NORGES GEOLOGISKE UNDERSØKELSE NR. 199

The Copper Deposits of the Birtavarre District, Troms, Northern Norway.

BY

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SAMMENDRAG:

KOPPERFOREKOMSTER
I BIRTAVARRE-OMRÅDET
TROMS

WITH 67 TEXT-FIGURES
AND 13 PLATES

OSLO 1957

I KOMMISJON HOS H. ASCHEHOUG & CO.

CONTENTS

ABSTRACT

The report gives the results of a 4-year (1952—55) programme for the investigation of a former copper-mining area in the north of Norway, carried out by the Geological Survey of Norway (NGU). The area lies in the county of Troms at latitude 69°30'N and longitude 21°E, about 85 kilometres due east of the city of Tromsø. Mining of the chalcopyrite-pyrrhotite ores took place, with several interruptions, between 1900—1919. In all, perhaps some 200,000 tons of ore were mined from several small deposits lying on the plateau surface at elevations between 900—1000 metres above sea level, on either side of the deep U-shaped valley of Kåfjorden which transsects the area in a SE-NW direction (see Plate I).

The stratigraphy and structure of the district have been described in a previous NGU publication (Padget 1955). The ore deposits occur in one particular division (Ankerlia Series) of the layered Caledonian schists which underlie the whole area (see Plates 1 and 2). No deposits have been found outside this division. The greatest concentration of deposits occurs in the centre of the area along the south limb of a major, open E—W anticline (Moskogaissa anticline). In this same area the normally NW-plunging linear structures of the schists show a marked swing to an E—W direction (Plate 2). It is suggested that this area of "structural anomaly" has been responsible for the concentration of the sulphides. However, all kinds of control have been relatively weak and nowhere have the orebodies reached significant size by modern standards. It appears that the ore-bearing solutions spread out over large areas along zones of minor shearing within the Ankerlia Series. These zones lie roughly concordant with the schistosity and bedding of the schists and manifest themselves at outcrop as bands of marked rusting which are easy to follow in the field. Within these "sulphide-zones" or "horizons", the ore-bodies worked in the past formed greatly elongated plates of variable dimensions (see pp 28-29, Figs. 3-5) with the greater axis always parallel to the direction of lineation of the schists (Plate 2). The thicknesses of the sulphides were variable in the extreme, ranging from perhaps 5 m. to some few centimetres. Diamond drilling in 1954 and 1955 confirmed the extreme variability in thickness of the sulphide plates in the unworked areas.

The country-rocks to the ore-bodies (pp 34-68) are mainly quartz-hornblende-plagioclase- and quartz-hornblende-biotite-(clino)zoisite-schists now in epidote-amphibolite or lower amphibolite facies of regional metamorphism. Analyses, modes and mesonorms are given for representative samples of each type of schist. In the upper part of the Ankerlia Series, especially the area of the

Moskogaissa mines, large amounts of apparently meta-basic amphibolites occur interlayered with the schists. Analyses, modes and catanorms of some of these rocks are given and it is concluded that they represent originally olivine-basaltic or doleritic types, both extrusive and intrusive, which are referable to a period of basic igneous activity during the Caledonian orogenic cycle.

Descriptions are given (pp 68-107) of the structural features of the sulphide zones as revealed in diamond-drill cores and in old workings still accessible. Conclusions are reached concerning the nature of the pre-ore movements and the walls of the ore-bodies. It is shown that weak post-ore movements occurred along one or both of the walls in places, involving polishing and slickensiding of the sulphides.

Investigations of the actual ores show they consist of two main types, breccia-ore and impregnation-ore, in close connection with each other and often with transitions between them.

The minerals of the ore and the textures exhibited by them are described (pp 108-132). The chief minerals are pyrrhotite, chalcopyrite, sphalerite, cubanite, with minor minerals pyrite, valleriite, molybdenite, galena and marcasite. Magnetite is present in some few localities. There is no evidence of any other mineral introduced with the sulphides and all the silicates are considered as being mechanically derived from the wall-rocks.

The paragenesis is discussed (p. 133) and it seems clear that the great bulk of the sulphides (i.e. the pyrrhotite and chalcopyrite) were introduced together and crystallised more or less contemporaneously. There is evidence that sphalerite has replaced the copper-mineral. Some time later than the main crystallisation, quantitatively minor replacement of the chalcopyrite by valleriite occurred. Lamellar textures exhibited in polished section by the pyrrhotite are discussed. Using the FeS-ZnS equilibrium method of Kullerud on sphalerites separated from the ores the probable temperatures of formation of the ores are given. (p. 135).

The chemistry of the main and trace elements of the ores is discussed (pp 136-148). Among the trace elements the distribution of Co and Ni in pyrrhotites is interesting. There is always an excess of Co over Ni, suggesting a hydrothermal as opposed to a magmatic origin for the sulphides. The geochemistry of Ag, Mo, Se, Cd and Mn in the sulphide minerals is discussed.

Metasomatic alteration of the wall-rocks along the ore-zones is marked in the area west of Kåfjorddalen (pp 148-174). The alteration involves the formation of rocks rich in anthophyllite and garnet, with subsidiary chlorite and minor staurolite. The anthophyllite was the first to form from the common hornblende of the schists and developed in places into large individuals often showing a "rosette texture". It was subsequently partly crushed during continued shearing along the ore-zones and has, to varying extents, been altered to chlorite. Garnets developed in large quantities in all the metasomatic rocks, but their time-relationships are not so easy to work out. Chemical analyses of the anthophyllite and the garnet are given. The former is an alumian anthophyllite, using Rabbitt's nomenclature; the garnet is dominantly almandine.

Chemically the metasomatism has involved addition of Mg and Fe and removal of Ca and alkalies. The changes are demonstrated quantitatively by several analyses (pp 163-169). The mode of formation of the metasomatic rocks is discussed on pp 169-174.

The origin of the ores is discussed on pp 174-188. After reviewing the development of ideas concerning the sulphide ores of the Norwegian Caledonides, the writer suggests that a common origin for the non-sedimentary types is indicated, involving one of the major processes of the orogenic belt. This process is considered to be the granitization of the geosynclinal sediments and volcanics during which the sulphur and metals were concentrated in front of the granitic front and subsequently emplaced along late-stage thrust- and shear-planes in the schists up-dip from the region of metallization.

The last section of the report deals with the history of mining and the economic factors that would affect mining in the area and gives descriptions of the individual mines and prospects of the area. It is shown that "ore" of a mineable width would be expected to have a copper content near, or below 1 %, which is definitely submarginal considering the price of copper to be expected in the forseeable future. Tonnages to be expected from any ore-body would be too small to warrant the necessary capital investment.

INTRODUCTION

Situation of the area investigated.

The Birtavarre district lies in the county or "fylke" of Troms in northern Norway at approximately 60°30′ N latitude and 21°E longitude (10°E of Oslo). The centre of the district is some 85 kilometres due east of Tromsø and about 15 kilometres from the Finnish frontier. Birtavarre itself is at the head of Kåfjord, which is a south-east-running inlet from the much larger, north-south, Lyngenfjord. From the head of Kåfjord the valley of Kåfjorddalen runs south-eastwards towards Finland for about 20 kilometres. The river running down the valley (Guollejok or Kåfjord elv) rises on the high ground known as Reisduoddar Haldde (Haldit) on the actual frontier (see map, Plate 1).

Habitation is confined to the actual valley floor and houses are spread along the whole length of Kåfjorddalen for some 8 or 9 kilometres from the sea. The post office, landingstage and main store are situated at Birtavarre itself at the head of the fjord, but there is no particular concentration in any one part of the valley which might be termed a village. Farms and individual dwellings are scattered along the north-east shore of Kåfjord as far as its junction with Lyngenfjord. On the south-west side of the fjord, which is much steeper, habitations are confined to the mouths of the two tributary valleys, Mandalen and Skardalen.

The main occupations in the area are small-holding, with a a few cattle and sheep, and a little fishing. For a large part of the population existence seems to be very precarious and many of the menfolk have to seek employment outside the area.

Physical Features.

The area comprises generally a very undulating plateau with an elevation between 800 and 900 metres above sea level, falling very steeply to the main fjords and coastline in the west. In places marked areas rise above this general level, as, e.g. Haldit, the Moskogaissas and Isavarre. Into this plateau have been excavated the present-day valleys which carry the drainage to the coast, in particular Kåfjorddalen, Skardalen and Mandalen. The valleys are typically U-shaped and of obvious glacial origin. Hanging-valleys and corries are common along their sides. The valleys become progressively deeper and more U-shaped towards the fjords and their walls are often quite sheer for anything up to 1000 metres, as for example the south-west side of Kåfjorddalen at Birtavarre.

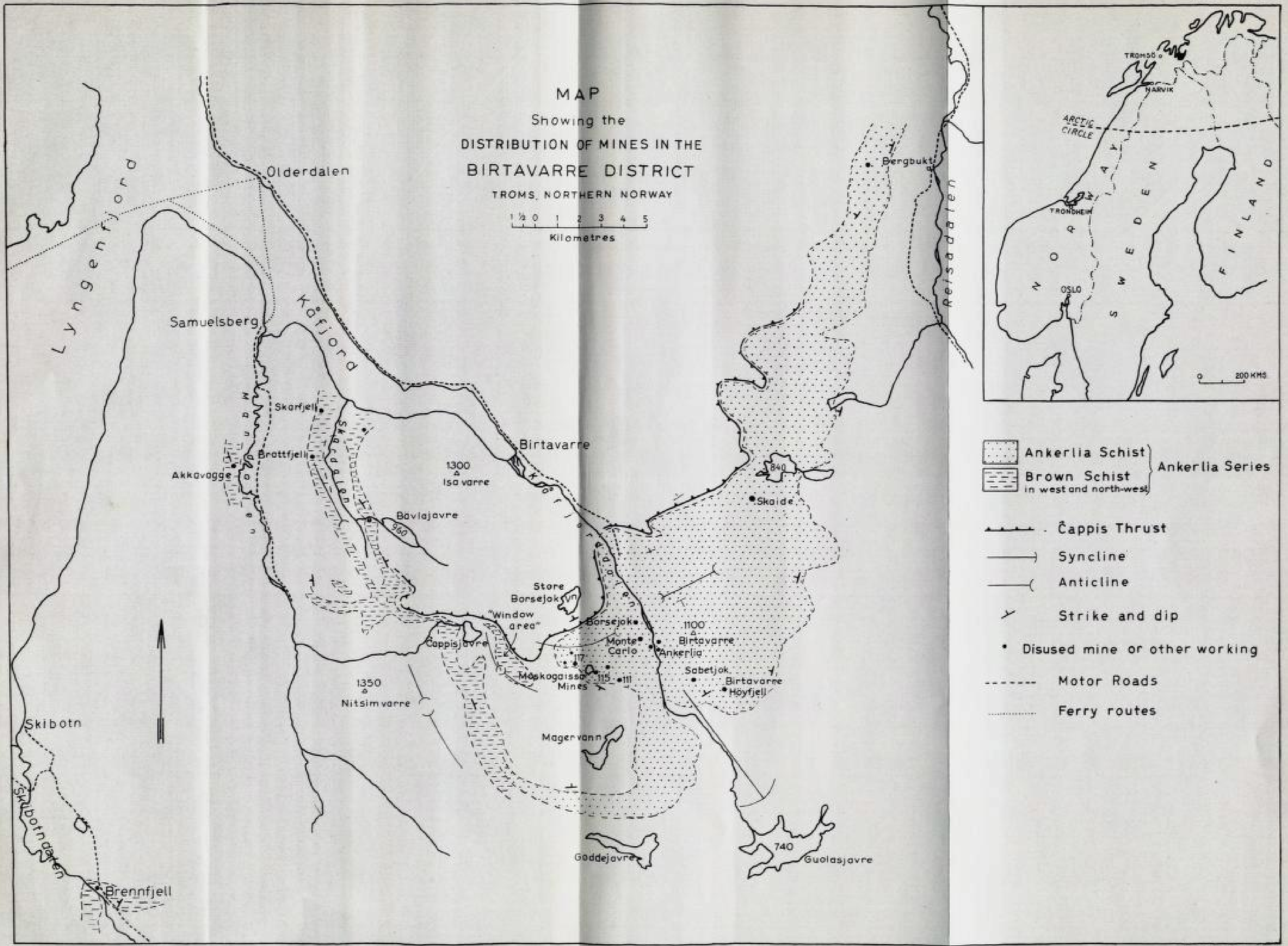
The main Kåfjord valley shows a remarkable "step" just above Ankerlia and after this the valley opens out rather rapidly on to the plateau. The Guollejok has incised itself into a deep canyon which stretches upstream from Ankerlia for about 2 kms.

The plateau surface is on the whole harsh and rugged, though differences in the geology cause marked modifications in places. Surface drainage is abundant and the area abounds in lakes of all sizes.

Climate and Vegetation.

The climate on the plateau, where most of the old mines are situated, is sub-arctic in character, the combination of high latitude and relatively high altitude producing very severe winter conditions. In the valleys this is somewhat ameliorated by the decreased altitude, proximity to the sea and more sheltered position. The growing season in the valleys is limited to the period late June to middle August. The main crops which can be grown are potatoes, roots and hay. Oats are grown as green fodder but it is only very exceptionally possible to ripen cereals.

In the valleys the natural vegetation is the northern birch (Betula odoracta) and the alder (Alnus incana), but these are confined to below a height of ca. 300 metres, the tree line being sharply marked. Above this, especially on the plateau the vegetation


MAP
Showing the
DISTRIBUTION OF MINES IN THE
BIRTAVARRE DISTRICT
TROMS, NORTHERN NORWAY
Kilometres
Olderdalen
Lyngenfjord
Samuelsberg
Kåfjord
Skarfjell
Skardalen
Brattfjell
Akkavagge
1300 Isa varre
Bavlajavre
960
Birtavarre
Kåfjorddalen
Store Borsejokvn
"Window area"
Čappisjavre
Borsejok
Monte Carlo
Ankerlia
1100 Birtavarre
117
115
111
Møskogaissa Mines
Sabetjok.
Birtavarre Høyfjell
1350 Nitsimvarre
Skibotn
Magervann
Skibotndalen
Brennfjell
Goddejavre
740
Guolasjavre
Bergbukt
Reisadalen
840
Skaide
TROMSØ
NARVIK
ARCTIC CIRCLE
NORWAY
SWEDEN
FINLAND
TRONDHEIM
OSLO
200 KMS.
Ankerlia Schist
Brown Schist in west and north-west
Ankerlia Series
Čappis Thrust
Syncline
Anticline
Strike and dip
Disused mine or other working
Motor Roads
Ferry routes

is sparse in the extreme, consisting of hardy grasses and mosses. The dwarf creeping birch (Betula nana) is found in more favourable places.

Communications.

Birtavarre is visited by small coastal steamers from Tromsø twice weekly and nearly all supplies, building material etc. are brought in by this means. On land there is a fairly good motor-road from Olderdalen to Birtavarre and beyond this for about 9 kms. up the valley. Olderdalen is the eastern terminus of a ferry service which carries all traffic on the main road from Narvik to Kirkenes (Riksvei 50) across Lyngen Fjord. It is 175 kilometres from Olderdalen to Tromsø by road. Access to the old mines from the valley is afforded by steep, winding mountain tracks which are negotiable by local horse and waggon transport. The track to the Moskogaissa mines is probably suitable for vehicles of the "jeep" type.

Previous work in the area.

When the present investigation was begun, very little was known of the geology of this part of northern Norway. The geology of the region around Birtavarre has been discussed at length by another member of the NGU survey team (Padget, 1955). He gives a resumé of the publications relating to the geology of the Birtavarre area, all of which are concerned with general regional geology or geomorphology.

Concerning the mines of the area there are available unpublished reports from mine managers, consultants, and inspectors of mines. Many of the reports from the first mentioned are obviously "selling reports" and must be read with a certain amount of circumspection. Useful information concerning the geology of the deposits is contained in a report (in German) by R. Støren (1912) and in one (in Swedish) by Aronsen and Hunger in 1919. These reports gave a limited idea of the nature of the ores as a starting point for the present work. T. Gjelsvik (1953) has published a short account of the first year's work in the present investigation, laying special emphasis on the correlation between the Birtavarre area and the Vaddas mining district to the north.

Present investigation.

In the summer of 1952 the Geological Survey of Norway started a systematic survey of the area in connection with the Government's "North Norway Plan", which provides for the investigation and development of the economic potentialities of the northern part of the country. The Birtavarre mining district was selected partly because of the presence of a rather large, somewhat "depressed" population, in the hope that a revived mining industry would provide the people with a surer means of livelihood. The social aspects of the problem carried as much weight as, or more than, the economic ones.

During the field season of 1952 geological mapping of the area on both sides of Kåfjorddalen, and embracing the old mines at Moskogaissa, Skaide and Sabetjok, was begun by a field team under the leadership of State geologist Dr. T. Gjelsvik, and comprising P. Padget and J. A. Dons, with F. Hageman as field assistant.

Following this work a map on the scale of 1 : 26500 was prepared of an area of roughly 220 sq. kms., using aerial photographs as a base. From this map the stratigraphical position of the ore-deposits was deduced and the geographical distribution of the ore-bearing formation plotted. Plans were drawn up for geophysical investigations of promising areas within the ore-bearing belt. The author joined the investigation for the field season of 1953 and, together with Padget, widened the area of general geological mapping and began the detailed mapping of the area around the mines at Moskogaissa. Underground investigations were made at Sabetjok and Skaide. At the same time geophysical measurements were made at Moskogaissa by a field team from Geofysisk Malmleting, Trondheim. This latter work outlined several areas of electro-magnetic indications in connection with the ore-horizons along which the old mines were situated. In particular a rather large one was found in connection with the mine known as Moskogaissa 115, the former largest producer in the area.

The 1953 field season saw the completion of the geological mapping in the area as a whole, but a certain amount of detailed work still remained in the area around the mines. This was completed by the author during the following season, 1954, when also diamond drilling was carried out on the Moskogaissa 115 anomaly and further geophysical measurements made around the old mines of Skaide and Sabetjok on the north-east side of Kåfjorddalen. The drilling at Moskogaissa was attended by many difficulties, the chief of which was the unexpectedly thick and bouldery nature of the overburden. As a result the original programme had to be revised and a smaller number of holes drilled than had been planned. In all 840 metres of core were drilled, seven holes being put down to the ore-horizon near Moskogaissa 115 and two on a smaller anomaly north of this. The results of the intersections were very disappointing. Details of the thicknesses and grade are given later (see p. 210).

The 1954 geophysical measurements revealed small and weak anomalies at Skaide, but a more promising one between Sabetjok and the prospect of Birtavarre Høyfjell. This indication of sulphides, approximately 1.5 kms. long and 400 metres wide, lay in a geologically favourable position, elongated along the ore-shoot direction between the two old workings and was obviously an area to select for drilling during the 1955 field season.

During this season seventeen holes were drilled over the anomaly with a total length of 1260 metres. The results were disappointing from an economic point of view and it was decided not to recommend further work in the area (see p. 217 for details of the 1955 drilling).

Acknowledgements.

As can be seen from the foregoing account, the Birtavarre investigation has been a team effort involving a large number of people. To all of them the author's sincere thanks are due for their friendly cooperation, help and advice, both in the field and in the office.

The author is indebted to Mr. S. Føyn, Director of the Geological Survey of Norway, for introducing him to the problem, for facilities made available during the investigation, and for his keen interest and friendly advice at all times.

Especial thanks are due to the author's colleagues in the Birtavarre "team", in particular Tore Gjelsvik and Peter Padget. Many of the ideas embodied in the report are due to stimulating discussions with them, especially the latter, in both field and office.

Professor Tom F. W. Barth and Dr. H. Neumann of the Geologisk Museum of the University of Oslo kindly read sections of the manuscript and offered highly valued and stimulating criticism and advice.

The author's thanks are also due to Mr. B. Bruun and Miss E. Christensen for chemical analyses of the rocks and ores, to Mrs. E. Holmsen and Miss S. Øverland who typed the manuscript and to Miss D. Engelsrud who drew the maps and most of the figures.

The author wishes to express his appreciation of the co-operation and help received in the field from the Staff of Geofysisk Malmleting, Trondheim, especially from geophysicist Per Singsås and diamond drill foreman Johs. Bratli.

THE GEOLOGY OF THE ORE DEPOSITS

The reader is referred to the publication by Padget for details of the stratigraphy and structure of the district. The present author is grateful to be able to make use of his results in so far as they relate to the ore deposits.

Distribution and general relationships.

Relation to stratigraphy.

The area is underlain by layered metamorphic schists of the Caledonian orogenic belt, having a general strike NE—SW and a regional dip to the NW of the order of 15°—20°.

Padget divides the succession in the area as follows:

2. Birtavarre Series
   a) non-granitized schists
   b) granitized schists
1. Sparagmitic schists
   Basal Caledonian overthrust.

The non-granitized schists of the Birtavarre Series are divided up into a number of conformable stratigraphic units, comprising mainly quartz-hornblende-, hornblende-, and biotite-schists and metalimestones.

The present work has shown very clearly that the copper deposits lie within and only within one of these stratigraphic units and it became apparent after the first season's geological work that the mapping of this unit would completely delineate areas where ore-deposits might possibly occur.

The ore-bearing formation has been termed the Ankerlia Series since it is exceptionally well-developed and exposed in the sides of Kåfjorddalen around the old smelting site of Ankerlia. Padget makes the following sub-divisions of the Ankerlia Series in the central part of the area:

Upper Brown Schist
Ankerlia Schists upper
— banded
— lower
Lower Brown Schist.

In the central area, i.e. embracing the mines at Moskogaissa, Sabetjok and Skaide, ore deposits are found only in the Ankerlia Schists, which attain a maximum stratigraphical thickness of 700—750 metres. (The map, Plate 1, shows the area underlain by the Ankerlia Schists together with the main mines.) The ores occur at several levels within these schists, but not in the central banded division. They lie within zones up to a few metres thick which are apparently concordant with the schistosity and bedding of the meta-sediments. The out-crops of these zones are noticeable, where exposed, because of the red-brown "rusting" produced along them by the weathering of pyrrhotite. Although the sulphidic horizons are numerous within the Ankerlia Schists, only one or two contain ore-bodies which have been worked in the past.

It will be seen from Plate 1 that there is a comparative concentration of mines and prospects on either side of Kåfjorddalen at about the latitude of Ankerlia. The old mine of Skaide lies about 7 km. NW of Ankerlia, somewhat isolated from the rest of the workings. About 15 km, north-east of Skaide, a small "showing" occurs in the banks of a stream running down to Bergbukt in Reisadalen (see p. 231). Beyond this Padget has mapped the Ankerlia division into Reisadalen and it seems that the old mine at Moskodal on the north-east side of Reisadalen lies in it. This lies outside the scope of the present investigation, but points to a stratigraphic link with the Vaddas mining area.

North-west of Moskogaisa the ore-bearing schists dip under overlying formations and cannot be traced in that direction. An anticlinal inlier of Upper Brown Schist occurs within the higher formations due west of Moskogaissa (the so-called "Window" area — see Plate 1), but erosion has not reached the underlying Ankerlia Schists.

In the outcrop of the Ankerlia Series, which swings west between Magervann and Goddejavre, the Ankerlia Schists rapidly thin out and the Upper and Lower Schists merge. Padget regards this as an original depositional feature and can demonstrate the facies change by interfingering and thinning of the Ankerlia Schists (see also pp. 31-34). The now diminished representative of the Ankerlia Series can be traced northwards past Čappisjavre and over into Skardalen and Mandalen. It consists mostly of the facies of the Brown Schists with, especially in its upper half, notable interlayering of green hornblendic schists. Above the Ankerlia schists comes a great thickness of typical Store Borsejok Schists, so that the Green Beds and the Schists-with-thin-Limestones Series are not represented in this area. The green hornblendic layers might represent intercalated volcanic tuff connected with the outpourings of lava which presumably formed the Green Beds in the central area.

At Skaidičokka (see Fig. 1) the sulphide-horizon occurs roughly 50 metres stratigraphically below the base of the Store Borsejok Series. The interlayered schists occur exclusively above the sulphide-horizon, with typical Brown (quartz-biotite) Schists below. The base of these schists is ca. 75 metres stratigraphically below the sulphides.

At Brattfjell the thickness of the "footwall Brown Schists" has increased to 200—300 metres, though cover on the lower slopes of the valley makes it difficult to determine the exact base.

In the bed of the Skardalen river under Skarfjell mine Brown Schists are also exposed. This means a thickness of about 300 metres beneath the ore-zone. It seems certain therefore that the Brown Schists have thickened considerably northwards along Skardalen.

The underlying Guolas Limestone series is exposed in the river bed immediately below Skaidičokka, but was not seen elsewhere in the area. This series has been sketched in on the section in Fig. 1 from structural and stratigraphical considerations, though the Guolas rocks were not actually observed at the point. The northward plunge of the anticline brings the Brown Schist down to sea level at the mouth of the valley, so the Guolas Series probably forms a limited inlier on the floor of upper Skardalen.

At Akkavagge, in Mandalen, exposures beneath the sulphide-horizon are limited. The wall-rocks are interbanded green and brown schists, with the latter type dominating. Above the ore-zone (see below) were found green hornblendic schists with white bands a few mms in thickness, strongly resembling the Banded Ankerlia schists of the Birtavarre central area.

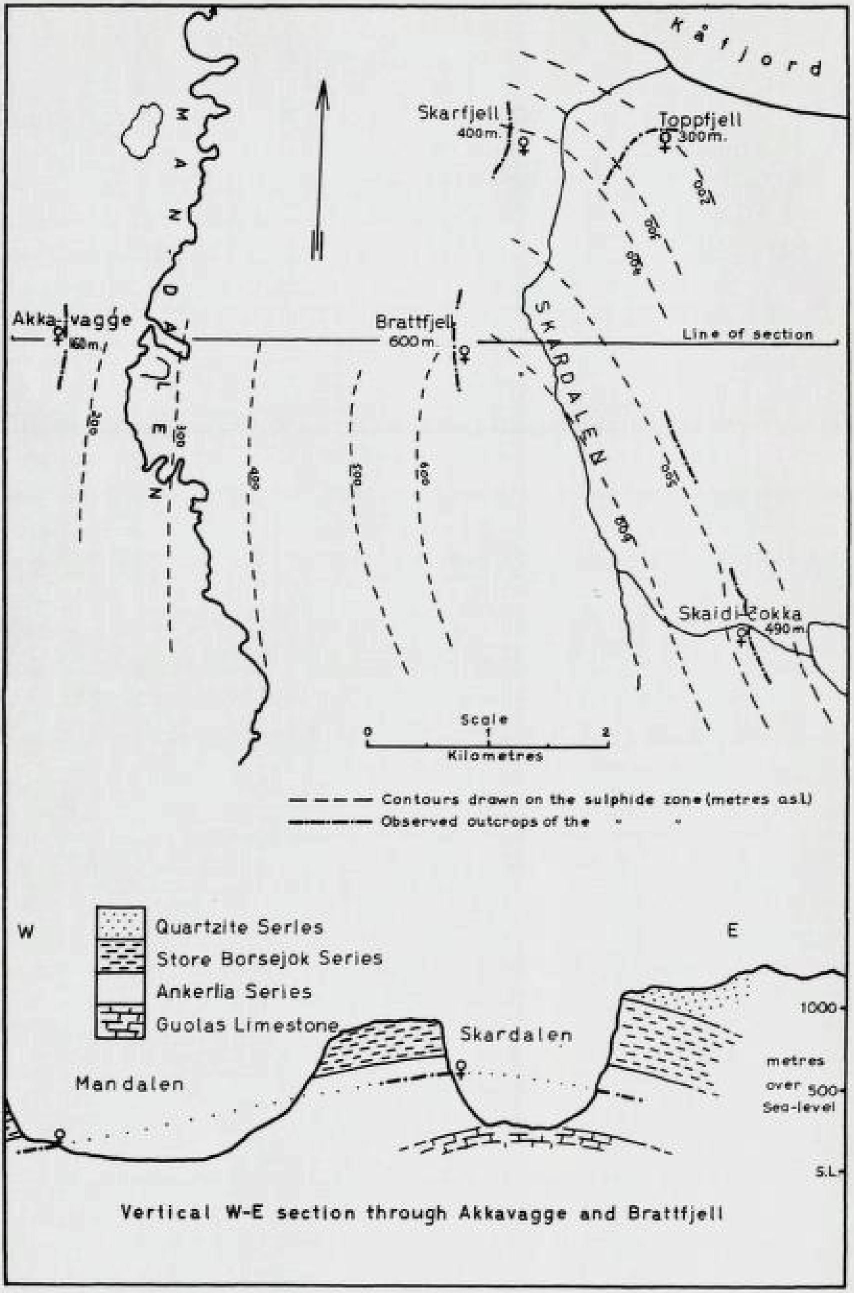


Fig. 1. Sketch map of the lower Skardalen—Mandalen area showing mines and prospects and the outcrop of the sulphide-horizon. W—E geological section through Brattfjell mine.

Kartskisse over området mellom nedre Skardalen og nedre Mandalen, som viser beliggenheten av gruver og skjerp og utgående av malmsonen. Geologisk profil V—Ø gjennom Brattfjell gruve.

The base of the Store Borsejok schists as determined in the Akkavagge stream is about 100 metres above the ore-zone. The tabulation below compares the section measured here with that at Skaidičokka.

Akkavagge.	*Skaidičokka.*
305 m. Store Borsejok musc. schist with a band of cryst. limestone.	
303 m. Impure limestone bands in green hbc. schist, 1—10 cm. thick.	
300 m. Green thin-splitting schist.	
275 m. Dark green hornblendic schist.	
250 m. Thin splitting, interbanded green and brown schists.	
245 m. Fine interbands of white, green and brown schist.	563 m. Store Borsejok muscovitic schist.
	540 m. As below with some amphibolitic layers.
235 m. White-banded green schist, strongly resembling Banded Ankerlia.	525 m. Brown schist with large numbers green bands.
215 m. Green white-banded schist with brown biotitic layers.	500—525 m. Brown schist with some green bands.
210 m. Green bands in brown schist.	490 m. Banded green and brown schists.
Ore	*Ore*
200 m. Brown quartz-biotite schist.	Brown quartz-biotite schist.
True thickness of Ankerlia Series above ore horizon, *90 metres.* (av. dip. 10°).	True thickness of Ankerlia Series above ore horizon, *50 metres.* (av. dip. 25°).

It can be seen that the Akkavagge section is much more complete. Not only does it seem that the Banded Ankerlia Schists are represented, but there are suggestions of Green Beds (300 m) and of Schists-with-thin-Limestones (303, 305 m).

The Skardalen area appears to have been an area of negative sedimentation for parts, at least, of the succession. This is also Padget's opinion (1955, p. 98). From broader structural considerations he concludes there has been a rigid block underlying the area (and to the south) and that this has been tectonically positive during the sedimentation of the series under discussion.

Whether the Akkavagge section means the beginning of a new basin of Ankerlia deposition to the west cannot be decided from the present work.

In the valley of Skibotn, in the SW of the area under consideration, a small outcrop of sulphides had previously been investigated by trenching and shaft-sinking, but no ore was discovered. (Brennfjell prospect, see Fig. 2.)

It is somewhat outside the Birtavarre area proper, but the stratigraphy and type of mineralization are exactly the same as further north. The country between Skibotn and lower Mandalen has not been directly investigated, but a study of aerial photographs and a knowledge of the geology of the region, make it fairly easy to link the Ankerlia series at Akkavagge with the rocks at Brennfjell.

The rocks in lower Skibotndal, just below the locality known as Lulle, are quite evenly bedded and dip fairly constantly in a north-westerly direction at values between 10° and 20° (Fig. 2). About 1 km. below Lulle impure limestone and calc-schists typical of the Guolas Limestone Series outcrop along the roadside. Their base is not exposed, but they are succeeded by about 400 metres of brown quartz-biotite-hornblende-schist, identical with the Brown Schist facies of the Birtavarre area proper.

This Brown Schist is quite homogeneous throughout its thickness here. It is very regularly "bedded", splitting readily into units from 2 to 30 cm. in thickness. There are many layers with large hornblendes (10 mm. long), and some with garnets. Many outcrops show concordant veins or lenses of quartz up to 10—20 cm. thick.

In the middle of the series, and at intervals in the upper half are layers up to 4 metres thick, extremely rich in dark hornblende. These layers carry considerable amounts of calcite as irregular, branching, but roughly concordant, veinlets. These are absent in the more "normal" Brown Schist. In some layers the veinlets are lens-shaped and composed of both quartz and calcite. The hornblendes have formed a mantle, or shell, up to 10 cm. thick, around these lenses.

Everywhere the carbonate or quartz-carbonate veinlets appear there is a very noticeable development of hornblende in the normal quartz-biotite schist.

Towards the top of the Brown Schist the alternating of the hornblende-rich and hornblende-free layers produces a market banding, units being 10—50 cm. thick.

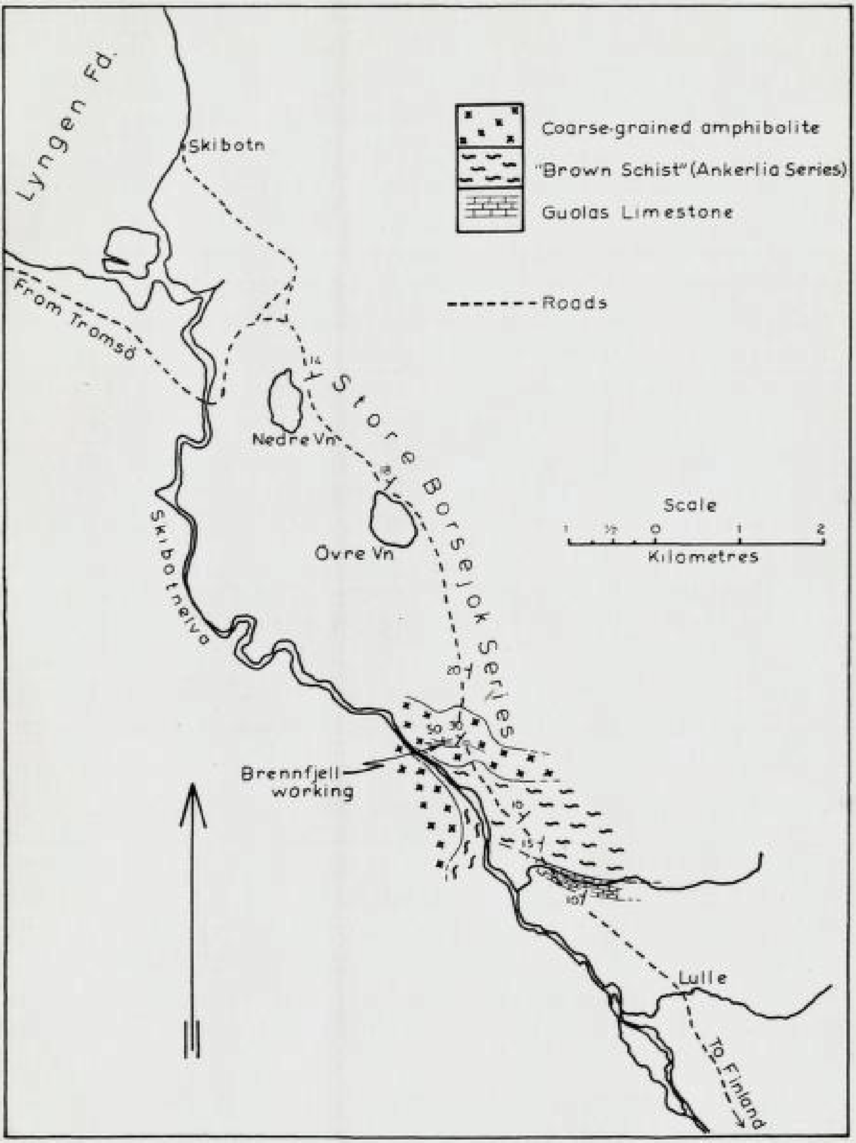


Fig. 2. Geological sketch-map of lower Skibotndal showing the location of Brennfjell prospect.

Geologisk kartskisse over nedre Skibotndal som viser beliggenheten av Brennfjell skjerp.

The field evidence seems to indicate that hornblende has formed in the quartz-biotite schist by reaction between the introduced calcite and the biotite.

These banded rocks of the Brown Schist series are overlain, some short distance south of Brennfjell prospect by a grey, coarse-grained meta-igneous rock (amphibolite). The rock carries yellowish carbonate veining in parts.

The ground around the prospect is almost completely covered and it is not possible to trace the rocks in detail. Other outcrops of the coarse-grained amphibolite occur north of the working, but in the spoil from this occur biotite-hornblende and hornblende schists as well as amphibolite. It may be that there is more than one layer of amphibolite lying in the top, banded part of the Brown Schist.

Overlying the amphibolite, and covering the ground northward to the sea, comes a large thickness of flatlying biotite and muscovite schists of the Store Borsejok series.

Thus although the immediate country rock at Brennfjell is not the same as in the main mining area, it is at the same stratigraphic horizon and the deposit may be considered to belong to the Birtavarre group.

Padget has shown that the great development of the Ankerlia Schists in the central part of the area is a comparatively local phenomenon. It is almost entirely confined to a short distance on either side of the axis of a large open syncline. This Kåfjorddalen syncline, named from its nearly exact coincidence with the main valley, is one of the large structural feature of the area, and it is Padget's opinion that the great thickness of Ankerlia Schists is due to deposition in an original trough, now represented by the syncline. The thickness of schists also increases north-westwards down the plunge of the syncline, i.e., towards presumed deeper water in the main Caledonian geosyncline, but they cannot be examined in this direction due to the cover of overlying rocks.

The coincidence of the *main* ore-bearing area with an abnormal thickness of a particular formation is quite striking, and seems to suggest some form of sedimentary control of the ore-formation.

Relation to regional structure.

The general north-westerly regional dip of the schists in the area is modified in places by fold structures of varying magnitude (see Plate I). The main one of these is the Kåfjorddalen syncline, mentioned in the preceeding section. The axis of this large fold runs almost along the centre of the Kåfjord valley, pitching at about 15° to the NNW in the vicinity of Guolasjavre, but lessening along Kåfjorddalen where it becomes almost horizontal. The dips of the beds on the limbs of this fold are usually fairly shallow, of the order of 10°—20°. The syncline is crossed almost at right angles in the vicinity of Ankerlia by a gentle anticlinal structure, pitching at about 10° to the west, which Padget has termed the Moskogaissa anticline. This structure loses its strength on the NE side of Kåfjorddalen where its northerly limb merges with the general northeasterly strike of the beds. Westwards, its axis curves round to the northwest as it pitches under the overlying beds. A couple of kilometres due west of Moskogaissa 115 mine an almost parallel anticlinal structure is marked by the inlier of Upper Brown Schist in the "window" area. Further northwest in Skardalen and Mandalen the structure is an open anticline pitching NNW (see Fig. 1). Northeast from Skaide the Ankerlia schists show moderate westerly dips on the east limb of the Kåfjorddalen syncline.

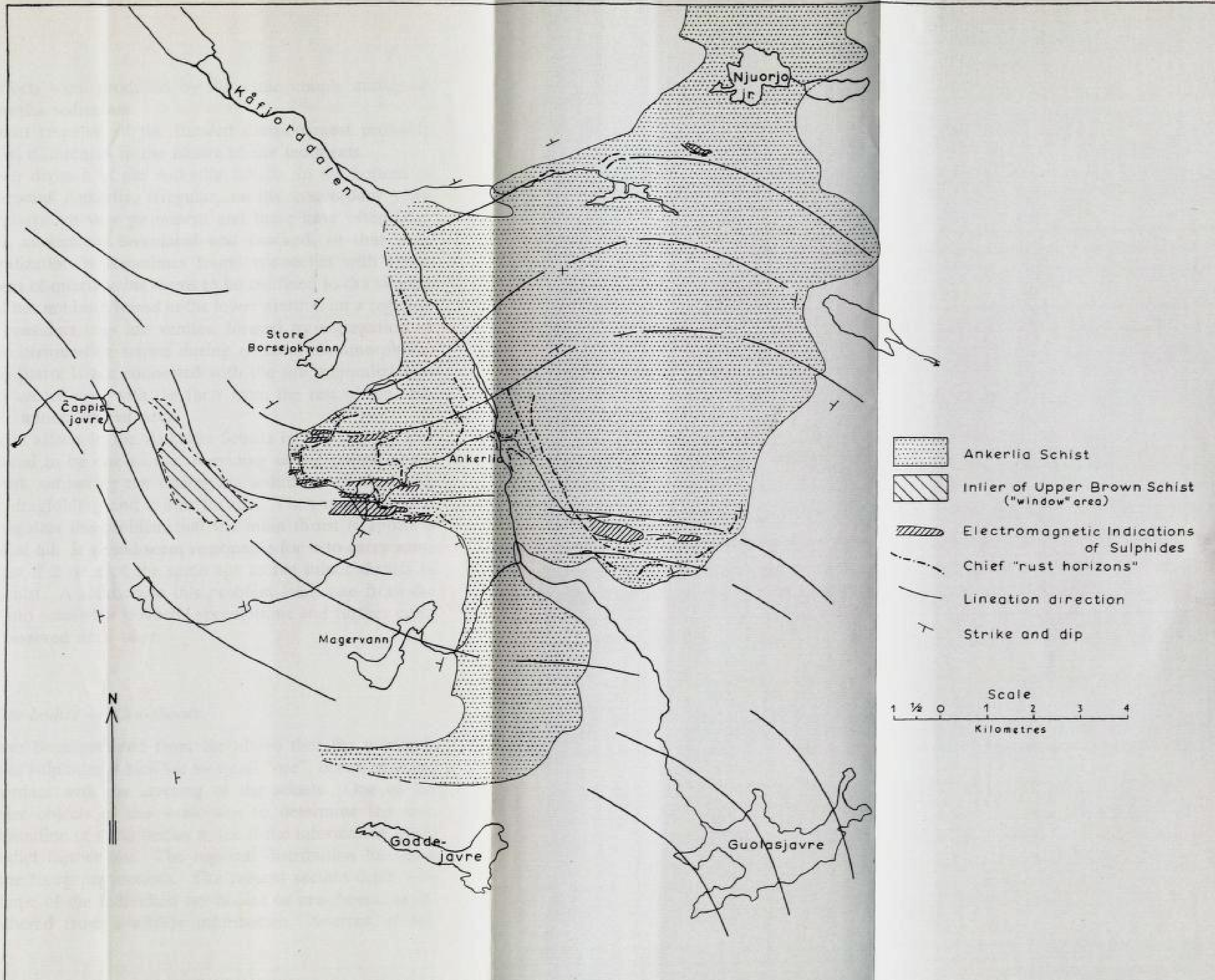
If one now considers the lineation in the schists of the area (orientation of elongated minerals, stretching, grooving and minor fold-axes) it is apparent at once that the central part of the area under consideration is anomalous. Padget's structural map of the region (op. cit. Plate I), shows that the general lineation direction is NNW, but that in the area on both sides of Kåfjorddalen there is a marked swing to an almost E—W direction (see Plate 2). The lineation is therefore parallel to the axis of the Moskogaissa anticline which indicates that this latter is a rather fundamental structure and not a later crossfold at right angles to the main structural grain of the region. These anomalous structures are thought to be due to a differential movement in a SE direction along the axis of the present Kåfjorddalen, during the main Caledonian orogeny.

Plate 2 shows that all the main mines and prospects of the central area are situated within this area of structural anomaly. In particular the mines at Moskogaissa, Monte Carlo and Borsejok occur along the Moskogaissa anticline itself. Skaide appears to be somewhat removed from this structure, but even here the lineation is in the anomalous E—W direction.

In the Mandalen—Skardalen area the lineation is in the regional direction, but there is a marked anticline parallel to the Kåfjorddalen syncline which is possibly of significance. Connecting this latter area with the Moskogaissa area there is the anticlinal structure revealed in the "window" area. Geophysical measurements have shown the existence of an elongated electromagnetic indication following the axis of this fold almost to Čappisjavre. This is most probably a continuation of the anomaly connected to Moskogaissa 115 mine.

Another structure of regional significance is the Čappis Thrust, the outcrop of which is shown on Plate 1. The rocks above this, i.e. to the NW, have been thrust forward to the SE over those beneath. In the SW part of its outcrop this thrust is separated from the ore-bearing Ankerlia Schists by a considerable thickness of schists, but towards the NE these intervening beds thin out, so that on the NE side of Kåfjorddalen it almost forms the upper boundary of the Ankerlia. On the whole this thrusting is only very slightly cross-cutting with regard to the layering of the schists, except in the Čappisjavre area (see Padget, op. cit. p. 77). The socalled ore-horizons in the underlying Ankerlia Schists also appear to be minor thrusts and shears on the whole concordant with the schists. Along them the schists have been mechanically and chemically affected, with the production of breccias and of sheared-out and crushed schist. There is no means of connecting these minor thrusts directly with the overlying Čappis Thrust, and it is not possible to determine the age relations between them. However, it seems very reasonable to suppose that the thrusts in the Ankerlia Schists were produced by pressure acting in the normal Caledonian direction in the area, i.e. NNW—SSE.

Within the Ankerlia Schists there have been differences in response to this pressure. In the upper and lower divisions the schists have in general failed by weak shearing and brecciation almost parallel to the schistosity, giving rise to structures favourable to ore deposition. In the Banded (or middle) division thrusting is absent and the rocks have been very markedly dragfolded, with overfolding consistently to the south. There seems every reason to suppose that


Kåfjorddalen
Njuorjo jr
Store Borsejokvann
Čappisjavre
Ankerlia
Magervann
N
Goddejavre
Guolasjavre
Ankerlia Schist
Inlier of Upper Brown Schist ("window" area)
Electromagnetic Indications of Sulphides
Chief "rust horizons"
Lineation direction
Strike and dip
Scale
1 ½ 0 1 2 3 4
Kilometres

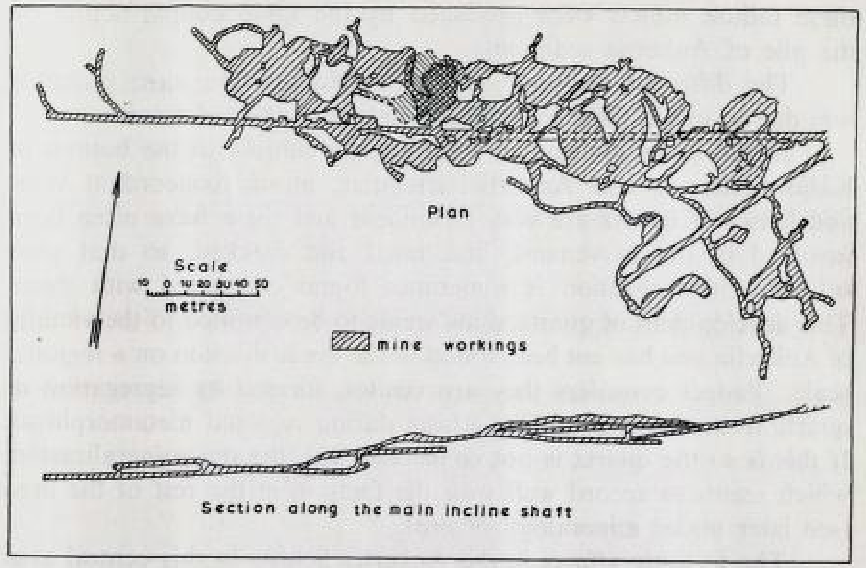


Fig. 3. Plan and section of Moskogaissa 115 mine. Drawn from the old mine plans.
Moskogaissa 115 gruve. Kart og profil tegnet etter de gamle gruvekartene.

information are the outcrops of the ore, inspections of accessible underground workings, old maps and records, geophysical measurements and diamond drilling.

In general it may be said that the outcrops tell very little about the form of the ore-bodies. Outcrops of sulphides were limited, and even these have been removed during working.

From the other sources of information the following generalizations can be made. The ores occur as very irregular "plates", greatly elongated along one axis, and of very variable dimensions. At Moskogaissa 115, which was the largest of the mines worked, the ore-shoot was about 300 metres long, with a maximum width of 60 metres (see Fig. 3). Skaide ore-shoot was 200 metres by about 80 (Fig. 4). The workings at Sabetjok show much less regularity as can be seen from Fig. 5. The geophysical measurements also confirm the elongated nature of the sulphide concentrations, a typical anomaly map showing cigar-shaped "leaders" at intervals along any particular ore horizon. Plate 2 shows the most important electromagnetic "leaders" in the Moskogaissa area and illustrates the

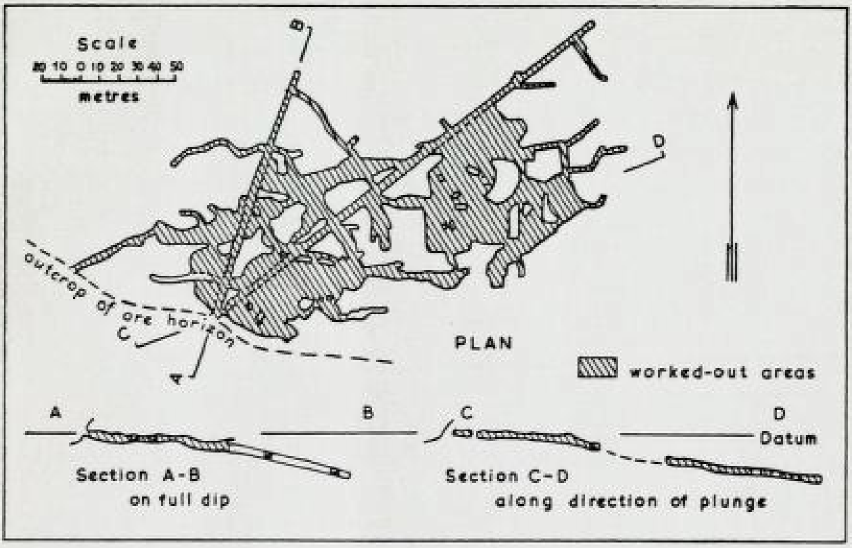


Fig. 4. Plan and sections of Skaide mine. Drawn from the old mine plans.
Skaide gruve. Kart og profil tegnet etter de gamle gruvekartene.

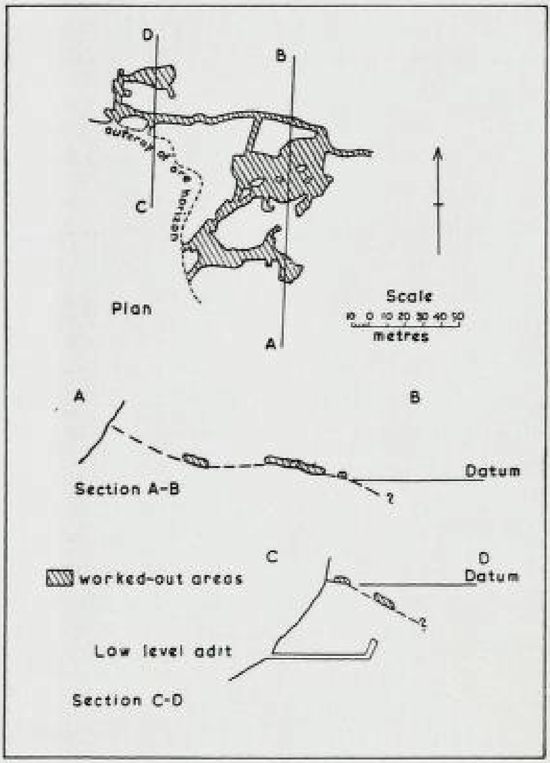


Fig. 5. Plan and sections of Sabetjok mine. Drawn from the old mine plans.
Sabetjok gruve. Kart og profil tegnet etter de gamle gruvekartene.

elongated nature of the "ore-bodies". It also illustrates a most important feature of the ores, that is the parallelism between the long axis of the shoots and the regional lineation. This parallelism is invariable in the area, as in other areas of sulphide deposits within the Norwegian Caledonides, and forms a valuable guide when following an orebody. It does not however, help very much in determining the presence of new ore-bodies.

Within each "plate" or ore-shoot the thickness of sulphides is subject to the greatest variations. According to the old mine plans and reports the "ores" varied very rapidly between 5 metres and a few centimetres. The unworked areas within the shoots no doubt represent places where the sulphides were too thin to be extracted economically. Occasionally local concentrations of sulphides occurred very unexpectedly. For example, in the Moskogaissa 115 mine in 1918 the workings struck a body of solid ore 6.5 metres thick, 18 metres long and 7 metres wide with an average copper content of 12.4 %. It is difficult to get a figure for the average thickness of the ore from the old reports, though it seems to have been around one metre at Moskogaissa 115. The 1954 drilling at Moskogaissa showed variations between 5 cm. and 2.60 metres in the thickness of the sulphide band. The vertical thickness of the mineralization in the Sabetjok—Birtavarre Høyfjell area was shown by the 1955 diamond drilling to vary between 10 cm. and 2.5 metres.

Although the ore occurs sensibly parallel to the schistosity, crosscutting relationship are evident in parts. Branching and splitting of the ore bands occur and in three out of seven holes drilled in 1954, there were two sulphide bands separated by up to 3 metres of country rock. The sections in Figures 3, 4, and 5, show the general form of the ores along the dip and plunge directions. Especially in the case of Moskogaissa 115 (Fig. 3) it can be seen that the ore band contains a number of downward "flexures" along the plunge. It is not clear, however, from the old plans what these flexures mean and the mine is inaccessible now. One cannot determine whether the flexures represent crosscutting to an underlying schistosity plane, or whether the schists themselves are flexed and the ore is wholly concordant. The records and plans also show that working took place to some extent on a sulphide plate lying about 5 metres under the foot-wall of the main ore, though not enough development took place to determine whether this was a

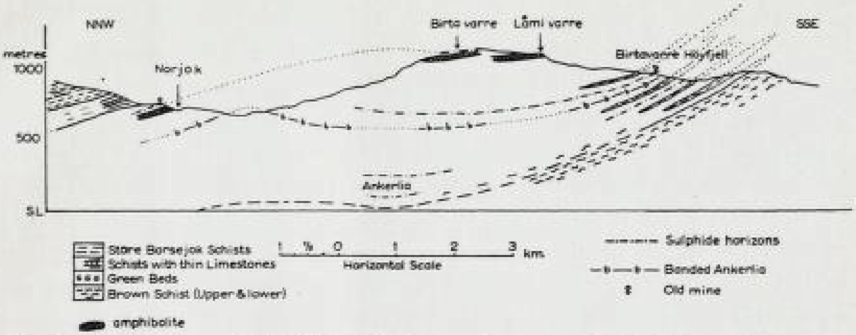


Fig. 6. Geological profile (NNW—SSE) along the east wall of Kåfjorddalen. (Interbanding of Ankerlia Schist and Lower Brown Schist in the neighbourhood of Birtavarre Høyfjell shown diagrammatically only.)

Geologisk profil (NNV—SSØ) langs den østlige vegg av Kåfjorddalen. (Veksling mellom Ankerlia Skifer og Nedre Brune Skifer tegnet diagrammatisk.)

separate horizon or merely a lower branch of the sulphides. The data gained during the boring in 1954 seem to point to the latter case.

The drilling carried out in 1955 between Sabetjok and Birtavarre Høyfjell again showed the tendency of the sulphides to split into two or more bands parallel to the schistosity of the surrounding rocks (see p. 219).

Correlation of the sulphide-horizons in the central area.

Since the sulphide-, or ore-zones in the Ankerlia series are essentially concordant with the bedding and schistosity of the rocks, it was of interest to try to form some idea of their areal extent and continuity. Such a study might have led to the identification of more important zones which might perhaps be of greater economic significance than smaller, local ones.

The correlation of the horizons on either side of Kåfjorddalen is not too easy, because of the distances involved and the fold structures on either side. The problem has been approached by drawing two profiles roughly parallel to the axis of the Kåfjorddalen syncline, one on either side of Kåfjorddalen, and two sections at right angles to these profiles, one through Sabetjok mine and the other through Ankerlia.

The profile along the east side of Kåfjorddalen (Fig. 6) shows diagrammatically the interbedding of the Ankerlia schist and Lower Brown Schist facies in the south, and the thickening of the Ankerlia schists as the beds are traced northwards down the plunge of the Kåfjorddalen syncline. The Sabetjok—Birtavarre Høyfjell sulphide horizon can be traced as a marked rust-zone along the steep walls of the valley to a point south of Ankerlia. At this place it has attained a slight southerly dip as a result of the E—W anticline which crosses the valley here. This dip brings the rust-zone up on to the flatter ground of the plateau and because of cover it cannot be traced further. If it does continue southwards, the structure would require it to dip south again, somewhere south of Norjok.

The Skaide horizon, with its associated amphibolite bodies, lies stratigraphically above the Sabetjok one. The amphibolite bodies, and a slight rust-zone on top of Birtavarre, and the amphibolites on Låmivarre represent an outlier of the Skaide "horizon".

Towards the base of the Ankerlia schists near Ankerlia itself are two small "rust" or sulphide-horizons. At Ankerlia the lower of these contains small bodies of sulphide-bearing quartz, which were worked on a small scale to provide smelter flux during the working period prior to 1919. The higher one, which can be examined in the steep hillside above the path down the valley from Ankerlia, shows one or two small outcrops of rich chalcopyrite. Several fallen blocks of this ore can be examined easily alongside the path, about a kilometre north of Ankerlia. Due to the distance involved and the lack of exposures it is not possible to correlate these last two sulphide horizons with those lying beneath the Sabetjok —Birtavarre Høyfjell horizon.

Fig. 7 is a profile west of Kåfjorddalen. It shows the interbanding of the two facies south of Magervann as described by Padget, and the thickening of the Ankerlia Series northwards. The E—W Moskogaissa anticline forms the main structural feature and involves the two sulphide horizons at Moskogaissa. Lying beneath the Banded Ankerlia Schists are the Monte Carlo horizon, the one lying below it (p. 225) and the Borsejok horizon. The latter two would appear to be one and the same, though the steep terrain and cover make it possible to confirm this directly. Lying beneath Magervann is another rust horizon which it is tempting to correlate with the Moskogaissa 120 horizon (and with Sabetjok, see below).

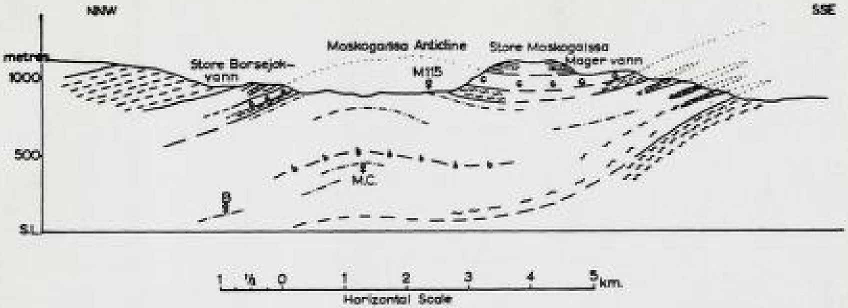


Fig. 7. Geological profile (NNW—SSE) west of Kåfjorddalen. M. C. is Monte Carlo mine; B, Borsejok mine; M 115, Moskogaissa 115 mine.

Geologisk profil (NNV—SSØ) vest for Kåfjorddalen. M. C.: Monte Carlo gruve, B: Borsejok gruve, M 115: Moskogaissa 115 gruve.

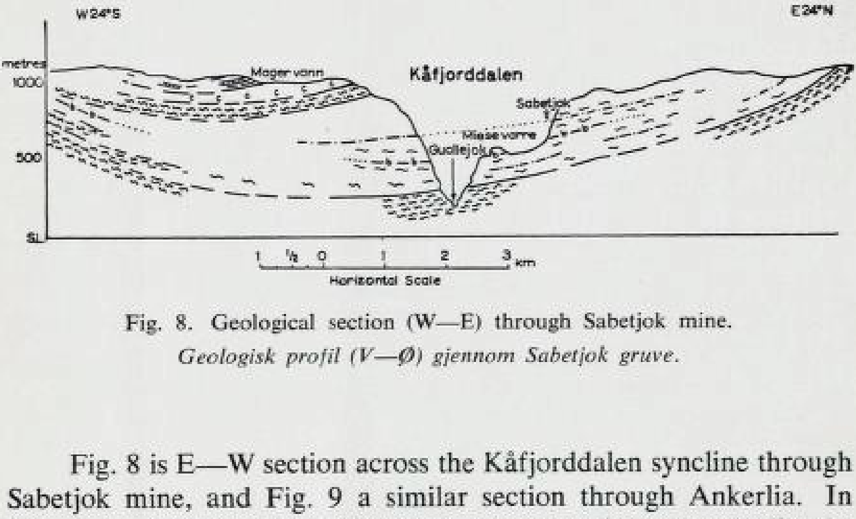


Fig. 8. Geological section (W—E) through Sabetjok mine.

Geologisk profil (V—Ø) gjennom Sabetjok gruve.

Fig. 8 is E—W section across the Kåfjorddalen syncline through Sabetjok mine, and Fig. 9 a similar section through Ankerlia. In Fig. 8 an attempt has been made to show diagrammatically the interbanding of the two sedimentary facies which is present all the way from the top of the Lower Brown Schist to just above the Sabetjok rust-horizon. This section does not give many cross-valley correlations, except the possibility of one between Sabetjok and the rust zone beneath Magervann.

Fig. 9 is probably the most important section. It shows the whole width of the Kåfjorddalen syncline between the outcrops of the base of the Lower Brown Schist. The remarkable thinning out

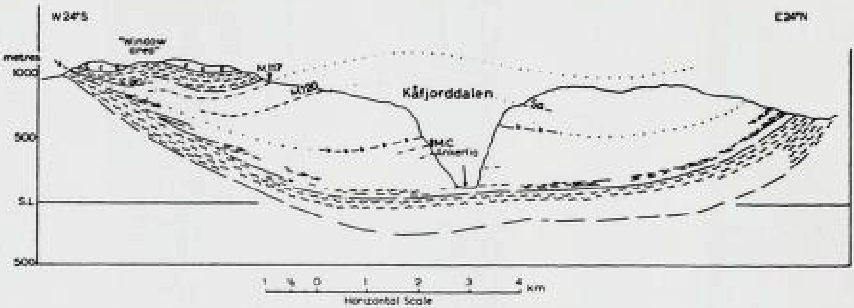


Fig. 9. Geological section (W—E) through Ankerlia. M 117 is Moskogaissa 117 mine; M 120, Moskogaissa 120 horizon; M. C., Monte Carlo mine; Sa, Sabetjok mine horizon.

Geologisk profil (V—Ø) gjennom Ankerlia. M 117: Moskogaissa 117 gruve, M 120: Moskogaissa 120 horisont, M. C.: Monte Carlo gruve, Sa: Sabetjok gruve horisont.

of the Ankerlia Schist to the west has been shown very diagrammatically as has also the interbanding near its base.

