THE
MASSIVE SULPHIDE DEPOSIT
of
NORDRE GJEITRYGGEN, NORWAY.

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R.S.M.
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SUMMARY

The massive sulphides of Nordre Gjeitryggen occur in amphibolite-chlorite schists which form part of the spilites of the Calaedonian Mountain Chain of Norway. These schists were produced by low grade regional soda metamorphism of the Calaedonian Orogeny. Associated with them are trondheimites and gabbros.

The deposit consists of a series of steeply inclined lenses, probably slightly offset, of massive pyrite with subsidiary pyrrhotite, chalcopyrite, sphalerite, magnetite and, rarely, galena. This is the sequence of deposition except for magnetite which may be contemporaneous with the pyrrhotite. Calcite and quartz are the main gangue minerals and accompanied the later sulphides. Gold and silver occur but are of minor importance.

A replacement nature is indicated by the mineralogy and minor structures, such as the "horses" and the retention of wall rock structures by the massive sulphides. Rock alteration is restricted to the contacts where felspars, micas, calcite, quartz and sulphides have the greatest development. The metasomatism is sodic in character and is probably related to the regional metamorphism.

The controls of deposition were dominantly structural.

Massive sulphides, due to their homogeneity and contrast in physical properties to the surrounding rock, offer opportunities for geophysical prospecting methods. Self Potential and Gravimeter investigations are

recommended.

The application of geochemical methods deserves some consideration and experiment.

The marked similarity of the Norwegian massive sulphide deposits is also noted.

INTRODUCTION

Nordre Gjeitryggen was visited during 1954 for the months of August and September. The work done was confined principally to mining. The geological field work was limited to the selection of specimens and notes based on daily observations. The major part of this study is the result of laboratory work carried out at the Royal School of Mines, London.

The approximate geographical position of the Mine is:-

10.00 E.
62.05 N.

Nordre Gjeitryggen lies above the tree limit, 961 ms. above sea level and 247 ms. above the Folla Valley. A locality open to the severer rigours of a northern climate. Some 35 kilometers east is Hjerkin. The district has a strong mining tradition, Folldal Verk having celebrated 200 years of mining in 1948. To the north north-east is Roros. Founded by King Christian IV of Denmark, a patron of mining, it is one of the oldest mining towns in Scandinavia. Both these mining groups produced massive sulphide copper ore which they smelted themselves.

Since the commencement of mining in 1748 production has not been continuous due to the low tenor of the ore (approximately 2% Copper) and fluctuations in the market price. In the 1850's the following process was developed which helped to extend the working life of the mines. Water percolating through the low-grade ore dumps dissolved appreciable quantities of copper compounds. This copper was precipitated from solution as the sulphide using hydrogen sulphide gas.

The Nordre Gjeitryggen deposit was discovered in 1920. After a period of uncertainty during which the calcite content of the ore hindered the flotation process it has grown into the largest mine in the district. With the Søndre Gjeitryggen mine it is all that remains of the once flourishing mining industry of Folldal.

THE ROCKS

The general geology of the district is shown by the accompanying Norwegian Geological Survey map of Folldal. This map is of the territory situated in the northern part of the Hedmark fylke, together with a small piece in the north-west belonging to the Sør-Trøndelag fylke. Three principal rivers traverse the area, the Folla in the south, the Glama in the east and the Einunna in the north-west. Heavy glaciation has carved out a country of rounded hills and steep-sided valleys floored with glacial sediments.

The rocks are of the Calaedonian Mountain Chain System in which occurs all the many pyritic deposits of Norway. Folding together with the intrusion of eruptive rocks have produced a regional metamorphism. The succession in the area is illustrated in a profile after C.W. Carstens and S. Foslie. The rocks exhibit a well-developed strike direction, north-east/south-west with a prevailing dip to the south-east. NW

To the south-east are the oldest formations, sericite quartzites and schists produced by alkali metamorphism of early Cambrian felsic sedimentaries. West of these occur phyllitic schists followed farther in the west by the Roros and hornblende schists.

Trondheimite occurs in zones along the regional strike direction, one passing through the Folldal and Gjeitryggen mining areas. Gabbro and olivine-serpentine have been intruded in the east.

During the Calaedonian orogeny the rocks were subjected to strong compressional forces which have altered their structure and composition. The Roros and hornblende schists show the greatest metamorphic development.

Few rock outcrops appear above an extensive and thick blanket of glacial deposits. Consequently detailed surface mapping is a difficult and lengthy process. The deposits consist of transported gravels and boulders on the hills with additional finer sediments in the valleys. Small concentrations of high-grade silica sand, exposed by the rivers, exist in many parts of the larger valleys.

Succession in the Caledonian Mountain Chain of Norway

Overthrusts. Continual folding and some metamorphism	Flysch formation with conglomerates, arcoses, marls, lsts., etc. Jasper conglomerates.	Ekne and Hovin Group.	L.Silur. Mid.Ord.
Erosion and Discordance.			
Metamorphism. Intrusions, basic to acid. Folding.	Gabbros, amphib. schists and sodic granites.		
	Greenstone formation (spilitic lavas). Phyllite and mica schists. Sparagmite (arcose) formation.	Roros Group.	L.Ord. Ord.-Cam. L.Cam
Discordance, Peneplain.			
	Archean rocks.		

PETROGRAPHIC DESCRIPTION OF THE ROCKS

Sericite quartzite. A fine grained schist composed of much quartz, altered plagioclase, chloritised biotite and in places calcite. It dips steeply to the north and north-west.

Phyllite. A well-developed fine grained schist composed of quartz, biotite, chlorite, graphite and subsidiary calcite and garnet. It dips generally to the north-west, but contains many folds.

Roros schists. These are not as fine grained as the phyllites. Consequently their schistosity is not so pronounced despite a subjection to greater compressional forces which created many contortions. The principal component minerals are quartz, biotite and chlorite sometimes with much garnet, a little hornblende and occasionally clinozoisite-epidote. Large lenticules of quartz also occur. Within these schists are contained bands of hornblende schists.

Hornblende schists. They outcrop at Folldal Verk, Gjeitryggen and other localities as bands between the phyllites and Roros schists and isolated in these formations. They have probably originated from basic volcanic and eruptive rocks. They are composed of hornblende-actinolite, plagioclase, clinozoisite-epidote and occasional quartz with subsidiary calcite, rutile and sphene. They are described in detail in the Appendix (Bore Holes 80 and 81).

Trondheimite. This bright, attractive rock is composed of sodic plagioclase, quartz and biotite with minor hornblende, chlorite and zoisite.

REGIONAL METAMORPHISM

The rocks of the area are of a spilitic kindred forming part of the Palaeozoic geosyncline which has been regionally metamorphosed. The metamorphism at Folldal was of a low grade. In the felsic sedimentary rocks chlorite and biotite developed.

As only a narrow zone extending 50 ms. on each side of the Nordre Gjeitryggen sulphide deposit and situated wholly in the hornblende schists was examined the following remarks have a limited application. A number of different mineral assemblages occur in the hornblende schists:-

a. Albite chlorite actinolite epidote-clinozoisite and minor biotite quartz rutile and sphene.

b. Albite chlorite quartz epidote-clinozoisite and minor calcite rutile and sphene.

c. Chlorite epidote-clinozoisite and minor biotite and quartz.

All are characteristic of a low-grade regional metamorphism of the greenschist facies type. The original rocks were probably basic volcanics. Variations in the mineral composition exist within very short distances - 2 or 3 cms. Albite and actinolite show the greatest variation. This may indicate that a stable mineral assemblage has not been reached or that the assemblage represents a state of equilibrium in a closed system. These differences in mineral composition may be due to:-

d. Original differences.

e. Selective circulation of the pore fluids during metamorphism.

In an environment deficient in water and carbon dioxide actinolite would form in preference to chlorite. Under the influence of circulating solutions the bulk composition tends to change to a simpler mineral assemblage. The common development of calcite suggests an excess of carbon dioxide. Rutile is probably a relict mineral remaining from the original rock.

During metamorphism the migration and recrystallisation of silica formed isolated quartz lenticules of varying size in the schists.

THE ORE DEPOSITS

Many massive sulphide lenses and bands exist in the Folldal district, several of them having been worked. Most notable among these are the Geitryggen, Folldal and Röstvangen deposits. The principal ore mineral is pyrite with minor chalcopyrite and sphalerite. The copper content is generally around 2%. This may be increased two or three times by supergene enrichment though it is rare owing to the past glacial activity. Gold also occurs, but in small amounts, and is reported to be contained mainly in the copper mineral.

The sulphide deposits are generally restricted to a zone in the quartz mica schists of the Roros formation containing amphibolite schists, bordered by the phyllites and intruded by sodic granites. This evidence suggests a relationship between the sulphides and the sodic granites. A similar granitic zone exists to the north-west which, however, has few recorded associated deposits. In this instance the granites have intruded a harder, more quartose schist than before. The location of soft, easily-replaceable sediments may also be a controlling factor.

NORDRE GJEITRYGGEN

Introduction

The massive sulphide lenses of Nordre Gjeitryggen were discovered as a result of a prospecting campaign carried out in 1920. Previously the local people had noted the unusual attraction which the area showed for lightning. Alluvial pyrite and a gossan assisted in its final location. Nordre Gjeitryggen has since developed into the largest mine of the district; it remains, however, comparatively small.

The lenses, of which only the largest is mined, form steeply-dipping, narrow tabular lodes. The sulphide ore is strong, hanging well. This feature, coupled with the comparative firmness of the wall rocks, facilitates the employment of open slope mining. Some dilution takes place owing to "slabbing off" of the hanging wall. This is compensated for by the low cost of mining. Also a flexible method is required as the Lode branches and varies in width from ½ to 7 ms. That below ½ m. is unpayable.

The property is small, some seventy men being employed on mining and transporting the ore. An inclined shaft, located in the foot wall, serves nine levels which are generally 40 ms. apart. A subsidiary shaft from No. 5 Level, inclined to the plane of the Lode, also serves the lower levels. Above No. 5 Level the Lode has been worked out.

Considerable development work has been carried out. Proved and Probable Ore Reserves amount to ca. 600,000 metric tons, enough for nine years' production at 200 tons a day.

An aerial ropeway transports the ore to a flotation plant at Folldal, 5 kilometers to the west.

Shape, Country Rocks and Tectonic Features

The following description is based on mine planes and a few scattered observations as no underground mapping was carried out, nor do any geological maps exist.

The Workings exist in three adjacent linearly-aligned, but slightly offset, tabular lenses. Their general strike direction coincides with that of the regional schistosity - 75° N. The lodes dip to the north. Along the strike the dip is fairly constant, increasing slightly to the east. The greatest variation exists down dip for between Etasjes 4 and 5 are marked increase from ca. 45° to 55° takes place. The two western lenses have been mined out to a depth ca. 150 ms. where they cease to be payable. The eastern lens is larger. It has a maximum length of ca. 360 ms. and has been developed to a depth of 320 ms. (8 Etasje). Below this the development work had not yet located the lode. The width of the eastern lens is between 1 and 3 ms. but may exceed 5 ms. occasionally. The following description is confined to this eastern lens.

Subsidiary parallel lenses and branches are frequent, generally occurring in the Foot Wall. These require a system of exploratory drilling and a parallel system of development.

Variations exist in the wall rocks which are predominantly amphibolite schists. Micaceous quartzites occur and are particularly evident in the eastern section between Etasjes 5 and 6. Also a well-developed chlorite schist exists below Etasje 8.

The massive sulphide lenses are hard, compact and crystalline composed of pyrite, pyrrhotite and the gangue minerals calcite, quartz and felspar. Disseminations occur to a limited extent in the confining quartzites and in the altered wall rocks. Parting planes at right angles to the lode walls have created a blocky structure in the massive sulphide. The contacts are sharp and well defined. In the chlorite schists a sheath of biotite has developed, containing disseminated pyrite, chalcopyrite and pyrrhotite. When unsupported this layer tends to leave the Hanging Wall in large slabs.

Lenticular "horses" of altered wall rock are common in the amphibolite schists. They give the impression of having undergone no movement retaining the original direction of schistosity.

Where contorted micaceous quartzite forms the wall rocks, the original fold shapes may be observed in the massive sulphide. The gangue too shows a vague layering parallel to that in the wall rocks. The sulphides preferentially replace the platy minerals outlining the fold structures in the rock undergoing replacement.

Faulting of the Lode is believed to be rare. In an ore pass between Etasjes 7 and 8 the Lode contains a series of carbonaceous fault planes. The lode material separates easily along these fault planes and may exhibit slickensiding but is not crushed, contorted, or noticeably displaced. Whether replacement of an originally faulted rock has taken place is not clear, but this would explain the absence of catalysis of the sulphides and the carbonaceous fault gouge. A fault plane breaks the Lode where disseminations in a micaceous quartzite take its place between Etasjes 6 and 6¾. Whether faulting of the Lode or replacement after faulting has taken place is again not clear.

The lenses may terminate in small lenticular bodies of sulphide and/or quartz occasionally accompanied by breccia. Examples occur on:-

a. A branch lens on Etasje 6 (Pt. No. 27).
b. Western end of Lode, Etasje 6 (Pt. No. 18).
c. Eastern end of Lode, Etasje 5 (Pt. No. 40).

No definite indications were observed suggesting that the Lode exists in a fault or shear zone. The general impression gained from visual observation is one of replacement rather than emplacement.

An important structural control certainly exists. It may be the presence of drag folds on a larger fold in which mineralising "solutions" were localised with attendant replacement.

MINERALS OCCURRING AT NORDRE GJEITRYGGEN

No individual mineral analyses have been made. The following is based on physical properties observed through the microscope:-

Plagioclase	$Al_9\ An_1$ Al= $Na\ Al\ Si_3\ O_8$ and An=$Ca\ Al_2\ Si_2\ O_8$
Chlorite	$H_8\ Mg_5\ Al_2\ Si_3\ O_{18}$ with varying amounts of ferrous iron
Actinolite = amfibol [illegible]	$Ca_2(Mg,Fe)_5\ (OH)_2\ (Si_4O_{11})_2$ with small amounts of $Al_2\ O_3$ and Na_2O
Clinozoisite-Epidote	$HCa_2(Al,Fe)_3\ Si_3\ O_{13}$
Calcite	$CaCO_3$
Quartz	SiO_2
Biotite	Essentially $H_2K(Mg,Fe)_3Al(SiO_4)_3$
Rutile	TiO_2
Sphene	$Ca\ TiO_2$
Garnet	Aluminium Variety
Mica	I Biotite-Phlogopite. Essentially $H_2KMg_3Al(SiO_4)_3$ with a little ferrous iron and sodium

II Muscovite. $(H,K)Al\ SiO_4$ probably contains sodium

K,Na Felspar	$(K,Na)Al\ Si_3\ O_8$
Sericite	As for muscovite
Amphibole	$Ca\ Mg_2\ (Al,Fe)_2\ Si_3\ O_{12}$ contains a little sodium
Pyrite	FeS_2
Pyrrhotite	$Fe_x\ S_{x+1}$
Chalcopyrite	$CuFe\ S_2$
Sphalerite	ZnS
Magnetite	Fe_3O_4
Galena	PbS
Min. X	Unknown sulphide

MINERALOGY OF THE WALL ROCKS, LODE AND GOSSAN

The mineralogy has been deduced from a number of selected specimens including drill cores. Diagrams of the locations with attendant petrographic descriptions of these specimens constitute the Appendix.

The following is summarised from these descriptions. For convenience the minerals are divided into two classes:-

a. The minerals composing the Wall Rocks include:-
    1. The original minerals.
    2. The minerals of "hydrothermal origin".

b. The economic minerals occurring in the Lode and in the Wall Rock.

The section is concluded with a brief description of the minerals of the Gossan and general notes.

