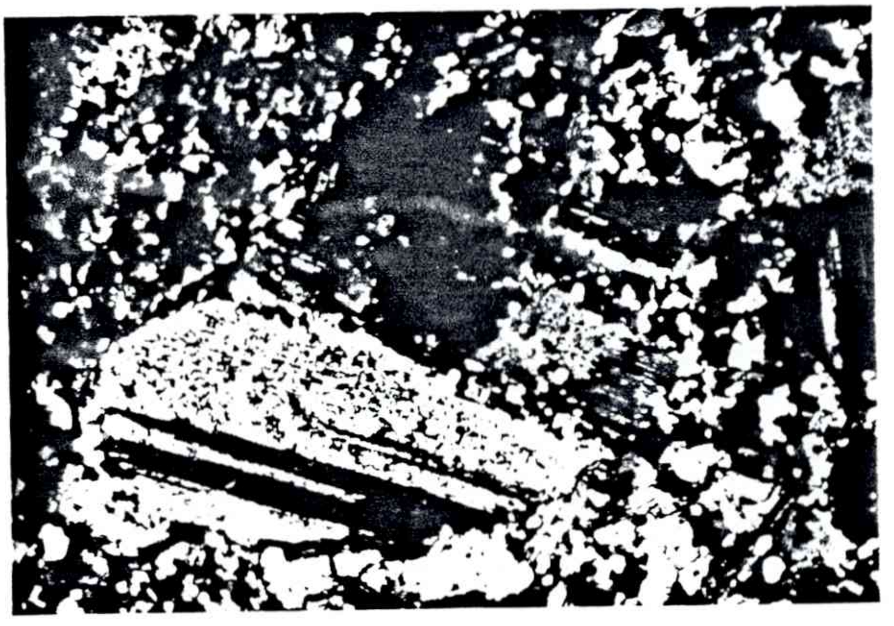


fig. 8: 8 4 0 1 0 2. fine-grained leptite with carbonate veinlets, thin section, X nicols, magnification x 25, altered plagioclase porphyroclast in fine-grained matrix including secondary products.

altered LEPTITES

mineral	801040	800902	840102	840109	840111	840112
quartz	++	+	+	++	++	++
plagioclase	++	++	++	+	++	++
albite	o	o	-	o	o	-
k-feldspar	+	+	+	++	++	++
zeolithes	++	++	-	-	-	-
biotite	+ sec.	-	-	-	-	-
muscovite	+	-	+	+	+	+
sericite	++	-	-	-	-	-
chlorite	+ sec.	-	+	+	+	+
calcite	-	-	++	++	++	++
fluorite	-	-	+	+	o	-
sphalerite	-	-	-	-	-	-
hornblende	-	-	-	-	-	-
garnet	-	-	-	-	-	-
epidote	-	-	-	-	-	-
clinozoisite	-	-	-	-	-	-
zircon	+	o	+	+	+	+
sphene	-	-	-	-	-	-
apatite	o	-	+	+	+	+
opaques	+	+	+	+	+	+
rutile	+	+	+	+	+	+
galena	-	-	-	-	-	-
leucoxene	+	++	+	-	+	-
limonite	+	++	+	-	-	-

++ = main constitue[nt]

\+ = minor constitu[ent]

o = traces

sec = secondary mine[ral]

3.1.3.3. Ordinary leptite

The ordinary leptites are subdivided into quartz-rich, and banded varieties. They differ slightly in mineral assemblages as well as structures.

3.1.3.3.1. Quartz-rich leptites

Quartz-rich varieties are characterized by a higher quartz content and an aplitic structure. Larger lensoid quartz crystals are found with typical developed morture texture. The typical mineral assemblage consists of plagioclase, k-feldspar and quartz with minor constituents of muscovite, biotite, secondary sericite and chlorite, epidote, zircon, apatite and opaques. Smaller amounts of yellowish-pinkish garnet may occur in the leptites. In the section the garnets occur heterogenously distributed. They occur in quartz-rich layers consisting of aggregates of small subhedral-anhedral-shaped crystals. Biotite crystals are partly colourless and altered to chlorite, whereas iron-ore and sulfides have been replaced by aggregates of leucoxene and limonite, apparently titanite and zircon. A slight gneissose banding is apparent due to leucocratic and melanocratic layers. The foliation planes are highlighted by the arrangement of iron-ore and sulfide minerals. In some sections sequences of quartz layers, muscovite-bearing quartzites, and garnet-bearing leptites (801056) were to be seen.

8 0 1 0 5 1: Fine-medium grained leptite (quartz-rich).

8 0 1 0 5 2: Fine-medium grained leptite (quartz-rich).

8 0 1 0 5 3: Fine-medium grained leptite (quartz-rich).

8 0 1 0 5 4: Fine-medium grained leptite (quartz-rich).

8 0 1 0 5 5: Fine-medium grained leptite (quartz-rich).

8 0 1 0 5 6: Fine-medium grained leptite (quartz-rich).

8 0 1 0 5 8: Fine-medium grained leptite (quartz-rich).

8 0 1 0 14: Fine-grained quartz-rich leptite (See 811065) with ophitic structure probably acid volcanic. The ophitic structure is caused by:

1) feldspar phenocrysts of various grain sizes with slightly curved but euhedral crystal-shape. The plagioclase crystals are strongly altered to sericite and enclosed by a thin later stage of overgrowth probably albitic. Biotite and chlorite are schlieren-like arranged in thin layers around the phenocrysts. (See also fig. 9).

2) fragments of quartz-feldspar-aggregates without distinct crystal-shape and grain size.

8 0 0 1 1 7: Fine-grained quartz-rich leptite with ophitic structure. (See 801014).

ordinary
quartzrich LEPTITES

mineral	801051	801052	801053	801054	801055	801056	801058
quartz	++	++	++	++	++	++	++
plagioclase	++	++	++	++	++	++	++
albite	o	o	o	o	o	o	o
k-feldspar	+	+	+	+	+	+	+
biotite	+	+	+	+	+	+	+
muscovite	+	+	+	+	+	+	+
sericite	-	-	-	o sec.	+ sec.	-	-
chlorite	-	+ sec.	+ sec.	+ sec.	-	+ sec.	+ sec.
calcite	-	-	-	-	-	-	-
fluorite	-	-	-	-	-	-	-
sphalerite	-	-	-	-	-	-	-
hornblende	-	-	-	-	-	-	-
garnet	-	-	+	-	-	+	-
epidote	+	+	+	-	-	+	-
clinozoisite	o	-	-	-	-	-	-
zircon	+	+ agg.	+ agg.	+ agg.	+ agg.	+	+ agg.
sphene	-	-	-	-	-	-	+ agg.
apatite	+	+	+	+	+	+	+
opaques	+	+	+	+	+	+	+
rutile	-	o	-	o	-	-	-
galena	-	-	-	-	-	-	-
leucoxene	-	-	-	-	o	-	-
limonite	o	o	o	o	o	-	o

++ = main constituent
\+ = minor constituent
o = traces

sec = secondary minerals
agg = agglomerates

ordinary
quartzrich LEPTITES

mineral	801014	801017	801019	Rok 6	Rok 7
quartz	++	++	++	++	++
plagioclase	+	++	++	++	++
albite	+	+	+	+	-
k-feldspar	+	++	+	++	++
biotite	+	+	+	+	+
muscovite	+	+	+	+	+
sericite	o sec.	o sec.	o sec.	-	-
chlorite	o sec.	+	+ sec.	-	-
calcite	-	o	+	-	+
fluorite	-	-	-	-	-
sphalerite	-	-	-	-	+
hornblende	-	-	-	+	+
garnet	+	-	-	-	-
epidote	o	-	o	-	+
clinozoisite	-	-	-	-	+
zircon	+	o	+ agg.	o	+
sphene	o	-	+agg.	o	-
apatite	+	-	+	-	+
opaques	+	+	+ agg.	+	+
rutile	+	-	-	-	-
galena	-	-	-	-	-
leucoxene	-	+ agg.	+ agg.	-	-
limonite	o	o	-	0	-

++ = main constituent
+ = minor constituent
o = traces

sec = secondary minerals
agg = agglomerates

8 0 1 0 1 9: Fine-grained quartz-rich mineralized leptite. Sulfide-mineralization as impregnation along quartz layers. Sulfides occur in elongated subhedral aggregates.

Rok 6: Fine-grained quartz-rich leptite. Slightly banded specimen. Secondary hornblende is found associated with altered biotite.

Rok 7: Fine-grained leptite.

3.1.3.4. Banded leptites

Rocks of this variety are fine-medium grained with a distinct banding caused of thicker melanocratic layers between the quartz-feldspathic layers. They consist of biotite, muscovite, epidote, garnet, zircon, sphene, opaques and apatite. On the other hand the leucocratic layers have a well developed 'fractionation' due to the variations in grain sizes of their mineral content such that gneissose banding also exists on a smaller scale in the leucocratic layers.

Rok 1: Medium-grained leptite with flaser structure.

Rok 2: Medium-grained leptite with flaser structure.

8 4 0 1 1 4: Medium-grained leptite with flaser structure.

8 0 1 0 0 2: Coarse-fine grained heterogenous leptite with flaser structure.

Gres 8: Medium-grained leptite with flaser structure. Typical ore mineralization along bedding-foliation-planes developed (fig. 9).

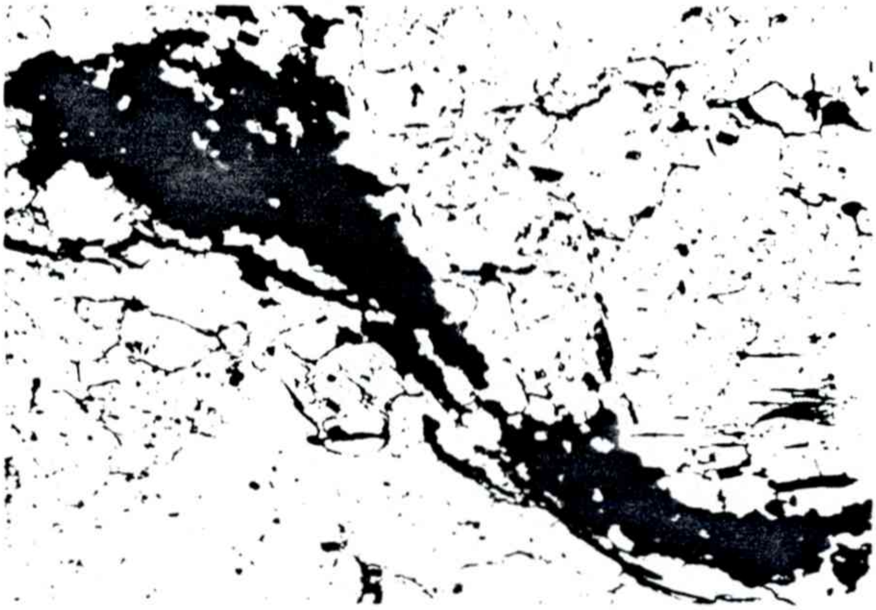


fig. 9: Gres 8, banded leptite, thin section, // nicols magnification x 73, mobilization of the ore content from bedding- to foliation planes.

ordinary
banded LEPTITES

mineral	Rok1	Rok3	840114	801002	Gres8
quartz	++	++	++	++	++
plagioclase	++	++	+	++	+
albite	o	o	o	o	o
k-feldspar	++	++	++	++	++
biotite	+	+	++	+	+
muscovite	+	+	++	+	++
sericite	o	–	+ sec.	+ sec.	o
chlorite	–	–	o	+ sec.	+ sec.
calcite	+ sec.	–	o sec.	–	–
fluorite	–	–	–	–	o
sphalerite	–	–	–	–	–
hornblende	–	–	–	–	–
garnet	–	–	+	–	–
epidote	+	–	++	+	–
clinozoisite	–	–	–	–	–
zircon	+	+	+	+ agg.	+
sphene	+	+	+	–	–
apatite	+	–	+	+	+
opaques	+	–	+	+	+
rutile	–	–	o	–	o
galena	–	–	–	–	+ sec.
leucoxene	–	–	–	–	o
limonite	–	–	–	+	+

++ = main constituent
+ = minor constituent
o = traces

sec = secondary
agg = agglomerates

3.1.3.5. Acid volcanics

The leptites occur in the field with dark horizons of so called fissile-leptite or augen-leptite. Under the microscope these are characterized by:

1) feldspathic phenocrysts (fig. 10) with well developed crystal-shape. They occur from mm-cm scale, commonly having overgrowths of later feldspar. The crystals are heavily altered to sericite and sometimes titanite which occurs in aggregates of small euhedral crystals in the feldspar (fig. 8).