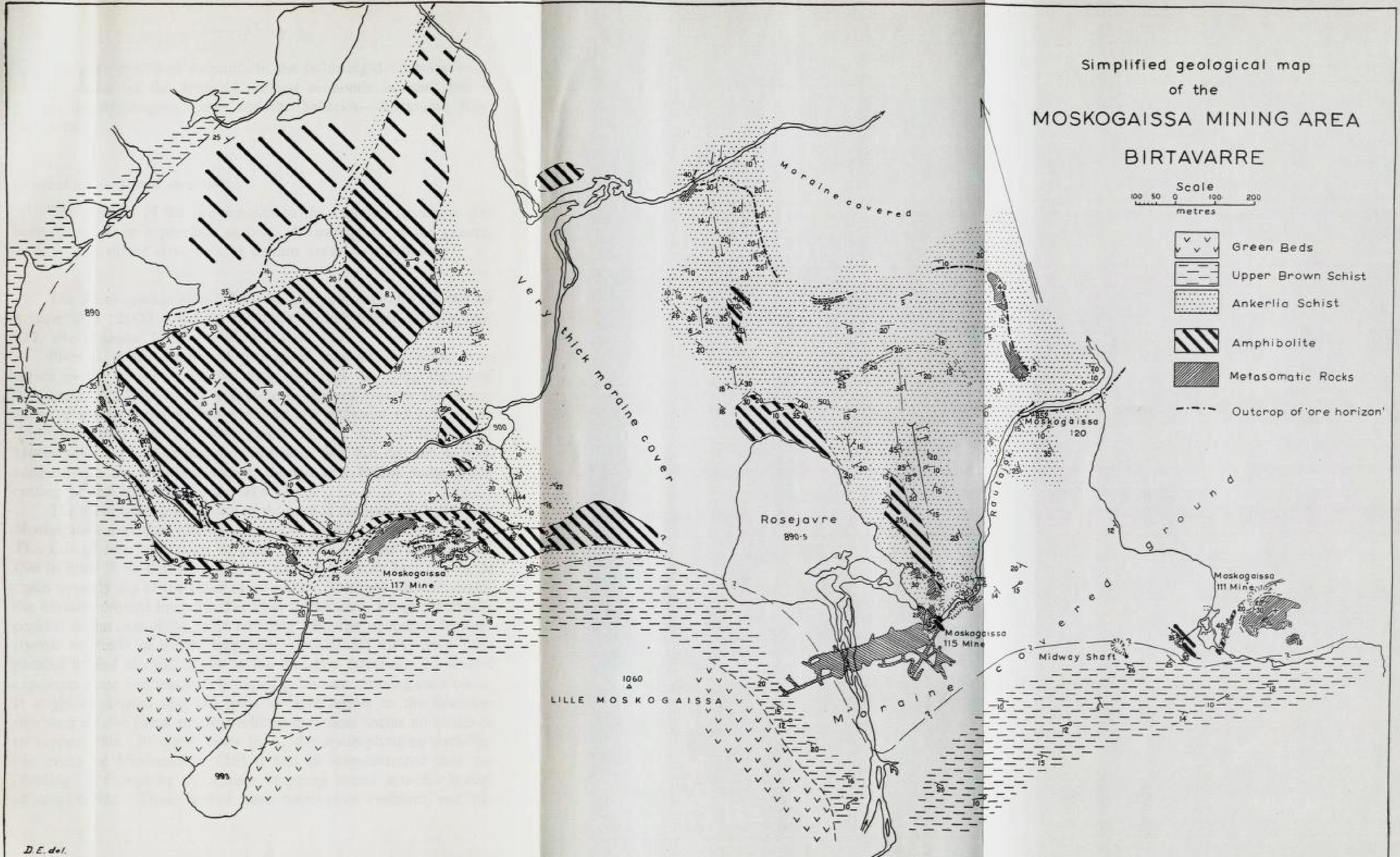
The upper Moskogaissa horizon does not appear on the east side of Kåfjorddalen on this line of section. North of here it would be linked with the Skaide horizon. The Moskogaissa 120 horizon has been tentatively linked with the northerly continuation of the Sabetjok horizon (Sa). The sulphidic horizons in the Lower Ankerlia Schist appear very limited in extent and very little correlation is possible.

Country-Rocks.

The country-rocks to the sulphide bodies in the Birtavarre area comprise fine- to medium-grained layered schists of apparently sedimentary origin which form parts of the Ankerlia Series of Padget.

In the case of the upper sulphide horizon at Moskogaissa amphibolites of apparently igneous origin occur in large amounts interlayered with the schists, and form, in parts, the wall-rock to the ores. Padget has dealt in detail with the various structures of the schists in his publication and has described the petrography of the Ankerlia Series in general terms.

The work in connection with the sulphide occurrences, especially the diamond-drilling has supplied additional information to supple-


Simplified geological map
of the
MOSKOGAISSA MINING AREA
BIRTAVARRE
Scale
100 50 0 100 200
metres
Green Beds
Upper Brown Schist
Ankerlia Schist
Amphibolite
Metasomatic Rocks
Outcrop of 'ore horizon'
Moraine covered
very thick moraine cover
Moraine covered ground
Rosejavre
890·5
Moskogaissa
117 Mine
Moskogaissa
115 Mine
Moskogaissa
111 Mine
Moskogaissa
120
Midway Shaft
Rautajok
LILLE MOSKOGAISSA
1060
890
900
940
993
D.E. del.

ment Padget's published account. In the following description stress will be placed on the areas of greatest economic interest, that is to say, the Moskogaissa area and the Sabetjok—Birtavarre Høyfjell area.

General geology and structure.

The relation of the ore-deposits to the regional structures has been discussed in a previous section. A description of the general geology and minor structures of certain areas now follows.

The Moskogaissa area. Detailed mapping was carried out on a scale of 1 : 2000 covering the three former mines Moskogaissa 111, Moskogaissa 115, and Moskogaissa 117.

Plate 3 is the simplified geological map of the area, from which it can be seen that the three workings lie along the same "ore-horizon". This is not everywhere exposed due to the heavy cover of glacial moraine, but outcrops are sufficient to indicate its continuity from east of Moskogaissa 111 to the north-west of Moskogaissa 117. The mapping indicates that this horizon is concordant with the enclosing schists, though very locally some crosscutting of the schistosity does take place.

The main structural feature of the area is the westward-plunging Moskogaissa anticline, already mentioned in the preceeding section. The axis of this fold seems to pass just south of the lake marked 890 in Plate 3, so that the schists in the mining area have a general south-westerly dip of the order of 10—20°. The map also illustrates the almost constant lineation direction in the area, being practically parallel to the axis of the main anticline. Smaller structural features consist of folds of small amplitude (1—10 m) with axes both parallel to and at right angles to the lineation dircetion. In several exposures these two sets of fold-axes can be seen crossing each other. It might be argued that the folds at right angles to the lineation represent a later phase of cross-folding, but there seems no evidence to support this. In many cases (e. g. the south-plunging anticline just north of Moskogaissa 115) it can be demonstrated that the "folding" is caused by the schists wrapping round lens-like bodies of amphibolite. These bodies have been more resistant and the schists have deformed round them, giving rise to the apparent cross-folding. In exposures just north of Moskogaissa 117, however, an excellent example of cross-folding can be seen away from any amphibolite. It is, however, considered that the minor folds of the area resulted from one period of deformation only.

In some instances the south-plunging folds have had one limb sheared-off along almost vertical joints, giving an appearance of faulting.

The main "ore-horizon", with the three old mines Moskogaissa 111, 115, and 117, lies some 60 metres stratigraphically below the base of the Upper Brown Schist which overlies the Ankerlia Schists in the area. Some 200 metres stratigraphically below this upper horizon there is a weaker horizon of mineralization which has been tested by a short adit in the banks of the Rautajok some 600 metres NW of Moskogaissa 115. This adit is marked as Moskogaissa 120 on the map. From an economic point of view this lower horizon has been insignificant.

The schists of the Ankerlia Series for about 100—150 metres below the base of the upper Brown Schist are interlayered with large quantities of amphibolite. This occurs as lenses or as sheets of varying dimensions apparently parallel to the original bedding of the schists. The sheets, though often of considerable areal extent, do not appear to reach great thickness. The largest example in the mapped area, just north-west of Moskogaissa 117, and in the nose of the main anticline, is probably up to 10 metres thick. Many of the other sheets are much less than this. The diamond drilling in 1954 gave a very good picture of the distribution of the amphibolites above the main sulphide zone. Fig. 10 is a block diagram showing the writer's interpretation of the results from from four of the drill-holes, from which the general form of the amphibolites can be seen. Surface mapping indicates that the same picture continues without much change into the footwall rocks of the "ore-zone" for maybe another 100 metres stratigraphically. By the time the underlying mineralized zone is reached the schists are free from amphibolite. In the north-west of the mapped area the proportion of amphibolite to schists has increased considerably, and north-east of Lake "890" the "ore-zone" follows a thin band of biotite-hornblende schist only about 3—5 metres thick, with hanging and footwalls of coarse-grained, blocky amphibolite.

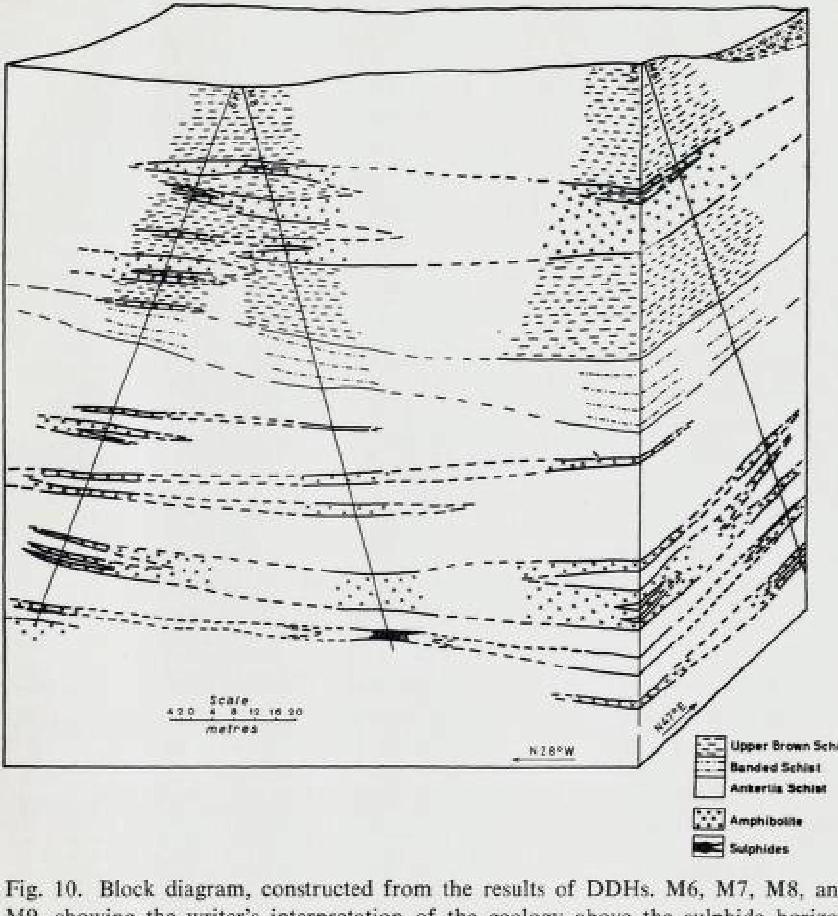


Fig. 10. Block diagram, constructed from the results of DDHs. M6, M7, M8, and M9, showing the writer's interpretation of the geology above the sulphide horizon at Moskogaissa.
Blockdiagram, tegnet etter resultatene fra borhull M6, M7, M8 og M9, som viser forfatterens interpretasjon av de geologiske forhold over sulfidhorisonten ved Moskogaissa.

At a point about 1000 metres north of Moskogaissa 117, the mineralized zone outcrops in a small inlier beneath the overlying amphibolite. Is has been tested here by shallow pitting, and the working has been registered as Moskogaissa 125.

Mapping, and the results of the diamond-drilling, indicate that there is a transition from the Upper Brown Schist into the Ankerlia

Schist, consisting of between 10 and 20 metres of interbanded biotite and quartz-hornblende schists. There is no evidence to suggest a tectonic break between the two series. The only places where positive evidence of movement is found is along the mineralized horizons, where distinct brecciation and shearing have occurred.

The metasomatic rocks accompanying the "ore-horizon" are intermittently exposed along the strike. The Moskogaissa area is the one where these rocks are developed *par excellence* and from which most of the information regarding them has been obtained. They appear to reach their greatest development in the hanging-wall of the ore-zone at Moskogaissa 111 where they have a thickness of up to 15 metres. In outcrop they are of a massive appearance with an extremely well-developed joint-system. They present a marked contrast to the schists in their massive appearance, but the original banding of the parent rocks can be traced as layers of different texture and mineral composition.

In their various outcrops the metasomatic rocks show minor folds and lineation identical with those in the surrounding schists and it is highly possible that these structures are inherited from the schists that were metasomatized.

At *Moskogaissa 111* the foot-wall country-rocks are poorly exposed in two trenches south-west of the adits, and along the steep slope beneath the outcrop of the sulphide horizon. They comprise interbanded quartz-hornblende schists and dark amphibolites, the individual units varying from a few centimetres to one or two metres in thickness. Lensing out and interfingering of the various units is very common.

In the trench exposures these foot-wall schists show a series of open symmetrical folds with axial directions around S30°W*. The lineation, i.e., parallel orientation of the hornblende needles, is at a high angle to the fold axes, having a normal plunge direction of about W. These folds are therefore of the "crossfold" type mentioned above. Certain breccias in the sulphide zone at this mine indicate that the folds were already formed when the movements causing the brecciation occurred. Thus the folds seem to date from the main period of deformation of the region and are older than the structures which gave access to the ores.

* The 360° circle is used throughout this report.

The main structural feature of the well-developed metasomatic garnet-amphibole rocks at Moskogaissa 111 is their excellent joint-system. The main joints strike N—S and E—W with a subsidiary set at N60°E. Most of them have dips between 70° and 90°. Otherwise they show two broad, shallow dome-structures marked by the horizontality of the mineral banding, surrounded by areas of low, variable, outward dips.

More definite structures occur along the working face of the open cut where the metasomatic rocks above the sulphide zone show a series of parallel shallow folds with axes at about S80°E. Lineation (i.e. amphibole orientation) is generally parallel to this direction. At the edge of the easternmost outcrop of the metasomatic rocks an open anticline may be deduced with its axes plunging gently at about N80°W.

Thus the fold direction in these (hanging-wall) rocks is almost at right angles to that in the footwall schists and amphibolites. The lineation direction is practically identical in both cases, being the general lineation direction in the Birtavarre region. It is the writer's opinion that both these fold directions were impressed on the rocks during the main deformation and metamorphism of the region. The folds in the skarn above the sulphide zone are therefore considered to be relict folds now preserved in the metasomatic rock.

At *Moskogaissa 115* the outcrops are even more limited. They consist mostly of metasomatic rocks but in the banks of the Rautajok below the mine a fairly complete section into the footwall rocks is shown.

The rock immediately underlying the ore-zone is a black, medium-grained, schistose amphibolite. This is exposed in the banks of the Rautajok and also north of the spoil dump where it forms the core of an anticlinal fold with a westerly plunging axis. Another ten metres or so further north further patches of amphibolite are exposed in the core of a parallel anticline. The same amphibolite forms much of the slight ridge of ground running north from the mine dump (see Plate 3). It would appear to be only about 2—3 metres thick and is underlain by quartz-hornblende schists at the northern tip of the waste dump.

The metasomatic rocks, which contain quartz-garnet, garnet-anthophyllite and anthopyllite types, show much tight folding, with amplitudes between a few cms. and ½ metre along EW axes, i.e.

parallel with the larger folds described above. It would appear that these rocks were formed from schists lying concordantly over the amphibolite and already folded during the regional deformation.

The Sabetjok—Birtavarre Høyfjell area. The sulphide zones and their related schists in this area have a generally north-westerly dip of the order of 15°—20°. To the east the strike swings gradually to a more northerly direction as one traces the beds into the eastern limb of the Kåfjorddalen syncline. The large-scale structure of the area in therefore simple. On a smaller scale the schists have developed structures giving evidence of the action of small shearing couples acting parallel with the regional layering. The main effect has been the production of marked dragfolds with middle limbs varying from 5 cms. to perhaps one metre. The cores from the diamond-drilling in 1955 provided excellent illustrations of this dragfolding.

Evidence of incipient, or minor-scale shearing of the beds is shown in the biotite-rich members of the banded schists in this area. In zones from 5—10 cms. thick the biotite has been coarsened and "sheared-out" and irregular patches of quartz-feldspar pegmatite have replaced the schists.

East of Birtavarre Høyfjell working the basal schists of the Ankerlia Schist group have been sheared-out and foliated on a large scale with the development of large hornblendes and chlorite which give a dark green appearance to the rocks.

The age of the movements producing these phenomena is not easy to determine. The dragfolds seem to be small-scale replicas of the large ones described by Padget from the Banded Ankerlia Schists below Moskogaissa (1955, p. 84). Earlier it was suggested that these folds were produced by the same shear couple which give rise to the brecciated and sheared zones now forming the sulphide horizons.

Petrology.

The petrography and chemical compositions of the main types of schists and of the amphibolites will be described below. Since the most detailed information regarding these rocks was obtained during the diamond drilling in 1954—1955 emphasis will be laid on the rocks in the Moskogaissa and Sabetjok—Birtavarre Høyfjell areas.

The schists. The Ankerlia Series is a rather large stratigraphical unit, reaching a maximum thickness of over 1000 metres, and is of somewhat variable lithology. The majority of the sulphide horizons lie in the central division of this Series which has been termed the Ankerlia Schists. As has been shown in the section "Relation to stratigraphy" the country-rocks of the mines in the western part are of the "Brown Schist facies" type which has a somewhat different petrography from the Ankerlia Schists of the central area.

Thus the wall-rocks of the different sulphide horizons show varying mineral compositions depending upon their position within the Ankerlia succession. In general two main types of schist are present; the first a quartz-hornblende-(zoisite)-(plagioclase)-schist and the second a biotite-plagioclase-zoisite-schist. Often these two types are closely interlayered and in places gradational types containing, for example, both hornblende and biotite, are present.

The grain-size of the rocks is on the whole quite fine, especially in the quartz-rich varieties. The grain-size normally varies between 0.1—0.5 mm for quartz and feldspar, while the hornblende occurs in needles up to 1 or 2 mm long. The biotite-rich schists normally show flakes of mica between 1—5 mm diameter. Where these rocks have been involved in shearing near the sulphide zones, large, lustrous flakes develop.

Padget (1955, p. 53) discusses the Ankerlia Schist on the basis of thin section work and a bulk chemical analysis. He compares this analysis to that of a typical greywacke, pointing out, however, the rather high lime content. The present mineral association resembles that of a basic (igneous?) rock except in the presence of free quartz (20—25 %). He therefore interprets the Ankerlia Schist as having been originally an impure muddy siltstone or sandstone. The high lime content may be due to a slightly higher primary lime content, or perhaps to lime metasomatism.

Detailed knowledge of the rocks enclosing two of the sulphide horizons was gained from the cores resulting from the diamond-drilling at Moskogaissa in 1954 and in the Sabetjok—Birtavarre Høyfjell area in 1955. The Moskogaissa horizon is the uppermost one in the upper Ankerlia Schist, while that at Sabetjok lies towards the base of the upper Ankerlia Schist. Petrographically the rocks enclosing these two horizons show notable differences, reflecting in great measure the conditions of original deposition of the sediments.

In the Moskogaissa area the sedimentary rocks are mainly fine-grained quartz-hornblende-zoisite-(plagioclase)-schists. Variations in composition occur mainly in the relative amounts of quartz and hornblende, giving rocks from almost pure quartz-schists to very hornblende-rich ones which are difficult to distinguish from the meta-igneous amphibolites in the field. Indeed it seems very possible that the dark hornblendic schists may represent types containing considerable additions of tuffitic material though, of course, this is difficult to determine since all original textures have been destroyed in the regional metamorphism.

The diamond drilling in 1954 showed clearly that the junction between the Upper Brown Schist and the Ankerlia Schist in this area is a transitional one, the transition being due to the change from one sedimentational facies to another. The quartz-rich, hornblende-bearing schists give way to dominantly biotite-plagioclase-schist by means of a variable zone, 10 to 20 metres thick in which the two types occur banded together in units of differing thickness. (See block diagram Fig. 10). Since the uppermost ore-zone occurs some 60 metres below this transition-zone, the biotite-rich schist will not be treated here.

The mineralogy of the Ankerlia Schists enclosing the upper sulphide horizon at Moskogaissa is almost invariably green hornblende, quartz and plagioclase. Biotite occurs in some bands, and as accessories occur zircon, sphene, sometimes rutile and very occasionally odd grains of (clino)zoisite.

The proportions of the main minerals vary from layer to layer and it would be difficult to say what forms an average composition. Texturally the quartz and feldspar occur as an interlocking allotriomorphic mosaic in which the hornblende, and biotite, when present, occur as elongated prisms or irregular grains. The parallelism of the ferromagnesians is striking, producing the characteristic linear schistosity of the rock. The index of elongation of these minerals varies between 5 and 10; in extreme cases it is even higher. The shapes of the hornblende prisms are nearly always determined by the bordering quartz-feldspar grains which project into the hornblende boundaries. Often grains of the light minerals are enclosed in larger hornblende crystals. In other words, the hornblende shows typical poikiloblastic development with reference to the light minerals. This may be interpreted as indicating that the present quartz-feldspar mosaic represents a recrysallisation of original sandy sediments, in which the ferromagnesians have grown from more muddy or clayey constituents rich in iron, alumina, calcium and magnesium. Presumably the biotite-rich layers represent layers in which potassium-bearing clay was present.

The feldspar in these schists mostly shows a composition around An_{40}-$_{48}$. Darker, more hornblende-rich types show feldspars with a composition around An_{50}. This is another indication that the dark schists represent tuffitic rocks and a transition to the meta-igneous amphibolites which have feldspars showing anorthite contents above 50 %.

The accessory minerals are usually very small in amount. Minute zircons(?) are very noticable in the ferro-magnesians because of the pleochroic haloes surrounding them. Sphene and occasionally rutile occur as small euhedral to subhedral grains. The virtual absence of (clino)zoisite is interesting since it is very abundant in the amphibolites interlayered with the schists. Also Padget (op cit. p. 55) shows nearly 14 % modal clinozoisite in his average Ankerlia Schist. However, thin section work shows that zoisite is absent (except for odd, small grains) in the schists immediately above the main ore-zone at Moskogaissa (within ca. 15 m of the sulphides).

The explanation seems to lie in in the metasomatic processes which have affected the rocks surrounding the sulphides. As will be shown below (p. 163) these processes, among other things, involved removal of calcium and it seems that the (clino)zoisite is the first mineral to be affected. Somehow the amphibolites do not respond to the metasomatism and show large quantities of this mineral.

Thus the schists surrounding the sulphide are probably not typical Ankerlia Schist since they have had some of their calcium removed. They show a transition, chemically, between the average composition published by Padget and the metasomatic anthophyllite-bearing schists which are discussed below.

	wt %	cation percent
SiO_2	60.38	56.2
TiO_2	0.81	0.6
Al_2O_3	14.61	16.0
Fe_2O_3	0.90	0.7
FeO	6.40	5.0
MnO	0.10	
MgO	4.79	6.7
CaO	5.80	5.8
Na_2O	4.61	8.2
K_2O	0.61	0.7
H_2O-	0.04	—
H_2O+	0.29	(1.9)
P_2O_5+	0.21	0.1
	99.55	100.0

Table 1. Ankerlia Schist. DDH. M8, 1954. 95.0-96.0 metres.

Analyst E. Christensen, NGU laboratory.

Table 1, above, gives an analysis of Ankerlia Schist taken from DDH M8 at about 15 metres above the hanging wall of the sulphides.

The CaO in this analysis is about 4 % lower than in the average analysis published by Padget and this is reflected by the absence of zoisite in the rock. The Na_2O is over twice as high, and is reflected in a great increase in the albite molecule. In thin sections of the analysed rock it can be seen that most of the twinned plagioclase crystals are surrounded by a wide rim of clear untwinned albitic feldspar, and there are many grains of untwinned feldspar of low RI which also must undoubtedly be very albitic feldspar. The maximum extinction angles of the twinned feldspars show a composition varying between An_{36} and An_{40}. In the calculated mode (Table 2) the andesinic plagioclase has been shown separate from the albite.

It is considered that influx of Na_2O into the schist is due to metasomatic processes prior to the ore formation and is discussed on pp. 166—167.

Table 2 also shows the mesonorm of this schist, calculated after the procedure of Barth (1955). Such norms have been proposed for rocks of the amphibolite facies of Eskola, and they are included

	Si	Ti	Al	Fe'''	Fe''+Mn	Mg	Ca	Na	K	P	(OH)		Observed Mode
	56.2	0.6	16.0	0.7	5.0	6.7	5.8	8.2	0.7	0.1	(1.9)		
	Calculated Mode												
Quartz	13.9											13.9	15.0
Albite	13.8		4.6					4.6				23.0	35.0
Plagioclase	6.0		3.2				0.6	1.4				11.2 (An_{38})	
Hornblende	19.8		6.6	8.8			4.4	2.2			(5.1)	41.8	40.0
Biotite	2.1		0.7	2.1					0.7		(1.4)	5.6	6.0
Sphene	0.6	0.6					0.6					1.8	2.0
Apatite							0.2			0.1		0.3	?
Ore				1.5								1.5	2.0
	56.2	0.6	15.1	12.4			5.8	8.2	0.7	0.1	(6.5)	99.1	100.0
	Mesonorm												
Q	18.1											18.1	
Ab	18.6		8.2					8.2				35.0 } An_{18}	
An	3.0		3.0				1.5					7.5	
Ho	14.4		4.1		3.1	5.1	4.1				(4.1)	30.8	
Bi	2.1		0.7		0.8	1.3			0.7		(1.4)	5.6	
Mt				0.7	0.4							1.1	
Il		0.6			0.6							1.2	
Ap							0.2			0.1		0.3	
	56.2	0.6	16.0	0.7	4.9	6.7	5.8	8.2	0.7	0.1	(5.5)	99.6	

Table 2. Calculated and observed modes and mesonorm of Ankerlia Schist. (See Table 1).

in this report for purpose of comparison, being much more satisfactory than the usual molecular norm (catanorm) for these metamorphic rocks.

The good agreement between this norm and the mode of the schist is to be noted.

The rocks enclosing the lower sulphide horizon at Moskogaissa (Moskogaissa 120) were intersected by two drillholes in 1954 (R1 and R2). The cores from these holes showed schists of a somewhat different nature from the ones just described. They were essentially banded into units of variable thickness. The main constituent was a hornblende-biotite-plagioclase-quartz-schist in which the quartz-plagioclase mosaic had a grain-size between 0.4—1 mm. The hornblende prisms were up to 2 mm long and the biotite flakes reached 3 mm diameter. These ferromagnesians showed the normal schistose texture within the quartz-feldspar mosaic, and frequently exhibited a poikiloblastic texture. The biotite and hornblende were mostly intimately intergrown and cases of replacement of the latter by the former could be seen. However, the larger biotite flakes appeared to have developed independently of the hornblendes. The feldspars more often than not showed single, wide rims of lower An-content than the cores. Maximum symmetrical extinction angles on cores and unrimmed grains showed a composition around An_{46}-$_{42}$, while rim measurements indicated about An_{30} (cf. Padget's figure of An $_{30}$, also).

The rims would seem to indicate recrystallisation of the feldspars to a lower lime-content in response to metamorphic conditions. The cores and other grains of higher An-content represent either the original detrital feldspars or those due to previous metamorphism in a higher facies.

Minute zircons (?) with marked pleochroic haloes were frequent in both biotite and hornblende. Sphene and a little zoisite occurred sparingly as accessories.

The other type of schist in the wall-rocks of the lower sulphide-zone had the mineral composition hornblende-zoisite-plagioclase-quartz-(sphene)-(zircon). The grain-size was noticeably smaller, in the quartz-feldspar mosaic it was from 0.1—0.2 mm, while the hornblende needles reached 0.7 mm.

The hornblendes showed the usual linear orientation and were markedly poikiloblastic towards the quartz-feldspar ground-mass. The feldspars were occasionally roughly zoned as in the type described above. Unzoned, fresh-looking, twinned feldspars showed a composition about An $_{40-44}$. The zoisite particularly showed a poikiloblastic development, occurring in very ragged, irregular grains or plates up to 2 mm diameter.

Sphene was widespread as small diamond-shaped or irregular grains of the order of size 0.05 mm. Zircons (?) as usual showed their pleochroic haloes in the hornblendes.

A composite sample of these two types of schist from DDH R1 was analysed during an investigation of the metasomatic processes taking place along the mineralized zone (see later, p. 164). This analysis is given in Table 3, below. For the purpose of the modal calculation rough estimates were made of the mineral composition of the two types of schist, the results being: First type, 20 bi, 30 hb, 40 plag, 8 quartz, 2 accessories. Second type, 35 hb, 15 zois, 15 plag, 30 quartz, 5 accessories.

In the sample the non-biotite schist was in excess, in the ratio of about 3 : 1.

	wt %	cation %
SiO_2	59.41	55.7
TiO_2	0.88	0.6
Al_2O_3	14.78	16.3
Fe_2O_3	0.83	0.6
FeO	6.22	5.0 (FeO + MnO)
MnO	0.16	
MgO	5.01	7.0
CaO	8.03	8.1
Na_2O	3.23	5.9
K_2O	0.62	0.7
H_2O-	—	—
H_2O+	0.51	(3.1)
P_2O_5	0.23	0.1
	99.91	100.0

Table 3. Ankerlia Schist. DDH R1, 1954, 40.00-41.22 metres.

Analyst E. Christensen, NGU Laboratory.

This analysis shows a composition more approaching that of Padget's average one. Na_2O is still high, probably due to the metasomatic process in the "ore-zone" which begins only about 1 metre below. The less intense nature of the metasomatism is reflected in the increased CaO-content, and (clino)zoisite is present in the rock.

	Si	Ti	Al	$Fe^{\cdot\cdot\cdot}$	$Fe^{\cdot\cdot}$ + Mn	Mg	Ca	Na	K	P	(OH)		Observed Mode
	55.7	0.6	16.3	0.6	5.0	7.0	8.1	5.9	0.7	0.1	(3.1)		
	Calculated Mode												
Quartz	17.3											17.3	20.0
Plagio-clase	14.7		6.9				1.5	3.9				27.0 (An_{28})	25.0
Horn-blende	18.0		6.0		8.0		3.9	2.0			(4.6)	37.9	35.0
Biotite	2.1		0.7		2.1				0.7		(1.4)	5.6	6.0
(Clino) zoisite	3.0		2.2	0.8			2.0				(2.0)	8.0	10.0
Sphene	0.6	0.6					0.6					1.8	2.0
Apatite							0.2			0.1		0.3	?
Ore					1.5							1.5	2.0
	55.7	0.6	15.7		12.4		8.2	5.9	0.7	0.1	(8.0)	99.4	100.0
	Mesonorm												
Q	12.0											12.0	
Or	2.1		0.7						0.7			3.5	
Ab	17.7		5.9					5.9				29.5	An_{27}
An	4.4		4.4				2.2					11.0	
Ho	18.5		5.3		3.9	6.7	5.3				(5.3)	39.7	
Di	1.0				0.2	0.3	0.5					2.0	
Mt				0.6	0.3							0.9	
Il		0.6			0.6							1.2	
Ap							0.2			0.1		0.3	
	55.7	0.6	16.3	0.6	5.0	7.0	8.2	5.9	0.7	0.1	(5.3)	100.1	

Table 4. Calculated and observed modes and mesonorm of Ankerlia Schist. (See Table 3).

In Table 4 are given the calculated mode and mesonorm of the schist. In the mode an average value has been given to all the plagioclase, though it will be clear from the rock description above that two types are present, one in the cores with a relatively high An-content, and a rim type with a low An-content.

The schists described above form part of the upper Ankerlia Schist division. In 1955, too, drilling took place in schists of this division in the Sabetjok—Birtavarre Høyfjell area. These schists are lower stratigraphically than the ones in the Moskogaissa area and they show evidence of a somewhat different original nature.

In essentials they are made up of two main petrographic types which occur interbanded with each other in units varying in thickness from a few mms to over 2 metres. The interbanding is highly irregular and it was not possible to trace units or groups of units from one drill-hole to another. In parts of the succession the units are large and the alternations even, in others there is rapid interbanding of units less than 5 cms thick.

The quantitatively major type is a fine-grained diopside-hornblende-quartz-plagioclase-zoisite-schist. This type is remarkably uniform in appearance and mineralogical make-up. In hand specimen it is light-grey, compact and very even-grained. The only variations of note are lighter-coloured lenses and bands, up to a few mms thick, which are very abundant in parts of the succession. Under the microscope these bands are seen to be hornblende-free.

The minerals occur in a fairly even-grained anhedral aggregate, the texture being determined by a quartz-feldspar mosaic with a grain-size between 0.05—0.2 mm. The diopside and hornblende are essentially interstitial to the light minerals, indicating, as in all the schists of the area, that the ferromagnesians were formed later than the quartz-feldspars. They occur as very irregular grains and are not particularly elongated, especially the diopside. Thus the schistose texture is not so apparent in this type as in the schists previously described.

Feldspar is normally subsiduary to quartz and shows a composition ranging between An_{46} and An_{54}. Some grains show a single outer zone of lower An-content. As accessory minerals occur sphene and apatite.

A composite sample of this type of schist from several drill-holes was analysed and the mode calculated from the analysis and thin-section estimates. (Tables 5 and 6.)

In the foot-wall zone beneath the sulphides occurs a band,

	wt %	cation %
Si_2O	65.56	62.1
TiO_2	0.81	0.6
Al_2O_3	11.14	12.4
Fe_2O_3	0.96	0.7
FeO	4.84	3.8
MnO	0.12	0.1
MgO	3.64	5.2
CaO	9.00	9.1
Na_2O	2.31	4.2
K_2O	1.39	1.7
H_2O-	0.02	—
H_2O+	0.20	(1.2)
P_2O_5	0.21	0.1
	100.20	100.0

Table 5. Ankerlia schist. (Diopside-bearing) Composite sample from drill cores, Sabetjok-Birtavarre Høyfjell 1955.

Analyst E. Christensen, NGU Laboratory.

usually only 2—3 metres thick, of a hornblende-quartz-plagioclase-zoisite-schist. This schist has a characteristic "streaked" or thinly banded appearance due to irregular bands a mm or two thick containing increased numbers of hornblendes.

Maximum symmetrical extinction angles of the plagioclases indicate compositions varying between An_{40} and An_{48}. Zoning is common in some specimens. Zoisite is present in increased amounts over the diopside-bearing types.

The absence of diopside is the most important single feature of this minor type of schist. It has probably all gone over into hornblende under the influence of retrogressive metamorphism. The streaked or banded appearance may be an expression of shearing in the zone, which may have been a part cause of the disappearance of the pyroxene.

In one thin section of this type of schist euhedral garnet grains with clear outlines were seen. Their formation is probably connected with the metasomatic processes in the ore-zone and discussion will be left till later (p. 154).

The second main rock type in the Sabetjok—Birtavarre Høy-fjell area is a brown mica-schist. This schist consists of biotite, hornblende, quartz, zoisite and plagioclase, with small amounts of accessory sphene and apatite. The grain-size is significantly larger

	Si	Ti	Al	$Fe^{\cdots}$	$Fe^{\cdot\cdot}$ + Mn	Mg	Ca	Na	K	P	(OH)		Observed Mode
	62.1	0.6	12.4	0.7	3.9	5.2	9.1	4.2	1.7	0.1	(1.2)		
	Calculated Mode												
Quartz	29.3											29.3	30.0
Plagio-clase	12.0		7.2				2.4	2.4				24.0 (An_{50})	25.0
Diopside	4.6				2.3		2.3					9.2	10.0
Horn-blende	15.6		5.2	7.5			3.6	1.8	0.9		(4.2)	34.6	35.0
Sphene	0.6	0.6					0.6					1.8	<1.0
Apatite							0.2			0.1		0.3	?
	62.1	0.6	12.4	9.8			9.1	4.2	0.9	0.1	(4.2)	99.2	100.0
	Mesonorm												
Q	24.0											24.0	
Or	5.1		1.7						1.7			8.5	
Ab	12.6		4.2					4.2				21.0	An_{36}
An	4.8		4.8				2.4					12.0	
Ho	6.0		1.7		1.2	2.2	1.7				(1.7)	12.8	
Di	9.6				1.8	3.0	4.8					19.2	
Mt				0.7	0.3							1.0	
Il		0.6			0.6							1.2	
Ap							0.2			0.1		0.3	
	62.1	0.6	12.4	0.7	3.9	5.2	9.1	4.2	1.7	0.1	(1.7)	100.0	

Table 6. Calculated and observed modes and mesonorm of diopside-bearing Ankerlia Schist. (See Table 5).

than in the diopside-bearing schist. The allotriomorphic quartz-feldspar mosaic shows a normal grain-size between 0.05 and 0.1 mm, while the biotite flakes average around 1 mm in length.

The biotite flakes define a well-marked planar schistosity in the rock, while the hornblendes tend to be more equi-dimensional and less well orientated. Many cases were observed in thin section where the hornblende had apparently developed crystalloblastically in the biotite-schist, pushing aside the enclosing biotite flakes.

The plagioclase, which is subsidiary in amount to the quartz in the groundmass, shows the same general anorthite content as that in the diopside schist, i. e., around An $_{48\text{-}54}$. More albitic plagioclase occurs as rims and occasionally as clear grains. This is shown separately in the modal calculation in Table 8.

Some bands of the biotite-schist are remarkable for the large amount of zoisite they contain. This mineral occurs in well-formed, elongated crystals up to 0.5 mm long lying parallel to the schistosity, as well as in smaller, more equi-dimensional grains. Interference colours shown are both normal and anomalous (deep blue) indicating crystals of both orientations. This means that both ferrian (anomalous) and non-ferrian (normal) varieties of zoisite are present.

A striking phenomenon associated with this mineral is the presence around many of the grains of pleochroic haloes in the biotite. These haloes vary greatly in intensity and width, being strongest around the small, equidimensional grains. Their widths vary from 0.02—0.04 mm around grains of the same order of size in diameter. No internal rings were observed, indicating overexposed haloes in which blackening has obliterated most of the inner structures (Rankama, 1954, p. 127).

Other minute grains also occur at the centre of haloes, most probably sphene. This latter, according to Rankama, is a recognised producer of pleochroic haloes, but it is not apparent whether such features have been recognised in connection with zoisite before.

In the tables below are given a chemical analysis and calculated mode of the biotite-rich schist just described. A quantitatively minor type of schist is one in which (clino)zoisite occurs as irregular poikilitic plates up to 2 or 3 mm in diameter in a medium- to coarse-grained biotite-hornblende-quartz schist. Plagioclase is almost absent. The (clino)zoisite has enclosed fragments of hornblende and biotite and is undoubtedly a late-developed mineral, probably formed at the expense of the plagioclase under conditions of retrogressive metamorphism.

Sphene occurs as usual as an accessory.

As one traces the Ankerlia schists in the Birtavarre Høyfjell area down the succession, i. e. south-eastwards, the proportion of

	wt %	cation %
SiO_2	56.32	53.0
TiO_2	0.93	0.7
Al_2O_3	17.36	19.3
Fe_2O_3	0.58	0.4
FeO	7.39	5.8
MnO	0.09	0.1
MgO	5.46	7.7
CaO	4.09	4.1
Na_2O	2.18	3.9
K_2O	4.00	4.8
H_2O-	0.08	—
H_2O+	1.32	(4.1)
P_2O_5	0.21	0.2
	100.01	100.0

Table 7. Ankerlia Schist (Biotite-rich). Composite sample from drill cores, Sabetjok-Birtavarre Høyfjell 1955.

Analyst E. Christensen, NGU laboratory.

biotite-rich schist becomes greater and its individual units thicker. At last the diopside-hornblende-quartz-schist bands cease and one is in the underlying Lower Brown Schist, which is indistinguishable from the biotite-rich intercalations in the Ankerlia Schist. The author cannot interpret this in any other way than as being due to an original sedimentary facies change.

Padget has come to the same conclusion as regards the boundary between the Ankerlia Schists and Lower Brown Schist in the Magervann area. Thus in this area the Lower Ankerlia Schists (i.e. below the Banded Schist) are represented by a thickness (estimated at 300 metres) of alternating quartz-hornblende and biotite schists. As one follows the horizon north-westwards down Kåfjorddalen there come in large quantities of dominantly hornblende schists, which at Ankerlia are at least 700 metres thick. This thickness must be due to primary sedimentary thickening down the axis of the Kåfjorddalen syncline. The wall-rocks of the Sabetjok—Birtavarre Høyfjell sulphide horizon may be interpreted as an interbanding of Ankerlia and Lower Brown schist facies — an eastward continuation of the same feature mapped by Padget south of Magervann and illustrated diagrammatically by him (1955, p. 29).

The question of the correlation of the various sulphide horizons is discussed elsewhere (see p. 31).

	Si	Ti	Al	$Fe^{\cdot\cdot\cdot}$	$Fe^{\cdot\cdot}$ + Mn	Mg	Ca	Na	K	P	(OH)		Observed Mode
	53.0	0.7	19.3	0.4	5.9	7.7	4.1	3.9	4.8	0.2	(4.1)		
	Calculated Mode												
Quartz	20.0											20.0	20.0
Albite	5.4		1.8					1.8				9.0	21.0
Plagio-clase	6.5		3.5				1.0	1.5				12.5 (An_{40})	
Biotite	13.5		4.5		11.6				4.5		(9.0)	34.1	35.0
Horn-blende	5.4		2.0		2.4		1.2	0.6	0.3		(1.4)	11.9	15.0
(Clino) zoisite	1.5		1.5				1.0				(1.0)	4.0	5.0
Sphene	0.7	0.7					0.7					2.1	3.0
Apatite							0.3			0.2		0.5	1.0
	53.0	0.7	13.3		14.0		4.2	3.9	4.8	0.2	(11.4)	94.1	100.0
	Mesonorm												
Q	19.5											19.5	
Or	1.8		0.6						0.6			3.0	
Ab	11.7		3.9					3.9				19.5	An_{49}
An	7.4		7.4				3.7					18.5	
C			3.2									3.2	
Bi	12.6		4.2		5.0	7.7			4.2		(8.4)	33.7	
Mt				0.4	0.2							0.6	
Il		0.7			0.7							1.4	
Ap							0.4			0.2		0.6	
	53.0	0.7	19.3	0.4	5.9	7.7	4.1	3.9	4.8	0.2	(8.4)	100.0	

Table 8. Calculated and observed modes and mesonorm of biotitic Ankerlia Schist. (See Table 7).

The country-rocks of the sulphide bodies in other parts of the district show often nearly the same petrography as the ones described above and they will not be discussed in detail. Most of the mines and prospects of the central area show either hornblende- or diopside-schists, or else these types interbanded with biotite-rich schists. In the western area the biotite-rich schists of the Brown Schist facies are dominant, with intercalations of green hornblendic schists in places.

The amphibolites. The term "amphibolites" is taken to include all more or less perfectly crystalloblastic rocks consisting mainly of hornblende and plagioclase. A common feature of these rocks is a sill-like habit, either intercalated with, or intruded into, schists and, on the whole, concordant with them.

Such amphibolites occur at all stratigraphic levels in the Birtavarre Series. Padget (1955) gives a brief summary of some of these under the heading "Basic intrusive rocks" on pages 58—62 and describes a presumably extrusive member (Green Beds) on pages 54—56.

The writer will concern himself mainly with the amphibolites which form part of the country rocks to the ores, that is to say, those in the upper part of the Ankerlia Schists. He is grateful for permission to use two of Padget's published analyses in this section.

The amphibolites present a fairly constant mineralogy, consisting essentially of green hornblende and a plagioclase with an anorthite content around 50 %. (Clino)zoisite and sphene occur in varying, though appreciable, amounts in nearly all specimens examined. Other minerals observed include rutile, zircon, biotite and calcite.

The textures of the rocks vary considerably, from coarse-grained, massive, slightly schistose to fine- or medium-grained, platy, schistose. In many cases there appears to be a gradual transition from the latter types to the hornblende-quartz-plagioclase schists of the Birtavarre series and a microscopical examination is necessary to establish the boundaries. It appears that the true meta-igneous rocks are free from quartz and this may be used to differentiate them from the basic schists which carry this mineral more or less abundantly.

One of the most massive of the amphibolites outcrops over a large area in the nose of the Moskogaissa anticline (see map, Pl. 3) north of Moskogaissa 117 mine. It consists essentially of a coarse-grained (1—3 mm) intergrowth of hornblende and plagioclase, showing weak orientation of the hornblende in the plane of the regional schistosity. The texture suggests part-retention of the intergranular texture of the original basic rock. The hornblende occurs as large irregular prisms, pale-green in colour, with a very slight pleochroism. The maximum extinction angle ($c \wedge \gamma$ or Z) shown is —20°. The feldspars occur as prismatic crystals showing albite and albite-carlsbad twinning. Measurements of the extinction angles of these twins indicated an anorthite content of 45. Both the hornblende and plagioclase have been extensively altered to (clino)zoisite and in addition the feldspar shows a cloudy, incipient sericitization along the cleavages in some crystals.

The (clino)zoisite is abundant as largeish plates or irregular grains. The latter show a well-marked myrmekite texture with the plagioclase they are replacing. This calcsilicate shows somewhat variable optical properties, at times having a deep blue, anomalous interference colour, at others a yellow colour, and again, with normal grey interference colours. This would seem to indicate that both zoisite and clinozoisite are present.

Sphene is noticeable as strings and clusters of small subhedral grains.

Occasionally the amphibolites show what appears to be a blastoporphyritic texture, and in such cases optical measurements indicate that the anorthite content of the porphyritic feldspar is higher than that in the more even-grained, schistose groundmass. Such characteristics were shown in a 3 metre thick amphibolite lying between the sulphide bands in DDH M9 (Moskogaissa Drilling 1954). In the recrystallized groundmass the anhedral plagioclases, between 0.05 and 0.1 mm in diameter had an indicated composition of An_{54}. The more porphyritic plagioclases were mostly lath-shaped, varying between 1 and 4 mm. in length, exhibiting an imperfectly parallel orientation. Some of the laths showed a clear, recrystallized rim surrounding a cloudy core which had a higher refractive index. The cores showed marked fracturing, probably a result of stresses accompanying the partial recrystallization. Most of the cores were untwinned and it was not possible to determine their anorthite content. Some of the more elongated, larger feldspars showed combined carlsbad-albite twinning, and measurements on these indicated an anorthite content of 68 %. (Clino)zoisite and sphene were present in small quantities. The sphene grains often showed small, rounded, irregular, opaque grains at their centres, as though these were replacement relicts (see later). Calcite occurred rarely as small interstitial patches, apparently quite late.

This seems to be a case of a partial recrystallization of an originally porphyritic (?) basic rock, the centres of the relict porphyrites showing a higher An-content than the rims and the recrystallized feldspars in the groundmass. These latter have presumably the calcium content consistent with the PT conditions of the regional metamorphism of the area. The calcium released from the original feldspars has apparently gone into formation of the (clino)zoisite and the sphene.

With more complete recrystallization the amphibolites become truly schistose, with their hornblendes aligned parallel to the lineation direction of the schists in the area. Such a texture is by far the most common, especially in the thinner amphibolites. A series of thin sections from a 2 metres thick amphibolite about 7 metres above the "ore-zone", showed abundant (60—80 %) green pleochroic hornblende in irregular prisms up to 1.0 mm long with a markedly linear orientation. Plagioclase with an indicated composition of An_{48-54} occurred in an allotriomorphic mosaic interstitial to the hornblende needles, with an average grain size of 0.3—0.4 mm. As in nearly all the amphibolites examined (clino)zoisite and sphene were very noticeable, the latter in characteristic groups and strings of very small grains parallel to the schistosity.

In all the amphibolites examined microscopically the ferric mineral was a green common hornblende, showing weak to marked pleochroism, and an extinction angle ($c \wedge \gamma$ or Z) of about —20°. One possible exception to this occurred in one slide of an amphibolite from Låmivarre, about 2 kms. NE of Sabetjok Mine. In the large plates of hornblende occurred ragged "ghosts" of a mineral with a higher birefringence and extinction angle than the hornblende. These could well be residuals of the original augite of the basic igneous rock which has otherwise gone over to hornblende under the facies conditions of the regional metamorphism.

Padget mentions (pp. 58—59) the presence of original augite in the wedge-like body of dolerite occurring on the summit of Store Moskogaissa. This body is stratigraphically several hundred metres above the Moskogaissa amphibolite belt and it is not possible to deduce any connection. Padget considers the dolerite to have been intruded into the schists at a later date than the regional metamorphism, on the evidence of the retention of subophitic textures and original augite.

The present work suggests that all the amphibolites in the Ankerlia Schists are pre-regional metamorphism and the textures are often dependent on the thickness of the individual amphibolites. Thicker, more massive bodies have resisted metamorphism to the greatest extent, with part retention of original textures and, in one case, possible survival of the augite. However, the great majority of amphibolites are completely recrystallized and show the lineation and schistosity exhibited by the metamorphic schists of the region.

Table 9 below shows analyses of four of these amphibolites and of the Green Beds, a formation which Padget considers a metamorphosed extrusive basalt, and which overlies the Ankerlia series in the Moskogaissa area.

The table shows the chemical similarity of all these rocks, especially the similarity between the Green Beds and the amphibolites. This closeness in composition indicates a common origin and in order to study them more closely, a variation diagram of the type suggested by Larsen (1938) was drawn. This is reproduced as Fig. 11. This type of diagram was originally prepared to show magmatic differentiation in unmetamorphosed igneous rock suites and there may be objections to using it for completely recrystallized rocks. Also the number of analyses is too small to allow definite conclusion to be drawn.

However, the figure shows that, in general, the points for the various oxides fall on fairly smooth curves, which would indicate that the original, magmatic, chemistry has not been appreciably affected by later metasomatic processes. Considering the curves for the individual oxides it can be seen that with exception of CaO and Na_2O they follow the normal differentiation trends, i.e. increasing SiO_2 and Al_2O_3 coincident with decreasing FeO and MgO. In the case of CaO and Na_2O the normal trends are reversed. (The dashed lines show the normal trends.) In particular the most basic rock (No. 4) is poorest in CaO. This rock (from DDH M8) lies just above the mineralized (sulphide) zone and may have been affected by the metasomatism accompanying the ore (see below). If there has been a leaching of CaO from this amphibolite it would explain the abnormal trend shown in Fig. 11. An increase of about 3 %

	1	2	3	4	5	6
SiO_2	48.72	47.50	49.94	47.43	48.91	48.5
TiO_2	1.57	0.78	0.84	1.66	1.26	1.2
Al_2O_3	16.83	22.19	16.05	15.74	15.52	17.3
Fe_2O_3	1.86	1.50	1.10	1.37	0.82	1.3
FeO	7.54	4.60	6.23	10.65	9.13	7.6
MnO	0.17	0.09	0.13	0.20	0.13	0.1
MgO	7.91	6.57	8.80	8.66	7.80	7.9
CaO	11.05	13.56	12.50	10.00	12.61	11.9
Na_2O	2.56	1.94	2.16	3.01	2.38	2.4
K_2O	0.39	0.23	0.28	0.16	0.34	0.3
H_2O	1.33	0.86	1.38	0.45	0.73	0.9
P_2O_5	0.14	0.25	0.73	0.22	0.15	0.3
Total	100.07	100.07	100.14	99.55	99.78	99.7

Table 9.

1. Green Beds composite. Analyst B. Bruun.
2. Amphibolite, Magervann elv. Analyst B. Bruun.
3. Amphibolite R6/3082. N. of Mosko. 117 mine. Analyst B. Bruun.
4. Amphibolite between 100.00 and 103.60 m DDH M8, 1954. Analyst E. Christensen.
5. Amphibolite, R6/6000, Låmivarre, Birtavarre. Analyst E. Christensen.
6. Average of the above five analyses.

(Analyses 1 and 2 are reproduced from Padget's paper).

CaO in amphibolite No. 4 would produce a quite normal variation curve.

The abnormalities in the Na_2O are probably explainable by the action of metasomatic processes along the ore-zone (see p. 166). This has already been commented on in the section covering the schist wall-rocks to the ores.

It is interesting from a genetic point of view that the most differentiated rock (No. 1, the Green Beds) is an apparently extrusive rock lying at a higher stratigraphical horizon than the amphibolites in the top of the Ankerlia Schists. This would suggest that the Green Beds represent a later volcanic phase of the same activity

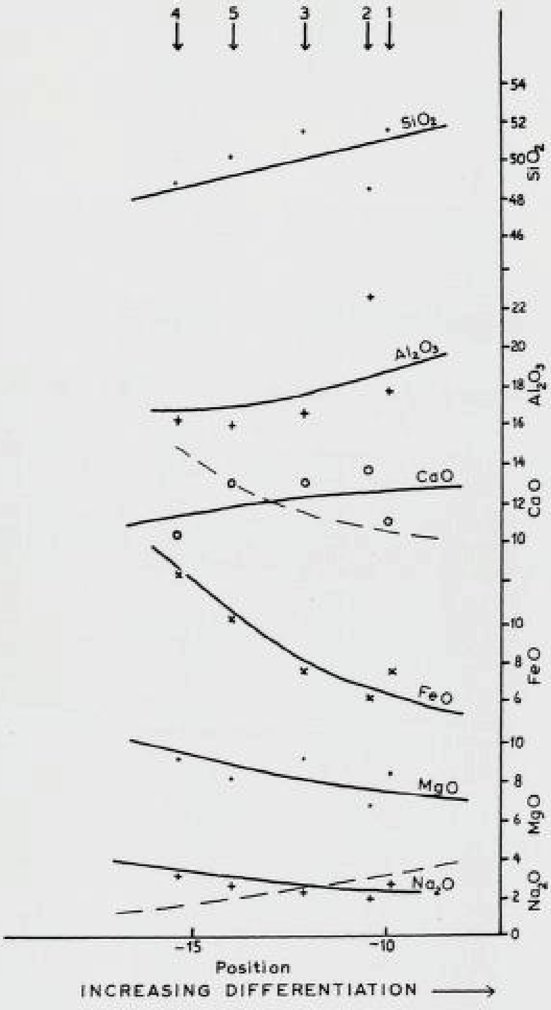


Fig. 11. Larsen variation diagram of the Green Beds and four amphibolites from the Birtavarre district. The numbers refer to the columns in Table 9.

«Larsen variasjons-diagram» for «Green Beds» og fire amfibolitter fra Birtavarre området. For analyse-numrene se tabell 9.

which produced the amphibolites. Some of these latter seem to be extrusive, others possibly intrusive (see below p. 66). If the variation curves can be taken to mean a great deal they would seem to show a period of basic, igneous activity extending through a definite interval of time in the central Birtavarre (Moskogaissa) area, with differentiation proceeding steadily to give the Green Beds lava as the latest product. The whole story, of course, would need an investiga-

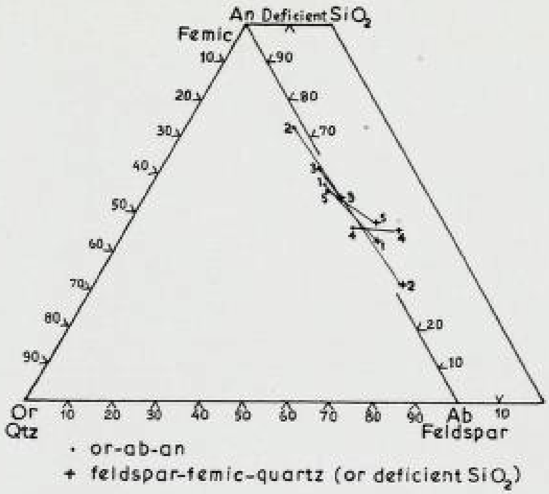


Fig. 12. Triangular variation diagram (after Larsen, 1938) of the Birtavarre meta-basic rocks. Numbers refer to analyses in Table 9.

Trekant-diagram (etter Larsen, 1938) for Birtavarre-områdets amfibiolitter. Se Tabel 9 for analyse-numre.

tion of the metabasic rocks throughout the whole of the area, which is outside the scope of this paper.

The analyses in Table 9 have been recalculated and plotted on a triangular diagram, also first suggested by Larsen (1938) (Fig. 12). This shows variations in normative feldspars or, ab, an, and in the normative quartz, feldspars and femics. (In the rocks in question here normative olivine appears and the deficiency in silica has been calculated and plotted.)

This diagram illustrates the Na_2O, K_2O and CaO of the feldspar, shows the undersaturation of all but one of the amphibolites, and shows the proportion of femic minerals in the rocks.

The gradients of the lines for each rock are fairly constant, again indicating chemical similarity and probably unaffected igneous chemistry. The exception is No. 4, which is strongly undersaturated compared with the others. This again suggests that this rock may have been affected by the metasomatism accompanying the ore-zone.

In the section on petrography and mineralogy above, the mineral constituents of the amphibolites have been described. The following tables (10, 11 and 12) give the calculated and observed modes of the analysed rocks. Padget (1955) gives the calculated modes of the Green Beds (analysis 1) and the amphibolite at Magervann elv (analysis 2).

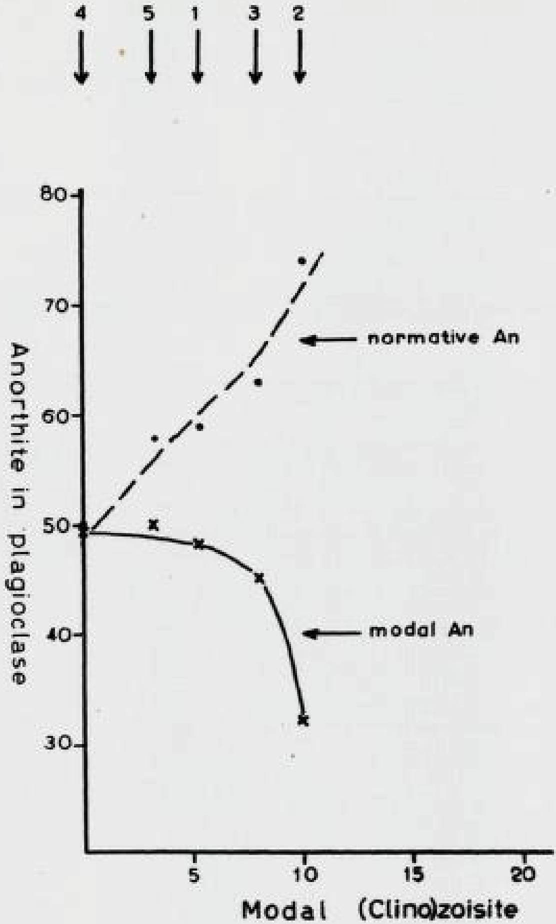


Fig. 13. Diagram illustrating the relation between the anorthite-content of the plagioclase and the amount of modal (clino)zoisite in the Birtavarre metabasics. (See Table 9).

Diagram som viser relasjonen mellom plagioklasenes anortitt-innhold og mengde av modal (klino) zoisitt i Birtavarre-områdets amfibolitter. (Se Tabell 9.)

The modes in Tables 10, 11 and 12 agree well with those given by Padget. The only exceptional one is that from Analysis 4 where there is an absence of zoisite, and rutile appears as an accessory. The low calcium content of this rock was remarked on above when it was suggested that it may be due to the metasomatism in the mineralized zone. A mineralogical change is suggested by the relation between the modal anorthite and modal clinozoisite in these rocks.

Fig. 13 shows these two quantities plotted against each other. It demonstrates clearly that the (clino)zoisite content varies inversely

	Si	Ti	Al	Fe'''	Fe'' + Mn	Mg	Ca	Na	K	P	(OH)		Observed Mode
	46.5	0.6	17.5	0.8	5.0	12.3	12.5	3.9	0.3	0.5	(8.5)		
	Calculated Mode												
Albite	8.7		2.9					2.9				14.5 } (An_{45})	25.0
Anorthite	4.8		4.8				2.4					12.0	
Hornblende	29.4		8.0	14.0			6.5	1.0	0.3		(7.7)	59.2	60.0
(Clino) zoisite	3.0		1.9	1.2			1.9				(1.9)	8.0	10.0
Sphene	0.6	0.6					0.6					1.8	2.0
Apatite							1.1			0.5		1.6	?
Ore				2.9								2.9	3.0
	46.5	0.6	17.6	18.1			12.5	3.9	0.3	0.5	(9.6)	100.0	100.0
	Catanorm												
Or	0.9		0.3						0.3			1.5	
Ab	11.7		3.9					3.9				19.5 } An_{63}	
An	13.3		13.3				6.6					33.2	
Di	10.2				1.5	3.6	5.1					20.4	
Hy	9.6				2.1	7.5						19.2	
Ol	0.8				0.4	1.2						2.4	
Mt				0.8	0.4							1.2	
Il		0.6			0.6							1.2	
Ap							0.8			0.5		1.3	
	46.5	0.6	17.5	0.8	5.0	12.3	12.5	3.9	0.3	0.5		99.9	

Table 10. Analysis 3, R6/3052. Calculated and observed modes and catanorm.

with the anorhite content of the plagioclase. This seems to indicate that the zoisite content of these rocks is due to a release of calcium from the feldspar during retrograde metamorphism, the feldspar becoming poorer in anorthite the more CaO is released to form (clino)-zoisite. The presence of small "droplets" or "skeletons" of opaques

	Si	Ti	Al	Fe···	Fe·· + Mn	Mg	Ca	Na	K	P	(OH)		Observed Mode
	43.9	1.2	17.2	1.0	8.4	12.0	9.8	6.0	0.2	0.1	(2.4)		
	Calculated Mode												
Albite	6.0		2.0					2.0				10.0 } (An_{49})	20.0
Anorthite	3.8		3.8				1.9					9.5	
Hornblende	34.1		11.6		16.0		7.7	4.0	0.2		(9.0)	73.6	73.0
Rutile		1.2										1.2	2.0
Apatite							0.3			0.1		0.4	?
Ore				5.4								5.4	5.0
	43.9	1.2	17.4		21.4		9.9	6.0	0.2	0.1	(9.0)	100.1	100.0
	Catanorm												
Or	0.6		0.2						0.2			1.0	
Ab	16.2		5.4					5.4				27.0 } An_{50}	
An	11.0		11.0				5.5					27.5	
Ne	0.6		0.6					0.6				1.8	
Di	8.2				1.4	2.7	4.1					16.4	
Ol	7.3				5.3	9.3						21.9	
Mt				1.0	0.5							1.5	
Il		1.2			1.2							2.4	
Ap							0.2			0.1		0.3	
	43.9	1.2	17.2	1.0	8.4	12.0	9.8	6.0	0.2	0.1		99.8	

Table 11. Analysis 4. DDH M 8, 100.0 - 103.6 m.
Calculated and observed modes and catanorm.

at the centres of the sphene grains in many cases seems to show that this mineral has been formed due to a reaction between original ilmenite in the rock and this released calcium. Eskola (1914 p. 103) noticed the same process in the amphibolites of the Orijärvi region. (Clino)zoisite would be likewise formed at the expense of the plagio-

	Si	Ti	Al	Fe···	Fe·· + Mn	Mg	Ca	Na	K	P	(OH)		Observed Mode
	45.8	0.9	17.1	0.6	7.2	10.9	12.6	4.4	0.3	0.1	(3.9)		
	Calculated Mode												
Albite	9.0		3.0					3.0				15.0 } (An50)	30.0
Anorthite	6.0		6.0				3.0					15.0 }	
Hornblende	22.8		7.0		13.8		4.6	1.4	0.3		(5.3)	49.9	50.0
Augite	5.8		0.5		2.7		3.0					12.0	12.0
(Clino) zoisite	1.2		0.6	0.6			0.8				(0.8)	3.2	3.0
Sphene	0.9	0.9					0.9					2.7	3.0
Apatite							0.2			0.1		0.3	?
Ore					1.6							1.6	2.0
	45.7	0.9	17.1	0.6	18.1		12.5	4.4	0.3	0.1	(6.1)	99.7	100.0
	Catanorm												
Or	0.9		0.3						0.3		1.5		
Ab	13.2		4.4					4.4			22.0 } An58		
An	12.4		12.4				6.2				31.0 }		
Di	12.4				2.2	4.0	6.2				24.8		
Hy	3.1				1.2	1.9					6.2		
Ol	3.8				2.6	5.0					11.4		
Mt				0.6	0.3						0.9		
Il		0.9			0.9						1.8		
Ap							0.2			0.1	0.3		
	45.8	0.9	17.1	0.6	7.2	10.9	12.6	4.4	0.3	0.1	99.9		

Table 12. Analysis 5. R6/6000, Låmivarre.
Calculated and observed modes and catanorm.

clase and hornblende, producing the characteristic myrmekite textures. The absence of sphene and zoisite in the amphibolite from DDH. M8 could be explained on this hypothesis as being due to the fact that the retrograde processes have not affected the rock to such an extent as to begin the breakdown of the plagioclase.

The present mineralogy of these rocks is that resulting from regional metamorphism in lower amphibolite- or epidote-emphibolite facies. Their chemistry and mode of occurrence point to an origin as basic igneous rocks, though it is not always easy to decide whether these were originally volcanics or intrusives. The field relations of the Green Beds, for instance, give good ground for supposing they represent an original flow of basalt, while stratigraphically higher dolerites show chilled contacts which strongly suggest they are intrusive.

The amphibolites of the upper Ankerlia Schists, by their layered forms and relatively small thickness seem most easily interpreted as original lava flows. In the cores from the 1954 drilling programme no chilled contacts were observed. The amphibolites at Magervann elv (analysis 2) occur as thick lens-shaped bodies which Padget considers were originally intrusive. These occur in the same general horizon as the ones at Moskogaissa, so it seems likely that both intrusive and extrusive types are present.

Whatever their origin, amphibolites are present in most of the formations of the Birtavarre district, representing a very widespread and general period of basic igneous activity.

As is well-known most fold-mountain regions show evidence of igneous activity broadly contemporaneous with orogeny. The first stage in this activity is the eruption of dominantly basic lavas during the geosynclinal phase of the tectonic cycle. The Green Beds and other extrusive-looking amphibolites can be classed as original basic lavas extruded during this geosynclinal phase. The dolerites of Lille Moskogaissa and other coarse-grained types with chilled margins were very likely intruded into the rocks at a later date, though it is not easy to place them in the tectonic cycle. Many of the amphibolites must have been emplaced before the regional metamorphism took place, while others (e.g. the dolerites) did not arrive until after this phase.