The Wall Rocks

1. The Original Minerals

Plagioclase This is albitic in composition. It occurs as fine grained, clear, shapeless (allotriomorphic) crystals varying generally between 0.025-0.05 mm. in diameter, which form layers or thin lenticules in the amphibolite and chlorite schists. Larger crystals (some 0.3 mm. dia.) are present as rounded xenoblasts or in small groups. Albite and Carlsbad twinning are infrequent; determinations of the extinction angles and R.I. indicate a composition ca. $Al_9 An_1$. Microscope inclusions of chlorite are common.

The plagioclase-chlorite crystal contacts are serrated where the chlorite cleavage planes abut the plagioclase. A texture characteristic of recrystallisation during metamorphism. This development of felspar has created a "sieve" texture readily apparent in thin section.

Chlorite Chlorite is the characteristic schist forming mineral. It has a variety of form, occurring as plates, scales, and in fan-shaped aggregates. The platy variety is light green and faintly pleochroic, a contrast to that of the fan-shaped varieties which vary from colourless to light green. The mineral is chiefly clinochlore.

Actinolite Actinolite occurs as idiomorphic acicular crystals grouped in strands along the schistosity outlining the minor fold structures. The crystal length varies from microscopic to at least 3 mms. Cracks and distortions are frequent, particularly in the longer crystals, and also corrosion is evident along the parting planes.

Pleochroism is well-defined. This indicates either:-

a. A high Fe^{++} content or,

b. A composition near that of Hornblende.

Crystals exhibiting fairly bright greens have a high Fe^{++} content. Others are similar to Hornblende, indicating an increase in the Al_2O_3 content - a hornblendic variety exists in Sec. No. 32.

Clinozoisite-Epidote is widely distributed in the wall rocks, forming an important secondary mineral. The greatest development is in the chlorite schists in which it forms idiomorphic acicular crystals having a considerable size variation; commonly they are ca. 3 mm. in length, with a maximum of 1-2 cms. More often it occurs as corroded fragments and grains partially replaced by quartz, plagioclase and carbonate.

Lack of colour and rather weak birefringent colours with anomalous greys indicates a composition near that of clinozoisite. A few crystals possess faint brown centres, which are susceptible to corrosion and replacement. This zoning is due to a variable iron content which decreases towards the crystal edges.

Calcite is present as a replacement mineral for the irregular grains (xenoblasts), singly and in patches and strings chiefly located in the mafic laminar. Microscopic interstitial blebs are frequent. The large grains often contain corroded islands of differently orientated calcite. Inclusions, residual grains of hard minerals and recrystallised rods of chloride, punctuate the whole.

Quartz Quartz is not common, though occasionally it forms an important component of some schist layers of the Foot Wall. It is in intimate association with the plagioclase.

Biotite is infrequently present as an original mineral. It is typical, but contains no pleochroic halos. Within the schist the crystal plates form thin strands as in B.H.81 at 35,13, and 2 ms. from the Lode.

Rutile is confined to particular schist layers. Fragmentation and corrosion have destroyed the original crystal form. Rare miscroscopic idiomorphic crystals indicate later recrystallisation.

Sphene is rare, occurring as microscopic idiomorphic crystals of characteristic form.

Garnet. One colourless idiomorphic crystal was observed which was full of inclusions.

2. The Minerals of "Hydrothermal Origin"

Carbonate-Calcite Calcite is a common replacement mineral of the wall rocks and shows many of the typical replacement textures. The harder minerals, with less well-developed cleavages - quartz, felspar and clinozoisite - remain as corroded islands. Its shape and form are variable, both rhombohedral crystals and irregular grains occur forming compact evenly-grained layers, clusters of idiomorphic crystals and disseminations.

Calcite is the dominant gangue mineral forming occasionally the principal constituent mineral of the Lode. Preferential replacement by the sulphides, particularly pyrrhotite and chalcopyrite, is the natural sequence. The composition shows little variation from that in the wall rocks.

Mica occurs in three forms:-

a. A variety intermediate between biotite and phlogopite
b. A variety of muscovite, very similar to a.
c. Biotite - the hydrothermal origin of this mineral is questionable.

a. A common constituent of the wall rocks replacing chlorite. It is characterised by strong pleochorism - colourless to brown. Developing in the chlorite it forms plates and lathes of an intimate association which retain a similar orientation. The birefringence is strong, similar to that of muscovite. It possesses near or straight extinction. Pleochoric halos are absent.

Its growth is shown in Sec. 22 (photograph). Formation commences with the development of a colourless area in the chlorite which possess white to yellow interference colours. The crystal outlines appear as the interference colours reach greens and reds.

b. The minerals of this variety lack colour, but are in every other respect similar to the above variety. The two minerals develop contemporaneously in the chlorite, are always associated and often intimately intergrown.

c. Normal biotite in which pleochroic halos are absent is rarer than the two above mentioned micas, but occurs with them in platy form. In B.H.81 at 5.8 ms. from the Lode a zone of unusually large crystals of biotite and clinozoisite traverse the schist. It is not known whether these are due to hydrothermal activity.

__Felspar__ Both albitic plagioclase and potassium felspar occur. Their development, particularly that of the K felspar, is greatest at the contact. This is illustrated in Sec. 36a (photograph).

The albitic plagioclase is variable in size forming small replacement grains in the chlorite and larger scattered cloudy porphyroblasts containing residual islands of the hard minerals. Very fine dark inclusions form a well demarcated central zone in a few crystals. Albite twinning is common.

The K felspar occurs as cloudy irregular elongated plates developing at the Lode contact. The plates are intimately intergrown, seldom show twinning and have their greatest length along the direction of schistosity. They replace the chlorite, quartz, mica and carbonate. Many of the microscopic inclusions exhibit a well-developed lath-like form. In the hand specimen the contact has a vitreous to greasy appearance where this felspar is present and contrasts to the clear patches of quartz.

Where twinning was absent a differentiation between the felspars was not always made as the sections are mounted in "Lakeside" which has a higher refractive index (ca. 1.6) than both varieties.

Sericite is not as frequent as the calcite or the micas though it occurs, associated with the micas, and develops with them in chlorite. It forms clusters and strings of fine interlacing needles which do not always retain the orientation of the chlorite.

Quartz occurs as veins, lenticules and isolated grains distributed throughout the wall rocks as a replacement mineral. The best development is in the chlorite schists where it forms thin strings of elongated interlocking watery grains characterised by flamboyant extinction and myriads of microscopic inclusions composed of calcite, chlorite and the harder minerals. In B.H.81 at the contact many fine black inclusions were contained in the quartz. These characteristics together with the larger grain size serve to differentiate the hydrothermal type from the original quartz. The replacement nature is indicated by elongation in the direction of schistosity - a retention of the chlorite form and by its invasion along the cleavage planes. Quartz also replaces the hydrothermal carbonate and mica.

After calcite quartz is the most common gangue mineral. Boundary relationships between the two minerals are ambiguous, a "caries" type texture is typical though some replacement of the calcite by the quartz is evident along the grain boundaries. A brown colouration in the gangue is occasionally present and this is thought to be due to iron oxides contained in the quartz.

<u>Amphibole</u> has formed as a contact mineral. It occurs in irregular patches and lenticules either sheathing or forming "horses" in the massive sulphide. These concentrations are composed of acicular black crystals orientated in the plane of schistosity.

The amphibole is characterised by an R.I. of ca. 1.65-1.68, and a marked pleochroism from dirty medium greens to medium blue-greens (Z direction), which together indicate a composition between that of hornblende and arfvedsonite.

<u>Chlorite</u> Due to the presence of original fresh chlorite the development of hydrothermal chlorite is not easily observable. Generally speaking, the chlorite shows few variations in form, colour and

birefrigence. The anomalous "Berlin blue" was not seen, which suggests the absence of the chlorite mineral pennine - a common alteration product. Adjacent to the carbonate zones the chlorite textures are unusually fine - Sec. 10b (photograph). Fresh microscopic rods of chlorite exist in the hydrothermal felspar, calcite and quartz.

Clinozoisite - Epidote The original minerals are replaced but are believed to undergo little alteration. As the form, composition and concentration vary throughout the original rock a true assessment of alteration was not made.

Many crystals exhibit a stronger birefringence near the Lode indicating an increase in the Fe^{++} content. Zoning due to a series of dark lines parallel to the crystal edges may exist in the chlorite schists, the crystals being surrounded by a green halo. In one instance a concentration of crystals had occurred adjacent to zone of felsic and sulphide minerals.

Garnet A rare solitary mass of indefinable sub-microscopic crystals, probably chlorite and/or sericite, may be the result of the decomposition of a garnet crystal.

The Economic Minerals of the Lode and the Wall Rock

Pyrite Pyrite is the dominant economic mineral and usually the chief component mineral of the Lode. It forms well-developed (idiomorphic) cubic crystals, generally ranging in size from 0.5 to 3.0 mms.

A small degree of anisotropism is exhibited, the colours varying between dark yellowish-greens to dark purplish-greys. Corrosion and replacement are universally evident. The crystal outlines are partially rounded and some are completely lost. Microscopic cracks in the crystals induce further replacement. Pyrrhotite, chalcopyrite, sphalerite, galena and the gangue minerals replace the pyrite in varying degrees. Corrosion is most usual in the carbonate gangue, occasionally crystal outlines border the pyrrhotite and chalcophyrite. Rounded inclusions of the replacement minerals are frequent and show a grouping about the crystal centres. The mineral replacing the pyrite has normally the maximum development in the crystal.

At the Lode contact the pyrite occurs disseminated in the wall rock preferentially replacing the platy minerals where it characteristically forms cubes. Within 2 or 3 ms. of the Lode it may constitute thin bands of cubic crystals, generally $\geq$ 0.3 mms. in diam., replacing the chlorite, carbonate and quartz of the altered schist - Sec. 10 (photograph). In these bands the crystals may coalesce to form isomorphous clusters which are bounded by a zone free from pyrite. Under high power the pyrite crystal edges appear minutely serrated by rectangular apophyses protruding into the containing mafic mineral (diagram). These apophyses are submicroscopic pyrite crystals which replace the containing mineral and so extend the boundaries of the larger pyrite crystal. This is the natural method of pyrite replacement in the schists.

A feature of particular interest is the complete absence of visible alteration in the containing chlorite and mica.

Pyrrhotite is the most important minor mineral. In the Lode the pyrite-gangue crystal contacts have localised pyrrhotite formation. It occurs as patches of allotriomorphic crystals replacing the carbonate gangue and to a lesser extent the pyrite. The mineral frequently encloses good crystal faces of the pyrite which suggests a protective character rather than a replacement character. It occurs rarely exsolving from the sphalerite and, it is thought, from the magnetite. Less commonly it is present as isolated patches in the gangue.

Pyrrhotite has the greatest development at the Lode contacts where amphibolite-chlorite schists compose the wall rock. The mineral forms in both the massive sulphide - by replacement of the gangue minerals - and in the wall rock - by replacement of the platy minerals. In the first case it occurs interstitially, in the second case disseminated as allotriomorphic elongate grains in the chlorite or less commonly replacing the felspars. Chalcopyrite is a common associate in the wall rock.

Chalcopyrite occurs less frequently than pyrrhotite for which it has a replacement preference and consequently shares its mode of occurrence. Rarely the major part of the pyrrhotite present may have been replaced. Isolated patches and veinlets are seldom present in the gangue. It replaces the pyrrhotite, gangue and pyrite. Textures with the magnetite are ambiguous; good crystal outlines of this mineral sometimes exist in the chalcopyrite, suggesting replacement by the latter. Amphibole also may rarely replace it. Sphalerite is a common associate and commonly formed contemporaneously with and after the chalcopyrite.

It is commonly associated with the pyrrhotite though in lesser amounts where the wall rock is of chlorite schists. Where quartzites occur it is the most prevalent mineral replacing chlorite and mica.

Sphalerite is an associate of chalcopyrite, both sharing a similar environment and form. The sphalerite has a deep Port Wine colour internal reflection which indicates an appreciable FeS content, Dana states the colouring range for the proportion of FeS to ZnS - 1:5 to 1:2 in the sphalerite. Rare ex-solution pyrrhotite confirms an iron content 10 per cent. The iron is believed to be present in the lower proportions.

The proportion of sphalerite present is variable though it always remains a minor mineral, in some sections it is rare or even absent, in others it is the dominant mineral having replaced most of the pyrrhotite.

Sphalerite does not usually occur in the wall rock.

Magnetite occurs as octahedra, either singularly or as granular aggregates, generally less than a quarter the size of the pyrite crystals. The content varies considerably though it always remains a minor constituent, rare crystal clusters occur. The content is greatest, occasionally the mineral becoming the dominant "minor", where pyrrhotite is absent; where pyrrhotite is notably present, magnetite is rare. The implications of this relationship are not understood. A change in acidity and/or temperature of the environment may render pyrrhotite unstable with the resulting breakdown and formation of pyrite and carbonate or pyrite and magnetite in alkaline or neutral conditions. No textures exist suggesting such an origin.

Octahedra occur in pyrrhotite, pyrite, chalcopyrite and the gangue. Corrosion in the gangue is pronounced. Pyrite crystals indent the octahedra, inclusions in the pyrite crystals are common and also minor boundary replacement by the pyrite has taken place. Occasionally the magnetite exhibits good crystal form in the chalcopyrite and sphalerite. Only one instance of crystal zoning was found.

The following phenomena suggested ex solution of pyrrhotite - inclusions of similarly orientated blebs and the presence of submicroscopic "ex-solution lamellar".

As a wall rock mineral it is infrequent.

Galena is of very minor importance. It is a rare constituent in Section No. 32 from 1 Etasje. The mineral replaces pyrrhotite preferentially then to a less extent sphalerite, chalcopyrite and pyrite (photograph). Isolated patches in the gangue are also present.

Mineral X is less frequent than galena, which it either replaces or exsolves (~~photograph~~). The occurrence is restricted to where the minerals replace the chalcopyrite. It is pinkish grey in colour, has a lower reflectivity than the galena and is isotropic.

Gossan

A small gossan exists comprised of hydrated iron and copper oxides - limonite and malachite - which encrust the massive sulphides. The carbonate gangue has been leached out and has neutralised much of the sulphuric acid resulting from pyrite decomposition. This has considerably reduced the depth of secondary enrichment. No cellular structure has developed in the gossan.

General Notes

Gold and Silver are extracted from the copper concentrates. An analysis of the massive sulphide from Stope No. 6 on 6 Etasje indicating the following precious metal content:-

Ag per metric ton - 20 gms.
Au per metric ton - 0.2 gm.

Gold and silver, either in the natural state or combined, were not observed using a magnification of X 400, consequently their mode of occurrence has not been ascertained.

A brief note on the sub-microscopical occurrence of gold is therefore pertinent. It may occur combined with another element (tellurium), in the native state mixed with silver or in the ionic form contained in a crystal lattice.

The ionic radii of gold and iron Fe^{++} are similar, 2.88Å and 2.50Å respectively. This allows the incorporation of gold ions in a crystal lattice partially composed of iron ions. Pyrite possesses this ability to absorb gold ions in its crystal lattice; sphalerite, arsenopyrite and chalcopyrite also possess this characteristic. The presence of gold in the minor sulphides has been established, its presence in the pyrite is not unlikely. Should the analyses record higher values an investigation of the manner of occurrence of the valuable metals would be merited.

In order to observe this ionic gold under the microscope aggregation is necessary. Edwards reports a successful method for achieving this. The pyrite is heated to 600°C and kept at that temperature for seven hours during which time the gold aggregates and is visible.

Traces of arsenic, cobalt and nickel are recorded in the analysis though minerals of the elements were not observed. Mineral X may contain either of these elements. The occurrence of cobalt and nickel may be investigated using chromographic contact prints.

