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The Geology of Grøndalen and a Comparison of the Grøndalsfjell Complex with other selected gabbroic Complexes within the Greenstone belts og the Norwegian Caledonides.

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Råstoffgruppe	Råstofftype
Malm/metall	Cu,Zn,Ni

Sammendrag, innholdsfortegnelse eller innholdsbeskrivelse

Beskriver feltets geolog med Grøndalsfjell som skjøvet oppå yngere bergarter i Gjersvikgruppen. Komplekset består av en sekvens gabbroer og senere dioritter med mindre faser med trondhjemittganger og basiske ganger. To typer mineraliseringer: a) Kumulus mineraliseringer innen intrusivene og b) Massive sulfider med tungmetaller i underliggende vulkanitter.

Sammenligning med flere intrusivkompleks i Norge, bl.a Hyllingen komplekset.

Geologisk kart synes å mangle.

Return: ~~OSH~~ !

THE GEOLOGY OF GRÖNDALEN AND A COMPARISON OF THE GRÖNDALSFJELL COMPLEX WITH OTHER SELECTED GABBROIC COMPLEXES WITHIN THE GREENSTONE BELTS OF THE NORWEGIAN CALEDONIDES

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FRONTISPIECE: Mr. C.Yule extracting the book from breakfast. Viewing southeast from fjell camp in Grundalen.

CONTENTS

7. COMPARISON BETWEEN THE GRÖNDALSFJELL INTRUSIVE COMPLEX AND OTHER SELECTED MAFIC INTRUSIVE COMPLEXES IN THE GREENSTONE BELTS OF NORWAY

7.A. COMPARISON WITH THE SULITJELMA GABBRO COMPLEX

7.A.(i) Relationship of the gabbro complex with the country rocks.

7.A.(ii) Nature and form of the intrusive rocks

7.A.(iii) Structure of the Igneous Complex

7.B. COMPARISON WITH THE STORELV GABBRO

7.B.(i) Relationship of the Gabbro Complex with the Country Rocks

7.B.(ii) Nature and form of the intrusive rocks

7.B.(iii) The structure of the Igneous Complex

7.C. COMPARISON OF THE GRÖNDALSFJELL COMPLEX WITH THE HYLLINGEN COMPLEX

7.C.(i) Relationship with the country rocks

7.C.(ii) The intrusive relationships

7.C.(iii) Structure of the complex

7.D. SUMMARY OF COMPARISONS

ACKNOWLEDGEMENTS

REFERENCES

ABSTRACT

Grøndalen is a northwest-southeast trending valley lying approximately 10 km. west of the mining village of Skorovas, in central Norway. The geology of Grøndalen comprises the western and southern margins of the Grøndalsfjell intrusive complex which has been thrust over younger rocks within the allochthonous Gjersvik nappe. Lithological distinctions in the field show the complex to be a sequence of gabbros and later diorites intruded into metavolcanics with minor phases of basic and trondhjemitic dykes. Beneath the thrust horizon a suite of schistose greenstones occurs, intruded by another igneous complex ranging in composition from trondhjemitic to gabbroic.

The lithologies have been subject to greenschist facies metamorphism, local hornfelsing and widespread deuteric alteration. Tentative sections of the Grøndalsfjell complex have been based on the work in Grøndalen and to the east of the complex by P. Walker (1972). A description of the economic geology of Grøndalen is given and comparisions have been drawn between the Grøndalsfjell complex and other selected gabbro-diorite intrusive bodies in the greenstone belts of Norway.

1 INTRODUCTION

During the summer of 1977, at the invitation of Elkem Skorovas Gruber A/S, geological mapping of Grøndalen was undertaken by Mr. I. L. Ferriday and the author. The objective of the study was to define the local geology and investigate the potential economic value of the area.

1.1 Geography

The mining village of Skorovas is situated in the upper Namdalen valley, Nord Trøndelag, about 30 km. from the Swedish border and about 260 km. north-east of Trondheim (Fig. 1). The Skorovaselva flows westward from Skorovas along the northern flanks of Grøndalsfjell, to the west of which lies Grøndalen. Grøndalselva flows approximately north-south from Grøndalsvatn, through Grøndalen and makes a confluence with the Skorovaselva about 12 km. west of Skorovas.

1.2 Physiography

Grøndalen is a glacial valley, evidently once occupied by a glacial lake. The valley floor lies at an average 400 m., is forested with Scots pine and is locally marshy, particularly to the south of Grøndalsvatn where exposure is low.

The valley sides rise gradually to 930 m. at Søndre Grøndalsfjell to the east and to 800 m. at Murfjellet to the west. The tree line usually occurs around the 500 m. level with scrub persisting upwards for another 100 - 200 m. In general there is almost total exposure above 700 m.

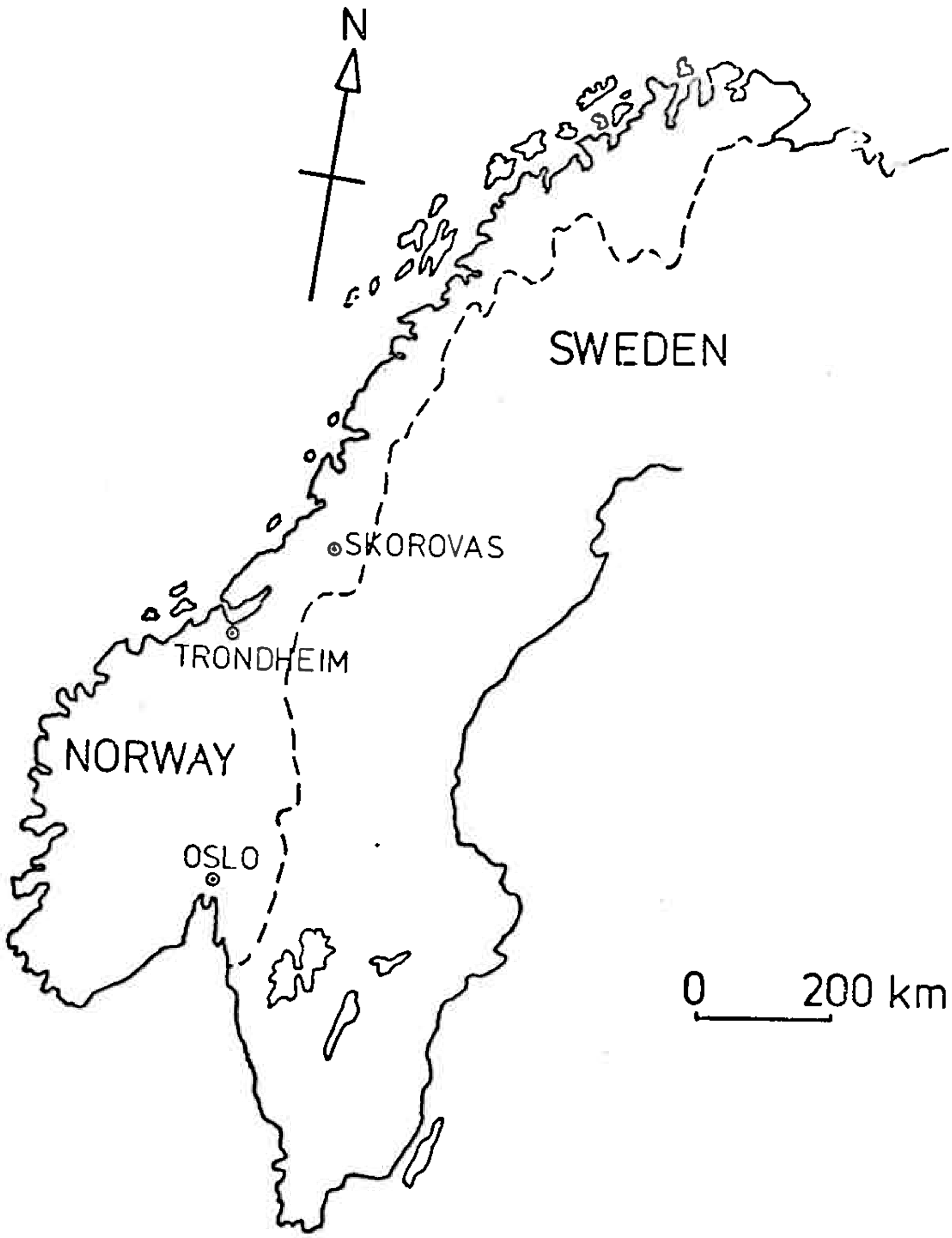
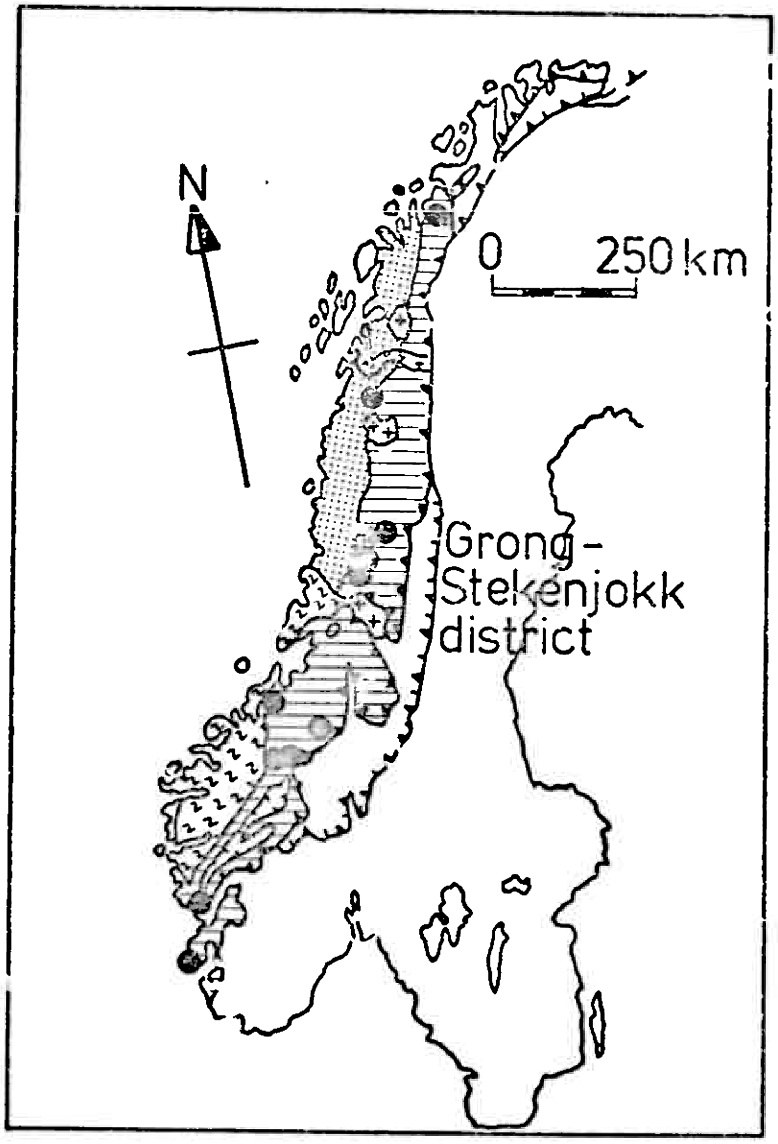