2) fragments of quartz and feldspar with irregular-angular crystal-shape.

3) flaser-like - schlieren-like texture formed by small rims of biotite-chlorite around slightly rotated phenocrysts (fig. 11). The groundmass consists of quartz-feldspar with minor consituents of biotite, chlorite, hornblende, titanite, apatite, opaques, zircon and sometimes garnet. Cracks in the rock are filled with quartz and epidote. No twinning could be observed in the feldspar-phenocrysts. K-feldspar has exsolved from the phenocrysts which are also enclosed by feldspathic rims, consisting of albite (fig. 9). The primary composition of the phenocrysts is suggested to be plagioclase.

8 0 1 0 1 2: Fine-grained dark leptite with aplitic structure.

8 1 1 0 6 5: Fine-coarse grained banded dark leptite with typical ophitic structure formed by large feldspar crystals in a fine-grained quartz-feldspar-matrix. The variably-sized phenocrysts are heavily altered to sericite and flaser-like by surrounded dark mineral components like biotite, chlorite, rutile, zircon, opaques and leucoxene.

8 0 1 2 1 5: Fine-coarse grained dark leptite with ophitic structure.

8 0 0 1 2 1: Fine-coarse grained dark leptite with ophitic structure.

8 0 1 1 1 8: Fine-coarse grained dark leptite with ophitic structure.

8 0 0 1 1 7: Fine-coarse grained dark leptite with ophitic structure.

8 0 1 0 1 8: Fine-grained leptite with typical flaser structure and ZnS-mineralization. Sphalerite is associated with elongated pyrite crystals in large aggregates surrounding feldspar phenocrysts oriented parallel to the layering of the host rock.

8 0 1 0 2 0: Fine-coarse grained leptite with typical flaser structure.

8 0 1 0 7 5: Fine-medium grained dark leptite.

8 0 1 1 1 3: Fine-coarse grained leptite with ophitic structure feldspar phenocrysts with well developed crystal shapes in all sizes were surrounded by rims consisting of dark minerals. The feldspar crystals are heavily altered exsolving k-feldspar and showing a feldspathic overgrowth. They include large broken needle-shaped apatite crystals. Cracks in the rock are filled with quartz and epidote.

fig. 10: 8 0 0 1 2 1: Banded leptite with schlierenlike - ophitic structure, thin section, // nicols, magnification x 25, heavily altered and slightly rotated feldspar-phenocryst filled with secondary minerals like titanite and sericite. The phenocryst is surrounded by biotite flakes in thin layers.

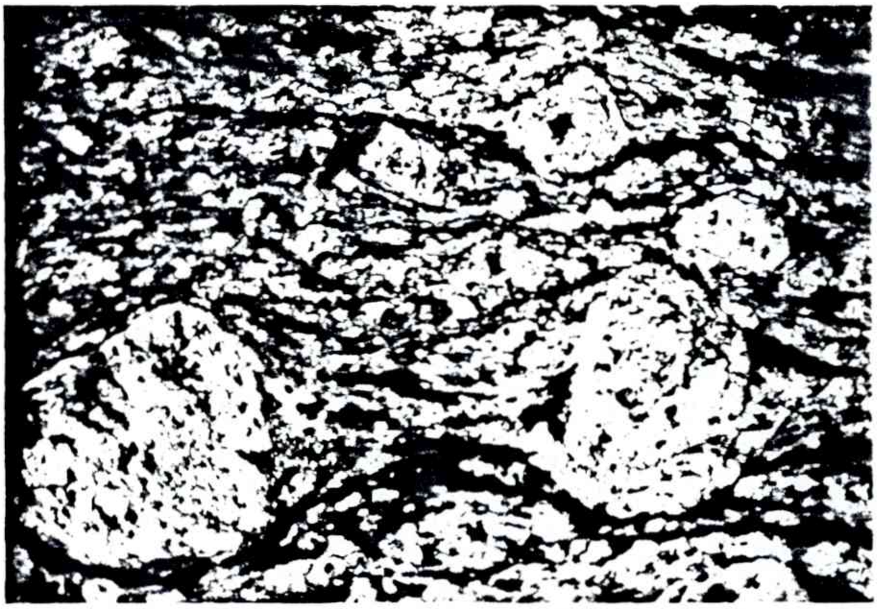


fig. 11: 8 0 1 0 7 5: Banded dark leptite with ophitic structure, thin section, // nicols, magnification x 25, slightly rotated feldspar-phenocrysts of all sizes and apparently well developed feldspathic overgrowth in fine-grained groundmass, typical augen-structure.

Mineral	800117	800118	800121	800125	801012	801018	801020	801113	801075
quartz	++	++	++	+	+	++	++	+	++
plagioclase	++	++	++	++	++	++	++	++	++
albite	o	o	o	o	o	o	o	o	o
k-feldspar	+	+	+	++	+	++	+	+	+
biotite	++	++	++	++	o sec.	++	++	+	+
muscovite	-	+	+	+	-	++	++	-	+
sericite	o	o	o	o sec.	o sec.	o sec.	o sec.	o sec.	+ sec.
chlorite	+ sec.	+ sec.	+ sec.	+ sec.	o sec.	+ sec.	+ sec.	-	-
calcite	-	-	-	+	-	-	-	-	-
fluorite	-	-	-	-	-	-	-	-	-
sphalerite	-	-	-	-	-	+	-	-	-
hornblende	-	-	-	-	-	-	-	-	-
garnet	-	-	+	-	-	+	+	-	+
epidote	++	++	++	+	-	++	++	+	+
clinozoisite	-	-	-	-	-	-	-	-	-
zircon	+	+	+ agg.	+ agg.	+	+	+	+	+
sphene	-	+	+	o	-	+	+	-	-
apatite	+	+	+	+	-	+	+	+	+
opaques	o	+	+	+	+	+ agg.	+	+	+
rutile	-	+	+	-	o	-	o	-	-
galena	-	-	-	-	-	-	-	-	-
leucoxene	-	-	-	-	+	-	-	-	-
limonite	-	+	o	o	+	o	-	-	o

3.1.4. Haervola granite

The Haervola granites are relatively deficient in mafic minerals. They are light-reddish coloured with scattered grains of dark minerals consisting predominantly of biotite, zircon and opaques. Micas, biotite and muscovite are often closely associated and biotite is commonly altered to chlorite. Alteration of the feldspar content has resulted in sericite flecks and inclusions of epidote or clouding of the feldspar. The rocks are granular and essentially contain quartz, plagioclase and k-feldspar in approximately equal quantities plagioclase sometimes being dominant. In the field a perfect gradation between the granites and surrounding leptites could be observed and this exists also under the microscope, if the more homogenous structure and coarse grain size of the mineral assemblages is neglected. Three specimens were examined. Two specimens belong to the Haervola granite intruded in the leptites at the southeast border of the Tømmerås window. The third specimen so called granitic gneiss is taken from a small lense-like inclusion of metasediments and leptites in the Haervola granite.

8 0 1 0 3 4: Coarse-grained granite.

quartz: A typical mortar texture is developed between larger strained lobate quartz crystals and feldspar. The small grains are not strained. They are recrystallized and mobilized, surrounding and including the feldspar-crystals. Quartz occurs also along cracks in the feldspars.

k-feldspar: Large anhedral k-feldspar-porphyroclasts with remnants of plagioclase give evidence that they have formed by metasomatism. The k-feldspar is a microclineperthite, including secondary alteration products of the primary plagioclases.

plagioclase: Larger plagioclase crystals are showing albite-twins often bent and only in parts of the crystals. The plagioclases are heavily altered to sericite, calcite and epidote. Albite exsolves marginal along cracks.

aggregates of the mafic minerals: Aggregation of chlorite, euhedral, zircon, leucoxene and apatite are common and interstitial to the leptite minerals. They are often associated with thin biotite fleckes, muscovite and secondary chlorite, which give faint foliation to the rock. The iron-ore minerals are altered to leucoxene comparable to the alteration of the iron-ore in the leptites whereas the sulfides still exist in the matrix closely associated with biotite, muscovite and chlorite.

8 0 1 0 3 4: Garnetbearing granite. (See 801036). Garnet occurs in small euhedral grains associated with muscovite. The garnet is yellowish coloured.

8 0 1 0 2 5: Medium-grained granitic gneiss. The rock is strongly deformed with larger fragments schlieren-like surrounded by a leucocratic matrix consisting of quartz and feldspar and forming an ophitic structure.

quartz: Quartz crystals display irregular curving outlines. Quartz is mobilized forming quartzitic layers of lensoid single crystals. Inclusions in the quartz are rare.

<u>k-feldspar:</u> K-feldspar is a microclineperthite angular-shaped including remnants of plagioclase. Partly the k-feldspar exsolves in small blocks from the plagioclase.

<u>plagioclase:</u> Plagioclase crystals are showing the same characteristically features like the plagioclases of the leptites. They occur in large anhedral grains including secondary light mica, calcite and epidote, which are partly arranged in small rims around the grains. Plagioclase is antiperthitic with small albite grains exsolved along cracks in the grains. Albite-twins are incompletely developed.

The second plagioclase generation forms a mortar texture around the primary plagioclases. Albite twins are also bent and exist in perfect shape after (010). The second plagioclase is strongly altered to sericite.

<u>biotite:</u> Biotite crystals are closely associated with muscovite flakes. Both minerals are colourless and distinctively bent. Biotite is predominantly altered to chlorite.

<u>epidote:</u> Epidote exists beside clinozoisite. The epidote crystals are small, greenish-yellowish coloured and xenomorphic. Clinozoisite is normally not existent in the leptites but occur in the granitic gneisses showing typically brownish-blue colours under crossed polars.

<u>zircon:</u> Zircon forms agglomerations of small crystals, surrounded by alteration products of the iron-ore such as limonite and leucoxene.

<u>opaques:</u> See zircon. Besides the iron-ore minerals, sulfides are also visible. They occur in the groundmass in single grains, often cubic shaped, or in larger aggregates of galena and pyrite.

HAERVOLA GRANITE

mineral	801025	801034	801036
quartz	++	++	++
plagioclase	++	++	++
albite	+	+	+
k-feldspar	+	++	++
biotite	+	+	+
muscovite	++	+	o
sericite	+	+	+
chlorite	+	+	o
calcite	–	–	o
fluorite	–	–	–
sphalerite	–	–	–
hornblende	–	–	–
garnet	–	+	–
epidote	–	+	o
clinozoisite	o	–	–
zircon	+	+ agg.	+
sphene	–	–	–
apatite	–	+	–
opaques	+	+	+
rutile	o	o	o
galena	o	–	–
leucoxene	+	+	o
limonite	+	+	+

++ = main constituent
+ = minor constituent
o = traces

agg = agglomerates

3.1.5. Roktdalen

The petrography of the Roktdalen area is characterized by the local occurrence of Pb-Zn mineralized carbonates and quartzites hosted by leptites. (See Chapt. 3.1.3.).

3.1.5.1. Carbonates

The carbonates can be classified as banded marble - banded calcareous gneiss due to their rock composition. The banded marble horizon is conformable to the surrounding country rocks and contains oval nodules of fluorite in a fine-grained matrix of calcite and fluorite with lesser amounts of ZnS, quartz and feldspar. The fluorite is colourless to greenish-greyish in hand specimens. Under the microscope the crystals show a faint violet tint. The carbonates are partly remobilized with quartz and sulfides forming local, very dense marbles of coarse-grained xenomorphic calcite with single inclusions of ore (sphalerite) minerals.

9 0 0 1 0 2 A: banded marble

9 0 0 1 0 2 B: banded marble

9 0 0 1 0 4: banded marble
Fluorite in thin layers of different size alternate with layers of calcite. The layers are impure, so that always a small amount of calcite occur interstitial in the fluorite and vice versa (fig. 12). In the section fluorite shows also very typical oval shaped crystals with granulated grain boundaries.

Fluorite crystals with inclusions of ore minerals are common, whereas sphalerite occurs in thin intercalations consisting of single grains parallel to the bedding planes. Plagioclase, quartz and k-feldspar are interstitial in single crystals on one side to calcite and fluorite but also forming thin alternating layers with the fluorite and the calcite.

9 0 0 1 1 1: banded calcareous gneiss.
See 800104. Plagioclase exsolves k-feldspar, which is forming small rims around the plagioclase crystals.