The specimens were examined for radioactivity, fluorescence and thermoluminescence but gave negative results. The phenomena of thermoluminescence is further discussed in the Section of Prospecting.

ROCK ALTERATION

Altered Rocks

As the wall rocks have a comparatively uniform mineral composition the products of alteration show little variation except in their intensity of occurrence. The micaceous quartzites are little altered.

Alteration adjacent to the Lode may be extreme with complete loss of the original texture. Its depth and degree are variable. Development of the alteration minerals, the sulphides excepted, is confined to a narrow zone about 2 ms. or less from the contact.

For the convenience of description wall rock alteration is considered according to original composition.

a. Alteration of the chlorite albite actinolite clinozoisite schists containing subsidiary rutile and sphene.
b. Alteration of the chlorite schists.
c. Alteration of the micaceous quartzites.

a. The hydrothermal activity has produced the greatest change in this group due to the original heterogeneous nature.

Alteration of the highest grade is characterized by Na-K felspar. This develops at the contacts replacing previously formed hydrothermal carbonate, quartz and mica. Associated is albitic felspar having a wider zone of occurrence. Quartz, mica, carbonate, sericite and residual shreds of the original rock form a heterogeneous matrix containing the felspars though of wider occurrence. Clinozoisite and rutile are noticeably resistant and remain as relict minerals. Calcite grains and crystals replace the schist and compose thin compact bands (photograph) or disseminations. When disseminated it is not easily differentiated from the original mineral. Quartz has a wide development occurring either as irregular scattered grains or as thin lenticules in the chlorite. The phlogopite and colourless varieties of mica are widely distributed in the chlorite and their development is one of the first indications of hydrothermal activity.

Irregular grains of pyrrhotite and chalcopyrite are scattered throughout this zone of alteration replacing the original and hydrothermal minerals.

b. In this environment phlogopitic mica sheaths the Lode replacing the chlorite. Both are intimately associated, the mica decreasing in quantity away from the contact as does its iron content. The mica plates are well developed forming a distinct border zone which easily "slabs off" when unsupported.

Dark acicular amphibole, associated with the iron rich varieties of mica, has formed where alteration is particularly intense. It develops in "horses" - remnants of the wall rock contained in the Lode - and at the immediate Lode contacts. Rarely it is disseminated in the massive sulphide.

c. The micaceous quartzites were not examined in thin section but appear to be but slightly altered. Adjacent to the contact the original platy minerals are replaced by pyrite, chalcopyrite and pyrrhotite; farther away brown micas develop.

Zoning

A simple form of zoning is evident from the specimens:-

a. A zone of intense alteration is characterised by sodic-potassic felspars in rock type a. A phlogopitic mica features this zone in the chloritic rocks.

b. A zone of low alteration in which calcite, colourless and phlogopitic mica and quartz occur.

Zone "a" is confined to the contacts and "b" to within 2 or 3 ms. of it, occasional irregular patches of calcite form at greater distances.

Bands, a few mms. thick, composed of calcite grains and crystals occur in the chlorite schists. These bands are short but well defined and compact in the central parts.

Mutual Relationships

The textures exhibited are characteristic of replacement. Ambiguity is common due to contemporaneous deposition. The order of formation is reflected by the zoning - calcite and mica first accompanied later by quartz and followed by albitic plagioclase and finally by sodic-potassic felspar.

The final felspar forms intimately interlocking plates replacing the earlier minerals and containing residual laths and flakes of mica. The albitic plagioclase occurs as rounded porphyroblasts with islands of the harder minerals - quartz, clinozoisite and rutile. The quartz forms irregular watery grains either isolated or in lenticules replacing the mica and original quartz and plagioclase. It is often interstitial to the calcite replacing this mineral along the grain boundaries. Calcite replaces the original rock, the chlorite preferentially. Development of the mica and sericite is confined principally to the chlorite in which it forms similarly orientated laths and plates although some crystals transgress the schistosity in the foot wall of the lower levels.

Relationships between the Sulphides and Altered Rocks

Pyrite and the group - pyrrhotite, chalcopyrite and sphalerite differ in their mode of occurrence and are considered separately. No specimens of the wall rock to the Lode where galena occurs were examined.

Pyrite is present as idiomorphic crystals, usually < 0.5 mm. dia., either disseminated or more generally forming bands in the chlorite schist analogous to those of the calcite (photograph). The disseminated crystals have a wide range of occurrence and are similar to the original pyrite. The pyrite bands form in the zones of low alteration in association with the carbonate bands as both prefer a chloritic environment. They nevertheless retain their identity, unlike the calcite bands, where alteration is intense.

The crystal faces transgress the chlorite cleavage but have produced no distortion or visible alteration in the chlorite. Such features as "pressure shadow" aureoles were not observed.

Pyrrhotite, chalcopyrite and sphalerite group These are sparsely but widely distributed, their concentration increasing towards the Lode. They occur alone and together in irregular grains. Their presence in B.H.81 25 ms. from the Lode indicates the range of occurrence.

Replacement by these sulphides is preferential to the platy minerals, whose form they retain to a slight degree, and to calcite. Areas of low pressure, e.g. fold apices, localize formation. In the zone of intense alteration replacement of all the hydrothermal minerals, excepting the K felspars, were observed.

Sphalerite is rare in the wall rock.

Conclusions

Wall rock alteration is of a limited extent seldom existent 2-3 ms. from the Lode. The sulphides exhibit the widest range of occurrence, though in a disseminated form. In nature, the alteration is thought to be dominantly sodic - though identification of the hydrothermal minerals is not complete. Mineral formation is dependent on original rock composition and the heterogeneous schists show the greatest mineral development.

Initial alteration is typified by calcite, colourless and phlogopitic mica and quartz which occur even adjacent to the Lode though separated by a thin layer of coarsely crystalline quartz. Less common is the superimposed later alteration of higher grade characterized by felspars and greater development of the micas - biotite and phogopite in the chlorite schists. Na-K felspars and amphibole indicate alteration of the highest intensity.

Pyrite is believed to be associated with the low grade alteration and pyrrhotite, chalcopyrite and sphalerite with the high grade alteration.

Suggested Cycle of Alteration

Early Stage	1. Invasion by carbon dioxide, sulphur and iron accompanied by redistribution of alkalis - predominantly sodic, lime and alumina and the migration and recrystallization of silica. a. Formation of calcite, mica, pyrite and soda plagioclase.
Late Stage	2. Lessening of activity but alkali invasion continued with probable appearance of potassium, accompanied by copper, zinc and lead and redistribution of alumina. Sulphur and carbon dioxide decreased in quantity. Recrystallization and migration of silica continued. b. Formation of felspars, mica, amphibole, pyrrhotite, chalcopyrite, sphalerite and galena.

ORES

Description

The ore of Nordre Gjeitryggen is a compact finely crystalline massive pyrite with a varying amount of calcite and quartz gangue. A thin layer of the sheathing wall rock generally contains disseminated pyrrhotite and chalcopyrite in payable quantities.

In the hand specimen prøver the ore appears uniform, though variations in gangue content innhold and grain size Korn størrelse are visible synlig in specimens from different locations. Small lenticules and veins of quartz and/or carbonate rarely traverse the sulphides. The ore has a blocky fracture in some stopes.

When examined under the microscope certain variations in form and composition are evident øyensynlig.

Pyrite, the principal ore mineral, occurs as well formed cubic crystals, varying in size from 0.5-3.0 mms. in dia., either isolated or in clusters when the crystal shape is lost. Corrosion of the crystal boundaries by the gangue, which is principally calcite, is general though variable in intensity. Pyrrhotite, the prime subsidiary mineral, replaces the gangue preferentially along the gangue-pyrite crystal contacts forming a protective beskyttende coating about the pyrite. It also fills small cracks in the cubes. Chalcopyrite and less common sphalerite are associated minerals. They replace erstatter the pyrrhotite assuming antar its form and habit and also occur forekommer interstitially replacing the gangue minerals. Magnetite is another minor subsidiary mineral forming crystal octahedra disseminated and in granular aggregates - then observable in the hand specimen. Galena and an associated unknown mineral are very rare.

Secondary enrichment was not encountered though specimens from immediately below the surface outcrop were not examined under the microscope. Its absence or limited occurrence is due to:-

a. Neutralization by the carbonate solutions, derived from the carbonates, of the sulphurous and sulphuric acids derived from the pyrite which are instrumental in the solution and transportation of the copper sulphides to lower levels and

b. Previous glacial erosion.

As previously mentioned disseminations of allotriomorphic pyrrhotite chalcopyrite and occasionally idiormorphic pyrite occur in the wall rock. It is not known whether this mineralization is greater in the Foot Wall than in the Hanging Wall.

Differences in Mineral Distribution

Differences in the distribution of the elements have produced variations in the mineral composition of the Lode. Pyrrhotite, chalcopyrite, sphalerite, magnetite and galena vary in occurrence and reflect the distribution of sulphur, iron, copper zinc and lead. Their occurrence is related to position in the Lode and to other minerals present.

Pyrrhotite exhibits the least variation rarely being absent in polished section. Its absence is due to extensive replacement by chalcopyrite and sphalerite and also a relationship exists between it and magnetite. In two specimens from the centre of the Lode on Etasje 6 pyrrhotite was absent where magnetite was plentiful. No textural relationships exist between these two minerals suggesting that magnetite is a decomposition product of pyrrhotite.

Variations according to depth exist. Between Etasjes 4 and 8 the sulphur and zinc contents decrease from 40 per cent to 33-35 per cent and 5-6 per cent to 2-4 per cent respectively. The copper content varies between 1-2 per cent on both Etasjes. Galena and Mineral X are present only in the upper portion of the Lode. A greater mobility of the zinc and lead ions during formation would account for this concentration in the upper levels.

Sequence of Formation

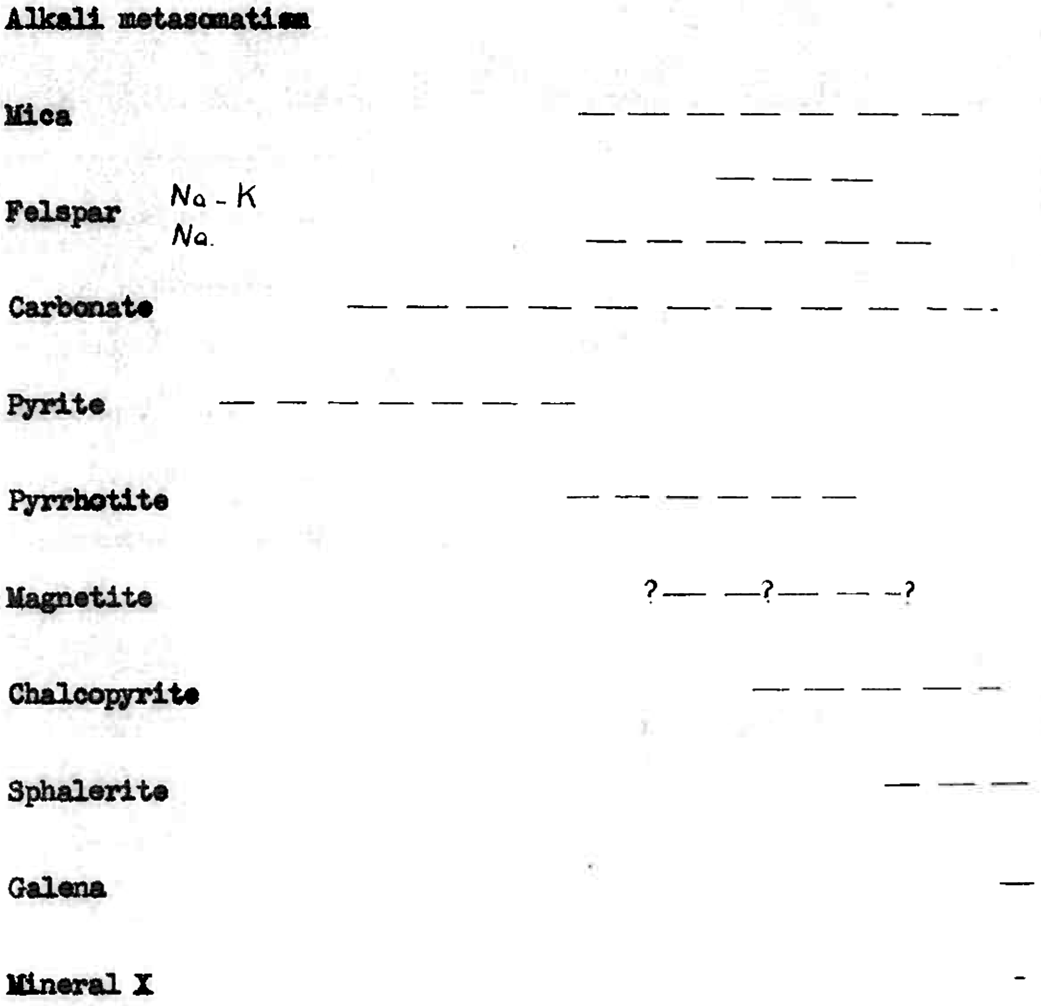
Idiomorphic pyrite formed by replacement processes during the first stages of the alkali metasomatism. Calcite and pyrrhotite, partially contemporaneous, followed. Corrosion and replacement of the pyrite by calcite took place preceding formation of pyrrhotite. This mineral replaced the calcite surrounding the pyrite eventually forming a protective coating. Migration and recrystallization of quartz accompanied this activity.

As the alkali metasomatism continued so chalcopyrite, sphalerite and galena replaced the previous sulphides and gangue minerals of the Lode and also formed disseminations in the wall rock.

The period of magnetite formation is probably contemporaneous with that of the pyrrhotite. This is suggested by the replacement of pyrite, the presence of possible pyrrhotite exsolution lamellae and their relation in occurrence.

The periods of mineralization are not clearly defined, rather they merge one into the other.

The accompanying table attempts to portray the sequence of formation. It records a gradual decrease in available sulphur - formation of pyrrhotite and possibly magnetite - and the appearance of copper, zinc and lead.



Note: Lines represent duration of deposition rather than amount.

TABLE OF RELATIONSHIPS IN LODE

Note. Main relationships only.

	PYRITE	PYRRH.	CHALPYR.	SPHAL.	MAGN.	GALENA	CALCITE	QUARTZ	AMPHIB.
PYRITE	Idiomorphic, corroded	Inclusions	Inclusions	Inclusions	Inclusions	Inclusions			↑ Ambiguous textures ↓
PYRRH.	Replaces	Allotriomorphic		Prob. exsolution blebs.	Relation in occurrence - seldom occur together		Replaces		
CHALPYR.	Replaces	Replaces Retains form	Allotriomorphic	Partly contemporaneous	Replaces		Replaces		
SPHAL.	Replaces	Replaces	Partly contemporaneous	Allotriomorphic	Replaces		Replaces		
MAGN.	Idiomorphic X's in pyrite	Possible exsolution lammellar?			Idiomorphic, corroded				
GALENA	Replaces	Replaces	Replaces	Replaces		Allotriomorphic Rare	Replaces		
CALCITE	Replaces				Replaces		Mosaic of allotriomorphic X's		
QUARTZ					Replaces		Replaces	Allotriomorphic	
AMPHIB.	← Ambiguous textures →								Idiomorphic, corroded Rare

REPLACEMENT NATURE OF DEPOSIT

Evidence for the replacement nature of the deposit is considered under three categories:-

i. Structural features.
ii. Contact relationships and included structures
iii. Textural and mineralogical features.

Structural Features

As no mapping was attempted a brief description is pertinent.

In shape the deposit may consist of three or more slightly offset inclined lenses parallel to the regional schistosity. This pattern may be due to:-

a. The replacement of folds situated on the limb of a large fold or
b. Differential movement, in the strike direction, along an undulating fault plane with the formation of alternate high and low pressure zones. These low pressure zones would localize mineralization of a replacement nature.