Fig.1 Geographical location of Skorovas,Central Norway

Fig.2 Synoptic geological map of the Scandinavian Caledonides showing main stratiform volcanogenic ore deposits at the Koli structural level. After Halls et al 1977.



Eastern thrust boundary of the Caledonian allochthon

Eastern thrust boundary of Seve-Koli nappe or equivalent

Basement inliers and culminations: Pre-Cambrian

Pre-Cambrian basement re-worked during the Caledonian orogeny

Helgeland and equivalent nappes with Lower Palaeozoic rocks at a higher metamorphic grade

Metamorphosed sediments and eruptives of Cambrian-Silurian age

Principal stratiform pyritic orebodies of vocanic affinity

2 REGIONAL GEOLOGY

Simplified maps of the Scandinavian Caledonides and the general geology of the Grong-Stekenjokk district are given in Figs. 2 and 3.

The greenschist facies Lower Palaeozoic rocks form part of the belt of allochthonous greenstones within the Central Norwegian Caledonides

In the Grongfelt region these comprise the Gjersvik eruptive complex, a sequence of gabbros that have been intruded by dioritic and granodioritic bodies which form the roots of a volcanic sequence. Unconformably over this sequence lies a polymict conglomerate and finally the Liming group, composed of a variety of calcareous flysch sediments. These meta-igneous and meta-sedimentary rocks together form the Gjersvik Nappe as defined by Halls et al (1977).

This nappe is contained as a klippe on the Seve - Køli Nappe which comprises Cambro - Silurian low grade meta-sediments and meta-volcanics overlying granitic bodies.

Thrust over these nappe units is the Helgeland Nappe, a sequence of high-grade metamorphic rocks of supposed Lower Palaeozoic age.

The entire nappe succession rests on a Pre-Cambrian granitic-gneissose basement which defines the Gjersvik Nappe in the Grongfelt region to the north and south as the Børgefjell and Grong basement culminations respectively (Figs 4, 5 and 6).

Mineralisation occurs at two levels within the eruptive sequence of the Gjersvik Nappe. The gabbro contains small bodies of cumulus mineralisation, generally of the pyrrhotite-pyrite-magnetite assemblage, including small but significant amounts of nickel, copper and platinum

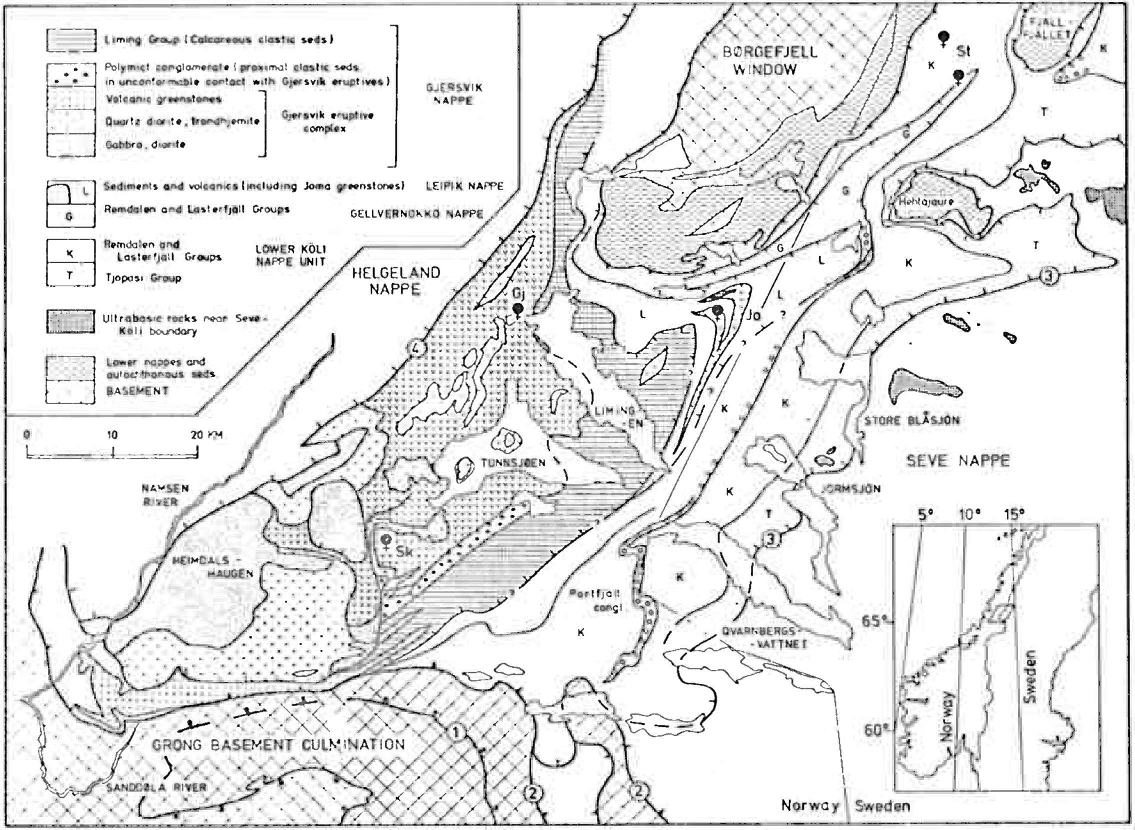


Fig. 3 Map showing location of main ore deposits in Grong–Stekenjokk district (Sk, Skorovas, Gj, Gjersvik, Jo, Joma and St, Stekenjokk) and main structural and stratigraphic units that can be distinguished within Köli Nappe. (1) Thrust at base of Olden basement nappe; (2) thrust at base of Seve–Köli Nappe; (3) thrust separating Seve and Köli sequences within Seve–Köli Nappe Complex; (4) thrust separating Gjersvik Nappe at top of Köli Nappe sequence from high-grade metamorphic rocks of Helgeland Nappe Complex. Boundaries based on geological information from Foslie, Oftedahl, Zachrisson, Gee and Gustavson (From Halls et al 1977).