8 0 0 1 0 4: course-fine grained banded calcareous gneiss.
The rocks essentially contains calcite, fluorite and quartz besides layers of feldspar, epidote, red-brown biotite, apatite and ore. The quartz crystals show marked strain shadowing of their extinction. Replacement of biotite by quartz is due to the remobilization of the quartz, which includes also apatite, biotite, ore and epidote. Cracks in the rock are filled with euhedral course-grained calcite crystals surrounded by quartz and sulfides (fig. 13).

8 4 0 1 0 4: fine-grained banded marble.
Fluorite occurs in oval nodules in a fine-grained matrix of calcite, fluorite, sphalerite and others.

8 4 0 1 0 6: banded marble

Rok 4: fine-grained banded marble.
In the section four alternating layers were to be found:
1. layer: homogenous intergrown matrix of fluorite and calcite crystals.
2. layer: sphalerite and calcite with quartz and interstitial feldspar.
3. layer: mixture of fluorite and calcite with stratiform sphalerite.

4. layer: coarse-grained calcite crystals intergrown with oval nodules of fluorite and quartz.

Rok 5: fine-coarse grained banded calcareous marble.
Layers of fluorite-calcite-sphalerite alternate with leptites- The mineral assemblage is the typical leptite composition described in Chap. 3.1.3.

8 0 0 1 3 1: fine-grained banded marble.

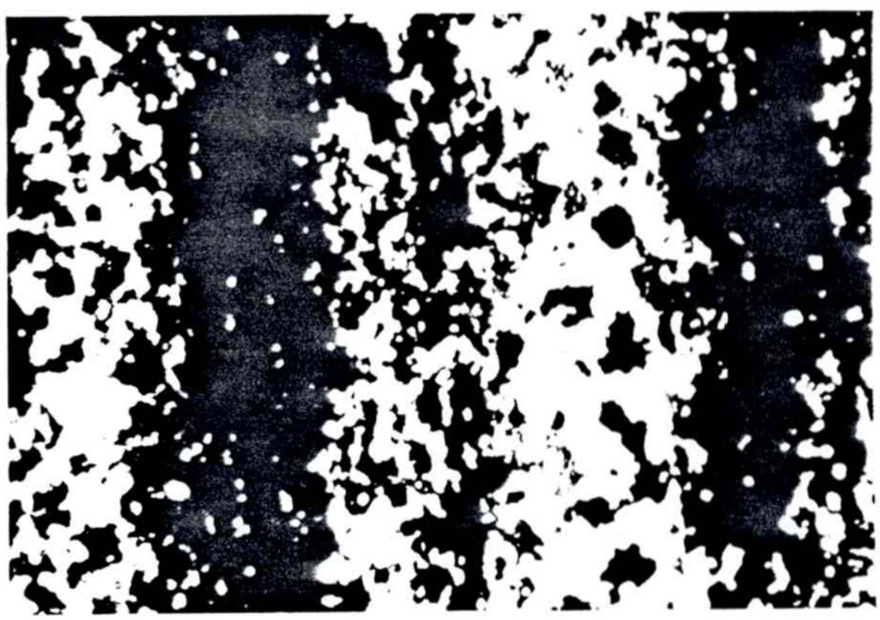


fig. 12: Rok 4, Roktdalen, banded marble, //nicols, thin section, magnification x 25, alternating layers of calcite-fluorite and fluorite-calcite.

fig. 13: 8 0 0 1 0 4, banded remobilized calcareous gneiss, // nicols, thin section, magnification x 63, vein-type like mobilization of calcite, quartz and sulfides.

CARBONATES primary

mineral	900102A	900102B	900104	900111	Rok 4	Rok5	840104	840106	800104
quartz	+	+	+	+	+	+	+	+	+
plagioclase	o	o	+	+	+	+	+	+	+
albite	-	-	-	θ	-	-	-	-	-
k-feldspar	o	o	-	o	+	+	+	-	o
biotite	-	-	-	+	+	+	-	o	+
muscovite	-	-	-	-	-	-	+	+	-
sericite	-	-	-	-	-	-	o	o	-
chlorite	-	-	-	-	-	-	-	o	-
calcite	++	++	++	++	++	++	++	++	++
fluorite	++	++	++	++	++	++	++	++	++
sphalerite	+	+	+	+	-	-	+	+	-
hornblende	-	-	-	-	-	-	-	-	-
garnet	-	-	-	-	-	-	-	-	-
epidote	-	-	-	+	-	+	-	+	-
clinozoisite	-	-	-	-	-	o	-	-	-
zircon	o	o	o	o	-	o	+	+	+
sphene	-	-	-	-	-	o	-	-	-
apatite	-	-	-	-	-	o	+	-	o
opaques	+	+	+	+	-	+	+	+	+
rutile	-	-	-	-	-	-	o	-	-
galena	-	-	-	-	-	-	-	-	-
leucoxene	-	-	-	-	-	-	-	o	-
limonite	-	-	-	-	-	-	-	-	-

8 0 0 1 3 1: This section was found to be a pure homogeneous carbonate without any characteristic fabric or mineral composition. The specimen is taken from the Gressamoen area and might be part of the metasedimentary horizons in the area. The section is obviously not comparable with sections of the Roktdal carbonates.

mineral	800131 (GRESSAMOEN)
quartz	+
albite	-
plagioclase	+
k-feldspar	-
biotite	-
muscovite	+
sericite	-
chlorite	-
garnet	-
epidote	-
clinozoisite	-
zircon	+
sphene	-
apatite	-
ore	+
rutile	-
leucoxene	-
limonite	+
fluorite	-
calcite	++
sphalerite	-

3.1.5.2. Quartzites

Quartzites have been affected by remobilisation. They show gneissose banding and granoblastic textures.

Rok 2: Coarse-grained quartzite.

quartz: In this section the quartz grains are oval with granulated grain boundaries, showing a mortar structure. The quartz crystals are strained and show triple junctions. New small grains are developed between quartz and quartz or quartz and sphalerite. Quartz includes apatite crystals and is closely associated with sphalerite and galena.

sphalerite: Under the microscope the sphalerite crystals are dark brown-red coloured intergrown with galena in dense aggregates. Sphalerite is either interstitial to the quartz crystals or surrounding the quartz. Inclusions of small anhedral apatite grains in the sphalerite are common.

galena: Galena is associated with sphalerite often filling cracks in the sphalerite. Muscovite and small grains of secondary not strained quartz occur marginal along the galena crystals.

opaques: Euhedral grains probably pyrite and pyrrhotite occur either as inclusions in the quartz or interstitial to the quartz. Larger aggregates include biotite flakes, and are closely associated with sphalerite.

fluorite: Fluorite occurs in large recrystallized aggregates and includes biotite and zircon.

biotite: biotite crystals are nearly colourless under the microscope and altered to chlorite.

8 4 0 1 1 0: Quartz mobilizate with sulfide impregnation. See Rok 2.

REMOBILIZED QUARTZITES

mineral	840110	ROK 2
quartz	++	++
plagioclase	-	-
albite	-	-
k-feldspar	-	-
biotite	-	+
muscovite	+	+
sericite	o	-
chlorite	o	+ sec.
calcite	+	-
fluorite	-	+
sphalerite	-	-
hornblende	-	-
garnet	-	+
epidote	-	-
clinozoisite	-	-
zircon	-	-
sphene	-	+
apatite	-	+
opaques	o	+
rutile	-	-
galena	-	-
leucoxene	-	-
limonite	-	-

++ = main constituent
+ = minor constituent
o = traces

sec = secondary mineral

list of thin sections

metabasites : 800116,800109/26/27, 840104

metasediments: 1. quartzites: Gres2/3/4/5, 811057/64, 800112/35A735B
2. carbonates: 800131
3. others: 800114/19/30, 840105/07/13

leptites: 1. brecciated: 801112, 800108/13
2. altered: a) zeolithisation of feldspars: 800902, 801040, 840109
b) saussuritisation of feldspars: 840102/11/12
3. ordinary: a) quartzrich: 801051/52/53/54/55/56/14/17/19, Rok 6/7
b) banded Rok 1/3/5, 840114, 801002, Gre 8
c) acid volcanics: 801012/18/20/75, 800117/18/21/25, 811065/801113

Haervola granite: 801025/34/36

Roktdalen: 1. carbonates: 900102A/B/04/11, 840104/06, 800104, Rok 4/5
2. quartzites: 840110, Rok2

4. Ore microscopy

4.1. Roktdalen

9 0 0 1 0 1 A: Massive lead-zinc-ore (type I). The most abundant ore minerals are sphalerite, galena, pyrrhotite, chalcopyrite and secondary pyrite as well as magnetite. Age relationships could not be observed. The sulfides showed typically recrystallized structures. The ore minerals were coarse grained and anhedral. Gangue and ore minerals are intimately intergrown and generally of comparable size. Especially galena shows well developed graphic intergrowths with quartz. Pyrite and magnetite are present in very large amounts as a product of alteration of pyrrhotite. Pyrrhotite has been partially to completely altered to an exceedingly fine grained intimate mixture of pyrite and marcasite.

pyrite: The crystals are anhedral. Smaller aggregates are surrounded and finely intergrown with quartz. The amount of pyrite is lower than that of pyrrhotite. The sulfides are partly secondary after alteration of pyrrhotite and often skeletally grown with secondary magnetite.

pyrrhotite: The sulfide occurs in the following ways:

a) as relict lensoid grains in sphalerite with twinning lamination due to pressure

b) with colloidal alteration products such as pyrite and marcasite

c) in subhedral aggregates with chalcopyrite in the matrix.

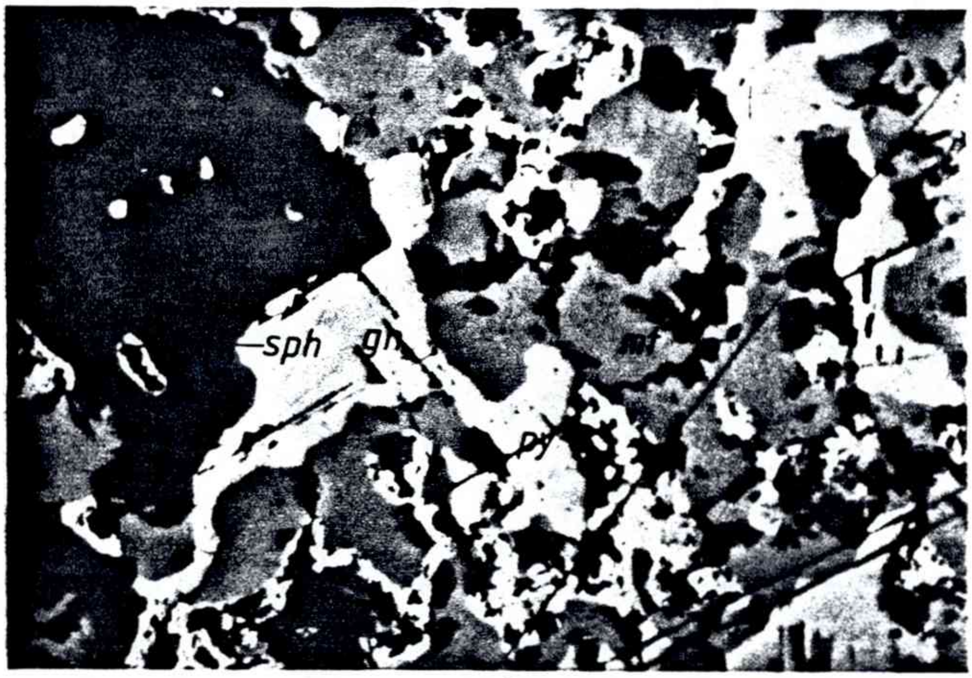


fig. 13: 9 0 0 1 0 1 A, Roktdalen, polished section, // nicols, typical massive sulfide ore with sphalerite, galena, magnetite and pyrite, magnification x50

9 0 0 1 0 1 B: Massive lead-zinc-ore (type I).