Evidence for earth movements of the last type is slight. Minor faulting is present in the Lode but is believed to be premineralization. Small zones of brecciation have a restricted occurrence to some terminations of the lenses.

Contact Relationships and Included Structures

The Lode contacts are sharp but undulating, the Lode width frequently varying.

A contact structure that is typical of many in the chlorite schists is illustrated in diagram 3 . It shows the massive sulphides traversing the Hanging Wall replacing minor fold forms.

A structure observed in the Lode where micaceous quartzites form the wall rock is described but not illustrated. In this fold structures incompletely replaced exist in the massive sulphide. Replacement of the platy minerals preceded sulphide dissemination in the "engulfed" quartzite.

"Horses" of the country rock occur as shreds and irregular lenticules in the Lode. They retain their original orientation and show no indication of movement during mineralization.

Textural and Mineralogical Features

From a consideration of the altered rocks formation of pyrite and calcite by replacement is indisputable. Individual crystals where isolated are idiomorphic truncating the bedding. In the chlorite schist each pyrite crystal is bordered by minute apophyses - cubes - of pyrite protruding into the containing mineral which advance the growth of the crystal. Clusters and isomorphous masses form where the crystals coalesce about which are sulphide free margins. The lode pyrite is analogous to that in the wall rocks differing only in size and intensity of occurrence. Both types are thought to have formed in the same manner.

Typical textures indicate replacement of the pyrite and surrounding rock by the later more complex sulphides and gangue minerals.

The hydrothermal minerals of the wall rock too have formed by replacement of the original minerals. Stages in the development of mica from chlorite were observed in Thin Section 22.

Little is known about the processes of replacement. Diffusion in the solid state through the crystal lattices is favoured at present.

CONTROLS OF ORE DEPOSITION AND ORE GENESIS

Prime controls of deposition were the structural features of the schists - at present unmapped. Suitable areas were those where "pressure lows" existed, such as drag folds on large fold limbs. A mineralogical control exists inasmuch as the mineral composition and textures of a rock define its competency.

The physical properties of the schist allowed migration to and concentration of the mineralizing "solutions" in the low pressure areas. The physics of migration are not understood but may well be by diffusion through pore spaces and along grain boundaries if not through the crystal lattices themselves.

The genesis of the deposit invites conjecture. Four facets of the problem exist:-

i. Source of the elements forming:-
    a. The ore minerals - S, Fe, Cu, Zn, and Pb, and
    b. The gangue and altered rocks.
ii. Method of migration of the elements.
iii. Method of concentration of the elements.
iv. Method of deposition and history of replaced material.

The above elements are contained both in sedimentary and eruptive rocks. Their concentration in either or both presents perhaps the greatest problem.

In this dominantly sodic environment the processes of regional metamorphism may have been instrumental in this concentration. Kania and others have demonstrated the solubility of Fe, Cu and Zn sulphides in sodic solutions. This suggests a possible method of solution, concentration and transportation in this area of soda metamorphism.

PROSPECTING

The massive sulphides of Nordre Gjeitryggen require for their location prospecting methods that will penetrate or be independent of the glacial overburden and produce characteristic anomalies.

Both geophysical and geochemical methods are considered.

Geophysical Methods

The Self Potential Method has been used previously with success as the deposits possess detectable natural currents. In principle it consists of the location and comparison of currents produced during the oxidation of a sulphide deposit. Such a deposit may be compared to an electrochemical cell. Ion interchange takes place between copper sulphate solutions and sulphuric acid though this is probably not the only chemical activity. It is as well to note here a previously suggested reason for the lack of supergene enrichment, i.e. the paucity of sulphuric acid due to the influence of carbonate solutions. Natural potentials of this type are confined to deposits traversing the water table and situated in a zone of oxidation.

As a considerable difference in density exists between the country rocks and the massive sulphides, approximately 2.5 and 4.0 respectively, gravimetric investigations using the Worden Gravimeter would seem to be worth while. This may be conveniently integrated with a Self Potential

Survey though a working grid with precisely levelled stations is necessary for the Gravimeter Survey.

Geochemical Methods

Little is known about the techniques and applications of geochemical methods in glaciated regions. Such investigations however have been carried out, with successful results, in similar environments on the Canadian Shield. This indicates an applicability in this region. After the initial research and derivation of a satisfactory method of investigation geochemical surveys are easily applicable and cheap. Such a method could indicate areas of mineralization for small prospecting costs and thus eliminate costly "hit and miss" methods previously employed.

Note:- Thermoluminescence

In certain environments wall rocks of deposits luminesce on heating due to included radio active elements and/or irregularities in the crystal lattices. Selected specimens were heated and cooled naturally during an examination for luminescence but gave negative results. This observation is in keeping with those on the wall rocks of other massive sulphides and may be a characteristic of these deposits.

OTHER DEPOSITS

Neighbouring

Sondre Gjeitryggen lies some 2 ms. south east of Nordre Gjeitryggen and shares the same geological characteristics. It previously consisted of three separate mines probably working the same lode or lens system. Now but one is worked and on a very small scale. This mine is divided geologically into two sections by a fault plane. One section consists of sulphide streaks and disseminations in micaceous quartzite, the other of a massive sulphide lens. The fault plane contains graphitic gauge and though dividing the deposit may be post-mineralization. The abrupt change in ore character may be due to differences in the abutting faulted rocks.

Foldal This group of mines, now closed, lies to the south west of Gjeitryggen in the same belt of mineralization. They again are geologically similar though occurring nearer trondheimite and gabbro.
G. Aasgaard reports their occurrence in a thin band of amphibolite schist contained in a harder crystalline felsic rock.

Norway

Sulphide deposits are singularly frequent in Norway. An accompanying map shows their confinement to the Paleozoics of the Calaedonian Mountain System to whose parent orogenic activity they are believed to be related.

Three types have been differentiated:-

i. Fine grained banded pyrite and pyrrhotite containing little copper.
ii. Massive pyrite and pyrrhotite containing a little copper and occurring in amphibolite and chlorite schists near gabbro and trondheimite - Roros Type.
iii. Massive pyrite with quartz and low in copper.

The deposits of the Roros Type, of which Gjeitryggen is one, are surprisingly similar. They generally occur in "plastic" highly folded chlorite and amphibolite schists and are associated with a late phase of eruptive activity which is sodic in character. Deposition by replacement rather than injection is generally indicated. A lack of extensive alteration and high temperature minerals is typical. Sven Gavelin's comment on the Skellefte deposit, Sweden, is notable in its probable applicability to these deposits.

"A striking feature is the tendency of the sulphides to accumulate in the anticlinal folds and especially in the central parts of the anticlines".

The spilitic environment of the larger massive sulphide deposits of the world is well known.

These facts indicate that the formation of massive sulphides in this spilitic environment is one of its characteristics rather than an accident of injection. Thus their formation may be closely related to the processes of metamorphism as well as those of eruption.

MAPS AND DIAGRAMS

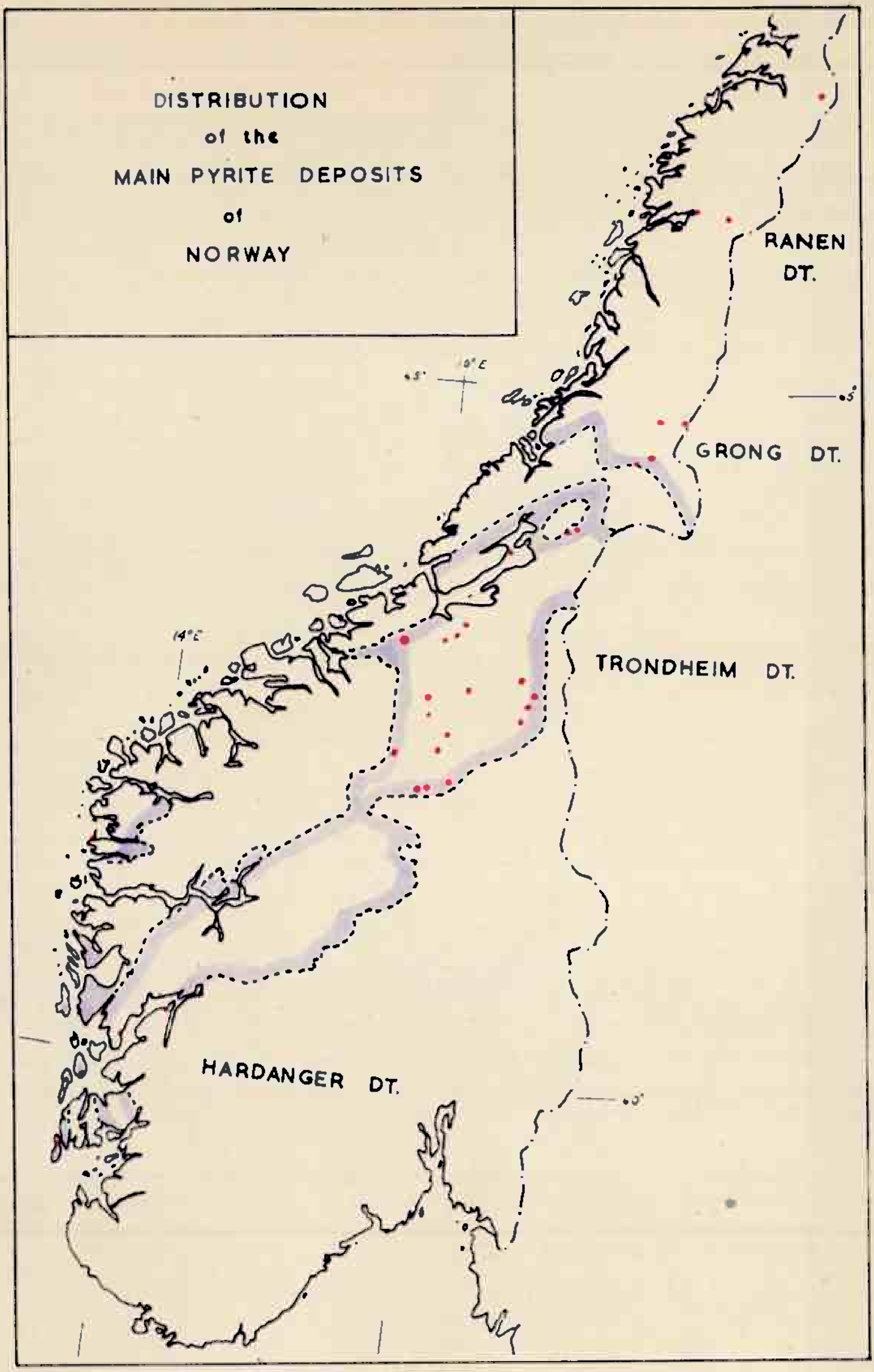


FIG. I
The figure shows the confinement of the pyrite deposits (red circles) to the rocks of the Calaedonian Mtn. Chain (blue).

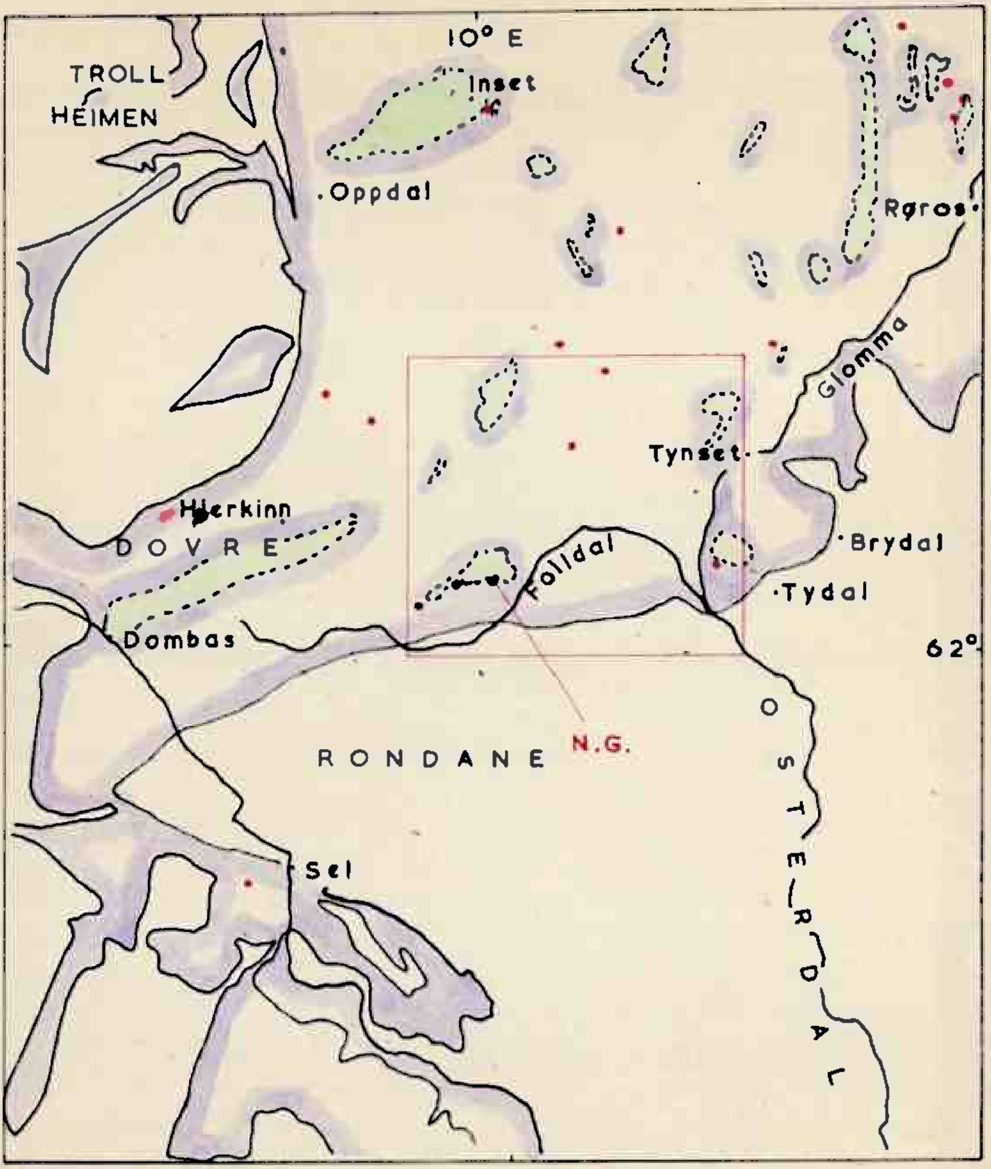


FIG.2. LOCATION OF THE FOLDAL MINERAL DEPOSITS.

Rocks of the Calaedonian Mtn. Chain - blue
Eruptive rocks - green
Pyrite deposits - red circles

The area represented by an accompanying large scale geological map is shown.