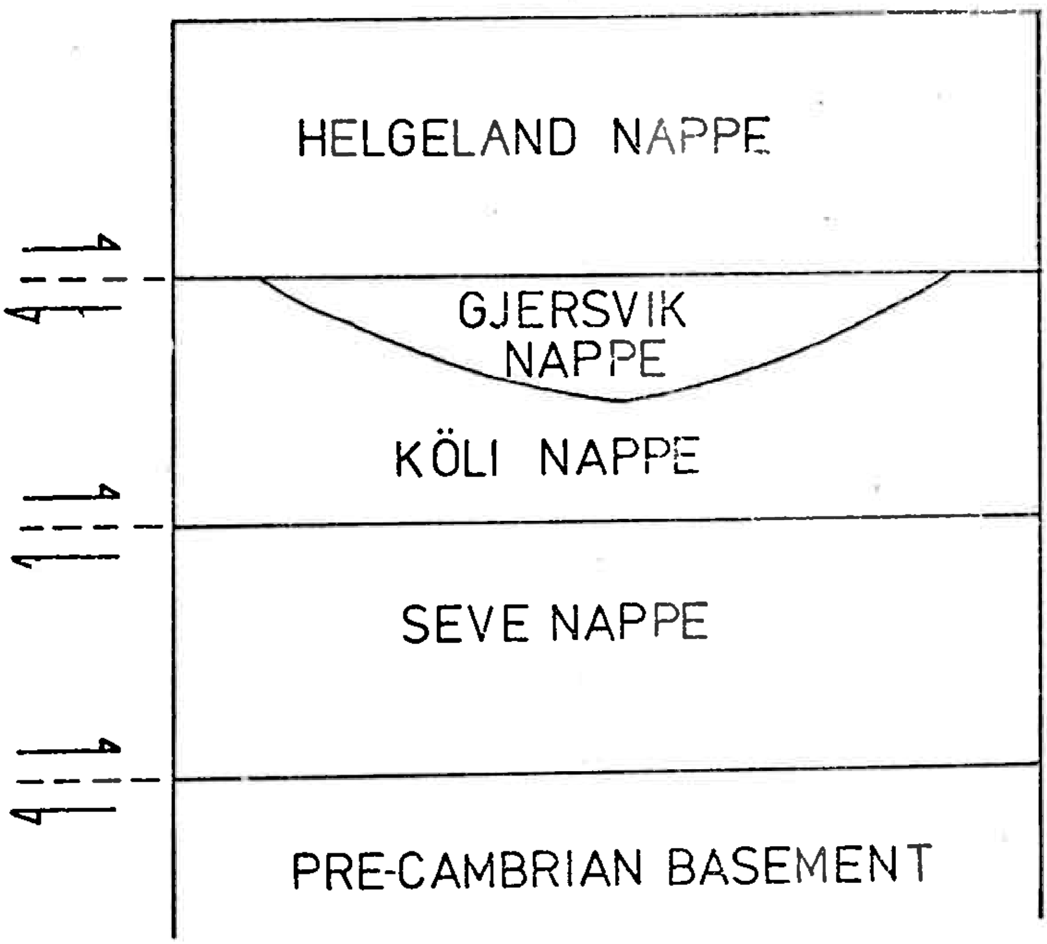
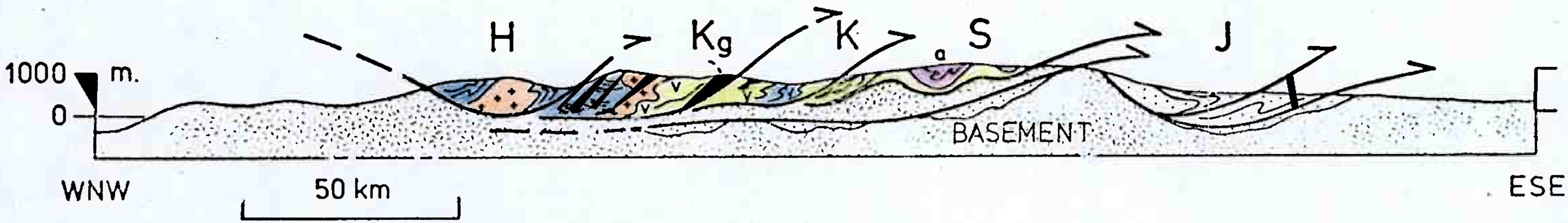


Fig. 4 Schematic diagram illustating the relative positions of the various nappe units in the Grongfelt region



FIGURE

Schematic section W.N.W.-E.S.E. through the Caledonian allocthon some 20km. north of the Grong culmination showing the major structural divisions.

H - Helgeland Nappe

K_g -Upper Köli (Gjersvik Nappe)

K -Lower Köli Nappe

S -Seve Nappe

J -Jämtland supergroup

Ultramafics

Layered gabbros

Dioritic and granodioritic plutons

v-volcanics

a-amphibolites

After Halls (1977)

as pentlandite, chalcopyrite and an unidentified platinum mineral. The volcanic sequence contains exhalative type mineralisation as defined by Carstens (1922), the strongest known expressions of which are the copper-bearing pyritic orebodies of Skorovas and Gjersvik. Other stratiform base metal deposits in the Grong - Stekkenjokk region occur at a higher stratigraphic level within the dominantly sedimentary supra-crustal units to the east of the Gjersvik Nappe.

The absence of fossils within the Gjersvik Nappe prevents precise dating of the Gjersvik sequence. By comparison with similar rocks of the Støren Group in the Trondheim region the age of the Gjersvik eruptives has been suggested as Llanvirnian through to Caradocian (Halls et al 1977).

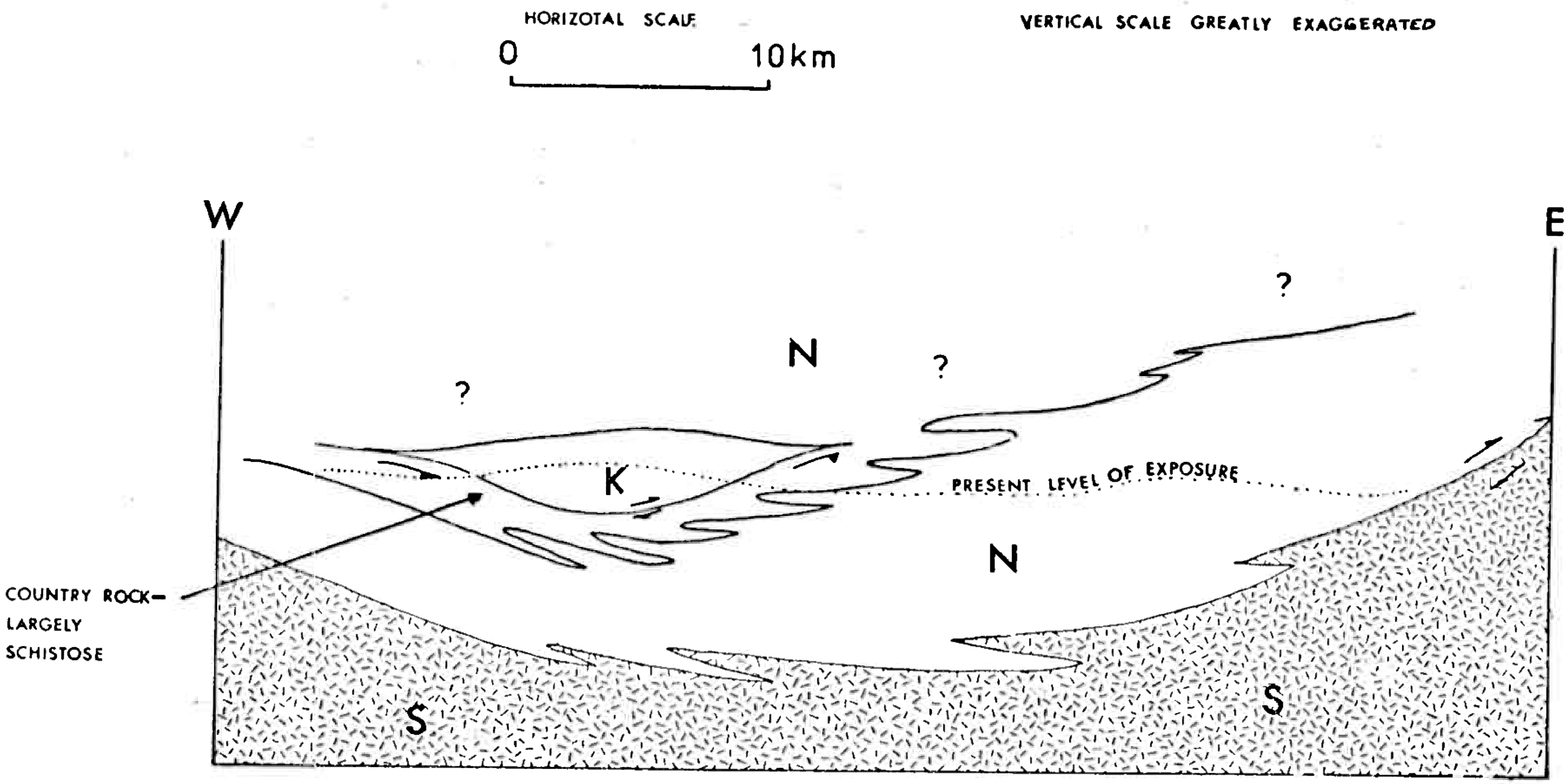


Fig.6 Schematic diagram illustrating the position of the Gröndalsfjell Klippe (K) within the Gjersvik Nappe (N). S-Seve-Köli Nappe.

3. THE GEOLOGY OF GRÖNDALEN

The geology of Grøndalen includes subvolcanic and extrusive rocks of the Gjersvik eruptive complex occurring within the Gjersvik Nappe.

The study area may be divided into two distinct structural units, a klippe of predominantly intrusive character; and older volcanics which themselves contain intrusives. The contact between these units is a thrust plane.

3.1. Klippe Lithologies

The klippe comprises the Grøndalsfjell intrusive complex which has been intruded into volcanic greenstones. This complex extends 8 km. by 10 km. ; only the southwest part outcrops in Grøndalen. Essentially this complex consists of rafts or xenoliths of gabbro or greenstone material in a dioritic matrix together with later minor intrusives of a predominantly trondhjemitic composition. The sequence of intrusive events is as follows:

1. Intrusion of the major gabbro phases and subsequent minor intrusives.
2. Introduction of large volumes of diorite resulting in alteration of the originally anhydrous gabbroic phase to gabbro-diorite hybrids and saussurite gabbros.
3. Intrusion of basic dykes.
4. Intrusion of trondhjemitic dykes.