9 0 0 1 0 3: Massive lead-zinc-ore (type II). Large amounts of galena, pyrite and pyrrhotite, sphalerite with granoblastic structure (fig. 14, 15) forming either coarse grained aggregates or dikes in the matrix or in graphic intergrowths with quartz, feldspar and possibly also fluorite.

galena: The sulfide appears in 2 forms:

a) small xenomorphic crystals in the matrix

b) in aggregates with irregular curved boundaries or in subhedral grains (fig. 15)

The b-type seems to be a recrystallized product which includes small, commonly lensoid grains of sphalerite, chalcopyrite and pyrrhotite, where galena also occurs as inclusions within pyrite. The pyrrhotite inclusions have cataclastic textures while sphalerite is obviously recrystallized with rounded or partly developed grain boundaries.

pyrite: Occurs in the following ways:

a) small cubes in the matrix

b) large cavernous crystals replacing galena

sphalerite: Is mostly coarse grained (fig. 13) with irregular to smoothly curving boundaries. Contacts with galena and other minerals are gently curving occasionally sub-polygonal to irregular. Ovoidal to spherical inclusions of silicates, galena, magnetite and pyrrhotite are common. Sphalerite is iron rich having red internal reflections.

galena: Galena is characterized by surfaces having typical triangle grinding scratches, due to bad polishing, being strongly associated with magnetite and silicates which form the bulk of the dense massive minerals. Wherever galena is the most abundant ore-mineral, aggregates of galena show also cusps into the surrounding minerals. Incomplete purification of galena during the recrystallization is a common feature.

others: Marcasite is the most abundant secondary mineral: It is closely associated with pyrite, forming dense anhedral masses of yellowishgreen aggregates, with a typical greenish-violet interference colour.

It is questionable whether the pyrite content is primary or secondary. Evidences exist (fig. 16), that at least part of the pyrite is a secondary product of the alteration of pyrrhotite. These alteration takes place around 300-350° C.

sphalerite: Red coloured sphalerite is abundant. In the massive ore the sphalerite is coarse grained and anhedral. Joints in the sphalerite are filled with galena and marcasite.

chalcopyrite: Chalcopyrite is less abundant. It includes fragments of galena and ovoid pyrrhotite.

pyrrhotite: Pyrrhotite is partly cataclastic, containing inclusions of silicates and locally also sphalerite. The pyrrhotite partly forms typical concentric "bird-eyes-structures" with a very dense pyrite-marcasite mixture with relicts of pyrrhotite in the centre parts. The secondary magnetite is more or less associated with the silicates (fig. 17).

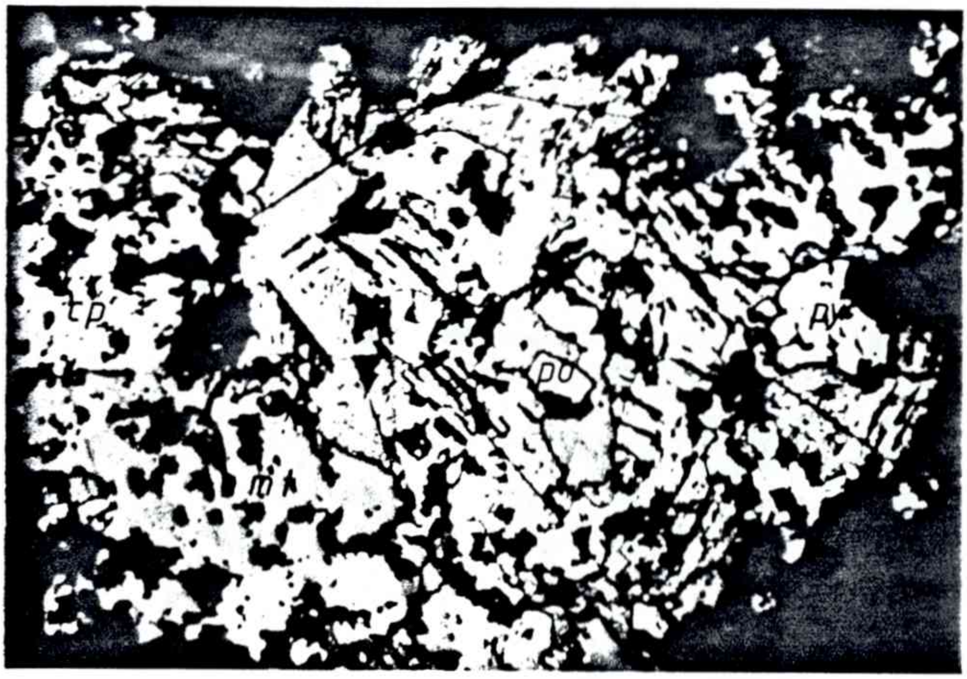


Fig. 14: 9 0 0 1 0 3 Roktdalen, polished section, // nicols, magnification x50, massive lead-zinc-ore type II (sph = sphalerite, gn = galena, po = pyrrhotite, py = pyrite, cp = chalcopyrite, mt = magnetite).

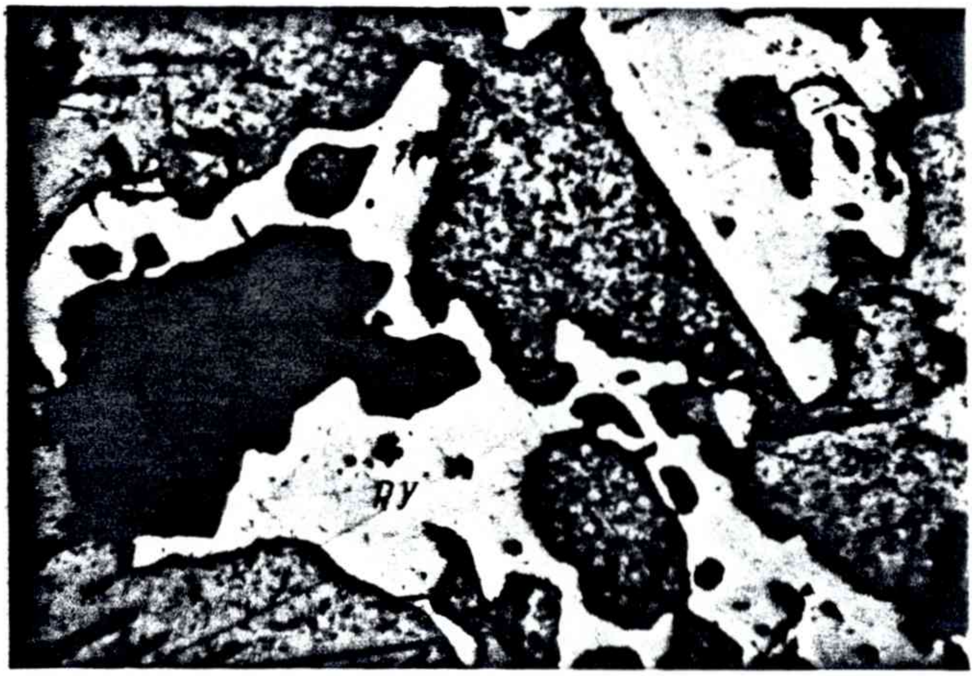


Fig. 15: 9 0 0 1 0 3 Roktdalen, polished section, // nicols, magnification x160, graphic intergrowth of pyrite and galena.

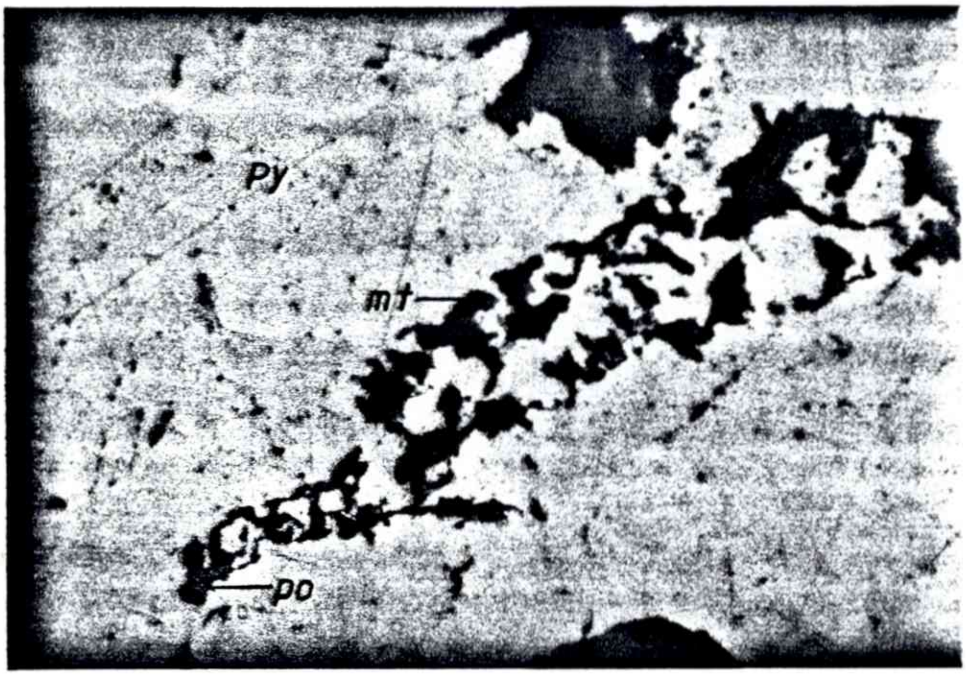


Fig. 16: 9 0 0 1 0 3 Roktdalen, polished section, // nicols, magnification x400 relict of an altered pyrrhotite, secondary minerals pyrite and magnetite.

Fig. 17: 9 0 0 1 0 3 Roktdalen, polished section, // nicols, magnification x160 galena replacing altered pyrrhotite with typically developed "bird-eyes-structures".

8 4 0 1 0 1: Roktdalen, feldspar pegmatite with amphibole, containing galena.

The rock is impregnated with ilmenite, galena, pyrite and chalcopyrite.

<u>ilmenite:</u> Lath-shaped small crystal in a coarse grained groundmass associated with amphiboles and micas as fragments of the surrounding rocks.

<u>galena:</u> Interstitial xenomorphic crystals in the matrix.

<u>pyrite:</u> The pyrite crystals are blastomylonitic with inclusions of ilmenite and zircon.

<u>chalcopyrite:</u> Chalcopyrite fills interstitial cavities in the matrix.

8 4 0 1 0 3: Roktdalen, medium grained amphibolite with stockwork like galena mineralization. The host-rock mineralization consists of Fe-Ti-oxides occurring in the matrix with amphiboles and micas. Pyrite, chalcopyrite and pyrrhotite occur hetero-

genously between the silicates. The massive ore is made up by galena, pyrrhotite and pyrite.

<u>ilmenite:</u> Ilmenite appears in large irregular-shaped crystals, including ovoid silicates and locally also pyrrhotite. Magnetite exsolved during a stage of recrystallization forms small flames along the ilmenite rims or is intergrown with the ilmenite in separated crystals along grain boundaries (fig. 18).

<u>magnetite:</u> Magnetite has sharp contacts with ilmenite, there being no evidence of any reaction between these. The crystals are not cataclastic. They are purified during a stage of remobilization so that most of the former inclusions of silicates are situated along the grain boundaries.

<u>galena I:</u> Exists in small cataclastic anhedral grains of medium size in the matrix and locally also aggregated with chalcopyrite.

<u>galena II:</u> Forms disseminations within the ground mass, and associated with crystalline floures together with platy minerals.

<u>galena III:</u> Fills fine joints in the host-rock, and forms aggregates with pyrrhotite as well as including rounded silicate fragments of the host-rocks. (fig. 19).

<u>pyrite I:</u> Forming large aggregates with biotite which show the effects of intense deformation.

<u>pyrite II:</u> Concentric to skeletal pyrite aggregates.

<u>pyrrhotite I:</u> Small cataclastic anhedral crystals in the groundmass containing flames of pentlandite. (fig. 19).

<u>pyrrhotite II:</u> Forms fine veins with pyrrhotite and silicate fragments (fig. 20). Inclusions of galena in pyrrhotite and vice versa are a common feature. Pyrrhotite II is pentlandite bearing.