The chemical analyses given in Table 9 above show that the amphibolites have the composition of basalts. Padget (1955, p. 57) compares the analysis of the Green Beds with that of Hebridean olivine-basalt (Walker and Poldevaart, 1949, p. 649). Table 13

	1	2	3	4
SiO_2	48.5	48.2	46.5	47.4
TiO_2	1.2	0.9	1.2	2.2
Al_2O_3	17.3	15.6	17.7	15.6
$Fe_{23}O$	1.3	3.4	3.7	3.7
FeO	7.6	7.4	6.2	9.2
MnO	0.1	0.2	0.2	0.3
MgO	7.9	7.6	8.9	8.5
CaO	11.9	11.1	11.5	10.2
Na_2O	2.4	2.6	2.2	2.1
K_2O	0.3	0.1	0.8	0.6
ΣH_2O	0.9	2.4	1.0	c. a.
P_2O_5	0.3	0.1	0.3	0.2

1. Average, Birtavarre metabasics. (See Table 9).
2. Støren greenstones (Vogt, 1945, p. 466).
3. Average 17 Olivine gabbros (Daly 1910, p. 225).
4. Hebridean olivine basalt (Walker and Poldevaart, 1949, p. 649).

Table 13. Comparison of average analysis of Birtavarre metabasics with other published analyses.

compares the calculated average of the five analyses of Birtavarre metabasics with other published analyses of similar rocks.

The table shows the similarity with the Hebridean olivine basalt already mentioned and with the average analysis of seventeen olivine gabbros. Of more immediate interest is the chemical similarity between the average Birtavarre analysis and that of the Støren greenstones, which are a series of effusive greenstones with pyroclastic material, up to 2500 metres thick occurring in the Caledonides of central Trøndelag (Vogt, 1945, p. 459). They appear to be in a somewhat lower metamorphic state than the Birtavarre rocks. According to Vogt they are in greenschist to epidote-amphibolite facies, but chemically they are almost identical with the amphibolites from Birtavarre. This fact would seem to point to a common origin for the basic rocks of the Caledonian orogenic cycle in both central Norway and in the Birtavarre region, 800 kilometres to the north.

In Tables 10, 11 and 12 are shown the catanorms of three of the Birtavarre amphibolites. All show an undersaturated chemistry, with normative olivine ranging from 2.4 % to 21.9 %. The high olivine content in the norm of Analysis 4 might lead one to suspect that, as mentioned above, there has been *some* influence from the Mg—Fe metasomatism associated with the ore-zone.

The above discussion is dependent on an assumption that there has been no regional metasomatism to affect the composition of these amphibolites. This is a debatable assumption. Evidence has been put forward above that the calc-silicates in the metabasics are due to CaO released from the plagioclase during retrograde metamorphism. The very good agreement in Table 13 and likewise the variation diagrams, Figs. 11 and 12, indicate that amphibolites still have the composition of the original basic igneous rocks.

The structures of the sulphide bodies.

This section contains more or less detailed descriptions of the sulphide bodies of the area. The sources of information are outcrops and old workings, but chiefly the diamond-drill cores obtained in 1954 and 1955. The information available is somewhat scattered and no complete picture can be drawn up for any particular ore-body. The drilling information is the most complete of any, but even here the distances between individual drill-holes are really too great to allow the variations in thickness, form and structure to be traced in great detail.

Evidence from drill-cores.

The "plates" of sulphide which form the potential ore-bodies as a rule show a composite make-up in vertical section. The two seasons' drilling gave in all 24 intersections in the Moskogaissa and Sabetjok—Birtavarre Høyfjell areas and enabled a fairly representative picture of the vertical variations in the sulphide zones to be obtained.

For purposes of description the two areas will be treated separately.

Moskogaissa area. The intersections of the mineralized zone varied from a strip of solid sulphide 5 cms thick to a composite breccia-impregnation zone over 2.50 metres thick. Of the seven holes drilled into the main "ore-plate" near the old Moskogaissa 115 mine, three showed small sulphide zones under about 30 cm thick, another three showed a "split" sulphide zone, while the seventh showed nearly continuous mineralization for 2.65 m.

The thinnest intersection (DDH M10) comprises a compact, fine-grained band of pyrrhotite just over 4 cm thick, with a notable content of very fine hornblende and anthophyllite needles scattered evenly through it. On the hanging-wall of this band is a clearly marked 1—2 mm strip of chalcopyrite, also with scattered amphibole. The hanging-wall contact with the overlying anthophyllite-quartz schist is sharp, "frozen" and slightly irregular, but on the whole concordant with the schistosity.

Beneath the foot-wall of the pyrrhotite band is up to 5 mm of fine-grained chalcopyrite impregnation in a rather coarse anthophyllite-staurolite schist. The foot-wall is also concordant with the schistosity.

A rather more complex sulphide zone can be seen in the core from DDH M3 (Fig. 14). The hanging-wall mineralization is an irregular, roughly lens-shaped veinlet of chalcopyrite occurring parallel to the schistosity of the anthophyllite-quartz schist. The schist shows open breaks, both parallel to and at a high angle to the schistosity. Just beneath this occurs an area of sulphide replacement or impregnation.

The hanging-wall of the 18 cm band of nearly solid pyrrhotite is very sharp and "frozen" but highly irregular. There is a selvedge of hornblende crystals up to 1—2 mm long. Closer examination shows replacement of the schist and cross-cutting of the schistosity. The band is solid, fine-grained, showing, megascopically, only pyrrhotite. The sulphide is, as usual, crowded with tiny hornblende needles and the lower 10 cms contain patches of hornblende schist and vein quartz, which appear to be brecciated pieces of the country-rocks. The largest of these pieces has been "invaded" and irregularly replaced by the sulphide.

The footwall is sharp, irregular and transgressive like the hanging-wall and at the very contact there occurs a thin, discontinuous film of chalcopyrite.

The footwall rock is garnet-anthophyllite schist containing garnets up to ½ mm dia. Disseminations of chalcopyrite and pyrrhotite occur in this schist for 5—6 cms below the solid sulphide band. The schist is broken up by very irregular open cracks (joints?) which seem to have opened later than the sulphides, although they show no sign of movement (no polishing or slickensiding). They carry thin coatings of a black, clayey material (Mn oxides?).

In DDH M4 another type of mineralization is shown. There occurs no solid sulphide or breccia band, but a thickness of about 13 cms of highly contorted and sheared schist has been impregnated with sulphides, mostly pyrrhotite (chalcopyrite occurs with the iron sulphide only in the top 6 cm). The hanging-wall mineralization consists of a thin chalcopyrite-pyrrhotite veinlet nearly parallel to the schistosity. Partly cutting through this veinlet is a curved open break also almost parallel to the schistosity. On both surfaces of the break the sulphides have been smeared-out and polished smooth. The pyrrhotite in particular shows very fine striations. This is clear indication of post-ore movement.

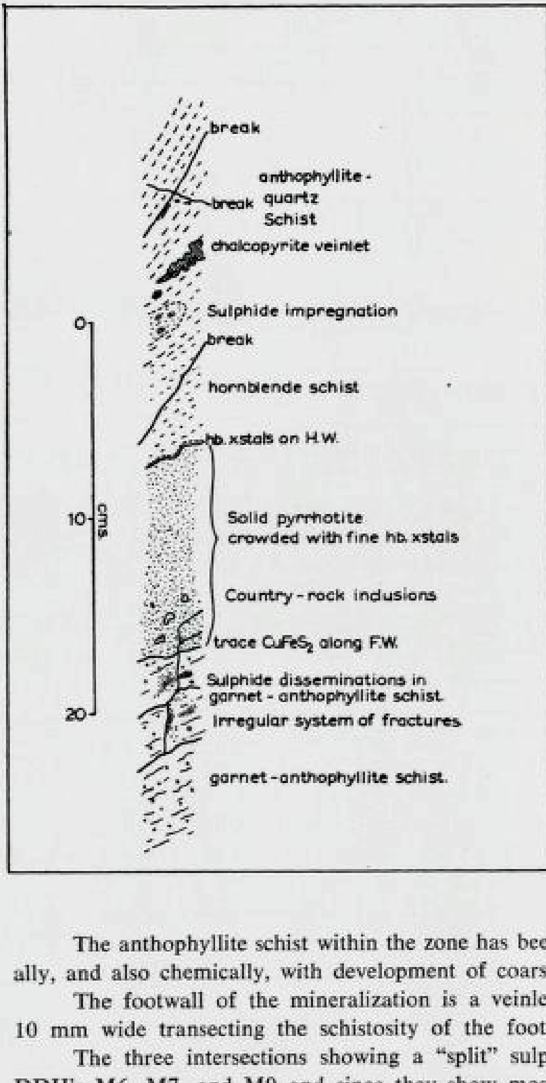


Fig. 14. Sketch of core from DDH M3 to illustrate the nature of the sulphide zone intersected.

Skisse av kjernen fra borhull M3 som illustrerer sulfidsonens struktur.

The anthophyllite schist within the zone has been extremely affected mechanically, and also chemically, with development of coarse aggregates of chlorite.

The footwall of the mineralization is a veinlet of pyrrhotite between 1 and 10 mm wide transecting the schistosity of the footwall anthophyllite schist.

The three intersections showing a "split" sulphide zone were obtained with DDH's M6, M7, and M9 and since they show most of their features in common only one of them will be described in detail (M7, Fig. 15).

The zone in M7 consists of two sulphide bands, respectively 27 and 34 cms thick, separated by 3.14 metres of schist. The upper band is nearly wholly solid, fine-grained pyrrhotite. For the first 5 or 6 cms the sulphide occurs in an irregular joint at right angles to the schistosity and up to 1 cm wide. At the top end this joint-filling sends out a finger along the schistosity for about 1 cm and in this finger is concentrated the only megascopically visible chalcopyrite in the band.

The footwall of the band is very clean and sharp ("frozen") though slightly

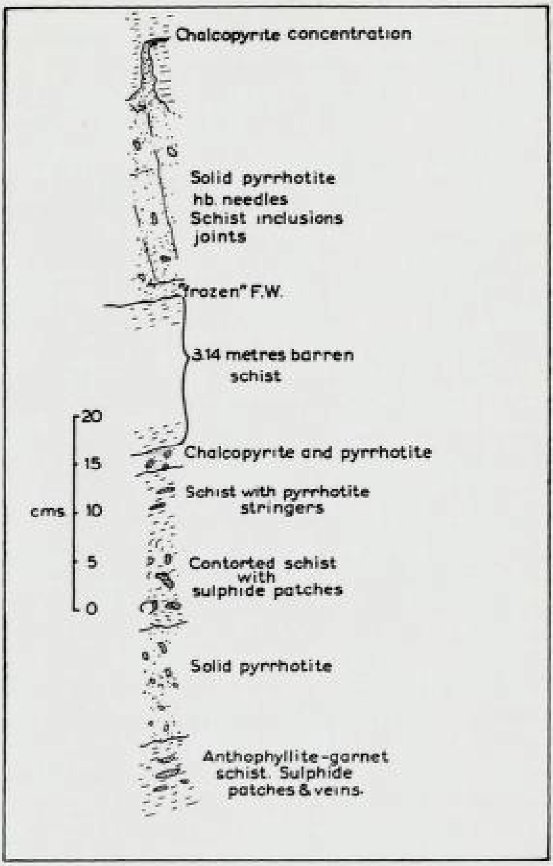


Fig. 15. Sketch of core from DDH. M7.

Skisse av kjernen fra borhull M7.

irregular. The band as a whole shows crowds of fine hornblende needles and occasional grey-green clayey inclusions. It is intersected by open cracks and joints with coatings of black oxide.

The lower sulphide band begins as a 2 cm thick band of nearly solid chalcopyrite and pyrrhotite. Small inclusions of schist and individual minerals indicate that this was originally a small breccia zone. The immediate hanging-wall is a thin strip (½—3 mm) in which the silicates have been crushed almost to powder before being cemented by the sulphides. No evidence is seen of any post-sulphide movement.

Below this band come 6 cms of grey anthophyllite-quartz schist with an occasional thin stringer of pyrrhotite, followed by 10 cms of folded and contorted lustrous anthopyllite-chlorite schist. In this occur large replacement patches of pyrrhotite, making up about 50 % of the rock. The next 11 cms is almost solid, fine-grained pyrrhotite, with the usual fine hornblende needles, and showing irregular but fused junctions to the schists on either wall. Below this, pyrrhoitite occurs sparingly as impregnations in anthophyllite-garnet schist for about 5 cms.

M9 shows post-ore movement along the hanging-wall of the upper band which consists of 18 cms of rich pyrrhotite-chalcopyrite breccia. The lower band 1.48 metres below is fairly strong sulphide impregnation in sheared schist. (16 cms thick.)

In M6 the upper band is composite and contains within itself two separate breccia bands each about 7 cm thick. The lower of these shows only chalcopyrite and assays over 10 % Cu. Both the hanging- and footwall are open breaks, but do not show signs of movement. The lower sulphide band is a rich chalcopyrite-pyrrhotite impregnation (20 cms).

DDH M8 gave the only continuous intersection of any thickness. The sulphide zone is here 2.65 metres thick, of which 2.30 metres is nearly continuous, solid sulphide. The hanging-wall of the ore is a very smooth surface at an angle to the schistosity of the overlying medium-grained anthophyllite-quartz schist. It shows polishing and has a coat of smeared-out black oxides. It shows definite post-ore movement. The first 23 cms of sulphides are almost pure pyrrhotite with small silicate inclusions. The split core showed a rough shiny surface, rather different from the dull surfaces exhibited by the fine-grained pyrrhotite bands in the other holes. The country-rock fragments increase downwards and become bigger, and at the same time the proportion of chalcopyrite rises to about one-third of the sulphides. There is a sharp footwall to this band, followed by 8.5 cm grey garnet-anthophyllite schist. After another 1 cm solid pyrrhotite breccia, and another 5 cm sulphide-free schist there comes a thickness of 1.80 m of almost solid sulphide. This is mostly pyrrhotite, but irregular patches of chalcopyrite appear in places, especially around inclusions of schist. These inclusions are mostly platy in keeping with the nature of the schist and they are aligned at all angles to the original schistosity direction. Open jointing is noticeable in the sulphides at places.

Below this band are 12 cms of anthophyllite-quartz schist with a 4 mm veinlet of sulphides concordant with the schistosity. The last 20 cms or so comprise a very rich impregnation with a high proportion of chalcopyrite. The lower 5 cms of this is made up of practically solid chalcopyrite, also showing a rough, shining fracture. Minute hornblende needles are numerous as inclusions in the sulphides.

The footwall is very sharp and transects almost at right angles the schistosity in the underlying hornblende-rich schist. About 5 cm below the footwall the hornblende-rich schist gives way to a garnet-rich band with garnet aggegates up to 5 mm in diameter.

The M8 intersection may be interpreted as a continuous breccia zone, with one or two thin schist partings near the top. The texture of the sulphides, especially on fracture surfaces seems to be distinct from that seen in the smaller breccia zones, but this question will be taken up below (p. 110).

The two holes R1 and R2 (see p. 205) also drilled in 1954 in the Moskogaissa area, but into a lower sulphide horizon, do not add much to our knowledge of the mineralization. R1 showed 5 cms of sulphide (mainly pyrrhotite) impregnation in garnet-anthophyllite schist, while R2 intersected the zone without revealing any sulphides.

The Sabetjok—Birtavarre Høyfjell area. Drilling was carried out on electro-magnetic indications in this area in 1955. The intersections revealed an irregular sulphide horizon showing many of the characteristics described above from the Moskogaissa drill-cores. Of the fifteen holes drilled, 8 revealed a single mineralized zone of varying thickness, 4 showed that the zone had split into two bands and 2 showed more "composite" zones. One hole did not intersect sulphides. The map on p. 218 (Fig. 62) shows the relative positions of the drill holes in this area.

Of the "single" sulphide-zone intersections we may pick out those holes bored in the western part of the area (DDH's S12, S13, S14 and S15) which showed only a zone of sheared schist with weak sulphide impregnations. No bands of breccia or other solid sulphides occur. The impregnated zones vary in thickness from just over 1 metre to 8 cms and the copper content is always less than 0.5 %.

These holes show the weak nature of both the pre-ore movements and the mineralization in the westerly part of the area drilled in 1955. In the more easterly part, the "single" sulphide zone intersections invariably show a band of rich breccia, with weaker impregnations on one or both walls. Though these breccia bands were never more than 30 cm thick (4—30 cms) they were quite rich in copper (2—4 %). Fig. 16 shows a sketch of the sulphide intersection in DDH S7. Here the mineralization is confined almost entirely to the breccia band which is rich in chalcopyrite (3.8 % Cu). An extremely weak impregnation occurs in the schists above the hanging-wall. In other holes this impregnation is continuous with the breccia and sometimes rich enough to be included for assaying.

In S7 the top 5 cms of the sulphide zone comprises a band of brecciated vein quartz with much chalcopyrite and pyrrhotite, while underlying it is 16 cms of sulphide-cemented breccia consisting of fragments of dark-green hornblende- and light-green chlorite-schist up to 5 mm diameter. The upper 5 cms obviously represents an original vein quartz band in the schists which has been crushed up in movements producing the breccia as a whole.

Under the sulphide breccia comes 2 cms of dark-green hornblende-schist, which could be part of a large fragment in the breccia. The last 4 cms is almost pure chalcopyrite, a very good example of the tendency of the copper mineral to concentrate on one or other of the walls.

The actual footwall is a plane of post-ore movement, showing slickensiding and polishing of the sulphides.

There appears to be no rule regarding the nature of the walls of these breccias. In some holes both walls show post-ore movement, in some one does, and in others both are "frozen".

The "split" sulphide-zone intersections show much the same character as those in the Moskogaissa region. They show as a rule one band of sulphide-rich breccia separated from another band of sulphide impregnation by barren schist varying in thickness between 40 cms and 1.30 metres. Fig. 17 shows a sketch of the core from DDH S11, as a typical example of this type of intersection.

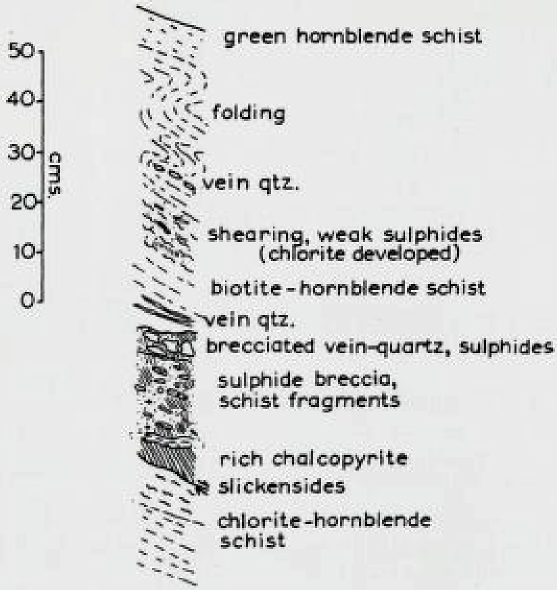


Fig. 16. Sketch of the Sabetjok—Birtavarre Høyfjell sulphide-zone as shown in core from DDH. S7.

Skisse av kjernen fra borhull S7 som illustrerer sulfidsonens struktur i Sabetjok—Birtavarre Høyfjell-området.

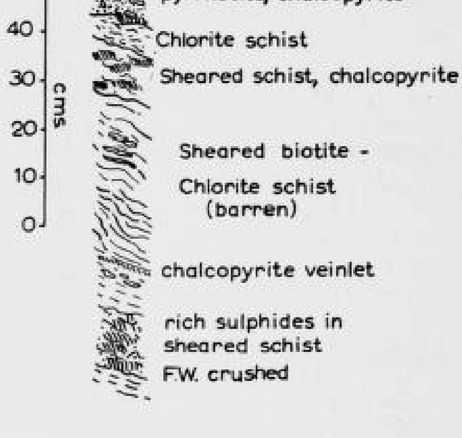


Fig. 17. Sketch of core from DDH. S11.

Skisse av kjernen fra borhull S11.

The hanging-wall is sharp and straight, parallel to the schistosity and "frozen". Underneath comes about 16 cms of breccia, with pyrrhotite as the main cementing material. The rock fragments included in this comprise vein quartz and hornblende- or chlorite-schist several cms across. The flat schist fragments lie roughly parallel to the schistosity of the surrounding rocks. Next comes 4 cms of dark-green hornblende-biotite-chlorite-schist which may be an extra large inclusion in the breccia. This is followed by a further 17 cms of sulphide breccia with quartz and schist fragments up to 2 cm across.

After 5 cms of soft, minutely folded chlorite-biotite-schist comes 10 cms sheared and brecciated green schist with quartz fragments carrying a rich chalcopyrite-pyrrhotite impregnation. The footwall of this is an open, smooth slip-plane.

The above represents the upper sulphide band. Beneath it comes 34 cms of highly sheared and in parts tightly folded chlorite-biotite schist. Originally concordant bands of vein quartz have been broken-up and lensed-out by the movements.

The lower sulphide band is represented by 24 cms of the above schist carrying chalcopyrite and some pyrrhotite as veinlets and irregular disseminations. The last 2 cms are relatively enriched in chalcopyrite. The footwall shows crushing.

Here the whole sulphide zone forms a continuous band of shearing and brecciation, with the greatest effect near its hanging-wall where the brecciation took place. The sulphides came in along this hanging-wall breccia and along highly sheared schist on the footwall of the zone.

The two "composite" intersections (DDH's S2 and S3) may be mentioned separately.

S3 shows sulphide concentrations in three separated bands. The hanging-wall one, 30 cms thick, consists of impregnation, mostly chalcopyrite, in the schists. 90 cms beneath this are two small bands of copper-rich breccia, respectively 7 and 9 cms thick, separated by 10 cms barren schist. 1.55 metres below this again the footwall sulphide band comprises 25 cm impregnation and breccia, the lowest 3 cms of which are pure chalcopyrite. This spreading-out of the sulphides at various levels in the schist is responsible for the low copper content of the zone as a whole.

S2 shows continuous, though irregular mineralization throughout a thickness of 2.03 metres and shows marked resemblance to DDH M8 in the Moskogaissa area. The mineralization begins as irregular disseminations of sulphides in somewhat sheared biotite-hornblende- and biotite-hornblende-chlorite-schist. The hanging-wall was determined by assay. The schist carries thin bands and lenses of vein quartz parallel to the schistosity. 75 cms below the hanging-wall is a 14 cms band of very rich (8.8 % Cu) sulphide-cemented breccia, the footwall of which is an irregular, open crack showing slickensiding.

Under this comes about 40 cms light-gray, fine-grained quartz-hornblende-schist, highly jointed, and carrying sparse flecks and "spots" of sulphides.

Under this is a composite sulphide band 50 cms thick, which is sketched in Fig. 18. This shows a central band of solid pyrrhotite with small schist fragments and marked joints. Towards the footwall there is a marked concentration of chalcopyrite, while towards the hanging-wall this mineral is again concentrated in an irregular vein-like form. The actual hanging-wall is remarkably straight and

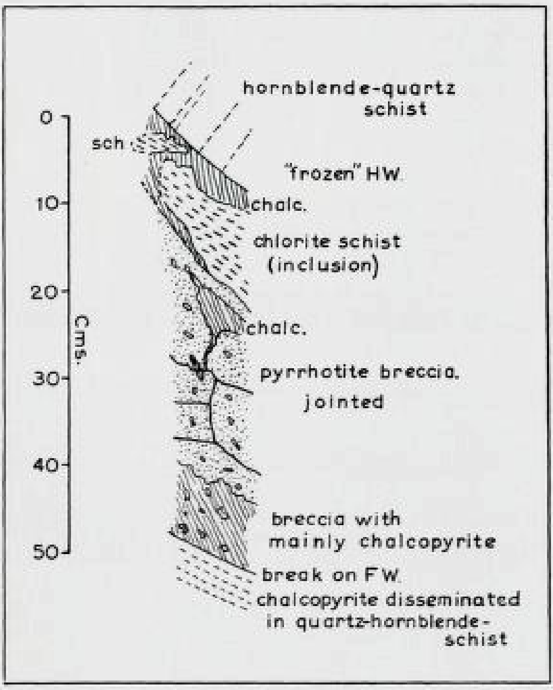


Fig. 18. Sketch of core from DDH S2 showing a part of the sulphide-zone intersected in this hole.

Skisse av kjernen fra borhull S2.

clear, being "frozen" against the overlying schist and cutting the schistosity almost at right angles.

The sulphides in this band, especially the copper mineral, show a very bright, shiny, coarse-grained surface on fracturing, a feature which was also noted in DDH M8. This will be commented on later.

Beneath the composite band just described comes 27 cms of quartz-hornblende-schist with fine sulphide dissemination, followed by a final 15 cm band of sulphide-cemented breccia. The footwall is an open irregular break, but no signs of movement could be seen.

The S2 intersection therefore shows at least three bands of breccia, with varying proportions of the two sulphides in each. There is clear evidence of post-ore movement (slickensiding) along the footwall of the uppermost band, and indications that the footwalls of the other two may be also tectonic.

Summary of drill-core evidence. The above information is the most comprehensive and systematic to hand regarding structure of sulphide bodies of the Birtavarre area. It covers two sulphide-'plates' or ore-shoots and it can be seen that the same features are shown in both of them.

The information stresses the extreme variation in thickness of the mineralization. This fact was already apparent from the old mining reports and records. For example, DDH's M10 and M8, which cut the same sulphide zone showed thickness of 5 cms and 2.65 metres respectively. The distance between their intersections is about 50 metres.

The information shows that the sulphides do not always keep to one plane or level in the schists, but often split into two or more bands, separated by barren schists. This has in many cases meant that the average grade of the zone is too low to be classed as workable ore.

Nature of pre-ore movements. The movements have in all cases been parallel to, or only slightly discordant with, the schistosity (and bedding) of the surrounding schists. This has given rise to the markedly banded structure of the sulphide zones. Within a single ore-plate the movements have produced different effects; a breccia-band at one place and only a weak shear at others. Examples can be found showing gradations between the two, and it may be that replacement of rock fragments by the sulphides plays a great role in isolating them from each other. It is difficult to distinguish between open tectonic breccias and replacement breccias in many cases.

The difference in the tectonic products is probably to be sought in a combination of the competence of the particular rock layer being stressed and the direction of the forces relative to the attitude of that layer. As an illustration of this it can be said that the weakly mineralized shears in the west of the area drilled in 1955 occurred in biotite-rich schist, while the more definite breccias tended to occur in harder quartz-hornblende-schist. Again the Rautajok drill holes R1 and R2 intersected only weakly mineralized shears in biotitic schists while the overlying sulphide-zone at Moskogaissa showed definite breccias in the quartz-hornblende- and hornblende-schist.

As regards the direction of the stress with respect to the attitude of the schists, it could be thought that where these two were parallel only weak shearing would result. Where the schists were folded movement might cut across the limbs of the folds, tending to give rise to breccias. Much of this cannot be proved due to lack of evidence, and it must remain as speculation.

Nature of the walls. Where the sulphide zone consists of disseminations or impregnation, the walls are usually gradual and it is a question of judgement (or depends on assay results) where to place them. The walls of the breccias are usually very clearly defined. As will be evident from the description above, the walls can be either "frozen" or the sites of planes of movement. The "frozen" walls can be seen to be due to replacement of the surrounding schist by the sulphides from the breccias. This is the same process which resulted in the partial digestion of country-rock fragments within the breccias.

Plate 4 shows photomicrographs of two examples of "frozen" walls. In many cases the walls of the sulphides intersect the schistosity of the wall-rock at high angles (cf. Fig. 18, DDH S2). This is invariably due to the presence of local folding in the schist before the emplacement of the ore-minerals.

Post-ore movements. The "non-frozen" walls are due to movements occurring after the solidification of the sulphides. Evidence of the later age of the movements is afforded by polishing and striations on both pyrrhotite and chalcopyrite. The movement planes do not seem to show much system and can appear on both the hanging- and footwalls of the sulphides. In some cores late movement planes were observed in the schists on either side of the mineralized bands.

There is no means of judging the magnitude of these movements, but they need not have been very great to produce the observed polishing.

In keeping with the general tectonics of the whole region, the post-ore movements have been generally flat, parallel with the schistosity. No evidence of cross-cutting faulting has been found.

Marked post-ore movements were studied in Skaide mine (see below, p. 103) apparently of the same type as those indicated from the drilled-core evidence.

Joints. The solid sulphide bands often show marked joints, or other, less regular, open cracks. These must have been developed after the solidification of the ore and cannot be inherited from the original jointing in the country-rocks.

Correlation between drill-holes. It is obvious, because of the distances between adjacent borehole intersections, that any attempt to construct vertical sections of the sulphide zones will involve more guesswork than factual knowledge. However, for the sake of completeness such attempts should be made.

Fig. 10 on page 37 is a block diagram showing, among other things, the supposed form of the sulphide zone in the Moskogaissa area from the results from DDH's M6, M7, M8 and M9.

The information from the Sabetjok—Birtavarre Høyfjell area is a little more complete and two attempts have been made to draw sections between drill-holes illustrating the form of the sulphide plates. These attempts are shown in Figures 10 and 20. Because of the scale the sulphide zone cannot be shown in detail and only the main mineralized bands are shown. In Fig. 19 the section is drawn N—S along a drill-hole profile, while in Fig. 20 the section is practically parallel to full dip. It is not possible to indicate where a "split" sulphide zone links up to form a single one, or vice versa, so the dashed connecting lines merely indicate the general thickness of the zone as a whole.

Evidence from old workings.

The drill-hole information can be supported and often clarified by the evidence in certain of the old workings of the area. The chief ones of these will be described in turn, detail being given when any new features are shown.

Moskogaissa 111 mine. This is the most easterly of the old workings in the Moskogaissa area, and its position is shown in Plate 2.

The mineralized horizon here, as a whole, has a gentle, somewhat undulating, dip in a southerly direction. Its outcrop is divided into two by a gentler slope covered with soil and rubble. The more easterly outcrop, about 55 metres long, has been explored by a shallow open-cut excavation and two short adits, designated Adits 3 and 4 respectively. The westerly outcrop is 35 metres long and Adits 1 and 2 have been driven short distances into the hillside on it.

In the eastern section the sulphides occur as irregular bands, veins and pockets, near or at the base of the open-cut face. Larger pockets have a brecciated apperance with fragments of the wall-rocks of all sizes enclosed in a matrix of sulphides. The sulphide horizon as a whole has a thickness varying between one and two

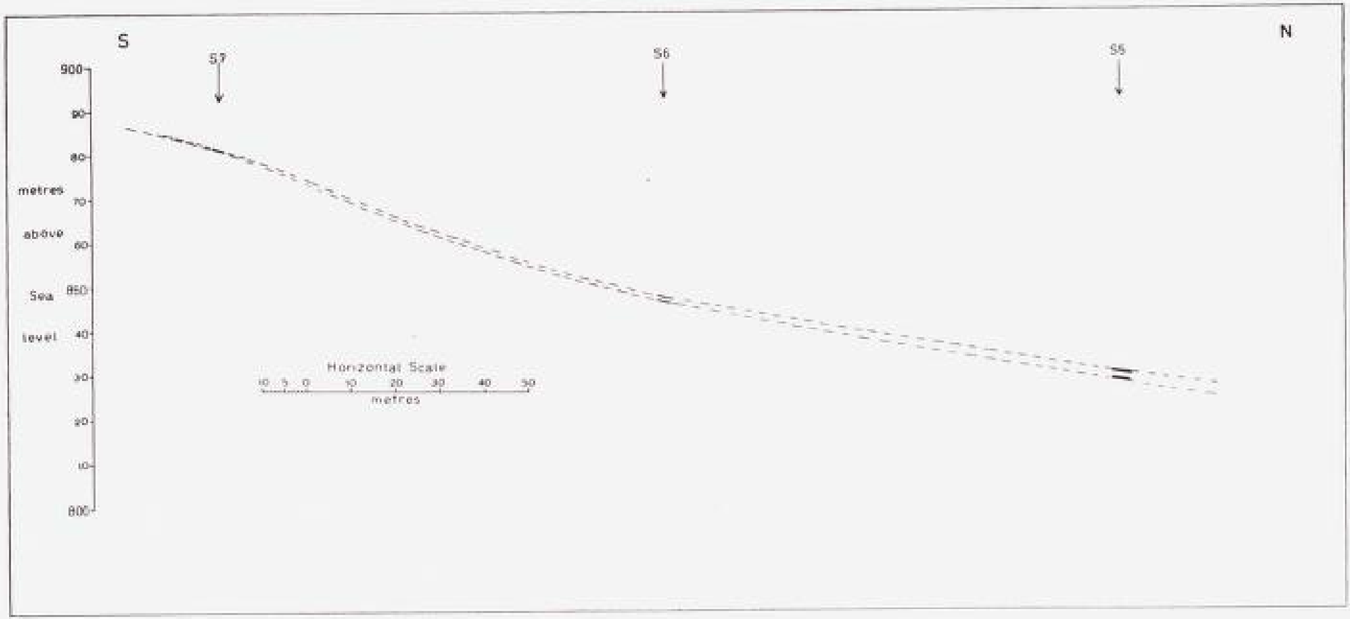


Fig. 19. Vertical S—N section showing the form of the ore-horizon as revealed from DDH's S7, S6 and S5.

Vertikalt snitt (S—N) som viser malmsonen i borhullene S7, S6 og S5. (Sabetjok—Birtavarre Høyfjell-området.)

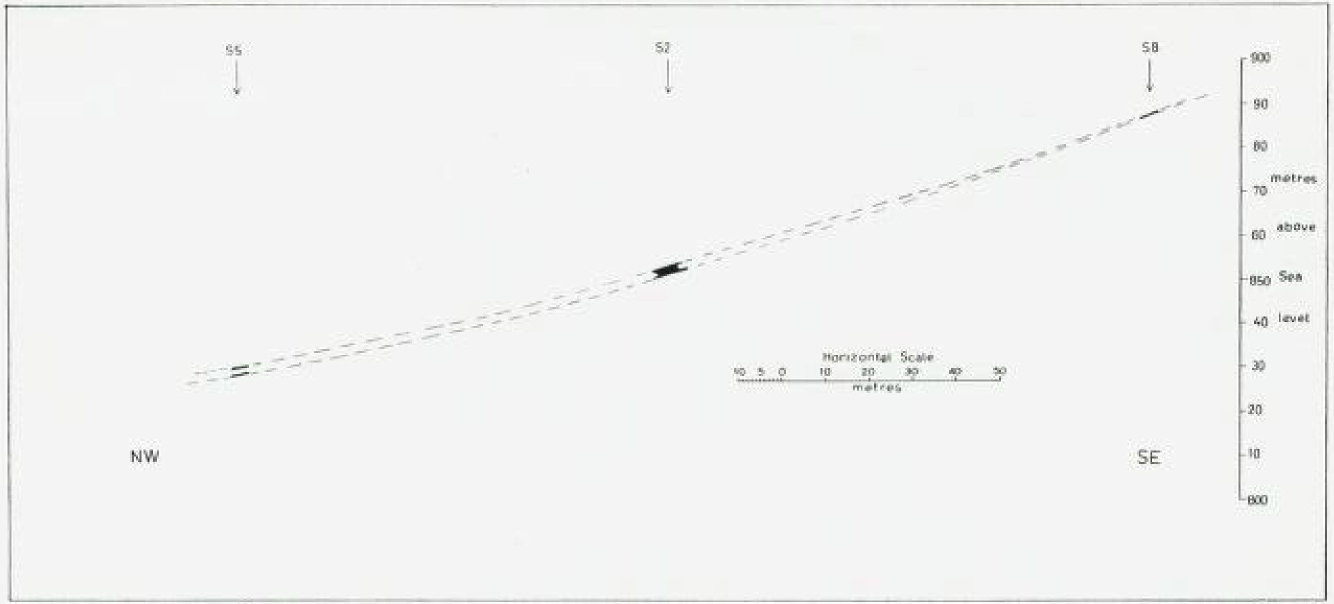


Fig. 20. Section through the Sabetjok—Birtavarre Høyfjell sulphide-horizon through DDH's S5, S2, S8. (Parallel to full dip.)

Vertikalt snitt gjennom malm-horisonten i Sabetjok—Birtavarre Høyfjell-området. (Parallelt med sonens fall.)

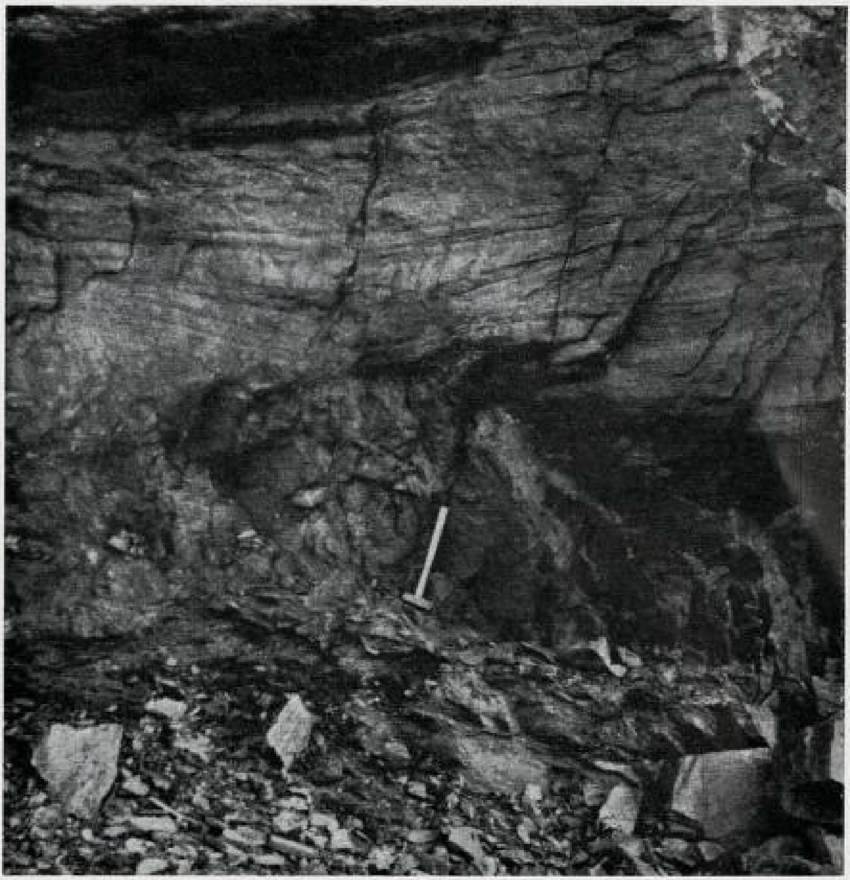


Fig. 21. Photograph of part of the wall of the open-cut at Moskogaissa 111 mine. Massive garnet-anthophyllite rock above, rusted sulphide zone in the middle, foot-wall shear-zone below hammer head.

Fotografi av en del av dagbruddet ved Moskogaissa 111 gruve. Granat-antofyllitt bergart øverst, rusten sulfid-horisont i midten, liggens oppknusnings-sone under hammerhodet.

metres, and along the face of the open-cut weathering has produced a characteristic staining or rusting of the rocks. (Fig. 21 is photograph of part of the face of the open-cut.)

Underlying the sulphide horizon, at about the level of the floor of the open-cut, is a zone of highly sheared and crushed schist. Due to spoil and other cover this cannot be very extensively examined

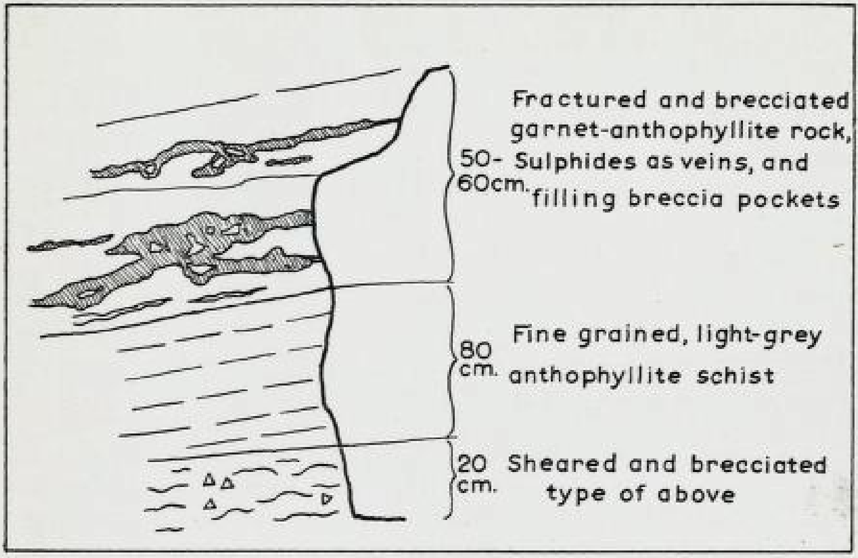


Fig. 22. Sketch of section through sulphide zone at portal of No. 3 adit, Moskogaissa 111 mine.

Skisse av sulfidsonen ved dagåpningen av stoll nr. 3, Moskogaissa 111 gruve.

and in particular the significance of this shear zone with regard to the mineralization is not clear. Within it there occur patches of sulphides, and the sheared and crushed schists are stained brown and yellow by iron from the weathering of the sulphides.

Adits 3 and 4 have been driven short distances following the irregular mineralization into the hillside. Fig. 22 shows a section of the sulphide zone at the entrance to No. 3 adit. Here the irregular sulphide zone occurs near the roof and has, as its immediate footwall rock, a light-grey, fine- to medium-grained schist, consisting essentially of quartz, plagioclase and anthophyllite, with secondary chlorite.

Towards the floor of the adit this schist takes on a sheared and partly brecciated appearance and there is a great development of chlorite along the slip planes within it. This probably signifies the nearness of the general zone of shear which underlies the whole sulphide zone along this section.

Other exposures along the face of the open-cut and in the adits reinforce the same general picture of a sparse sulphide mineralization at the base of the garnet-amphibole rock. The following is a typical section measured in No. 4 adit:

	Roof
Garnet-anthophyllite schist, basal 5 cm softened	30 cm.
Sulphides, mostly pyrrhotite	10 »
Garnet-anthophyllite schist, with irregular patch vein quartz below the sulphides	15 »
Sulphide breccia with elongated fragments of country-rock	15 »
Hard, grey amphibole schist. Shear zone 5 cm thick in middle, thin splitting and softened	20 »
Irregular stringers of sulphides	5 »
Hard, light-grey amphibole schist	30 » +
	Floor

The face of the open cut is at a small angle to a series of very shallow folds which affected the overlying rocks and probably also the sulphide zone. The latter occurs as a continuous but very irregular band or series of parallel bands practically concordant with the banding of the overlying rocks. Locally, there are larger irregular, brecciated patches, and small off-shoots and cross-cutting veinlets are common, apparently following more or less vertical joints. The picture presented by this eastern section of Moskogaissa 111, therefore, is that of a gently dipping band of sulphide mineralization at the base of the metasomatic rocks, underlain by a zone of indeterminate thickness consisting of sheared and rusted schist, often with irregular lumps of sulphide (see section, Fig. 23). Evidence afforded by the adits and by the geophysical measurements in 1953 indicates that the mineralization does not become any more important down dip. At the eastern extremity of the open cut the shear-zone dies out and very little evidence of it can be found further east, though the characteristic garnet-anthophyllite rock does outcrop in places.

The western section of the outcrop, that containing adits 1 and 2, shows a less continuous band of sulphide mineralization and there appear petrological and structural features not seen in the eastern section. The mineralized zone outcrops at the base of a cliff, about 10 metres high, composed of massive garnet-anthophyllite rocks. At the base of this, running continuously along the outcrop, is a band 20—50 cm wide, of a highly sheared chlorite-garnet schist. Beneath this band

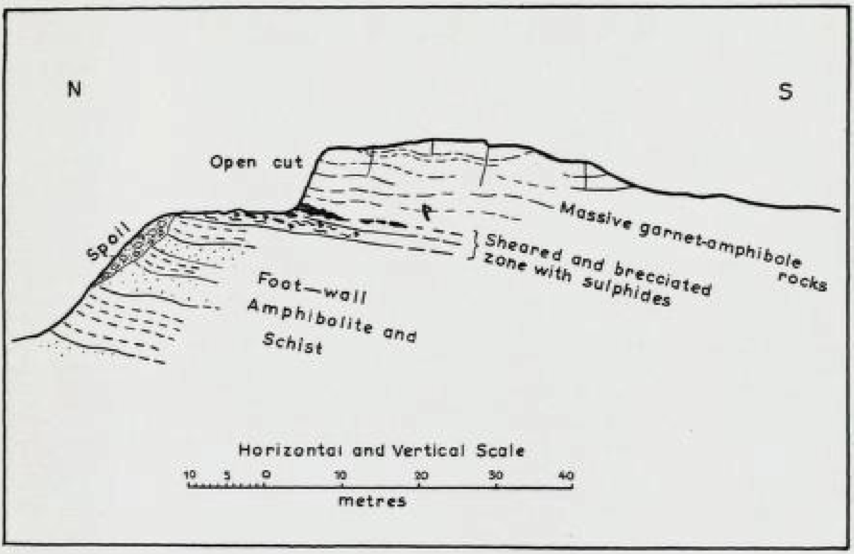


Fig. 23. N—S geological section through the eastern part of Moskogaissa 111 mine.
Geologisk profil N—S gjennom den østlige delen av Moskogaissa 111 gruve.

come quartzitic and amphibole schists, often very softened and stained. Below these again, in the entrance to No. 1 adit there is a very striking breccia. Fig. 24 is a longitudinal section between adits 1 and 2 showing the general relationships. The sulphides occur sparsely as "clumps", disseminations and pockets throughout the whole of the rocks from the base of the massive rocks downwards.

The chlorite-garnet schist is a most distinctive feature of the petrology of this section and will be discussed later (p. 156). It thins out when traced into the hillside along No. 1 adit. It also ends rather abruptly a short distance west of No. 1 adit. To the east it disappears under a cover of rubble and soil. Another, smaller, band of the same schist appears in the massive rocks, about 3 or 4 metres from their base, just west of No. 1 adit.

The schists underlying the garnet-chlorite band are quartz- and quartz-amphibole-schists, often flaggy and soft, sometimes stained. They vary between one and two metres in thickness, though the nature of the exposures does not allow the full relationship to be seen. At Adit 2 they underlie the garnet-chlorite schist and extend beneath

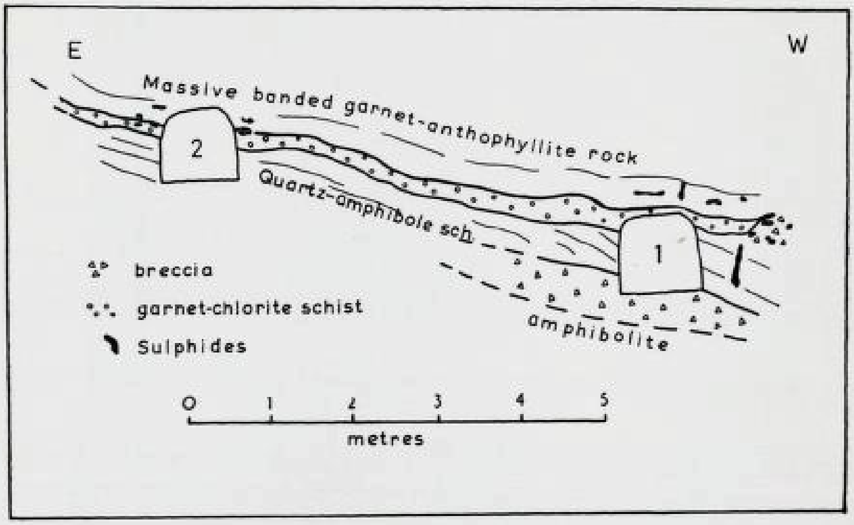


Fig. 24. Geological profile (E—W) between adits 1 and 2, Moskogaissa 111 mine.
Geologisk profil (Ø—V) mellom stollene nr. 1 og 2, Moskogaissa 111 gruve.

the floor level. An apparent shear zone a few cms thick is present. At Adit 1 these schists are about 1 metre thick and are underlain by a breccia (see Fig. 25). This consists of close-packed angular fragments ranging in size from 1 or 2 cm to 10—20 cm. A layer of 20 cm or so at the top consists wholly of fragments of the overlying quartzitic schists, while the lower part is composed wholly of fragments of dark amphibolite, which comes immediately beneath the breccia. The whole mass of fragments is loosely cemented together by a dark brown iron oxide cement. This may be in the nature of a gossan formed by the weathering of an original sulphide cement, but no such original cement could be found in the breccia.

The breccia lenses-out about 3 metres from the portal of No. 1 adit, and the underlying amphibolite comes into contact with the overlying quartzitic schist, here extremely soft and crumbling. Further in the adit the schists show sheared bands which seems to indicate some movement over the top of the apparently more rigid amphibolite below.

The section at No. 1 adit is interesting in that it shows the complete sequence from the garnet-amphibole rock to the amphi-

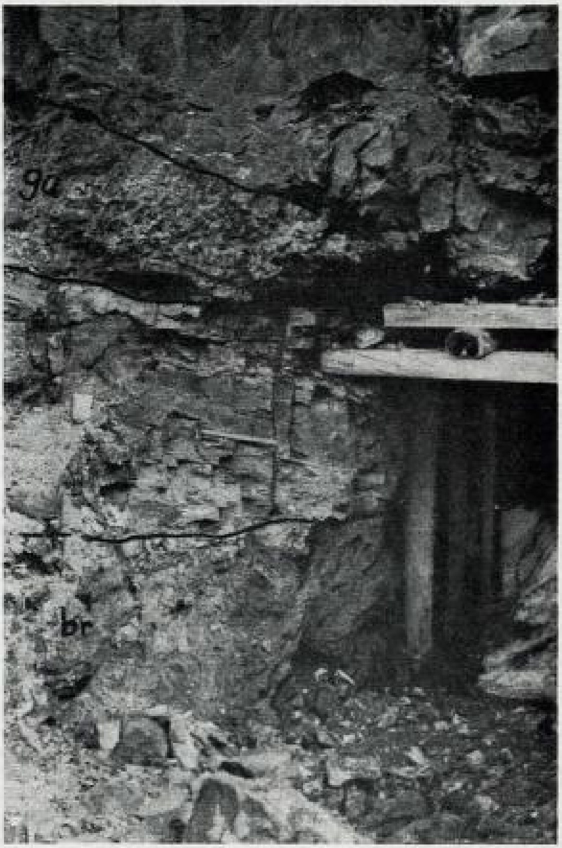


Fig. 25. Photograph taken at portal of No. 1 adit, Moskogaissa 111 mine, showing the breccia, br, and the band of garnet-chlorite-schist, ga. (Photo, P. Padget.)

Fotografi fra dagåpningen av stoll nr. 1, Moskogaissa 111 gruve. Breksjen: br., granat-kloritt-skiferlaget: ga. (Foto, P. Padget.)

bolite of the footwall rocks, and more especially for the evidence of the breccia. The clear dependence of the composition of this latter on the rocks immediately above and below, shows that the movements causing it cannot have involved any great displacement. It seems to have formed by shattering almost in situ. In all but its attitude it has the nature of a fault breccia formed by short, sharp "shock" movements. It appears to be widening out away from the present exposure and this raises the point as to how large it was originally. It would not be an unreasonable suggestion that the breccia now exposed is a small fraction of an originally larger lens. The breccia-ores of the Birtavarre region seem to be in the form of such lenses, and we may therefore come to the not unreasonable conclusion that the greater part of Moskogaissa 111's "ore" has long ago been eroded away and that the present outcrops are merely the down-dip edge of the mineralization.

The soil- and rubble-covered slope separating the two sections at 111 seems to be the locus of a geological disturbance. On the east the rocks of the shear zone are turned up sharply and show a marked discordance in strike and dip with amphibolitic schists of the foot-wall zone just beneath them (see geological map). Also the rocks of the western section begin to become more steeply inclined just before they disappear beneath the covered slope. Lack of exposures makes it difficult to deduce the true nature of the disturbance, but it seems to be an asymmetric anticline with its axis approximately N—S and the steeper limb to the east. This limb has probably also been the locus of a certain amount of displacement, to give the angular unconformity with the footwall rocks.

Certain similarities with the drillhole intersections may be noted from Moskogaissa 111. In the eastern section there is a "split" sulphide zone. The upper band is the breccia pockets, replacement patches and veins at the base of the garnet-anthophyllite rocks, while the lower band consists of sulphide impregnations in the sheared rocks underlying the open-cut.

Moskogaissa 115. Very little information can be obtained from the outcrop at this mine to supplement the drill-hole information. In the collar of one of the incline shafts can be seen a small remnant of massive sulphide breccia but lack of exposures make it impossible to study it in detail. Other exposures show a marked zone of shear, now highly rusted, at the base of the garnet-anthophyllite rocks. From the scanty evidence it would seem that the sulphides were deposited along this shear zone, in places as a plate of massive sulphide forming the ore-shoot, and in others as impregnations which did not constitute workable ore.

Moskogaissa 117. Fig. 26. The small underground working at this mine is now completely flooded and partly caved-in. Evidence of the form and structure of the ore-zone is obtainable from two trenches and from the collars of the old incline shafts. These show that the sulphides occured very irregularly within a zone of garnet-anthophyllite- and anthophyllite-schists. In parts thicker bodies of

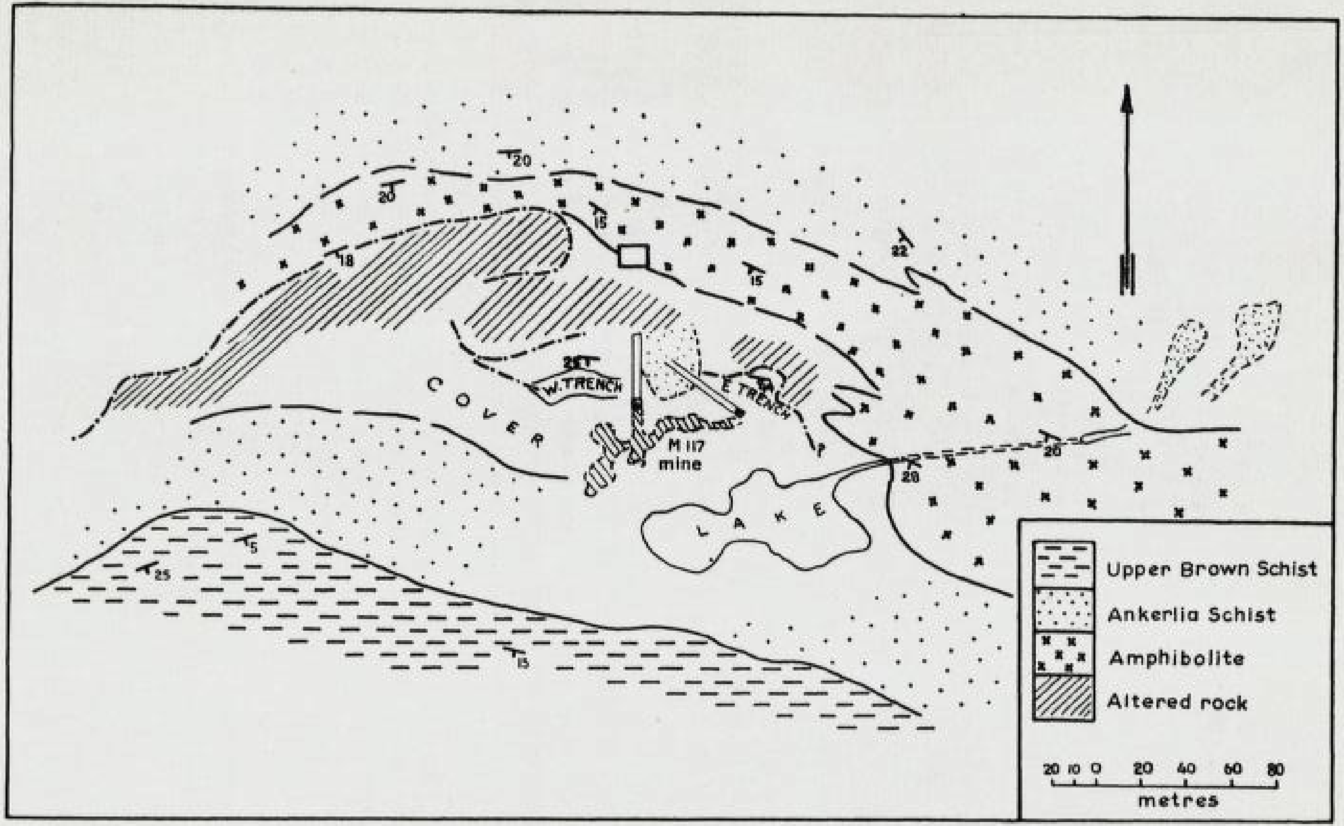


Fig. 26. Geological sketch-map of area around Moskogaissa 117 mine. Old workings drawn from mine plan.
Geologisk kartskisse av området omkring Moskogaissa 117 gruve. Strossene tegnet fra det gamle gruvekart.

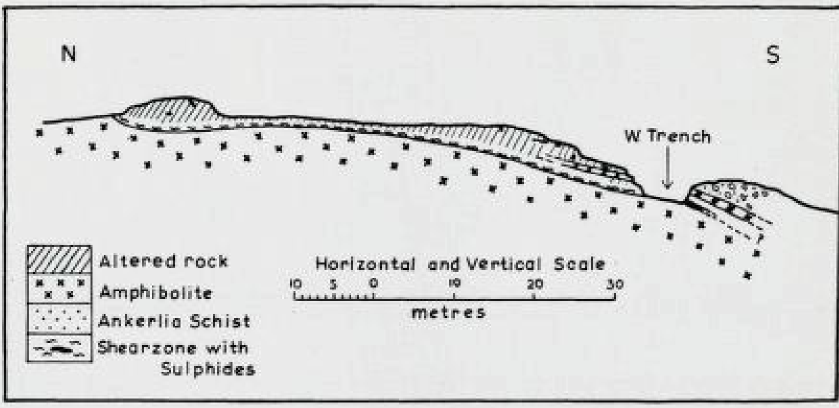


Fig. 27. Geological section (N—S) through the westerly trench at Moskogaissa 117 mine.

Geologisk profil (N—S) gjennom det vestlige dagbrudd, Moskogaissa 117 gruve.

massive sulphide breccia occurred. A remnant of one of these can be seen in the southern wall of the more westerly of the two trenches. It is a band 30—40 cms thick of fine-grained, pyrrhotite-cemented breccia and is overlain by light quartz-amphibole-schist and amphibolite. On the northern bank of this trench sulphides, most copper-rich, occur as irregular pockets and veins at random throughout the mineralized zone. West of this trench the schists are highly sheared and rusted, but the sulphide mineralization does not seem to continue in this direction. Fig. 27 is a section through the westerly trench at 117. Small remnants of massive sulphide can be seen in the collars of the two incline shafts; they represent a rather irregular band of sulphides which was in parts thick enough to be followed by the former miners.

The eastern open-cut or trench reveals several interesting features. (Section, fig 28.) It has been excavated into the sheared and mineralized zone through the overlying metasomatic rocks, and the north wall shows a very fine section (see Photo, Fig. 29). In the upper part of the wall the metasomatic rock is banded, with bands between 10 and 20 cm thick. These have been thrown into a tight series of folds along N—S axes. In between the bands of more solid rock a chlorite-schist has been squeezed into the crests and troughs of the folds in an incompetent manner.

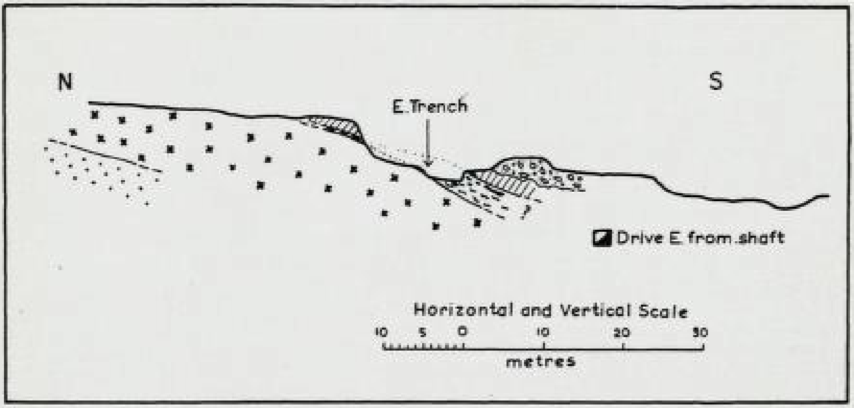


Fig. 28. Geological section (N—S) through the easterly trench at Moskogaissa 117 mine.

Geologisk profil (N—S) gjennom det østlige dagbrudd, Moskogaissa 117 gruve.

Underlying these folded metasomatic rocks and cutting off the folds is a plane, or zone, of very sheared, soft schist, striking almost east-west and dipping south at 40°. Beneath this zone, which is about 0.5 metre in thickness, comes a white quartz-amphibole schist, very disturbed and carrying irregular pockets and veins of sulphides. In a small pit in the floor of the open-cut a dark schistose amphibolite appears. This is the footwall amphibolite which outcrops strongly to the north of the working and dips south at angles between 20—40° underneath the mineralized zone.

Within this general zone of shear, which is probably about 2 metres true thickness, the original quartz-anthophyllite and quartz-hornblende schists have been crushed and folded tightly into small crumples of about 1 cm's amplitude. No new minerals appear to have been formed (megascopic exam.) except in the zone of more intense shear where there is slight chloritization of the schist. The sulphides occur as irregular pockets, clumps and veinlets, often of very pure chalcopyrite. One noticeable vein, about 10 cm thick occurred near the west end of the open-cut along the top of the shear-zone beneath the folded metasomatic rocks.

The sheared and crushed mineralized zone at Moskogaissa 117 reaches a maximum thickness of perhaps 3 metres at the centre, but it rapidly thins out on both the east and west. To the west it can be

Fig. 29. Photograph of the north wall of the easterly trench at Moskogaissa 117 mine. The intense shear-zone is shown by the hammer and the map-case. Above this are the highly folded metasomatised rocks with their fold axes almost at right angles to the plane of the paper.

Fotografi av nordveggen av det østlige dagbrudd ved Moskogaissa 117 gruve. Hammeren og kartmappen ligger på oppknusnings-sonen. Over denne sees de sterkt småfoldede metasomatiske bergarter, hvis foldningsakser danner en nesten rett vinkel med papirets plan.

followed as a zone of rusted and crushed schist at intervals all the way to the lake marked 890 on Plate 3. On the east it cannot be traced much beyond the eastern opencut. This is mostly due to lack of exposures and it seems that it must cross the mouth of the outlet from the lake as suggested in Fig. 26. Nowhere between Moskogaissa 115 and 117 can the mineralized zone be seen exposed at the surface.

It is not easy to see the reason for this comparatively sudden thickening of the mineralized zone here. Structural conditions have been such that shearing and crushing have occurred through an increased thickness of schists. This produced openings which admitted the sulphides to form the small ore concentrations here.

Moskogaissa 120. A lower mineralized zone occurs some 200 metres stratigraphically below the main one at Moskogaissa. In most of the outcrops it is only a weakly rusted zone of slightly sheared schist, but in the banks of the Rautajok, about 600 metres NNW of Moskogaissa 115, sulphides occur in the outcrop and a short adit has been driven in it.

This adit is about 2 m long and is excavated in flatlying, sheared schist with very irregular veins of sulphides. Near the footwall, close to the portal, small patches of sulphide breccia are revealed. About half a metre above this is a markedly sheared zone carrying strong sulphide impregnations. Due to cover and the steep walls of the gorge of the Rautajok little can be seen of the mineralized zone downstream from the adit. Upstream from it, on the flat slabs at the top of the waterfall irregular bodies and patches of sulphide occur in the same general zone. The rocks are here hornblende and biotite schists, with a zone of metasomatized rock apparently about 2 metres thick.

One prominent body of nearly pure chalcopyrite was about 2 metres long and 60 cms wide at its widest. It appeared to be sitting in a widened joint at right angles to the lineation in the schists. It did not extend vertically for any distance. The chalcopyrite contained irregular fragments of garnet-anthophyllite- and hornblende-schists, and in places carried a selvedge of white quartz. At one extremity of the lens a small patch of magnetite-anthophyllite schist occured in the wall-rocks, but did not appear to have any direct connection with the copper mineralization.

Chalcopyrite also occured near here as a "ribbon" about 30 cms wide, elongated parallel to the lineation and apparently occupying the crest of a small fold in the schists. This, too, showed a brecciated nature with the copper mineral surrounding fragments of vein quartz, anthophyllite- and hornblende-schists, garnets and garnet-anthophyllite-schist. Impregnations of pyrrhotite in some of the fragments might conceivably be earlier in age than the surrounding chalcopyrite.

On the opposite (north) bank of the stream other irregular sulphide veinlets, up to 20 cms could be seen. These were both concordant and cross-cutting as regards the schistosity.