3.1.1. The Massive Greenstones

In this report the term "greenstone" refers to fine-grained igneous rocks of extrusive origin which contain an assemblage of minerals produced by regional greenschist metamorphism.

The greenstones of the Grøndalsfjell complex are prograded and outcrop to the west of Grøndalselva, lying directly above the major thrust horizon. They also occur as a large raft-like body in diorite to the northeast of Grøndalsvatn. The greenstones commonly have a gradational contact with the diorite.

In the south of the complex a zone of greenstone xenoliths in diorite is mappable, trending east-west, within which the relationship between rafts suggests the nature of the dioritic intrusion to be passive. This zone is usually over 100 m. wide, reaching 400 m. west of Grøndalselva. However it is apparently absent around (-13200, 70100) where the greenstones have a sharp contact with massive diorite and around (-14500, 71300) where the greenstone makes a contact with diorite containing gabbroic xenoliths.

The greenstone xenolith zone passes gradationally through a zone of greenstone containing irregular dioritic veining into more massive greenstones. The veined zone is of varying thickness and is not always apparent. The veins occasionally form net complexes, are usually persistent over no more than a metre and are up to 5 cm. thick.

The relationship of the greenstones to the surrounding xenolithic belt is more obscure to the east of Gróndalselva. The wide belt of xenoliths, up to a kilometre wide, surrounding the small greenstone body suggests the latter represent the remnants of a much larger unit of greenstones that underwent digestion by the diorite.

In the field the greenstones are seen to be dominantly massive with very few primary textures being evident. Alteration of the primary mineralogy by thermal and regional metamorphic events has probably obscured many primary textures.

Well banded volcanic rocks occur however around (-13100, 70250). The bands comprise segregations of mafic and felsic minerals into layers up to 1 cm. thick. Within a few metres of this outcrop however, the rock takes on the more typical hornfelsed appearance.

Segregations of amphibole and epidote are present locally (Fig 7). These are probably the result of deuteric processes, possibly related to sea floor metamorphism, altering the greenstones.

Two different compositional types of greenstones within the Grøndalsfjell igneous complex were recognised in the field:

3.1.1 (a) Andesitic to Basic Greenstones

These are the more abundant type of greenstone in Grøndalen They are fine-grained, grey-green rocks which contain occasional rust zones, indicating the presence of sulfides (Chapts 5). Locally this lithology is slightly magnetic due to the presence of magnetite and possibly pyrrhotite.

Mineralogically the rock comprises a groundmass of highly saussuritised plagioclase (usually oligoclase, An_{10-30}) which exhibits albite twinning, chlorite replacing amphibole, epidote, clinozoisite and minor quartz. Disseminations of magnetite or ilmenite are common. Knots of clinozoisite, up to .75 cm. in diameter, may represent relict amygdales.

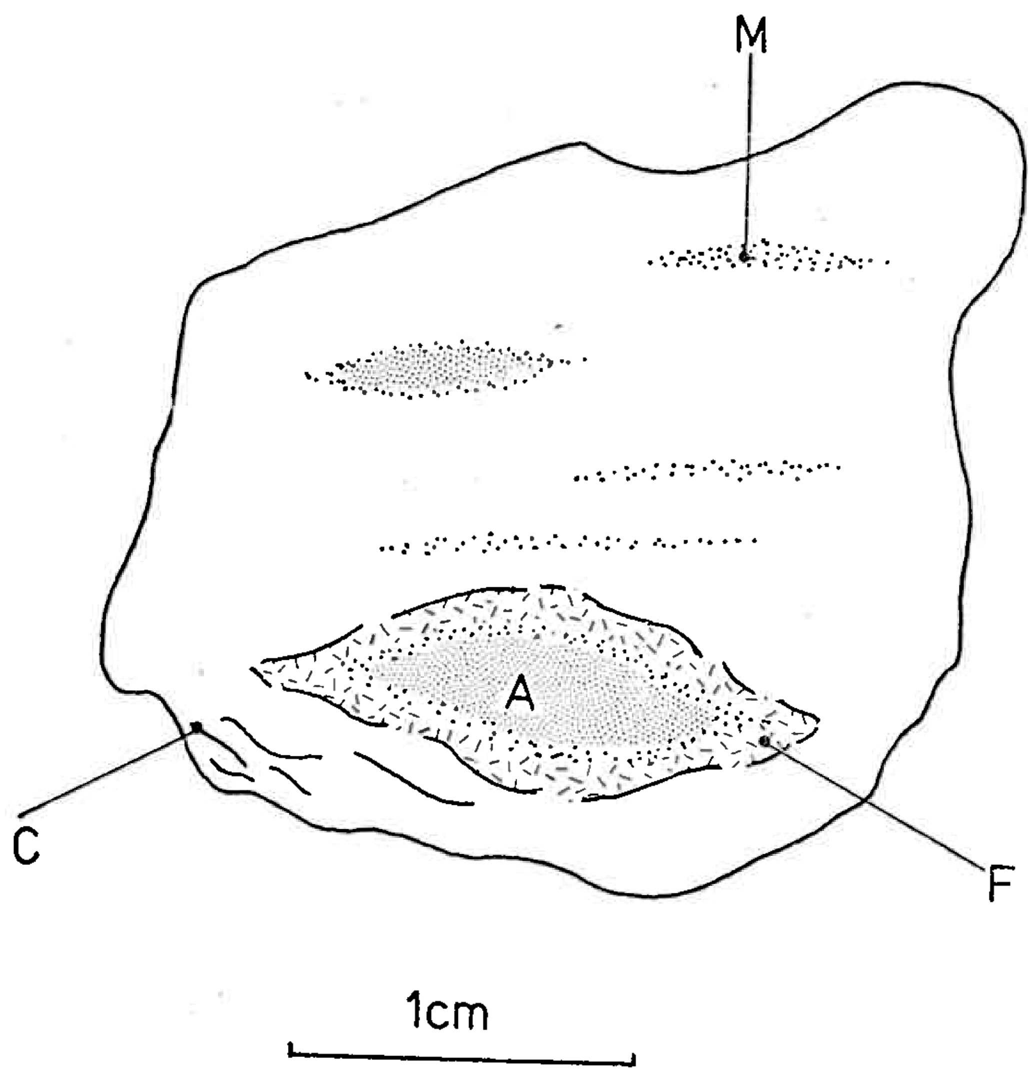


Fig. 7 Segregation of amphibole (A), magnetite (M), chlorite-epidote (C) and feldspar (F) in greenstone at (13050,70250)

3.1.1. (b) Acidic Greenstones

The acidic greenstones are fine-grained, whitish, keratophyric rocks, often containing abundant epidote-rich veins. Plagioclase (albite - oligoclase) and quartz are the most abundant minerals. Minor amounts of epidote, chlorite, clinozoisite, calcite and sphene are also present. Rust zones are frequently associated with the acidic greenstone lithologies (Chapt. 5).

The acidic extrusives were only recognised amongst the greenstones to the west of Grøndalselva where they reach a maximum thickness of 200 m. but are commonly only about 20 m. thick. The thicker units are the more persistant and may be traced for up to 500 m. along strike.

Primary textures are absent from these aphanitic lithologies. The units are thus presumably acidic flows or highly altered tuffs.

Chert or jasper horizons were found at only one locality in the massive greenstones (-11150, 68495). Composed almost entirely of quartz with abundant stringers of euhedral pyrite, this rock has a grey-green colouration suggesting the presence of small amounts of magnetite.

The keratophyric bands and chert horizons are the only stratigraphic indicators within the massive greenstones. Unfortunately they are not abundant enough to be valuable structural guides.

3.1.2. The Gabbro

The gabbro is a coarse grained rock occuring as xenoliths or rafts up to 50 m. in diameter in a dioritic matrix. The xenoliths are generally equidimensional and may be angular or rounded, making sharp to gradional contacts with diorite.

The rock usually has a dark green to dark brown, heavily pitted surface due to the preferential weathering of the olivines. It is usually massive but occasional steeply dipping layering is evident (Fig. 8) due to variations in relative amounts of feldspars and ferromagnesian minerals over 1 to 10 cm. The sub-vertical dips of the layering probably indicates a post-cumulus displacement (Mason 1970).

Variations in the composition of the gabbro are recognisable in the field by the colour of the weathering surfaces:

3.1.2. (a) Brown Gabbro

This is the most common type of gabbro occuring in the Grøndalsfjell complex and it may be massive or layered. This lithology also occurs as xenolith-like bodies within green gabbro at (-12110, 70740) and (-120070, 71070).

In thin section brown gabbro is seen to comprise olivine, pyroxene and secondary hornblende in a matrix of plagioclase. The olivines have largely been replaced by augite and less commonly orthopyroxenes (Fig. 10). The olivine cores have been serpentinised and have also suffered alteration to minor iddingsite. Serpentine occurs as veinlets along fractures in the olivine, extending into the surrounding pyroxenes. Magnetite has separated out into the centre of these veinlets. Plagioclase laths (labradorite, An_{60-68}) forms ophitic intergrowths with pyroxene and has suffered relatively minor saussuritisation.

Figure 8. Layered gabbro at (-14550, 71880).