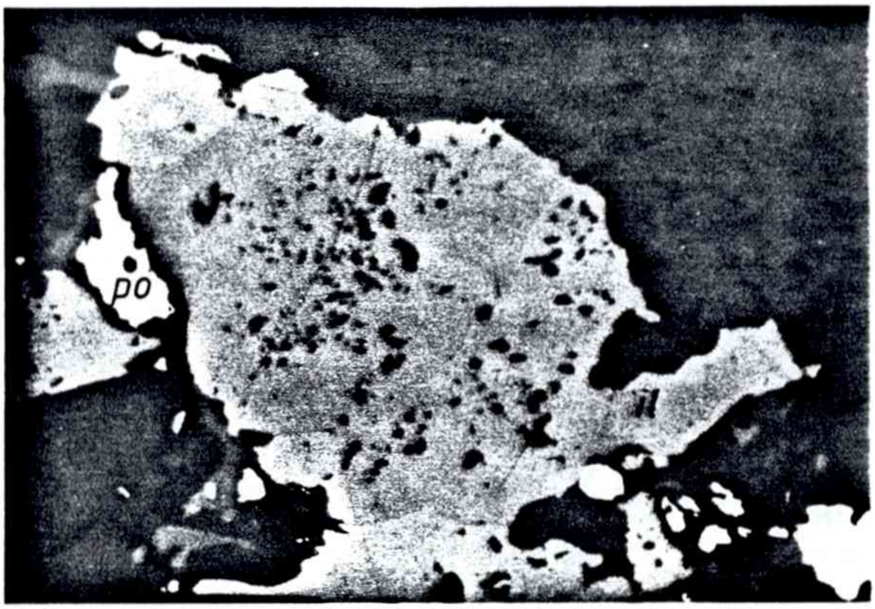


Fig. 18: 8 4 0 1 0 3 Roktdalen, polished section, // nicols, magnification x50, accretionary crystallization of lensoid to ovoid silicates in recrystallized ilmenite (il) with magnetite (mt), and pyrrhotite (po) exsolving pentlandite.

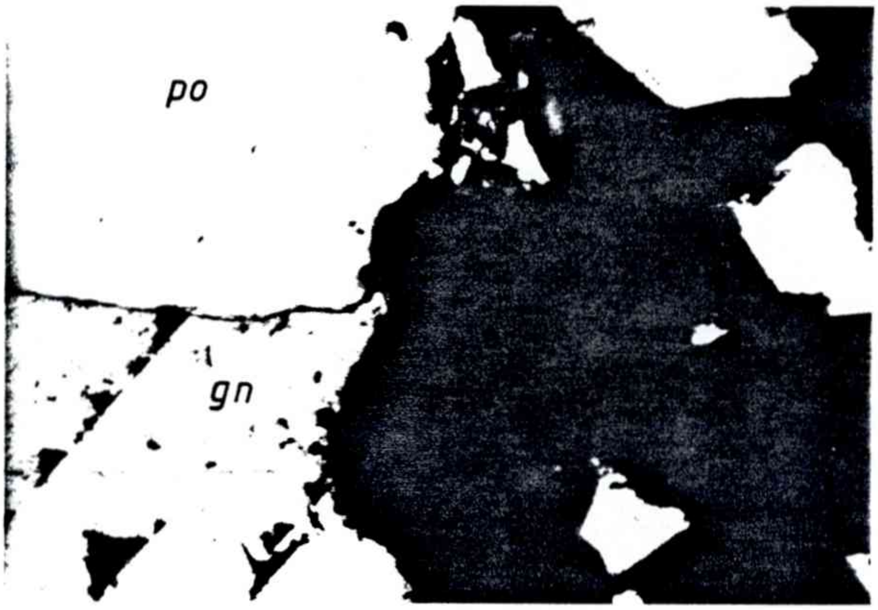
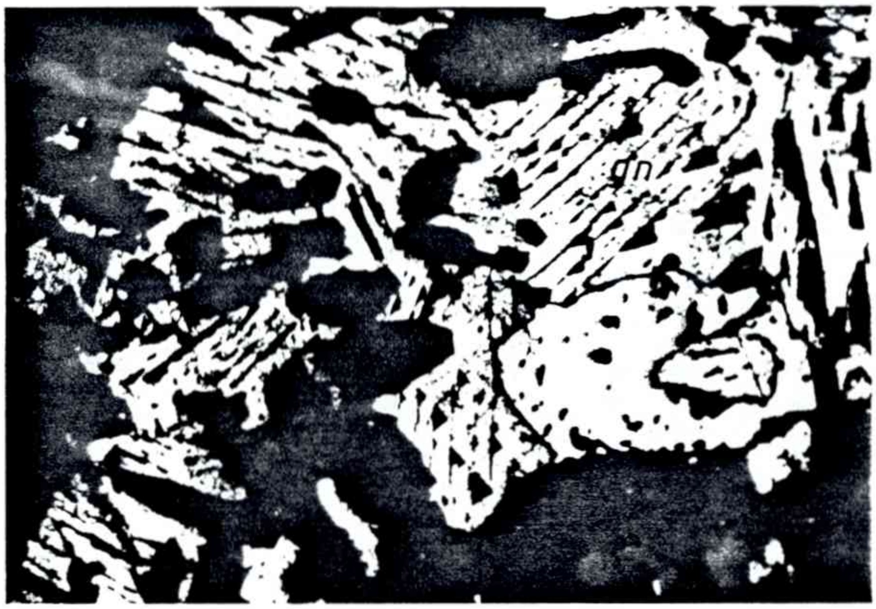


Fig. 19: 8 4 0 1 0 3 Roktdalen, polished section, // nicols, magnification x50, galena with pyrrhotite II, the latter showing typically flames of pentlandite. Triangular wrench-pits and scratches in galena are formed by poor polishing.



Fig, 20: 8 4 0 1 0 3 Roktdalen, polished section, // nicols, magnification x50, galena aggregates with silicate inclusions.

8 4 0 1 1 3: Coarse grained amphibolite with galena impregnation. The mineralization is identical to 8 4 0 1 0 3, but chalcopyrite occurs in addition in irregular aggregates with pyrrhotite I. Chalcopyrite shows inclusions of small lensoid to drop-like sphalerite crystals.

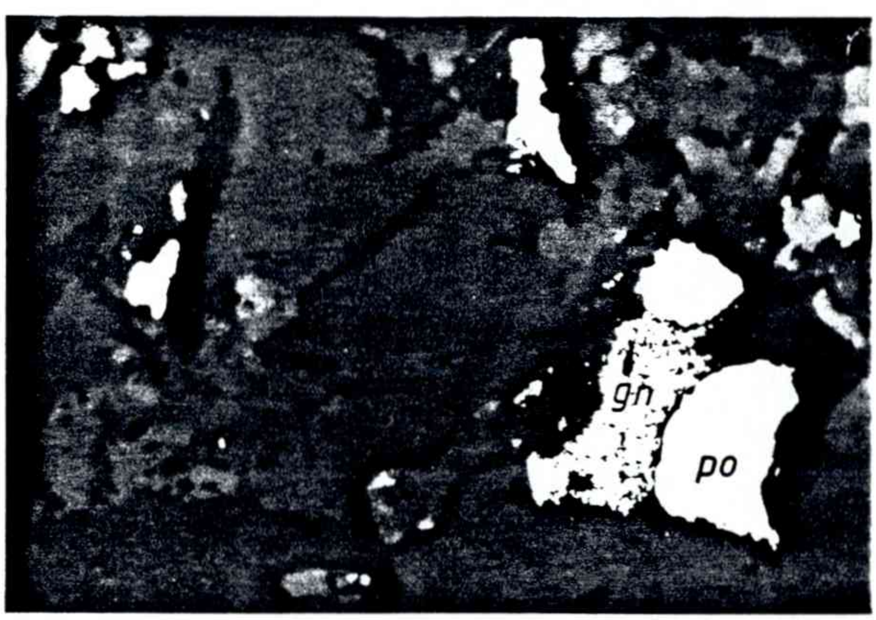


Fig. 21: 8 4 0 1 1 3 Roktdalen, polished section, // nicols, magnification x120, irregular shaped aggregates of galena and pyrrhotite institial to the groundmass.

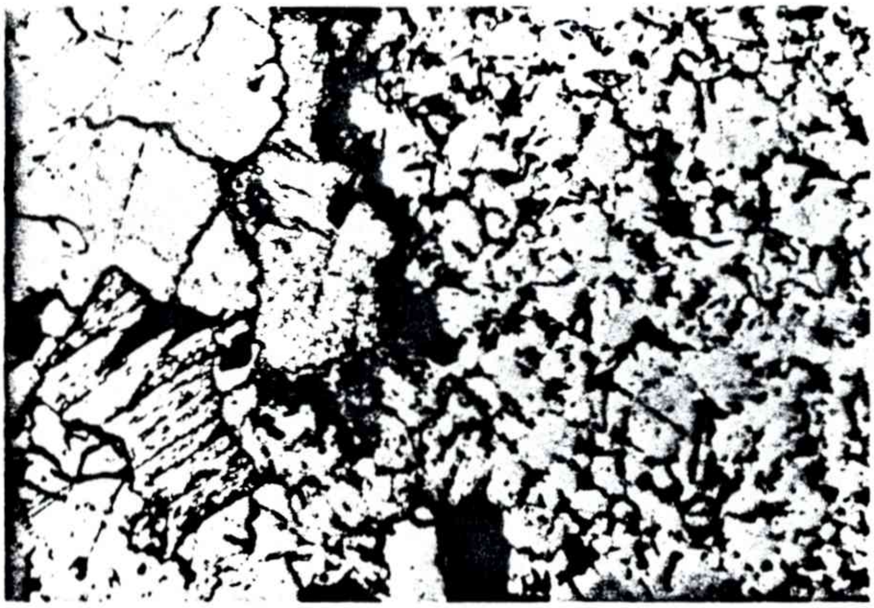


Fig. 22: 8 4 0 1 1 3 Roktdalen, polished section, // nicols, magnification x50, irregular-shaped galena crystals at the boundaries between secondary quartz and host-rock.

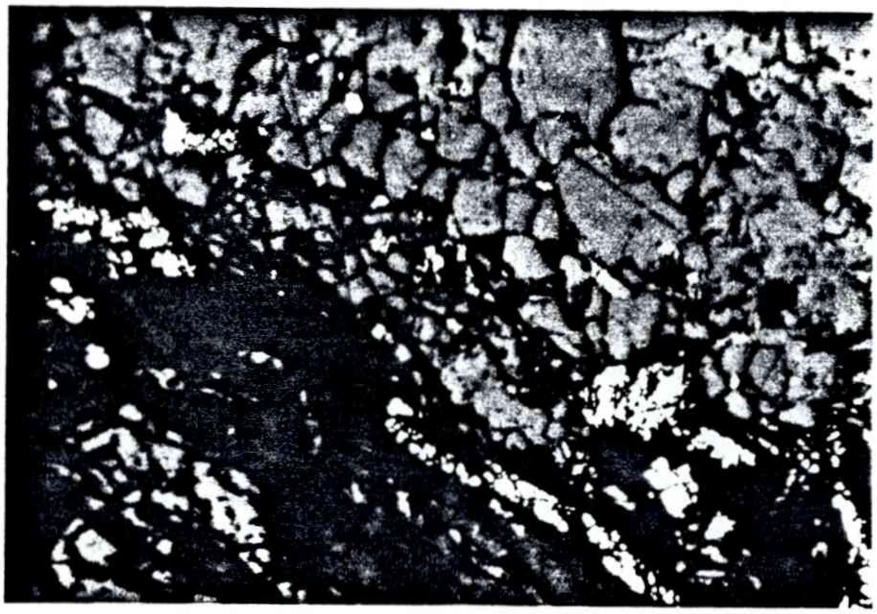


Fig. 23: 8 4 0 1 1 3 Roktdalen, polished section, // nicols,magnification x50, irregular-shaped galena crystals and elongated cataclastic chalcopyrite crystals along the border zone of a biotite rich layer in the host-rock.

Fig. 24: 8 4 0 1 1 3 Roktdalen, polished section, // nicols, magnification x40, skeletal intergrowth of quartz and pyrite II.

8 4 0 1 0 4: Roktdalen, banded carbonate-fluorite, with remobilized galena and sphalerite mineralization. Mineralized horizons in the carbonate-fluorite demonstrate the most primary aspects of Roktdal mineralization, being conformable to the layering of the host rocks. The layering consists of mm-thick alternating layers of calcite, fluorite and sulfides (mainly red sphalerite), gneisses, mica schists and quartz-feldspar. Mineralized zones pinch and swell according to content of coarser crystalline sphalerite and lenses of dark fluorite.

Local concentrations of sulfides exist, consisting of galena and sphalerite with lesser amounts of pyrite and traces of chalcopyrite. Sulfide-rich layers pass gradually into sulfide-poor zones.

galena I: Small anhedral crystals in the matrix.

galena II: Large anhedral aggregates with sphalerite II.

sphalerite I: Red sphalerite (iron-rich variety) is the most abundant mineral. The small crystals are confined to fluorite-rich zones, where they occur interstitially to fluorite.

sphalerite II: Massive aggregates with galena II.

sphalerite III: Ovoid or lensoid inclusion in pyrite.

pyrite I: Thin rims around the silicates of the groundmass.

pyrite II: Secondary pyrite associated with magnetite rims.

chalcopyrite: Small anhedral crystals in the groundmass. Chalcopyrite occurs in all section of the Roktdalen suite - independent of the content of other sulfides.