These irregular bodies of sulphides are probably filling joints or other fractures in the rocks above the main mineralized zone,

Fig. 30. The lower sulphide horizon, Moskogaissa. Photograph showing the rust zone (darker) cutting across the limb of a fold in the schists of the footwall zone (to right).

Den lavere sulfid-horisont, Moskogaissa. Fotografi viser «rustsonen» (mørkere) som skjærer sjenkelen av en fold i skifrene (til høyre).

which due to the nature of the topography is not exposed here. The chalcopyrite seems to be of the coarse-grained type and is, as far as can be seen with a hand lens, free from pyrrhotite. This fact is in keeping with the tendency, previously described, for the copper mineral to segregate to the walls of the ore zone and to be often enriched in joints.

Other outcrops of the zone occur intermittently between the Rautajok and the next stream to the NW, with development of metasomatic rocks in places (see Map, Pl. 3). The zone crosses this second stream as a very marked shear structure dipping west at 40°. Underneath, the schists have been folded into a large open fold on a N—S axis, the westerly limb of which appears to have been partly cut off by the shear-zone (Photo Fig. 30). This is a very good illustration of the locally cross-cutting nature of the shear-zone.

Up dip the zone flattens off and climbs slowly up the steep banks of the gorge north of the river. It has not been investigated in detail beyond this point. On the whole this lower sulphide zone appears much less significant than the higher one. For the greater part of its outcrop it appears as a zone of weakly to moderately sheared schist, never more than 2—3 metres thick. Such a structure appears to have been "closed" or relatively unreceptive of mineralization, with the result that it carries weak sulphides, or none at all. There appears to have been a relative concentration around the banks of the Rautajok (Moskogaissa 120), but this appears too small to be of economic significance. The conditions leading to this concentration are not clear.

Sabetjok mine. This mine is in parts accessible for underground inspection. Since, practically speaking, all the ore has been removed, there is not a great opportunity to study the structure of the sulphide zone here. The evidence that can be obtained reinforces that obtained from other sources and very little that is new can be seen.

In the extreme eastern face of the southerly part of the workings there is an irregular band of breccia ore up to 50 cms thick near the footwall, with another mineralized band 10—20 cms thick some distance above this — yet another example of a "split" sulphide zone.

In a short drive north from this part of the workings occurred remnants of a rather thick sulphide breccia, which since it contained wholly pyrrhotite had not been worth taking out. It illustrated very clearly the irregular form the sulphides often take, suddenly swelling out and cross-cutting the schists locally (cf. the body of sulphide in Moskogaissa 115, p. 30). Fig. 31 is a sketch of the east wall of the drive showing the outline of the breccia and the rather large inclusions of schist in it. These fragments were large enough for the lineation on them to be measured. This was within a few degrees of the general lineation direction, which seems to indicate very little disturbance during the fracturing.

Elsewhere in the mine, the walls of the stopes showed only thin bands of sulphides. In the east-west drive north of the central ore-shoot no signs of mineralization could be seen which either indicates that the ore-zone has given out on this side or that the workings have failed to follow the ore.

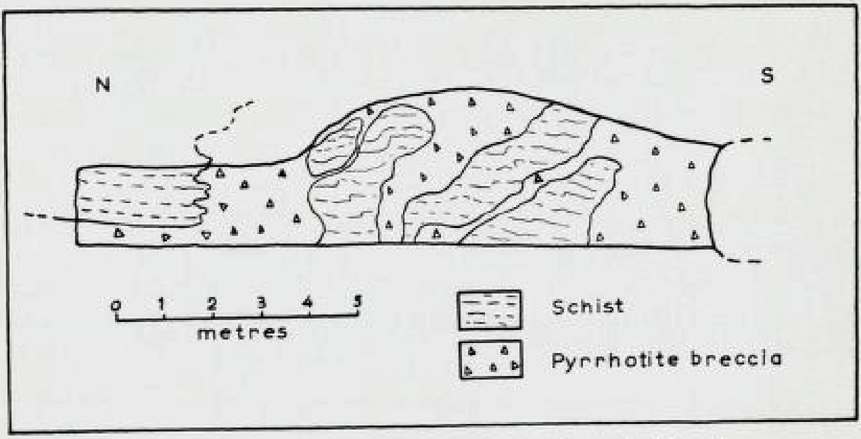


Fig. 31. Sketch of massive pyrrhotite breccia, Sabetjok mine.
Skisse av en magnet-breksje, Sabetjok gruve.

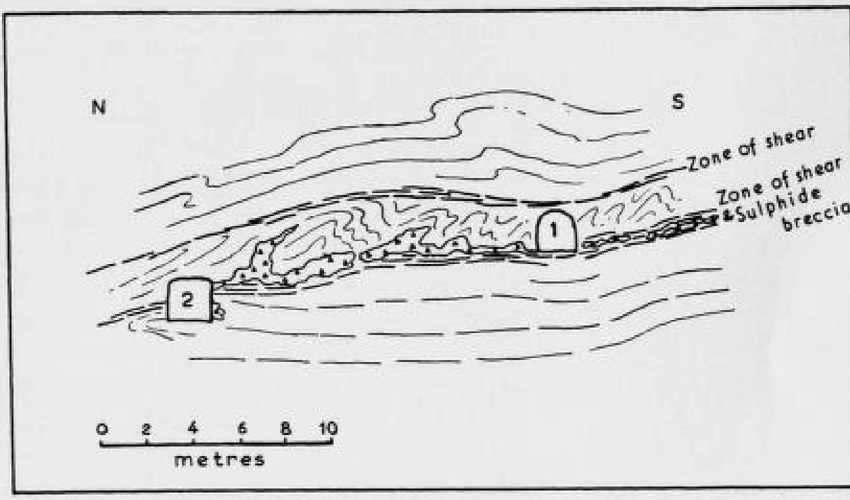


Fig. 32. Sketch section (N—S) between adits 1 and 2, Sabetjok mine.
Profil (N—S) mellom Nr. 1 og 2 stoll, Sabetjok gruve.

The outcrop of the sulphide zone at Sabetjok is rather difficult to study due to the steep terrain and the waterfall which covers the central part of it.

Near the portals of the two southernmost adits it is possible to see two mineralized zones separated by 1—2 metres of highly folded schist (Fig. 32). The uppermost of these zones is a horizon of rusty, sheared schist, while the lower one is an irregular band of breccia occurring within a zone of soft, sheared schist. The folds between the two mineralized zones have an axial direction of about S10°W, plunging at 5°—10°. It was difficult to determine whether the folding predated the shearing, or was formed at the same time. More folding occurred above the ore-zone, but this was more open in character, with larger amplitudes.

Due to the very steep nature of the terrain north of Sabetjok mine it was not possible to conduct a systematic survey along the ore horizon. It was accessible at a point about 2 kilometres north of Sabetjok at the side of a stream gorge which falls into the main valley there. In the south side of the gorge one can study (from a distance) two rather marked rust-zones. The upper one is 3—4 m. thick and the lower one 1—2 m. and they are separated by about 3 m. of schist. As far as could be seen the lower band was made up of sheared, softened schist while the upper band was apparently undisturbed. A closer examination on more accessible ground south of the stream gorge showed a marked flexure in the lower zone with axis parallel to the lineation (S80°E). This flexure had a cross-cutting relationship to the schists on either wall, but a few metres away in both directions had become completely conformable again. Such cross-cutting flexures appear to be a feature of the mineralized zones in the Birtavarre area and have been noticed or deduced in other places (cf. Skaide, Moskogaissa 115, lower rust zone at Moskogaissa).

No sulphides could be found in the rust zone at this place, but blocks of gossan breccia were seen in the scree beneath it.

South of the above locality the rust zone is accessible for some metres; a little distance along, shallow trenching has exposed sulphides. These comprised a band of breccia varying from a mere stringer to 10 cms thick. The breccia was mainly of schist fragments but there were one or two pieces of vein quartz up to 5 cm dia. Underlying the breccia was a band of very soft chloritic schist.

Birtavarre Høyfjell working. This small working lies on the same sulphide-horizon as Sabetjok mine, the one which was investigated by diamond drilling in 1955. The mineralization exposed at the working shows quite different characters from that in most other places in the area. The ore is essentially a body of mainly quartz, which has been fractured and partly brecciated and then infiltrated by sulphides to produce a fairly rich ore. Exposures are not sufficient to determine the relations of this quartz body to its walls. In places it does seem to have a footwall which is quite conformable with the underlying schists. These have been slightly sheared, and in places carry weak sulphide impregnation.

The hanging-wall is nowhere exposed, but at the thickest part of the body, fairly large, irregular fragments of schist occur toward the top. This seems to indicate brecciation of the hanging-wall rocks and subsequent invasion by the quartz. Since the sulphides are definitely later than the quartz, there must have been at least two ages of fracturing here.

The evidence indicates that there was originally a largish body of vein-quartz in the schists at this place which subsequently became mineralized by the sulphides.

As mentioned previously (p. 27) concordant lenses and veins of quartz are prominent in the Lower Ankerlia Series around Ankerlia itself. In places these have been fractured and mineralized in a manner similar to Birtavarre Høyfjell. Other sulphide-quartz bodies of the same type occur in the lower part of the Store Borsejok Series just west of Store Borsejokvann (see Plate 1). Because none of these quartz bodies reached large dimensions, the "ore-bodies" resulting from their fracturing and mineralization cannot be of great size either. The one at Birtavarre Høyfjell is one of the largest, but even it is too small for profitable working.

Skaide Mine. Underground inspection on this mine showed, as expected, a very variable thickness of mineralization. Although most of the workable ore has been removed, odd remnants show that it consisted of massive sulphide breccia, while other exposures show that the thinner, non-economic parts of the deposit comprised the weakly mineralized shear-zones.

It seems that an irregular, gently dipping sheet of breccia was formed in the schists prior to the introduction of the sulphide minerals. In many places (as seen in the pillars in the old stopes) the breccia is absent and its place is taken by a thin shear-zone which was not worth mining.

There occur throughout the mine marked structural features which suggest — by their form and relations to the ore bodies — that they are the results of movements taking place after the ore came into position.

They are for the most part flat or low-angle thrusts or shears which in places form the hanging-wall of the ore, and in other places cut through the mineralization. In the accessible parts of the mine these are markedly folded along two more or less parallel zones (see below).

The flat-lying shears are perhaps the most noticeable feature of the structure of the mine, since their upper surfaces form remarkably smooth and sound roofs to the two main inclines and other parts of the workings. Due to inaccessible areas it was not possible to prove that roofs in all parts were one and the same plane, but it was obvious that they did not differ by a vertical distance of more than one or two metres.

The roof plane(s) was markedly lineated along an E—W direction which was also the axial direction of minor folds and "inverted domes". These latter were especially noticeable in the flatter part of the westerly incline. They would seem to point to a movement in a west to east direction over the top of the ore, i.e. at a slight angle to the longer axis of the ore-shoot.

The relation of the shear plane with respect to the ore-bodies is shown in the two sections of the incline shafts, (Fig. 33). The sections marked "packed" probably represent thicker parts of the ore-body which were stoped out and subsequently filled with waste stone. In these places the shear plane probably formed the immediate hanging-wall of the ore. In other places it occurs at some small but variable distance above the ore-zone.

The only place where the relation between the shear plane and the thicker ore could be studied was near the portal of the westerly incline. The hanging-wall to the ore is a smooth plane, markedly corrugated or grooved along the lineation direction (due W). This plane is separated from the ore by a zone of variable width, consisting of sheared and softened schist, and a definite clay-gouge. Near the entrance about 10 cms of sheared schist separates the ore from the gouge zone, but down dip the gouge rests directly on the ore. There is a marked down-fold of the roof at the entrance, apparently nipping out the ore here, though the complete picture is obscured by debris

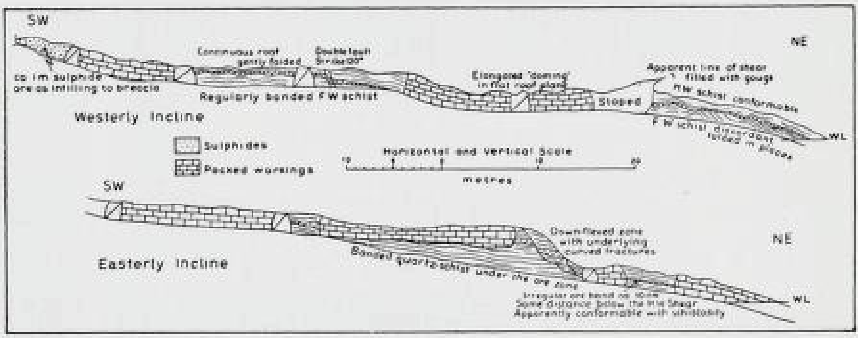


Fig. 33. Geological sections down the two incline shafts at Skaide mine.
Geologiske profiler langs synkene, Skaide gruve.

in the portal of the incline. Fig. 34 is a sketch from this exposure showing the relations of the hanging-wall to the breccia-ore.

The evidence is that the post-ore movements have occurred in a narrow zone above the top of the ore-bodies. In some places the actual shear, or mechanical break has occurred a short distance above the ore, in others the clay-gouge rests directly on the ore. Whether any of the ore has been mechanically displaced by this movement is not possible to prove.

The footwall of the ore is generally not a movement plane, except in the cases where this could be referred to the postulated original shear which formed the opening for the ore solutions.

Fig. 34 shows that the solid ore at the portal of the westerly incline has a marked footwall, which is apparently concordant and undisturbed. Impregnations of sulphides occur in the schists beneath the main breccia-ore here. In some places there is so much sulphide in the schists that the economic footwall would be beneath the footwall of the breccia-ore.

Towards the bottom of the westerly incline (see Fig. 33) the ore zone has narrowed down to a thin band of sulphide-impregnated, sheared schist, 5—20 cm wide. Here the footwall schists exhibit folding and marked discordance with the ore, as though the initial pre-ore shear had cut through pre-existing folds in the country-rock.

As mentioned above the marked roof planes in the shear zone above the hanging-wall have been folded along two parallel zones

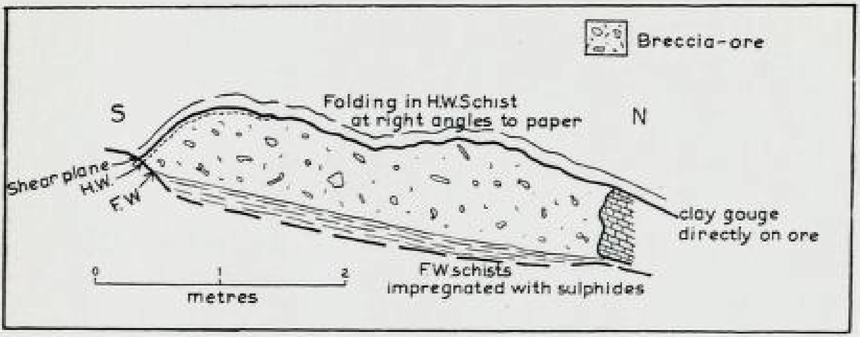


Fig. 34. Sketch of ore-remnant near portal of westerly incline shaft at Skaide mine.
Skisse av malmen i bergfestet ved dagåpningen av den vestlige synk, Skaide gruve.

running roughly east—west and almost parallel to the lineation. The upper of these zones is more of a downwards flexure of the shear zone than a true fold. Within this flexure the ore is narrow and irregular and has been intersected and displaced by curved fracture planes underneath the main shear. The flexure is best studied in the easterly incline at about 50 metres from the portal, and in the drive running from this incline. Fig. 35 is a sketch across the flexure zone in this easterly incline. It will be seen that there is a main curved or downflexed shear plane overlying the ore-zone and forming the roof of the working. Under this, the ore-zone has been intersected by several subsidiary curved fracture planes which have caused it to be slightly displaced. There appeared no doubt that these subsidiary fractures terminated upwards against the main shear plane.

There is no evidence, therefore, that the usually slight downwards displacement of the ore-zone is due to any form of normal faults. Rather there seems to have been a movement along the main, flat-lying thrust plane, with consequent imbrication of the rocks beneath. According to the grooving and striations the movement was almost east—west, i.e. at right angles to the plane of the sketch.

When traced westwards this flexure seems to die out, and in the westerly incline it has disappeared except for a slight fold in the roof plane just on the down-dip side of the third pillar from the portal.

This pillar does, however, show a double fracture in form of

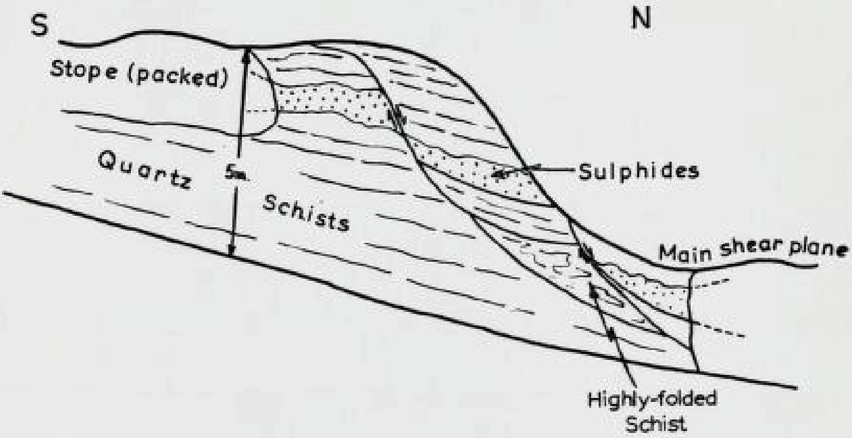


Fig. 35. Sketch of "flexure" in sulphide zone, easterly incline shaft, Skaide mine.
Skisse av «fleksuren» i sulfid-sonen, den østlige synk, Skaide gruve.

two closely spaced normal faults which displace the ore a matter of a few cms. As far as can be seen these do not extend into the smooth roof plane, showing that this is later in age.

West of the westerly incline the zone becomes more marked. Fig. 36 shows a section across the zone here. The main roof plane appearing from the stoped area up-dip is bent sharply up into the roof of the drive and gives the impression of being folded backwards. On the down-dip side of the drive the banded quartz-schists appear to be dipping normally and carry a rather thin, concordant band of ore. This is, however, intersected by a double fracture dipping at 50°, which appears to show reversed faulting, since a wedge-shaped piece of the ore is found above the fault planes along the edge of the lower stope drive. The roof over the stope has a marked anticlinal fold in it.

The banded quartz-schists above the ore would, if projected up-dip, intersect the main shear plane above the drive at a high angle. Evidence is insufficient to say whether or not such a discordance did exist, or whether the schists were bent downwards here to more or less confomability with the shear plane.

The second, or lower fold-zone, shows a marked similarity to

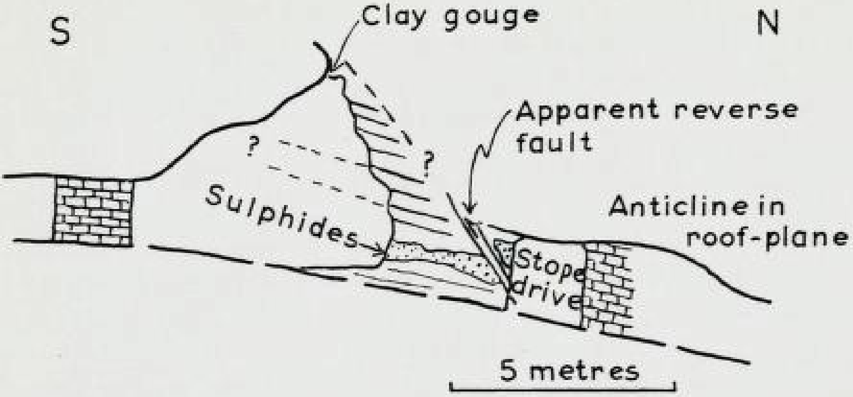


Fig. 36. Sketch section across upper "flexure", west of the westerly incline shaft, Skaide mine.

Profil tilnærmet loddrett den «øvre fleksuren», vest for den vestlige synk, Skaide gruve.

the upper one west of the westerly incline. It is best seen in an open working or "room" accessible from the westerly incline about 65 metres from the portal.

The main band of ore, which seems to have been about one metre thick, has been worked out under the shear plane on the up-dip of the room and followed, in apparent continuity, down-dip by a winze opening into another stope. Mineralization occurs in the schists above the winze as narrow seams of sulphides, none of which was apparently thick enough to be followed by the miners.

This fold-zone could not be followed eastwards because of water; to the west it crosses the westerly incline in the roof with the form indicated in Fig. 33. The zone of soft, sticky clay-gouge is about 10—20 cm thick here.

Post-ore movements. In keeping with the "sheeted" nature of the Caledonian schists and with the movements observed in the area as a whole, the post-ore movements at Skaide have almost wholly consisted of flat-lying thrusts or shears. In the observable exposures in the mine a failure occurred on, or just above, the hanging-wall of the ore-bodies. The movements produced a characteristic clay-gouge varying in thickness from 10 or 20 cm down to one or two. This gouge may lie directly on the hanging-wall of the ore, or be present in the immediately overlying schists.

It seems that there was not one single sheet or mass thrusted over the ore, but rather a series of overriding slices, the junctions between which are responsible for the flexure or "fold" structures observed in the mine. Fig. 37 and 38 are profiles down the dip of the schists, constructed to show the nature of the hanging-wall thrusting.

In Fig. 37, which is the more easterly, two of the postulated slices are shown, number 1 apparently overriding number 2. The curved fractures beneath the upper "flexure" probably represent imbricate structures beneath the main plane of movement. The lower slice contains sulphide bands in it, showing that the movements did in some places transect the ore zone.

In Fig. 38, which is drawn parallel to, and just west of, the westerly incline, three slices are shown, with the middle one (number 3) overriding the two outer ones.

From the present study it is very difficult to be sure of the direction of the movements which produced the shearing over the ore.

From the marked grooving and "doming" of the roof plane, it would seem the movements had taken place in a west to east direction. However, it must be reckoned that part at least of these structures is a relict of the main regional lineation which was impressed on the schists considerably before the ore-forming period.

The form of the profiles shown in Fig. 37 and 38 would probably be more easily explained by a north-south pressure, causing overriding of the separate slices in directions parallel to the dip. Certain slickensiding noted on the upper "flexure" in No. 2 incline shows this north-south direction, so the final movements may well have been at right angles to the regional lineation direction.

The observations at Skaide give a fairly complete picture of the nature of the post-sulphide movements, and enable one to interpret certain features seen in the diamond-drill cores from the Moskogaissa and Sabetjok—Birtavarre Høyfjell areas.

It seems that these late movements were widespread in the area. They consisted of a sliding of units of the rocks over each other with no brecciation effects. A little clay-gouge was produced in parts. No subsequent mineralization was introduced into the openings produced; this seems to suggest they are of a quite late age, but it is not possible to determine just how late.

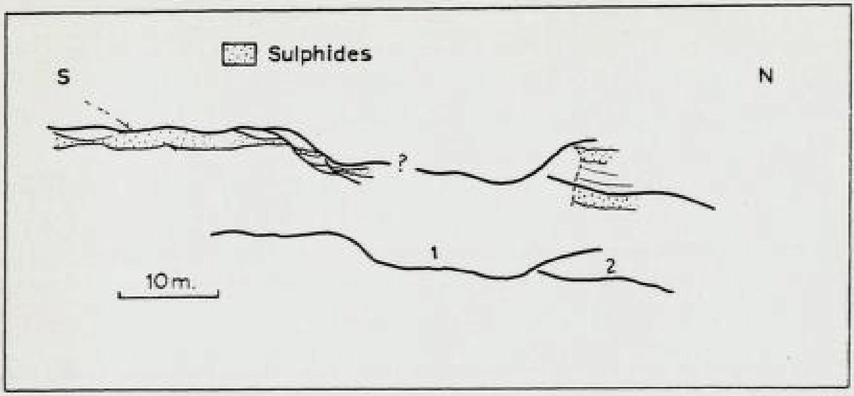


Fig. 37. Structural profile, easterly part of Skaide mine, drawn parallel to dip. *Profil som viser strukturene i den østlige del av Skaide gruve, tegnet parallelt med fallet.*

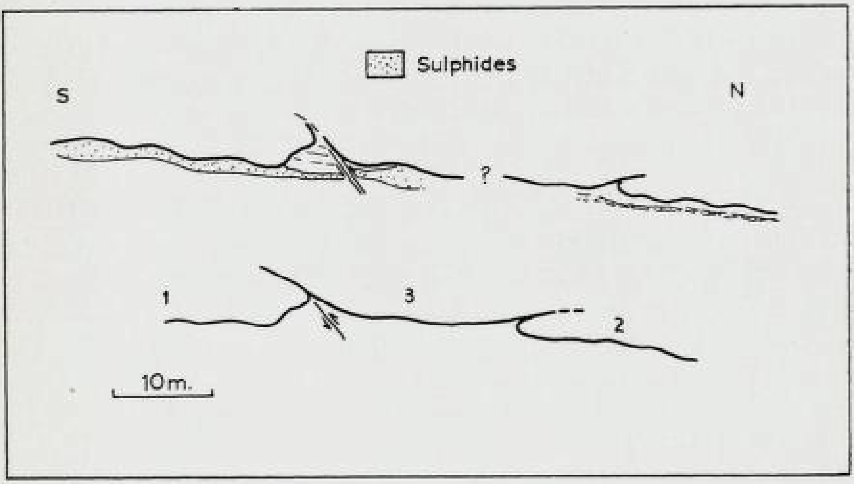


Fig. 38. Structural profile, westerly part of Skaide mine, drawn parallel to dip. *Profil som viser strukturene i den vestlige del av Skaide gruve, tegnet parallelt med fallet.*

Monte Carlo mine. This working shows differences from the rest of the area. The sulphides occur as irregular concordant and discordant veins between 5 and 30 cms in thickness in the altered and sheared rocks of the mineralized zone.

This zone is folded into a low, open anticline, which has its axis at No. 1 adit (see p. 224). It also reaches its maximum thickness here, about 10 metres. The adit seems to have been driven along the axial direction of this fold, and it would seem that the room into which it leads was excavated in a body of ore localized by this structure.

Brecciation has been confined to thin bands not more than 30 cms thick, but such bands do not figure greatly in the mineralization. The sulphide veins seem to have been introduced along partings, fractures and joints in the ore-zone rocks.

Other deposits. Examination of the other workings in the Birtavarre district, in Mandalen and Skardalen and in lower Skibotndalen showed similar features to those already described above.

At Skarfjell mine in lower Skardalen there is an extremely fine example of a breccia-ore concordant, or practically so, with the enclosing schists. The mineralized zone is of very variable width, from 5 to 50 cms in thickness. It is a band of brecciated and sheared schists and quartz which has been infilled by the sulphides.

The fragments vary considerably in size, being up to 10—20 cms long in the thicker parts of the zone. In keeping with the schistose nature of the country rock, a large proportion of fragments are elongated. Within the zone, too, thin stringers of sulphides follow the planes of schistosity both above and below the main breccia. Two sketches (Fig. 39) illustrate typical forms of the mineralized zone as seen in the portal of the raise at Skarfjell. At another prospect in Skardalen, called Toppfjell, the sulphide zone consists of a very weakly mineralized zone of sheared biotite schist only about 10 cm thick. No breccia is developed.

Other mines and prospects show one or other of the characteristics described above.

Conclusions.

The evidence presented in the above descriptions points clearly to the action of tectonic forces acting parallel to the schistosity and bedding of the schists of the area, producing concordant shear-zones and breccias which formed the hosts for the subsequent sulphide mineralization.

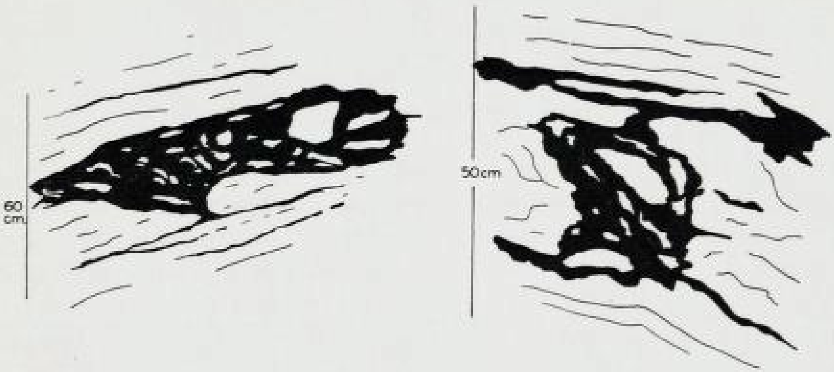


Fig. 39. Sketches of sulphide-filled breccia along ore-horizon at Skarfjell mine, Skardalen.
Skisser av sulfid-breksje fra malm-horisonten ved Skarfjell gruve, Skardalen.

In the section on Regional Structure (pp. 25—27) these forces have been described as couples due to overthrusting from the NNW, which also was the cause of the formation of the Ĉappis Nappe above the ore-bearing formation.

These tectonised zones are present throughout nearly the whole of the Ankerlia Series, (see pp. 31—34). They are of very great areal extent, but as can be gathered from the foregoing, none reaches a very great thickness. Consequently the 'ores' resulting from their mineralization have not proved very significant economically. The great thickness of the Ankerlia Schists has in itself been detrimental, as the sulphides have spread along breccias and shears at several horizons in it, and at no place have been concentrated to form a workable ore-body. The total amount of copper present in the central area of the Birtavarre district must be considerable, but it is widely dispersed along the several sulphide-horizons.

The cause of this is the failure of the schists by means of multiple shear-zones or minor thrusts parallel to the regional sheeting, none of which was big enough to produce an mineable ore-body by present standards.

The ores

Types of ore.

For the purposes of description, the sulphide "ores" may be divided into two, perhaps three classes. Firstly, there are the more or less massive sulphide-cemented breccias, and secondly the impregnations of sulphides in schist. A possible third class, about which relatively little information exists, is a more coarse-grained segregation of massive sulphide as veins in joints and other fractures. It will be clear from what has been said before that the first two types, at least, can occur together in any particular section through an "ore-zone", and that all stages exist in the transition between breccia-ore and strong impregnations.

Breccia-ore. The textures of the sulphide-cemented breccias vary considerably depending on the proportion of sulphide to country-rock fragments, and on the nature of these fragments. Variations have been noted from a massive, "open" breccia consisting predominantly of sulphide to one in which the country-rock has only just been shattered in situ and in which the sulphides occur as irregular veinlets in the fractures.

When the country-rock fragments consist mainly of schist, they are characteristically elongated or "platy". Their size-range is extreme. Sometimes it can be noted that they are more or less parallel to the schistosity of the surrounding rocks, but more often they have been rotated by movements producing the breccias. A characteristic which many included fragments share to varying degrees is a "rounding" or smoothing-off of their outlines. This may be attributed to corrosion or partial digestion by the sulphides.

The fragments of vein-quartz in the ores show this rounding to a marked degree, some fragments resembling water-rounded pebbles. The quartz in these fragments is characteristically clear and glassy, with a somewhat coarse grain-size. This is most probably the result of the recrystallisation of the originally milky vein-quartz by the heat of the introduced sulphide-bearing solutions. Specimens from Skaide and Sabetjok mines show very good examples of these rounded quartz-fragments. The ore at Birtavarre Høyfjell is an extreme example of a quartz-rich breccia in which the sulphides represent only a small percentage of the mineralized material — so small that they have had little or no heat-effects on the quartz.

This phenomenon of the rounding of quartz-breccia fragments in a sulphide ore has been described by Foslie (1946) from Melkedalen in Ofoten, about 200 kms south-west of Birtavarre. Here the smaller quartz-fragments are almost perfectly circular — Foslie describes them as "drops" of clear quartz.

The smaller fragments in the breccias often consist of single grains of a particular mineral. Hornblende is a ubiquitous representative of this class. It appears, especially in the finer-grained pyrrhotite-rich breccias, as a swarm of subhedral to anhedral grains a fraction of a millimetre across. In thin section many of these hornblende crystals present smooth, clean contacts with the sulphides, but they have also been "rounded-off" or corroded; very few sharp angular crystal outlines were noted. Fractured crystals always have the cracks infilled with sulphide. It is the writer's opinion that these hornblendes are derived from the surrouning schists which are rich in them. There is no conclusive evidence that any of them have been introduced with the sulphide minerals.

The same applies, with more force, to the other mineral fragments in the sulphides. Garnet or anthophyllite fragments or crystals have been cracked in the movements which formed the breccias and the cracks are now filled with tiny sulphide veinlets.

The evidence of the breccias is clearly that the sulphides are later than the silicate minerals included in them.

Plates 5 and 6 illustrate some of the textures of the sulphide-filled breccias.

Impregnation ore. Where the deformation of the country-rocks produced "sheared" or "crushed" zones instead of definite breccias, the sulphide-bearing solutions found their way along what openings and cracks were available to them. The resultant textures are irregular in the extreme. At one end there are the very sparse disseminations of single grains, or small aggregates of sulphides in apparently undisturbed, fine- to medium-grained schist.

At the other end, highly "irregular" textures are to be found where the metasomatic rocks of the sulphide-zones have been mineralized, especially where the lustrous garnet-chlorite schist has developed. The sulphides, often coarse-grained, have been deposited in between the chlorite foliae, and have moulded themselves around the euhedral garnets, intimately penetrating cracks in them. This type of ore can be seen at nearly all the Moskogaissa mines, at Monte Carlo, and the smaller workings at Toppfjell and Akkavagge.

Moskogaissa 125 working shows good examples of the sparsely disseminated type, where small specks of sulphide less than 1 mm across occur evenly disseminated in a medium-grained quartz-anthophyllite schist.

Plate 7 illustrates some of the textures of this class of ore.

Coarse-grained sulphide-veins. This type of sulphide has been noted infrequently in the ores. More evidence would be necessary before it could be fully assessed. The sulphides appear to be filling joints or other cracks and have a characteristic "bright and shiny" appearance on fracture, whereas the finer-grained breccia-fillings often tend to be dull in appearance. This class was noted in DDH M8, DDH S2, at Moskogaissa 120 and Moskagaissa 117. It may be that it is even more widespread since it could closely resemble vein-like forms in sheared schist. The sulphides in this class appear to have been deposited in more or less open spaces in which they developed their coarse-grained, and consequently bright, fracture surfaces.

Little further can be said due to lack of evidence.

Mineralogy.

Silicates. The silicate minerals of the ores are all derived mechanically from the surrounding schists. They have been dealt with in the sections on these schists and will not be mentioned directly here.

Oxides. Magnetite, Fe_3O_4, is a small, though variable, constituent of the ores in many parts of the field, especially in the Moskogaissa area. It occurs among the sulphides as euhedral or subhedral grains, less commonly as aggregates. It preserves its crystal boundaries against the sulphides, which appear to have "moulded" round the magnetite and therefore to be later in age of crystallisation. (Plate 8, Fig. 1).

Relative concentrations of magnetite were found at Moskogaissa 120, in the bed of the Rautajok, and at Moskogaissa 117 B, a prospect pit about 600 metres west of Moskogaissa 117 mine. In both these cases there occur small patches of magnetite-rich schist which appear to be independent of the sulphide mineralization. That is to say, sulphides could be seen as veinlets cutting through this magnetite-schist. Polished sections of the Moskogaissa 117 B material showed the magnetite to occur in bands, usually less than 1 cm wide parallel to the schistosity of the hornblende-rich schist. Within the bands the subhedral to anhedral magnetite grains were intimately intergrown with the silicates strongly suggesting simultaneous crystallisation.

The magnetite in these localized patches must be considered an original constituent of the schist, and does not seem due to any stage of the mineralization which formed the sulphides.

Sulphides. The following sulphide minerals have been identified in the ores of the Birtavarre district. (They are given in approximate order of abundance.)

Main constituents	Minor constituents
Pyrrhotite $Fe_{n-1}S_n$	*Pyrite* FeS_2
Chalcopyrite $CuFeS_2$	*Valleriite* $Cu_3Fe_4S_7$
Sphalerite ZnS	*Molybdenite* MoS_2
Cubanite $CuFeS_3$	*Galena* PbS
	Marcasite FeS_2

Pyrrhotite and *chalcopyrite* together probably constitute 95 % of the sulphides of the area, and together with sphalerite are the only ones usually visible megascopically in specimens of the ores. They appear so often in intimate intergrowth with each other that it is very difficult discuss their textures separately. All gradations exist from almost pure chalcopyrite-ore to almost pure pyrrhotite-ore and no evidence has come to light to suggest that there is ever any systematic variation in their respective proportions.

As mentioned previously there is a tendency for chalcopyrite to be concentrated near the hanging-wall and/or footwall of a particular sulphide band, and it is often concentrated around inclusions of country-rock. It has not been possible to attach any real paragenetical significance to this fact. It suggests perhaps that the country-rock has had power to deposit chalcopyrite preferentially from the ore-bearing solutions, leaving the centres of the sulphide bands relatively enriched in pyrrhotite.

The textures of these two sulphides have proved very inconclusive as regards order of deposition. Features have been seen which suggest chalcopyrite crystallised before pyrrhotite and vice versa. In the absence of conclusive evidence of age-difference it has been concluded that the two sulphides are mainly contemporaneous. Minor exceptions will be noted below.

The textures vary slightly according to the relative proportions of the two minerals. In copper-rich specimens the chalcopyrite tends to form a smooth, flat field in which occur more or less rounded grains or aggregates of pyrrhotite giving the appearance of being older than the copper mineral.

In pyrrhotite-rich specimens chalcopyrite occurs as irregular bodies which often appear to be "filling in" between the pyrrhotite grains. Small irregular patches of pyrrhotite again occur within the larger chalcopyrite areas, suggesting replacement residuals. However, the boundaries between the two minerals, though often irregularly curved, are nearly always smooth even under the highest magnification and do not suggest replacement of one mineral by the other. They seem to be a good example of so-called "mutual boundaries" usually taken as indicative of simultaneous crystallisation.

An exception to this mutual boundaries rule was noted in one or two polished sections of diamond drill cores from the 1955 drilling. Under high power and oil immersion it was revealed that the chalcopyrite-pyrrhotite contacts were ragged in a manner suggesting replacement. In many places sharp-pointed veinlets of pyrrhotite penetrated into the chalcopyrite from the contact, or ragged, irregular veinlets of pyrrhotite were found along clear cracks in the copper mineral. (Fig. 40.) These veinlets appear to have been formed by replacement of the chalcopyrite on either side of the cracks. Similar veinlets on either side of cracks in the chalcopyrite were occasionally seen beginning from silicate fragments. In these cases it appears that the replacing solutions have used the chalcopyrite-silicate contacts as a means of access (cf. the habit of valleriite, p. 127).

The amount of material involved in the veinlets is extremely small. They are confined almost solely to the actual boundaries

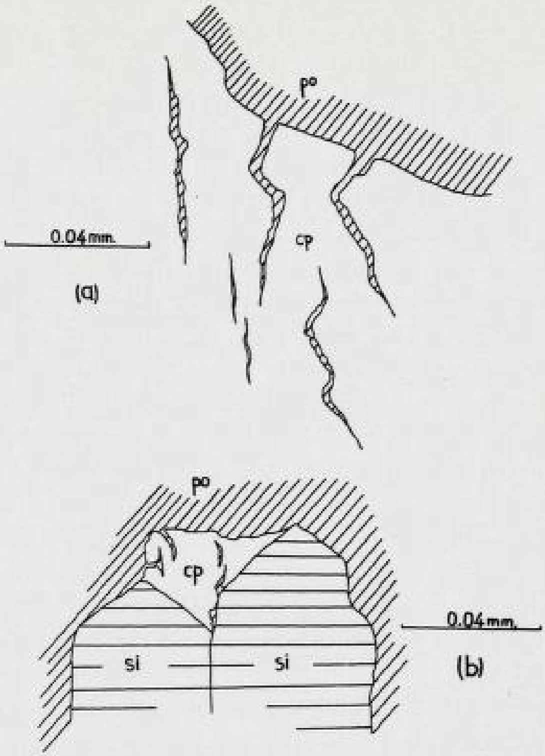


Fig. 40. Sketches of microscope fields showing small veinlets of pyrrhotite (po) penetrating chalcopyrite (cp).
Skisser av mikroskop-preparater som viser små ganger av magnetkis (po) som trenger seg inn i kopperkis (cp).

between the two minerals and have not affected the chalcopyrite for more than a few microns from the pyrrhotite contact.

Since the general textures of the two minerals are so indefinite as regards age relationships, it is unwise to use micro-veinlets as proof of a great age disparity. They could be due to very local corrosion effects after the main crystallisation of the sulphides. Also they were only seen in the Sabetjok-Birtavarre Høyfjell drill cores; the majority of polished sections examined showed perfect "mutual boundaries".

Both these sulphides appear to have replaced the silicate fragments to a certain extent. Apart from the "rounding" of the fragments described above, thin and polished sections show irregular penetration and partial digestion of the silicates along their borders with the sulphides. (See Plate 8, Fig. 2.)

The texture of the *pyrrhotite* is always allotriomorphic, no crystal outlines were observed. Typical texture is a mosaic of subrounded or polygonal grains with a grain-size ranging from 0.1 to perhaps 1.0 mm. A coarser grain-size is very rare.

In most of the polished specimens from the area west of Kåfjorddalen the pyrrhotite grains show a very characteristic and noteworthy internal texture. This may be distinguished without the use of the analyzer due to differences in colour, pleochroism and hardness of the components.

The texture consists of fine, sinuous lenses or lines, and of flame- or feather-like forms of one component in a matrix of another. The widths of the units of the minor component vary considerably, but are normally of the order of 0.005—0.01 mm. Plate 9 shows examples of the texture.

This feature has been recognized by previous workers with pyrrhotite, and has been discussed by R. W. van der Veen (1925), Schneiderhöhn and Ramdohr (1934) and by Ramdohr (1950). The latter figures (p. 408) a photomicrograph of pyrrhotite from "Lillehammer, Norwegen" which shows a texture almost identical with that exhibited by a good deal of the Birtavarre pyrrhotite. Ramdohr's specimen doubtless comes from the former nickel mine at Espedalen 60 kms NW of Lillehammer.

All these authors attribute the texture to exsolution. Ramdohr suggests that it is may be due to the segregation of FeS from iron sulphide containing a slight excess of sulphur which is always revealed in the composition of pyrrhotite.

D. L. Scholtz (1936) discusses at length similar textures in the magmatic nickeliferous ores of East Griqualand and Pondoland. He distinguishes two components which he terms α- and β-pyrrhotite. The former is the major component which usually constitutes the matrix, enveloping the segregation lamellae of the latter. α-pyrrhotite is described as being darker and harder, while β-pyrrhotite is paler and softer.

In the case of the Birtavarre pyrrhotite these relations appear to be reversed. The lenses of the minor constituent are darker than the matrix, and the Becke line test indicates that they are softer. Other workers have also arrived at slightly different results, as summarized in the following table.

Author	*Locality*	*lamellae*	*matrix*
Scholtz	E. Griqualand	paler, softer	darker, harder
Ramdohr	Espedalen	paler, harder	darker, softer
Uytenbogardt (1951)	General remarks	paler, softer	darker, harder
Vokes	Birtavarre	darker, softer	paler, harder

Scholtz mentions that the proportions of the two components vary somewhat and that the β-component may locally dominate, or even envelope, lamellae of the α-variety. This was especially the case in protuberances of pyrrhotite from large crystals which were entirely surrounded by silicates.

Thus variations in the relative proportions of the two components seem to be usual. From the nature of things it would be almost impossible to separate these components in order to determine their true nature, so that discussion of them lacks a quantitative basis.

The lamellae in any one pyrrhotite grain are always parallel to a common direction, and no cases were observed of two sets of lamellae crossing each other. In specimens from Brattfjell mine, however, much more complex forms were observed. They consist of flame-like lenses, often en echelon, and often with a sharp, double-bend, giving a Z-like form. The lamellae are distributed fairly evenly over the grains and show no tendency to segregate to grain boundaries, fractures, etc., in the manner described by Scholtz.

The pyrrhotite grains sometimes show a weak twinning under crossed nicols. According to Schneiderhöhn and Ramdohr twinning in pyrrhotite is rare and unimportant and can almost invariably be attributed to stress. This view is reinforced by occasional observations from the Moskogaissa ore of slight, though marked changes of direction of the exsolution lamellae on crossing the twin planes. Fig. 41 shows such bent lamellae diagrammatically, with the apparent directions of slip shown by the arrows. This feature indicates stress acting on the ore after the solidification and exsolution of the pyrrhotite, stress which may be connected with the post-ore movements previously described.

A more definite textural indication of movement after the solidification of the pyrrhotite was observed in a polished section from DDH S11. The specimen was taken from the immediate hanging-wall of a band of sulphide-filled breccia. The actual wall-

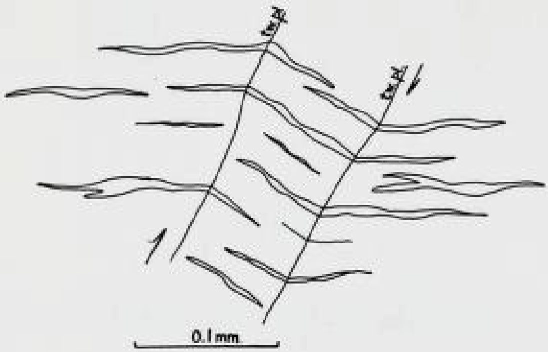


Fig. 41. Lamellae in pyrrhotite doubly bent due to slip along stress twin-planes.
Lameller i magnetkis bøyet på to steder ved glidning langs tvillingplan.

contact showed slickensiding and polishing of the sulphides, clearly indicating post-ore movement. This movement had affected the sulphides for about ½ cm below the contact in a marked way. The pyrrhotite showed a gneissose texture in which the grains were drawn out along axes parallel to a direction of apparent flow around the silicate fragments in the breccia. The maximum length of the grains in this zone was about 0.05 mm and the ratio of length to width about 5 : 1 or 10 : 1. Away from this ½ cm zone the pyrrhotite rapidly assumed its normal even-grained allotriomorphic texture with a grain-size around 0.2—0.3 mm.

Such texture is clear evidence of deformation and recrystallisation of the solid sulphide under stress — a stress which must have been moderate only, since it did not cause crushing of the silicate fragments to any marked extent.

In specimens of sulphides from the Skardalen and Mandalen areas fine examples of a late alteration of the pyrrhotite are found. This alteration involves the formation of both marcasite and pyrite but may be dealt with here. The alteration proceeds from irregular cracks in the pyrrhotite or from grain boundaries, especially against silicate fragments. From these cracks or grain-boundaries the alteration attacks the pyrrhotite along the cleavages. Several textural effects are produced by this alteration depending on the degree to which the pyrrhotite has been affected. The first effect is slight replacement from the irregular cracks and grain boundaries. The pyrrhotite goes over to marcasite and thin hair-like fingers develop outwards along the cleavages. The original cracks appear merely as lines even under the strongest magnification, but evidence from other textures seems to show that an introduction of carbonate is responsible for the alteration. For instance Plate 10, Fig. 1 is a photomicrograph of a vein of pyrrhotite in a partly shattered fragment of quartz. Alteration has proceded inwards from both walls of the vein, and has linked across in places. Nearest the walls are irregular tongues of an iron-rich carbonate (red internal reflections). A marcasite alteration has preceeded the carbonate. The parallelism with the cleavage of the pyrrhotite is striking.

Another expression of the alteration is the development of a rib of pyrite along both sides of the original cracks, which still stand out clearly as sharp lines when seen in polished section (Plate 10, Fig. 2).

This alteration of pyrrhotite to marcasite and pyrite is fairly well known from sulphide ores. Among others, Ramdohr discusses it and figures an illustration closely resembling Plate 10, Fig. 2 (1950, p. 412). This author refers the change to supergene agencies acting on the pyrrhotite. Edwards (1954), however, ascribes the formation of marcasite from pyrrhotite as being due to a change in the acidity and temperature of the residual mineralizing solutions which renders the pyrrhotite unstable, so that it dissolves spontaneously. The change usually coincides with the appearance of hypogene carbonate deposition. Plate 10, Fig. 1 shows that carbonate is associated with the change pyrrhotite-marcasite in some of the Brattfjell ore. On the other hand the specimens showing this alteration come from either dump or outcrop material and have been exposed to weathering agencies for a considerable time. No such alteration was observed, for example, in drill-core material.

Pyrrhotite is always regarded as being a magnetic mineral, but experience with the Birtavarre material shows that its magnetic properties are very variable. In some specimens a good deal of the pyrrhotite can be picked out with a hand-magnet, while in others the mineral responds very weakly. Again, when cleaning crushed samples of pyrrhotite for spectrographic work on the Franz isodynamic separator it was found that the mineral was concentrated at all amperages from 0 to 0.50, indicating a wide range of magnetic properties.

Two samples of pure pyrrhotite, one magnetic and the other apparently non-magnetic, were analysed for total acid-soluble Fe and for S, and their formulae calculated. The results are given below.

Pyrrhotite from Moskogaissa 117 mine, non- or weakly-magnetic

Fe	S	Cu	Total
62.11	37.33	0.80	100.24

Calculating the Cu as $CuFeS_2$ this gives pyrrhotite formula as $FeS_{1.036}$

Pyrrhotite from Skaide mine, strongly magnetic

Fe	S	Cu	Total
59.14	37.28	0.80	97.22

Calculating the Cu as $CuFeS_2$ this gives pyrrhotite formula as $FeS_{1.088}$

In a recent publication Grønvold and Haraldsen (1952) have discussed the relations between the structures, chemical composition and magnetic properties of synthetic pyrrhotites and natural pyrrhotites from localities in Norway. They confirmed the existence of hexagonal pyrrhotite minerals relatively poor in sulphur and monoclinic types comparatively rich in sulphur. The ferromagnetic properties were found to increase from sulphur-poor to sulphur-rich specimens. This is confirmed for the Birtavarre pyrrhotites by the analysis figures given above.

Chalcopyrite. Owing to the very weak anisotropism of this mineral little information could be gained of its internal textures. In polished section the chalcopyrite presented a flat, even field and grain boundaries could not be distinguished. Under crossed nicols the most usual texture shown was a parallel lamellar one, sometimes with spindle-shaped lamellae crossing each other at right angles. It was not possible to decide whether these lamellae represented individual crystals or whether they were twin-lamellae within larger crystals.

The most note-worthy feature in connection with the chalcopyrite is the frequent occurrence of exsolution lamellae of cubanite (see below).

In one single polished section from Skaide mine fine veinlets, 0.002—0.004 mm wide, of chalcopyrite were seen cutting through fractured grains of pyrrhotite and sphalerite. The veinlets appeared to be continuous with the chalcopyrite in the rest of the section, which showed the usual textures as previously described. Though the copper mineral in these veinlets is undoubtedly later than the pyrrhotite and sphalerite which it transects, this fact cannot be used to prove the later age of all the chalcopyrite. The feature is of very local development and may represent limited remobilization of the chalcopyrite at a later date after slight fracturing of the ore.

Sphalerite. The zinc mineral is a ubiquitous constituent of all the sulphide specimens examined. Its proportions to the other sulphides are extremely variable, however, and for the most part it must be regarded as a minor constituent.

At Skaide and at Moskogaissa 125 sphalerite becomes a major sulphide and is clearly visible in hand specimens. In some of the Skaide specimens sphalerite is equally as abundant as the other sulphides. Specimens from Moskodal mine, in Reisadalen, show that the ore there is rich in the zinc mineral, too.

Otherwise, sphalerite can only be detected in polished sections under the microscope. It is least abundant in specimens of the drill cores from the Moskogaissa area, and from the mines of the Skardalen—Mandalen area. The sulphides of the Sabetjok—Birtavarre Høyfjell area show an increase in sphalerite compared with those to the west of Kåfjorddalen.

No geological reasons for the uneven distribution of sphalerite have come out of the present investigation.

The occurrence of sphalerite in hand specimen gives little clue to the paragenesis. It occurs as coarsely (0.5—2 mm) crystalline dark-brown grains or crystals with an adamantine lustre.

In the Moskogaissa 125 specimens the sphalerite occurs in places as irregular vein-like forms in the country-rock, but these give no clue to its relation to the other sulphides.

In polished sections the sphalerite occurs as extremely irregular bodies or groups of bodies and irregular patches. (Plate 11.) Its occurrence is confined almost entirely to the areas of chalcopyrite and it is extremely rare to find sphalerite associated solely with pyrrhotite.

From a paragenetical point of view the sphalerite textures are, for the most part, difficult to interpret. The irregular bodies in the chalcopyrite could equally well have resulted from simultaneous crystallisation or from replacement. However, there do occur textural

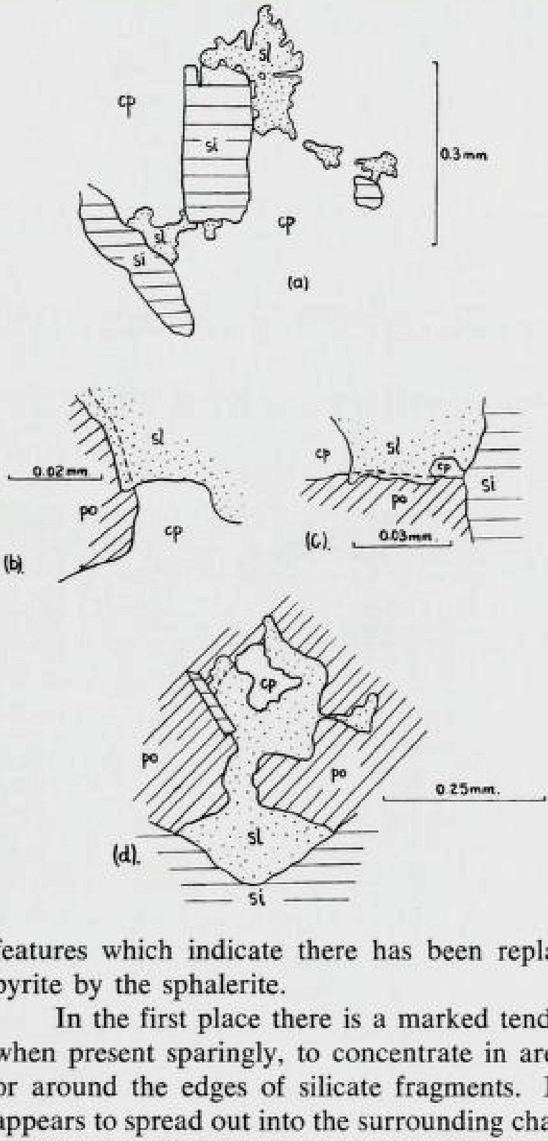


Fig. 42. Sketches from microscope fields showing textures indicative of replacement of chalcopyrite (cp) by sphalerite (sl). Grains of silicates marked si.

Skisser av mikroskop-preparater som viser strukturer som indiserer at sinkblende (sl) har fortrengt kopperkis (cp.) Silikat-korn merket si.

features which indicate there has been replacement of the chalcopyrite by the sphalerite.

In the first place there is a marked tendency for the sphalerite, when present sparingly, to concentrate in areas of crushed silicates, or around the edges of silicate fragments. From these positions it appears to spread out into the surrounding chalcopyrite in the manner illustrated in Fig. 42 a.

What seems to be a definite indication of replacement is a texture where the sphalerite has "flooded" across an area of chalcopyrite and slightly replaced the pyrrhotite in contact with the copper mineral (Figs. 42, b, c, d). In these cases it is sometimes possible to see the original contact preserved as a crack in the sphalerite.

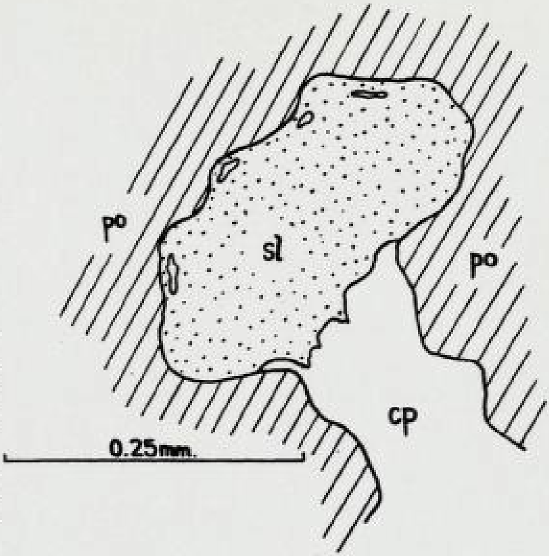


Fig. 43. Sphalerite (sl) replacing area of chalcopyrite (cp) in pyrrhotite (po) and leaving small residuals near the grain boundaries.

Sinkblende (sl) fortrenger kopperkis (cp) i magnetkis (po).

Residuals of chalcopyrite are sometimes left in an area of sphalerite. Fig. 43 illustrates such residuals. The sphalerite has almost wholly replaced an area of chalcopyrite surrounded on three sides by pyrrhotite and shows an embayed replacement front to the remaining chalcopyrite along the fourth side.

Embayed and "scalloped" sphalerite-chalcopyrite contacts are quite common, again indicating replacement.

Other textural features considered indicative of replacement of the copper mineral by sphalerite are sketched in Fig. 44.

In specimens from Akkavagge, Mandalen and in one or two finer-grained specimens from Skaide mine, the copper and zinc minerals occur in a extremely intimate intergrowth. In the absence of the above indications of replacement, these textures would almost prove simultaneous deposition. However it is highly probably that they could equally well result from the irregular replacement of the chalcopyrite by the sphalerite. As Schouten (1934, p. 655) says when discussing the results of synthetic replacement experiments, "hardly one of the known textures or structures in ore specimens, considered separately, is a safe criterion against replacement".

The evidence of the polished sections is that the sphalerite is later than the major sulphides, and has replaced the chalcopyrite to a large degree and the pyrrhotite very sparingly.

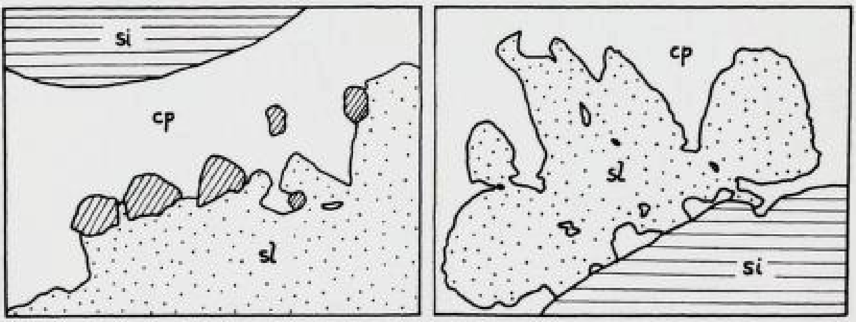


Fig. 44. Drawings from photomicrographs showing chalcopyrite-sphalerite relationships. a) Sphalerite (sl) "front" replacing chalcopyrite (cp) but not attacking grains of pyrrhotite (shaded). Skaide. X 130. b) Irregular replacement patch of sphalerite (sl) in chalcopyrite (cp). Skaide X 300.

Tegninger (etter fotografier) av mikroskop-preparater som viser aldersforholdene mellom kopperkis og sinkblende. a) En sinkblende (sl) «front» fortrenger kopperkis (cp) men angriper ikke korn av magnetkis (skravert). Skaide X 130. b) Kopperkis (cp) uregelmessig fortrengt av sinkblende (sl). Skaide X 300.

The sphalerite in the Birtavarre sulphides is normally very dark brown in colour, indicating a high Fe content. As is well-known ZnS has the ability to dissolve appreciable amounts of FeS, the amount dissolved being determined by the temperature and pressure conditions existing during the formation of the sulphides, always provided sufficient iron sulphide is present at the time.

Kullerud (1953) has used the ZnS—FeS system in sphalerite as a geological thermometer and Kullerud, Padget and Vokes (1955) have applied the method in determining the temperature of formation of certain sphalerite-bearing ores in northern Norway (see also p. 134 below).

Pure specimens of sphalerite from Skaide, Moskogaissa 125 and Moskodal were analysed for iron and the results are given below to give an idea of the make-up of the mineral in the area.

Locality	*Wt% FeS*	
Moskogaissa 125	9.99	
Skaide	13.63	Analyst E. Christensen
Moskodal	15.18	NGU Laboratory

From an economic point of view such a high content of iron would reduce the value of a possible zinc concentrate from these ores, since, of course, it could not be removed by mechanical means.

Cubanite. This copper-iron-sulphide occurs extensively in the sulphides of the area. Particularly fine examples were observed in polished sections from Sabetjok mine and from the Skardalen area. In general it can be said that the copper-rich parts of the ores from the whole area show cubanite to a greater or lesser degree. In keeping with the known habits of the mineral it occurs solely in chalcopyrite where it forms single lamellae, groups of lamellae or larger elongated laths. The lamellae have variable dimensions, but their widths usually range from 0.01 to 0.5 mm and their lengths may run up to 50 mm. This latter dimension depends to a certain extent on the size of the fields of chalcopyrite.

In most sections the cubanite occurred as single lamellae, or as series of lamellae parallel to a common direction, but occasionally two sets of lamellae occurred crossing each other at an angle. (Plate 12.)

In ordinary light the cubanite showed slight pleochroism, whilst under crossed nicols it exhibited a strong anisotropism, from light sky-blue to deep purple. Some of the larger lamellae show a patchy or mottled texture under crossed-nicols due to two components exhibiting different anisotropism. Ramdohr (1950, p. 431) figures a photomicrograph of cubanite from Skardalen which shows such a texture. This author ascribes the texture to twin lamellae within the cubanite. At the temperature of exsolution (from chalcopyrite) cubanite is hexagonal and as the temperature falls it becomes rhombic pseudo-hexagonal. Thus the cubanite lamellae as a whole will show a pseudo-hexagonal structure, built up of small rhombic individuals, the resultant texture becoming apparent under crossed nicols.

Schwartz (1927) summarized the habits of cubanite and showed by experiment that it is deposited out of solid solution with chalcopyrite at temperatures between 400°—450°C. Thus ores showing intergrowths of the two minerals must have initially been above these temperatures (see p. 134 below).

Other workers (Buerger and Buerger, 1934) have shown that at the temperature of solid solution the chalcopyrite exists as a "high chalcopyrite" modification which has a disordered structure and that on cooling it reverts to the ordered, "low chalcopyrite" form, the reversion to order causing a precipitation of all atoms present in excess of the simple rational proportions of chalcopyrite as blades of cubanite, the blades being commonly oriented in the (111) directions of the chalcopyrite.

In several polished sections of the drill-cores from the Sabetjok—Birtavarre Høyfjell area it was observed that many of the cubanite lamellae enclosed, or partly enclosed cubes, or less regular grains, of pyrite (Plate 13, Fig. 1). The euhedral grains of pyrite showed more or less even, regular contacts against the copper minerals, but often the outlines of the less regular grains were raggedly embayed, suggesting replacement, or at least corrosion, by the surrounding later minerals. The chalcopyrite fields away from the cubanite were noticably free from pyrite, though this mineral was present without accompanying cubanite in the copper-poor parts of the sections. Also cubanite lamellae were observed without any enclosed pyrite.

However, the occurences of two minerals together were numerous enough to suggest some genetical interdependence. It would seem that the pyrite grains have acted as nuclei for the growth of some of the cubanite lamellae during their ex-solution from the chalcopyrite.

It is not possible to say anything definite regarding the areal distribution of the cubanite or its distribution in vertical sections through the sulphide zones. Since it is so intimately associated with the chalcopyrite it is usually most abundant where this mineral is predominant. Its distribution therefore roughly follows that of the chalcopyrite, roughly, because it is not equally abundant in all chalcopyrite fields.

Pyrite. Unlike the case in most of the other Norwegian Caledonian sulphide deposits, the proportion of pyrite in the ores of the Birtavarre area is vanishingly small. It has not been observed in polished section in any of the ores west of Kåfjorddalen, or in specimens from Skaide mine. Until 1955 it was considered that pyrite was completely absent from the copper sulphide deposits of the area. In that year it was seen as small grains in the drill-cores from Sabetjok—Birtavarre Høyfjell, and subsequently in polished sections of these cores.

The following remarks regarding pyrite refer solely to observations from these drill-cores.

Megascopically pyrite was seen very occasionally in thin veinlets along with carbonate cutting the schists in the walls of the sulphide zones. These were apparently of quite a late age, later than the main mineralization. Later similar veinlets were seen in polished section, carrying pyrite and marcasite, with a gangue of carbonate. These observations prove a late, extremely minor, generation of pyrite, distinct from the main occurrence of the mineral which is clearly older than the chalcopyrite and pyrrhotite.

The usual habit of the pyrite is as euhedral or subhedral crystals and grains, or as very irregular patches, enclosed by both chalcopyrite and pyrrhotite. (Plate 13, Fig. 2.) The pyrite has clearly been attacked and partly replaced by the copper mineral and their contacts are often extremely ragged and embayed. Such an effect is not so marked in the case of pyrrhotite, but it seems clear that this mineral has "moulded" itself around grains and crystals of the pyrite.