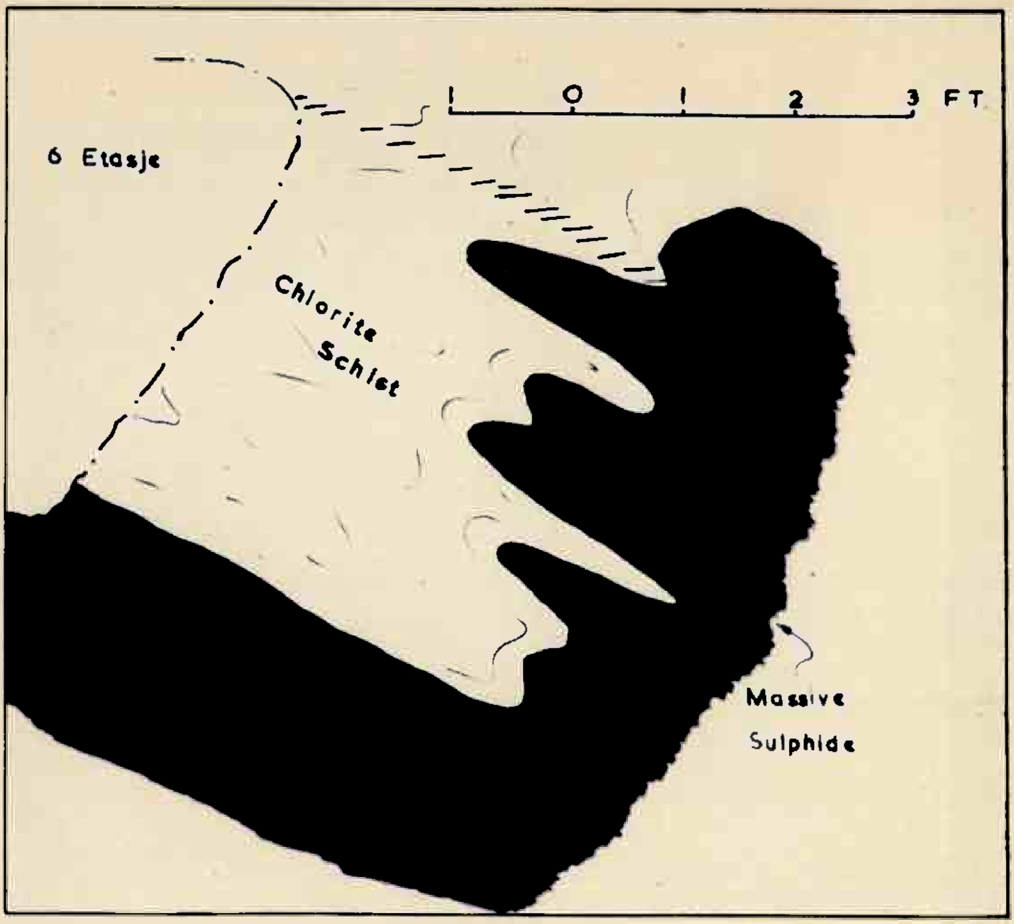
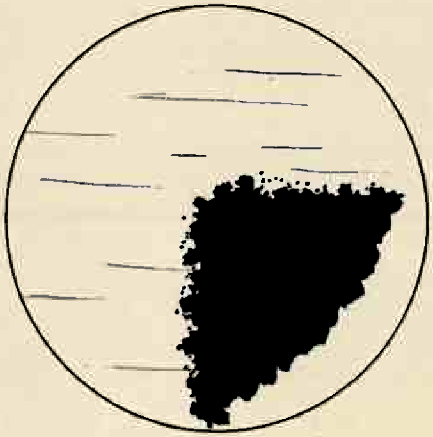


FIG 3. HANGING WALL CONTACT - 6 ETASJE

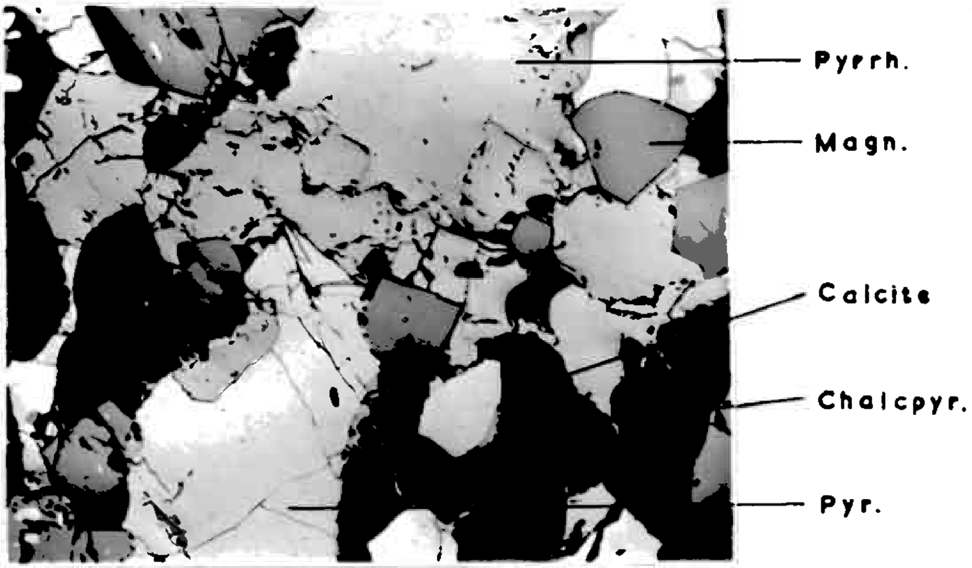
The massive sulphide has replaced the chlorite schist along fold forms.



Illustrates the growth of pyrite crystals by the development of microscopic apophyses from the cube walls.

FIG. 4.

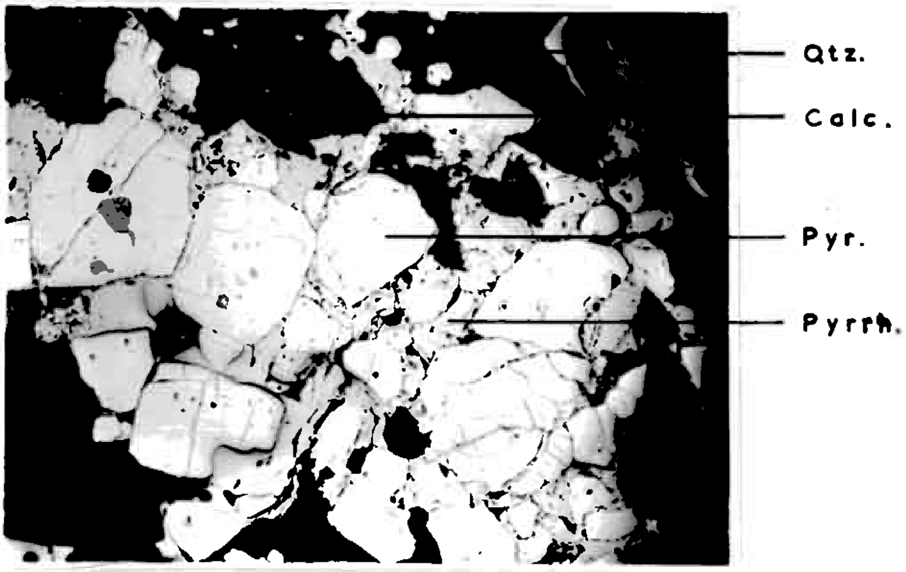
PHOTOGRAPHS



P.S. No. 3. (x 40)
8 Etasje, centre of Lode in the Back
The Massive Sulphide

Corroded idiomorphic pyrite is surrounded by allotriomorphic pyrrhotite. A few idiomorphic crystals of magnetite occur. Minor chalcopyrite replaces the carbonate gangue sometimes bordering the pyrite.

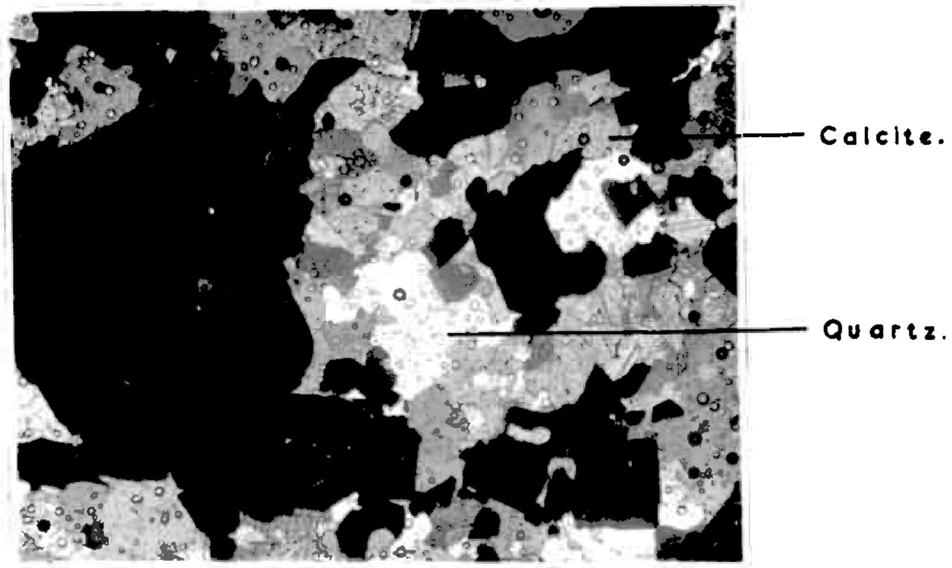
Described on page xx.



P.S. No. 5. (x 28)
8 Etasje, adjacent to Foot Wall
The Massive Sulphide

The texture shown is typical and general. Corroded pyrite cubes are surrounded by pyrrhotite and gangue. Chalcopyrite replaces the carbonate gangue and pyrrhotite.

Described on page xxiii.



T.S. No. 5. (x20)
8 Etaaje, adjacent to Foot Wall
The Massive Sulphide

Illustrates the relationship between the economic ore minerals and the gangue. Chalcopyrite and pyrrhotite replace the carbonate. Minor quartz has developed later at the expense of the carbonate.

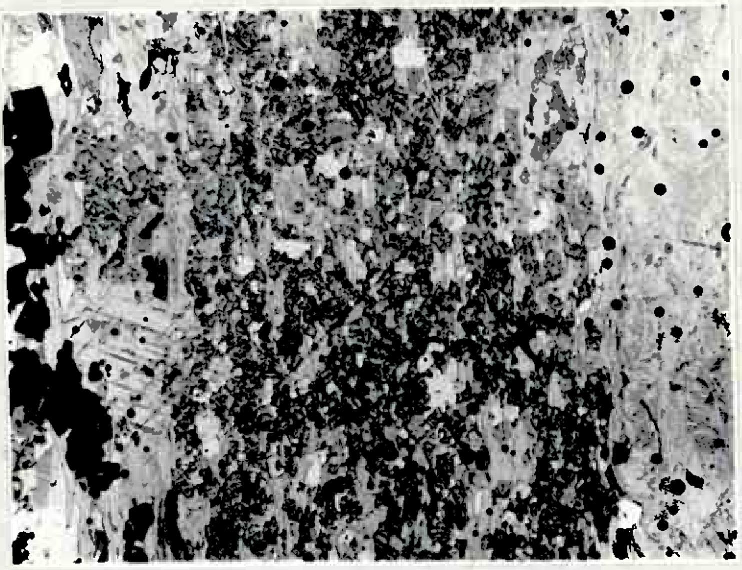
Described on page xxii.

Spec. No. 10

8 Etasje, 160 cms. from the Lode in the F.W.

A hydrothermally-altered chlorite schist in which layering has developed owing to selective replacement by calcite and pyrite.

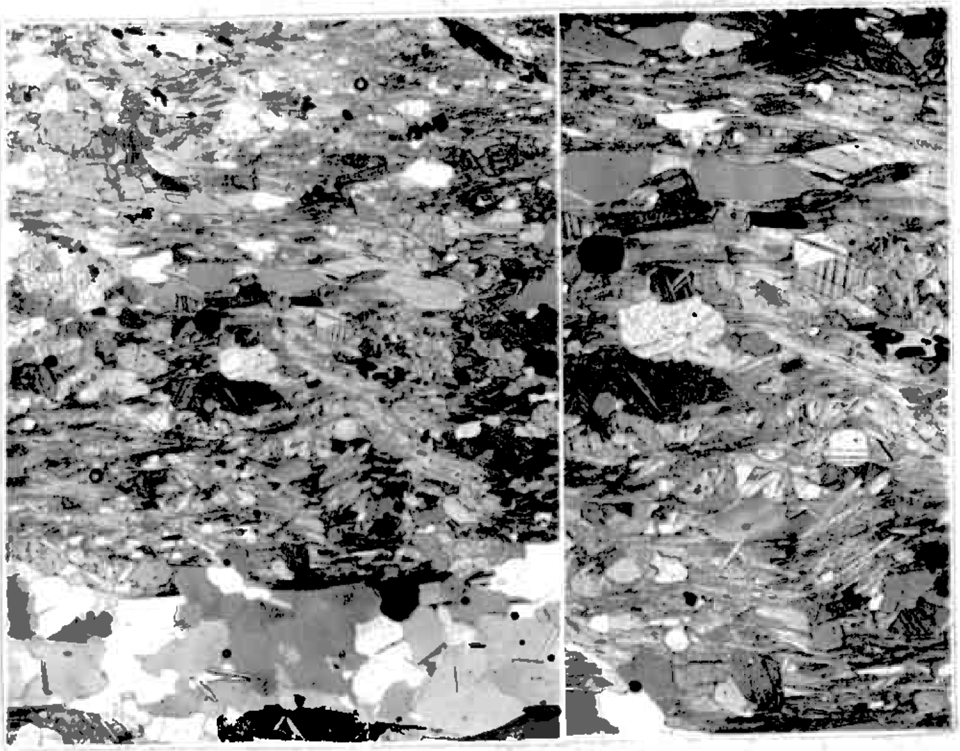
The locations of T.S. 10a and 10b are shown and these are described on pages x and xi.



T.S. 10a zone 3. (x 16)
8 Etasje, 160 cms. from the Lode in the F.W.

A mosaic of calcite crystals have replaced the schist in the centre of the photograph. Idiomorphic pyrite has developed to the left. The finely-textured mineral to the right is chlorite, probably recrystallised.

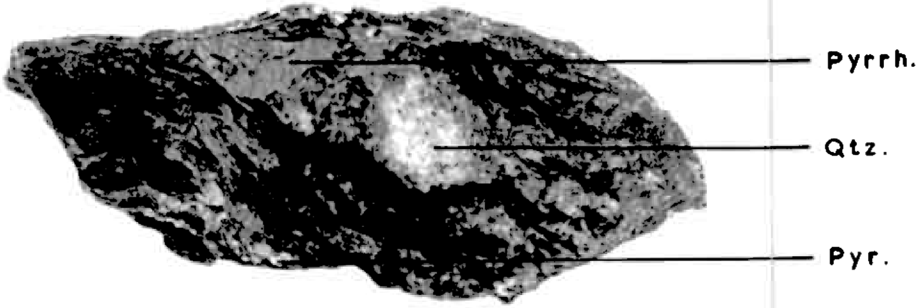
Described on page x.



T.S. No. 10b, zone 3. (x 20 and 40)
8 Etasje, 160 cms. from the Lode in the F.W.
A hydrothermally-altered chlorite schist

Calcite, quartz, sericite, mica and pyrite have developed irregularly in the schist. The sericite and mica are easily differentiated from the chlorite by the birefringence colours. A vein of recrystallised quartz containing small laths of chlorite has also developed in the schist.

Described on page xi.

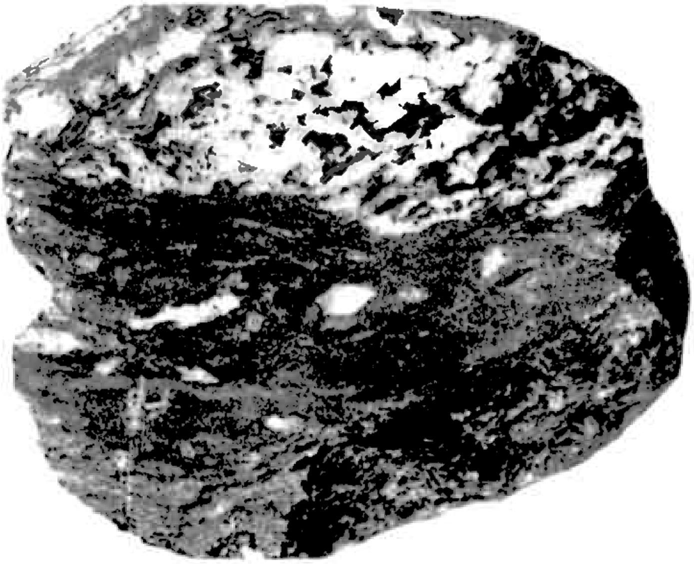


Spec. No. 13

8 Etasje, from Foot Wall at the Contact

A mineralised chlorite albite quartz schist

The growth of pyrrhotite and quartz is particularly apparent. Some chalcopyrite and idiomorphic pyrite are also visible.