8 4 0 1 0 8: Roktdalen, banded fluorite-bearing carbonate with remobilized galena and sphalerite. The mineralization consists of coarse grained massive galena, sphalerite, pyrrhotite, pyrite, lesser amounts of chalcopyrite as well as secondary marcasite and magnetite.

galena I: Small anhedral crystals in the groundmass.

galena II: Coarse-grained spathic in massive aggregates with pyrrhotite, large crystals are considerably scratched with triangular renching by polishing. Large crystals commonly show slight anisotropism caused by later deformation as well as faint undulations of cleavage planes. Galena shows irregular to smoothly curving crystal boundaries with granoblastic textures in the recrystallized ore. Inclusions of silicates and ore minerals are common.

pyrrhotite I: Anhedral to subhedral small grains in the matrix.

pyrrhotite II: The crystals are rose-coloured with a brownish tint with strong anisotropism. Pentlandite flames occur in the pyrrhotite and are developed by exsolution during slow cooling temperatures. Inclusions of zonar euhedral zircons and ovoid small sphalerite grains are a common feature. Finer grainsize is typical of crystals of pyrrhotite localized within granoblastic galena grains in the recrystallized ore. Pyrrhotite is altered to a mixture of secondary marcasite-pyrite and magnetite.

marcasite: Marcasite is faint yellowish with a greenish tint against pyrite. Anisotropy is strongly developed. Single crystals of marcasite are rare. Marcasite is intergrown with pyrite in a very fine-grained mixture filling the interstices between crystals of altered pyrrhotite. Larger marcasite grains between galena and pyrite show polysynthetic twinning. Such marcasite demonstrates a secondary generation formed by recrystallization, being small, anhedral and more white coloured than the first generation. Contacts between these two generations were rare.

chalcopyrite I: Small anhedral chalcopyrite crystals occur in the groundmass.

chalcopyrite II: Small anhedral crystals in the massive ore associated with pyrrhotite and galena. See also cubanite.

sphalerite I: Large crystals with irregular or subpolygonal outlines in the massive ore.

sphalerite II: As ovoid ultra-fine grained sphalerite enclosed by pyrite.

pyrite I: Thin rims around silicates in the groundmass.

pyrite II: Secondary, formed by alteration of the pyrrhotite.

cubanite: Very fine grained cubanite crystals occur at the borders between chalcopyrite and pyrrhotite. They are formed by exsolution of the chalcopyrite and also by secondary accretionary recrystallization.

magnetite: See pyrrhotite.

limonite: Thin rims of limonite around the sulfides are produced by weathering.

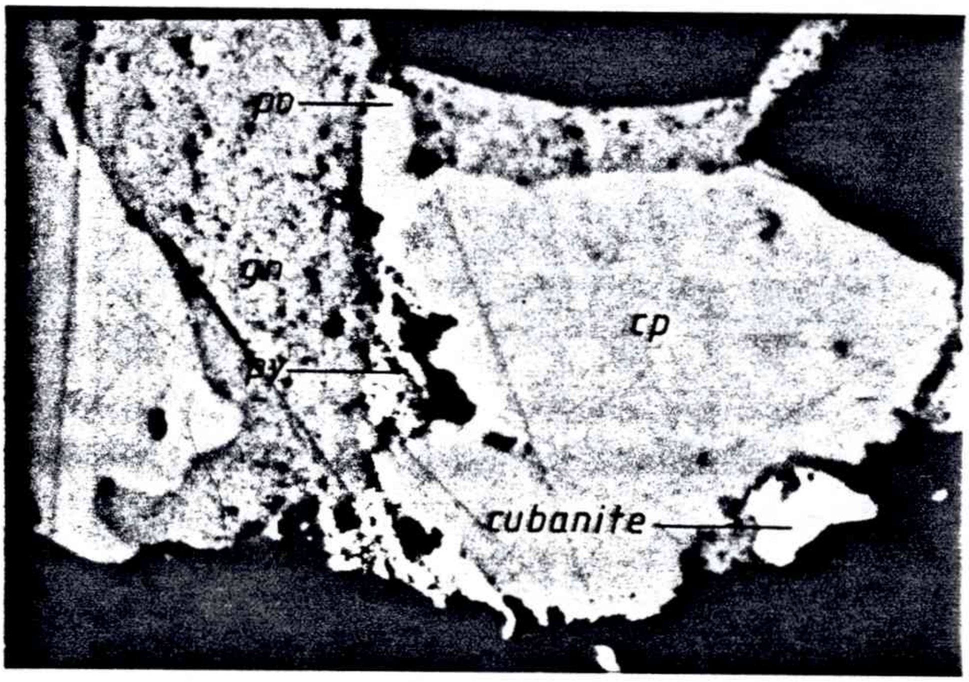


Fig. 25: 8 4 0 1 0 8 Roktdalen, polished section, // nicols, magnification x40, large recrystallized chalcopyrite crystal divided by galena and pyrrhotite- (marcasite-pyrite-mixture). Chalcopyrite and cubanite occur in small amounts.

4.2. Gresåmoen

8 0 0 1 3 5 A/B: Quartzite with galena impregnation. The mineralization in Gresåmoen is conformable with a quartzrich metasedimentary series within the leptites. The leptites are considered to be acid metavolcanics. The mineralization appears to be closely associated with quartzites which are variably graphite-bearing, and carbonates. The mineralized horizon consists of disseminated galena-pyrite-sphalerite impregnation conformable to the layering (bedding) of their host rock. The sulfide minerals are accompanied by layers of light micas. The thickness of the sulfide-layers in the section was only of the order of a few millimeters. The mobilization of the sulfides along the layering has formed laminae of sulfide impregnation. Most of the mobilized sulfides are located at cleavage-bedding intersections.

galena I: Small elongated crystals in the matrix associated with micas, or forming small irregular aggregates with pyrrhotite.

galena II: Larger irregular aggregates of galena-pyrrhotite-chalcopyrite.

pyrrhotite: See galena I and II, pyrrhotite is altered to marcasite and lesser amount of pyrite.

pyrite I: Small subhedral crystals in the ground mass.

pyrite II: See pyrrhotite.

sphalerite: Small anhedral grains in the groundmass.

leucoxene: Leucoxene is a mixture of rutile, zircon, limonite and sphene formed by weathering of the ilmenite-magnetite content of the host rock. These weathering products are typical in the leptites of the Grong-Olden-culmination and the Tømmerås window. Leucoxene aggregates occur with angular outlines to the surrounding minerals and are often replaced by quartz (fig. 26, 27).

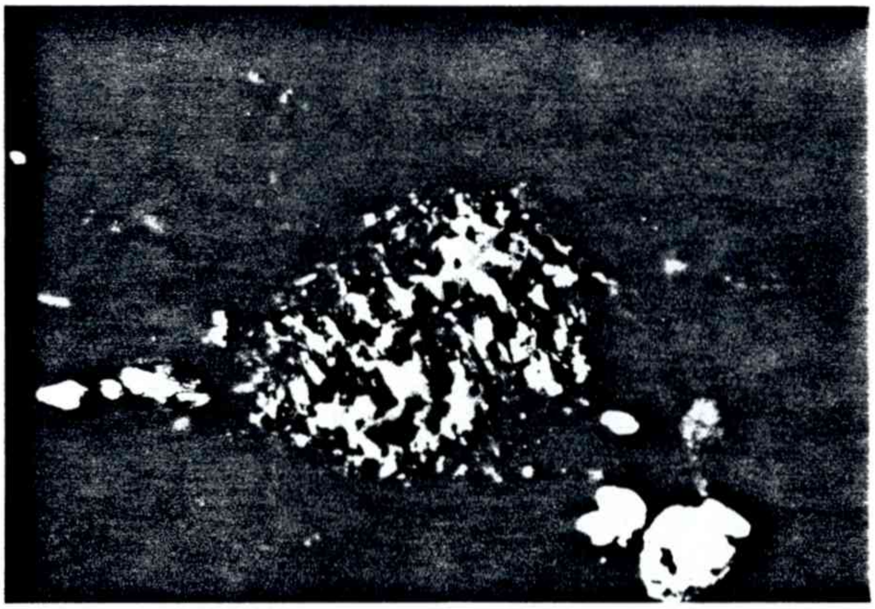


Fig. 26: 8 0 0 1 3 5 A Gressåmoen, polished section, X-nicols, magnification x50, typical aggregate of leucoxene besides zircon.

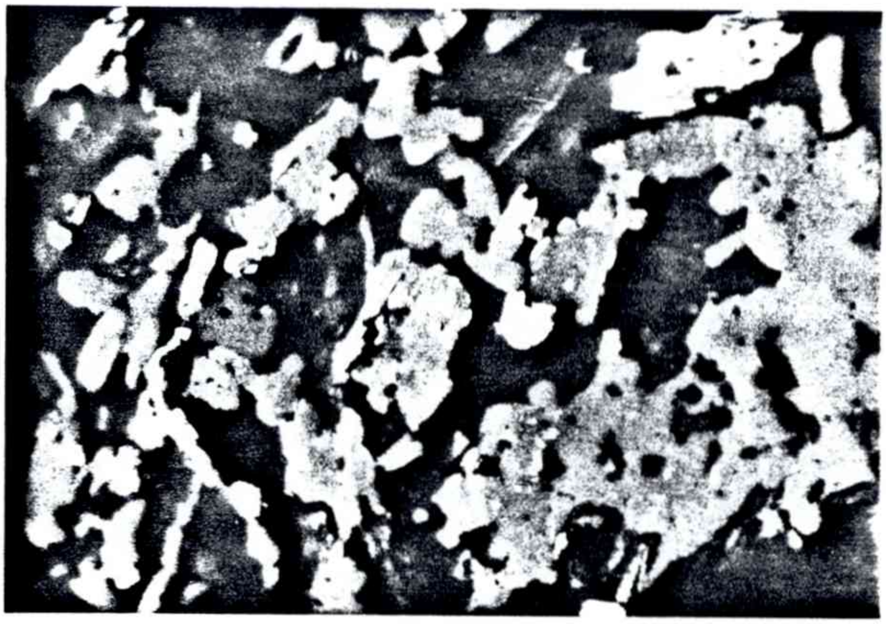


Fig. 27: 8 0 0 1 3 5 A Gressåmoen, polished section, X-nicols, magnification x400 leucoxene a mixture of sphene, rutile and limonite with lesser amounts of zircon.

4.3. Metabasites

8 0 0 1 1 6: Garnet-bearing amphibolite.
Typical impregnation with sulfides, pyrite, pyrrhotite, chalcopyrite. Fe-Ti oxides, such as magnetite, ilmenite are closely associated with silicates. Rock does not belong to the Tømmerås rock sequences (see also 3.1.1.).

4.4. Granitic gneisses and Haervola granite

8 0 1 0 2 5: Granitic gneiss.
The rock is comparable to altered leptites. Ore minerals in the host rock are magnetite, ilmenite heavily altered to leucoxene and pyrite strongly weathered to limonite (fig. 28).

pyrite I: Anhedral crystal disseminated in the groundmass. Sometimes elongated in small rims along the bedding plane. See lim II.

magnetite: Magnetite occurs in small anhedral-subhedral cataclastically deformed crystals in the groundmass.

limonite I: Filling joints and cracks in the matrix.

limonite II: Is replacing the pyrite in layers (see fig. 28).

limonite III: Part of the leucoxene content besides rutile.