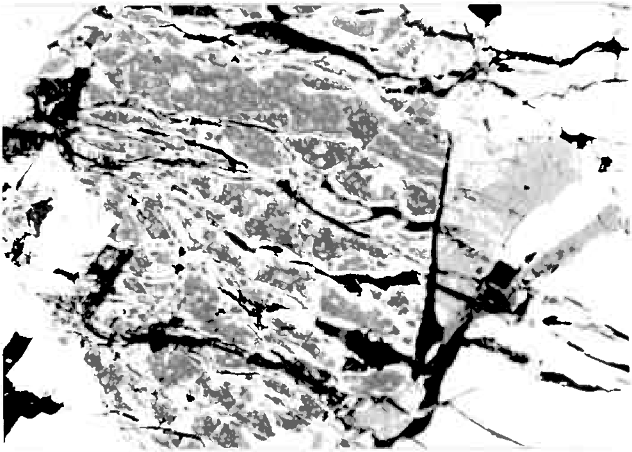


Figure 10. Serpentinite veins in olivine with segregation of magnetite. Local replacement of the olivine to augite. In brown gabbro at (-18110, 70740).

3.1.2. (b) Green Gabbro

This rock is composed of about 60 per cent plagioclase, the bulk of which is corroded and broken, few crystals showing zoning. The feldspars form a sheared and broken matrix around chlorite and minor clinopyroxene both which have become sheared and broken under stress, many crystals having suffered extreme displacement along their cleavage planes (Fig. 11). Twinning is commonly observed in the less deformed crystals.

This lithology probably represents an alteration product of the brown gabbro; under shearing the gabbro deformed in a brittle manner, presumably when it was still anhydrous. Subsequent alteration by hydrous magmas altered the primary mineralogy.

3.1.2. (c) Red-Brown Gabbro

This very hard, dense, magnetite-rich lithology occurs as angular xenoliths within the green gabbro at (-11650, 70690).

In thin section it is seen to comprise highly serpentinised anhedral olivine crystals, serpentinite veins extending into neighbouring pyroxenes, where a greater amount of segregated magnetite occurs in the veins. Most of the olivines are rimmed by magnetite and hypersthene. Occasionally an outer rim of hornblende-spinel is present and rarely augite replaces the olivine.

The interstitial plagioclase, largely altered to clinozoisite, albite, quartz and epidote, forms ophitic intergrowths with the ferromagnesian minerals.

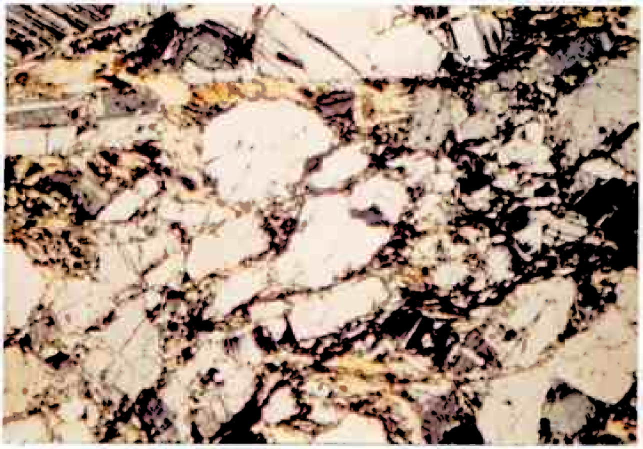


Figure 11. Cataclastic feldspars in green gabbro at (-12110, 70740).

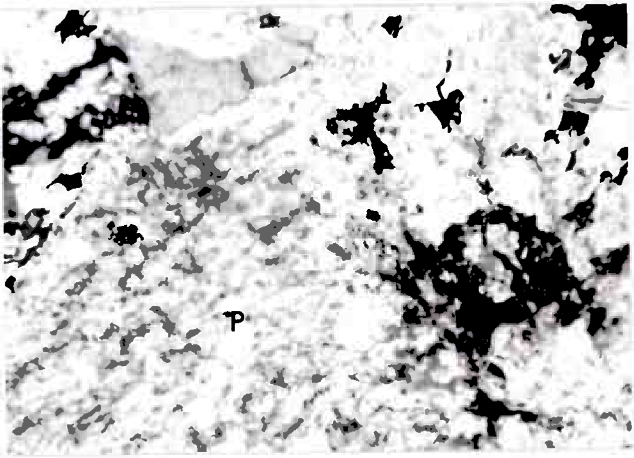


Figure 12. Highly saussuritized plagioclase in diorite at (-12070, 69350), displaying relict twinning.

This lithology probably represents an olivine-rich cumulate phase of the gabbro.

Alteration of the Gabbro

The green gabbro represents an alteration product of the brown-coloured gabbros (see above).

Where the gabbro occurs as xenoliths within a trondhjemite dyke. (Fig 12), a 5 cm. halo of quartz-gabbro occurs around the xenolith. The quartz most probably originated from hydrous fluids evolved from the trondhjemite.

3.1.3. The Diorite

The diorite is a dominahtly medium or coarse-grained rock consisting essentially of hornblende and plagioclase. Late-stage dykes of a finer dioritic dyke occur however at eg. (-12000, 73350). A pegmatitic phase is also recognisable.

The diorite has suffered extensive saussuritisation; the plagioclase appears clouded in hand specimen and in thin section is seen to have been replaced by very fine-grained intergrowths of quartz-albite-sericite and epidote or clinozoisite (Fig 13). Relict laths with albite or combined carlsbad - albite twinning are common. Occasional zoned crystals are present with the calcium rich cores suffering greater alteration than the rims. Free quartz is present as a metamorphic product.

Where the effect of saussuritisation has been minimal, for example to the south of Middagshaugen, the feldspars appear more glassy, free quartz is absent and the rock has a bluish tinge (Fig 14). This lithology

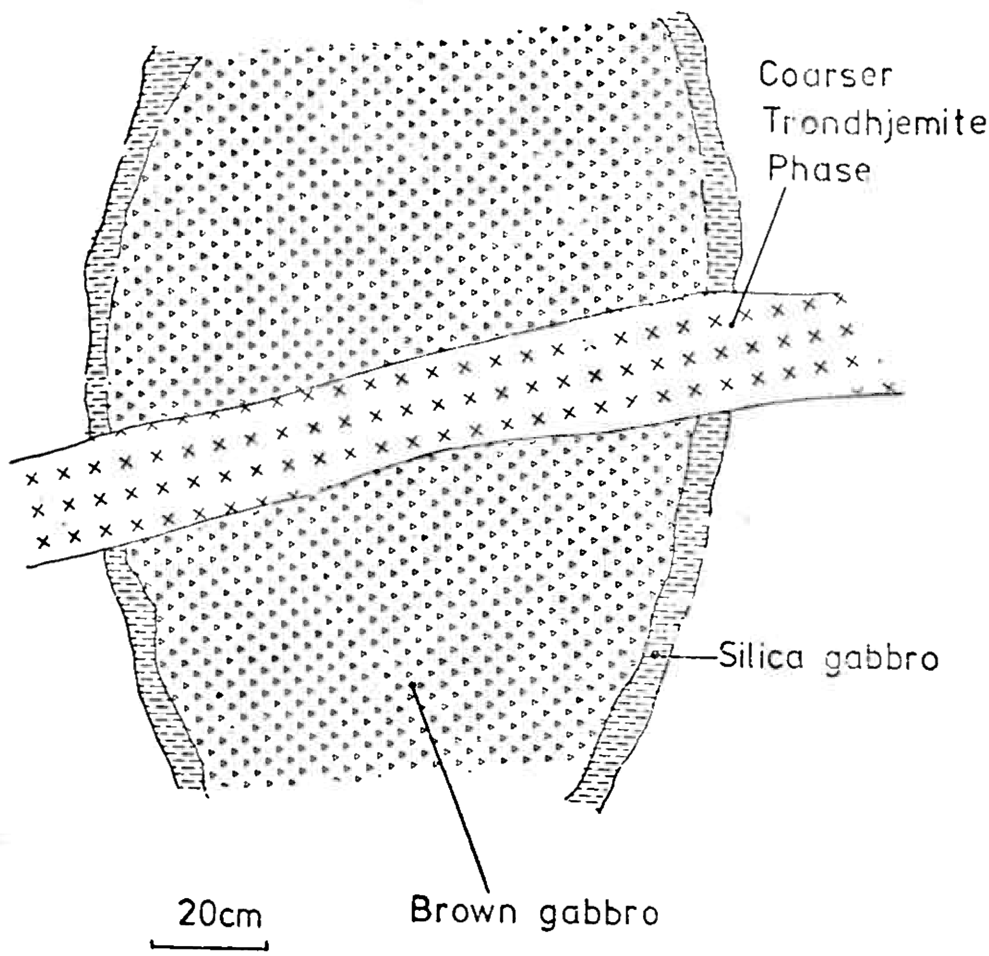


Fig.12 Quartzified gabbro haloe around brown gabbro xenolith in trondhjemite dyke at (-12930,70750).

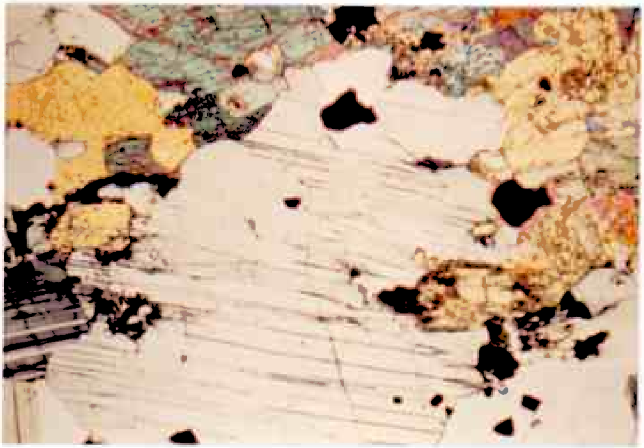


Figure 14. Fresh plagioclase with hornblende and a pyroxene at (-12380, 72640) in blue diorite.