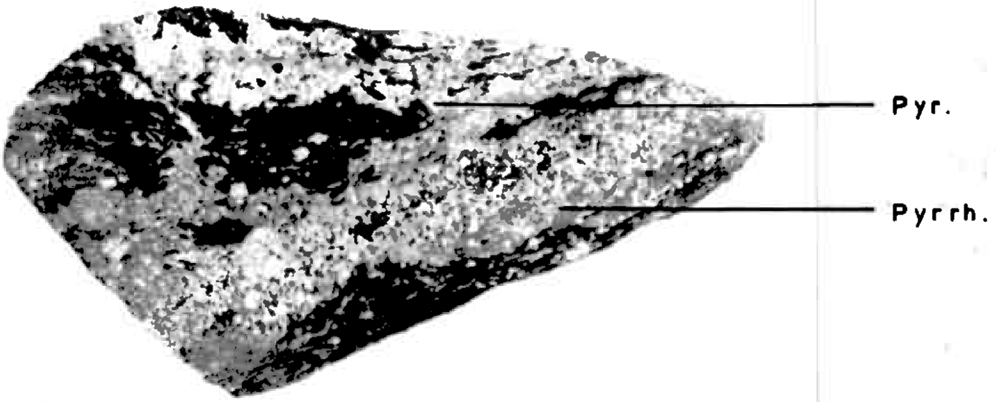


Spec. No. 14a

Etasje 6, Foot Wall Contact

An altered albite chlorite clinozoisite schist

Idiomorphic calcite, mica and fresh chlorite have developed selectively in the schist. The speckled appearance of the remaining schist is due to the growth of microscopic albite, calcite and quartz.

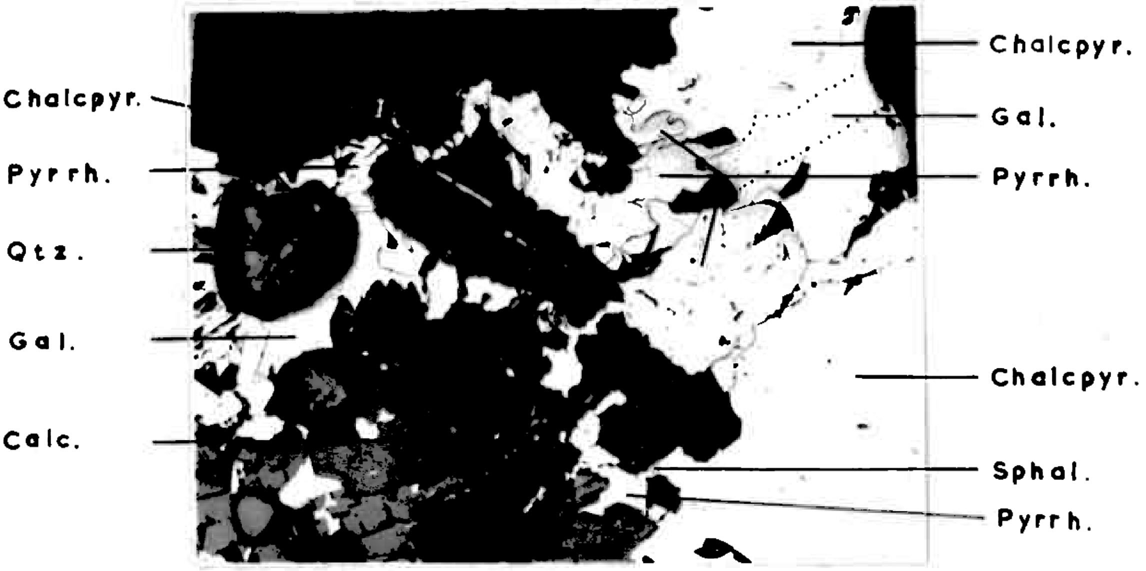


Spec. No. 16

6 Etasje, in the Lode adjacent to the Hanging Wall

A mineralised amphibole schist

Idiomorphic pyrite and allotriomorphic pyrrhotite have developed by replacement of the schist.



P.S. No. 32. (x 120)

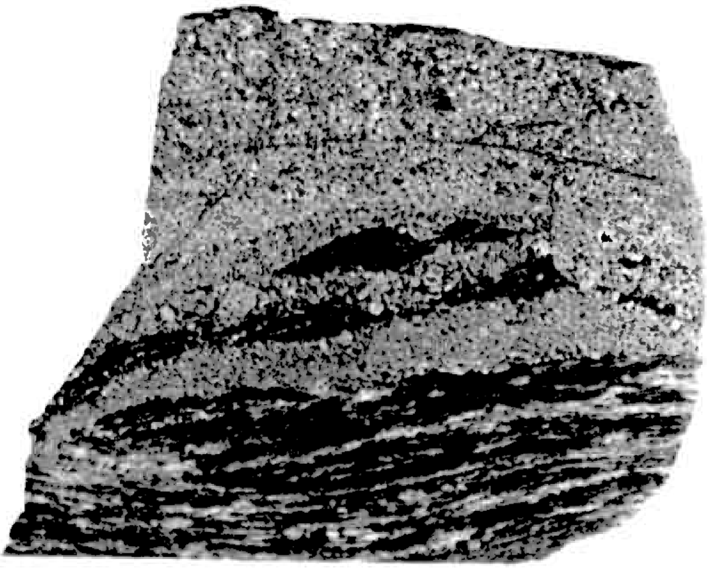
1 Etasje, adjacent to Hanging Wall

The Massive Sulphide

Chalcopyrite and galena have partially replaced pyrrhotite and calcite. Galena developed later than the chalcopyrite, replacing it on occasions.

The contrast in the gangue minerals is readily apparent.

Described on page xxvii.

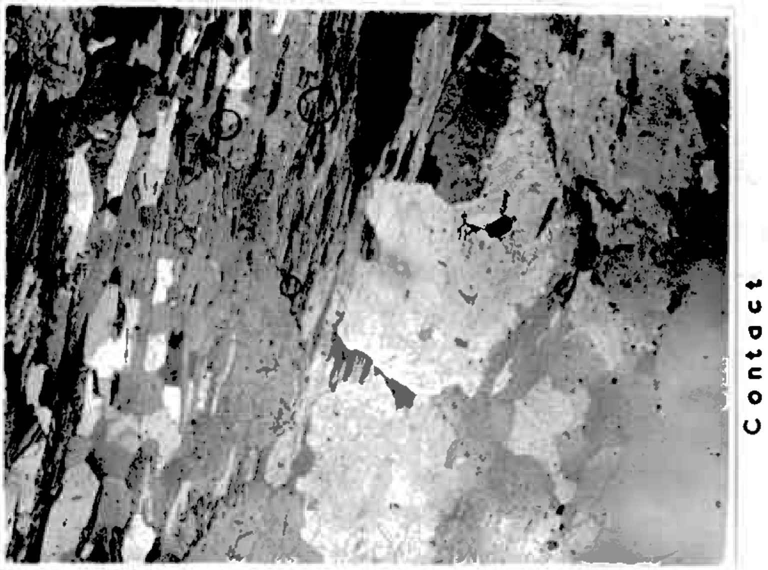


Spec. No. 36

Lode Contact. Loose specimen taken from an ore chute on Etasje 6

The massive pyrite has partially replaced the chlorite schist. This illustrates the linear nature of replacement and the residual nature of the schist "islands". Minor chalcopyrite is interstitial to the pyrite.

The original wall rock schist has been considerably altered by late alkali metasomatism and is now a felspar-quartz-mica-chlorite schist.



T.S. No. 36a. (x 25)

Loose specimen taken from ore chute on Etasje 6

Lode Contact

Felspar (Na-K) has developed at the Contact, replacing the previous hydrothermal minerals - calcite, mica and quartz. Quartz has recrystallised a little farther from the Contact.

Described on page xvii.

APPENDIX

The appendix is composed of descriptions of thin and polished sections taken from the Lode and Wall Rocks at localities indicated on the Mine Plan.

Only the mineralogy of the Eastern Lens was examined. The specimen suites are from the following localities:-

Surface Outcrop	3 specs.
Etasje 1	2 specs.
Etasje 5	2 specs.
Etasje 6	17 specs. and 2 drill cores.
Etasje 7	2 specs.
Etasje 8	13 specs.

The polished sections are generally similar and consequently the final descriptions are brief.

The Wall Rocks

The Hanging Wall (Bore Hole 80)

A core was examined which represented 60 ms. of the country rock at right angles to the lode. In the hand specimen the rock appears as a chlorite schist interbedded with layers of quartzite and containing quartz nodules. Ill-defined biotite bands occur adjacent to the lode.

Thin sections of the core cut across the schistosity were taken at intervals of 58 and 33 ms. from the lode and at the contact. Both sections disclosed:-

> Felspar chlorite actinolite epidote-clinozoisite schists with subsidiary biotite, quartz, rutile and sphene.

The Segregation of the mafic minerals and felspars in separate laminar and the general uniform orientation of the platy and micaceous minerals have produced the schistose structure. Numerous small thrusts and drag-folds (limb length of 1cm.) exist in this highly-contorted schist.

Felspar. This is albitic in composition. Crystals are interlocked and uniformly fine grained (0.025-0.05 mm. dia.). Larger crystals (0.3 mm. dia.) form clusters and often contain blebs and needles of the surrounding minerals as minute inclusions. Twinning is rare.

Chlorite occurs as clear platy and scaly forms and in fan-shaped aggregates. The platy variety is light green and faintly pleochroic, a contrast to the pleochroism of the fan-shaped varieties which is colourless to light green. Microscopic flakes and needles of the mineral exist along the borders and in the larger felspar crystals.

Actinolite shows a variation in length from microscopic to that of approximately 1 mm. This acicular mineral occurs as straggling concentrations either in a chloritic or felspathic ground mass. It is cracked, distorted and fragmented.

Epidote-Clinozoisite. The mineral occurs as fragments and as distorted and corroded crystals which show replacement by quartz and felspar. General grain length is approximately 1 mm. or less. Zoning is not unusual and records a reduction in the iron content towards the crystal edges.

Carbonate. Calcite occurs as irregular grains (xenoblasts) singly and in patches and strings chiefly located in the mafic laminar. They are zoned, the large grains often containing corroded islands of differently-oriented carbonate. The whole is punctuated with residual grains of felspar and quartz. The mineral also forms microscopic blebs in the larger felspar crystals and around their peripheries.

Biotite. A biotitic mineral possessing extreme biotite pleochroism and abnormally strong birefringent colours (R.I. 1.621-1.635) is occasionally closely interleaved with the chlorite, with which it has a replacement association.

Quartz is uncommon and is associated with the felspar.

Rutile. It is confined to particular zones in the mafic minerals. Corrosion and fragmentation have resulted in the destruction of the original crystal form.

Sphene is rare and occurs as microscopic crystals of typical form.

Contact. Actinolite felspar chlorite carbonate rutile schist.

The schistosity is well developed and follows many small contortions. Actinolite is more abundant than in previous sections and the felspar less so. No readily-noticeable change in the felspar grain size exists. Xenoblasts of calcite increase towards the lode. These are composite containing two periods of the mineral. Biotite is rare, occurring in the chlorite.

A few irregular elongate grains of pyrrhotite replace the platy minerals.

The Foot Wall (Bore Hole 81)

A core was examined which extended for a distance of 55 ms. into the country rock at right angles to the lode. In the hand specimen it is very similar to the hanging wall - a chlorite schist interbedded with quartzite bands and containing thin layers of biotite at intervals of 35 and 5.5 ms. from the lode.

Thin sections cut across the schistosity were taken at intervals of 55, 25, 13, 5.8 and 2.2 ms. and at the contact. These sections disclosed:-

Felspar quartz chlorite schists interbedded with green schists.

At 55 ms: Felspar quartz chlorite epidote-clinozoisite schist with subsidiary carbonate, rutile and sphene.

25 ms: Green schist. Chlorite epidote-clinozoisite schist with subsidiary biotite, quartz and sulphides (pyrrhotite and chalcopyrite).

13 ms: Felspar quartz carbonate biotite actinolite epidote schist with subsidiary rutile, sphene and sulphides (pyrrhotite, pyrite and chalcopyrite). This is traversed by narrow zones a few cms. in width of biotite epidote and chlorite epidote.

5.8 ms: Felspar biotite epidote carbonate schist with subsidiary quartz, chlorite, sulphides (pyrrhotite and chalcopyrite) and rutile. A zone of unusually large crystals of clinozoisite and biotite traverse the schist.

2 ms: Sericite schist containing lenticules composed of felspar and/or chlorite with subsidiary epidote-clinozoisite, carbonate, rutile and sulphides (pyrite and chalcopyrite).

The Foot Wall (Bore Hole 81)

A Description of the Thin Sections Cut.

The general structure is similar to that of the Hanging Wall - a highly-contorted schist containing numerous small thrusts and dragfolds.

The mineral assemblage also is similar and in the following only the main features are enumerated.

55 ms: Felspar quartz chlorite epidote-clinozoizte schist with subsidiary carbonate, rutile and sphene.

The plagioclase (albite) and quartz are fine grained and intimately mixed and form a sieve texture in the chlorite which occurs as fan-shaped aggregates. This has resulted in the partial loss of the schistose structure. The character of the crystal boundaries between these minerals suggests either contemporaneous crystallisation or replacement of the chlorite. Occasional scattered allotriomorphic crystals of quartz, ca. >1.5 mms. in c.s. occur. Microscopic rods of chlorite exist along the borders of and in these crystals. Porphyroblasts of calcite, containing inclusions, replace the rock.

Idiomorphic to sub-idiomorphic crystals of pyrite replace the platy minerals and contain residual islands of the more resistant minerals, e.g. quartz.

25 ms: Green schist. Chlorite epidote-clinozoisite schist with subsidiary biotite, quartz and sulphides (pyrrhotite and chalcopyrite).

Chlorite with a little epidote-clinozoisite are the component minerals and form a prominent schistosity that is seldom attained in the observed rocks. The chlorite occurs in fans and sheaves and is noticeably pleochroic (colourless to light green). The epidote-clinozoisite crystals are acicular and exhibit good crystal form. Cracks, fragmentation and some replacement of their centres by quartz is evident. The birefringent colours are strong and indicate a composition near the epidote end of the series. Rare quartz grains with wavy extinction are scattered throughout.

Irregular grains of pyrrhotite (dominant) and pyrite replace the chlorite. Generally the grains are oblong in shape, have parallel sides, lie in the direction of schistosity and sometimes occur at the crystal contacts between the hard and soft minerals.

13 ms: Felspar quartz carbonate biotite actinolite epidote schist with subsidiary sulphides, rutile and sphene. This is traversed by narrow zones a few cms. in width of biotite epidote and chlorite epidote.

Small actinolite crystals having a cross-sectional length of 0.5 mms. or less occur concentrated in layers and strands reflecting the fold forms. Zoned carbonate porphyroblasts are located in the layers containing felspar and quartz replacing favourably the platy minerals. The harder minerals remain, forming strings of residual islands. Idiomorphic pyrite and small irregular grains of chalcopyrite and/or pyrite also replace the platy minerals.

5.8 ms: Felspar biotite epidote carbonate schist with subsidiary quartz, chlorite, sulphides and rutile. A zone of unusually large crystals of clinozoisite and biotite traverse the schist.