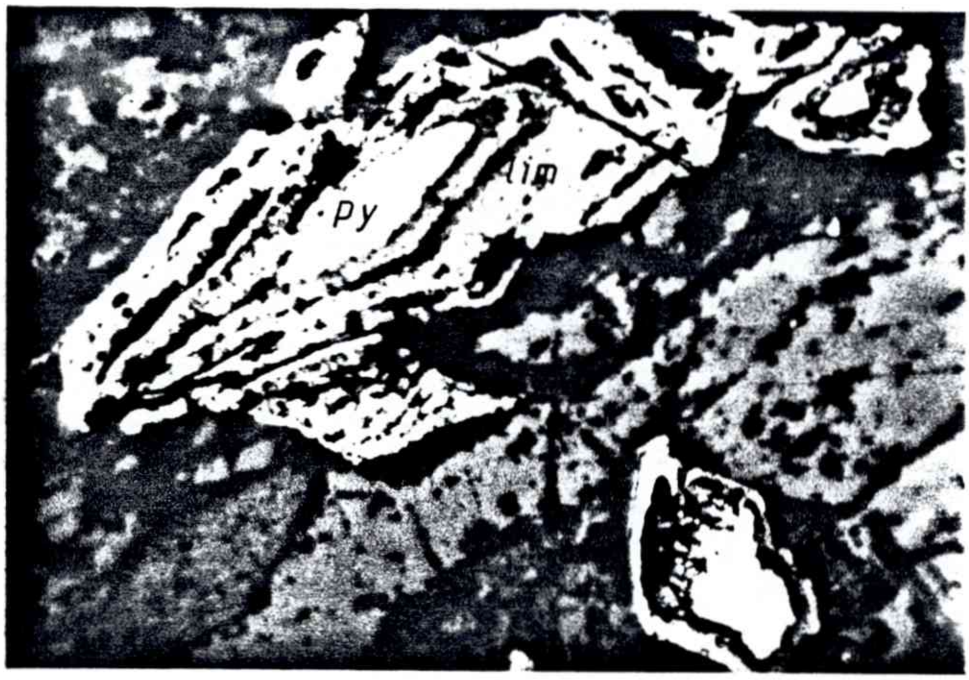


Fig. 28: Granitic gneiss, Haervola besides rutile, polished section, // nicols, magnification x160 replacement of pyrite with limonite.

8 0 1 0 3 9: (Section I) Haervola granite with galena mineralization of the host rock. Very fine grained stratabound mineralization of sphalerite, chalcopyrite, secondary magnetite, galena and limonite after pyrite. The sulfide layers, of a few millimeters thickness, are associated with biotite and except of sphalerite and galena similary

to the granitic gneisses and even to the leptites.

pyrite: Heavily altered to limonite (compare with 8 0 1 0 2 5). Two generations of limonite form concentical layers.

magnetite: Small euhedral or subhedral, often cubic grains in the matrix. Partly altered to limonite.

limonite: See pyrite and magnetite.

sphalerite:
galena :
chalcopyrite: Forming elongated aggregates of anhedral crystals.

8 0 1 0 3 9: (Section II) granite, Haervola, vein-type mineralization of galena-chalcopyrite-sphalerite in cavernous quartzitic matrix. Two types of aggregates were to be seen:

I

galena crystal enclosed by thin pyrite-covelline rims.

II

galena, pyrite, sphalerite, magnetite, hematite, secondary limonite and covelline.

galena: Occasionally the crystals show sub-polygonal outlines against quartz and are enveloped by thin covelline rims. Contacts between galena and chalcopyrite are smoothly curving. Galena is also filling joints in the quartz.

chalcopyrite: Forming cavernous aggregates with galena, magnetite, hematite and lesser amounts of limonite. Chalcopyrite is altered into covelline (fig. 32).

sphalerite: Very dark, almost black sphalerite forms irregular inclusions with rims of chalcopyrite (fig. 31) in the magnetite. Larger zoned crystals with curving boundaries are filled with ultra fine-grained inclusions (fig. 28).

magnetite: Magnetite crystals are anhedral, exsolving the hematite content in irregular formed blocks. Magnetite is intergrown with chalcopyrite and quartz (fig. 30). Under crossed nicols a spindle-shaped network that forms exsolution of hematite in magnetite is to be seen.

hematite: See magnetite.

Fig. 29: 8 0 1 0 3 9 Haervola granite, polished section, // nicols, magnification x40, zoned sphalerite with curving crystal boundaries between magnetite and chalcopyrite.

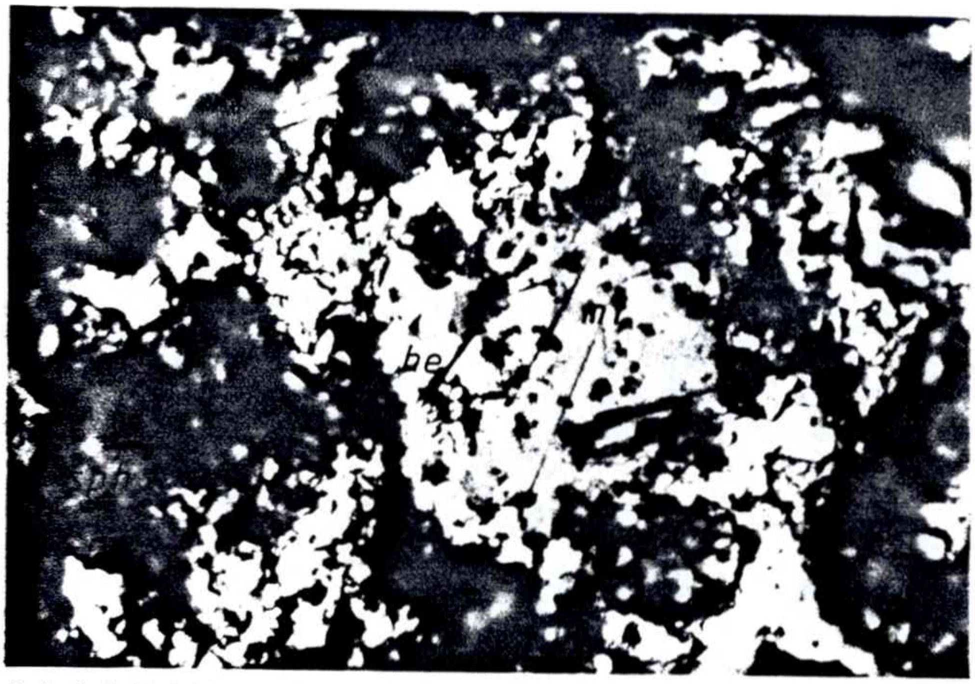


Fig. 30: 8 0 1 0 3 9 Haervola granite, polished section, // nicols, magnification x400 vuggy aggregate of sphalerite, (covelline), hematite-magnetite and sphalerite.

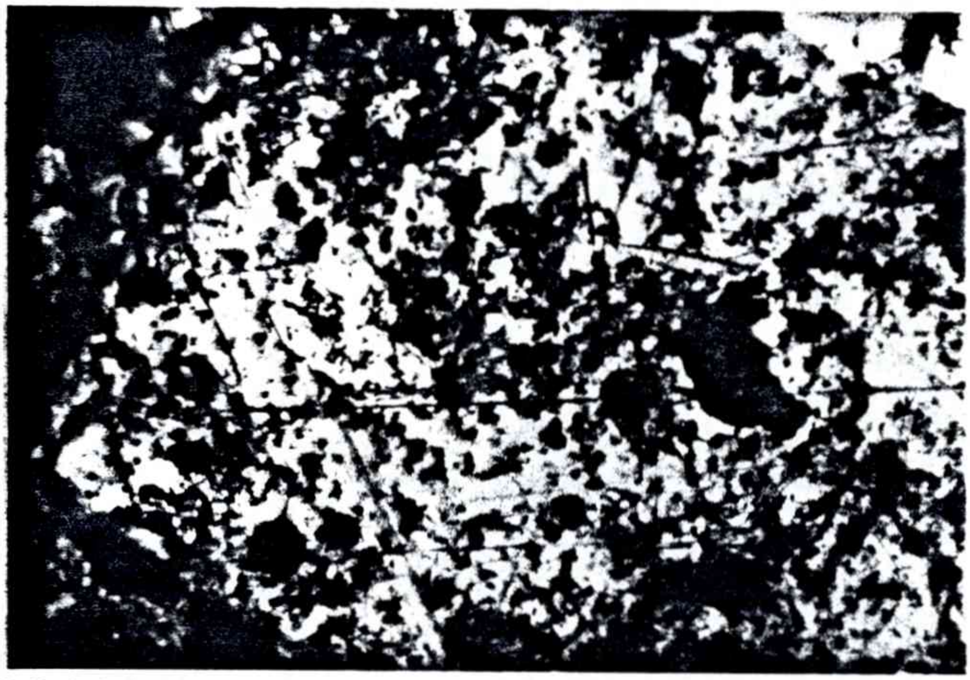


Fig. 31: 8 0 1 0 3 9 Haervola granite, polished section, // nicols, magnification x400, sphalerite inclusion with chalcopyrite rim in magnetite.

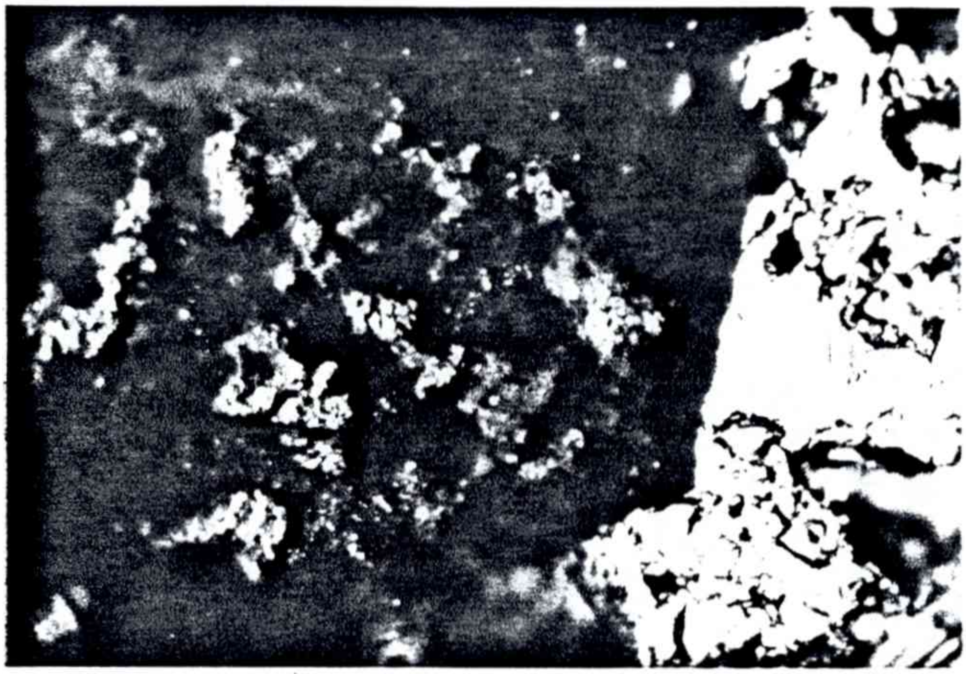


Fig. 32: 8 0 1 0 3 9 Haervola granite, polished section, // nicols, magnification x400 vuggy aggregate of chalcopyrite, covelline showing the typically violet tarnish.

4.5. Fremstfjellet

Mo i 81 (4): Vein-type mineralization of pyrite-chalcopyrite-molybdenite in quartzitic matrix.

pyrite I: Anhedral-subhedral crystals in the groundmass or as small ovoid inclusions in silicates. Pyrite I is also forming thin layers around the margins of biotites.

pyrite II: Anhedral, cataclastic but recrystallized pyrite interstitial to silicates of the groundmass with irregular-formed outlines, as ovoid or lensoid inclusions of chalcopyrite and pyrrhotite.

pyrite III: Anhedral cataclastic but larger recrystallized aggregates in a quartzose matrix with small ovoid inclusions of pyrrhotite and sphalerite.

chalcopyrite I: Ovoid small inclusions of greenish chalcopyrite in pyrite.

chalcopyrite II: An-subhedral cataclastic crystals in the groundmass.

molybdenite: The white molybdenite with strong pleochroism (white-darkgrey) is further characterized by high anisotropism. The crystal are of tabular shape, subhedral with irregular basal face. Molybdenite shows high degree of cataclastic deformation e.g. broken crystals, partly curved tabulars with highly developed translation along "imbricate structure". Where the tabulars are broken the molybdenite forms very fine grained crystals in quartzose matrix in a similar way to graphite. Fragments of coarser-grained molybdenite are included and surrounded by gangue minerals, pyrite and chalcopyrite, so that molybdenite appears to belong to a primary mineralization.

pyrrhotite: See pyrite III.

sphalerite: Black sphalerite, Fe-rich, as small lensoid inclusions in pyrite III.