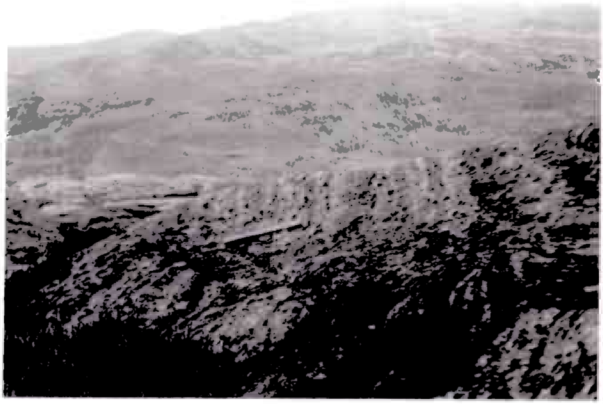


Figure 15. Banded diorite at (-13740, 72570). viewing north.

occurs as raft-like bodies up to 50 m. in diameter within the more abundant altered diorite.

The hornblende in the diorite is brown, occurs either as a primary igneous phase or as uralite and is frequently altered to chlorite. Deuteric alteration has commonly induced "clotting" of the amphiboles to produce more mafic segregations within the diorite at eg. (-11900, 70400), this lithology weathering with a distinctly more pitted surface. This more mafic diorite frequently occurs within the gabbro xenolith zones, possibly indicating a transitional or hybrid phase between the diorite and gabbro.

In the coarser diorites the feldspar has developed as a cumulate phase, illustrating the essentially magmatic character of at least parts of the diorite (Fig. 14). Local segregation of the hornblende and plagioclase into layers gives the rock a well developed planar fabric (Fig. 16).

Occasional relict pyroxenes, possibly hypersthene, are present in much of the diorite (Fig. 17). These are thought to be indicative of later magmas digesting gabbro to produce diorite.

A diorite containing red-brown biotite occurs to the north of Grøndalsvatn. The biotite displays crenulated cleavage, contains apatite inclusions and is partially chloritised. This lithology occurs as the eastern extension of a greenstone xenolith zone and may represent local total digestion of the xenoliths by dioritic magmas.

The quartz in the diorite occurs interstitially between the feldspar laths as anhedral, strained crystals. Where quartz was recognisable in hand specimen, the lithology was mapped as quartz-diorite.

A porphyritic diorite occurs around (-10550, 68150) and also in

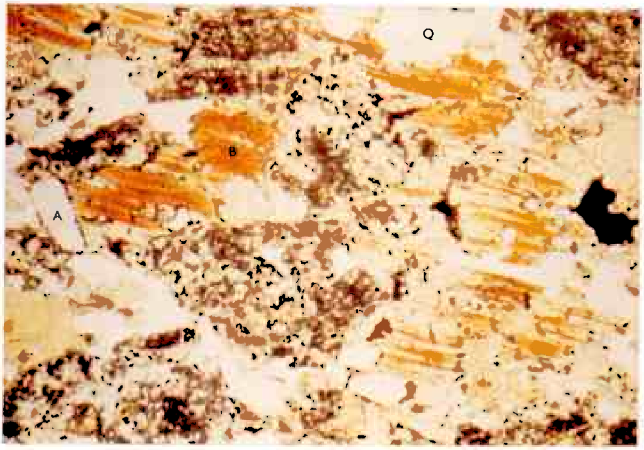


Figure 17. Brown mica diorite containing red-brown biotite (B), saussuritised feldspars , amphibole, quartz (Q), apatite (A) and possible pyroxene at (-13210, 69450).

Murfjellet. This comprises well developed plagioclase phenocrysts, up to 2 cm. long, randomly orientated in a matrix of medium-grained diorite.

A pinkish weathering diorite is recognisable, particularly within the gabbro xenolith belts. This colour is probably due to the presence of very evenly dispersed iron derived from the digestion of gabbroic material.

All the above variations in lithology are gradational into the more abundant, light-weathering, saussuritised diorite. Accessory minerals common to the diorites are magnetite, apatite and occasional sphene. Disseminated sulfides occur locally in the diorites (Chapter 5).

A further type of diorite occurs just north of Grøndalsvatn at (-12400, 69220). This lithology is fine-grained and banded. It is thought to be a mylonite formed by movement along the major thrust horizon (Chapt. 4).

<u>Origin of the Diorite</u>

Geochemical work undertaken by Walker (1972) showed similar concentrations of the trace elements Ni, Co and Cu in both the diorite and the gabbro in the eastern part of the Grøndalsfjell intrusive complex. If the diorite is considered to have been intruded as a separate magma these concentrations are unusually high. This thus suggests that the diorite was produced at least partially by metasomatic alteration of the gabbro.

The cumulus textures and layered nature of some of the diorites however indicates that a magmatic phase was also important in the production of the diorite.

Pegmatitic Diorite

Pegmatitic diorite is rare in Grøndalen; some of the coarsest massive diorites however could be termed sub-pegmatitic The pegmatitic phase occurs in two different forms: in discrete veins and in more diffuse zones or patches.

3.1.3. (a) Pegmatitic Veins

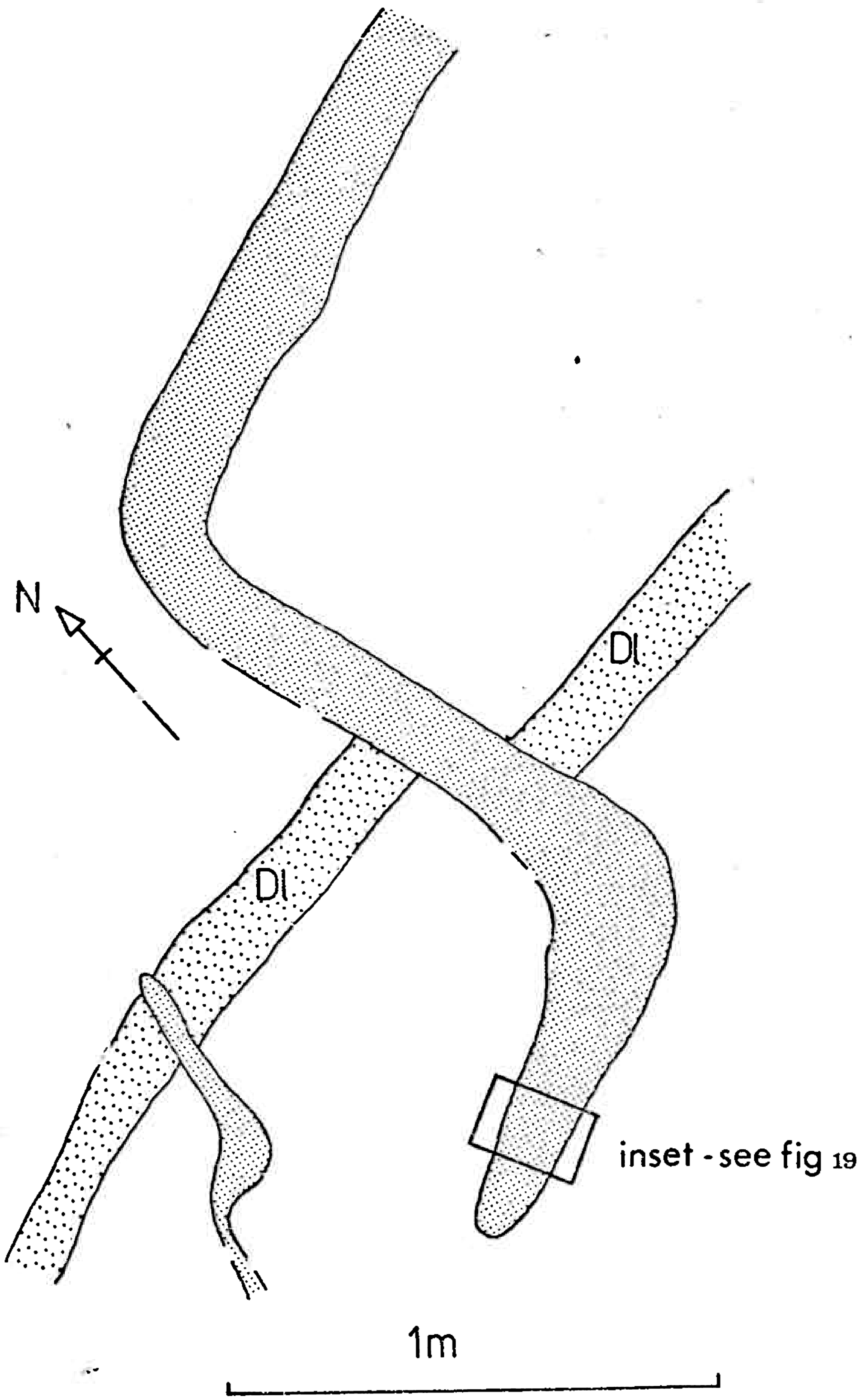
The pegmatitic veins occur within diorite, with gabbro xenoliths just south of Middagshaugen. The veins are up to 30 cm wide and 20 m long and their boundaries with the diorite are diffuse over 3 to 4 cm. (Fig. 18).