In the zone of smaller crystals the growth of felspars in clusters and lenticules has resulted in the partial loss of the schistose texture. Grain size is generally smaller than in the previous sections. Biotite and epidote are present in approximately equal amounts. The epidote is cracked and fragmented; zoning occurs, the crystal centres showing slight colouration and stronger birefringence colours. Selective replacement by quartz and occasionally biotite of these iron-rich zones has taken place. The carbonate clusters tend to form strings parallel with the direction of schistosity.

Crystals of clinozoisite, some 1.2 cms. long in c.s., together with sheaths of biotite, occur adjacent to the previous zone. This clinozoisite is also zoned, corroded and replaced. Microscopic crystals of rutile are included in both minerals. The biotite sheaths show replacement by irregular grains of pyrrhotite. Subordinate amounts of chalcopyrite are present in the sulphide grains.

2 ms: Sericite schist containing lenticules of felspar and/or chlorite with subsidiary epidote-clinozoisite, carbonate, rutile and sulphides.

The sericite includes occasional lenticules of (a) plagioclase (b) plagioclase and chlorite and (c) chlorite. Scattered grains of plagioclase surround both (a) and (b). Rutile, though still a minor mineral, is more common than previously observed. Its crystal form varies from idiomorphic crystals 0.2 mm. in c.s. to small acicular crystals and strings of fragments. Calcite marks a transition to a zone of well-developed, intimately-mixed biotite and chlorite. Both minerals are punctuated with plagioclase grains.

Pyrite with a little chalcopyrite occurs in the sericite. A gradual increase in the sulphide content takes place towards a chlorite biotite zone where it reaches a maximum and granules develop, composed of many small grains and crystals.

Contact: A hydrothermally-altered felspar chlorite epidote rutile schist containing sericite, mica and carbonate.

Much of the order and texture of the original schist has been lost. Alteration has produced heterogeneity in size and content. Crystals of carbonate, quartz and plagioclase, scattered and in separate clusters, form, with islands of the original schist, the principal components. The calcite is similar in form and relationships to that already described, but has now become predominant. The quartz crystals are <3-4 mms. in c.s., cracked, possess wavy extinction and serrate edges when adjacent and contain many fine black inclusions. The plagioclase, however, is smaller generally retaining its original size. Mica and plagioclase form intimate clusters, and when in contact with quartz and carbonate respectively suggest a replacement association. Sericite has developed in the chlorite of the residual rock and also as patches in the altered areas.

A grain composed of magnetite and chalcopyrite was observed.

Section 1. 8 Etasje, Main Shaft

A fine grained actinolite plagioclase epidote-clinozoisite schist with subsidiary carbonate and rutile.

The principal minerals possess a very fine grain and are similar to those in B.H. 81 at 58 ms. Actinolite is present as acicular crystals contained in a matrix of fresh chlorite. These crystals outline the many contortions existing in the schist. Variations in the chemical composition of the epidote-clinozoisite minerals are indicated by zoning and intermittent pleochroism which together suggest a decreasing iron content. Rutile is present as corroded fragments and microscopic idiomorphic crystals.

Section 9. 8 Etasje, 80 cms. from the Lode in the F.W.

A chlorite plagioclase quartz epidote schist with subsidiary carbonate, biotite and sulphides.

The quartz consists of two types differentiated by size. The larger variety tends to form clusters and veins, possesses flamboyant extinction and has minute inclusions of quartz and chlorite. Crystal boundaries lying against the cleavage faces of biotite show a serrate form. Well-developed chlorite rods accompany the quartz clusters. Epidote crystals, some 3½ mms. in c.s., are corroded and replaced by quartz.

Grains of pyrrhotite exist in the chlorite containing residual quartz.

Section 10a. 8 Etasje, 160 cms. from the Lode in the F.W.

A hydrothermally-altered chlorite schist in which four zones are discernible. Each zone is described independently.

Zone 1. A chlorite plagioclase epidote clinozoisite-epidote schist with subsidiary quartz, carbonate and rutile containing as hydrothermal-alteration products mica and further carbonate and quartz.

A heterogeneous mass of chlorite and biotite plates and laths, scattered grains of plagioclase and quartz and isolated patches of carbonate. Quartz occurs as large grains showing flamboyant extinction and possessing minute inclusions of the original rock minerals, i.e., rutile. A sericitic mineral forming strings of interlaced fine needles traverses the chlorite. The epidote-clinozoisite crystals are corroded and replaced by chlorite. Each crystal is surrounded by a light green halo.

Adjacent to a vein or cluster of quartz crystals idiomorphic pyrite marks the transition to the next zone, one of pure chlorite schist. The pyrite crystals, $\lesssim 0.3$ mm. in c.s., occur singularly and in dense clusters replacing principally chlorite.

Zone 2. A chlorite schist with rare carbonate, clinozoisite and pyrite.

The chlorite has a scaly texture. Dark lines zone the clinozoisite.

Zone 3. A carbonate chlorite quartz rock with subsidiary mica of hydrothermal origin.

The carbonate chlorite crystal boundaries suggest a replacement relationship. Many small residual inclusions exist in the carbonate. Rare sericite and mica occur in the chlorite. Occasional grains of quartz punctuate the whole.

Zone 4. A carbonate quartz chlorite rock with subsidiary mica, epidote and pyrite of hydrothermal origin.

The pyrite is similar in occurrence and appearance to that previously described, though the clusters merge into larger isomorphous lumps.

x

Section 10b. 8 Etasje, 160 cms. from the Lode in the F.W.

A heterogeneous hydrothermally-altered chlorite schist showing vague zoning.

Zone 1. A chlorite schist containing plagioclase, quartz, carbonate, sericite, mica, rutile and garnet.

Zone 2. A carbonate rock with subsidiary quartz, mica, chlorite and pyrite.

The carbonate forms a mosaic of small crystals in which the associated minerals are unevenly distributed.

Zone 3. A sericite chlorite schist with subsidiary carbonate, quartz, plagioclase, clinozoisite, mica, rutile and pyrite.

The plagioclase and quartz consists of small grains unevenly distributed in the sericite chlorite ground mass. Larger grains of quartz of a hydrothermal character occur in clusters associated with the carbonate.

Zone 4. Predominantly quartz with minor chlorite and biotite.

Zone 5. A mixture of quartz and carbonate with less-frequent chlorite and micaceous minerals.

Sections 13a and 13b. 8 Etasje, from Foot Wall at contact

An altered chlorite felspar quartz schist containing hydrothermal carbonate felspar quartz and sulphides.

The remnants of the schist are isolated and traversed by the hydrothermal minerals. Mica and sulphides have developed in the chlorite and later minerals.

Original rock. A chlorite felspar quartz schist with subsidiary calcite and clinozoisite.

A description of the hydrothermal minerals follows. The term hydrothermal is applied to those minerals formed during the hydrothermal activity.

Carbonate-Calcite forms clusters and strings of crystals replacing the original rock. It has a preference for the chlorite-mica stringers, initial replacement taking place along the cleavage planes. The original epidote is resistant and forms corroded islands in the porphyroblasts. Often corroded islands of a differently-orientated carbonate exist within the porphyroblasts indicating two periods of carbonisation.

Felspar occurs as irregular interlocking plates, or as rounded porphyroblasts, one 3 mms. long in c.s., replacing the original rock. Albite twinning rarely occurs, otherwise twinning is markedly absent. Some porphyroblasts exhibit a central zone containing many fine dark inclusions, with them are associated larger grains of a metallic mineral (probably pyrrhotite). The felspar replaces the chlorite-mica stringers. Felspar carbonate contacts are rare. A "shore line" type of contact exists in one instance. In the felspar adjacent to the contact are many fine inclusions forming a pattern of islands.

This relationship suggests replacement of the carbonate. The relationship with the hydrothermal quartz is not clear. Strings of the original felspar and quartz traverse this and the other later minerals.

Quartz. Irregular clear grains having a fluid form and flamboyant extinction replace the platy minerals. Clinozoisite, chlorite and biotite remain as inclusions. Replacement of the carbonate along crystal boundaries has occurred. Also a "shore line" texture exists between adjacent grains, then the quartz contains many microscopic carbonate inclusions.

Mica of two types has developed in the chlorite. One is typically biotitic, the other is strongly pleochroic with bright interference colours.

Sulphides. Pyrrhotite, pyrite and chalcopyrite together form irregular grains preferentially replacing the chlorite. Pyrrhotite is dominant Replacement of the hydrothermal minerals is indicated by pyrrhotite intergrowths in the felspar.

Sections 14a I, II and III. Etasje 6, Foot Wall contact.

A hydrothermally-altered layered felspar chlorite clinozoisite schist possibly containing some quartz. Alteration, typified by carbonate, felspar and quartz, follows particular zones parallel with the schistosity. Sections across them illustrate their character.

Section I

A felspar chlorite schist containing hydrothermal plagioclase, carbonate, mica and pyrrhotite.

Felspar is both hydrothermal and original. Albite twin determinations indicated the composition $Al_{9.3}An_{0.7}$ or $Al_{6.7}An_{3.3}$ for the original felspar.

Chlorite is generally similar to that in B.H. 80 at 33 ms. The two varieties of mica which occur in Section 13 have developed along the cleavage planes, forming laths and plates identical to the chlorite except for colour.

Carbonate-calcite, as is usual, forms porphyroblasts replacing the original rock. The more resistant minerals, quartz and felspar, remain as residual islands.

Section II

The schist is here almost entirely replaced by carbonate. A little hydrothermal quartz borders the carbonate crystals. As before, mica is developed in the chlorite.

Section III

Similar to Sections I and II. Albite twin determinations gave identical results to those previously made. An accompanying R.I. determination suggested albite. A single idiomorphic colourless garnet occurs as an original mineral.

Section 18. Etasje 6, Hanging Wall contact where the Lode pinches out.

A highly-contorted felspar chlorite schist in which mica has developed in the chlorite. Pyrrhotite and less-common chalcopyrite replace the chlorite. A concentration of the sulphides exists in the fold apices.

Section 19. Etasje 6, country rock ca. 5 ms. from Lode termination.

A felspar actinolite clinozoisite schist with disseminated pyrite. The absence of chlorite indicates a schist of a more competent character than those previously examined. Evidence of hydrothermal alteration is rare. A few strands and strings of carbonate replace the actinolite and felspar.

Section 22. Etasje 6, a "horse" in the Lode.

A hydrothermally-altered rock composed of a heterogeneous mass of chlorite, white mica, biotite and subsidiary plagioclase, quartz, clinozoisite-epidote, pyrite, rutile and garnet. This grades sharply into a quartzose rock containing a network of fine pyrite crystals.

Chlorite forms plates and scales.

White mica develops as rods and laths (length varies around 0.5 mm. in c.s.) in chlorite. Formation commences with the development of a colourless area possessing white to yellow interference colours. Crystal outlines appear with the brighter interference colours (green and red).

Biotite replaces chlorite. One plate of biotite was traversed by a well-developed sheath of chlorite.

Plagioclase is an original mineral forming a sieve structure in the chlorite. Simple twinning is occasionally apparent. Inclusions are numerous, some showing strong birefringence.

Quartz occurs as a few scattered grains.

Clinozoisite-epidote corroded crystals and fragments, some 1 mm. long in c.s., constitute part of the original schist. A few crystals exhibit brownish centres.

Pyrite. Idiomorphic crystals, one 3 mms. in width, replace the schist. Rutile and quartz are contained as inclusions.

Garnet. A lone well-formed crystal full of minute inclusions occurs.

Section 30. Etasje 6, main shaft

A plagioclase hornblende chlorite schist with subsidiary clinozoisite-epidote, quartz, metallic mineral, mica and carbonate.

Idiomorphic hornblende readily observable in the hand specimen and showing no preferential orientation has developed in the chloritic layers. Small drag folds produce a slight irregularity in the layering. The rare development of mica indicates little hydrothermal activity.

Plagioclase forms layers streaked with the mafic minerals. Porphyroblasts (one 0.5 mm. in c.s.) are rare.

Hornblende occurs as idiomorphic acicular crystals whose average length in cross section is ca. 3 mms. Some distortion and fragmentation accompanied by corrosion along the planes of parting has taken place.

Chlorite forms plates and scales.

Clinozoisite-epidote is comparatively rare, occurring as minute crystals and corroded fragments.

Metallic mineral forms irregular grains of a poikolitic texture containing included felspar. Its colour is rather dark for pyrrhotite. Ilmenite or pyrrhotite.

Mica, carbonate and quartz are rare constituents.

Section 35. Surface outcrop adjacent to Lode

A felspar mica chlorite carbonate clinozoisite-epidote schist with subsidiary sulphides and rutile.

The development of felspar, mica and carbonate evidence hydrothermal alteration. Both original and hydrothermal felspar are present. The original occurs in its typical form and contrasts to the closely-interlocking plates, containing many inclusions, of the hydrothermal variety. Mica is widely distributed in the chlorite. It possesses strong pleochroism (colourless to varying shades of brown). The outer zones of the carbonate porphyroblasts have a frosted appearance and contain many fine inclusions. The hydrothermal felspar may be replacing the carbonate. Pyrite forms irregular grains and shreds (one 1½ mms. long in c.s.) replacing the platy minerals. Chalcopyrite is also rarely present.

Sections 36a and 36b. Lode Contact. Loose specimen taken from ore chute on Etasje 6.

Wall Rock. Felspar quartz mica chlorite schist with subsidiary carbonate, clinozoisite, sulphides and rutile.

Separation of the felsic and platy minerals has resulted in a distinct layering of the wall rock. Idiomorphic pyrite crystals, forming well-defined strands and layers, replace the original minerals. Occasional "horses" of the wall rock remain in the massive sulphide. The pyrite shows no preferential replacement - it advances on a broad front across the original layering. The average dimensions of the pyrite cubes are between 0.5 - 1.0 mm.

Minor amounts of allotriomorphic pyrrhotite and chalcopyrite occur as replacement minerals,

i. Interstitial to the pyrite,
ii. In the chlorite mica layers of the wall rock.

Felspar is predominantly potassic. It occurs as cloudy, irregular, elongated plates developing at the Lode contact. The plates are intimately intergrown, seldom show twinning and have their greatest length along the direction of schistosity. They replace the chlorite, quartz, mica and carbonate. Parts of these minerals remain as residual inclusions. Many of the microscopic mica inclusions exhibit a well-developed lath-like form.

Quartz occurs as clear grains forming lenticules and strands in the plane of schistosity. The grains interlock with moderately regular boundaries. They contain many minute inclusions. The quartz appears to be replacing the platy minerals, similarly orientated fragments of biotite are contained in the grains.

Mica. Two varieties:-

i. Variety pleochroic in brown and possessing strong birefringence.

ii. Biotite

Both are intimately associated and have developed from the chlorite. Clinozoisite is almost confined to the chlorite as it has replaced both the felspar and the quartz.

The Lode

POLISHED SECTIONS

No. 3. 8 Etasje, centre of Lode in the Back.

Economic mins., major:- Pyrite and pyrrhotite
minor:- Chalcopyrite, sphalerite and magnetite

Gangue mins:- Calcite and quartz

Pyrite, the predominant mineral, exhibits well-developed cubes generally enclosed in allotriomorphic pyrrhotite and rarely containing islands of gangue and magnetite. Where clusters have formed the crystal outlines are lost. The pyrite shows considerable replacement by pyrrhotite along its crystal boundaries.

Pyrrhotite. Allotriomorphic. It is the main replacement mineral of pyrite.

Sphalerite. Allotriomorphic. It occurs with chalcopyrite replacing the pyrrhotite and pyrite. Rare blebs of pyrrhotite exist in the sphalerite.