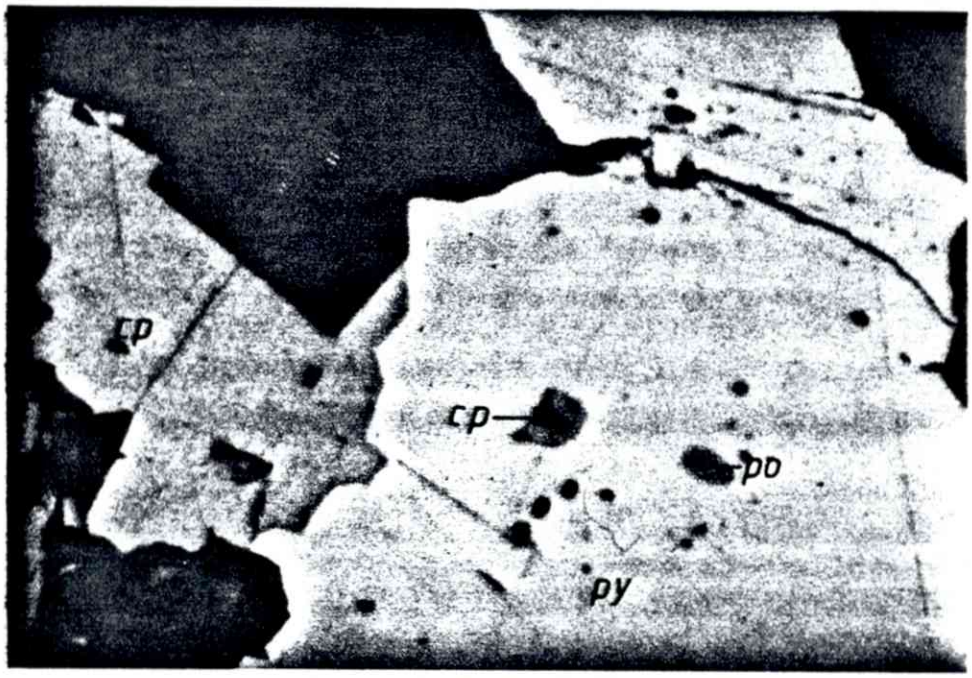


Fig. 33: Mo I 81 (4) Fremstfjellet, polished section, // nicols, magnification x400 chalcopyrite-pyrite-aggregate with ovoid inclusions of pyrrhotite and irregular-formed fragments of chalcopyrite.

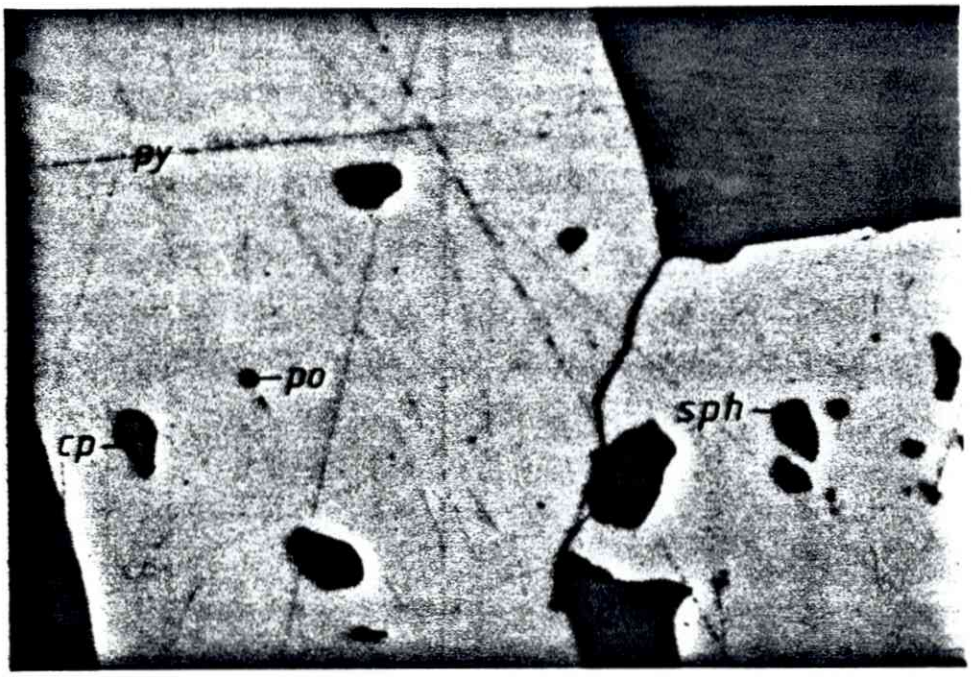


Fig. 34: Mo I 81 (4) Fremstfjellet, polished section, // nicols, magnification x400, subhedral pyrite within inclusions of ovoid-irregular formed chalcopyrite-pyrrhotite and sphalerite.

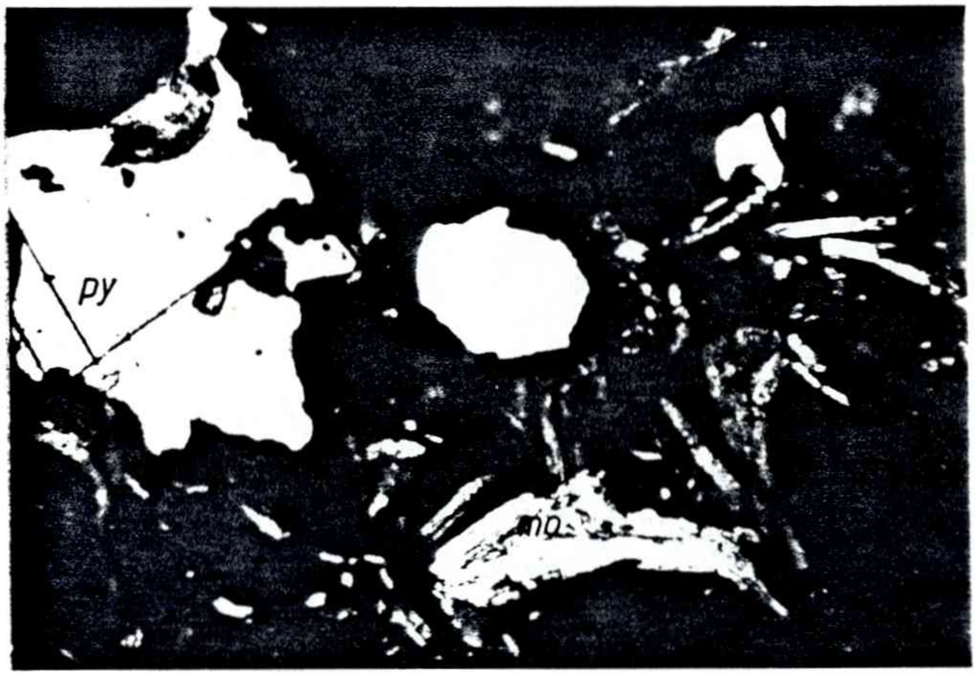


Fig. 35: Mo I 81 (4) Fremstfjellet, polished section, // nicols, magnification x160, pyrite with cuspate outlines and molybdenite in quartz. Pyrite includes fragments of molybdenite.

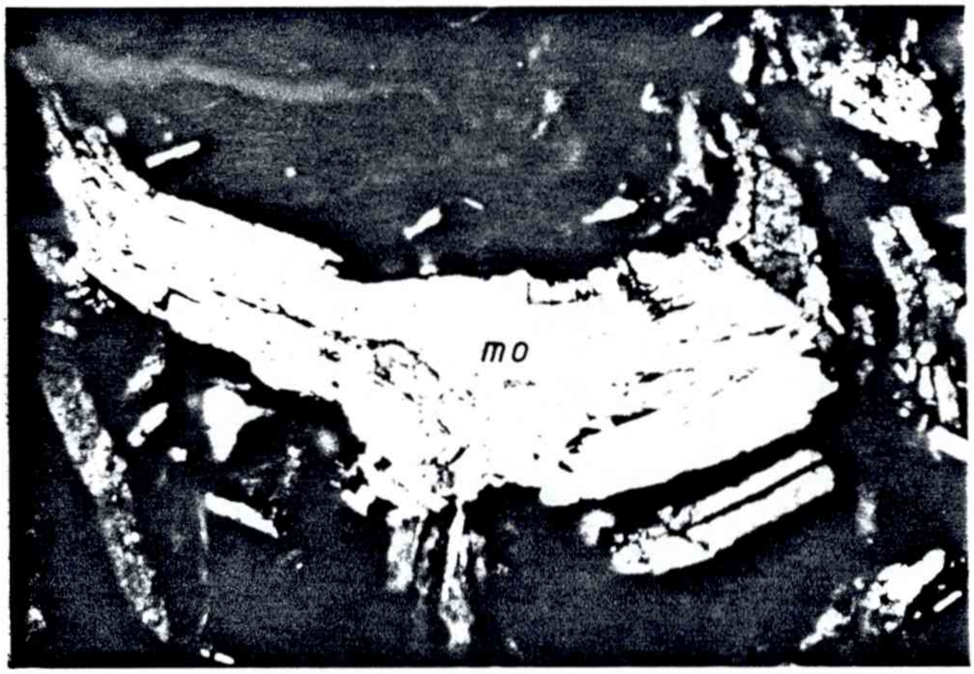


Fig. 36: Mo I 81 (4) Fremstfjellet, polished section, // nicols, magnification x400, deformed molybdenite tabular in quartzitic matrix (section of fig. 24).

4.6. Leptites

8 0 1 0 1 9: Altered leptite with sphalerite mineralization. The stratabound mineralization is formed as impregnation of elongated pyrite and sphalerite crystals in banded leptites. Besides pyrite, chalcopyrite and magnetite-ilmenite occur as primary ore minerals of the host rock. The mineralization is very fine-grained and heterogenous.

magnetite: Small anhedral crystals in the groundmass.

magnetite-ilmenite: Larger anhedral aggregates of magnetite and ilmenite. Ilmenite is strongly weathered to limonite.

pyrite: Cataclastic anhedral and elongated larger crystals in the groundmass closely associated to biotite-muscovite-layers (fig. 26).

chalcopyrite: Small anhedral crystals in the groundmass interstitial to the silicates.

sphalerite: Sphalerite crystals are associated with pyrite forming large elongated aggregates with biotite-muscovite, while locally platy quartz is also involved.

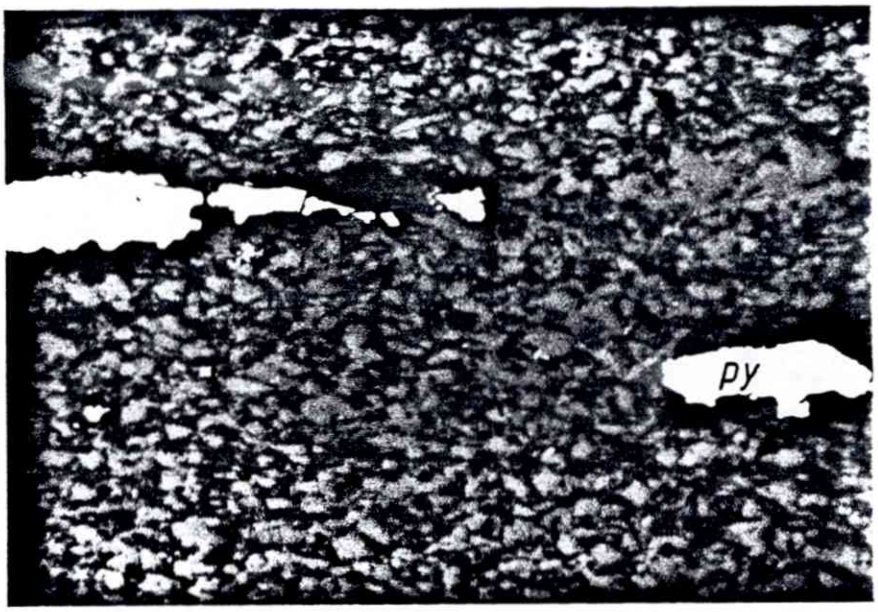


Fig. 37: 8 0 1 0 1 9 leptite, polished section, // nicols, magnification x50, elongated pyrite aggregates with irregular crystal shape, closely associated with biotite forming layers together with quartz.

4. List of ore sections

4.1. Roktdalen:	900101A/B	840101
	900103	840103
		840104
		840108
		840113
4.2. Gressamoen:	800135A/B	
4.3. Metabasites:	800116	
4.4. Haervola Granite:	801025	801039
4.5. Fremstfjellet	Mo I 84(4)	
4.6. Leptites	801019	

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