The evidence is therefore that pyrite is the oldest sulphide in the Birtavarre area, but it is present so sparingly that there is little which indicates its original condition. It is not clear if pyrite was originally present in the rocks before the brecciation and invasion of the main sulphide minerals, or whether it is an early-crystallised sulphide of the main mineralization which has been corroded and partly replaced by the later deposited minerals.

In this connection attention could be drawn to the remarkable rounded (corroded) cubes of pyrite in the ore of Sulitjelma. Here it would appear that the pyrite formed euhedral crystals early in the sequence, which were afterwards attacked by the surrounding mineralizing solutions, before the chalcopyrite and pyrrhotite crystallised round them.

The other similarities between the deposits of the Birtavarre region and those of Sulitjelma make it not unlikely that the pyrite in the two regions had the same geological history. The author considers that the pyrite in the Sabetjok—Birtavarre Høyfjell drill-cores is part of the main sulphide mineralization; it was the first sulphide to crystallise, and was later replaced to varying extents by other sulphides.

The view that the rounded pyrite crystals in the Sulitjelma ore were due to "resorption" by the surrounding ore-bearing solutions was originally advanced by Brøgger (1901). However, C. W. Carstens (1944) was of the opinion that they represented porphyroblasts, on evidence of inclusions showing they had been rotated during growth — in a similar manner to rotated garnets in cartain metamorphic schists. None of the pyrite grains in the Birtavarre sulphides showed any evidence of being porphyroblastic.

In this section it is convenient, for the sake of completeness, to mention briefly the pyritic mineralization at Kilen, on the northeast slopes of Kåfjorddalen, about 5 kms from the head of the fjord. Here pyrite occurs in euhedral cubes and irregular aggregates, averaging about ½ cm diameter in a graphite schist at the base of the Store Borsejok series. Graphite schists are known from several localities at this stratigraphical level, but Kilen is the only one known to carry pyrite. The zone has been tested by one or two adits, and old reports speak of diamond-drilling which intersected up to 20 metres of pyrite-impregnated schist.

The mineralogical and lithological associations point very suggestively towards stagnant-water (anaerobic) conditions of deposition, and it is tempting to assign the Kilen mineralization to sedimentary agencies. The lithology of the rocks on either side of the pyrite-bearing schists suggests deposition in not too great a depth of water, but under conditions of stability. At the base of the Store Borsejok series are the impure limestones of the Schists-with-thin-limestones which indicate fairly clear-water deposition. The Store Borsejok schists themselves represent a quite uniform series, probably originating from muds, clays and other fine sediments deposited under a steady and slow depression of the land. The pyrite- and graphite-bearing schists could be interpreted as indicative of local, stagnant lagoonal conditions during this period of slow depression. They would seem to be the metamorphic equivalent of the lithological type represented by the alumshales (Cambro-Silurian) of, e.g., the Oslo region, which also show patchy syngenetic sulphide mineralization.

Valleriite. This mineral has only been recognised in polished sections, where its identification depends on its extremely characteristic optical properties and its mode of occurrence.

Valleriite exhibits marked reflection pleochroism and anisotropism, as follows:

Pleochroism — bright yellowish or pinkish cream to dark grey.
Anisotropism — extreme, white or pink-white to dark grey.

These properties approach those of molybdenite, but the latter has recognisable differences in pleochroism. These, and the different habits of the two minerals enable them to be easily distinguished from each other after some practice.

According to Ramdohr (1950) the mineral crystallises orthorhombic pseudo-hexagonal, but crystals are extremely rare, very small and quite thinly tabular.

J. E. Hiller (1939) made a detailed study of the structure of valleriite and concluded that it was rhombic, having the cell-constants a = 6.13, b = 9.81, c = 11.40. He considered the formula to be $Cu_2Fe_4S_7$ or possibly $Cu_3Fe_4S_7$.

Scholtz (1936, p. 169) gives a short history of the identification of valleriite and discusses its occurrence in the magmatic nickel ores of the Bushveld and Insizwa areas. His sketches of the microscopic appearance of valleriite (p. 177, Fig. 13) are almost identical with those prepared by the present writer (Fig. 47). In these S. African ores valleriite is best developed in the chalcopyrite-cubanite ore bodies, where it may sometimes be megascopically visible as soft flakes a millimetre or two in diameter, characterized by a perfect cleavage. In polished sections the mineral always shows traces of this basal cleavage, which is most conspicuous in the more massive aggregates. In the Birtavarre material the cleavage was extremely difficult to distinguish, probably due to the very minute flakes in which the mineral occurs.

The mode of occurence of the valleriite in the Birtavarre sulphides is extremely constant and very characteristic. It is present in most of the ores in small but variable amounts, always with a constant association with chalcopyrite. It was never observed in any other mineral, a fact which is in agreement with most of the accounts of its occurrence in the literature.

Within areas and patches of chalcopyrite, valleriite can occur:

a) as minute flakes, or irregular patches always at the grain boundaries of the copper mineral. The most frequent position is along the contacts with silicates, but it also occurs at chalcopyrite-pyrrhotite junctions (see Fig. 45).

b) as similar flakes, situated along microscopic cracks in the chalcopyrite (Fig. 46). The sketch, Fig. 46 (b), shows how a single crack

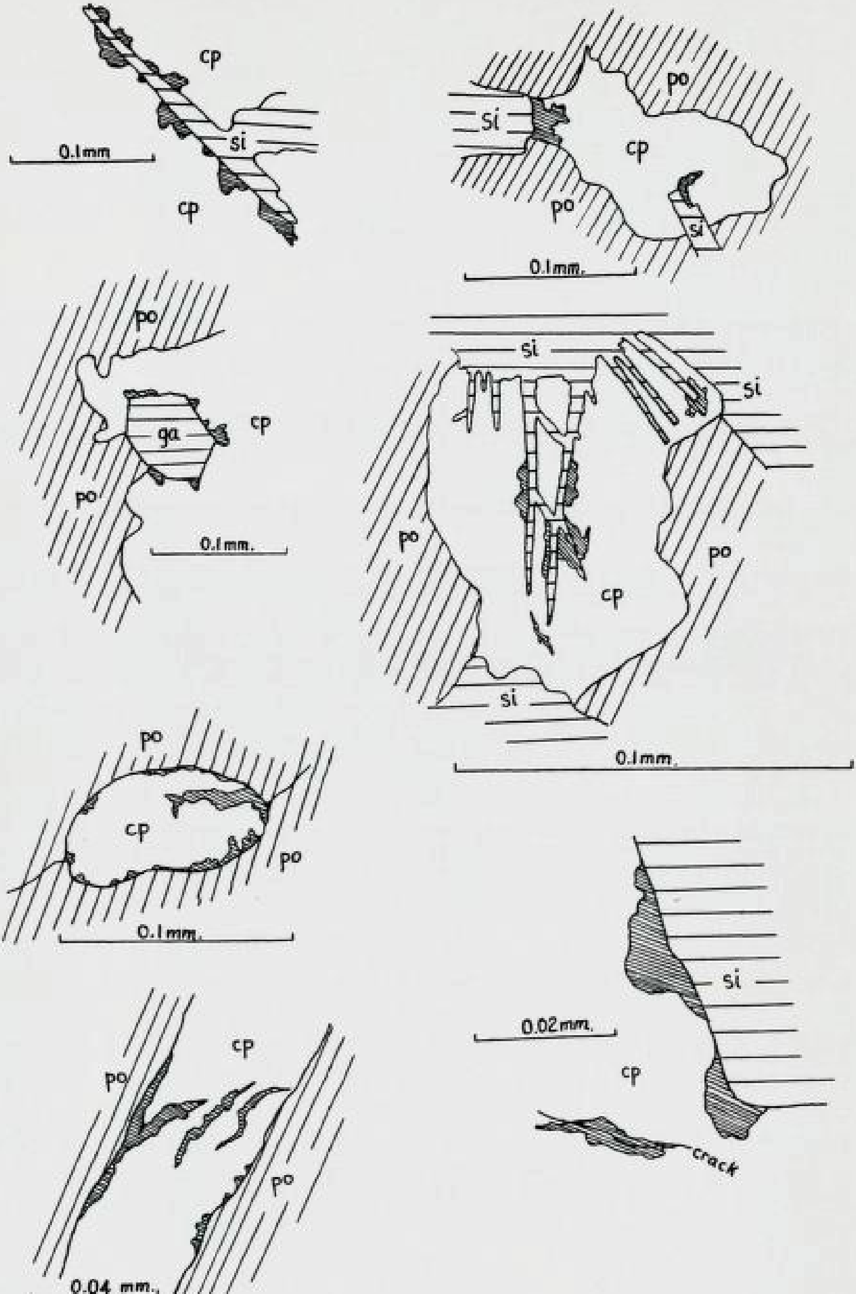


Fig. 45. Sketches showing characteristic occurence of valleriite (shaded) as minute flakes and patches in chalcopyrite (cp) at its grain-boundaries with pyrrhotite (po) and silicates (si).

Skisse som viser det karakteristiske utseende av valleriitt (skravert), som meget små flekker og flak i kopperkis (cp) langs grensene mot magnetkis (po) og silikater (si).

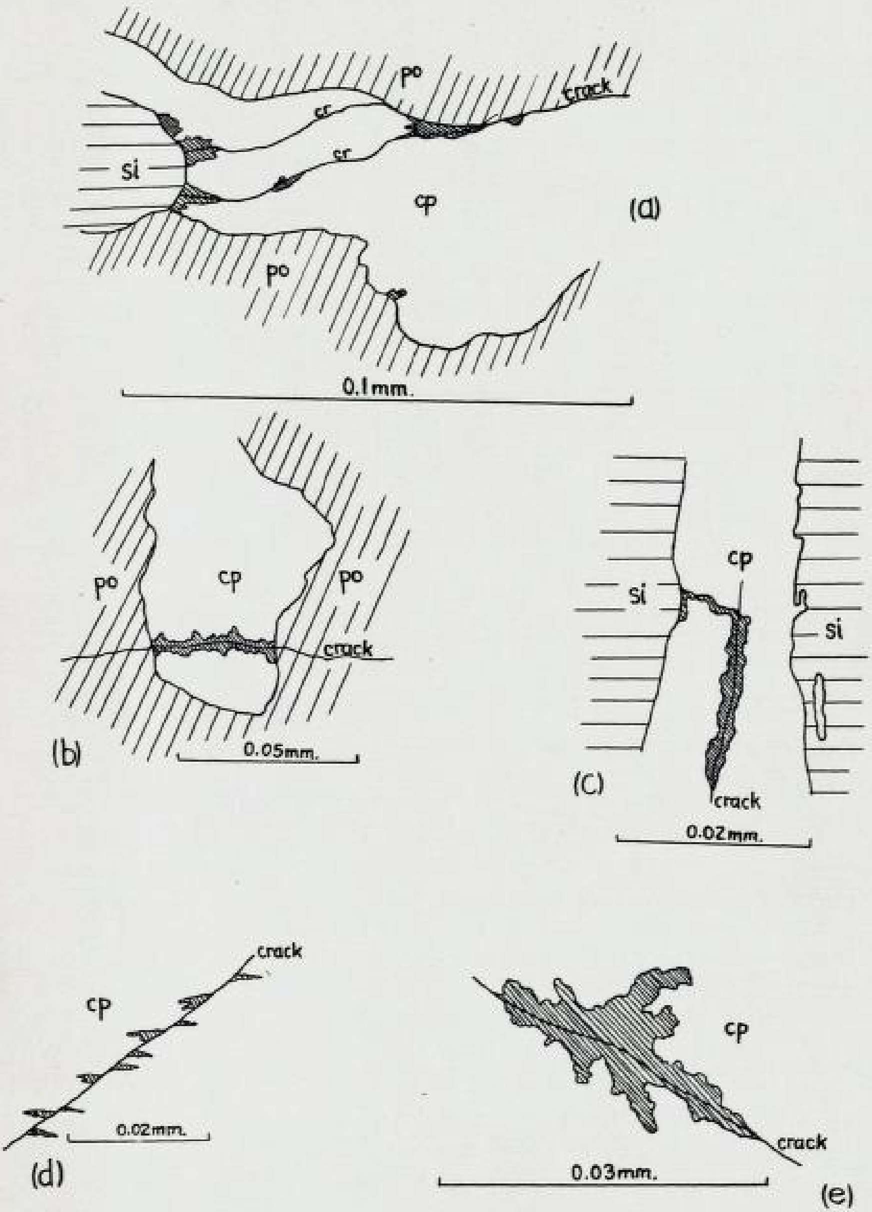


Fig. 46. Sketches showing the occurrence of valleriite (shaded) replacing chalcopyrite (cp) along microscopic cracks.
Skisser som viser hvordan valleriitt (skravert) fortrenger kopperkis (cp) langs mikroskopiske sprekker.

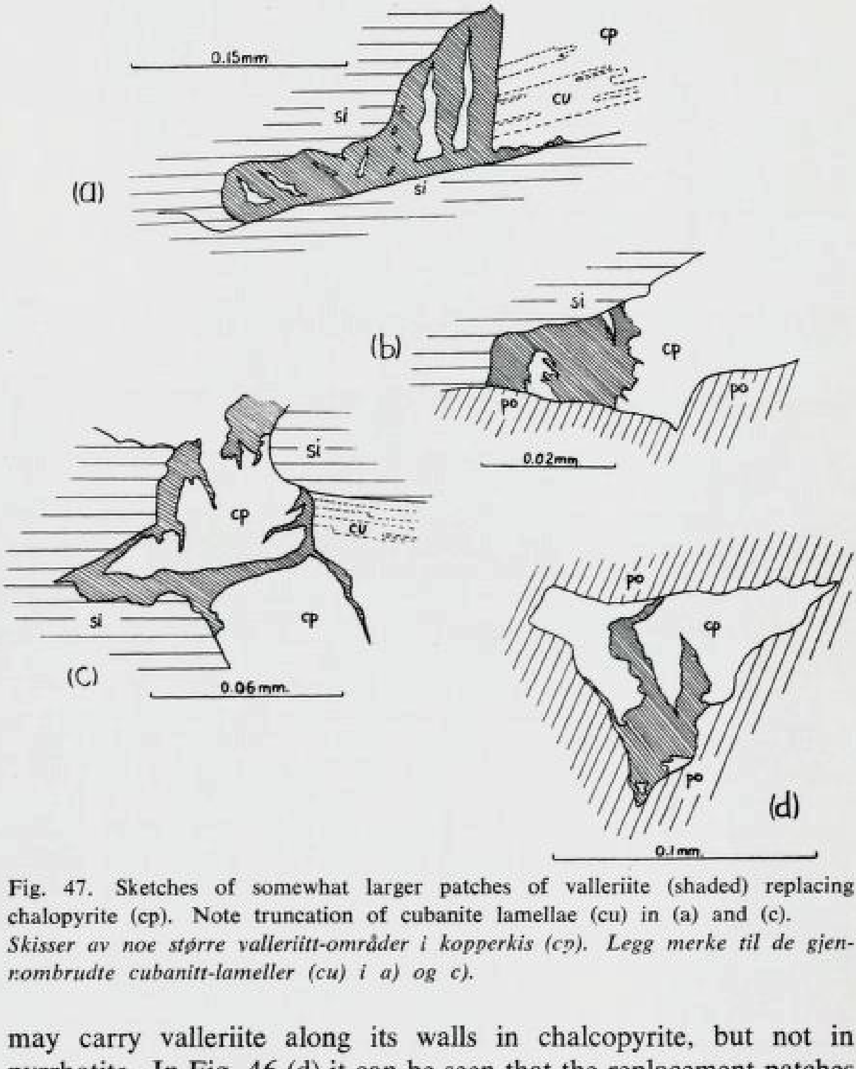


Fig. 47. Sketches of somewhat larger patches of valleriite (shaded) replacing chalopyrite (cp). Note truncation of cubanite lamellae (cu) in (a) and (c).
Skisser av noe større valleriitt-områder i kopperkis (cp). Legg merke til de gjennombrudte cubanitt-lameller (cu) i a) og c).

may carry valleriite along its walls in chalcopyrite, but not in pyrrhotite. In Fig. 46 (d) it can be seen that the replacement patches of valleriite have been oriented in a structural direction of the chalcopyrite.

c) as somewhat larger, irregular patches of valleriite replacing chalcopyrite, as illustrated by the sketches in Fig. 47. In Fig. 47 (a) and (c) it appears that the valleriite has truncated the ends of cubanite lamellae in the chalcopyrite, proving it to be later than the unmixing of those minerals.

The above textures seem to point clearly to the formation of valleriite by replacement of chalcopyrite. The contacts between chalcopyrite and silicates, between chalcopyrite and pyrrhotite, and the microscopic cracks in the chalcopyrite, have acted as means of access for solutions which have changed the chalcopyrite in small irregular patches and veinlets. Such a change necessitates the removal of copper from the chalcopyrite or its substitution by iron.

Similar conclusions regarding the origin of valleriite have been reached by Scholtz (op cit), and by Ödman (1933) who investigated the sulphide ores of Kaveltorp in Sweden, from which locality valleriite was first described by Blomstrand in 1870. Buerger (1935) studying the copper ores of Orange County, Vermont found the valleriite to occur as minute, dagger-like crosses evenly distributed throughout the chalcopyrite, and as minute veinlets and worm-like masses near the grain boundaries with pyrrhotite. Buerger considered the cross-like forms evidence of unmixing of valleriite from the chalcopyrite. Grondijs and Schouten (1937) mention that they found valleriite in the ores of Røros and Sulitjelma among other localities, but do not go into details.

The weight of evidence from the literature seems to support an origin by replacement of chalcopyrite. It does not seem possible that the relationships observed in the Birtavarre ores can be interpreted in any other way.

Molybdenite is a very rare constituent of the ores. It has been mostly observed as rounded flakes ca. 0.25—0.5 mm diameter in the most non-magnetic fractions from the Franz separator. Microscopially it has only been observed, in three instances, in polished sections from the Moskogaissa drill-cores. The flakes varied from 0.5 mm $\times$ 0.05 mm to 0.15 $\times$ 0.02 mm in dimension. In every instance they appeared as isolated individuals surrounded by a field of allotriomorphic pyrrhotite. One of the flakes had a pronounced 60° bend in passing from the pyrrhotite to an adjacent patch of silicates.

The flakes clearly showed the basal cleavage of molybdenite and had the following optical properties.

Pleochroism: dark sphalerite-grey to galena-white (silvery).

Anisotropism: light pinkish grey to very dark grey. Extinction occurred parallel to the cleavage traces.

The number of observations of molybdenite is far too small to allow any firm deductions to be made regarding its paragenetical relations. The few flakes seen seemed to be quite euhedral and earlier than the surrounding sulphide fields. Molybdenite is not a usual constituent of such ores, and its occurrence seems very erratic and of minor importance.

Galena has only been seen in loose specimens from the dumps at Skaide mine. It was seen megascopically as small irregular grains and patches up to 5 mm across impregnating a specimen of coarse quartz-plagioclase-biotite-schist. In polished sections it occurred sparingly, also "filling-in" between silicate grains in the breccia fragments. No instances were seen where it was in contact with the other sulphides, so its place in the paragenesis could not be determined.

The occurrence of galena at Skaide is noteworthy in view of the high content of sphalerite in the ore at this mine. This association may be a weak representative of the strong lead-zinc mineralization which is found in several ore-bodies further south in the Caledonian mountain-chain, eg. Bleikvassli, Mofjell.

Marcasite. The occurence of marcasite has been discussed previously in the sections on pyrrhotite and on pyrite. Quantitatively it is an almost negligible constituent of the ore, and its appearance must be due to a late alteration of pyrrhotite, possibly hypogene, but more probably supergene.

Other minerals. Carbonate (mostly calcite) is observable in irregular patches or veins cutting the ore-zone rocks at several places in the area — eg. Moskogaissa 115, Skaide, Birtavarre Høyfjell. At the last locality it is quite a notable constituent of parts of the quartz-rich ore. It occurs as coarse-grained patches up to several centimetres across, associated with the sulphides. It shows clear replacement boundaries to both the sulphides and enclosing quartz and must be regarded a very late mineral.

Fluorite. In crushed specimens of some of the ores odd specks of a deep purple fluorite were observed. It was not seen in situ.

Paragenesis.

The textures observed in the Birtavarre sulphides, are on the whole not too satisfactory when it comes to estimating the order of deposition of the various minerals. In particular the inconclusive relations between the two major constituents, pyrrhotite and chalcopyrite are rather disappointing. It must be considered that the chalcopyrite and pyrrhotite were deposited practically simultaneously from a common iron-copper-sulphide "solution". The wall rocks and silicate inclusions seem to have had an influence on this deposition since chalcopyrite *tends* to be concentrated on one or both walls and around country-rock fragments in the ore. This influence could be chemical, but is also could be physical — a temperature effect, whereby the chalcopyrite was deposited slightly in advance of the pyrrhotite along the cooler walls.

In one part of area pyrite had crystallised prior to the other sulphides and was subsequently corroded and partly replaced before they solidified round it.

The sphalerite shows textures indicating it has replaced both the pyrrhotite and the chalcopyrite, the greatest effects being confined to the latter. The mode of access of the sphalerite to the ore is not so clear. It is frequently associated with country-rock fragments, and often appears to have replaced chalcopyrite from grain borders against silicates. This suggests these boundaries had provided the means of access for the sphalerite-bearing solutions.

In response to falling temperature cubanite came out of solid solution from the chalcopyrite and formed lamellae oriented in the crystal directions of the latter mineral. Temperature considerations (see p. 134) seem to indicate that this unmixing occurred after the crystallisation of the sphalerite.

At some later stage further replacement, quantitatively very minute, of the chalcopyrite took place along grain boundaries and micro-fractures to give the mineral valleriite.

Marcasite formed as a late stage alteration of the pyrrhotite and in very minor veinlets with a second generation of pyrite, and with carbonate.

The paragenetical positions of molybdenite and galena are not clear.

It is a noteworthy fact that no brecciation or fracturing of previously deposited sulphides occurred — if we except the one instance of thin chalcopyrite veinlets cutting fractured sphalerite and pyrrhotite. It seems that all the constituents of the ores were introduced more or less simultaneously into the country-rock breccias and that the paragenesis is a result of crystallisation from a common mineralizing medium. It is significant that nearly all the minerals present can be formed by combination of two or more of the elements Cu, Fe, Zn, and S. It is suggested, therefore, that there occurred an almost contemporaneous crystallisation of chalcopyrite and pyrrhotite and that residual solutions containing mostly zinc later replaced part of these earlier sulphides to give the iron-rich sphalerite. The formation of valleriite, quantitatively of little significance, involved the removal of copper from parts of the chalcopyrite.

Areal distribution of minerals.

Information is not complete enough to give a really complete idea of the mineral variations over the area, but certain main trends seem clear.

Chalcopyrite and pyrrhotite are present over the whole district and nothing suggests there is any systematic variation in their proportions.

Pyrite is only present in the Sabetjok—Birtavarre Høyfjell area. The Birtavarre area as a whole is remarkable, in comparison with the other Caledonian sulphide areas in Norway, for the near absence of this mineral. It is present again in considerable amounts in the Vaddas area north of Reisadalen.

Sphalerite shows an erratic distribution. While present in all the ores to some extent it is only a significant mineral at Moskogaissa 125, Skaide, and at Moskodal mine.

Temperatures of deposition.

The subject of the temperatures of formation of some of the Caledonian sulphide ores in northern Norway has been discussed in a recent paper (Kullerud, Padget and Vokes, 1955). In this paper use was made of the FeS-ZnS system as a geological thermometer, a system first investigated by Kullerud (1953).

Among the deposits investigated were three from the Birtavarre area, viz. Skaide, Moskogaissa 125 and Moskodal. The figures obtained in this investigation gave the apparent temperature of formation of the sphalerite contained in the ores, on the assumption that enough iron sulphide was present to enable equilibrium to be reached between FeS and ZnS. Microscopic investigation of the ores suggests that this condition was fullfilled, with the possible exception of Moskogaissa 125. Here the pyrrhotite content is low and insufficient FeS may have been available to allow the equilibrium to be attained. In the 1955 paper this fact was suggested as an explanation of the low temperature figure obtained for the sphalerite from this deposit (412° ± 25° C).

The other two deposits gave closely corresponding figures for the temperatures of formation of the sphalerite in them, viz.

Skaide .... 517° ± 25° C
Moskodal .... 552° ± 25° C

The presence of cubanite exsolution lamellae in chalcopyrite may be used to give another figure for the temperature of formation of the ores. As mentioned on p. 123, Schwartz has shown that ores containing intergrowths of cubanite and chalcopyrite must have initially been at temperatures above 400 or 450° C. This agrees quite well with the figures arrived at for the sphalerite, which probably relate to the maximum temperatures reached.

Since there is some evidence that sphalerite replaces chalcopyrite it seems that this must have occurred at quite a high temperature, so that the sphalerite acquired its present chemical composition before the cubanite lamellae ex-solved from the disordered "high chalcopyrite".

The maximum temperature generally accepted for the amphibolite facies of metamorphism is about 500° C. The country-rocks of the sulphides under discussion are in the lower amphibolite, or epidote-amphibolite facies, so that they were never at a temperature exceeding this figure; probably the maximum attained during regional metamorphism was less than this. Again, since the introduction of the sulphides was a comparatively late event, the country-rocks may have cooled before the ores were formed. These considerations point to the possibility of a noticable temperature difference between the "ore-fluids" and the country-rock.

Edwards (1954, p. 161) remarks that the preservation of ex-solution intergrowths (eg. cubanite-chalcopyrite) is an indication of relatively rapid cooling of the ores and that such intergrowths are much more common in narrow veins than in large ore-bodies. In ores which cool slowly the minerals precipitated from solution segregate into granular textures — rapid cooling prevents this. So there is evidence of a marked temperature difference between the ores, as introduced, and their country-rocks.

Edwards (1954, p. 107) states that valleriite is stable at temperatures of 410° C if it occurs alone, but when it is included in chalcopyrite it is converted to pyrrhotite and chalcopyrite if heated above 225° C. This would indicate that the temperature of the ore had fallen to below this figure before valleriite formed by replacement of the major copper sulphide.

Thus it seems that the deposition of the Birtavarre sulphides took place over a temperature range from about 550° C down to about 200° C. The main bulk of the minerals appears to have been deposited between 550° and 400° C.

The chemistry of the ores.

Main elements.

As mentioned previously, the sulphide ores of the Birtavarre district are chemically rather simple. Elements occuring in more than trace amounts are Fe, S, Cu and Zn, the proportions of which vary considerably from place to place, even within the same ore-plate.

It would be impossible to give anything at all resembling average values for the area, short of mining out all the sulphides and processing them.

However, certain information has been gathered regarding metal values and this will be summarized here. The most systematic sampling resulted from the two drilling programmes in 1954 and 1955.

In 1954, the Moskogaissa drilling intersected bands of sulphides ranging in copper content from over 10 % to less than 1 %. The distribution of values in the horizontal plane is given in Fig. 56 (p. 208). The information is too scanty to allow any "copper shoots" to be outlined. The average copper content of the seven holes drilled into the main ore plate was 0.98 % and the average thickness 1.70 m.

In 1955 the diamond drilling showed a wide range in copper analyses, of the same order as in the Moskogaissa area. Fig. 62 (p. 218) shows the calculated copper contents and thicknesses for the 15 holes drilled in 1955. It will be seen there is a tendency towards an elongated shoot of higher copper content within the "ore-plate".

The average copper content based on "ore" above 1 metre in thickness was 1.16 % and the average thickness 1.40 metres.

Thus when averaged out, the results from the two seasons' drilling show fairly good agreement, indicating an average copper content around 1 %. This low value is mainly due to the fact that in many instances the sulphides occur as separate bands with a thickness of barren schists in between, which, of course, had to be included in the calculations.

It has already been pointed out that the values vary considerably in vertical section. Fig. 63 shows graphically the vertical variations in copper content in the Sabetjok — Birtavarre Høyfjell area. Similar graphs could be drawn for the Moskogaissa drill holes.

In the course of the Birtavarre survey several further analyses of the ores have been made, of varying degrees of "representativeness". These are given below.

Birtavarre Høyfjell. Bulk sample of quartz-rich ore at outcrop. (Thickness 2 metres.) .... 2.74 % Cu

Birtavarre Høyfjell. Bulk sample of quartz-rich breccia ore at collar of shaft .... 1.37 % Cu
(See Fig. 60 for location of these samples.)

Moskogaissa drilling 1954. DDH M8. Composite sample of whole sulphide band 2.76 % Cu, 0.04 % Zn, 23.72 % S, 49.31 % total acid sol. Fe.

Moskogaissa drilling 1954. DDH M6. Composite sample of both sulphide bands (intervening waste not included). 4.13 % Cu, 0.06 % Zn, 14.35 % S, 27.19 % total acid sol. Fe.

In order to get some idea of the chemical composition of the introduced ore-minerals in the various deposits, bulk sulphide concentrates were made in a 600 gm laboratory Fargergren flotation cell. By repeated cleaning and scavenging the sulphides were separated almost completely from the gangue minerals.

The results were:

Locality.	*Cu %*	*S %*
DDHs Moskogaissa 1954	3.45	35.95
DDHs Sabetjok—B. H. 1955	7.30	33.46
Sabetjok mine	8.62	35.45
Birtavarre Høyfjell, outcrop	9.94	35.72
— — shaft collar	13.79	35.09

Of these samples only the first two have really any claim to be "representative".

The constancy of the S content is rather striking. It seems to suggest the ores are basically a S-medium in which the Cu, Fe and Zn atoms have varying concentrations to give the different ore minerals.

No systematic sampling of the zinc-rich types was undertaken. Specimens were collected from the mine dumps at Skaide and were bulked together to form a sample for flotation tests, but this cannot be regarded as being in any way an average for the Skaide ore.

The analysis of this material showed:

6.37 % Cu, 6.09 % Zn, 24.31 % S.

With so little information available regarding the chemistry of the ores, no idea could be obtained to show if there are any systematic regional variations.

Trace elements.

Preliminary investigations. The flotation concentrates obtained from the ore samples collected after the first season's field work were analysed spectrographically at Sentralinstituttet for Industriell Forskning, Oslo, in order to see whether they contained any trace elements of economic interest. The following elements were found to be present: Co, Ni, Ag, Fe, Ti, V, Mn, Cd, Pb, Zn, Cu. The following elements were sought for but not detected: Mo, Au, Pt, Pd, Sb, Bi. The semi-quantitative results of this analysis are shown in Table 15.

The following notes deal with the results in this table.

Co and *Ni* are dealt with in detail below.

Sample	Co	Ni	Ag	Ti	V	Mn	Cd	Pb
Pyrrhotite concentrate Skaide mine	tr.	tr.	tr.	++	n. d.	+	n. d.	n. d.
Copper concentrate Skaide mine	tr.	tr.	tr.+	+	n. d.	+	n. d.	n. d.
Zinc concentrate Skaide mine	tr.	tr.	tr.+	++	n. d.	++	tr.	tr.
Tailings Skaide mine	tr.	tr.	v. w. tr.	+++	+	+	n. d.	tr.
Pyrrhotite concentrate Moskogaissa	tr.	n. d.	v. w. tr.	tr.	n. d.	n. d.	n. d.	n. d.
Copper concentrate Moskogaissa	tr.	n. d.	tr.	tr.	n. d.	n. d.	n. d.	n. d.
Tailings Moskogaissa	tr.	n. d.	tr.	++	tr.	+	n. d.	n. d.

tr. — trace, n. d. — not detectable, v. w. tr. — very weak trace.
Co and Ni less than 1/10 % as oxides.
Ag, order of size 1/1000 % as Ag. Analyst: Sentralinstituttet.
+ V $\leq$ 1/10 % as V_2O_5.
+ Mn, order of size 1/100 % as MnO.

Table 15. Trace elements in flotation concentrates from the Birtavarre ores.

Ag has its greatest concentrations in the copper and zinc concentrates.

The presence of discrete silver minerals has not been proved in the ores of the Birtavarre area. At Skaide there are minor amounts of galena which may contain Ag, but as will be shown later this element is practically wholly present in chalcopyrite.

Ti was present in estimable amounts in all the samples and showed no preferential distribution. The relative concentrations in the tailings are most certainly due to titanite and rutile which are common accessory minerals in the schist country-rocks and, perhaps, to ilmenite. The ferromagnesian gangue minerals would also contribute to the Ti content.

V was only present in the tailings samples where it probably occurs in magnetite and amphiboles. In these minerals V^{4+} and V^{5+} can replace Fe^{3+} and Al^{3+}.

Mn. The concentrations of this element in the Skaide samples are almost wholly due to sphalerite in which Mn^{2+} is replacing Zn^{2+}. (See below for Mn contents of sphalerite.) Mn is present in the garnets and anthophyllite of the ore-zone, which would account for it appearing in the tailings samples. In these silicates Mn^{2+} (0.91 Å) often substitues for Fe^{2+} (0.83 Å).

Cd is obviously present in sphalerite (see below).

Pb, only appearing in Skaide samples, is due to the small amounts of galena in the ore there.

Molybdenum was not detected in the spectrographic analyses, but it will be clear from the mineralogy of the ore that there is a small Mo content due to molybdenite (see also below).

In addition to the above spectrographic analyses, chemical analyses showed the *absence* of *P* and *As* from the copper concentrates from both localities.

Selenium was determined chemically (see below).

More detailed investigations were made of the distribution of certain elements, particularly those which might be of possible economic interest.

Cobalt and Nickel in the ores. The distribution of these elements among the sulphide minerals was determined by having spectrographic analyses made of pure samples of each mineral from several localities. Unfortunately pure samples of sphalerite could only be obtained from two of these localities.

The analytical results are given in Table 16. Since no discrete nickel or cobalt minerals have been detected in the Birtavarre ores we can assume that these elements are incorporated in the crystal lattices of the individual sulphide minerals. The above table shows that in every case the Ni and Co are overwhelmingly concentrated in the pyrrhotite of the pyrrhotite-chalcopyrite ores. Where sphalerite is present it appear to have Co-Ni contents intermediate between the other minerals.

Thus the order of increasing ability to concentrate both Co and Ni in the Birtavarre ores can be written as

chalcopyrite — sphalerite — pyrrhotite.

Locality	Pyrrhotite		Sphalerite		Chalcopyrite		Co: Ni ratio in pyrrhotite
	Co	Ni	Co	Ni	Co	Ni	
Moskogaissa DDHs 1954	0.070	0.015	—	—	0.0015	0	4.7 : 1
Sabetjok mine	0.058	0.050	—	—	0	0	1.2 : 1
Brattfjell mine	0.068	0.024	—	—	0	0	2.8 : 1
Skaide mine	0.047	0.027	0.026	0	0	0	1.7 : 1
Moskogaissa 117 mine	0.061	0.013	—	—	0.0015	0	4.7 : 1
Birtavarre Høyfjell	0.091	0.120	—	—	0	0	0.76 : 1
DDHs 1955	0.082	0.065	—	—	0	0	1.3 : 1
Moskogaissa 125	—	—	0.026	0	0	0	—

Analyst: Sentralinstituttet.

0 — not detectable,
less than 0.003 % as oxides in chalcopyrite
less than 0.005 % as elements in sphalerite.

Table 16. Co and Ni contents in various minerals from the Birtavarre ores.

This order seems to be in agreement with results obtained by other workers with similar ores. For instance Gavelin and Gabrielson (1947) worked on sulphide ore from the Swedish Precambrian and gave the following orders of increasing ability to concentrate the two elements.

For Co, chalcopyrite — pyrrhotite — pyrite — arsenopyrite.

For Ni, chalcopyrite — pyrite — pyrrhotite — arsenopyrite.

Table 16 also shows that Co is generally present in excess over Ni, the latter element only occurring in detectable amounts in pyrrhotite. Even in this mineral it is subordinate to the cobalt, the Co : Ni ratios varying from nearly 5 : 1 to about 1 : 1.

According to figures quoted by Rankama and Sahama (1950, p. 679) the Co : Ni ratio in early magmatic sulphides is around 0.07, i.e. nickel is enriched in these sulphides. Cobalt on the other hand is more plentiful than nickel in late magmatic sulphides. "In hydrothermal sulphides the Co : Ni ratio is greater than 1 : 10, often even greater than 1 : 1 and thus cobalt may predominate over nickel".

The values in the cases of the Birtavarre pyrrhotites, with one exception, are all over unity, i. e. cobalt is predominant. Such a predominance would seem to argue against an early magmatic origin for the ores.

Rankama and Sahama state further that nickel predominates in all pyrrhotites, but in pyrites, independent of their temperature of formation the content of the cobalt is greater than that of nickel. Pyrite is quantitatively negligible in the Birtavarre ores, but the pyrrhotite appears to have a Co : Ni ratio characteristic of a pyrite.

C. W. Carstens (1941) discussed the Co : Ni ratios in magmatic and hydrothermal sulphides from Norwegian ores, thus:

"In the upper part of the earth the average weight ratio Ni : Co, after Goldschmidt, is 2.5 : 1. In our typical magmatic nickel ore bodies the ratio Ni : Co is 20 : 1 .... In our vein sulphide deposits it seems that this ratio is almost reversed ...... Cobalt, contrary to Nickel, is almost only enriched in rest solutions, against practically never in the first crystallized minerals."

The evidence from Birtavarre is again in agreement with this.

Gavelin and Gabrielson (1947) give a large number of Co and Ni values from pyrrhotites in copper and zinc ores in Sweden. The Co values vaguely tend to be high in Cu ores, while Ni is higher in Zn ores. However, the dissimilarities between Cu and Zn ores are not so general as to permit in each individual case the pyrrhotite of a Cu ore to be distinguished from that of a Zn ore. Skaide, the only really "zinc ore" in the above table, shows the above tendency, too, the Co : Ni ratio is much reduced as compared with the first three. However, Sabetjok pyrrhotite shows the lowest ratio of all, and as far as is known, the ore from this mine carries only small amounts of zinc.

Other workers, such as Rost (1939), Hegemann (1941) and Carstens (1941) have shown that when pyrite and pyrrhotite occur together Co is enriched in the pyrite and Ni in the pyrrhotite. Gavelin's and Gabrielson's results show a tendency towards the separation of cobalt and nickel due to enrichment of Co in pyrite and Ni in pyrrhotite, yet this is less pronounced than in the examples cited by Rost, Hegemann and Carstens. Often the Co : Ni ratios of different sulphide minerals disclose a similar tendency in all minerals from the same deposit and this feature is more conspicuous than the tendency towards concentration of Co and Ni, respectively, in separate minerals.

The sulphides of the Birtavarre district, probably because of their relatively simple mineralogy, disclose fairly clear-cut tendencies of Co—Ni distribution and enable one to make more definite conclusions than in the large-scale regional studies carried out by the above-named authors:

a) both cobalt and nickel are very largely concentrated in pyrrhotite.

b) cobalt is predominant over nickel in all the sulphide minerals investigated.

c) the Co : Ni ratios for the pyrrhotites investigated are reverse of what is usually found for this mineral; these ratios are more characteristic of hydrothermal pyrite.

To conclude, a few words may be said regarding the areal distribution of the Co and Ni values. An inspection of the last column of Table 16 seems to reveal a significant grouping of the Co : Ni ratios on either side of Kåfjorddalen. To the west (Moskogaissas, Brattfjell) the ratios are above 2.5. To the east of the valley the ratios are all below 2.0 and at one place the ratio is less than 1.

Kåfjorddalen has in other respects appeared as a dividing line of some significance. It marks the easterly limit of strong metasomatic alteration and the western limit for the appearance of pyrite.

The geological significance, if any, of the change in Co : Ni ratios across Kåfjorddalen is not easy to deduce A relative increase in nickel should mean a trend towards more early magmatic sulphides, yet this would be expected in a westerly, not an easterly direction. Since pyrite concentrates Co preferentially to Ni the explanation could lie in the presence of this mineral east of the valley. This pyrite would absorb a larger proportion of the Co originally present, thus making less available for the pyrrhotite and giving an increase in the relative Ni content of this mineral.

Silver. In the ores of the Birtavarre type it is to be expected that any silver content will be present in solid solution within the chalcopyrite, and will, if the ores come to be treated, report in the copper concentrate. It was therefore of possible economic interest to investigate the silver contents of samples of the copper mineral from various localities in this area.

From a geochemical point of view the data might reveal useful information regarding the areal distribution of the Ag and its relation to other minerals in the ore.

Samples of pure chalcopyrite were prepared and sent for spectrographic analysis at Sentralinstituttet.

The results are given in the following table. (Table 17).

Locality	*% Ag*	*Clarke of concentration**
Skaide Mine	0.0067	670
Birtavarre Høyfjell	0.0043	430
Moskogaissa 125	0.0028	280
DDHs, 1955	0.0026	260
Brattfjell Mine	0.0020	200
Moskogaissa 115 (drill core)	0.0011	110
Sabetjok Mine	0.0008	80
Moskogaissa 117	0.0004	40

* av. Ag content of earth's crust taken as 0.1 g/ton (0.00001 %) (Mason, 1951 p. 41).

Table 17. Silver contents of chalcopyrites from the Birtavarre ores.

The results do not show any satisfactory variation over the area. There is a little more correlation with mineralogy. Both the Skaide and the Moskogaissa 125 ores contain considerable amounts of sphalerite, and at Birtavarre Høyfjell the zinc mineral is definitely more abundant than at the localities listed lower in the table. Skaide also shows very minor quantities of galena, which is a well-known concentrator of silver.

Pure samples of sphalerite from Skaide and Moskogaissa 125 showed silver contents less than or equal to 0.0005 % in each case. Thus the silver is concentrated very definitely in the copper mineral. This is in perfect agreement with the order found by Goldschmidt (1954, p. 194). He classified the host minerals of silver in sequence of increasing effectiveness as

sphalerite, chalcopyrite, galena.

Galena is so insubordinate in the Birtavarre area that it was not investigated.

The relation between the copper mineral in the ore and the silver content is also seen from the results of analyses of "bulk sulphides" from several localities. (Table 18). (The samples represent the total sulphide minerals in the ore after the removal of silicates and other non-sulphides.)

Locality.	*Cu %*	*Ag %*	*Cu/Ag ratio*
Birtavarre Høyfjell, 1	13.79	0.0016	8600 : 1
Birtavarre Høyfjell, 2	9.94	0.0018	5500 : 1
Sabetjok Mine	8.62	0.0008	10700 : 1
DDHs, 1955	7.30	0.0008	9100 : 1
DDHs, 1954 (Moskogaissa)	3.45	0.0007	4900 : 1

Table 18. Cu and Ag contents of some bulk sulphide concentrates from the Birtavarre ores.

The relation here is not strictly linear, but it is clear that the Ag increases with the Cu, and this must mean that it is present in the copper mineral.

Molybdenum. Following the detection of molybdenite in polished sections from the Moskogaissa drill cores, colorimetric determinations were made of Mo in various samples in the laboratory of NGU (Analyst: B. Bruun).

The results showed very small and variable quantities:

Copper concentrate, Moskogaissa drill cores	0.003 %
Pyrrhotite concentrate, Moskogaissa drill cores	0.0006 %
Flotation feed for above concentrates	0.0008 %
Random ore sample, drill hole M 6	0.003 %
—„— — M 8	0.003 %

The first three results show that, as would be expected, the molybdenite reports in the copper concentrate.

According to Mason (1951, p. 41), the average content ("clarke") of Mo in the earth's crust is 0.0015 %, so that even in the richest samples there is only a 2-fold increase over this, in spite of presence of free MoS_2. Rankama and Sahama (1950, p. 626) quote the figure of 20 g/ton (0.002 %) as the average content of Mo in magmatic sulphides. Molybdenum is usually to be found in connection with granitic rocks and the low contents in the Birtavarre sulphides are what would be expected in such a geological environment.

Selenium. This element was determined chemically in the laboratory of NGU (Analyst: E. Christensen).

In copper flotation concentrates the following values were obtained:

Moskogaissa 115	ca. 50 g/ton	(Cu 14.77 %)
Skaide	100 g/ton	(Cu 20.35 %)

In specially cleaned samples of the ore-sulphides from various localities, the following values were obtained. (Table 19). (Because of the low concentrations involved the last figures have no real significance; the figures are quoted to show the order of the selenium contents).

Locality.	*Se %*	*Cu %*	*S %*
Birtavarre Høyfjell	0.0013	13.79	35.09
— —	0.0007	9.94	35.72
Sabetjok Mine	0.0008	8.62	35.45
1955 drill cores	0.0011	7.30	33.46
1954 drill cores	0.0014	3.45	35.95

Table 19. Selenium contents of some bulk sulphides from the Birtavarre ores.

These figures do not reveal any conclusive variations of the selenium content with either the Cu or S values. The radii of S^{2-} (1.74 Å) and Se^{2-} (1.91 Å) are alike and Se replaces S diadochically in sulphide minerals of high temperature origin, this replacement occurring more rapidly at elevated temperatures than at low ones (Rankama and Sahama, 1950, p. 746). The Se is undoubtedly substituting for S in the sulphide lattices.

C. W. Carstens (1941) quotes many figures for the selenium contents and sulphur: selenium ratios of ores and concentrates from Norwegian sulphide deposits. In ores the S : Se ratio varies from 42 000 : 1 for copper-poor samples to 1800 : 1 for copper-rich ones. The figures for the concentrates indicate that the selenium follows with the chalcopyrite, the figures of 93—182 g/ton quoted being of the same order as in the Birtavarre samples. However, the present work cannot be taken as supporting Carstens' conclusions that selenium varies sympathetically with copper content.

Carstens also shows that the Se content may be used to distinguish sedimentary sulphides from epigenetic ones, the former having next to no Se. The presence of Se in the epigenetic Birtavarre ores can be taken as supporting this.

Trace elements in sphalerite. Cadmium occurs in the sphalerite of the Birtavarre ores, and spectrographic determinations of the element were carried out on pure samples of the mineral from one or two localities in the area. In addition a sample from the Sulitjelma area was analysed for purposes of comparison.

Locality.	*% Cd*
Skaide Mine	0.12
Moskogaissa 125	0.16
Moskodal Mine	0.20
Jakobsbakken, Sulitjelma	0.19

The content is fairly even for the samples investigated and agrees well with the figure of 0.20 % given by I. Oftedal (1940) as the average for "high hydrothermal" sphalerites from the Norwegian Caledonides, and 0.25 % for "low hydrothermal" sphalerites from the same province. Oftedal's results indicate that more Cd occurs in sphalerites formed at medium and low temperature than in those formed at high temperatures. However, Fryklund and Fletcher (1956) after quantitative analysis of 59 samples of sphalerite from the Coeur d'Alene district, Idaho concluded that temperature has had no influence on the distribution of the minor elements, except Mn. In particular Cd shows no correlation whatsoever with the iron content of the sphalerites (and hence with the temperature of formation, following Kullerud's results). The authors believe the Cd content of the zinc mineral to be dependent on that in the original ore-forming solutions and that each major metallogenetic area shows a characteristic Cd content in the sphalerites of the ores. A table is given showing the average Cd contents of sphalerites from various ore-districts. For example the Swedish Skelleftefelt ores show an average of 0.14 % Cd in sphalerite (Gabrielson); the Precambrian of Southern Norway 0.50 % Cd (Oftedal), etc.

The present writer has re-examined the available data for the Norwegian Caledonian pyritic and copper-sulphide bodies, sources being the present work, Kullerud (1953) and Oftedal (1940). This has shown no correlation at all with iron content and hence with temperature, and an average of 0.19 % Cd, (25 determinations), which is under one half of that obtained from Oftedal's data for the southern Norwegian Precambrian.

These results are therefore in full agreement with the conclusions of Fryklund and Fletcher.

Manganese. During the analyses of the samples of pure sphalerite for temperature-estimation purposes it was necessary to determine the manganese-sulphide contents. These are given below, together with the relevant iron-sulphide contents.

Locality.	*Wt % MnS*	*Wt % FeS*
Skaide Mine	0.37	13.63
Moskogaissa 125	0.02	9.99
Moskodal	0.04	15.18
Jakobsbakken, Sulitjelma	0.24	12.70

Sphalerite is known to be the only natural sulphide mineral into which manganese enters freely and the element is commonly found in this mineral (Goldschmidt 1954, p. 632). The factors facilitating this entry are the close ionic radii of the elements concerned, Mn^{2+} 0.91 Å, Zn^{2+} 0.83 Å, Fe^{2+} 0.83 Å. The pink modifications of MnS also show similar structures to ZnS and CdS and can thus form mixed crystals with both these compounds.

The MnS values given in the above table show no correlation with either FeS or Cd values, nor with the determined temperatures of formation of the sphalerites. No geological explanation can be advanced for the very variable manganese contents.

A plot of Mn content against Fe content for 25 sphalerites from Norwegian Caledonian sulphide deposits (see above under Cadmium) showed a very imperfect proportional variation. This may be taken as indicating a general increase of the Mn contents of these sphalerites with increasing temperature of deposition. Fryklund and Fletcher (1956) noted the same tendency with the sphalerites they investigated.

Metasomatic alteration along the ore-zones.

General statement.

The schists along many of the sulphide horizons have been affected by chemical and mineralogical changes which have given rise to very distinctive rock types. The stratigraphical thicknesses of altered rock vary considerably, from a few centimetres to a maximum of perhaps 20 metres. The evidence suggests that these zones of alteration follow stratigraphical horizons in the schists. Any one sulphide band keeps roughly within the zone of altered rock, but may occupy, at different places, a position on its hanging- or footwall, or in the middle.

Two types of alteration seem to be involved:

a) an early, pre-ore, metasomatism of the schists to form rocks very rich in anthophyllite with minor amounts of cummingtonite and staurolite.

b) a chloritization of the earlier-formed metasomatic rocks producing quantitatively minor, but at times very distinctive, rock types.

Garnet is a major mineralogical constituent of nearly all the altered rocks, but the age of its formation relative to the other minerals is a little puzzling, (see below).

The rock-types produced by the metasomatism include anthopyllite, garnet-anthophyllite, garnet-anthophyllite-staurolite and garnet-chlorite schists. They have been referred to previously by various terms, including metasomatic rocks, altered rocks, etc. There seems to be no one definite term to apply to them, such, as for example, the word *skarn*, used for the products of metasomatism of limestone.

Distribution.

The anthophyllite and garnet-anthophyllite types are quite sharply limited to horizons west of Kåfjorddalen.

The most spectacular development of the rocks occurs along the main ore-horizon at Moskogaissa, reaching a maximum thickness of about 15—20 metres at Moskogaissa 111. The lower sulphide horizons west of Kåfjorddalen show less strongly developed metasomatic zones, eg. Moskogaissa 120, and Monte Carlo, while thin bands occur above the sulphides in the Skardalen mines and at Brennfjell in Skibotndal. East of Kåfjorddalen there is a very marked lack of these types. Sparse garnets are developed in places at Sabetjok mine and in the ore-horizon east of it, but the main alteration is a chloritic one. Skaide mine shows very little alteration at all in the wall rocks exposed to investigation.

Thus it seems that the metasomatic alteration reached a maximum in the Moskogaissa area and then faded away to the east, so that the area east of Kåfjorddalen does not show its total effects.

The anthophyllite-bearing rocks.

Most information concerning these rocks has been obtained from specimens from Moskogaissa 111 mine and from the drill-cores obtained during the 1954 drilling near Moskogaissa 115. The specimens investigated from these localities covered all the types seen there and at other places in the area.

At Moskogaissa 111 these rocks form a compact unit overlying the sulphide-zone and forming the top of a small hill lying beneath the cliffs of Store Moskogaissa. In field appearance they are massive, almost igneous-looking and very well-jointed. In detail they show considerable mineralogical and textural variations. They are composed chiefly of the following minerals, in order of abundance; anthophyllite, garnet, quartz, staurolite, a little plagioclase, some secondary chlorite, and rutile as an accessory. The variations are expressed in the form of banding within the rock, various bands being determined by the relative proportions of the various minerals and by the grain size. The bands themselves vary in thickness from a few centimetres to one or two metres and there does not seem to be any regularity or order in the variations either of thickness, grain size or mineral composition.

The most abundant type is a fine- to medium-grained rock consisting essentially of quartz, garnet and some amphibole. Staurolite may or may not be present. In this type the quartz forms an allotriomorphic mosaic as the groundmass to the rock, with a grain size varying between 0.1 and 0.5 mm. It may also be present as veinlets 1—2 mm wide cutting through the other minerals. The quartz in these veinlets is much more coarse-grained than in the rest of the rock and shows remarkable sutured boundaries and strain shadows. The garnets are thickly scattered throughout the rock as subhedral to euhedral crystals, average diameter 0.5—1 mm. This grain size may vary in different examples of the rock, producing a banding on a larger or smaller scale. All the garnets show a striking poikilitic texture with small grains of quartz, and often the crystal outlines of the garnet are indented by the partial inclusion of other grains of quartz. This evidence indicates very strongly that the garnets have developed poikiloblastically in the quartz groundmass, enveloping and perhaps partly replacing the quartz in the process.

The proportion of anthophyllite varies considerably in this type of rock. In the most quartzose types it is present sparingly as fibrous needles up to 1 mm long and as less regular wisps and shreds set in the quartz between the garnet grains. The larger needles always show a directed texture, which may vary between complete lineation and planar schistosity. Amphibole needles with inclined extinction, up to 20°, occur sparsely along with the anthophyllite in some parts of the rock. These are most probably cummingtonite (see later).

Transition to less quartzose types takes place by increase in the amphibole content and the appearance, at times, of staurolite. Along the face of the open-cut at Moskogaissa 111 such rocks show fine banding into anthophyllite-rich and garnet-rich bands. Anthophyllite crystals with lengths up to 10 mm show marked linear orientation. The garnets show diameters of the order of 1—2 mm, but occasionally reach over 10 mm, especially in the amphibole-rich bands.

In thin section the garnets show anhedral to subhedral outlines. In the garnet-rich bands they are usually in contact and appear to have mutually interfered with each other's growth. They exhibit the usual poikiloblastic or "sieve" texture, enclosing small grains of quartz, needles of amphibole and rounded opaques. The garnet appears to have developed later than the anthophyllite and has partly replaced or absorbed crystals of the latter.

The anthophyllite occurs in irregular, elongated, and often fibrous crystals developing the greatest dimensions in the garnet-free bands.

Staurolite is subordinate as subhedral crystals showing a typical sieve texture.

Chlorite occurs as tabular flakes up to 0.3 mm long oriented in all directions together with the amphibole interstitial to the garnet.

Garnet-free types of the alteration rocks usually consist of anthophyllite, staurolite and quartz with a little rutile as accessory. Though minor in amount they are very striking in appearance. Hand specimens show an interlocking mesh of coarse anthophyllite crystals, up to 2 or 3 cm long, often showing a radiating or "rosette" structure. Staurolite is often quite abundant as red-brown grains or groups of grains. Interstitial to the amphiboles or segregated in patches is much clear "sugary" quartz.

In thin section the quartz appears as an anhedral mosaic with a grain size of 0.2—0.4 mm forming the groundmass of the rock. Anthophyllite occurs in elongated often fibrous, colourless crystals. It appears as parallel aggregates, radiating clusters or as isolated crystals. In quartz-poor bands the amphibole forms a completely interlocking mesh.

Staurolite is fairly abundant as very irregular plates and clusters of grains showing marked poikilitic texture with quartz. A minor mineral showing roughly the same habit as the staurolite was tentatively identified as kyanite.

Plagioclase is a very minor constituent of the metasomatic rocks at Moskogaissa 111, and is confined to the more quartz-rich types. Measurements of maximum extinction angles indicate a low to middle andesinic composition.

The cores from the diamond-drilling operations in 1954 gave very good sections through the altered rocks accompanying the ore-zone at Moskogaissa 115. They revealed thicknesses varying from 5 to 15 metres of anthophyllite and garnet-anthophyllite rocks. The alteration occurred in bands parallel to the schistosity and bedding of the wall-rocks. The hanging-wall of the alteration was marked by the appearance of a light-grey amphibole-quartz-plagioclase-schist very similar in appearance and mineralogy to the normal hornblende-quartz-plagioclase wall-rocks, except for the presence of light grey amphibole instead of common green hornblende. Bands of the normal wall-rock schist occurred with decreasing frequency downwards in the altered zone, but after some metres the schists were completely altered to anthophyllite-bearing types. Bands of almost pure anthophyllite often appeared, usually having a very sheared and minutely crenulated appearance as though they had been subjected to movement after their formation. The most intensely altered part of the zone was reached by the appearance of abundant garnets giving garnet-anthophyllite and garnet-quartz rocks of the type described from Moskogaissa 111.

Normally the altered zone seemed to stop abruptly beneath these garnet-rich types. The foot-wall part of it did not show less altered amphibole-rich schists corresponding to those in the upper part.

Occasionally thin bands of meta-igneous amphibolite occurred in the altered zone. These showed no mineralogical effects at all, and an analysis of one of them (see p. 59) from DDH M8 indicates there has been very little chemical effect on these rocks by the processes responsible for the metasomatism. This is a feature noted from all parts of the area, that where amphibolites occur in the mineralized zone they have not been affected by the process of metasomatism which has so completely altered the surrounding schists.

Although, from a descriptive point of view, the types of altered rocks from the drill cores resemble those from Moskogaissa 111, microscopic work has revealed one or two features which seem to be of importance for the understanding of the chemical and mineralogical processes in the alteration zone.

The amphiboles. The normal amphibole of the alteration zone is an orthorhombic one, and may be termed an alumian anthophyllite (see below, p. 159). However, towards the top of the zone, a colourless amphibole with acicular habit, but having an inclined extinction up to — 20° is fairly common. Some bands near the top of the zone contain this amphibole alone. In other bands both orthorhombic and monoclinic amphiboles are present, often in homoaxial intergrowth with each other in the same crystal. Such a crystal is composed of three lamellae, the middle one showing inclined extinction, while the two outer ones show parallel extinction. This phenomenon has been noted and described previously, for example, by Eskola (1914) in his great work on the petrology of the Orijärvi region in S.W. Finland (p. 183). He concluded that the monoclinic amphibole was chemically identical with the anthophyllite and identified it as *cummingtonite,* which name can safely be applied to the monoclinic amphibole from the Moskogaissa drill cores.

The presence of the monoclinic amphibole near the top of the alteration zone leads to a suggestion regarding the transition from the normal hornblende-bearing schists to those carrying the colourless amphiboles. As has been mentioned, the latter, to begin with, are almost identical with the former except as regards the amphibole mineral. No instance has been observed in thin section of hornblende altering to colourless amphibole, but it seems clear that this is what must have occurred. There must first have been a rearrangement of the ferromagnesian mineral and it is suggested that the transition took place thus:

common hornblende — monoclinic amphibole — orthorhombic amphibole.

This process would involve the expulsion of Ca from the hornblende and the loss of Ca is one of the most marked chemical changes during the metasomatism (see below, p. 163).

The feldspars. It was shown in the section on the petrology of the wall-rock schists that the plagioclase has a composition varying around An_{40}, which is near the value given by Padget for the average Ankerlia schist. In addition there occurred large quantities of much more albitic feldspar, mainly as rims round the other grains. Thin sections taken at intervals down the cores from some of the drill holes show that the anorthite content of the plagioclase falls even further as the metasomatism becomes more intense. The average value in the zone of greatest alteration appears to be about An_{30}. At the same time the quantity of feldspar greatly diminishes, so that although it does become more sodic, the rock as a whole has very little Na_2O as compared with the schists above. CaO and Na_2O are lost and the Al_2O_3 from the feldspars seems to be incorporated in the alumian anthophyllite and the garnet. Chemical evidence is given below to indicate that the Na_2O migrates into the immediate hanging-wall rocks and is responsible for the large amount of albitic feldspar found there.

The garnets. The main point as regards this mineral is that it everywhere shows porphyroblastic relations to the other minerals, even to the amphiboles. It is certainly the latest mineral to have acquired the form in which it is found to day. Evidence will be shown below that a lot of garnet is later even than the chlorite which seems to have resulted in part from alteration of the amphiboles.

Thus the striking garnet-anthophyllite alteration rocks do not seem to be the result of a single recrystallisation following the metasomatic change. The amphibole crystallised first and at a later date the garnet formed porphyroblastically. The difficulty is to decide whether there have been two metasomatic changes, or whether the formation of the garnet involved only a recrystallisation under changed conditions of pressure and temperature.

Relation to the sulphides. The alteration rocks were clearly formed before the introduction of the sulphides. This is shown by fragments of these rocks which are included in the sulphide ores, and by veinlets of sulphide which occupy cracks within individual crystals of amphibole and garnet. There is also the fact that the sulphide band(s) may occur anywhere within the altered zone and not necessarily have the most intensely altered rocks adjacent to it (them). The breccias and shears which received the sulphide mineralization opened up in the metasomatic zone, but varied in the vertical plane within this zone from place to place along it.

The chloritic alteration.

Nearly every thin section of the metasomatic rocks showed more or less chlorite as a minor constituent, but in places this mineral forms a major component and gives rise to some very striking rock types.

In the "normal" metasomatic rocks chlorite occurs in variable amounts as flakes, tabular crystals and shreds along with the anthophyllite. Many instances were seen of the chlorite appearing within aggregates of amphibole in a manner strongly suggesting it had formed by replacement.

In specimens from the drill-cores (1954) several instances were observed where the anthophyllite schist had been severely crushed and sheared after its formation. Very few individual crystals remained whole, they had been crushed down into wisps or shreds and thrown into irregular waves or folds. Chlorite had developed extensively in the crushed anthophyllite as large undeformed flakes, especially in the cores of the folds. At other places the chlorite had apparently filled in open shears in the rock and occurred as more irregular flakes or shreds.

Where chlorite formed a large proportion of the rock it often appeared in forms which suggested pseudomorphs after the anthophyllite. When, in the same thin section, ragged remnants of the latter occurred with wide rims of chlorite, the evidence seemed quite conclusive that the latter mineral had formed by replacement.

Many instances were seen of this method of formation of the chlorite but at times it also crystallised as an independent mineral. This was chiefly in quite thin quartz veinlets which cut clearly through the metasomatic schist and were of a definitely late origin. The ultimate source of the chlorite may have been the alteration of anthophyllite, but if so, it had been transported in solution for some short distance and re-deposited along with quartz in straight-walled cracks. The chlorite in this instance occurred as small, roughly circular, radiating rosettes set at random within the crystalline quartz.

In a general way it can be said that the chlorite replacement is more abundant in areas of irregular sulphide replacement in the rocks, in a way suggesting that the chloritization was connected with the emplacement of the sulphides. However, the evidence seems to suggest that the main part of the chloritization was earlier than the sulphides.

The rocks in which chlorite forms a major constituent are very striking garnet-chlorite schists which usually occur in concordant bands up to 30 cm thick within the metasomatic rock of the mineralized zones. Notable examples can be seen at Moskogaissa 111, Moskogaissa 117 and Monte Carlo mine.

The schist consists of euhedral garnets from 2 to 5 cms in diameter, set in a matrix consisting of large, lustrous foliae of chlorite. The garnets are present in great numbers and show excellently developed crystal faces (rhombic dodecahedron (110)). The garnets are very impure and have enclosed shreds of chlorite, fragments of amphibole as well as many rounded opaque inclusions Small irregular patches of sulphides are located along cracks in the mineral and appear to have been introduced at a later date.

Another type of garnet-chlorite schist with garnets roughly the size of peas is common at places along the open-cut faces at Moskogaissa 111, and occurs occasionally at the other Moskogaissa mines and at Monte Carlo. Again the garnets show almost perfect crystal outlines against the chloritic matrix.

The garnets in the above cases would therefore appear to have crystallised porphyroblastically as the latest mineral in these schists. The occurrence of the latter as concordant bands within the other metasomatic rocks suggests they represent zones of somewhat greater stress and probably greater chemical activity along which there occurred a) intense chloritization and b) porphyroblastic development of garnet, either due to the rearrangement of existing elements or with the help of new elements circulating along these zones of stress.

It was mentioned above that east of Kåfjorddalen the metasomatism along the ore-zone had been restricted to chloritization. Occasionally euhedral garnets were observed to have developed in sheared chlorite-biotite schists, but no anthophyllite has been identified from this area.

In the Sabetjok—Birtavarre Høyfjell area the altered rocks along the sulphide zone are dark green or nearly black chlorite and biotite-chlorite schists. The thickness of the altered zone is not very great and probably does not exceed 3 to 4 metres.

At Skaide mine the exposures are poor and no drill cores are available, but the chemical alteration here seems to have been very weak. The only evidence of anything of this sort is very sheared-out bands of biotite schist with small amounts of chlorite in parts.

The areal distribution of the metasomatic rocks is a striking feature of the geology and shows a decreasing intensity of alteration eastwards across the mining field.

Mineralogy.

In the course of the work on the metasomatic rocks the two main minerals, anthophyllite and garnet were investigated rather thoroughly, especially as regards their chemistry. The results are given below.

Anthophyllite.