Chalcopyrite. Allotriomorphic. With sphalerite it occurs in the interstices of the pyrite crystals, following their boundaries. Pyrrhotite is replaced preferentially to pyrite. Some replacement of the gangue has taken place. With sphalerite a "shore line" texture exists. Rare unorientated blebs are distributed in the pyrite.

Magnetite occurs as octahedra and granular aggregates. Good crystal form is exhibited against the sulphide minerals but for one exception where replacement by pyrite was observed. Pyrite rarely forms indentations in the octahedra. Exsolution blebs of pyrrhotite show replacement by chalcopyrite. Pyrrhotite and pyrite were observed in one bleb.

No. 2 8 Etasje, adjacent to Foot Wall.

Economic mins., major:- Pyrite and pyrrhotite
minor:- Chalcopyrite, sphalerite and magnetite

Gangue mins:- Calcite and quartz

Pyrite. Corrosion and replacement by pyrrhotite is more advanced than in Section No. 3. Only a few small crystals in the pyrrhotite possess good crystal outlines. The pyrite contains blebs of magnetite, chalcopyrite, sphalerite and gangue.

Chalcopyrite. Forms small scattered groups replacing pyrrhotite, pyrite and gangue.

Sphalerite. Possesses a "caries-like" boundary texture with its associated mineral chalcopyrite. It replaces pyrrhotite preferentially to pyrite.

Magnetite. Minor replacement by pyrite and chalcopyrite has occurred. Pyrrhotite is present in the possible form of exsolution lamella.

No. 4. 8 Etasje, adjacent to the Hanging Wall.

Economic mins., major:- Pyrite and pyrrhotite
minor:- Sphalerite, chalcopyrite and magnetite

Gangue mins.

Pyrite. Corrosion and replacement of the pyrite is less well developed than in Section No. 2. Inclusions of pyrrhotite, sphalerite, chalcopyrite, magnetite and gangue are contained in the crystal centres.

Pyrrhotite shows a proportional increase compared to Section No. 3.

Sphalerite replaces pyrrhotite preferentially to the gangue.

Chalcopyrite is less common than in Section No. 3. It replaces pyrite in preference to magnetite.

(Thin Section No. 5). 8 Etasje, adjacent to Foot Wall

Economic mins., major:- Pyrite and pyrrhotite
minor:- Chalcopyrite, sphalerite and magnetite

Gangue mins., major:- Calcite
minor:- Quartz, amphibole and rutile.

The sulphides are contained in a closely-interlocking mesh of calcite grains. Quartz occurs as islands in these grains and also along their boundaries.

Pyrite. Corroded idiomorphic crystals. Its relationship with the calcite is generally indeterminate though replacement of this mineral was observed along its grain boundaries and cleavage planes. Similarly with quartz; the pyrite crystals generally lie across its grain boundaries.

Chalcopyrite replaces both the gangue and the sulphides-pyrite and pyrrhotite.

Pyrrhotite replaces the gangue and pyrite.

Calcite has a fairly even grain size. It shows replacement by the sulphides and quartz.

Quartz occurs as clear intimately-intergrown granules possessing a flamboyant extinction. A "caries type" boundary exists with the calcite.

Amphibole is uncommon. It occurs as corroded crystals; some, 2 mms. in length. They exhibit a marked pleochroism, dark green to blue-green. Replacement by the gangue and sulphide minerals is evident.

Rutile rarely occurs. Generally it is contained in the sulphides.

The relationships between the pyrite, calcite and quartz are generally ambiguous.

No. 5. 8 Etasje, adjacent to Foot Wall.

Economic mins.,	major:-	Pyrite and pyrrhotite
	minor:-	Chalcopyrite, sphalerite and magnetite
Gangue mins:-		Calcite, quartz and amphibole.

Section is generally similar to Section No. 4.

Chalcopyrite shows a slight increase. It surrounds the pyrite occurring in the gangue, replacing the gangue in preference to the pyrite. An acicular gangue mineral replaces the chalcopyrite.

Sphalerite is rare.

No. 6. 8 Etasje, centre of Lode in the back.

Economic mins., major:- Pyrite
minor:- Pyrrhotite, sphalerite, chalcopyrite and magnetite

Gangue mins: Calcite and quartz.

Pyrite is less common than in the previous sections. Corrosion is more pronounced than in Section No.4 and No. 5.

Pyrrhotite shows a marked decrease.

Sphalerite is more plentiful than in any of the previous sections. It replaces the gangue and pyrrhotite in preference to pyrite.

Magnetite is present as a few small euhedral crystals.

No. 8. 8 Etasje, adjacent to Hanging Wall.

Economic mins., major:- Pyrite and pyrrhotite
minor:- Chalcopyrite and sphalerite

Gangue mins:- Calcite, quartz and amphibole.

Pyrite. Corrosion is less evident.

Chalcopyrite is more abundant than in Section No. 5 and No. 6.

No. 15. 6 Etasje, centre of Lode in the Back.

Economic mins., major:- Pyrite
minor:- Magnetite, chalcopyrite and sphalerite

Gangue mins:- Calcite and quartz.

Pyrite. The idiomorphic crystals show considerable corrosion, particularly when in contact with the gangue. Inclusions are numerous and large, magnetite predominating.

Magnetite occurs as corroded crystals in the gangue which may form granular aggregates. Using a mag. of X400 the smaller crystals exhibit a good shape. Replacement of the pyrite is suggested by some contacts.

Chalcopyrite occurs, replacing the gangue and also pyrite along its crystal boundaries and cracks. Its relationship with the magnetite is ambiguous; the magnetite exhibits good crystal form against the chalcopyrite but also replaces it.

Sphalerite is generally associated with the chalcopyrite. Similarly it replaces the pyrite and also the chalcopyrite.

Pyrrhotite is rare. It was observed as a bleb in the pyrite undergoing replacement by chalcopyrite.

Gangue is composed of quartz and calcite.

No. 16. 6 Etasie, in the Lode adjacent to the Hanging Wall.

Economic mins., major:-	Pyrite
minor:-	Chalcopyrite, pyrrhotite and sphalerite
Gangue mins:-	Calcite, quartz and amphibole.

Pyrite retains its idiomorphic form. Corrosion is most pronounced in the gangue.

Pyrrhotite is a replacement mineral forming irregular patches and shreds.

Sphalerite is rare. It forms small round patches in the chalcopyrite.

Gangue predominates. Its components are calcite, quartz and amphibole. The relation of the transparent mins. to the sulphides is ambiguous. The hard acicular needles of the amphibole traverse the sulphides, indicating later development.

No. 17. 6 Etasje, in the Lode adjacent to the Hanging Wall.

Economic mins., major:- Pyrite
minor:- Pyrrhotite and chalcopyrite

Gangue mins:- Calcite, quartz and amphibole.

The mins. present have similar relationships to those existing in previous sections. The pyrite grain size is more constant than usual. Amphibole is a minor gangue mineral and shows replacement by the sulphides. Chalcopyrite is present in small quantities.

No. 26. 6 Etasje, near centre of Lode at breast height.

Economic mins., major:- Pyrite
minor:- Magnetite, chalcopyrite, pyrrhotite and sphalerite

Gangue mins:- Calcite and quartz.

The Section is generally similar in nature to those from 6 Etasje previously described. Idiomorphic pyrite and the gangue minerals predominate. Magnetite is an important subsidiary, occurring as corroded idiomorphic crystals showing replacement by pyrite. Minor localisations of chalcopyrite are common. Pyrrhotite and sphalerite are rare.

No. 25. 6 Etasje, in Lode near Hanging Wall.

Economic mins.,	major:-	Pyrite
	minor:-	Magnetite, chalcopyrite and pyrrhotite.
Gangue mins:-		Calcite and quartz.

The minerals occurring have similar relationships to those described previously. The gangue minerals predominate.

No. 32. 1 Etasje, adjacent to Hanging Wall.

Economic mins.,	major:-	Pyrite
	minor:-	Sphalerite, chalcopyrite, pyrrhotite, galena and an unknown mineral
Gangue mins.,	major:-	Calcite
	minor:-	Quartz and mica-chlorite.

Pyrite. Idiomorphic. Average crystal size generally less than usual, ca. 1-3 mms. in dia. The crystals are cracked and corroded. Replacement by the sulphides and gangue has taken place. Microscopic inclusions of these minerals are frequent.

Sphalerite preferentially replaces the pyrrhotite, forming irregular wreaths about the pyrite. Minute inclusions of chalcopyrite are frequent. Calcite occasionally shows replacement by the sphalerite.

Chalcopyrite occurs as patches and shreds around the pyrite and in the gangue. It replaces the pyrrhotite and the gangue, the pyrrhotite preferentially.

Pyrrhotite crystals form segregations bordering the pyrite and replacing the gangue.

Galena preferentially replaces the pyrrhotite and also forms isolated patches in the gangue.

Mineral X is less frequent than galena which it either replaces or exsolves (Photograph). The occurrence is restricted to chalcopyrite which the mineral(s) replace(s). It is pinkish grey, has a lower reflectivity than the galena and is isotropic.

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Note: Well known textbooks are excluded from this list.

NORGES GEOLOGISKE UNDERSØKELSE

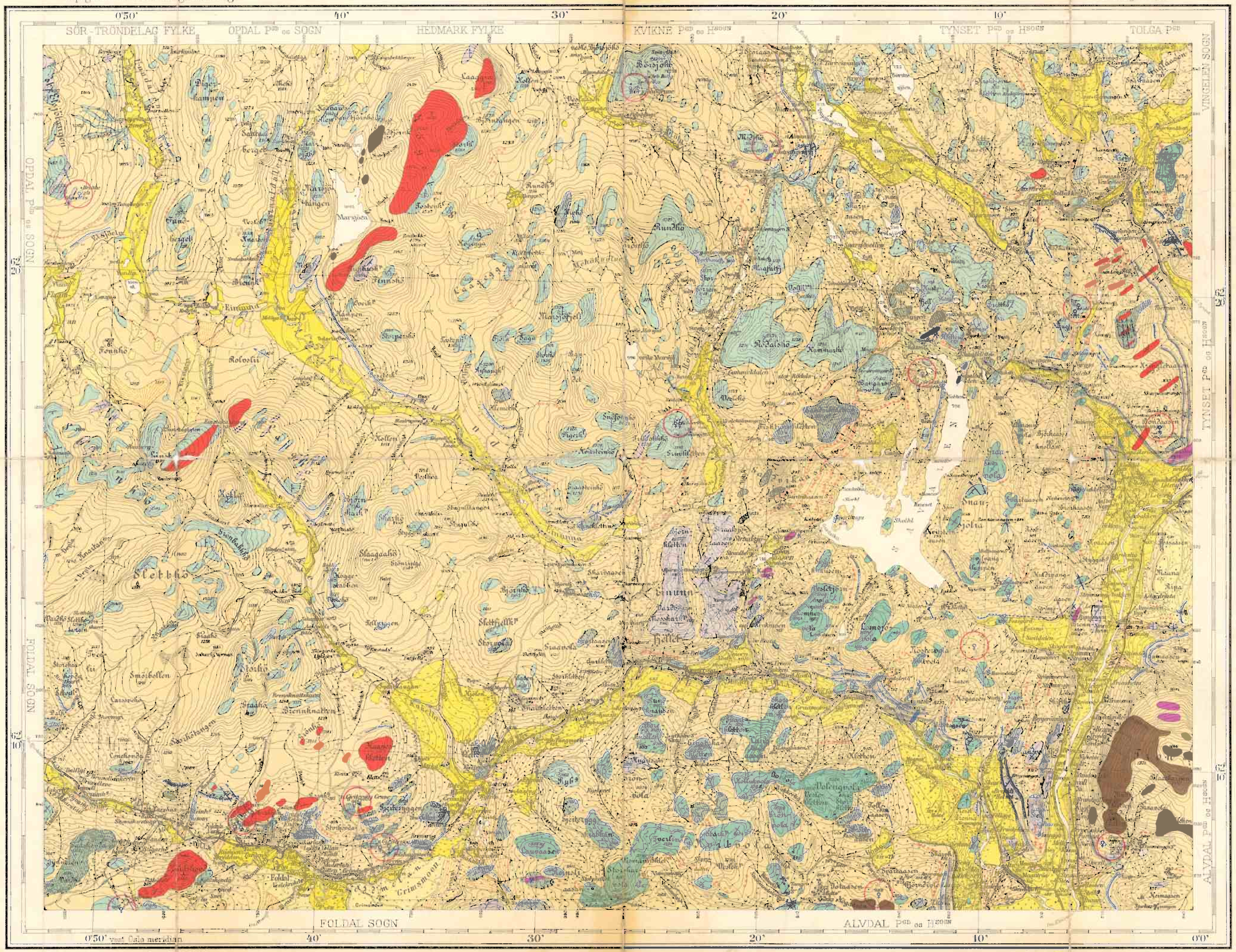
Geologisk Kart

FOLDAL

Oslo 1936.

Topografisk kart over kongeriket Norge

Rektangel 37 D



- Hovedkirke
- Sognekirke, kapell
- Gård
- Plass, seter
- Villa, skole, hotell, turisthytte, mindre industriell bedrift o. l.
- Fiskerbu, skytterbu, fjelager, o. l.
- Större fabrikk, elektrisitetsverk, mölle o. l.
- Kvern
- Sag
- Trigonometrisk punkt
- Ekserserplass
- Fyr, lykt
- Sjömerke
- Båe i vannflaten
- " under vannflaten
- Riksgrense, grenseröis
- Fylkesgrense
- Prestegjeldsgrense
- Sognegrense
- Bygrense
- Hovedvei
- Bygdevei
- God privat kjörevei
- Kjerrevei
- Klövvei, sti
- Vintervei
- Jernbane (dobbelt spor), stasjon, stoppested
- Jernbane (enkelt spor), stasjon, stoppested
- Jernbane under arbeide
- Tertiærbane, elektrisk sporvei
- Hestejernbane
- Taubane
- Telegraflinje, stasjon
- Kystkontur med fjære og slaggrunnslinje
- Nåleskog
- Lövskog
- Myr

Målestokk 1 : 100000

Ekvidistanse 30 m

Höider og dybder i meter

Løse avleiringer

(Glacialt og postglacialt)

- Sortert sand og grus (elveavsetning)
- Gruskjegle
- Ås
- Bresjøavsetning
- Morenevoller, bunnmorenerygger (drumliner)
- Bregrus med blokker (morenegrus)

Berggrunn

Yngre eruptiver

- 🟥 Trondheimitt (Protogingranitt)
- Olivin-serpentinsten
- K Klebersten
- Gabbrobergarter

Antatt kambro-silur

- 🟩 Fyllitt
- Hornblendeskifer
- Kvartsrik glimmerskifer
- 🟦 Kalksten
- Sericittkvartsitt og sericittskifer
  Inneholder tildels feltspat, epidot og finkornig, grønlig hornblende
- Konglomerat
- Erosjonsstrandlinje
- Skuringsstripe med observasjonspunkt
- Strøk og fall
- ♀ Kobber- og kisforekomst
- ⚒ Sten- og skiferbrudd

Utarbeidet på grunnlag av rektangelkart Foldal.
Litografert og trykt i Norges geografiske Opmåling 1936.

Angående utførelsen av den geologiske kartlegging henvises til: W. Marlow N. G. U. nr. 145.

Gjetryggen nordre grube. (Nordgruva)

Grunnplan

1:1000

THIN SECS.

B.H. 80, at 58 & 33 ms. & Contact.

B.H. 81, at 55, 25, 13, 5·8, 2 & Contact.

8 Etje. — 1, 9, 5, 10 a & b, 13 a & b.

6 Etje — 14a, 18, 19, 22, 30

Surf — 35

Loose — 36 a & b.

POL. SECS

8 Etje — 2, 3, 4, 5, 6, 8.

6 Etasje — 25, 26, 15, 16, 17.

1 Etje. — 32.