The veins consist of large prismatic amphibole crystals reaching 5 cm. in length set in a matrix of finer clots of amphibole or feldspar. The amphiboles grow inwards from the margins or occur in bands centrally positioned in the veins (Fig. 19).

The sinusoidal form of the veins may be the form in which they were initially emplaced since the veins cut an apparently untectonised basic dyke. This dates the pegmatites as younger than at least the first generation of basic dykes, ie. late in the intrusive history of the Grøndalsfjell intrusive complex. It is thought that the veins were produced by late stage hydrothermal (deuteric) fluids escaping through the consolidating diorite.

The lithology may be termed an appinite and, according to Halls et al (1977) "their presence implies that the level of exposure seen in the eastern margin of the Grøndalsfjell massif corresponds to the upper portion of a differentiated dioritic body"

Fig.18 Pegmatitic diorite vein in diorite, cutting dolerite (Dl) - at (-12060, 72525).



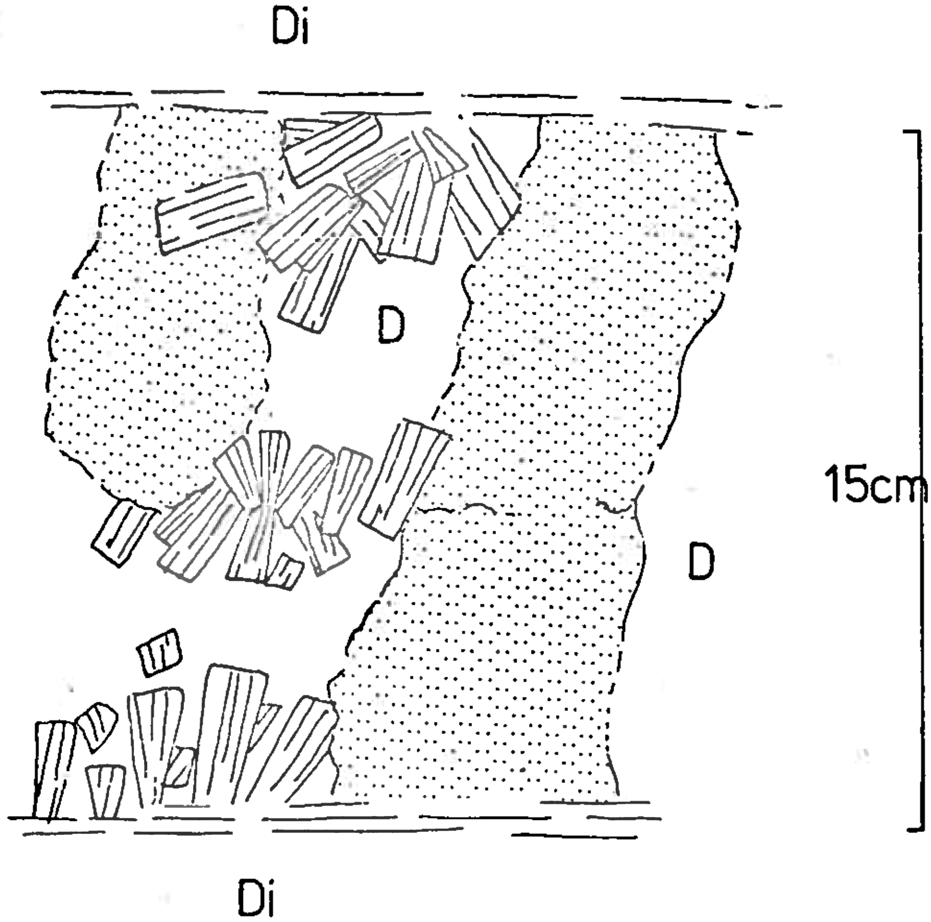


Fig.19 Pegmatitic diorite at (-12060,72525)
Amphibole crystals growing into a fine-grained dioritic matrix (D) with clots of amphibole (stippled). Vein is in diorite (Di).

3.1.3 (b) Pegmatitic Zones

A 15 m. wide zone of pegmatitic diorite occurs at (-11000, 68350), striking northwest-southeast and being composed largely of coarse saussuritised plagioclase together with amphibole crystals up to 3 - 4 cm. in length. Like the pegmatitic veins, the pegmatite zones are evidently the result of deuteric alteration processes.

The xenolithic diorite containing the pegmatite veins has locally well developed amphibole crystals up to 1 -5 cm long in a matrix of medium-grained diorite. This may represent a poorly developed pegmatitic facies.

3.1.4. Greenstone Xenoliths in Diorite

Greenstone xenolith zones surround the massive greenstones The xenoliths are typically tens of cms. in diameter although occasional rafts tens of metres wide are found. The larger xenoliths and rafts are usually veined irregularly with diorite and sometimes display interlocking features, indicating the relatively passive way in which the rafts were broken up (Figs. 20 and 21).

The xenoliths usually have rounded and sometimes corroded edges indicating partial digestion by the diorite although locally, angular xenoliths with sharp boundaries occur. Pods of chert with magnetite occur occasionally in the larger xenoliths at eg. (-12900, 70520) and minor disseminations of sulfide minerals are common. At (-12430, 69210) a large rust zone in an acidic xenolithic raft is present (Chapt. 5).

The diorite containing the greenstone xenoliths is darker than the more massive diorite, probably due to incorporation of greenstone

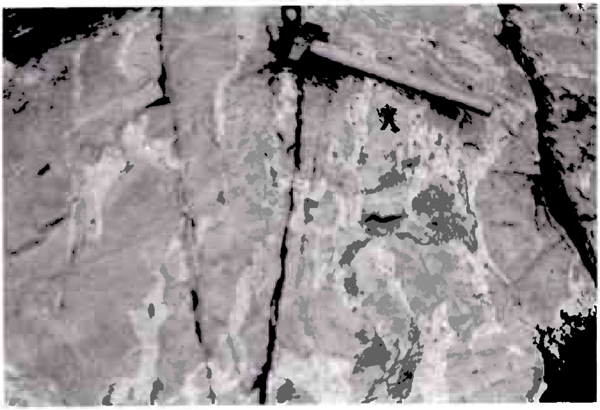


Figure 20. Greenstone xenoliths at (-11300, 68550) in diorite, having sharp to gradational contacts.

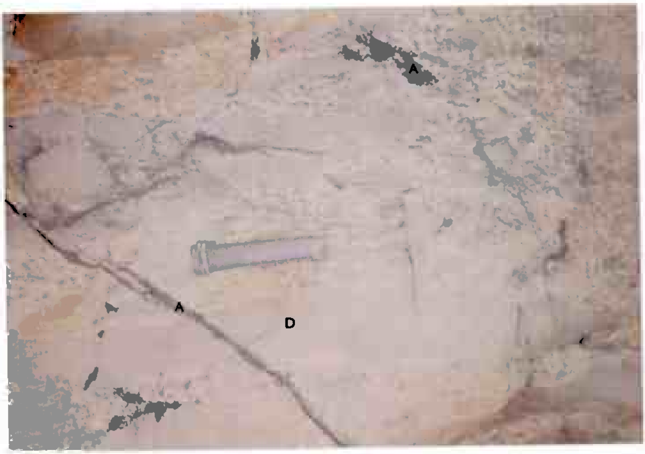


Figure 21. Lenticular greenstone xenolith in diorite with dolerite dyke (D). Late stage dioritic veins with knots of amphibole traverse the outcrop at (-15910, 70560).

and gabbroic material containing disseminated sulfides. In the northwest of Grøndalen, around (-14400, 70750) gabbro xenoliths and greenstone xenoliths occur together in a particularly dark diorite.

3.1.5. Minor Intrusive Phases

3.1 5. (a) Basic Dykes

The basic dykes occur more abundantly in the major intrusive phases of the Grøndalsfjell complex than in the extrusives to the west. They consist of a dense, dark-grey, fine to medium-grained rock and reach maximum , evidently tectonically controlled dimensions of 50 cm. in width and about 20 m. in length.

The dykes have an approximate northeast-southwesterly trend and most commonly dip fairly steeply to the north (Fig. 22). Sinstral or dextral displacements of the dykes by distances of up to a metre are common. Folding does not seem to have greatly affected the dykes unless parallel sets of dykes represent F1 isoclinal-type folding

At least two generations and several different compositional types of basic dyke are recognisable in the field:

3.1 5. (a) i Quartz - Diorite Dykes

Quartz-diorite dykes are only of rare occurrence in Grøndalen, eg. at (-12645, 69780) and (-14112, 69780) where they are found within diorite. The dykes strike predominantly northeast-southwesterly and dip steeply northward and are usually offset by small fractures.

In hand specimen the dyke is seen to aphinitic with clearly recognisable quartz along with saussuritised feldspar and amphibole.