In order to determine the position of the Moskogaissa orthorhombic amphibole within the anthophyllite series a specimen of powder was separated and analysed. The rock chosen for the separation was a coarse-grained anthophyllite-quartz rock from the westerly trench at Moskogaissa 117. Megascopically, the rock consisted of 'blades' and acicular crystals of anthophyllite up to 4 cm long, with a rough orientation parallel to the general schistosity. In places it occurred in semi-radiating aggregates or "rosettes". In between the amphibole needles occurred a fine-grained "sugary" aggregate of quartz (and feldspar). The rock was chosen for separation since it seemed to contain a minimum of heavy minerals other than the amphibole. Two thin sections of the piece used in separation confirmed the dominance of the above-named minerals. Other minerals occurring in accessory amounts as small grains were rutile, apatite, biotite and garnet. Chlorite occurred sparsely as flakes and aggregates in the amphibole aggregates, apparently resulting from a secondary alteration of the anthophyllite. No monoclinic amphibole was observed.

The specimen was crushed, sieved and separated in Clerici solution and acetylene tetrabromide. The intermediate fraction was run through a Franz isodynamic separator until microscopic examination showed it to be sensibly free from impurities.

The results of the analysis and the calculation from it are given in Table 20 below.

Table 20.
Anthophyllite, Moskogaissa 117.
Analyst: E. Christensen, NGU laboratory.

	Wt %	Equivalent molec. pptns	Subtract apatite	Cation %	Recalculated on basis $(O,OH,F)_{24}$
SiO_2	45.06	751		41.9	6.33
TiO_2	0.63	8		0.4	0.06
Al_2O_3	16.98	334		18.1	2.81
Fe_2O_3	0.81	10		0.5	0.07
FeO	16.71	232		12.9	1.95
MnO	0.08	1		0.1	0.01
MgO	15.80	395		22.0	3.32
CaO	0.49	9	3	0.3	0.04
Na_2O	1.76	56		3.1	0.47
K_2O	0.05	1		0.1	0.01
H_2O-	0.06	—		—	
H_2O+	1.42	(158)		(8.8)	(1.33)
P_2O_5	0.14	1	1	—	
	99.99				

Anions OH 8.8
O 150.1
Sum 158.9

$$\frac{24}{158.9} = .151$$

The chemistry of the anthophyllite series has been discussed in great detail by Rabbitt (1948). He examined the chemical composition of 96 varieties of the amphibole rejecting those which he showed to be unsatisfactory for various reasons. From the 96 he chose 46 as "Selected Modern Analyses" which fullfilled certain criteria he considered necessary. It is pleasing to see that the present analysis fullfills these criteria.

1. It is a modern analysis.
2. Summation is within 100 % ± 0.5 %
3. In the calculation of the formula (see below) on the basis of 24 (O,OH,F) and 8 (Si, Al) atoms, the summation of

(Ca, Na, K, $Fe^{\cdot\cdot}$, $Fe^{\cdot\cdot\cdot}$, Mg, Mn, Ti, Al) must be 7 ± 0.5 (actually 7.07).

4. There are no unreasonable amounts of any of the elements.

From Table 20 we may write the formula for the mineral in the form used by Rabbit, thus:

Ca	Na	K	Mg	$Fe^{\cdot\cdot}$	$Fe^{\cdot\cdot\cdot}$	Mn	Ti	Al	*Total*	Al	Si	*Total*	OH	O
0.04	0.47	0.01	3.32	1.95	0.07	0.01	0.06	1.14	7.07	1.67	6.33	8.00	1.33	22.67

The ratio of Al replacing Si to Al replacing Mg, Fe, etc., which should theoretically be 1, is 1 : 1.46. It was shown there was F present in the anthophyllite, though the amount was not determined. This fluorine would come in the hydroxyl bracket.

Rabbit discusses the various oxides present in the anthophyllite series. The values obtained for the Moskogaissa anthophyllite fall well within the limits found for the series as a whole, except that Na_2O is a little higher than the maximum found in the previously analysed material (1.76 % against 1.34 %).

Chemical Field. Fig. 48 shows the analysis of the Moskogaissa anthophyllite (M) plotted on a triangular diagram. The analysis falls in the centre of the diagram where Rabbitt shows there to be a relative concentration of anthophyllite analyses. The figure also shows the outlines of the anthophyllite (A) and cummingtonite (B) fields. Unfortunately the cummingtonite seen in the thin sections from Moskogaissa was too intimately intergrown with anthophyllite for effective separation.

Variety of Anthophyllite. Rabbit concludes from his studies that "the name anthophyllite should be used for all members of the series" and that "Chemical suffixes .... can be used to indicate any variation in the composition if known". He proposes the termed *gedrite* should be dropped for aluminium-rich anthophyllites which should be called *alumian anthophyllite*. The present author therefore proposes to use this term as a specific description of the orthorhombic amphibole from Moskogaissa.

X-ray diagram. A powder-pattern diagram was taken of the analysed material in the X-ray laboratory of the Geologisk Museum, Oslo, which confirmed it as being anthophyllite.

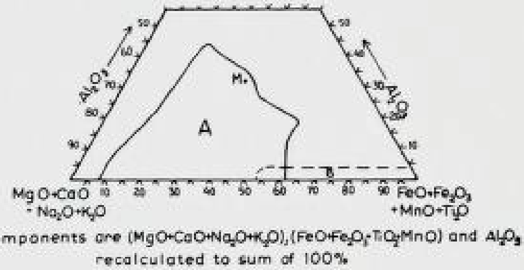


Fig. 48. The position of the Moskogiassa anthopyllite (M) in the chemical field of anthophyllite (A): B shows the cummingtonite field. (After Rabbitt, 1948.)

Trekant-diagram som illustrerer den kjemiske sammensetning av Moskogaissa antofyllitten. Antofyllitt-området (A) og cummingtonitt-området (B) etter Rabbitt, 1948.

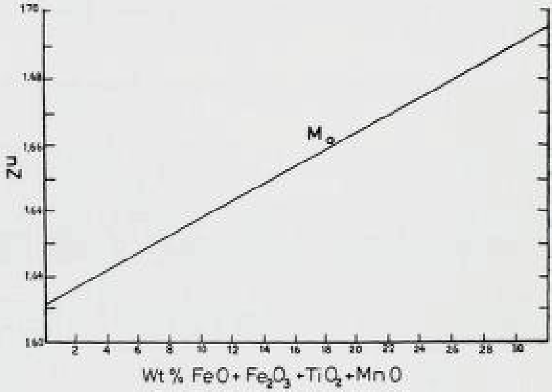


Fig. 49. The relationship between nZ and the total weight percent $FeO + Fe_2O_3 + TiO_2 + MnO$ for the Moskogaissa anthophyllite. (Diagram after Rabbitt, 1948.)

Relasjonen mellom nZ og vektprosent $\Sigma\ FeO + Fe_2O_3 + TiO_2 + MnO$ for Moskogaissa antofyllitt. (Diagram etter Rabbitt 1948.)

Optical properties. The Index of refraction nZ was measured on grains of the analysed powder by the ordinary immersion method. The value obtained was 1.661 ± 0.002. Rabbitt has plotted nZ for the 46 analysed specimens against the total weight percent $FeO + Fe_2O_3 + TiO_2 + MnO$. Fig. 49 shows the line obtained by him and the position of the Moskogaissa anthophyllite (M).

The diagram shows that the anthophyllite falls very close to the line. However, Rabbitt showed (p. 296) that the anthophyllites high in alumia tended to fall significantly above the line, whereas those low in this oxide fall near to it. In this respect the Moskogaissa material does not agree so closely with the general trends.

Birefringence was measured by Berek compensator in thin section. The highest value obtained was *0.019*.

The optic sign determined in thin sections of the Moskogaissa rocks was always positive. None of the Moskogaissa anthophyllite showed pleochroism.

Density. Density of the analysed powder measured by pycnometer was *3.16*. This density, when plotted against the weight percent total $FeO + Fe_2O_3 + Ti_2O + MnO$ (18.23 %) falls under the curve drawn by Rabbit from his data (1948, p. 300), but well within the limits of variations shown by the anthophyllites he investigated.

Garnet.

The garnet occurring as large euhedral porphyroblasts in the garnet-chlorite schist at Moskogaissa 111 was identified as almandine by means of an X-ray powder diagram early in the investigations. Later a fairly pure sample of the mineral (as powder) was prepared from a specimen of garnet-anthophyllite schist carrying garnets about 2—3 mm in diameter. This rock was chosen as the smaller garnets appeared much more free from inclusions than the large ones. The rock was crushed and sieved and the garnet sample prepared by help of heavy liquids and the Franz separator. The analysed powder was examined under the binocular microscope and appeared free from foreign grains. However, it undoubtedly contained contamination in the form of minute inclusions in the garnet grains.

The result of the analysis and the calculations from it are given in Table 21 below.

	Wt %	Equivalent molec. pptns.	Cation %	No. of O	Recalculated to 12 O
SiO_2	36.75	612	36.6	73.2	2.89
Al_2O_3	23.02	450	26.8	40.2	2.11
Fe_2O_3	5.27	66	3.8	5.7	0.30
FeO	26.35	367	21.9	21.9	1.73
MnO	0.62	8	0.5	0.5	0.04
MgO	4.73	118	7.0	7.0	0.55
CaO	3.17	57	3.4	3.4	0.27
Na_2O	0.01				
K_2O	0.04				
H_2O	0.03				
H_2O+	0.04				
	100.03		100.0	151.9	

Table 21.

Garnet, metasomatic schist, Moskogaissa 111.

Analyst: E. Christensen NGU laboratory.

$$\frac{12}{151.9} = .079$$

The formula of the mineral may then be written thus

$$Ca_{0.27}\ Mg_{0.55}\ Mn_{0.04}\ Fe^{\cdot\cdot}_{1.73}\ (Fe^{\cdot\cdot\cdot}_{0.30}\ Al_{2.11})\ (Si_{2.89}\ O_{12})$$

This would give the general formula

$$R^{\cdot\cdot}_{2.59}\ R^{\cdot\cdot\cdot}_{2.41}\ Si_{2.89}\ O_{12}$$

which, when compared with the accepted garnet formula, $R_3^{\cdot\cdot}\ R_2^{\cdot\cdot\cdot}$ Si_3O_{12}, shows chiefly an excess of three-valent ions over two-valent ones. This is probably due to an excess of ferric iron in the analysis. It is well known that it is hard to obtain the full value for ferrous iron in garnet analyses due to the difficulty of bringing all the mineral into solution for the determination. It may well be that some of the ferric iron in the above analysis should have been estimated as ferrous.

Recalculating to the standard garnet molecules we get:

			%
Almandine	$Fe_3Al_2Si_3O_{12}$	$Fe_{1.73}Al_{1.15}Si_{1.73}O_{6.92}$	66.8
Pyrope	$Mg_3Al_2Si_3O_{12}$	$Mg_{0.55}Al_{0.37}Si_{0.55}O_{2.20}$	21.2
Spessartite	$Mn_3Al_2Si_3O_{12}$	$Mn_{0.04}Al_{0.03}Si_{0.04}O_{0.16}$	1.6
Andradite	$Ca_3Fe_2Si_3O_{12}$	$Ca_{0.27}Fe_{0.18}Si_{0.27}O_{1.08}$	10.4
			100.0

This leaves as excess 0.12 $Fe^{\cdot\cdot\cdot}$, 0.38 Al, 0.40 Si, 1.64 O. If the $Fe^{\cdot\cdot\cdot}$ is reckoned as being $Fe^{\cdot\cdot}$ this would give more almandine molecule, thus:

$Fe_{0.11}Al_{0.07}Si_{0.11}O_{0.44}$, increasing the almandine content to 68.1 %. The other excess ions must then be reckoned as being due to impurities, possibly amphibole. The analysis and calculation show that the garnet in the metasomatic rocks at Moskogaissa is dominantly pyralspite (89.6 %).

The *specific gravity* of the analysed powder was determined by pycnometer as 4.10, and the *refractive index* as 1.797 ± 0.002.

The chemistry of the metasomatism.

It is clear from the above mineralogical description that the formation of the metasomatic rocks has involved considerable chemical changes. The presence of large amounts of anthophyllite and garnet point to a marked increase in magnesia and ferrous iron, while the decrease in the plagioclase content and the (clino)zoisite show that calcium has been removed. In order to determine these chemical changes more quantitatively a composite sample of garnet-anthophyllite rocks from Moskogaissa 111 was analysed. This is compared with the average Ankerlia Schist analysis, given by Padget, in Table 22 below.

	Ankerlia schist		Metasomatic rock	
	wt %	St. Cell	wt %	St. Cell
SiO_2	61.20	55.7	54.82	50.9
TiO_2	0.84	0.6	0.84	0.6
Al_2O_3	13.91	14.9	14.24	15.6
Fe_2O_3	1.54	1.0	1.80	1.2
FeO	4.05	3.1	15.47	12.0
MnO	0.09	—	0.07	—
MgO	4.47	6.1	10.35	14.4
CaO	9.78	9.5	0.66	0.7
Na_2O	1.88	3.3	0.65	1.2
K_2O	1.36	1.6	0.06	0.1
H_2O-	0.03	—	0.01	—
H_2O+	0.76	4.6	1.24	7.7
P_2O_5	0.20	0.1	0.16	0.1
	100.11	100.5	100.37	104.5

Table 22.

Average Ankerlia schist and metasomatic rock, Moskogaissa 111.

Analyst B. Bruun, NGU laboratory.

A quick study of the wt % columns in Table 22 shows the marked increase in FeO and MgO and the decrease in CaO and alkalies between the schist and the metasomatic rock.

A more precise notation of the changes is given by the calculated standard cells of the two rocks. These are based on the reasonable assumption that the change occurs at constant volume and that the total of O-atoms remains the same. Each standard cell is calculated on the basis of 160 O atoms (see Barth 1948).

To form the altered rock from the schist, the following chemical changes appear to have taken place.

Added	*Subtracted*
0.7 Al-ions	4.8 Si-ions
0.2 Fe···-ions	8.8 Ca-ions
8.9 Fe··-ions	2.1 Na-ions
8.3 Mg-ions	1.5 K-ions
Sum 18.1 metal ions	Sum 17.2 metal ions
+ 3.1 H-ions	(40.4 valences).
(40.2 valences).	

This summation shows the chemical changes to have been considerable, and to agree with those expected from the mineralogical evidence. The process is clearly one of "basification".

However, the two rock analyses above bear no close spatial relationship to each other, they are "average samples" (?) of the two rock-types supposed to have been involved.

More definite proof of the chemical changes was obtained by analysing samples from the diamond drill cores through the altered zones. First a sample each of wall-rock schist and metasomatic rock 1—2 metres from each other in DDH R1 (1954) was analysed (Table 23). These samples are from the lower mineralized horizon at Moskogaissa and show that the chemical changes are of the same

	1		2	
	wt %	St. Cell	wt %	St. Cell
SiO_2	59.41	54.7	61.63	56.4
TiO_2	0.88	0.6	0.87	0.6
Al_2O_3	14.78	16.0	12.85	13.8
Fe_2O_3	0.83	0.6	1.76	1.2
FeO	6.22	4.8	12.69	9.7
MnO	0.16	0.1	0.21	0.2
MgO	5.01	6.8	5.97	8.2
CaO	8.03	7.9	1.25	1.2
Na_2O	3.23	5.8	1.49	2.6
K_2O	0.62	0.7	0.27	0.3
H_2O-	—	—	0.05	—
H_2O+	0.51	3.0	0.69	4.2
P_2O_5	0.23	0.1	0.25	0.2
	99.91	100.4	99.98	98.6

Table 23.

1. Ankerlia Schist, DDH R1, 40.00 to 41.22 metres (see Table 3, p. 47).
2. Metasomatic rock, DDH R1, 42.31 to 43.04 metres.

Analyst E. Christensen, NGU laboratory.

type as in the upper horizon. The changes indicated by these analyses may be set out as follows

Added	*Subtracted*
1.7 Si-ions	2.2 Al-ions
0.6 Fe···-ions	6.7 Ca-ions
4.9 Fe··-ions	3.2 Na-ions
0.1 Mn-ions	0.4 K-ions
1.4 Mg-ions	
0.1 P-ions	
Sum 8.8 metal ions	Sum 12.5 metal ions
+ 1.2 H-ions	(23.6 valences).
(23.1 valences).	

The metasomatism along this lower zone has, therefore, been of the nature indicated by the two average analyses but the exchange of material was not so great as that indicated by these latter. The most marked increase was in Fe·· which used mainly in the formation of almandine. The increase in Mg is not so marked, but anthophyllite is not such an important constituent of the altered rocks in this lower zone.

The data from DDH R1 seem quite conclusive that the garnet-anthophyllite rock is due to a metasomatism of the wall-rock schist. The altered rock here is relatively thin (90 cms) and the transition from wall-rock schist quite abrupt.

In the diamond drill cores from the upper horizon at Moskogaissa greater thicknesses of metasomatic rock were encountered and these provided a chance to study the changes rather more closely. The drill hole chosen for the purpose was M8. This hole disclosed a vertical thickness of metasomatic rock of about 11 metres, with, in the bottom half, a continous band of sulphides 2.65 metres thick. Four samples were selected from the core, covering the different mineralogical types seen, from the apparently unaltered wall-rock schist to the most intensely metasomatized rock beneath the sulphide zone. From the analyses the standard cells were again calculated in order to study the changes quantitatively. The analyses and the standard cells for the four samples are shown in Table 24, below.

The more important cations in the standard cells have been plotted against depth in the drill-hole in Fig. 50. Also the figures obtained for the average Ankerlia schist and composite sample of

	1		2		3		4	
	wt %	St. Cell	wt %	St. Cell	wt %	St. Cell	wt %	St. Cell
Si_2O	60.38	55.6	57.22	52.9	61.55	56.0	57.72	54.0
Ti_2O	0.81	0.6	0.90	0.6	0.87	0.6	0.80	0.6
Al_2O_3	14.61	15.8	16.73	18.3	13.07	14.0	13.04	14.3
Fe_2O3	0.90	0.7	0.65	0.4	0.35	0.3	0.25	0.2
FeO	6.40	4.9	7.56	5.9	11.58	8.9	15.11	12.0
MnO	0.10		0.13		0.12		0.19	
MgO	4.79	6.6	5.67	7.9	5.53	7.5	8.90	12.5
CaO	5.80	5.7	4.06	4.0	1.98	2.0	1.24	1.3
Na_2O	4.61	8.1	5.97	10.6	3.62	6.4	1.27	2.2
K_2O	0.61	0.7	0.11	0.1	0.09	0.1	0.18	0.2
H_2O-	0.04	—	0.07	—	0.06	—	0.01	—
H_2O+	0.29	1.9	0.41	2.5	0.50	3.1	0.61	3.8
P_2O_5	0.21	0.1	0.28	0.2	0.24	0.2	0.22	0.1
	99.50	100.7	99.76	103.4	99.56	99.1	99.54	101.2

1. M8.S0, schist DDH M8, 95-96 m.
2. M8.S2, schist (slightly anthophyllite-bearing) DDH M8, 104.78 to 106.00 m.
3. M8.S3, anthophyllite schist, DDH M8, 108.25 to 108.60 m.
4. M8.S4, garnet-anthophyllite schist, DDH M8, 114.35 to 114.70 m.

Analyst: E. Christensen, NGU laboratory.

Table 24. Analyses of schists and altered rocks from DDH M8.

metasomatic rock from Moskogaissa 111 have been added to this figure.

The main curves of interest are those for Ca, Na and K, on the one hand, and $Fe^{\cdot\cdot}$ and Mg on the other. It can be clearly seen how these two sets of curves vary antipathetically with each other. This confirms again that the metasomatism has involved an addition of Fe and Mg and a removal of Na, Ca and K. The decrease in K seems certainly due to the breakdown of the biotite in the original schist, while Ca decreases with the disappearance of (clino)zoisite and the reduction of both the total amount of plagioclase and its anorthite content. Little evidence is available as to what becomes of these two elements, presumably they are removed to some distance from the zone. In the case of Na, however, the curve, together with mineralogical evidence presented previously, seems to suggest that this element is removed from the most intensely altered part of the zone, and is redeposited in the rocks a few metres above the most

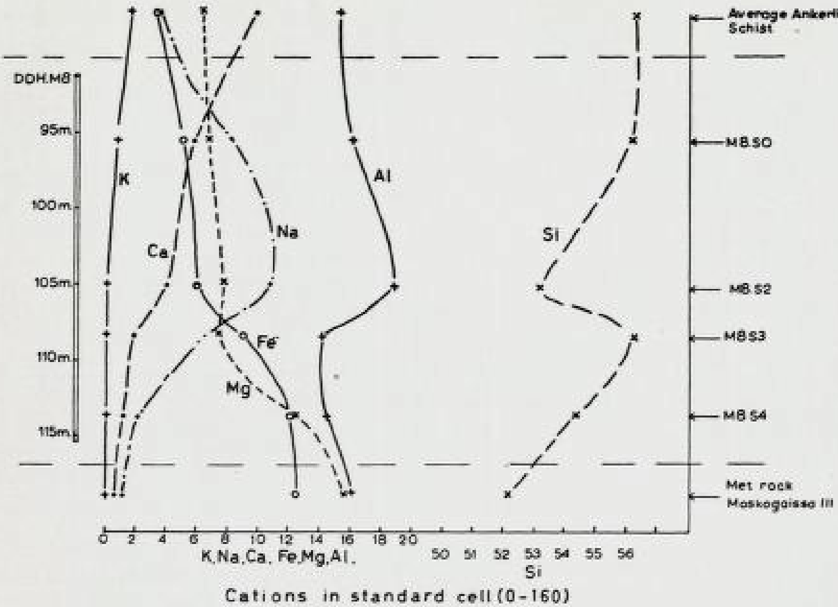


Fig. 50. Curves showing the variations in the cations of the standard cells (Barth 1948) of analysed rocks from DDH M8 (See Table 24). Also shown for comparison are the data for average Ankerlia schist and the metasomatic rock from Moskogaissa 111. (See Table 22).

Kurvene viser variasjonene i antall kationer i standardcellen (Barth 1948) for analyserte bergater fra borhull M8. (Se tabell 24.) Data for Ankerlia skifer og den metasomatiske bergart fra Moskogaissa 111 (Se tabell 22) er gitt til sammenligning.

intense part, as the albitic rims to the plagioclases (see p. 44). Thus in the rocks near the hanging-wall of the alteration zone there is a marked increase in Na_2O, as compared with the normal schists, due to the addition of this oxide which has been expelled during the formation of the garnet-anthophyllite rock.

The curves for Al and Si show little regularity. There seems to be a slight increase in Al in M8.S2, coincident with the higher Na value there. This possibly represents the Al combined in the albite. Si shows no decipherable variation, but this is to be expected since it is due to a large extent to the original (detrital) quartz present in the schists. It does show an expected, marked falling-off in the most highly altered rocks.

	1		
	wt %	St. Cell	2
SiO_2	53.54	49.2	56.0
TiO_2	0.94	0.7	0.7
Al_2O_3	15.92	17.2	15.5
Fe_2O_3	1.01	0.7	0.5
FeO	9.20	7.0	4.7
MnO	0.19	0.2	0.1
MgO	9.03	12.4	6.3
CaO	2.75	2.7	6.3
Na_2O	3.40	6.1	4.0
K_2O	1.40	1.7	3.2
H_2O-	0.12	—	—
H_2O+	2.24	13.7	2.6
P_2O_5	0.92	0.1	0.1
	99.96	111.7	99.9

Table 25.

1. Chloritized schists, composite sample from DDHs S5, S9, S12, and S13 (1955).
2. Average standard cell of wall-rock schists (see pp. 50-53).

Analyst E. Christensen, N.G.U laboratory.

In order to study the chlorite alteration in the ore-zone in the Sabetjok—Birtavarre Høyfjell area, a composite sample was made up of the most altered rocks from the cores from 4 of the drill holes. This analysis was compared with the average of the two analyses of the schists in the area (see pp. 50—53). The analysis of the altered rock, its standard cell, and the "average standard cell" of the schists are shown in Table 25.

The table shows the following chemical changes to have taken place

Added	*Subtracted*
1.7 Al-ions	6.8 Si-ions
0.2 Fe····-ions	3.6 Ca-ions
2.3 Fe···-ions	1.5 K-ions
6.1 Mg-ions	Sum 11.9 metal ions (39.5 valences).
0.1 Mn-ions	
2.1 Na-ions	
Sum 12.5 metal ions + 11.1 H-ions (39.5 valences).	

In this case the addition has been mainly one of Mg, reflected in the formation of chlorite. The smaller increases in Fe and Al would also be accounted for by the formation of this mineral.

One surprising item on the "added" side is Na, and this is not easy to account for. Plagioclase is not very noticeable in the altered rocks from the 1955 drill cores, but the increase in Na must be ascribed to a relative increase in the albite content of the rock as a whole.

On the "subtracted" side appeared Ca and K as expected, together with Si. The decrease of this latter element seems reflected in the change from hornblende (7 Si) to chlorite (2 Si).

The chemical evidence given above shows a very distinct type of metasomatic change from the hornblende- (and biotite-) bearing quartz-plagioclase-(clino)zoisite-schists to the anthophyllite- and garnet-anthophyllite rocks. In each case there has been an increase in the ferromagnesian elements at the expense of the silica and alkalies.

The petrographical work has shown that there must have been three stages in the formation of the rock types seen today.

a) The formation of anthophyllite-bearing schists from the hornblende-bearing schists of the Ankerlia series.
b) The chloritization of the rocks formed under a) and of hornblende and biotite schists, the latter especially in the Sabetjok—Birtavarre Høyfjell area.
c) The porphyroblastic development of garnets in large numbers in both the anthophyllite- and chlorite-bearing rocks.

The changes studied chemically above represent the sum total of these separate stages and it is not possible to sort each of them out.

Mode of formation.

Iron-magnesia metasomatism is a process already well-known in geological literature. Turner and Verhoogen (1951, p. 489) distinguish two principal types; a) the introduction of iron and magnesium into limestone, with crystallisation of calc-silicates rich in these metals, and b) the metasomatic development of noncalcic ferromagnesian minerals in silicate rocks and in quartzites.

We are concerned with the latter type in the present case. The classical examples of this kind of metasomatism occur in the Precambrian of Finland and Sweden, but a similar instance has been described from the Precambrian rocks of southern Norway.

Eskola (1914) ascribed the origin of the cordierite- and anthophyllite-bearing rocks in the aureole of the Orijärvi granite in S.W. Finland to the introduction of magnesium, iron and silicon from the granite. "The rocks .... owe their peculiar characters to pneumatolytic agencies which have caused considerable changes in their composition. These changes have, for the greatest part, consisted in the metasomatic replacement of lime, soda and potash by iron oxides and magnesia".

From a chemical point of view the metasomatism described by Eskola seems to be identical with that in the ore-zones at Birtavarre. However, the mineralogical changes involved seem to be different in the two areas, mainly due, it seems, to differences in the original rocks which were metasomatized. The leptites of the Orijärvi region, which seem to be the parent rocks involved in the metasomatism, are dominantly quartzo-feldspathic rocks with very small amounts of coloured minerals. The order of crystallisation of the metasomatic minerals, according to Eskola, has been firstly cordierite, by the action of magnesia on the plagioclase, then anthophyllite following further additions of magnesia and ferrous iron.

In Birtavarre the schists were already very rich in hornblende, and it has been suggested above that the first step was the conversion of this hornblende to, first cummingtonite, and then to anthophyllite, a process which involves the removal of lime, but which may not require further additions of MgO or FeO.

A process similar to this seems to have occurred in one instance at Orijärvi where the common hornblende of an amphibolite has been changed to cummingtonite by a process involving the replacement of the lime by magnesia and ferrous oxide. As stated above no metasomatic minerals have been observed in the amphibolites of the Birtavarre area. They seem to have been in some way "armoured" or protected against the iron-magnesia metasomatism which has so greatly affected the adjacent schists.

The Birtavarre region differs decidedly from that of Orijärvi in that there is no granite in view which could have given rise to the solutions which presumably carried the iron and magnesia. Thus the ultimate origin of the metasomatism must be sought from other sources (see below).

No accounts are to be found in the literature concerning similar metasomatism in the Norwegian Caledonides, but Bugge (1943) discusses the origin of corderite-anthophyllite-bearing rocks from the Precambrian Kongsberg—Bamble formation in southern Norway. This author opines that the rocks were formed after the amphibolitization of the region's gabbroid rocks and in many cases by the metasomatism of pre-existing rocks through the addition of magnesia. It is often possible to show the change common hornblende to gedrite (alumian anthophyllite), which was proposed above for the Birtavarre schists.

Bugge concludes that the magnesia has been derived from the gabbros and amphibolites by the leaching action of "disperse solutions" during the period of migmatization which occurred in the area he discusses.

The magnesia was then bound in the relatively acid rocks bordering the amphibolites in the form of the magnesia-rich mineral assemblage.

In the Birtavarre area no dependence on the border zones of the amphibolites can be obeserved. The upper ore-horizon at Moskogaissa occurs in a zone rich in layered amphibolites, but the rocks surrounding the lower horizon (Moskogaissa 120) are quite free from them. Also Monte Carlo mine shows none of these types, though there are very hornblende-rich schists at this place.

It seems that if we are to seek an origin for Fe- and Mg-bearing "solutions" it must be in the same direction as we look for the ore-bearing solutions, i. e., down the direction of plunge of the lineation and at deeper levels in the orogenic zone.

Elsewhere (pp. 179—185) in this report it is suggested that the ultimate origin of the sulphide ores of the Birtavarre region is to be sought in the processes of granitization occurring in the deeper levels of the Caledonian geosyncline. It is possible, following the ideas put forward in recent years by certain writers, eg. Reynolds (1947) to assign the origin of the Mg- and Fe-bearing "solutions" to the granitization processes too. These elements would be displaced from the rocks undergoing granitization and become fixed in a "basic front" in advance of the granitization. Access to the present area for these basic elements would be afforded by the shear- and thrust-zones along which the altered rocks occur.

Brøgger (1934) had suggested an alternative explanation for the cordierite-anthophyllite rock of the Kongsberg—Bamble formation, namely that the mineral assemblage was due to the metamorphic removal of calcium and alkalies from amphibolites, leaving them relatively enriched in Mg, Fe and Al.

Similar ideas have been more recently put forward as an alternative explanation for the cordierite- and anthophyllite-bearing rocks of the Orijärvi region by Tuominen and T. Mikkola (1950). These authors consider that under folding relatively thin clayey beds were subjected to strong penetrative movement, under which the rock gradually recrystallised into minerals with sheet structure. At the same time the elements in excess migrated, with a consequent enrichment of Mg and Fe in the residue. As the result of a later recrystallisation the rocks attained their present mineral composition.

In the Birtavarre region the metasomatic rocks are not related to fold-structures, but they do occur along zones of minor thrusting which have obviously been intensely sheared and thus presumably subjected to "strong penetrative movement". This movement could have provided the conditions necessary for metamorphic differentiation of the type postulated by Tuominen and T. Mikkola. Such a mode of genesis might explain why the amphibolites in the ore zone at Moskogaissa have not been affected by the metasomatism. Being more homogeneous, and more massive than the enclosing schists they would not be so affected by the shearing and any hydrothermal action accompanying it.

Metamorphic differentiation along zones of stress concentration has been advanced to explain the occurrence of ultrabasic rocks as bands in amphibolite at Tovqussac by Sørensen (1953). This author considers that "stress of high order in connection with chemically and mechanically generated heat is regarded to be the cause of the metamorphic differentiation that was responsible for the formation of the ultrabasic rocks". The chemical changes in the rocks investigated by Sørensen consisted of a great addition of Mg, together with reductions in Si, Al, Ca and alkalies. Total Fe remained unchanged. Sørensen's theory is possibly applicable to the metasomatized zones at Birtavarre. It has been shown above that Na, for example, has moved out into the wall rocks, which would seem to be a good example of the migration of elements to be expected in connection with metamorphic differentiation. It is less easy to prove a corresponding "inward migration" of Fe and Mg, but the surrounding schists are comparatively rich in these elements and could easily have been their source.

The derivation of the metasomatising elements locally would obviate the necessity of postulating their long-distance transport in the form of "disperse emanations" etc. On the other hand it would be difficult to explain the diminution of the intensity of metasomatism in the western part of the mining field on this basis. Obviously shearing occurred along the ore-zones in this part too, and one would expect it to have the same effect as regards metamorphic differentiation.

The author does not feel that the evidence is conclusive enough to enable a choice to be made between the two proposed methods of formation, i. e., addition of elements from some distant source on the one hand, and metamorphic differentiation on the other.

However, it does seem clear that the metasomatism and the emplacement of sulphides are the result of one continous series of processes acting along stratigraphically concordant zones in the schists of the Ankerlia Series. These zones have been zones of stress concentration produced by the action of couples due to the continued outward pressure from the geosyncline.

Along the zones of stress were initiated chemical and mineralogical changes. Existing elements would become re-arranged as a response to the rise in stress and temperature, and micro-openings along grain-boundaries and crystal cleavages would facilitate the ingress of fluids which possibly carried new elements into the zone.

At some point after the formation of the anthophyllite-bearing schists the breaking limit of the rocks was exceeded and failure occurred by shearing and gliding. The newly formed anthophyllite was in part crushed and folded on a small scale and was in places subjected to the action of hydrothermal fluids circulating in the rocks, giving rise to the formation of chlorite. Along certain zones of apperently intensified shearing, lustrous chlorite schist was developed. The actual point at which garnet started to develop in the rocks is not clear. It is all later than the anthophyllite and much is later than the chlorite. We may consider that garnet probably started to develop during the process of shearing which was initiated by the mechanical failure of the rocks and that it continued to develop in favourable layers until just before the introduction of the sulphides.

The continuation of stress, together, apparently, with lowered rock temperature, next caused the rock to fail in a more brittle manner, producing the breccias and more open shears which acted as channel-ways and host-structures for the sulphides. Some evidence suggests that a slight chloritization accompanied the sulphides, but on the whole it is clear that the processes of metasomatism were completed before the metallization took place.

The origin of the ores.

Regional Setting.

The sulphide deposits of the Birtavarre district must be seen in their relation to the Caledonian orogenic belt of Norway as a whole. This belt, which stretches from the vicinity of Haugesund in the SW, to Troms in the NE, constitutes a classical example of a metallogenetic province. Since the deposits contained in it are all, as far as present knowledge goes, of Caledonian age, we can speak of a corresponding metallogenetic epoch, during which ores of similar chemical composition were emplaced along a fold-mountain region some 1500 kms long. Fig. 51 shows the locations of the main mineral districts in relation to the folded metamorphic rocks of the orogenic belt. (After Foslie, 1926.)

This metallogenetic province is characterized ores consisting dominantly of S, Fe, Cu and to a much lesser extent Zn. Other metals are entirely subordinate. In spite of this relatively simple chemistry, there occurs quite a variety of ore-types, dependent on the minerals present, their relative proportions and the form and attitude of the ore-bodies. Theories regarding the origin of the sulphide deposits within the Norwegian Caledonian orogenic belt have varied considerably with the passing of time. They have been excellently summarized (in Norwegian) by C. W. Carstens (1944.) Originally a sedimentary origin was held for all the deposits, till the 1870s when Kjerulf came forward with the idea that the sulphide deposits of the Trondheim area derived directly from the eruptive rocks there. The greatest of Norwegian ore-geologists, J. H. L. Vogt, was originally an exponent of the sedimentary theory of origin, until in 1894 he published his work "Über die Kieslagerstätten von Typus Røros, Vigsnäs, Sulitjelma in Norwegen und Rammelsberg in Deutschland". In this work Vogt went over to an eruptive (or epigenetic) theory of origin. A little later Brøgger (1901) described

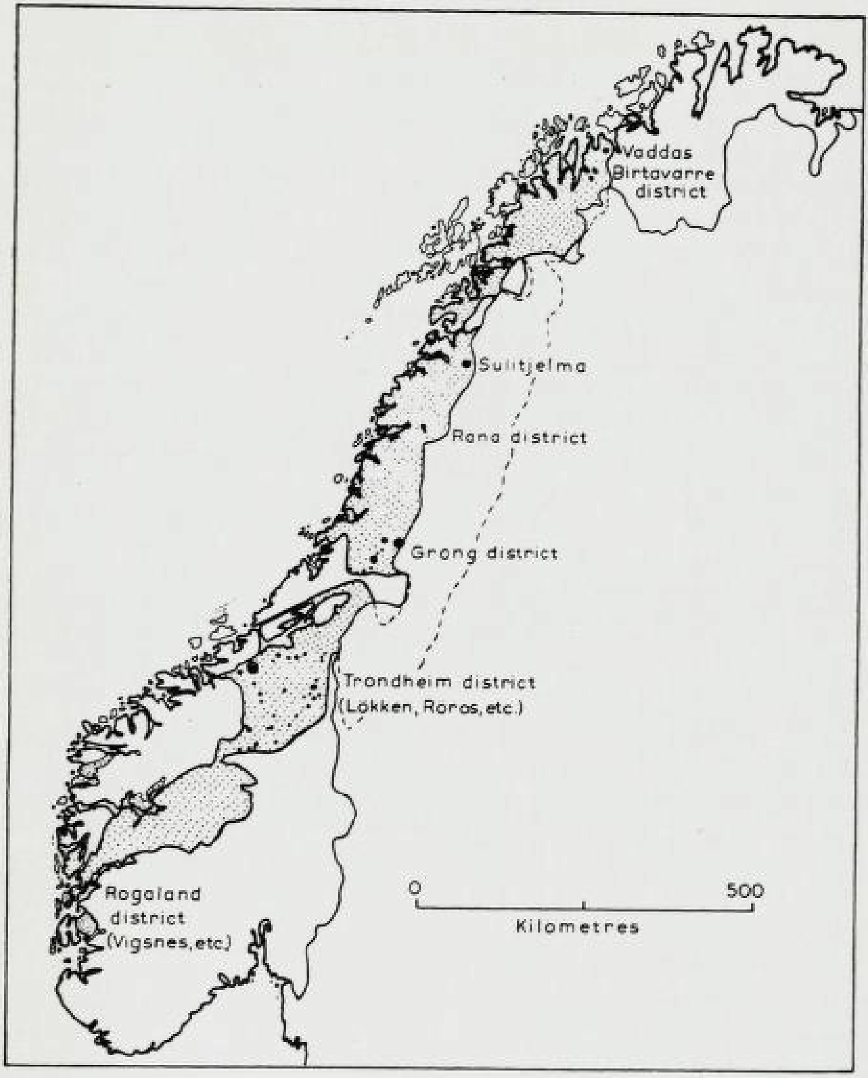


Fig. 51. Map showing the location of the main Norwegian sulphide deposits of Caledonian age. Metamorphic schists of presumedly Cambro-Silurian age are shown stippled. After Foslie (1926). The eastern front of the Caledonides in Sweden is shown dashed.

Kart som viser beliggenheten av de viktigere norske kisforekomster av kaledonsk alder. Prikkete områder viser metamorfe skifre av sannsynlig kambro-silurisk alder. Den stiplete linje viser Kaledonidenes østgrense i Sverige.

the ore of Charlotta Mine at Sulitjelma as being "a magmatic injection".

Up to about 1920 the whole of the deposits had been considered either as sedimentary or as magmatic, the possible presence of both types had apparently not entered into the picture. In 1919 Carstens showed that there existed a quantitatively minor type of deposit which was undoubtedly sedimentary and to this he gave the name *Leksdal type*. Thus in recent years Norwegian geologists have recognized two main groups of Caledonian sulphide deposits, the minor sedimentary type and the major epigenetic type, connected to eruptive rocks.

The question of the origin of the epigenetic type has been the subject of much discussion, and this discussion has ranged not only over the Norwegian deposits, but over similar sulphide deposits abroad, e. g. Rio Tinto, Japan, Tasmania etc. In Norwegian literature the weight of opinion was for a long time heavily in favour of a direct magmatic derivation, the injection of a sulphide "magma" formed by processes of magmatic differentiation.

Meanwhile geologists abroad had come more and more to regard apparently similar deposits as being formed by metasomatism of the country-rocks by hydrothermal agencies. In his 1944 publication Carstens comes out very strongly in favour of such an origin and gives convincing evidence that metasomatic processes had been responsible for the Norwegian sulphide ores that he had worked with. Another of the foremost Norwegian ore-geologists of later years, S. Foslie, in his publication "Norges Svovelkisforekomster" (1926) referred to most of the deposits as being gabbroic magmatic differentiation products. At the same time he regarded those sulphide deposits which occur in connection with granitic rocks as having a hydromagmatic or hydrothermal origin.

In Foslie's publication "Copper Deposits of Norway" (1933) there is a classification of the Caledonian sulphide deposits which is based partly on theories of origin. The classification shows considerable influence by Carsten's work. Three classes are recognized:

1) Leksdal type: Fine-grained pyrite and pyrrhotite without copper. Biochemical sediments between basaltic (spilitic) lava beds, metamorphosed in the greenstone facies. Source of the sulphur, volcanic exhalations.

2) Røros type: Pyrite and pyrrhotite with varying amounts of copper, near gabbroic intrusives always metamorphosed to saussurite-gabbros, amphibolites or chloritic schists. Precise conditions of ore formation not quite certain.
3) Bjørkåsen type: Mainly pyrite with quartz, low in copper, younger than the trondhjemites and similar acid differentiation products, following the basic intrusions. Ore formation at a lower temperature than the Røros type and often accompanied by extensive sericitisation. (Carstens referred to this class as the Rødhammer type.)

Within the Røros group Foslie distinguished deposits rich in pyrite and producing copper as a by-product. They nevertheless produce the bulk of Norway's copper. Such are the mines of Løkken, the Grong district and Sulitjelma (see below.) Then there are relatively small non-pyritic pyrrhotite-chalcopyrite deposits which are, or have been, worked for copper only. These include the mines at Røros and those of the Birtavarre and Vaddas areas.

The present writer's first-hand knowledge of the Norwegian sulphide deposits is confined to those of the Birtavarre—Vaddas district, the Sulitjelma area and the Vigsnes area in S.W. Norway, (Rogaland). In particular he was very impressed with the similarity between the Birtavarre deposits and those of Sulitjelma. The stratigraphy and tectonics of the two regions are very close. The ore-bearing Furulund schists at Sulitjelma show a close resemblance to the Brown Schist facies of the Ankerlia Series. The form of the ore-bodies is identical in the two areas, except of course, that the Sulitjelma ores are thicker, and therefore economic. According to Kautsky (1952) the Sulitjelma ores lie in minor thrust planes within the great Seve Nappe which is thrust over the Precambrian basement to the east in Sweden. Padget's studies of the regional geology of the area have shown that the Birtavarre sulphides occupy a similar tectonic position in the Caledonides.

Mineralogically the Sulitjelma ore differs in its high pyrite content. The proportions of the various sulphides in the Norwegian Caledonian ores, however, vary so frequently that one cannot classify them solely on the basis of their mineralogy.

It is clear that the Birtavarre deposits fall into the Røros group, showing very close similarity to the "type" deposits at Røros itself and those at Sulitjelma. Modern geological opinion in Norway assigns to these deposits a hydrothermal origin, and the present writer is convinced that this is the only one applicable to the Birtavarre sulphides.

Many of the arguments put forward so convincingly by Carstens could be used to show hydrothermal origin. The writer will confine himself to those which seem to have a particular application to the present case.

The strongest arguments seem to be the field relations of the ores. They occur in fine-grained schists of sedimentary origin or schistose amphibolites interlayered with these schists. They are demonstrably younger than both these types of country rock. There is a marked lack of bodies of igneous rock in the vicinity which could have produced any "sulphide magma" by magmatic differentiation, liquid immiscibility etc.

The presence of sulphides as both breccia-fillings and impregnation in schist in the one and same zone seems to imply somewhat tenuous solutions which have been able to penetrate minute cracks and grain boundaries.

The trace-element content of the sulphides indicates strongly a hydrothermal, as opposed to a magmatic, origin. Deposits of sure primary magmatic character are invariably nickeliferous. In Norway representatives of this class are known from Flåt in Telemark (Bjørlykke 1947), Hosanger in West Norway (Bjørlykke 1949) and from Råna in Ofoten. In these ores, according to Carstens, the ratio Ni : Co generally lies between 20 : 1 and 12 : 1. In the hydrothermal class the ratio is approximately reversed. It has been shown above that the Birtavarre sulphides are characterized by a Co : Ni ratio that is always above unity even in pyrrhotite, a mineral which normally holds more Ni than Co.

The wide and rapid variations in metal values have often been stressed in this account. This is another feature usually characteristic of hydrothermal deposits. Primary magmatic deposits tend to have much more even tenor.

Carsten lays considerable stress on the metasomatic processes which have been at work in the emplacement of the Norwegian sulphide deposits. These processes seem to have played a relatively minor role in the Birtavarre area. They seem to have been confined to a partial digestion of the rock fragments of the breccias. The writer is not of the opinion that metasomatic processes have in themselves produced the observed textures. The process was a filling of an already existing breccia with slight replacement, rather than the production of a breccia-texture by replacement from minor fractures in the rocks.

The alteration accompanying the sulphides in the Birtavarre area has been a chloritization, with sericitization playing a very minor role, or being completely absent. Such alteration is typically the result of hydrothermal rest-solutions and would not be expected in magmatic deposits.

Having shown the hydrothermal, as opposed to the primary, magmatic, nature of the deposits, the very important question remains as to the source of the "solutions". Carsten and other Norwegian geologists point to the connection between the sulphides and bodies of gabbro and trondhjemite, and suggest this indicates that the circulating sulphide solutions originate from the "source magma" of these eruptives. "The older type, the Røros type (is) connected to the gabbroic rocks and the younger type, the Rødhammer type, is connected to the youngest trondhjemites". (Carstens 1944, p. 48.)

The derivation of the Birtavarre sulphides.

It seems to be a case of "stating the obvious" to say that the ore-bearing (hypogene) solutions must have come "from depth". But in the case of the Birtavarre deposits "from depth" is by no means vertically upwards. The solutions came up along the relatively flat-lying thrusts parallel to the layering of the schists. In particular they came up channelways aligned parallel to the regional lineation direction in these schists. Thus "depth" in this case means from north-west. The zone which seems to the writer to have been the main channel of movement for the solutions is indicated in Fig. 52. It points to a source deeper within the orogenic belt of the Caledonides. At first glance it also points towards the tremendous massif of basic rocks west of Lyngenfjord, known as the Lyngen gabbro. This massif is little-known geologically but it appears that it is not a single gabbro-body, but a rather heterogeneous, sheeted complex consisting of rocks ranging from dunites to amphibolites.

The writer had the opportunity of studying the schists underlying this complex at Strupen, north of Lyngseidet on the west coast

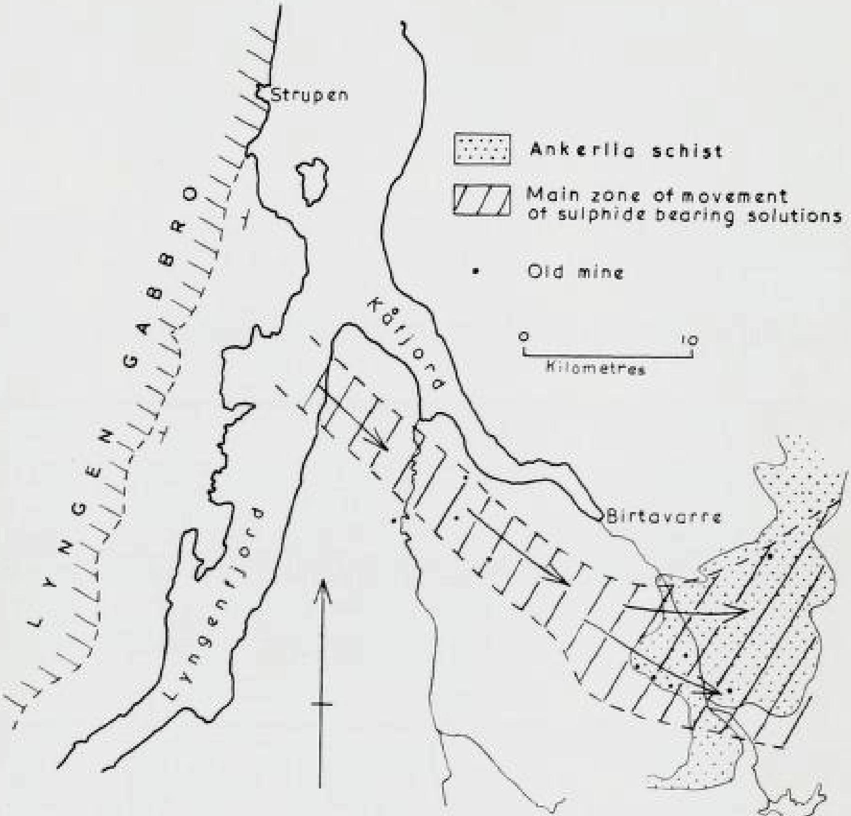


Fig. 52. Map to show the presumed direction of derivation of the Birtavarre sulphides.
Kartet viser den antatte tilførselsretning for Birtavarre-områdets sulfidmalmer.

of Lyngenfjord. The rocks here are dipping steeply to the west under the basic complex and it is clear that the Ankerlia Series at this point lie several thousand metres below the gabbro. Thus a promising "magmatic source" for the ores has to be eliminated on structural grounds. It seems highly unlikely that hydrothermal solutions would penetrate *downwards* several thousand metres, seek out a particular division in the schists and then follow it up to the southeast again.

The origin of the sulphides must be sought within the orogenic belt of the Caledonides itself and the processes of formation of the ore-bearing "solutions" must be regarded as an integral part of the geochemical processes within this belt. The most profound of these processes are the ones of migmatization and granitization (palingenesis, anatexis) by means of which the rocks of the geosynclinal pile are transformed into rocks of granitic composition. In recent years several students of ore-deposits have come forward with ideas linking the formation of ore-deposits with these granitization processes. Foremost among these have been Locke (1941), Dunn (1942), Sullivan (1948), and Goodspeed (1952). The mechanism envisaged is the "driving-out" of siderophile and chalcophile elements from the original rocks, their concentration ahead of the front of granitization and their subsequent emplacement in suitable structural environments as ore deposits. Sullivan lays emphasis on the ionic radii and valencies of the particular elements concerned. Elements with ionic radii and valencies differing from those of the elements forming the minerals of the granitic rocks will not be accepted into the crystal lattices and will therefore be concentrated. For example Sn has a high valency and a small radius (Sn^{4+}; 0.73 Å) compared with the elements forming the acid granites (Na^{+} 0.98, K^{+} 1.33, Ca^{2+} 1.01, Al^{3+} 0.57). Thus Sn would tend to be concentrated during the formation of acid granites and this is advanced as an explanation of the relation of tin deposits with acid granites in many parts of the world. In the case of copper (Cu^{2+} 0.98 Å) its low valency is said to lessen its tendency to enter crystal lattices and thus copper may be concentrated during the formation of a number of rock species. Goodspeed points to the water content of the rocks of the geosynclinal pile, a content which is more than sufficient to form the source of hydrothermal solutions that could produce mineralization.

Among Swedish geologists, Magnusson and Kautsky, and more recently Gavelin (1955) have expressed their belief in the role played by granitization in the formation of some of the Swedish sulphide ores.

Of these Kautsky has worked with deposits of Caledonian age in Västerbotten and Norrbotten. In a contribution to a discussion on a lecture by Magnusson (1948) he puts forward the following conclusions regarding the deposits. The *mineralization* is for the greater part referable to the intrusions of greenstones and to the basic volcanicity occurring in the geosynclinal belt. The *concentration* of the sulphide minerals to form the present day ore-deposits, occurred later in connection with palingenetic processes. Thus the occurrence of sulphide ores is a function both of the presence of greenstones and the operation of the palingenetic processes. By means of these processes the sulphides originating from the basic rocks were concentrated in certain tectonic zones in their close vicinity in a zone parallel to the eastern border of the zone of plastic folding.

In his 1952 publication Kautsky refers shortly to palingenetic processes in connection with the formation of the deposits of the Sulitjelma district. In this he seems to place a more structural role on the greenstones and suggests that the mineralization could in part have originated from the ubiquitous black (carbonaceous) schists.

A Norwegian geologist, H. Carstens, has discussed the origin of the sulphide-bearing iron-ores of the Fosen peninsula in the Trondheim district (1955). He concludes these deposits are of mixed sedimentary-volcanic origin, the iron being introduced into the geosyncline by means of volcanic exhalations and later deposited as a chemical sediment. Carstens also shows the close genetic connections between these pyrite-bearing magnetite ores and the sedimentary pyrite ores of the Leksdal type which carry subordinate magnetite. The two types are presented as representing respectively an oxidic and a sulphidic facies of iron deposition under differing sedimentary environments in the same geosyncline.

In the Oslo area of Southern Norway sulphide-bearing shales of Cambro-Silurian age are abundant in a succession which has been relatively little affected by Caledonian orogeny and metamorphism, and which includes no intrusive greenstones or volcanics.

Elsewhere in the Caledonides are seen the metamorphic equivalents of black, sulphide shales in the form of graphite schists, often pyrite-bearing. As examples of this may be mentioned Rendalsvik in Nordland and the Langøy area of Lofoten.

The foregoing seems good evidence that the Caledonian geosyncline contained both sedimentary and igneous rocks of such a nature that their granitization would provide concentrations of dominantly sulphidic "solutions" or "emanations" which would be available for introduction and emplacement along favourable zones of structural weakness.

In the Birtavarre area there are several horizons of basic igneous rock, which deeper in the geosyncline, may have been granitized and their small contents of heavy metals concentrated into hydrothermal solutions. There are also sulphide-bearing graphite schists (see

p. 126), which could also, at deep levels, down dip, have taken part in the same processes.

It is not possible to judge definitely how far the ore-bearing solutions travelled before they were deposited. Evidence of the granitization processes affecting the rocks is afforded in the metasomatic gneisses of Ĉappis Thrust Zone (Schist-with-thin-limestones), and the granitization of the Store Borsejok Schists in the Trollvikdal area. These may be interpreted as tongues of granitization preceeding the main "front" along zones of structural weakness.

Padget has shown that the top of the granitization front in the SE of the area is cross-cutting as regards the layering of the schists. It therefore could be that this front takes in higher stratigraphical zones at depth in a north-westerly direction from its outcrop. Just where the front is beneath the Birtavarre area it is not possible to judge with any degree of certainty. Fig. 53 is a very diagrammatic attempt to show the large-scale relationships which might possibly hold.

It is realised that the above explanation is based mainly on the position of the Birtavarre area with respect to the Caledonian geosyncline, and on the postulation of processes which *should* occur there from comparison with other areas, and from the accepted ideas of palingenetic processes in geosynclinal belts. In the field there is little to show that the ores *as they are now* originally derived from more dispersed mineralization in schists and basic volcanic rocks. But these rocks are present in the succession and it can be seen that processes of granitization are acting on the schists lower in the succession.

The occurrence of sulphide deposits of apparently similar origin extending along 1500 kms of the Caledonian orogenic belt of Norway indicates the operation of processes of a very fundamental nature. It seems to the writer that palingenesis and granitization are the very processes which would be operative along the whole of this belt, and which could give rise to such widespread metallization.

The above theory may be seen in relation to the classification of the Norwegian sulphide deposits given above. The Leksdal type represents the original sedimentary sulphides deposited in the Caledonian geosyncline by biochemical (?) agencies, the iron and sulphur being supplied by gaseous emanations accompanying the contemporaneous volcanic activity. (At the same time, under different conditions of oxygen-supply, pH, etc., the magnetite-pyrite ores of the

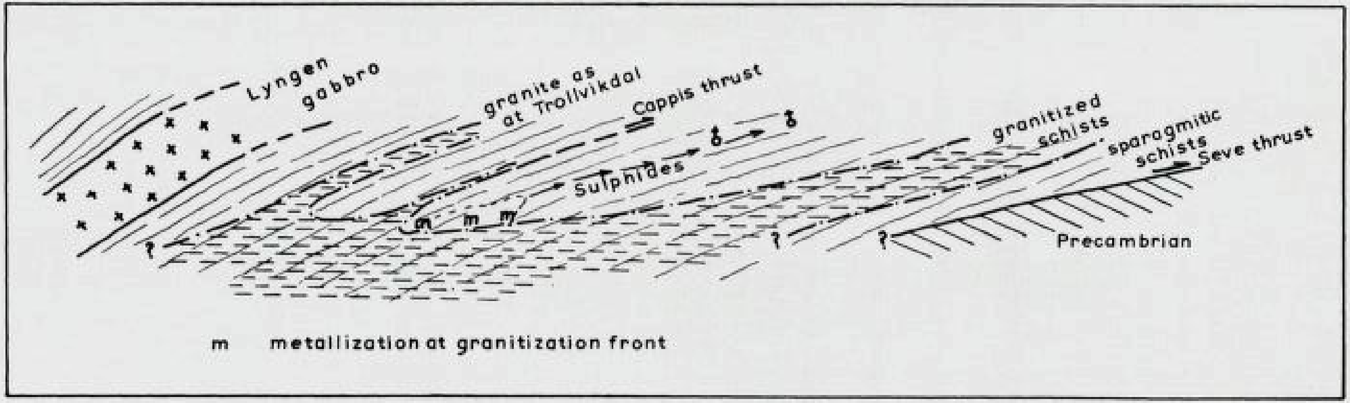


Fig. 53. Schematic diagram to show the suggested position of the granitization front in the Caledonian schists between the basal ("Seve") thrust and the Lyngen "gabbro". Length of section about 90 kms.

Skissen viser det antatt forløp av «granitteringsfronten» i de kaledonske skifre mellom «Seve»-skyveplanet og Lyngen-«gabbroen». Snittets lengde ca. 90 km.

Fosen type were deposited.) Under the orogeny, during the phase of plastic folding these sediments and the basic volcanics interlayered with them were, in parts, depressed into the deeper zones of the belt, or otherwise subjected to rising temperature, and ultimately, to palingenesis. Under the granitization the iron and sulphur and other chalcophile elements from the sediments and from the accompanying basics were "driven" out of their original rocks and concentrated to form "ore-solutions". This may explain the relatively minor amounts of Leksdal-type ore to be seen at the present day. It has only survived the palingenesis in a few places, otherwise it has been mobilised to form the hydrothermal pyrite deposits. In some of these latter, e. g. Løkken, the hydrothermal pyrite occurs in close proximity to the sedimentary pyrite, even as veinlets in a breccia of the latter type. In others the hydrothermal solutions have moved much further and there are no traces of the sedimentary ore. The deposits of the Birtavarre area, and of Sulitjelma are representives of this latter type.

The Leksdal type of ore is practically speaking copper-free. The Fosen type of magnetite-ore contains small quantities of copper sulphide, which may be of primary depositional origin. However, it seems as if we must look to the basic volcanics themselves as a source of this metal. Sullivan (op. cit. p. 476) shows there has been a progressive enrichment of copper in the earth's crust by the addition of basalts, which bring the element from deeper zones. The copper would be contained in the crystal lattices of the ferro-magnesians, where its substitution for Fe and Mg would be relatively easy (Cu^{2+} 0.98 Å, Fe^{2+} 0.79 Å, Mg^{2+} 0.75 Å). On granitization of the basic rocks the copper will be concentrated and become available for transport and redeposition.

Thus the statistical relation between copper-sulphide deposits and volcanic rocks in the Norwegian Caledonides first noted by J. H. L. Vogt (1905) is explainable on the basis of the above theory as easily as on one of magmatic differentiation from the source magma of these basics.

Tectonic History.

It is clear that the bodies of sulphides were introduced from their source of concentration and emplaced in their present positions at some time after the main phase of the orogeny. The rocks had already become crystalline schists and had been plastically stretched to give the pronounced lineation textures and structures observable in them.

Continuing outward pressure (from NW) acting on these crystalline rocks caused failure partly by drag-folding (e. g. in the Banded Ankerlia), but also, as the rocks became less plastic in their behaviour, by shearing and brecciation along minor thrust planes parallel or nearly so to the layering of the schists. The shear and breccia zones formed channel-ways for the sulphide-bearing solutions coming from the deeper zones of the geosyncline and the ores were deposited along these presumably in response to decreasing pressure and temperature.

Thus the ore-formation can be classed as synorogenetic, belonging to a late phase of more clean-cut thrusting coming after the main period of plastic deformation in the orogenic belt.

It is therefore apparent that the "ribbon" or linear forms of the ore-bodies are due to the shape of the channel-ways and the host-breccias in which the sulphides were deposited. There is no question in the Birtavarre area of the plastic stretching of the bodies of sulphides to give the elongated forms.

This brings us to the processes which produced the linear forms of the channel-ways, and it seems we must look at the basic structure of the area to elucidate these. Padget has shown how the outward pressure from the geosyncline acting against submerged foreland blocks in the south-west and north-east gave rise to the marked area of structural anomaly in the centre of the area. This is best marked by the swing in lineation directions as shown in Plate 2.

The later thrusting which must be presumed to have been produced by pressure still from the NW would in the centre of the area be moving at an angle to the linear structures, in places at right angles (Fig. 54). It is suggested that this movement across the linear "grain" of the schists would result in failure by fracturing and brecciation, rather than by shearing as would the case when the movement was parallel to the lineation.

The thrusting would be overriding the corrugations formed by the linear structures and would especially shatter the crests of these structures, producing breccias in the form of long, narrow ribbons parallel to the lineation.

The area shaded in Fig. 54 shows the area where this type of

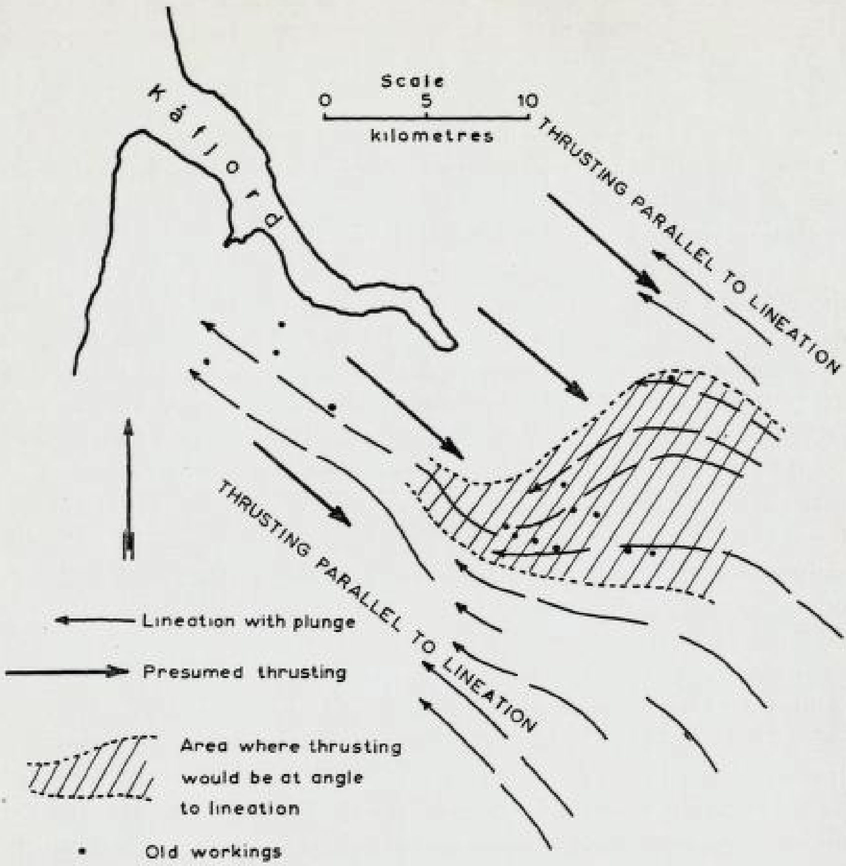


Fig. 54. Schematic diagram showing the relationship between linear structures in the Birtavarre district and the main sulphide deposits.
Skisse som viser forholdet mellom linearstrukturene og sulfidforekomstene i Birtavarre-området.

failure could have taken place, and it can be seen how the majority of deposits falls within it.

Sequence of events.

The history of the geological processes leading to the formation of the sulphide deposits in this area of the Caledonian mountain chain can be said to have begun when the continuation of pressure from NW, following the period of plastic deformation, caused states of strain to be set up in certain zones in the Ankerlia schists. Metasomatic action was initiated along these zones either as a form of metamorphic differentiation or due to the action of disperse emanations penetrating along the zones from some distant source. The main result of the metasomatism was an addition of Mg and Fe and a removal of Ca and alkalies. Anthophyllite was formed from the common hornblende of the country schists, with, probably, cummingtonite as an intermediate product.

Continuation of the outward pressure caused the rocks along the affected zones to fail mechanically, with shearing and crushing of the metasomatic rocks already formed. Following the failure chlorite was formed from the anthophyllite, probably by the action of hydrothermal solutions circulating within the zone. The release of the strain-energy in the zones by the actual failure and movement would also in effect lower the facies conditions within the zones so that chlorite might also form as a retrograde product of the amphibole. Possibly also at this time almandine garnets began to grow porphyroblastically in the metasomatic zone and continued to grow, often to large dimensions after the other silicates had fully crystallised.

Consequent on the cooling of the rocks a more brittle type of failure next occurred producing breccias and open shears which received the sulphide bearing "emanations" from their place of concentration deeper in the geosyncline. The metallization must be regarded as having been a single "surge" of material from which most of the minerals crystallised almost at once, except for some quantitatively minor ones which formed by replacement.

After the solidification of the sulphides further slight "end-movements" caused minor sliding on either or both of the ore-walls, along internal planes in the sulphides, or along schistosity planes in the wall-rocks close to the ore.

Late, minor, mineralization, mainly in the form of calcite, occurred in the well-developed joint-system, especially in the western part of the field.

The "end-movements" mentioned two paragraphs above must be regarded as the dying 'kicks' of the Caledonian orogeny. Since that time the sulphide deposits of the Birtavarre region have not been tectonically disturbed.

Any secondary mineral formation which may have occurred was removed during the Pleistocene glaciation and at the present day the only effect of secondary agencies is the thin coat of brown-red "rust" due to pyrrhotite which forms such a striking feature along the outcrops of the mineralized zones.

MINING IN THE BIRTAVARRE DISTRICT.

History of mining.

As can be seen from the map (Plate 1) the mines and prospects of the area are scattered over a belt some 30 km long and 12 wide. The main concentration lies in the south-east part of the belt and contains the most important of the old workings, namely, the mines at Moskogaissa, Skaide and Sabetjok. Somewhat separated from these are a small number of mines and prospects in the valleys of Skardalen and Mandalen. Very few records and no plans exist of the mines in the latter area.

The first recorded find of ore in the Kåfjorddalen district occurred in the 1860's when a small sample load was excavated and sent to Alten Copperworks. The location of this first prospect is uncertain.

In the middle of the 1890's the deposit later to be called Sabetjok mine was discovered, following the finding of a piece of ore in the screes below its outcrop by a Lapp. This piece of ore was seen by one Rikardsen, who registered the claim and came into contact, at second hand, with Chr. Anker of Fredrikshald.

In 1896 Anker sent up the university ammanuensis Gudbrand Thesen to investigate the deposit, and immediately afterwards initiated a prospecting programme. As a result of this programme a series of similar deposits were found and in 1898 Anker succeeded in interesting an English company to join him in setting up a copper works in the area. Consequently a company was founded in London under the name of Norwegian Copper Mines Ltd., with a capital of £ 50 000.

This capital amount proved to be much too small, and the English interests added further capital with time. However, as a result of this there arose disagreements between Anker and the English side and the company's holdings were sold under execution, by means of which the English interests bought the assets in the autumn of 1903, with the intention of immediately completing the installations and putting the works to full production.

During this period, Moskogaissa 115 mine had been in production, exploration had been carried out on other promising prospects, and living accommodation provided. Smelting began in the valley at Ankerlia in 1899 with a 42″ waterjacket furnace producing a 40 % matte. In 1900 an aerial ropeway was constructed between Ankerlia and the Moskogaissa mine. A 12 km long horse railway was constructed between Ankerlia and the sea for the export of ore and matte and to bring up materials and provisions. An electric power station of 150 HP was established on the Guollejok some distance up-stream from Ankerlia. The ore mined was hand-sorted on the spot and exported either as lump ore or as matte.

Towards the end of 1903 a fire destroyed the surface installations and the pumping machinery at Moskogaissa and the mine filled with water.

In all, up to the time of this incident a capital of 2 mill. Norwegian kroner (£ 100 000) had been invested, but by 1903 this capital had been used up without a profitable production being established. Norwegian Copper Mines was therefore declared bankrupt and the English financial interests, representing the Venture Corporation took over the mines. This company undertook an amount of exploration work in the mines until 1906. A lake covering the outcrop of the ore at Moskogaissa 117 was partly drained, and after many difficulties, the development of the mines was continued. During 1907 A/S Sulitjelma carried out a certain amount of diamond drilling in the area, the results of which were not disclosed. Another catastrophe occurred in 1908 when the roof of Moskogaissa 117 collapsed and the workings filled with mud and water, in which condition they have remained to the present day.

The difficulties of a direct administration from London made it necessary that the company's structure should be revised, and in the summer of 1909, the new company of A/S Birtavarre Gruber was formed and took over direction of the mines. This company had a capital of kr. 200 000 (£5000) of which Venture Corporation held a half-share, the remaining half being raised by Norwegian subscription. The company's board of directors was to meet in Norway in order better to control operations. During 1909 and 1910 there were built a new electric power station of 400 HP capacity and a new smelting works, using the pyritic smelting system in connection with bessemerizing, with an estimated capacity of 1 ton copper per day. Moskogaissa 115 mine was brought into production again and connected with the smelter at Ankerlia by an aerial ropeway.

The operations suffered yet another blow in 1910 when the spring flood waters broke the dam of the power station reservoir, destroyed the station and caused flooding in the valley downstream. This damage was set right by the autumn of the same year.

1911 saw the first full year's working when the final production amounted to 200 tons of copper. After that time until the final close production did not have any serious breaks and the mines at Sabetjok and Skaide were brought into operation.

In the period 1909—1913 Venture Corporation was in practice owners of the company, but it came into economic difficulties in the latter year and ownership changed hands several times. In 1914, on outbreak of the First World War, the company was transferred entirely to Norwegian hands, and in 1916 the company's name was changed to A/S Birtavarre and it was voted to write up share capital from kr. 900 000 to an amount which corresponded to the capital already set into the operations — kr. 2 160 000.

When the price of copper fell at the end of the First World War and numbers of copper mines all over the world had to close down, Birtavarre tried to keep going with its cheap electric smelting. But in the autumn of 1919 the smelting works burned down, as a result of which the operations had to cease.

Output of Copper.

(The production figures in the following account are taken from an unpublished report by State geologist A. O. Poulsen, who visited the area in 1950.)

The operations in the mines of the Birtavarre area were planned for the production of a rich sorting- and smelting-ore. During the latter years of the mines' life a small dressing plant using primitive bulk flotation methods was set up. This was really in the nature of a pilot plant, having a capacity of 3 tons raw ore per hour. Concentrated ore did not contribute in any appreciable way to the mines' total production.

In the period 1898—1903 42 017 tons of sorted ore were produced with a copper content of 1700 tons (4.05 % Cu average).

In the period 1910—1919 72 700 tons containing 3130 tons of copper (4.30 %) were produced. From this ore 2343 tons of bessemer copper were recovered. The greatest production was in the years 1913 and 1914 when it reached 446.5 and 486.5 tons of copper metal, respectively.

There is no information on the actual quantity of ore mined during the first period. During the period 1915—1919 the statistics show that 37 116 cubic metres of ore and waste were hoisted, giving 33 267 tons of ore, that is to say 0.9 tons per cubic metre.

For the year 1918 there are more detailed records which are of interest since they give a better picture of the nature of the ore and the results of the mining operations.

For this year the mines produced the following:

Moskogaissa . . .	4281 tons	run-of-mine ore giving	2478 t.	smelting ore
Sabetjok	3357 tons	—„—	1647 t.	— -
Skaide	997 tons	—„—	223 t.	— -
Total	8635 tons		4348 t.	

The average copper content of the ore was 3.8 %. The combined production of sorting- and smelting-ore in the Kåfjorddalen area amounted to 115—120 000 tons, so the total amount of ore broken can be reckoned at 200 000 tons. In judging these figures it must be kept in mind that the operations were based on the mining and smelting of a rich ore. It is not easy to judge how much larger the production might have been if modern methods of concentration could have been used to treat an ore having a lower copper content than that necessary for direct smelting.

Though trustworthy reports are few and far between it seems that some of the prospects were not developed because they consisted chiefly of "concentrating ores" with copper content between 2—3 %. In this class come some of the Sabetjok ore, and the prospects of Birtavarre Høyfjell and Monte Carlo.

It seemed clear at the beginning of the survey that a present-day industry could not be based on the small, irregular, high-grade ores, such as those worked in the past. Attention was therefore focussed on proving or disproving the existence of workable quantities of ore which could be treated by modern oredressing methods.

Economic Factors affecting Mining.

Price of copper.

The peak copper price reached on the London metal market during the First World War when most of the production from the Birtavarre district took place was £ 150 per ton. Following the cessation of hostilities a reaction set in and in 1921 the price had declined to £ 70 per ton. As has been related, this fall in the price of copper was not the direct reason for the end of mining and smelting in the Birtavarre district, but even with the cheap hydroelectric metallurgy it is difficult to see that the operations could have survived for many more years, even providing sufficent ore was still forthcoming.

The results of the present investigations seem to show that the quantity of ore *was* very limited. Moreover it occurred in comparatively high-grade "shoots" of not too large areal extent. Once such a shoot was worked out, the particular mine had to be abandoned. Money was never available for underground prospecting or exploration to discover 'blind' ore-shoots either in depth or along the strike. By the end of the period of operations all the ore which outcropped at the surface had been found and the out-look for further tonnage to be mined must have been very black.

At the beginning of the present investigation the price of copper on the world markets stood at about £ 250 per ton (kr. 5000) and at the time of writing it is nearer £ 300 per ton.

In an article in Engineering and Mining Journal, W. P. Shea (1955) discusses the future outlook for copper up to 1960, and the long-term prospects after that date. He predicts a fairly stable price of 30 cents per 1b (£ 240 per ton) over the period 1956—60, with a "reasonable expectation" that this would also be the long-term price level.

Thus the prospective ore of the Birtavarre area could be assessed on the basis of a copper price about twice that prevailing during the best period of forming working. Meanwhile mining costs had advanced to a far greater extent.

Mining.

During the life of the mines the operations were of a comparatively simple nature. Nearly all the working took place in the ore-zone and there was little need to drive in the country rock. Most of the drilling was by hand until the last year or so. The miners followed the richer ore and hand-sorted it in the stopes, sending to the surface the material which could be smelted directly. Most of the waste rock was stowed in the stopes as roof support.

Present-day mining methods would require an ore-body which could be worked continuously by mechanized means, employing workers less skilled in following the ore. All the material broken in the stopes would probably have to be hoisted and this again would entail better hoisting facilities.

Because of the relatively flat dip of the ore-horizon little help would be provided by gravity in moving broken ore and power-scraping would be needed between transport levels. The low dip would also impose a higher minimum stoping-width than would be required in an ore-body nearer the vertical. Under the prevailing conditions a minimum stoping-width would probably be 2 metres, using a room-and-pillar type of mining method.

The present investigations have shown that to maintain such a stoping-width in the Birtavarre ores would mean the dilution of the copper content to a point where it ceased to be economic. To take one example, based on the results of the 1955 diamond drilling in the Sabetjok—Birtavarre Høyfjell area. A "possible" ore-body of about 400 000 tons was outlined within the 1 metre isopach (see Fig. 62, p. 218. The copper content was 1.16 % and the average thickness 1.40 m. If one reckons with the 2 metre limit, the tonnage will be increased to about 570 000 tons, but the copper content will decrease to 0.80 %.

It would not be easy to state the cost per ton of possible mining operations in the Birtavarre area. The problem is complicated by the latitude and altitude of the mining fields. In most cases the surface plant of the mines would lie at 900—1000 metres above sea level and the distances from present habitations are such that accommodation for workers would be needed on the spot. All buildings would have to be of a substantial nature because of winter conditions, and transport of supplies would be costly, and in winter, extremely difficult. Though the milling plant could be placed with advantage in the valley, costs would be entailed in transporting the raw ore down the almost vertical valley sides.

An idea of the possible costs of an operation in the Birtavarre area can be obtained by comparing costs for similarly placed operations in other parts of Norway. It appears that an overall cost of kr. 40 per ton might be expected, covering both mining and milling costs.

As indicated just above here it seems that the maximum grade of ore one could expected from the ores of the district may be less than 1 %. If one takes into account milling losses and the fact that the concentrate would have to bear transport charges to the nearest smelter, it is clear that at the 30 cent/1b (4800 kr./ton) price of copper the operation would be submarginal.

What is more the small tonnage which could be expected from any one ore-body is not sufficient to allow the recovery of the large capital investment needed to start up an industry at the present day.

Milling.

In view of the poor economic results of the field investigations in the area, very little work has been done to test the milling characteristics of the ores. After the first season's field work samples of ore from the old dumps at Skaide and Moskogaissa were sent for flotation tests at the firm of Ferdinand Egeberg and Co., Oslo. The following notes are taken from this firm's report.

An attempt to float the Moskogaissa ore selectively was not successful since the pyrrhotite tended to accompany the copper-concentrate, lowering its grade and the percentage recovery.

In the next attempt a bulk chalcopyrite-pyrrhotite concentrate was made, which was later selectively floated to give separate copper- and sulphur-concentrates. The bulk concentrate contained 99.9 % of the copper and 98.8 % of the sulphur in the ore. The selective flotation produced a copper-concentrate assaying 14.74 % Cu with a recovery of 98.8 %, and it was estimated that further cleaning would easily prouce a concentrate with 18—20 % Cu, at a recovery of 90—95 %. The pyrrhotite-concentrate contained 36.10 % S.

The Skaide sample was selectively floated for Cu, Zn and pyrrhotite. The copper-concentrate held 20.9 % Cu with a recovery of 95 %, while the zinc-concentrate held 20.70 % Zn, with a recovery of 86 %. Both these were rougher concentrates and in practice one could reckon with 2 or 3 cleaning operations which would give final concentrates with a much higher metal content. The sulphur content of a final pyrrhotite-concentrate would be about 36 % S.

The report remarks on the high iron content of the sphalerite in the zinc-concentrate (see p. 122). With further cleaning operations it was possible to produce a concentrate assaying 45.5 % Zn and 16.4 % Fe. This iron content would involve a penalty, but the zinc-concentrate would still be a saleable product. However, since the zinc-rich ore is of minor importance quantitatively, this point is not so important. For most of the ores investigated the flotation characteristics and products would resemble those of the Moskogaissa sample.

The flotation attempts were made after grinding to 64—68 % minus 200 mesh, but in practice this would have to be lower, probably 45—50 % minus 200 mesh.

Addition of reagents cannot be given exactly, but the following were used in the laboratory tests and should give satisfactory products.

Bulk flotation — Moskogaissa.

50 g potassium amyl xanthate	per ton	added after grinding
50 g pine oil	- -	added after grinding
500 g lime	- -	added to conditioning tank before cleaning

Selective flotation — Skaide.

1000 g lime	per ton	added to ball mill
50 g sodium cyanide	- -	added to ball mill

Copper flotation.

50 g potassium amyl xanthate	per ton
25 g pine oil	- -

Zinc flotation (added to conditioning tank).

400 g copper sulphate	per ton
500 g lime	- -
20 g sodium ethyl xanthate	- -
25 g pine oil	- -

Sulphur flotation (added to conditioning tank).

1500 g sulphuric acid	per ton
150 g sodium ethyl xanthate	- -
50 g pine oil	- -

In conclusion the report says that the ores must be considered easy to treat by flotation, since they are relatively coarse-grained and easy to free by grinding.

The Moskogaissa ore would be cheap to treat by bulk flotation followed by selective flotation of the copper, but it would also be quite possible to float by selective methods.

The treatment problem thus must be considered to be easy of solution. The flow-sheet would follow that now being used at several Norwegian mines, e. g. Sulitjelma, Røros, Vigsnes, and should not present any difficulties.

The possible economic products from the Birtavarre ores seem to be limited to copper and sulphur concentrates, but even the latter would be a doubtful product in view of the availability of pyrite concentrates of much higher S content from mines already operating in Norway. The nickel and/or cobalt contents do not appear to be such that the pyrrhotite could be used as a source of these metals. The copper concentrate would hold between 10—70 g/ton silver which might eventually be recovered during electrolytic refining of the copper.

Exploration.

The programme carried out by NGU has given a fairly sound idea of the efficacy and fields of application of the various prospecting methods tried. These may be classified for sake of description though it should be clear that they are interrelated and form to a large extent a continuous succession of steps.

Surface prospecting. Because of the well-exposed nature of the ground and the number of people who have looked for surface ore, both in the past and during the present investigation it is considered that no ore remains to be found merely by "looking for it". The recognition of the stratigraphical and structural control of the ore distribution and of the fact that all possible ore-bodies occur in well-marked "sulphide-horizons" following the layering of the schists made it possible to eliminate large tracts of country and concentrate on more favourable ground, with a resulting increase in prospecting efficiency.

One result of the extreme irregularity of the ore within the shoots has been that it has been very difficult to assess the importance of any particular outcrop of sulphides. It is not possible to tell whether a 20 cm band of mineralization is the beginning of an ore-shoot a few metres under the outcrop, or whether such thickness will continue for several hundred metres. The only method of testing such occurrences is obviously to drive or sink along the ore zones, especially when the terrain is steep, as is often the case in the area. This method must be considered as too expensive in view of the possible targets.

Geological Methods. The recognition of geological controls in the distribution of the ore-bodies led to greater efficiency in the investigation of the area. Not only in surface prospecting methods, but in the selection of sites for geophysical measurements and subsequent diamond-drill holes, the application of geological reasoning led to a more concentrated and efficient application of the resources available.

Geophysical methods. Because of the mineralogical nature of the ore, electro-magnetic methods were applied to the problem of finding ore-shoots within the sulphide horizons. The method, which resembles the Swedish 'Turam' method, involved the laying out of a network of pegs at 25 to 50 metre intervals and was fairly time consuming. (In the window area readings were taken across profiles with much wider spacing in order to give a quicker, reconnaissance-type survey.)

The results given by the geophysicists were in the form of maps showing areas where there appeared to be favourable concentrations of ore within a horizon. As mentioned previously these "leaders" were ribbon- or cigar-shaped with the greatest dimensions parallel to the lineation direction in the schists.

Thus the "targets" were successively narrowed down until they reached the size of the electro-magnetic "leaders". These were often of large areal extent in themselves and it was not always possible to say from the geophysical results if more favourable areas occurred within any one "leader". Moreover drilling-results subsequently showed that a geophysically favourable indication did not necessarily mean copper-bearing sulphides. The electro-magnetic anomalies were dependent on the presence of conducting sulphides, and pyrrhotite proved to be an excellent conductor. Bands of only a few cms. of this mineral often gave rise to strong electro-magnetic indications. On the other hand, comparatively rich disseminated copper sulphide (e. g. Birtavarre Høyfjell) did not form a conductor and did not give rise to a geophysical anomaly.

However, it is considered that the use of geophysical methods of prospecting did enable areas to be outlined inside which the chances of hitting economic sulphides were much greater than in the rest of the sulphide zones. The fact that subsequent drilling did not discover large quantities of workable ore in these favourable areas must be taken as indicating the weak nature of the mineralization and not the failure of the methods used.

Diamond drilling. The last, and most expensive stage of the prospecting operation was restricted to areas which, after due consideration of the geological and geophysical evidence, were the most favourable for the delineation of an ore-body. It was known that drill-hole spacing would have to be fairly close if any reliable indications of the ore were to be obtained. It was considered that a spacing of 50 metres was the maximum which could be allowed in order to follow the rapid variations in thickness of the ore. For the purposes of estimation of ore quantities a much closer hole spacing would be necessary, perhaps down to 20 metres or less. Such a spacing involves a large total drilling meterage when hole-lengths of up to 100 metres are involved as was the case in both seasons' drilling. The holes had to be placed in order to obtain the maximum number of intersections possible with the limited total length of holes determined by the money voted to the programme each year. In the case of the 1955 drilling, it was possible to produce some numerical basis for estimating the amount of money which might reasonably be used in a drilling campaign.

The possible target, based on the geophysical measurements and a knowledge of the usual thickness of the ore-zones in the district, seemed to be plate-like body having an area of $1500 \times 300 =$ 450 000 square metres.

Assuming an average thickness of 1 metre and specific gravity of 3.5 this represented about 1 500 000 tons of ore.

At 1 % Cu content this would contain 15 500 tons metal, having a value in situ of about kr. 50 000 000.

The present outlay on prospecting in most parts of the world at the present is between 1½—2 % of the possible value of the target. (In Canada in 1953 the figure was 2.5 %).

In the present case 1 % of the possible value would have been ½ million kroner. For the first year's reconnaissance drilling the sum of kr. 200 000 would have represented a reasonable business risk. The sum voted to the survey was kr. 150 000.

The diamond drilling in both 1954 and 1955 was undertaken by Geofysisk Malmleting, Trondheim, at an overall cost to NGU of 100 kroner (£ 5) per metre. This figure included everything from diamonds to the rather expensive horse-transport of supplies. Transport costs constituted a substantial proportion of the total charges due to the isolated situation of the area.

Not all the geophysical indications were tested by drilling, but those that were tested were the most promising, and enough information was obtained to indicate very strongly that the mineralization is of a uniform nature, and that it is uneconomic by present-day standards.

Future of the district.

The total amount of copper-bearing sulphides contained within the Ankerlia Series in the Birtavarre district probably reaches considerable proportions. However, it is clear from the geological account that these sulphides are dispersed along a number of horizons within the schists, each having a large areal extent and being separated from the ones above and below by up to several hundreds of metres. It appears that in no one horizon have the sulphides been concentrated enough to give an ore-body big enough to form the basis for a mining operation. This is a direct result of the weak controls acting during ore-deposition. Nowhere was there any control, structural or otherwise, which was strong enough to arrest and impound the ore-bearing "solutions". Consequently these spread out and dispersed along the several zones of breccia and shear.

The conclusion must be reached, therefore, that under foreseeable conditions of price and supply of copper metal, a mining industry could not be restarted in the Birtavarre district.

The mines and prospects of the area.

The following contains more or less detailed description of the individual workings in the Birtavarre area.

The information has been gathered from old plans and records, surface and underground inspections, diamond-drilling results, and geophysical measurements. The economic prospects of each area are discussed briefly.

The Moskogaissa area.

Former Mining Operations. There were three mines or workings in the area of which only one, designated as Moskogaissa 115, had any noteworthy production. Sinking operations were started here in 1898 with an incline shaft which followed the dip of the ore from its outcrop in the banks of the Rautajok just downstream from the small lake Rosejavre. During the first period of productivity (1898—1903) it was the only producing mine in the area and accounted for nearly all the 42 000-odd tons of sorted ore produced in that period. By 1900 the mine had been developed 110 metres down-dip and 180 metres along the plunge of the oreshoot. (The incline down-dip soon ran out of ore and a new one had to be started following the elongation of the ore along the plunge direction.)

Even during this early period, when the ore mined seems to have been exceptionally rich, reports stressed the sharp variations in thickness which led to an unusual amount of development in order to follow the ore successfully. Variations in thickness from zero up to 5 metres are mentioned, with an average of 2 m. Copper content was from 6 to 8 %.

Reports written after the reopening of the mines mention the two shafts, each apparently serving two separated parts of the mine, an eastern and a western part. Of these most work seems to have been done in the western part, which also appeared to be the richer. Thicknesses mentioned vary between a few cm. and 5—6 metres.

In 1919 Aronsen and Hunger formed the following picture of Moskogaissa 115:

«Moskogaissa 115 must be reckoned as the most significant of the now known deposits. The ore here consists of two separate layers with a 5—6 m. thick band of schist between. The upper layer which has been mined ca. 330 m. along the plunge has a strike length of ca. 60 m. and thickness varying between a few cm. and 5 m. We reckon that about 1 metre must be considered as being the average thickness. In 1916 Director Quale reckoned that this upper layer had produced 18 000 tons of ore at 4.5 % Cu, and that in round figures another 18 000 tons remained. The mine reports since indicate that up to the end of 1918 another 7500 tons had been won, thus there should remain ca. 10 000 tons, but after our visit we consider that with the exception of a few small pillars, *all mineable ore above the bottom of the mine at 330 m. has been taken out.*

"At this depth it seems that the ore has gone over to a small band of sulphide impregnation. This has been followed 50 metres down dip and 35 metres on strike without showing any noteworthy variations. Besides this there was driven in the foot-wall under the ore an 80 m. long level with a crosscut in the direction of the ore's main axis, in which, according to the mining engineer and mine captain, 30 cm. thick ore was met.

"This part of the mine was filled with water during our visit and we cannot therefore express ourselves on the matter.

"After Director Quale wrote his 1916 report, stoping has mainly been carried out in the underlying ore layer which is now being worked from four separated levels. This ore seems to have the same characteristics as the ore in the hanging-wall layer. Up to now ca. 1200 cub. metres of ore have been broken. Since the upper (hanging) ore contained about 20 000 cub. m. one might reckon that perhaps 18 800 cub. m. remain in the lower ore, but before this could be shown with any certainly a great deal of exploration would be necessary. From the present stand point no noteworthy quantity of "visible ore" can be said to be at hand."

About 1200 metres west of 115 was the working known as Moskogaissa 117. This produced relatively small quantities of ore, but the copper content appears to have been somewhat above the average for the area. Trenching of the outcrop began in 1898, exposing a strike length of 180 metres of what was termed "fine ore" up to 1½ metres thick. The next year open-cut working on the outcrop produced 1680 tons of ore. In 1900 a further 1194 tons were won by the same method, with a copper content of 6 %. Work was then started to drain a small lake which overlay the ore.

Later a shaft was sunk 25 metres down dip, the last ten metres being in a very poor sulphide impregnation. A level was driven out on either side of the shaft in solid ore. Here the long axis of the ore-body seems to have been almost parallel with the strike. Little further work seems to have been done on this small ore-body. After the close-down in 1903, exploration work, including some boring, was undertaken, but a collapse of the roof in 1908 caused the workings to be flooded and since then no further work was done underground.

The working designated as Moskogaissa 111 lies about 900 metres due east of 115. It contributed a very negligible amount to the ore production of the Birtavarre field. Activity there was confined to a small open-cut working, a little adit-driving, and the sinking of some shallow shafts. In 1899 a diamond drill hole intersected 3½ metres of ore and a shaft was sunk to develop this. Development proved there to be only a very small lens of sulphides. The statistics indicate that open-cut working produced 1800 tons of ore at 3—4 % Cu in 1900.

Following the temporary close-down in 1903 Moskogaissa 111 does not appear in the records and it seems that no ore was won from there in the second working period. Director Quale's report of 1916 put the ore reserves of 111 at 100 000 tons at 2.7 % Cu, on the basis of very optimistic estimates of extension down dip and along strike. Aronsen and Hunger remark that these figures must be regarded as extremely doubtful.

Moskogaissa 111. The sulphide horizon at this place outcrops along the steep, northern side of a small rocky hill under the cliffs of Store Moskogaissa. The total length of outcrop is about 150 metres and it has been explored by four short adits, and an open-cut along its eastern part.

West of the two westerly adits at 111 (No 1 and No 2) the sulphide horizon is next seen in a surface pit and trench about 200 metres southwest of No 1 adit. Here the limited exposures shows a fairly steeply dipping horizon of sheared schists separating amphibolitic schist on the foot-wall from garnet-amphibole rock on the hanging wall. A shaft has been sunk on the shear horizon, probably following a patch of sulphides, but it is now flooded and cannot be examined.

Between Moskogaissa 111 proper and this excavation there is no sign of mineralization as the ground is covered by marsh and morainic debris.

Further west, the so-called Midway Shaft, now waterfilled, had been sunk to the sulphide horizon, to judge from blocks in the spoil round its collar. No records exist of any workings from this shaft. It lies just within the southern boundary of the extreme eastern lobe of the geophysical indication outlined by the 1953 survey.

The 1953 geophysical work in this area did not reveal any promising electromagnetic anomalies around this old prospect. There was a weak conducting zone along the very outcrop of the sulphides, but this did not continue very far down dip. The "ore" at outcrop is definitely sub-economic and there is no reason to suppose that anything better will be found down-dip. As mentioned previously the observations indicate an eroded sulphide lens up-dip from the present outcrop.

West of Midway Shaft the "ore-horizon" is not exposed again till Moskogaissa 115 mine is reached.

Moskogaissa 115 mine. Although this was the main producer of the Birtavarre region, it is very difficult to obtain first hand information about the geology here. The mine itself is flooded and the workings could not be inspected at all.

Exposures are extremely limited around the entrance to the mine, most of the area being covered by thick, bouldery moraine. The ore originally outcropped in the banks and bed of the Rautajok, just after its discharge from Rosejavre. The first inclined shaft was sunk on the actual sulphide band, the remnant of which can be seen to-day forming the collar of the shaft.

The area overlying the old workings is thickly covered with morainic debris (see below p. 207). In the upper levels of the mine, at least, there cannot have been a very thick rock cover between the workings and this overburden. In fact this was so thin that in places the roof has caved-in and the lines of the old inclines can be traced on the surface by means of a number of "craters" where the moraine has "funneled" down into the mine. Thus the task of reopening the mine would have been a tremendous one, for not only would the water problem have had to have been solved, but the upper sections of the inclines would have had to have been, in effect, re-mined.

Moskogaissa 117. A brief account of the mining activity at this locality was given at the beginning of this section. The accessible workings comprise, at the present day, two open-cuts or trenches excavated on the outcrop of the ore-zone. These are marked as W. Trench and E. Trench respectively on the sketch-map, Fig. 26. The ore originally outcropped on the north bank of a small lake which was drained during the working period so that now only a small remnant remains. It appears that the floor of the lake dipped almost as steeply as the ore zone, and the upper part of the W. Trench shows the almost undisturbed outcrop of rusted ore-zone rocks with some sulphide pockets. In places the sulphide has weathered into a true limonitic "gossan". The bottom of this trench has been excavated into the old lake bottom, revealing a thin band of sulphides, mainly pyrrhotite.

The main, south-dipping, incline at 117 was driven down the full dip of the sulphide band, remnants of which are exposed in the mouth of the shaft. It is now full of water and inaccessible. The old mine plans show that a level was driven along the strike both east and west of the shaft, to the east for about 50 metres and to the west for about 25. In places, especially west of the shaft, this level has been stoped out to widths of up to 5 metres where small bodies of workable ore were encountered. As mentioned previously the roof collapsed here while working was still in progress, but all the evidence seems to point to there being a small, concentrated body of comparatively rich copper ore at this mine. The electro-magnetic measurements in 1953 revealed one or two small, strong, cigar-shaped indications west of this working, along the lineation direction. These probably indicate similar bodies to that worked in the past.

East of the main shaft the ore-zone has been explored by an incline and an open cut. The incline does not reveal much since it is collapsed and full of water. There is a band of up 20 cm. of solid sulphides at the collar, which seems to be the continuation of the same band exposed at the mouth of the main shaft.

About 600 metres west of Moskogaissa 117 the thin mineralized zone has been tested by shallow pitting (designated Moskogaissa 117 B). The only feature of note at this place is the relatively high content of magnetite in the dark, amphibolitic schists. This has been discussed in the section on mineralogy (p. 111).

Moskogaissa 125. This is the number given to shallow prospect-pits about 1 kilometre north of Moskogaissa 117. The schists are here dipping NW, on the northern limb of the Moskogaissa anticline. The mineralized zone outcrops as a small inlier from beneath a shallow cover of coarse-grained amphibolite. It shows most of the normal features of the zone, except for the noticeable quantity of sphalerite and the apparently diminished proportion of pyrrhotite. The sulphides here are disseminated through the rocks and no signs of any bands or pockets of solid sulphides could be seen.

During the 1953 electro-magnetic measurements a small indication was discovered in connection with this prospect. It was between 25—40 metres wide and was elongated along the lineation direction (WSW) for about 400 metres from the outcrops of the sulphides. A similar parallel indication was found 100 to 150 metres south of Moskogaissa 125.

Moskogaissa 120. Another sulphide-zone occurs about 200 metres stratigraphically below the main one at Moskogaissa. The only working along this zone, a 2 metre long adit in the south bank of the Rautajok, has been termed Moskogaissa 120. This adit revealed only very weak mineralization. Sulphides are on the whole sparse or lacking along the whole outcrop of this zone, which usually manifests itself as weak rusting in the schists.

In 1953 an electro-magnetic indication was found in connection with this mineralized zone and the following summer two drillholes (R1 and R2) were drilled to test it.

R1 was sited some 70—80 metres from the bank of the Rautajok opposite Moskogaissa 120, and some 60 metres inside the border of the indication. The mineralized zone in this hole consisted of 75 cm. vertical thickness of metasomatic rock, with a 5 cm. pyrrhotite-impregnated band at its base.

The position of R2 was 100 metres south of R1, 40 metres from the bank of the Rautajok, towards the somewhat diffuse southern boundary of the indication. This hole revealed nearly 1½ metres of weak metasomatised rock but no sulphides.

Thus it appears that, west of Rautajok at least, this lower sulphide horizon does not offer any economic possibilities.

Diamond drilling in the Moskogaissa area, 1954. The 1953 geophysical work gave several electro-magnetic indications of ore, mainly connected with the upper sulphide horizon. These are shown on Plate 2. The largest and most definite indication was that found in connection with Moskogaissa 115 mine. In plan it had a ribbon-like pattern, extending from near "Midway Shaft" to the 70-metre high cliffs of Lille Moskogaissa (Photo Fig. 55) in the west, a distance of some 1000 metres. Its width varied from 100 to 200 metres, being greatest in its western part, south and south-west of the old mine workings. The presence of Lille Moskogaissa made it impossible to continue the geophysical measurements for any distance west of the bottom of the mine. However, reconnaissance measurements in the area of the inlier of Upper Brown Schist known as the "Window Area", picked up a ribbon-like indication in apparent continuation of that east of Lille Moskogaissa. It appeared therefore that there was a continuous electro-magnetic indication of sulphides some 4—5 kilometres long and up to 200 metres wide. This followed perfectly the lineation direction of the schists, swing-

Fig. 55. Diamond-drilling, Moskogaissa 1954. Photograph showing exposed drilling position near the foot of the cliffs of Lille Moskogaissa (upper left). The white tent served as core-shed. Note the flat-lying schistosity and bedding in the Upper Brown Schists exposed in the cliffs.

Diamantboringen, Moskogaissa 1954. Fotografiet viser den utsatte borplassen ved skråningen av Lille Moskogaiassa (øverst til venstre). Det hvite telt var «kjerne-hytte». De Øvre Brune Skifre i skrenten viser tydelig den flattliggende skifrighet og lagdeling.

ing to a north-westerly direction in accordance with the structure west of Moskogaissa.

The drilling programme was therefore based on the assumption that this indication represented a ribbon-like plate of sulphides, and it was laid out in order to test the thickness of this possible plate in a systematic manner. From previous knowledge of the behaviour of the sulphides here it was obvious that a fairly close borehole spacing was necessary in order to obtain anything like a true picture of the thickness variations. The maximum borehole spacing which would give the necessary information was reckoned to be 50 metres.

It was necessary because of the topography to confine the season's drilling to the area east of the cliffs of Lille Moskogaissa. The area south and south-west of the old mine workings was selected and it was decided to drill a line of holes down the axis of the anomaly, with one, possibly two, shorter lines at right angles to this. With the financial resources available, it was calculated that a total of twelve holes could be drilled, depths varying between 50 and 100 metres.

The terrain in this area is almost flat, being largely formed of the gravel and boulder fan of the Rautajok after it debauches from the high ground towards Rosejavre. It was apparent that considerable overburden would be encountered during the drilling. However, the depths and nature of the cover proved far worse than any expectations and after several costly and abortive attempts to penetrate it, the original programme had to be abandoned. Depths of up to 25 metres of heavy, "blocky" ground were encountered. It seems that the whole area was originally a depression, probably the corrie of a former glacier, into which the Rautajok had poured an unsorted mass of rock fragments of all sizes, from fine gravel to blocks of schist several metres across. Because of the size and shape, much of the material must be locally derived, and probably originates from the screes along the cliffs which bound the area to the south.

The revised drilling programme consisted of boring holes from the nearest available solid ground so as to obtain as many intersections of the sulphide-zone as possible in the time then available. It might be pointed out here that climatic conditions in this latitude and at the altitude of Moskogaissa limit the field season in normal years to July and August. Even at the end of August the risk of drilling water freezing in the pumps and hoses is not inconsiderable.

In all, seven holes intersected the sulphide horizon within the area of the indication, five of which were drilled from rather exposed positions at the foot of Lille Moskogaissa cliffs. (Photo Fig. 55). The positions of the holes are shown in Fig. 56. Table 26 gives a summary of the drilling.

Fig. 57 is a section drawn through three of the boreholes along the plunge direction of the ore. It shows the position of the ore-zone with respect to the base of the Upper Brown Schist and to the interlayered amphibolites in the upper part of the Ankerlia

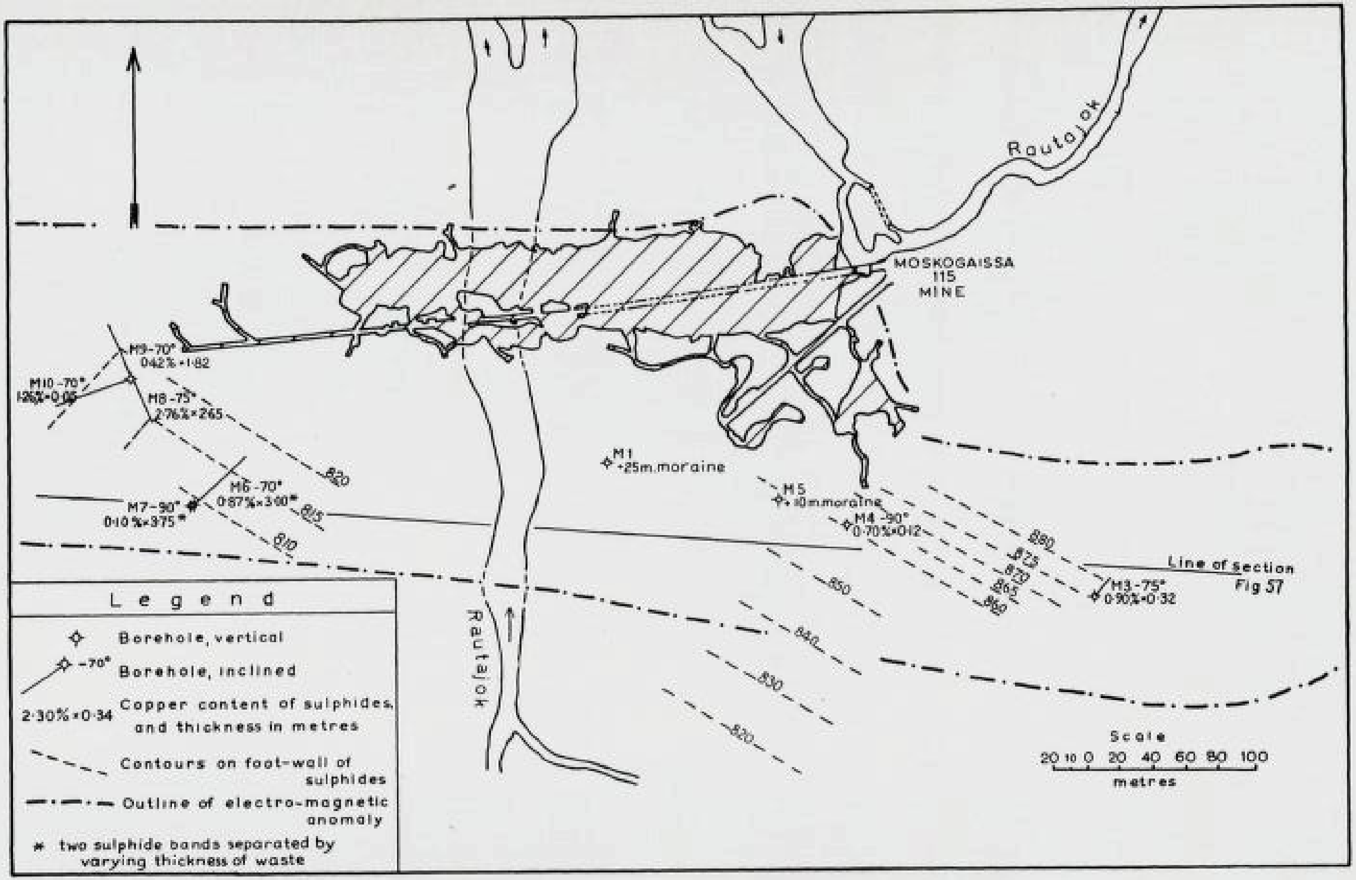


Fig. 56. Diamond-drilling, Moskogaissa 1954. Map showing the positions of the drill-holes, the values of their intersections and their situation relative to the old workings of Moskogaissa 115 mine.

Diamantboringen, Moskogaissa 1954. Kartet viser plaseringen av borhullene og opp-

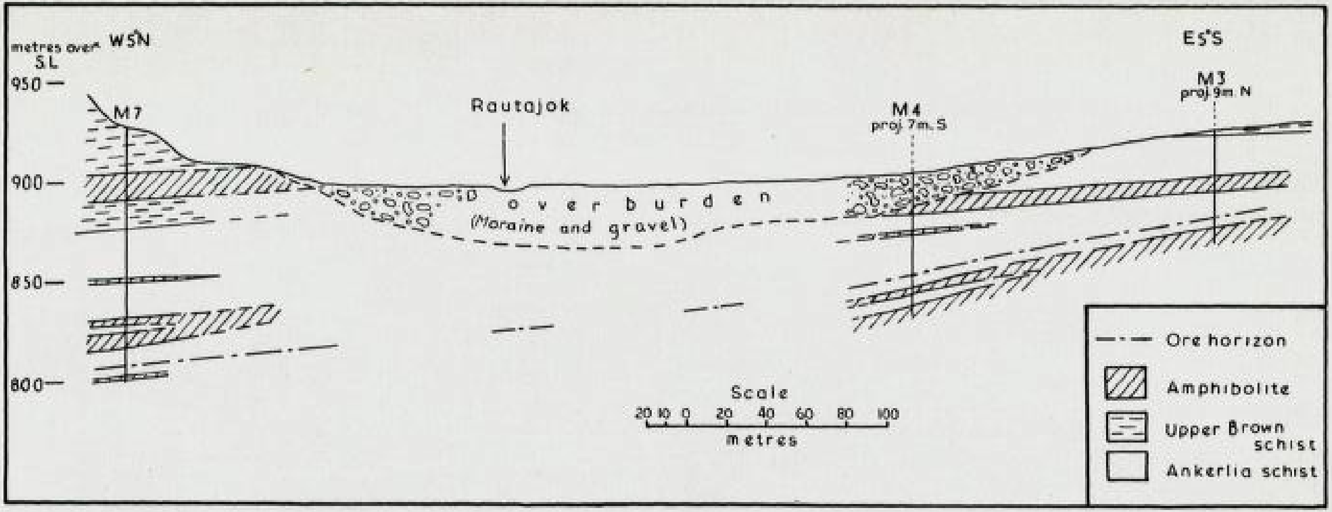


Fig. 57. Moskogaissa sulphide-horizon. Section along the plunge direction south of Moskogaissa 115 mine. See Fig. 56 for line of section.

Sulfid-horisonten i Moskogaissa. Snitt langs lineasjonens retning sør for Moskogaissa 115 gruve. Fig. 56 viser snittets beliggenhet.

Schist. The section illustrates that the ore-zone approaches the base of the Upper Brown Schist in an easterly direction. This has already been previously remarked upon.

As mentioned above two short holes were also drilled in an anomaly connected with the underlying mineralized zone, with negative results.

Hole no.	Total length (m.)	Mineralized zone		Calculated value of zone	
		Thickness (m.)	Copper %	Thickness (m.)	Copper %
M 6	129.94	0.88 1.92 0.20	1.39 0.0 6.94	3.00	0.87
M 7	127.60	0.27 3.14 0.34	0.33 0.0 0.89	3.75	0.10
M 8	115.00	2.65	2.76	2.65	2.76
M 9	110.50	0.18 1.48 0.16	1.80 0.0 2.77	1.82	0.42
M10	128.00	0.05	1.26	0.05	1.26
M 3	57.69	0.32	0.90	0.32	0.90
M 4	54.85	0.12	0.70	0.12	0.70

Table 26. Results of Moskogaissa boring 1954.

These results show that only one hole (M8) out of the seven contained "economic" sulphides. In three of the holes (M6, M7, M9) the splitting of the sulphides into two bands, with barren schist in between, produced an unworkable copper content. In the other three holes (M10, M3 and M4) both width and grade were completely uneconomic.

The drilling results illustrated the extremely erratic nature of the sulphide mineralization, confirming a picture which had been obtained from geological considerations and a study of the old mine records and plans. The drilling was perforce of a very exploratory nature. It was not sufficient to give a systematic picture of the sulphide zone. It did, however, give a good idea of the chances of meeting workable ore, chances which must be considered very slight.

The results were judged to be so negative as not to warrant the expenditure that would be involved in a large-scale drilling-programme to test the anomaly exhaustively. Any possible orebody would have to extend down plunge under Lille Moskogaissa and hole depths to test it would reach several hundred metres, involving very high expenditure.

In view of the smallness of the possible target, such expenditure did not seem justifiable.

The Sabetjok—Birtavarre Høyfjell area.

As can be seen from Plate 1 the old mine at Sabetjok lies on the east side of Kåfjorddalen, almost due east of Moskogaissa 111 mine and some three kilometres distant.

The mine is situated on a sulphide horizon which outcrops as a very prominent rust zone along the very steep eastern walls of Kåfjorddalen, being traceable from north of Ankerlia to a point south of Sabetjok where it goes under cover as the slope of the valley decreases. Fig. 58 is a photograph taken from the opposite side of Kåfjorddalen. The zone has been traced at intervals to the south-east and east to the old working known as Birtavarre Høyfjell, 2 kms. ESE of Sabetjok. At least one, possibly two, minor "rust-zones" are traceable in the schists beneath the Sabetjok—Birtavarre Høyfjell zone. Shallow trenching has taken place at one or two points east of Birtavarre Høyfjell but nothing of economic importance was found.

It will be seen from the maps that the direction between the two workings, Sabetjok and Birtavarre Høyfjell, coincides almost exactly with the lineation direction, or the ore-shoot direction. The old reports from Sabetjok seemed to suggest that the ore was not exhausted before the mines had to close down in 1919. Birtavarre Høyfjell, to judge by the reports, had shown several metres of 2 % Cu ore, which was not amenable to handsorting and direct smelting in the old days, but which might provide excellent concentrating ore. These considerations seemed to point to the advisability of testing the sulphide zone between the two workings to see if there were an ore-shoot between them. Consequently in 1954 electro-magnetic measurements were carried out in the area, and these gave a rather large indication of sulphides. This was tested by 1260 metres of diamond drilling in 1955. Before describing the results of this work, descriptions of the old workings will be given.

Sabetjok Mine. As stated in the section on the history of mining in the Birtavarre area, the discovery of the outcrop of the ore at Sabetjok in the 1890's was the initial step in the exploration and exploitation of the field as a whole. The first record of work on the deposit is dated 1898 when the driving

Fig. 58. Distance view of the eastern wall of upper Kåfjorddalen. Sabetjok mine lies at the top of scree fans on either side of the waterfall. Birtavarre Høyfjell working lies up on the plateau behind, and to the left of, Sabetjok. (Photo P. Parget.)

Østveggen av Øvre Kåfjorddalen. Sabetjok gruve ligger ved toppen av urene på begge sider av fossen. Birtavarre Høyfjell skjerp ligger på platået bak og til venstre for Sabetjok. (Foto P. Padget.)

of adits on either side of the waterfall of the Sabetjok is mentioned, and production is given as 113 tons.

The following year operations at this mine were curtailed and concentrated in the Moskogaissa area. Sabetjok is not mentioned for some time after this.

In 1912 the Bergmester's report mentions a visit to the outcrop of the deposit which was not being worked at the time. A sketch section is given of the outcrop and stress is laid on the quartz-rich nature of the ore.

Work began on the Sabetjok ore again in 1915 using the two original adits as means of access. These adits were situated 140 metres apart along the rust zone, which was, however, considerably longer than this distance. The workable ore seemed to occur in two separate parts, a northerly one and a southerly one.

In the southerly part occurred an 80 metre wide ore-shoot with an easterly elongation and an average thickness of 1 metre. Proved ore in 1919 was stated to be approx. 900 cubic metres.

In the northerly part the ore was more irregularly defined. Its length was about 150 metres of which only 35 metres constituted mineable ore. The ore had been followed down dip for 30 metres and a level had been driven another

Fig. 59. Photograph showing the situation of Sabetjok mine on the steep eastern wall of upper Kåfjorddalen. The outcrop of the ore-horizon is shown dashed. The numbers show the positions of the adits along the ore-outcrop. FW is the adit driven into the footwall rocks. (See fig. 5.)

Fotografiet viser beliggenheten av Sabetjok gruve på Kåfjorddalens bratte østvegg. Den stiplete linje viser utgående av malmsonen. Tallene viser beliggenheten av stollåpningene langs sonen. FW er stollen drevet inn i bergartene i liggen av malmsonen. (Se fig. 5.)

30 metres. The ore along this level consisted of chalcopyrite-impregnated quartz holding 1—1.6 % Cu. It is difficult to correlate this old information with the plan of the mine (Fig. 5). The two parts mentioned could possibly be the "Central" and "South" ore-shoots used in the estimation of ore quantities below.

In order to test the possible continuation of the ore in depth a foot-wall adit was started from the foot of the cliff below the ore outcrop on the north side of Sabetjok stream. This adit had been driven about 50 metres by the time the operations ceased; the ore zone is probably about 70 metres ahead of the face, if it maintains its dip.

Sabetjok is one of the mines in the area which is accessible to underground inspection. Situated high up the steep, almost vertical wall of the valley, it is drained naturally and is practically free from water. The photograph, Fig. 59, shows the mine's situation with the adit entrances on both sides of the waterfall of the Sabetjok, the stream which gives the mine its name. The ore zone has a generally northerly, somewhat variable dip so that most of the workings dip away from the outcrop, especially the northerly part of the mine. As has been seen from the plan of the mine (Fig. 5) working took place in three separated areas, probably representing separate ore-shoots. There is a rough elongation of each of these shoots in the regional lineation direction (here E—W). A rough calculation based on the areas worked and measurements of the height of the old stopes indicates that the following quantities of ore have been won from Sabetjok.

"North ore-shoot"	1400 tons
"Central ore-shoot"	9100 —
"South ore-shoot"	3500 —
	14 000 tons

The "Central" and "South" areas were inspected by P. Padget and the author in September 1953. The north area was inaccessible due to the connecting drive being choked with snow and ice. The walls of the old stopes showed very thin bands of sulphides, in no place were found any remnants of the original ore which was worked. It seems from the inspection that working must have taken place on uneconomic thicknesses of ore before the mine was finally abandoned. This is also shown by the quantities of schist from the foot- and hanging-walls which have been used as packing in the old workings.

Birtavarre Høyfjell working. The prominent outcrop of rusted sulphide-bearing quartz at this place early attracted the attention of prospectors in the area. The outcrop was investigated by trenching and a number of shallow shafts. Old reports speak of a borehole intersecting 10 metres of 2 % Cu ore, but the location of the borehole was not given. Apparently the type of ore was not suited to direct smelting and no production was attempted in the period of activity at the beginning of this century.

Fig. 60 shows the layout of the old workings, together with information derived from the 1955 investigations. The work revealed that there is a body of quartz and quartz-calcite apparently lying conformably in the schists. In the trenches across the outcrop along the south side of the working this quartz body can be seen to have a well-marked foot-wall of softened rusted schist dipping west at 15°—20°. The hanging-wall of the body is not exposed, but the thickness revealed is about 2 metres. A bulk sample taken in one of the old trenches revealed a copper content of 2.74 % (see Fig. 60). Two of the shafts are apparently connected by a now waterfilled drive in the quartz-sulphide body. Fig. 61 is a sketch section along the line of this drive. A bulk sample from the top of the shaft had a copper content of 1.37 %. Due to water almost filling this shaft is not possible to say what the thickness of the ore is here. The shaft itself is 9.80 m. deep (measured by plumbing).

Other shallow prospect pits had been dug north of the outcrop, but to judge by the spoil, they did not intersect any thickness of ore. In 1955 a diamond-

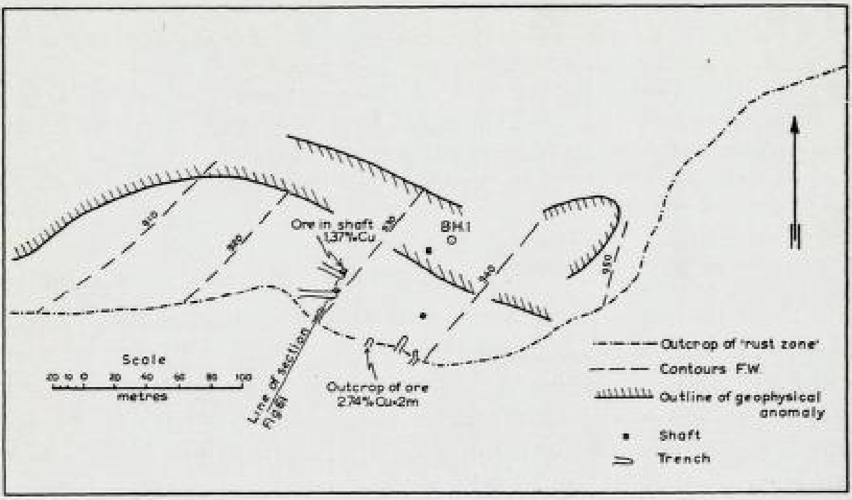


Fig. 60. Sketch map of the workings of Birtavarre Høyfjell.
Kartskisse over Birtavarre Høyfjell skjerp.

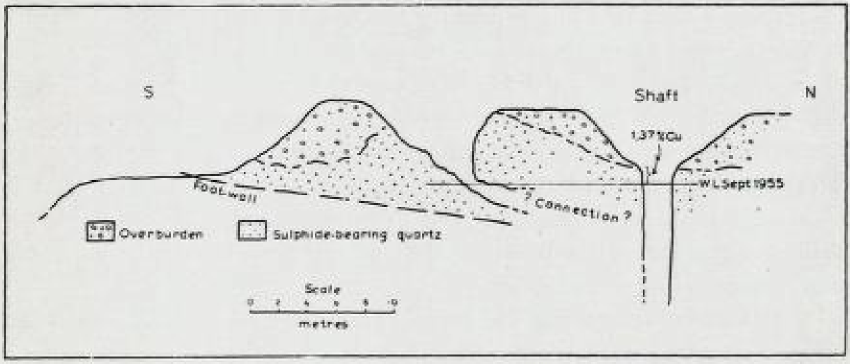


Fig. 61. Section through the southern end of Birtavarre Høyfjell workings. See fig. 60 for line of section.

Snitt gjennom sørenden av Birtavarre Høyfjell skjerp. Fig. 60 viser plaseringen av snittet.

drill hole (B.H.1) was put down a few metres from the most northerly of these two pits. It was located in the centre of a small, but well-marked electromagnetic indication outlined during the 1954 measurements. The hole intersected a 4 cm. thick band of brecciated quartz with pyrrhotite between 4.60 and 4.64 metres. Between 5.80 and 6.07 m. there was a very sparse sprinkling of chalcopyrite as small patches 2—3 mm. in diameter. The hole was continued to 10.10 m. without finding any further mineralization. B.H.1 was located 70 metres from the outcrop and in that distance, or less, the mineralization had diminished in thickness from over 2 metres to 4 cm.

The investigations indicate a rather localized body of fairly rich quartz-sulphide ore. Indications are that it is not more than 100 metres long, 50—70 metres wide and from less than a metre to perhaps 5 metres thick.

To judge from the talus on the slope below the outcrop a great deal of ore has been removed by erosion (cf. Moskogaissa 111).

Diamond drilling at Sabetjok, 1955. The indication outlined by the 1954 geophysical measurements ran eastwards from Sabetjok mine for ca. 1400 metres with a width varying between 300 and 400 metres, having a broad "closed" nose at the eastern extremity. Eastwards from this a small, weak indication ran just down-dip of the outcrop to link with the small closed indication at Birtavarre Høyfjell. 600—900 metres east of Birtavarre Høyfjell another clear indication was found in connection with an underlying sulphide zone.

The drilling programme was based on a total of 1500 metres of core and was laid out primarily to cover the main indication between Sabetjok and Birtavarre Høyfjell. Conditions of overburden were very good and no delay was experienced in this respect. The drilling pattern was laid out to avoid high ground in the centre of the area and so keep the length of each hole as short as possible. The final pattern and the results obtained are shown in Fig. 62. Table 27 gives a summary of the drilling results. The total metres drilled were less than planned due to continual trouble with the machines during the summer.

It will be seen from the table below that both thicknesses and copper contents vary very markedly, yet when these are plotted on the map of the area it is possible to deduce a tendency to a "shoot" of thicker ore elongated in the usual lineation direction. Obviously the boreholes are too widely spaced to provide a complete picture, but by drawing thickness contours (isopachs) between them and interpolating where necessary, it was possible to outline an area where the "ore-zone" was more than 1 metre thick. This area was 6—700 metres long and about 200 metres wide. The maximum thickness, just over 2.00 metres occurred in the east of the area (see Fig. 62). By making use of these isopachs and similar lines of equal grade, it was possible to make a rough calculation of the

Hole No.	Length (metres)	Sulphide zone		Remarks
		Thickness (m)	Cu %	
S1	45.61	0.13	1.72	Alternative 0.44 m × 0.66 %
S2	63.96	2.03	3.02	
S3	77.00	2.07	1.25	Alt. 3.29 m × 0.88 %
S4	105.50			No values
S5	85.78	2.29	0.82	
S6	102.67	1.00	1.55	
S7	60.63	0.28	3.79	
S8	29.40	0.36	1.08	
S9	11.04	1.63	0.94	
S10	79.37	0.67	2.69	
S11	115.67	1.09	1.00	
S12	132.14	1.13	0.44	Alt. 1.72 m × 0.31 %
S13	98.07	0.08	0.29	
S14	122.22	0.13		Not analysed. Very low Cu.
S15	120.13	0.42	0.44	
BH1[1]	10.10	0.04		Only pyrrhotite present
Total	1259.29			

1 At Birtavarre Høyfjell, see p. 215.

Table 27. Diamond drilling results. Sabetjok-Birtavarre Høyfjell 1955.

order of size of "possible ore" in the area. This calculation gave the figures 3—400 000 tons at 1.20 % Cu, average thickness 1.40 m.

The poor results obtained from the boreholes in the western part of the area indicate that there is no connection with the ore formerly worked in Sabetjok mine. The "ore-shoot" found is an isolated one, though the number of boreholes was insufficient to determine whether or not it had any connection with Birtavarre Høyfjell.

As regards the geophysical results, it will be seen that the indication covers a much larger area than the "ore-shoot", and that

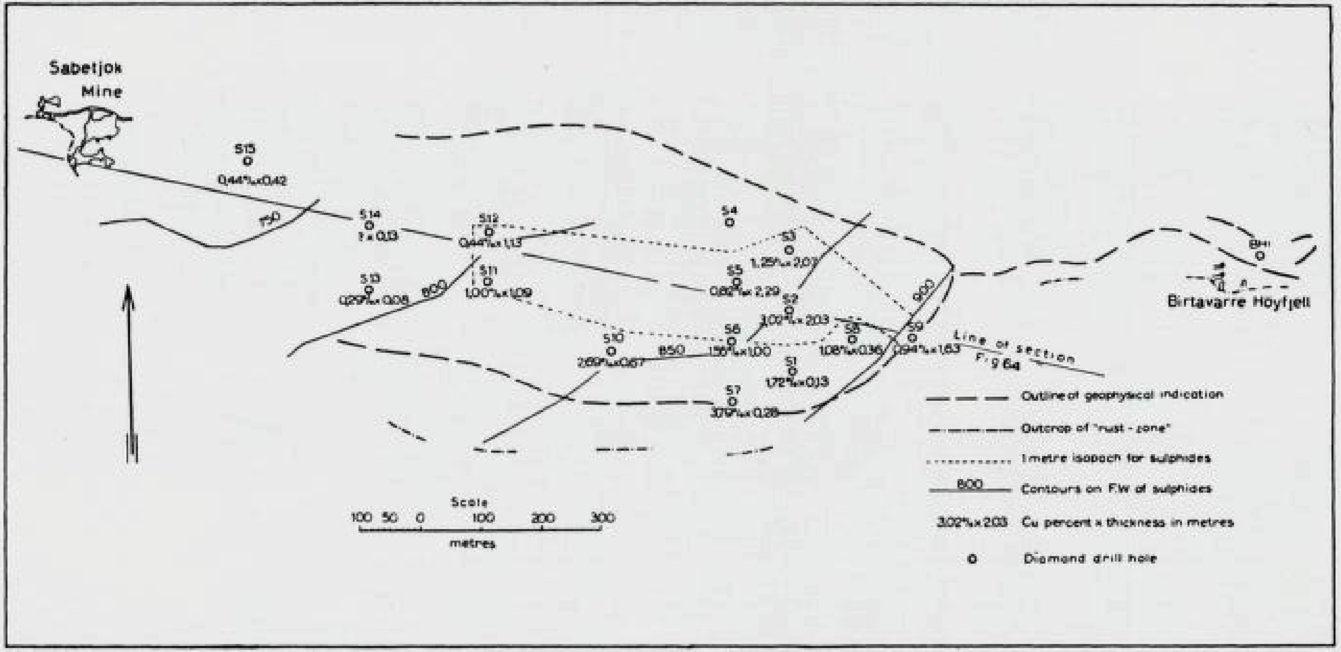


Fig. 62. Diamond drilling, Sabetjok—Birtavarre Høyfjell, 1955. Map summarizing the drilling results.

Diamantboringen i Sabetjok—Birtavarre Høyfjellområdet, 1955. Kartet viser resultatene.

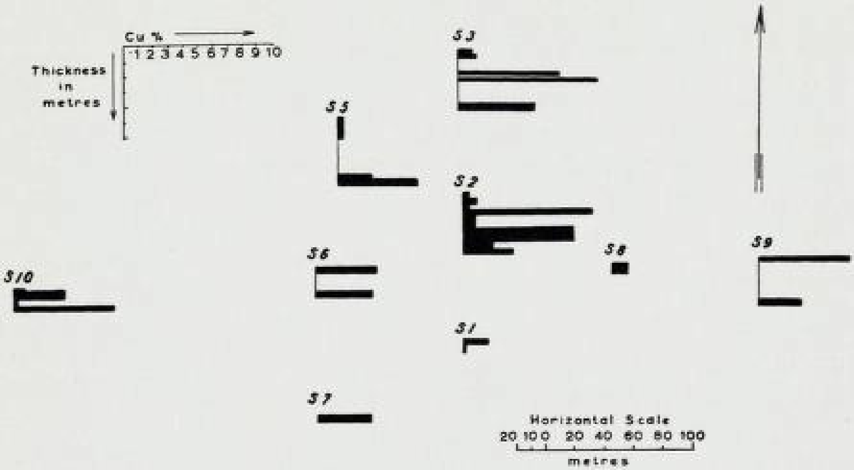


Fig. 63. Diamond drilling, Sabetjok—Birtavarre Høyfjell, 1955. Graphical representation of the vertical variations in copper contents through the ore-zone. *Diamantboringen i Sabetjok—Birtavarre Høyfjell området, 1955. Grafisk framstilling av variasjonene i koppergehalt gjennom malmsonen.*

the presence of an electro-magnetic indication did not necessarily mean the presence of "ore". It did indicate that there was a continuous plate of sulphides, but this could be as thin as 5 cm. It was not possible with the resources available to test the sulphide-zone outside an anomaly. However, the fact the quartz-sulphide ore at Birtavarre Høyfjell did not produce a significant anomaly can be taken as indicating that not all the commercial mineralization is included in the areas of electromagnetic indications.

As regards the drilling results it seems clear that the area will not produce an orebody large enough to justify the capital investment needed for a present-day mining operation. Further, both the thickness and grade of the "ore" are too low for profitable mining, more so when one takes into account the flat dip (15—20°).

From a more scientific point of view the results are of great interest. The tendency of the ore to occur in bands parallel to the schistosity is shown by analyses taken at short intervals along drill cores. Fig. 63 shows these results graphically, illustrating the extreme variations in Cu content between adjacent bands. It shows, too, how the sulphide-zone is often split into two separated bands with completely barren schists in between. In one or two holes, for example S2, the whole zone has been mineralized and the schists between the solid sulphide bands are more or less impregnated by sulphides.

Contours along the foot-wall of the ore-zone are shown in Fig. 62. They show a slightly irregular strike with a general direction N 70° E (70° true bearing) and a dip to NNW between 15—20°. A point of interest is a swing in the contours in the area of drill holes S1, S2, S5, S6. This swing indicated a very shallow syncline or downwarp in the footwall of the sulphide zone. A comparison with the isopach map showed a slight correlation between this feature and the thickest part of the ore zone. Information is not sufficient to be able to develop this comparison and to decide whether it is merely coincidental or of some significance.

Fig. 64 is a section through the sulphide zone drawn along the plunge direction.

Rust zones in the Lower Ankerlia schists in the Sabetjok area. There are at least two zones of rusting in the schists below the Sabetjok—Birtavarre Høyfjell sulphide zone, neither of which seems of much economic importance. The upper one of the two is only seen in a small stream outcrop about ½ km. SE of Birtavarre Høyfjell working and consists of from 1—2 metres of weak rusting, concordant with the schistosity. No sulphides were seen.

The lower one is much more well marked and can be followed for a considerable distance at intervals. It lies about 150 metres stratigraphically below the Sabetjok—Birtavarre Høyfjell zone. It can be first seen in the path leading up to Birtavarre Høyfjell as a zone of sheared rusty schist with occasional patches of sulphides. It outcrops with variable strength in the banks of the stream which runs down to the Lapp camp of Sabetjok. Thence it swings concordantly with the schists to an almost N-S strike until it cannot be traced further, at a point 2½ kilometres NW of Birtavarre Høyfjell working. The zone has been trenched at one or two points. At a place 1½ kilometres almost due west of Birtavarre Høyfjell the trenches show a body of massive, sulphide-impregnated quartz lying concordantly in the schists, here striking N-S and dipping west at 40°.

About 1 kilometre due north of these trenches, two small pits have been dug about 15 metres apart on the outcrop of a rusty zone in sheared green hornblende schist. Poor exposures indicate a thickness of up to 2 metres. In pieces of the spoil were seen irregular spots and lumps of coarse-grained chalcopyrite.

Half a kilometre north again is less than 20 metres of rusty, sheared schist between 10 and 50 cm. thick. This has been trenched shallowly, but does not reveal anything of note.

Fig. 65 is a map of the area showing the "rust-zones" and main workings.

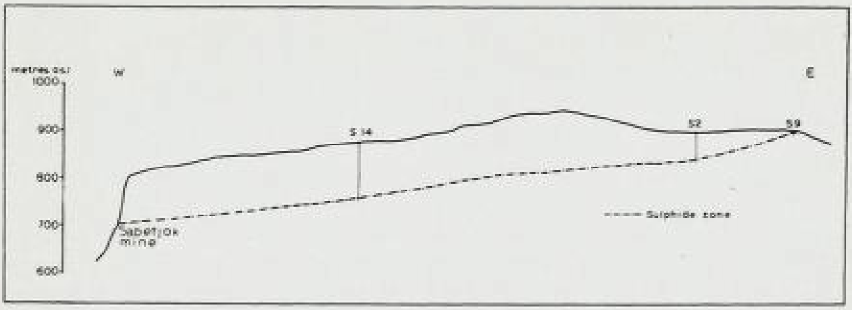


Fig. 64. Diamond drilling, Sabetjok—Birtavarre Høyfjell 1955. Section along the ore-horizon parallel to the plunge direction. Drawn from drilling results and outcrop measurements. See fig. 62 for line of section.

Diamontboringen i Sabetjok—Birtavarre Høyfjellområdet 1955. Snitt gjennom malmhorisonten, parallelt med stupningen av lineasjonen. Tegnet etter bor-resultater og observasjoner på overflaten.

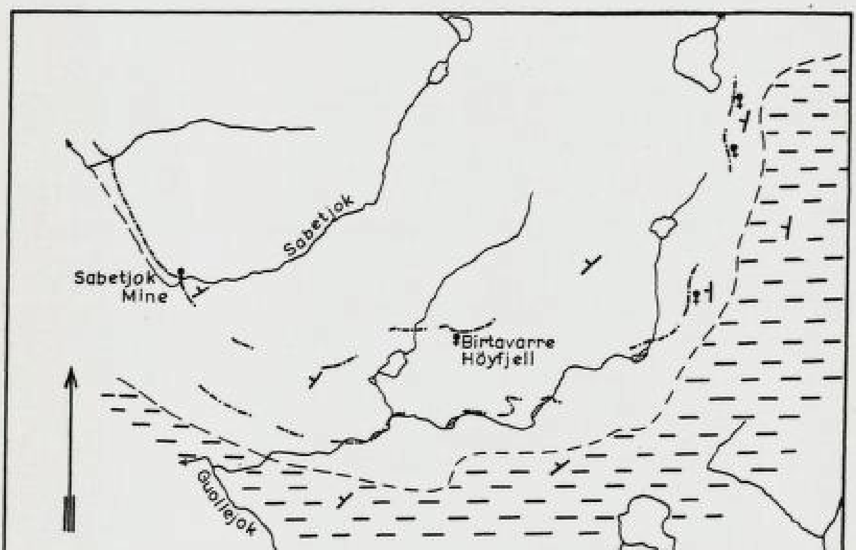


Fig. 65. Map showing the known outcrops of "rust-zones" in the Sabetjok—Birtavarre Høyfjell area. Ankerlia schists shown white.

Kartet viser de kjente «rustsone»blotninger i Sabetjok—Birtavarre Høyfjell området. Ankerlia skifre i hvitt.

Skaide Mine.

This old working lies about 6 km. east of Kilen in Kåfjorddalen and about 10½ km. NE of Moskogaissa 115 (see Plate 1 for location). It is situated on the steep southern slope of a prominent hill which rises behind the mine to a height of about 920 metres above sea level.

The deposit lay somewhat outside the main sulphide belt of the Birtavarre district, and probably for that reason, coupled with the covered nature of most of the ground around the outcrop, it was not discovered and worked until comparatively late in the period of mining.

Skaide was first discovered in 1911 and work was commenced on it in the same year. Between this time and July 1916 18,780 tons of ore at 6.2 % Cu were won from it, but from then until the end of 1918 only 5,300 tons at 4.4 % Cu.

The ore here was stated to be quite a different type from that at Moskogaissa in that it held free quartz — though not as much as at Sabetjok and other places. In addition Skaide held an appreciable zinc content, which had not been met with elsewhere. At the same time the ore was somewhat richer in copper and contained less pyrrhotite.

Reports give the length of the outcrop as 300 metres, of which 200 m. was said to be continuous. Of this length only 70 metres constituted workable ore under the conditions prevailing at the time. The rest showed "concentrating ore" (2—2½ % Cu) which could not be used.

The "shoot" of useable ore plunged in a north-easterly direction within the ore-zone, which as a whole had a dip of 1 in 4 to the north. The thickness varied between a few cm. and 5 metres. The ore was followed along its length by an incline shaft which at 185 metres from the portal met a small fault-slip against which the good ore seemed to have ended. The shaft was driven another 25 metres beyond this and a cross-cut from its bottom hit the ore-zone again, but only as a thin band of sulphide impregnation.

Aronsen and Hunger were not impressed by the mine's possibilities — "the mine must .... be reckoned as emptied of lump ore".

The area around the mine is heavily covered with glacial debris and few geological observations can be made on the surface. The mine is accessible to water level by two incline shafts sharing a common portal. These two shafts are shown on the plan of the Skaide workings in Fig. 4, (p. 29). At the time of the inspection (Aug. 53) the water level stood at a distance of 66 metres from the portal of the more easterly of the two inclines.

The main features of the geology revealed by the underground investigation fit well with the ideas gained from the old reports and show similarities with those seen in Sabetjok mine. The deposit was in essence tabular and gently dipping. The magnitude of dip varies between 5° and 10°. Fig. 4 shows a somewhat irregular ore-shoot elongated in an ENE direction, which is the lineation direction in the schists.

Very little ore has been left as remnants, and for evidence of ore thicknesses reliance had to be placed on the widths of the old stopes. In doing so allowance has been made for the ripping of hanging- or foot-walls to provide stone for packs. Maximum stope widths of 3 metres were found, which may indicate about 2 metres of ore. A rough estimate of the average thickness in the old stoped areas is between 1½ and 2 m.

The mineralogy of the ore has been discussed in a preceeding section. Some macroscopic features may be mentioned now. The only remnants of solid "ore" left for examination occur at the portal of the westerly incline. Here there is up to 70 cm. of sulphides consisting of fine-grained chalcopyrite and pyrrhotite surrounding fragments of vein-quartz and schist. The fragments are obviously a pre-ore breccia involving the Ankerlia Schists and concordant lenses of vein-quartz. They vary in size from fractions of a cm. to 20 cm. It seems that the quartz-rich nature of the ore, which was stressed in the old reports, was due to the fact that the breccia contained so many fragments of quartz from lenses originally in the schists. An extreme case of this has already been described from Birtavarre Høyfjell where the breccia consisted almost wholly of quartz. Nowhere has there been found evidence of a large-scale influx of quartz with the sulphides.

Prospects at Skaide. The presence of water in the mine rendered impossible an examination of the lower levels. In the accessible workings it was obvious that no workable ore had been left by the former miners. The stopes had been driven to the limits of the ore-lenses, in some cases beyond these limits in an effort to find new ore. For all practical purposes the mine above the water level can be regarded as worked out.

The geophysical measurements made at Skaide in 1954 revealed several fairly weak electro-magnetic indications, the chief of which was up to 200 metres broad and about 500 metres long. This lay with its long axis E-W and its southern boundary almost coinciding with the northern edge of the old mine workings.

After due consideration it was decided that the indications found at Skaide did not warrant the expenditure of money for diamond-drilling. The resources available were concentrated on the much clearer and stronger indication at Sabetjok, as has been described above.

Monte Carlo mine.

This small working lies at an altitude of approx. 450 metres on the steep ridge formed by the intersection of the northern wall of the lower Rautajok canyon with the main valley. It is almost directly above the old smelter site at Ankerlia and some 350 metres higher. The workings consist of three adits driven into the steep hillside along a rather thick zone of sheared rusty schist (sketch plan Fig. 66).

No 1 adit, the most northerly, leads into a room about 20 m. long, 15 wide and some 7 metres high. The adit continues for about 15 metres beyond the room.

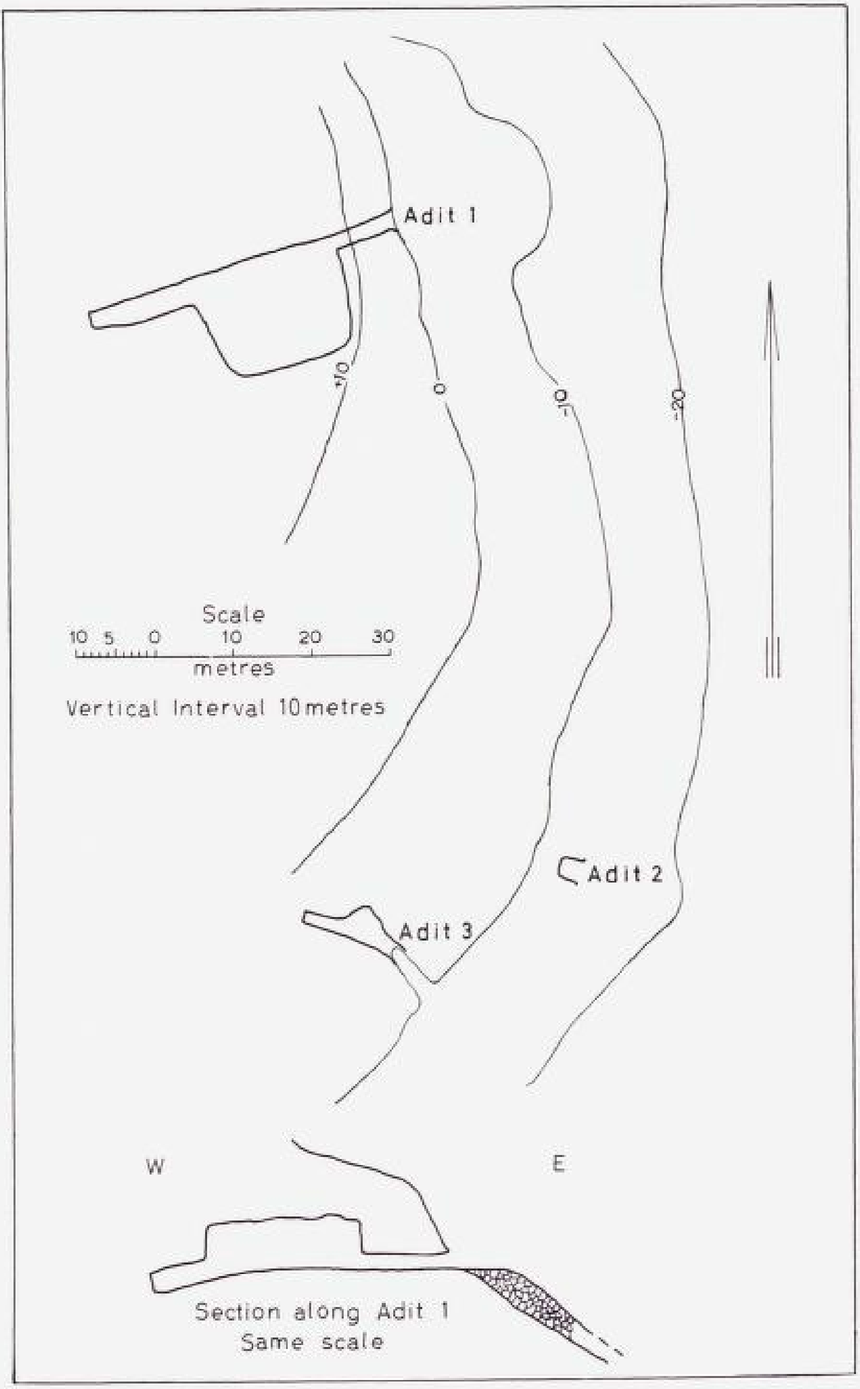


Fig. 66. Sketch of the workings at Monte Carlo mine.
Kartskisse av Monte Carlo gruve.

No 2 adit, 85 metres SSE of No 1, is only about 2 metres long and has been driven in a zone consisting of rapid alternations of garnet—chlorite schist and dark amphibolite schist. Little sulphide mineralization can be seen.

No 3 adit, the most southerly, 90 metres south of No 1, leads into a small stope about 5 × 3 metres, with a drive leading off to the NW. The eastern wall of the stope and drive seems to consist almost solely of fine-grained sulphide, chiefly pyrrhotite.

The sulphide zone at this place appears to be stratigraphically in the Lower Ankerlia, according to Padget's map of the central Birtavarre area (1955, pl. 2). On this map Monte Carlo is shown lying below the Banded Ankerlia schist.

About 200 metres in altitude lower than Monte Carlo, and about ½ km. north of it, there is a small open-cut in another mineralized zone. This shows about 7 metres of highly sheared and folded rusty schist with irregular semi-concordant lenses of vein-quartz. The zone is folded into tight symmetrical folds of amplitude 10—20 cms., with an axial direction of S40°E. Bands of lustrous, foliated chlorite are developed in the zone, which is irregularly and sparsely disseminated with copper sulphide. Small garnets are scattered throughout in fair abundance.

The mineralization is obviously of minor importance here.

Borsejok Mine.

This minor working also lies on the west side of Kåfjorddalen about 2 kilometres NW of Ankerlia at an elevation of about 190 metres, about 100 metres above the valley floor. The mineralized zone here has been explored by a small open-cut "bench" from which lead two adits. One, the more southerly, is only 2 metres long. The other, at the north of the bench runs horizontally for about 15 metres before dipping at an angle of 26°. 5 metres after the change of dip the incline was filled with water (Sept. 1953)

The mineralization here seems to be an irregular sulphide impregnation of an extremely crushed and sheared zone in the Lower Ankerlia Schists. Blocks of unaffected schist up to one metre across occur mixed up in the highly sheared zone, the thickness of which varies from 1 to about 4 metres.

The Skardalen—Mandalen area.

Some 8—10 kms. NW of the Moskogaissa area, an "ore-horizon" outcrops in the steep sides of the deeply-eroded valley of Skardalen, and on the western slopes of Mandalen (see Pl. 1).

In Skardalen ore was won from two mines on the western slopes of the valley, while small "diggings" occur in two or three other places. In Mandalen the single prospect was not taken beyond the shallow, surface-pitting stage.

The stratigraphical relations in this area have been discussed previously (p 19). From the map, Fig. 1, it will be seen that the sulphide-horizon shows a broad, open anticlinal structure with an axial direction of about N30°W. The north-easterly limb, especially at Skaidičokka, has a steeper dip than the south-westerly one.

Individual prospects. The following mines and prospects have been investigated during the present work (in August and September 1953).

1. Brattfjell mine. A formerly productive mine accessible by four adits driven into the steep west side of Skardalen about 300 metres above the valley floor and some 3 kms. from the sea.
2. Skarfjell mine, some 1½—2 kms. north of Brattfjell along the valley side but about 200 metres lower in elevation. This small working is accessible by a horizontal adit driven into the foot-wall of the ore-zone.
3. Toppfjell "prospect", on the steep southern slope at the mouth of the valley. It is merely the beginning of an adit on the ore-horizon which here is entirely uneconomic in appearance.
4. Skaidičokka "prospect". The ore-zone is exposed in the sides of the stream coming down from Bävlajavre, at an elevation of about 490 m. In several places, notably south of the stream, shallow pits or trenches have been dug through overburden to expose the ore-zone.
5. Akkavagge, Mandalen. A very weakly mineralized zone is exposed for a length of about one hundred metres and has been tested by shallow pitting.

It is considered that none of the prospects investigated in the area under consideration shows very great economic promise. Of the three last named in the above list, Toppfjell and Akkavagge can be ruled out on the surface showing. Skaidčokka exposures were slightly more promising, but the steep nature of the ground practically rules out any possibility of undertaking a geophysical survey or of drilling with holes of economic length. Further trenching along the strike would be not too difficult, but ore thicknesses greater than the ones already exposed would have to be found before any underground exploration could be warranted.

The two former mines, Brattfjell and Skarfjell, have apparently been driven to the limits of the ore-bodies, in common with the other mines inspected in the Birtavarre area.

Brattfjell Mine. The ore-zone at Brattfjell outcrops at the base of a vertical cliff high on the steep western slopes of Skardalen. It has a strike length of 140 metres and in elevation varies from 625 metres at the southern end to 590 at the northern.

Along the zone four adits have been driven into the cliff. Of these the most important is the most southerly one, giving access to the main incline of the mine ("Tuna sink"), from which an aerial ropeway carried the ore down to the dumps in the valley floor 300 metres below.

The incline dips initially at about 25° along a bearing of about N60°W. This dip varies down the incline, flattening and then steepening to a value of about 30°. At intervals horizontal drives have been turned off the incline, giving access to the stopes.

Just inside the entrance a raise has been driven 5—6 metres vertically into the hanging-wall in an unsuccessful attempt to find an ore-zone at a higher level.

The zone affected by the ore formation is about 5—6 metres thick, and within it the rocks are stained yellow and brown and often softened and partly decomposed. The zone contains several planes of shear, parallel to the schistosity, which are characterised by the development of a coarse-grained brown biotite schist from the normal grey quartz-hornblende schist of the wall rocks. Sulphides are not at all obvious in the outcrop and are confined to thin stringers in certain shear zones, and sometimes in joints. The mineralogy is the same as for the region as a whole, i.e. pyrrhotite and chalcopyrite.

The incline seems to have been driven along a very irregular zone of shear, carrying stringers of sulphide varying between about 5 and 20 cms., though in places irregular clumps of much bigger dimensions occur.

Due to lack of illumination the extension of the incline and the stopes opening off it were not examined, except in one place where the drive connecting the incline with the next adit north was followed. This drive opened into an old stope with an extremely flat, smooth roof, the strike of which varied from S80°E to N50°E.

Brecciation of the country rock occurs in places in the ore-zone, with the sulphides filling-in the spaces between the fragments.

Fine-grained garnet-rock with garnets ca. 0.5 mm. in dimensions developed in places in the ore-zone.

At Adit No 2, about 40 metres north of the main incline, the mineralized zone occurs as a thin stringer of sulphides, now mostly converted to limonite, overlain by about 3 metres of yellow-brown metasomatic rock of medium to fine grain size. This is sharply differentiated from the altered banded schists above by a marked plane which could be a plane of subsequent movement. The section is sketched in Fig. 67.

Similar relationships are seen in the next adit, No 3, where there is a band of ore, 5 to 10 cm. thick, underneath 2—3 metres of the garnet rock.

At Adit No 4, the mineralized zone is much less strong, and is represented by a zone of rust, 1—1.5 metres thick, with only a few sparse sulphide grains.

Skarfjell Mine. This small working lies at about 400 metres over sea level, near the top of the thickly wooded slopes rising from the west bank of the Skardalselv about 1 km. from its mouth.

The workings are entered by a horizontal adit driven ca. 1½ metres square into the foot-wall rocks about 5 metres below the outcrop of the ore-zone. These foot-wall rocks are grey and brown fine-grained quartz-biotite-hornblende schists, with small concordant quartz lenses.

The adit strikes the ore-zone at about 13 metres from its portal and a raise has been driven up the dip of the ore-zone to outcrop.

In the outcrop and the sides of the raise the mineralized zone is of very variable width, varying between 5—50 cm. and is apparently concordant with the surrounding schists.

The ore-zone is a band of brecciated and sheared schist and quartz which has been infilled by the sulphides. (See sketch Fig. 39). Metasomatic alteration of the schists above the sulphides has produced up to 20 cms. of garnet-anthophyllite rock. The garnets vary in size between 0.5—1 mm. The foot-

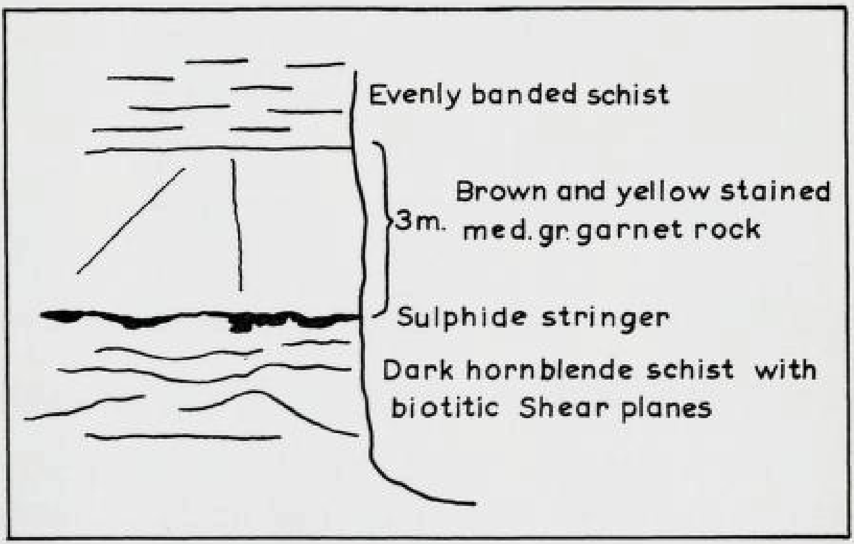


Fig. 67. Vertical section through the outcrop at Brattfjell mine, Skardalen.
Vertikalt snitt gjennom malmsonen ved Brattfjell gruve, Skardalen.

wall schist is in many places softened and stained yellow, but this may be a weathering effect, and not due to the ore mineralization. The shearing and crushing of the rocks may have helped in this softening too.

The rock on the hanging-wall is notably banded, alternate layers consisting of fine dark-grey quartz schist, and a lighter, more micaceous type.

Topfjell prospect. The ore-horizon has been tested by the beginnings of a small adit on the wooded slopes south of the mouth of Skardalselv at a height of 200 metres over sea level.

The small "pit" has been excavated in dark-grey, banded quartz-biotite-hornblende schists similar to the country rocks at the other mines.

At the bottom of the exposure is an indefinite band about 1 metre thick, sparsely rusted and carrying odd irregular patches of chalcopyrite. Due to collapsed overburden and rock it is not possible to say if this zone extends beneath the floor of the adit or not.

In a narrow band about 10 cm. thick near the top of the rust zone the schist has been sheared and is heavily biotitic. In parts this shear zone carries spots of sulphides. This shear zone obviously represents the plane of movement which has localized the ore horizon and which is present as a zone of breccia and sheared schist at Brattfjell and Skarfjell. It may be that the movement was less intense here, or that the nature of the schists was such as to take up the movement more plastically.

Toppfjell does not seem to hold much prospect of immediate ore and the heavily wooded and steep nature of the ground would make prospecting difficult and expensive.

Skaidičokka prospect. The ore-horizon is exposed at an elevation of about 490 metres on both sides of the stream falling down from Bävlajavre. It can be traced in outcrops and surface pits for some distance both north and south of this stream. To the north it crosses a second small stream and then disappears under the scree and moraine covering the steep eastern slopes of Skardalen.

On the immediate north bank of the stream the mineralization has a true thickness of about one metre and is apparently conformable to the strike and dip of the enclosing schists. The ore is the characteristic chalcopyrite-pyrrhotite ore, of varying richness. In texture, the sulphides are compact and medium-grained, with the copper mineral occurring as irregular patches and specks in a groundmass of more or less solid pyrrhotite.

In general the latter mineral predominates. The zone consists essentially of a breccia which is infilled by the sulphides and the richness of the ore is dependent on the amount of fragments present — in general the solid sulphide ore is less abundant than ore consisting of breccia with sulphides scattered through more sparsely.

The fragments of the breccia are mainly schist, often with fine-grained garnets, vein-quartz and occasional individual garnet crystals. Towards the walls the sulphides become more scattered and disseminated through the schists, though in places there is a sharp junction between the mineralized rock and the wall rocks.

The fragments of quartz are rounded in nature and are probably derived from the concordant vein-quartz lenses in the schists.

The walls of the mineralization are well-defined in the richer parts of the outcrop and there seems to be no sign of movement along them.

The ore-horizon can be traced north towards the second small stream as occasional outcrops of rusted schist, often with thin stringers or small patches of sulphides. The width of mineralization decreases to between 5 and 10 cm. and by the time it crosses the second stream it is under 5 cm.

Patches of rust north of the stream indicate further extension, but a thick mantle of drift on the slopes makes it imposible to say how far north the mineralization extends.

The impression is given that there is another small locus of mineral deposition with its centre at about the stream coming down from Bävlajavre. The greatest thickness of sulphide observed is about one metre and this decreases fairly rapidly along the strike in each direction. The ore is not particularly rich — certainly not rich enough to bear working at a width of one metre.

As to extension underground, there is no reason to suspect that this "deposit" does not obey the regional rule of being elongated in the direction of lineation. This latter has a value of S20°E at the stream, so any ore body, if present, would plunge into the hillside from the stream in this direction.

Exploration might be undertaken by diamond drilling from the hillside above the ore-zone, but could not be carried very far due to the length of holes which would be required to reach the ore-zone from the steep hillside. It is debatable whether the prospect warrants the transport of a machine up Skardalen and its employment on the difficult, steep slopes. Skaidičokka seems to be the only place in Skardalen that could be prospected by diamond drilling methods.

Akkavagge. The ore-horizon outcrops again on the western slopes of Mandalen just to the south of the river coming down from Akkavagge (Kjerringdalen). It is approached by a footpath leading from the road bridge over the river just beyond the "bygd" at Kjerringdalen.

The mineralization extends south from the steep banks of the river for about 80 metres and has been tested by a series of shallow pits, about six in all. The pits reveal a very poor pyrrhotite mineralization associated with sheared and brecciated schist and vein-quartz. Chalcopyrite is scarce and mainly occurs as small stringers in the vein-quartz. The pyrrhotite is quite fine-grained where it occurs as compact patches.

There are no garnet-amphibole rocks. Dark brown biotite is very abundant in the ore-zone especially in the sheared parts. Biotite and vein-quartz often form a ribbon-type structure probably due to shearing, and the sulphides are disseminated through it in irregular stringers.

In the largest of the pits dug on the zone of mineralization, about 40 cm. thickness of the zone is revealed. The main mineralization was a patch or clump of fine-grained, compact pyrrhotite ore with practically no chalcopyrite. On the hanging-wall side of this patch is a width of parallel layers of white vein-quartz and foliae of dark brown biotite which carries chalcopyrite as irregular stringers and patches. This type is repeated again in a thin band beneath the compact pyrrhotite.

The contacts between the ore-zone and the wall rock are mostly sharp and very few effects, either crushing or mineralization, extend much outside the zone.

Brennfjell working (Skibotndal).

This consists of an irregular trench, about 2 m. wide by 1—1½ m. deep and 30 m. long, running in an approximately E—W direction. About 10 m. from the east end of the trench and slightly south of it, is a water-filled shaft about 3 m. wide The spoil from this shaft contains much dark-grey quartz-biotite schist with vein-quartz bands. There is also much of the amphibolite, often with thin quartz-carbonate veins.

The strike of the schists in the trench is roughly E—W with a dip to the north between 50° and 60°. This is much higher than the dip of the enclosing rocks in general, showing the mineralized zone has a cross-cutting relationship, locally at least.

The schists consist of rusty quartz-biotite and hornblende schists with bands rich in garnet and anthophyllite. The sulphides (pyrrhotite and chalcopyrite) occur as irregular bands and dissemination layers parallel to the schistosity. In no place did there appear to be any solid sulphide, or breccia ore. The whole trench exposure is a zone of intense shear in the schists and amphibolite which has been weakly impregnated with sulphides.

The importance of Brennfjell is certainly more scientific than economic. It shows the southwards continuation of the Birtavarre-type mineralization at the same stratigraphic horizon and provides a link between the Birtavarre area and the small deposits of the same type to the south-west in Signaldalen.

Reisadalen.

A small working occurs on the upper western slopes of Reisadalen, about 2½ km. west of Bergbukt. This was examined by Padget in September 1953, and the following account is taken from his field-book.

The working is situated at an altitude of about 500 m. a.s.l. on the south side of a steep gully running down to the main valley.

The working consists of a single incline, with a gradient of about 15° driven into the side of the valley along a direction of S40°W. After about 5 metres the bearing changes to S60°W, for another 20 metres. The incline is about 2 m. high, but down the incline water covers the foot-wall to an increasing depth rendering the lower reaches inaccessible.

The wall rocks are Ankerlia Schists, about 100 m. above the Banded division. The "rust-zone" outcrops for about 20 m. on the south side of the gully only and is about 1½ metres thick at the portal. The sulphides occur in a band 20—30 cm. thick a little above the portal. They consist mainly of disseminated chalcopyrite. A 5 cm. band of soft gouge-like clay occurs immediately above the sulphide band. The band dips more steeply than the incline, so that after a few metres it can be seen in both sides of the tunnel; further down it cannot be inspected because of water.

The spoil heap is not very extensive. It shows a few blocks of more solid pyrrhotite and chalcopyrite.

SAMMENDRAG.

Kopperforekomster i Birtavarre-området, Troms.

Det foreliggende arbeid meddeler de malmgeologiske resultater av NGU's undersøkelser i Birtavarre-området 1952—55.

Den regionale geologiske stratigrafi og struktur er beskrevet av en annen av NGU's geologer, P. Padget (NGU, Nr. 192, 1955), og denne avhandling bruker en del av Padgets resultater som et grunnlag for en diskusjon av malmforekomstene og deres dannelse.

Rapporten er delt opp i tre hoveddeler:

1. En innledning (Introduction), hvor områdets beliggenhet, klima, kommunikasjoner osv. er beskrevet, og med en kort historikk over NGU's feltarbeid.
2. Malmforekomstenes geologi.
3. Gruvedrift i Birtavarre-området.

Malmforekomstenes geologi. Den geologiske kartlegging viste en tydelig sammenheng mellom malmkroppenes opptreden og områdets stratigrafi og struktur. De forekommer utelukkende i en bestemt bergartsformasjon i de kaledonske skifre som danner hele området fra den finske grense til sjøen. Denne formasjon har Padget kalt Ankerlia Serien, og den har en tykkelse loddrett lagdelingen av fra ca. 200 til over 1000 m. Den er tykkest i Kåfjorddalen—Moskogaissaområdet (se Planche 1) hvor den består av tre avdelinger.

Øvre brune skifer (Upper Brown Schist)
Ankerlia skifer (Ankerlia Schist)
Nedre brune skifer (Lower Brown Schist)

I dette (centrale) området forekommer malmkroppene bare i Ankerlia skifrene. Vestover, i Skardalen, Mandalen og Skibotn-

dalen, tynner Ankerlia Skifrene ut, og de øvre og nedre brune skifre kommer sammen og kan ikke adskilles. Her forekommer malmkroppene bare i disse brune skifre. Etter at kartleggingen var foretatt, kunne de videre malmundersøkelser konsentreres i områder innenfor Ankerlia Serien.

Den geologiske struktur har en tydelig kontroll over malmkroppenes opptreden. Planche 1 viser foldestrukturene i området, og det vil sees at de fleste gamle gruver og skjerp ligger langs en SV-NØ-gående antiklinal (Moskogaissa anticline) som krysser den store Kåfjorddalen synklinal i nesten rett vinkel. Skaide gruve er den eneste som ikke ligger på denne antiklinal. Gruvene i Skardalen og Mandalen ligger langs en NV-stupende antiklinal som er en fortsettelse av strukturene i Moskogaissa-området.

Planche 2 viser «lineasjons-retningen» i bergartene, dvs. retningen av småfoldinger, glidestriper og av hornblende-nålenes lengste akser. Denne viser at de fleste malmkropper forekommer i det området hvor «lineasjonen» svinger fra den vanlige NV-retning til en som er mer Ø—V. Selv Skaide gruve ligger i dette «strukturelt anomale» området.

Planche 2 viser også en fast regel for malmkroppenes opptreden i området. En typisk malmkropp er formet som en uregelmessig «plate» med én akseretning mange ganger lenger enn den andre. Denne lengste akse er alltid parallell med lineasjonsretningen i de omgivende bergartene. Platenes horisontale dimensjoner varierer sterkt. På den ene side var den gamle Moskogaissa gruve 115 drevet på en malmkropp 300 $\times$ 60 m., og Skaides malmkropp målte 200 $\times$ 80 m.; på den annen side fantes det en rekke små gruver drevet på malmkropper som bare var noen få kvadratmeter i areal. Tykkelsen i en enkelt plate varierte sterkt fra nesten ingenting opptil 4-5 meter.

Malmkroppene forekommer langs visse nivåer i Ankerlia Serien, de såkalte sulfid-horisonter, eller malmhorisonter. Kartlegging viser at de fleste av sulfid-horisontene i det centrale området ligger i øverste delen av Ankerlia skifrene.

Petrologiske og kjemiske undersøkelser av bergartene som omgir malmkroppene er beskrevet på s. 40—s. 68.

Sidebergartene deles opp i:

a) Hornblende-(biotitt)-kvarts-plagioklas-førende skifre av sedimentær opprinnelse, nå metamorfosert i amfibolitt- eller epidotamfibolitt-facies. De var opprinnelig urene, sandige sedimenter, ofte med mer leiraktige lag.

b) Amfibolitter. Mørke, forholdsvis massive bergarter, som forekommer i lag opptil 10 m tykke, i veksellagning med skifrene, særlig i Moskogaissa-området. Disse var sannsynligvis opprinnelig basiske eruptive bergarter, (lavaer o. l.)

Detaljerte undersøkelser av diamantborkjerner og de gruver som er tilgjengelige viser at sulfidmineralene har trengt seg inn langs soner i skifrene som var blitt breksjert og delvis oppknust under de siste faser av den kaledonske fjellkjedefolding. Malmene består delvis av rik breksje-malm, delvis av fattigere impregnasjonsmalm. Bruddstykkene i breksjene består av skifer, amfibolitt etc., som er blitt delvis oppspist eller korrodert av sulfidene. Særlig er bruddstykkene av kvarts blitt avrundet under denne prosess. Overgangene fra breksjene til sidebergartene er oftest skarpe, og i mange tilfelle finner man yngre forkastninger langs malm-grensene. Impregnasjons-malmer forekommer ofte i breksje-malmenes ligg eller heng.

Malmmineralene består hovedsakelig av kopper- og jernsulfider. En fullstendig liste over dem, med deres kjemiske sammensetning finnes på side 111.

Mikroskopiske undersøkelser viser at sulfid-mineralene krystalliserte tilnærmet samtidig og at det ikke finnes mer enn én generasjon av malmmineraler. Malmdannelsen antas å ha funnet sted i et temperatur-intervall fra ca. 520° C for de eldste mineraler til ca. 400° C for de yngste.

Ved spor-element-undersøkelser er det ikke påvist metaller som kunne tenkes å gi verdifulle biprodukter under eventuell drift. Magnetkisen inneholder små mengder Co og Ni og kopperkisen litt Ag.

Sidebergartene nærmest sulfidene er blitt omdannet ved kjemiske prosesser som fant sted før sulfidene ble avsatt. Under denne omdannelse (metasomatose) er Ca, Na og K blitt drevet vekk og/eller Mg og Fe er blitt tilført. De omdannete bergarter er meget bemerkelsesverdige i feltet og inneholder store mengder antofyllit og granat — det sistnevnte mineral tildels i meget store individer (f. eks. ved Moskogaissa 111).

Det er forfatterens oppfatning at malm-oppløsningene er kommet fra NV og fra dypet. Malm-bestanddelene er blitt drevet fra dypereliggende bergarter ved kraftige fysiske og kjemiske prosesser under den kaledonske fjellkjedefolding. Mindre skyveplan i Ankerlia Serien har fungert som transportkanaler, og malm-mineralene er blitt spredt ut over store områder av en temmelig tykk lagrekke. Intetsteds fantes det noen struktur som kunne «arrestere» malmløsningene og føre til dannelsen av en større malmkropp. Den veldige utspredning av malm-mineralene til tross for en betydelig malmtilførsel, har vært årsaken til at det ikke er å finne malmkropper som kan gi grunnlag for drift.

Gruvedrift i Birtavarre-området. I siste del av rapporten er det gitt en historikk over gruvedriften i området fra 1900—1919. Deretter følger en diskusjon over de økonomiske faktorer vedrørende mulig fremtidig gruvedrift i følgende avsnitt:

Gruvearbeid (Mining)
Oppredning (Milling)
Undersøkelsesarbeid (Exploration)

Konklusjonen er at drift i området ikke er berettiget med de nåværende og sannsynlige fremtidige priser for kopper. Brytnings- og oppredningsomkostninger pr. tonn vil være like store eller større enn malmens verdi. Det er heller ikke tilstrekkelige mengder malm til å amortisere den nødvendige kapitalinvestering.

Gangen i undersøkelsesarbeidet har vært først geologisk kartlegging og strukturanalyser, deretter geofysiske målinger, og til slutt diamantboring. Arbeidsmetodikken er beskrevet i korthet og diskutert.

I siste avsnitt beskrives de nedlagte gruver og de skjerp som ble befart i forbindelse med NGU's undersøkelser. Her finnes også resultatene av diamantboringer ved Moskogaissa (1954) og ved Sabetjok—Birtavarre Høyfjell (1955); Tabellene 26 og 27 (sidene 210 og 217) gir tykkelsen (thickness) av malmsonen i meter og kopperprosent (copper %) for hvert borhull.

Disse resultater viser de store variasjoner både i tykkelse og kopper-gehalt langs malmsonene. Fig. 63 viser de store variasjoner i vertikal retning gjennom sonen i Sabetjok—Birtavarre Høyfjellområdet.

Konklusjonen er at gjennomsnittsgehalten av malmene undersøkt ved boring er omkring 1 % Cu, og gjennomsnittstykkelsen er ca. 1.5 m.

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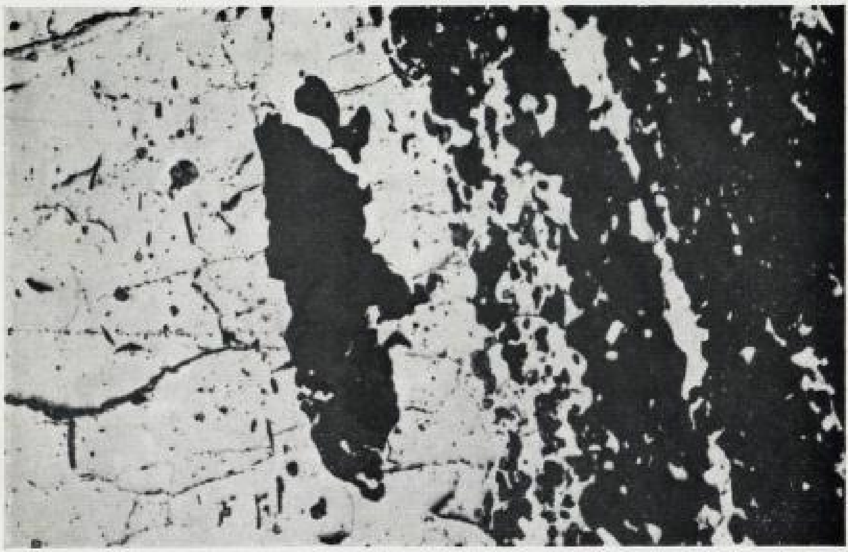
PLATES 4-13.

Plate 4, Fig. 1. "Frozen" hanging-wall of a sulphide band. The compact sulphides (light-coloured) to the left show a fairly rapid transition to an impregnation in the schistose country-rock (dark). DDH M6. Reflected light X 12.

Heng-grensen av sulfid-båndet i borhull M6. De kompakte sulfider (lyse) viser en temmelig rask overgang til impregnasjons-malm i den skifrige sidesten (mørk). Reflektert lys. X 12.

Plate 4, Fig. 2. Footwall to a sulphide band. Normal breccia ore to the left, sulphide-impregnated country-rock to the right. In the centre is a pre-sulphide crush-zone in which the country-rock has been partly reduced to a fine powder. DDH M6. Reflected light. X 12.

Ligg-grensen av sulfidbåndet i borhull M6. Normal breksjemalm til venstre og sulfid-impregnert sidesten til høyre. I midten sees en oppknusnings-sone hvor sidestenen er delvis knust til et fint pulver. Reflektert lys. X 12.



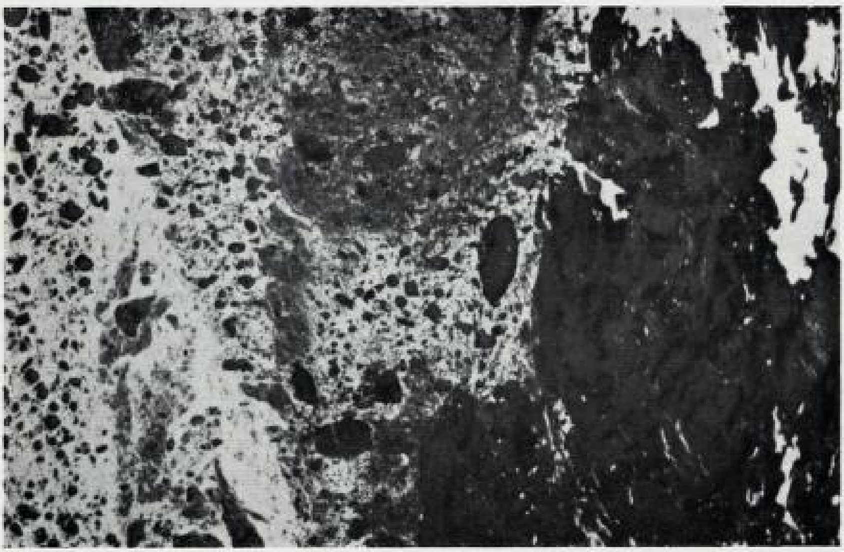
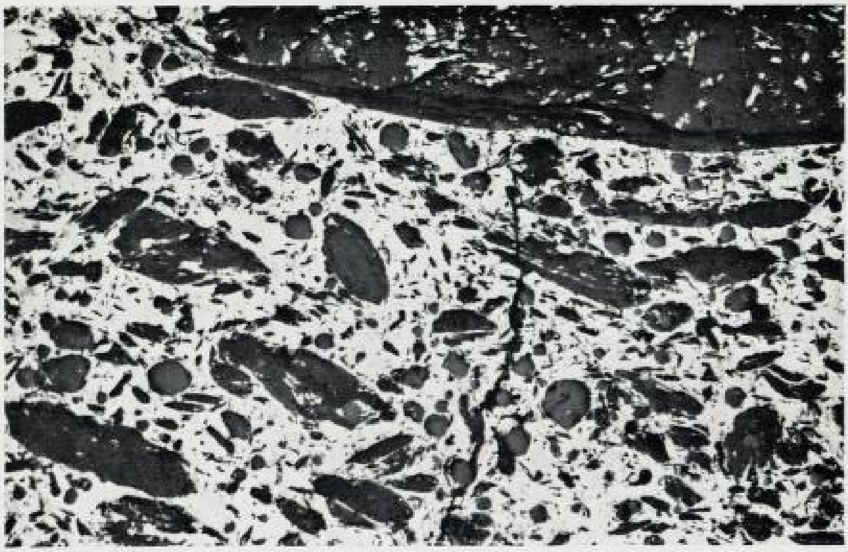


Plate 5, Fig. 1. Typical breccia texture. Sulphides (white), mostly chalcopyrite, cementing and partly replacing elongated schist-fragments, which still retain a certain parallelism to the original schistosity direction. DDH S10. Reflected light. X 12.

Typisk breksje-struktur. Sulfidene (hvite), hvorav kopperkis er det viktigste, sementerer og fortrenger i noen grad langaktige skiferbruddstykker som fremdeles viser en viss parallelitet med den opprinnelige skifrighet. Borhull S10. Reflektert lys. X 12.

Plate 5, Fig. 2. Fine cracks in shattered hornblende crystals (dark grey) infilled with chalcopyrite (white). This texture again indicates relatively little disturbance in connection with the introduction of the sulphides after the initial shattering. DDH M6. Reflected light. X 200.

Kopperkis (hvit) fyller smale sprekker i oppsprukne hornblende-krystaller (mørke grå). Strukturen indicerer at sulfidiseringen ikke har medført nevneverdige forstyrrelser etter den opprinnelige oppsprekning av hornblende-krystallene. Borhull M6. Reflektert lys. X 200.



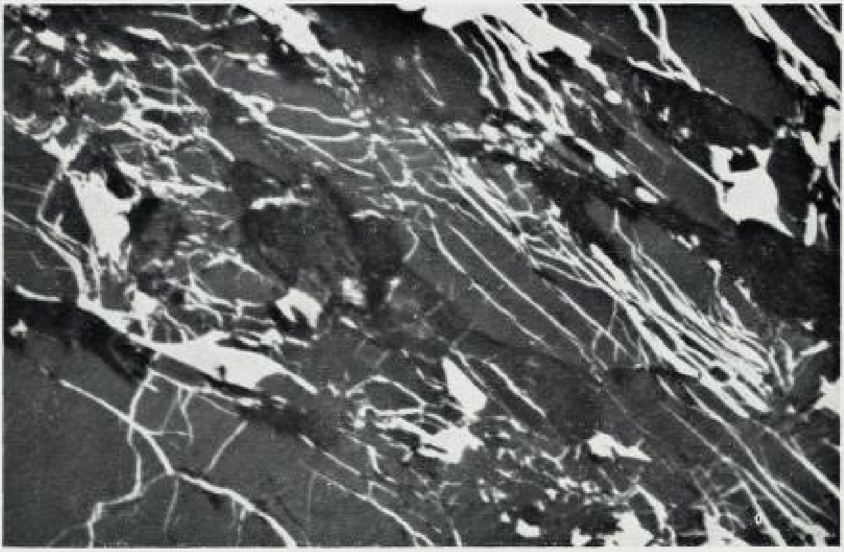


Plate 6, Fig. 1. Rounded, recrystallised quartz "drop" in a breccia of quartz and hornblende fragments cemented by sulphides (black). Moskogaissa 111. Transmitted light. X 11.

Avrundede, rekrystalliserte kvarts-«dråpe» i en breksje bestående av kvarts og hornblende bruddstykker i en grunnmasse av sulfider (sorte). Moskogaissa 111. Gjennomfallende lys. X 11.

Plate 6, fig. 2. Hornblende crystals in sulphide breccia. These crystals show corrosion and rounding-off of their outlines and are considered to be mechanically derived from the hornblende-rich country rocks. Moskogaissa 115. Transmitted light. X 20.

Hornblendekrystaller i en sulfid-breksje. Krystallene er korrodert og har derved fått en avrundet form. Den antas å stamme fra de omgivende hornblende-rike bergarter. Moskogaissa 115. Gjennomfallende lys. X 20.

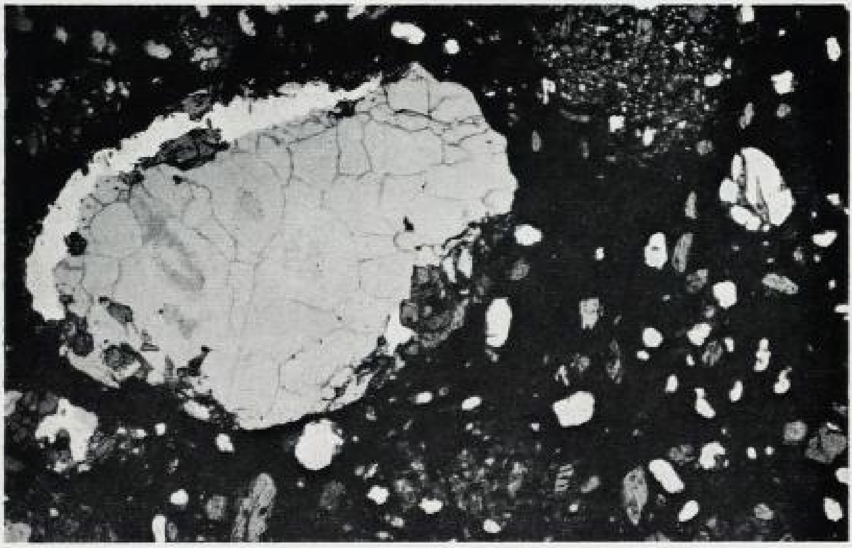


Plate 7, Fig. 1. Fine impregnation of chalcopyrite (white) in schist. DDH M8. Reflected light. X 12.

Impregnasjon av kopperkis (hvit) i skifer. Borhull M8. Refrektert lys. X 12.

Plate 7, Fig. 2. Sulphides (black) partly replacing hornblende schist. The retention of the schistosity indicates a quiet "soaking" of the rock by the sulphides. Moskogaissa 117. Transmitted light. X 12.

Hornblende-skifer delvis fortrengt av sulfider (sorte). Sulfidering har ikke medført noen forstyrrelser av den fortrengte bergarts opprinnelige struktur. Moskogaissa 117. Gjennomfallende lys. X 12.

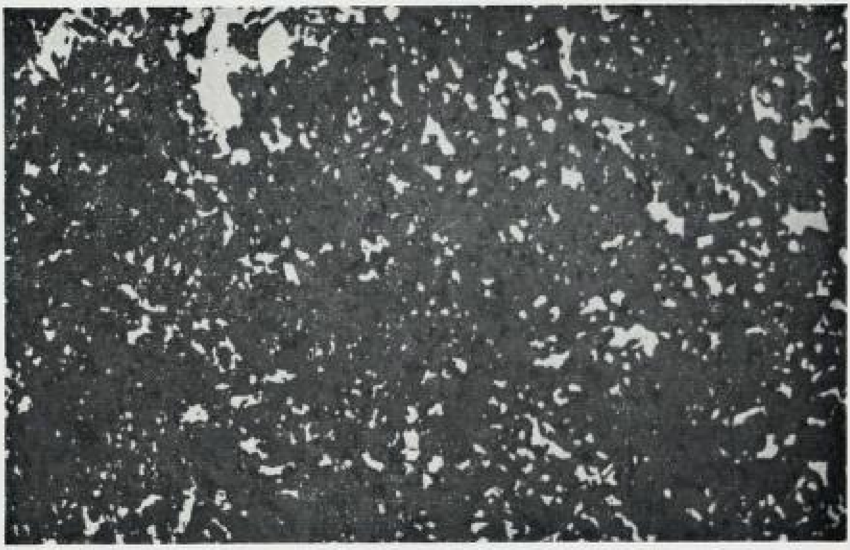


Plate 8, Fig. 1. Partly shattered magnetite grain (grey) in a vein of later chalcopyrite (white) cutting through silicates (black). DDH M6. Reflected light. X 175.

Delvis oppsprukket magnetitt korn (grått) innesluttet i yngre kopperkis (hvit) som gjennomskjærer silikatene (sorte). Borhull M6. Reflektert lys. X 175.

Plate 8, Fig. 2. Irregular veinlets of sulphides (black) in garnet-anthophyllite rock with ragged (replacement) borders. DDH R1. Transmitted light. X 190.

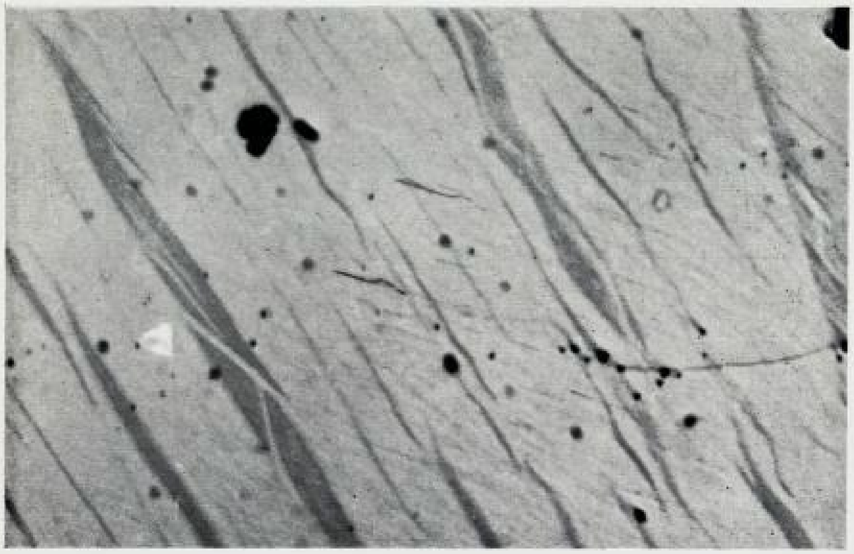
Uregelmessige små årer av sulfider (sorte) dannet ved fortrengning av den omgivende granat-antofyllittbergart. Borhull R1. Gjennomfallende lys. X 190.

Plate 9, Fig. 1. Lamellar texture in pyrrhotite. Brattfjell mine. Reflected light. X 286.

Lamellær-struktur i magnetkis. Brattfjell gruve. Reflektert lys. X 286.

Plate 9, Fig. 2. Flame-like lamellar texture in pyrrhotite. Brattfjell mine. Reflected light. Oil immersion. X 460.

Flammet lamellær-struktur i magnetkis. Brattfjell gruve. Reflektert lys. Olje immersjon. X 460.



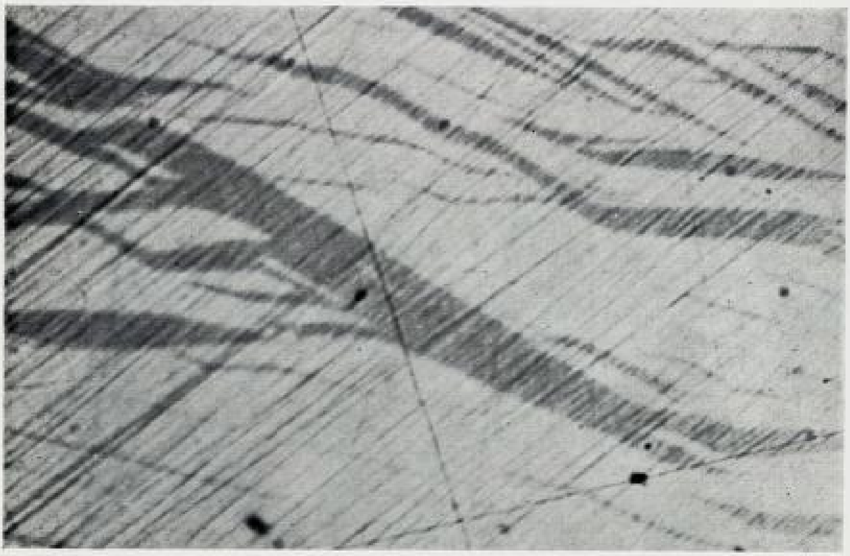


Plate 10, Fig. 1. Vein of pyrrhotite (white) in quartz (black). Irregular tongues of carbonate (dark grey) are replacing the pyrrhotite from the vein-walls inwards. Note parallelism with cleavage of the pyrrhotite. Brattfjell mine. Reflected light. X 255.

Åre av magnetkis (hvit) i kvarts (sort). Uregelmessige tunger av et karbonat (mørkegrått) fortrenger magnetkisen fra grensen av magnetkis-åren og mot midten av denne. Karbonat-tungene er tilnærmet parallelle med magnetkisens spalteretning. Brattfjell gruve. Reflektert lys. X 255.

Plate 10, Fig. 2. Replacement ribs of pyrite (light) developed along the sides of cracks in pyrrhotite which exhibits lamellar texture. Brattfjell mine. Reflected light. Oil immersion. X 375.

Oppsprukken magnetkis med lamellær struktur er fortrengt langs sprekkene av svovlkis (lys). Brattfjell gruve. Reflektert lys. Olje immersjon. X 375.

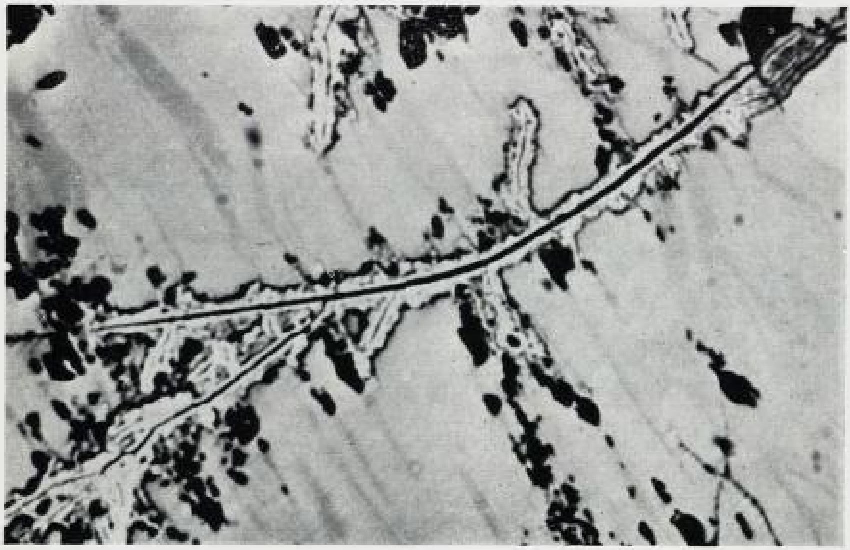


Plate 11, Fig. 1. Typical texture of sphalerite-rich ore. Sphalerite dark grey), chalcopyrite (light grey) and three rounded grains of pyrrhotite (medium grey). Skaide mine. Reflected light. X 130.

Typisk sinkblende-malm. Sinkblende (mørkegrå), kopperkis (lys grå) og tre avrundede korn av magnetkis (grå). Skaide gruve. Reflektert lys. X 130.

Plate 11, Fig. 2. Replacement (?) patch of sphalerite (grey) in chalcopyrite (white). DDH S3. Reflected light. X 240.

Sinkblende (grå) dannet ved fortrengning (?) av kopperkis (hvit). Borhull S3. Reflektert lys. X 240.

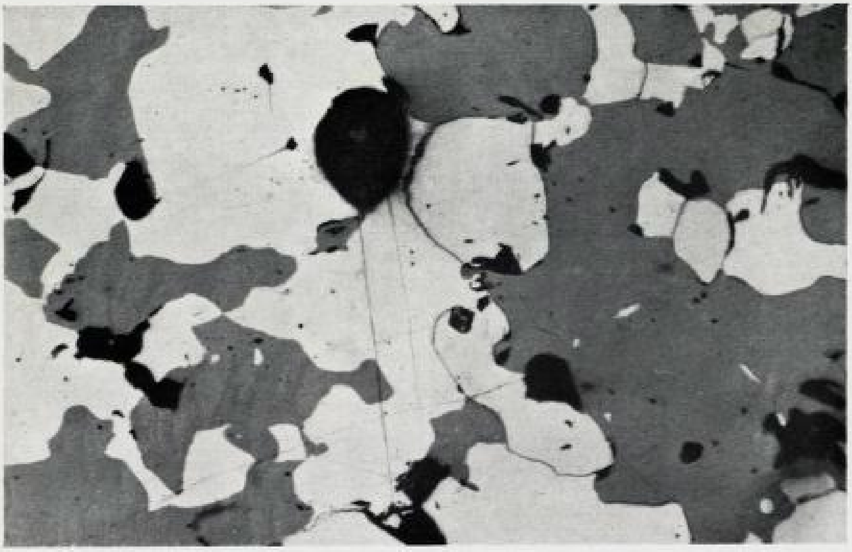
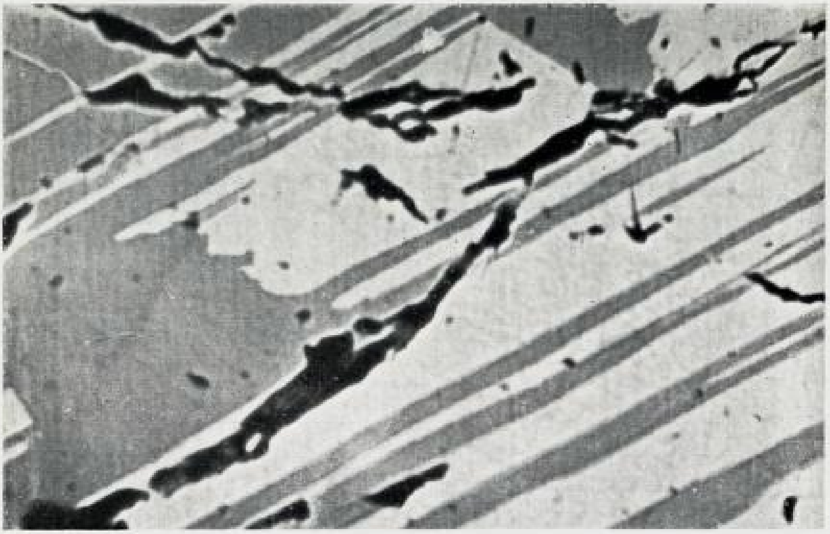


Plate 12, Fig. 1. Cubanite lamellae (dark grey) in chalcopyrite. DDH S2. Reflected light. X 210.

Lameller av cubanitt (mørk grå) i kopperkis. Borhull S2. Reflektert lys. X 210.

Plate 12, Fig. 2. Cubanite lamellae occupying two crystallographic directions in chalcopyrite. Brattfjell mine. Reflected light. X 130.

Cubanitt-lameller parallell to krystallografiske retninger i kopperkis. Brattfjell gruve. Reflektert lys. X 130.



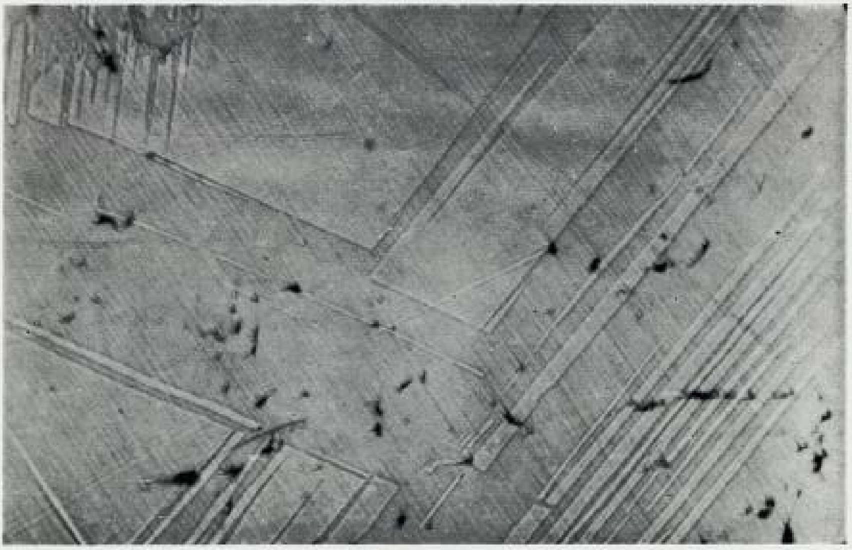


Plate 13, Fig. 1. Cube and less regular grains of pyrite (lightest) in cubanite lamellae within a field of chalcopyrite. DDH S10. Reflected light. X 130.

En terning og noen ikke krystallografisk begrensete korn av svovlkis (lyseste mineral) i cubanitt-lameller i kopperkis. Borhull S10. Reflektert lys. X 130.

Plate 13, Fig. 2. Partly replaced residual of pyrite (light) in field of other sulphides cementing a breccia of country-rock silicates (black). DDH S3. Reflected light. X 130.

Delvis fortrengt rest av svovlkis innesluttet i andre sulfider som danner grunnmassen i en breksje med bruddstykker av silikater (sorte) som stammer fra sidebergarter. Borhull S3. Reflektert lys. X 380.