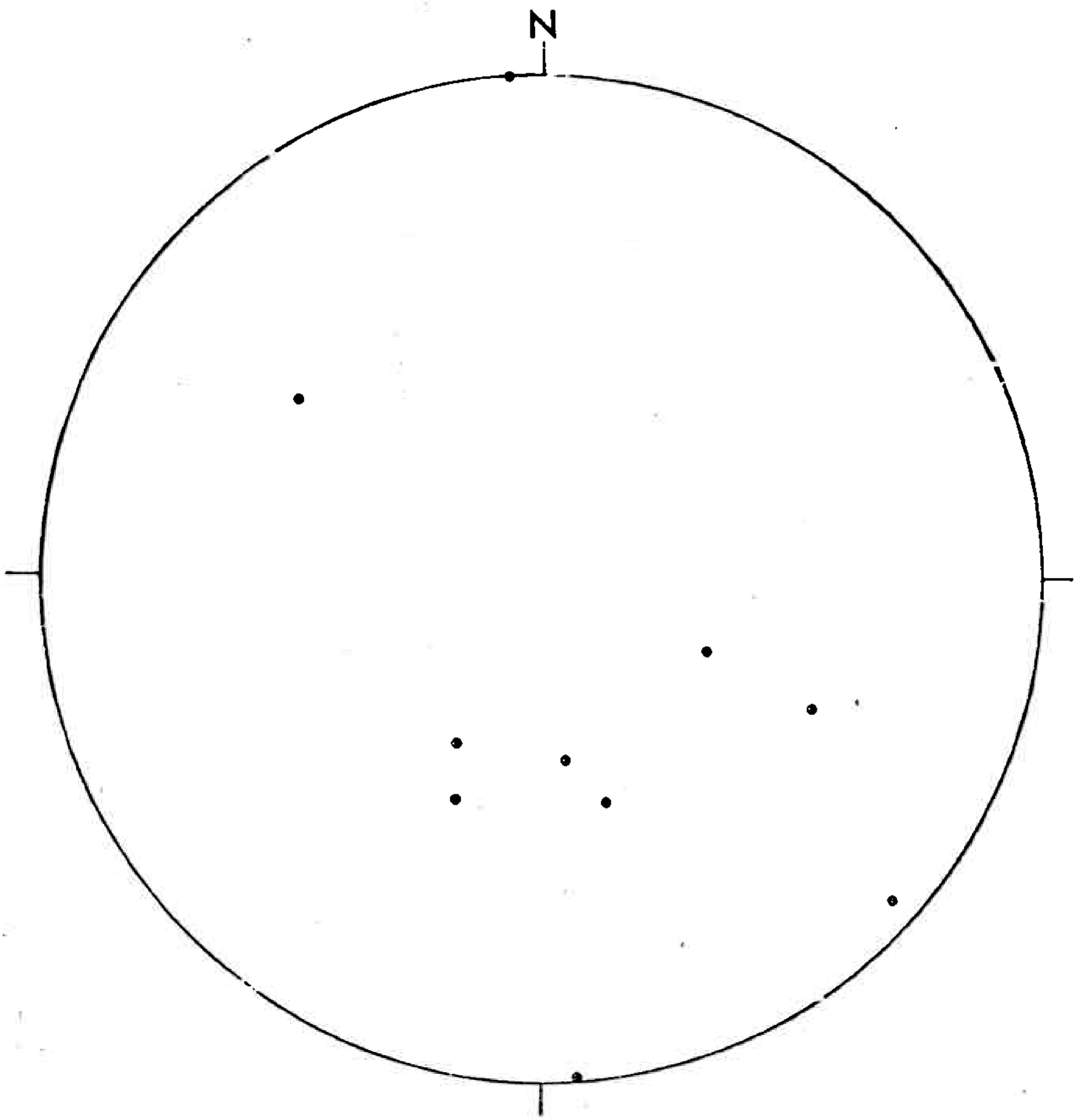


Fig. 22 Stereoplot of basic dykes in the Gröndalsfjell complex.

3.1.5. (a) ii Late-Stage Doleritic Dykes

The late stage doleritic dykes are the most abundant of the more basic minor intrusive phases. The doleritic textured dykes are composed of a plagioclase and amphibole in slightly varying proportions such that on weathering, their colour may vary from a light to a much darker grey (Figs. 23 and 24).

Disseminations of sulfide mineralisation are common in the dykes and some are magnetic, suggesting locally abundant magnetite. Phenocrysts of plagioclase, up to 1 cm. in length may occur in the larger dykes and segregations of amphibole are also locally present (Figs 24 and 25).

At one location (-12060, 72525), a basic dyke is found within a gabbroic raft, but which did not extend into the surrounding diorite. The dyke is composed of a coarse, dense, light-grey weathering rock.

Thin section reveals the rock to consist primarily of olivine, pyroxenes, an amphibole and plagioclase.

The olivine has been partly serpentinised and altered to uralite or rarely clinopyroxene (with segregation of magnetite in the serpentinite veins) and is usually in ophitic or subophitic intergrowths with one of the other major phases (Fig. 26).

Clinopyroxene is also present as a primary phase, being usually schillerised with spindles of magnetite. Sphene is a common accessory.

The presence of this dyke within a gabbro raft suggests that emplacement of a minor intrusive phase occurred before the introduction of the diorite.

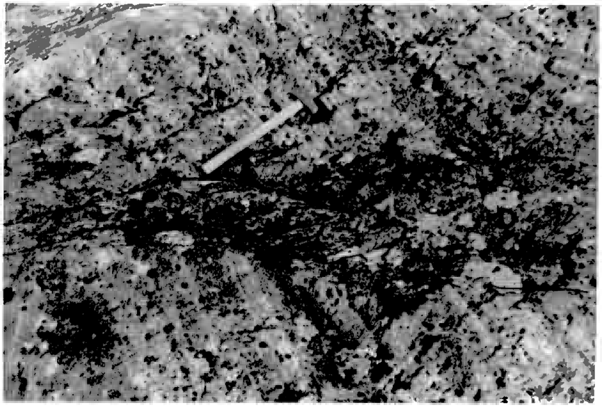


Figure 25. Dolerite dyke cutting banded gabbro at (-14380, 71970).

Figure 26. Olivine in subophitic intergrowth with plagioclase. Olivine is serpentinized and has segregations of magnetite in veinlets. From a basic dyke at (-12[illegible], [illegible]525).

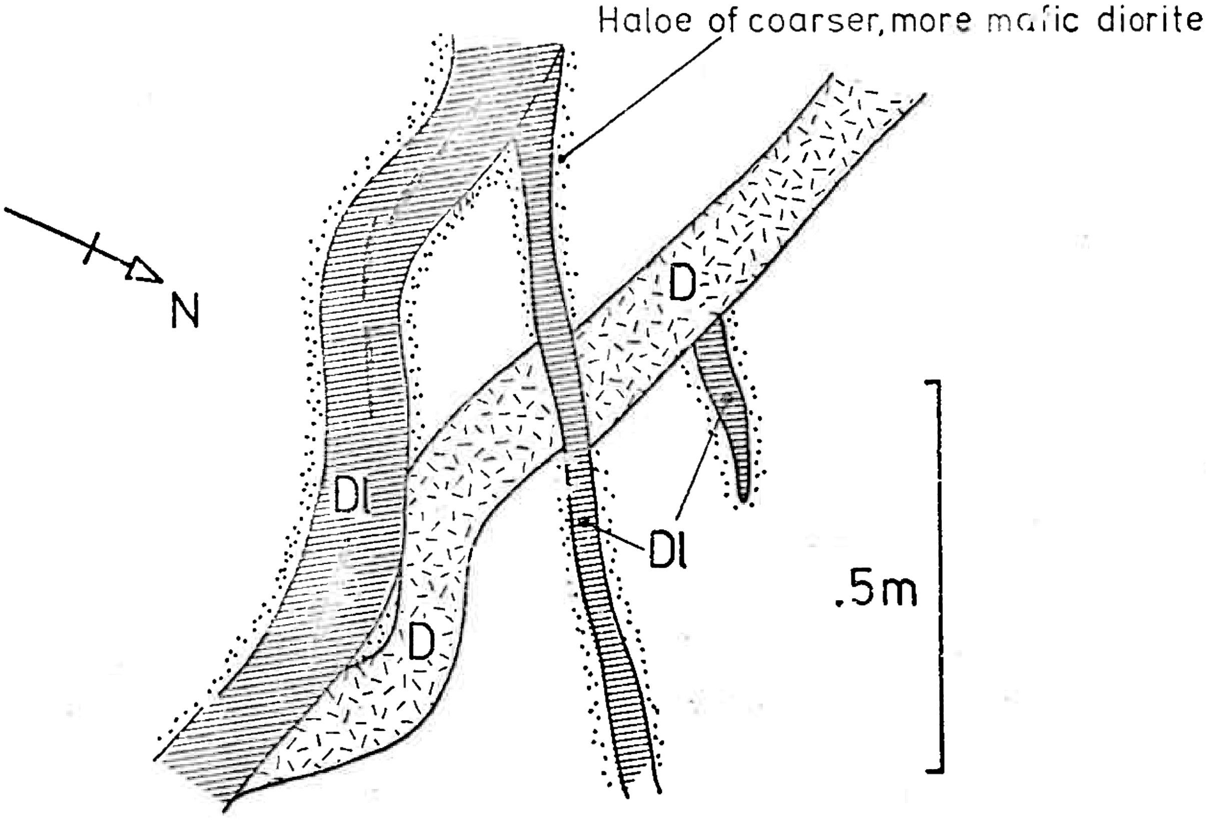


Fig. 24 Clots of amphibole in late stage dolerite (Dl), cutting a diorite dyke at (-12000,73350). In diorite.

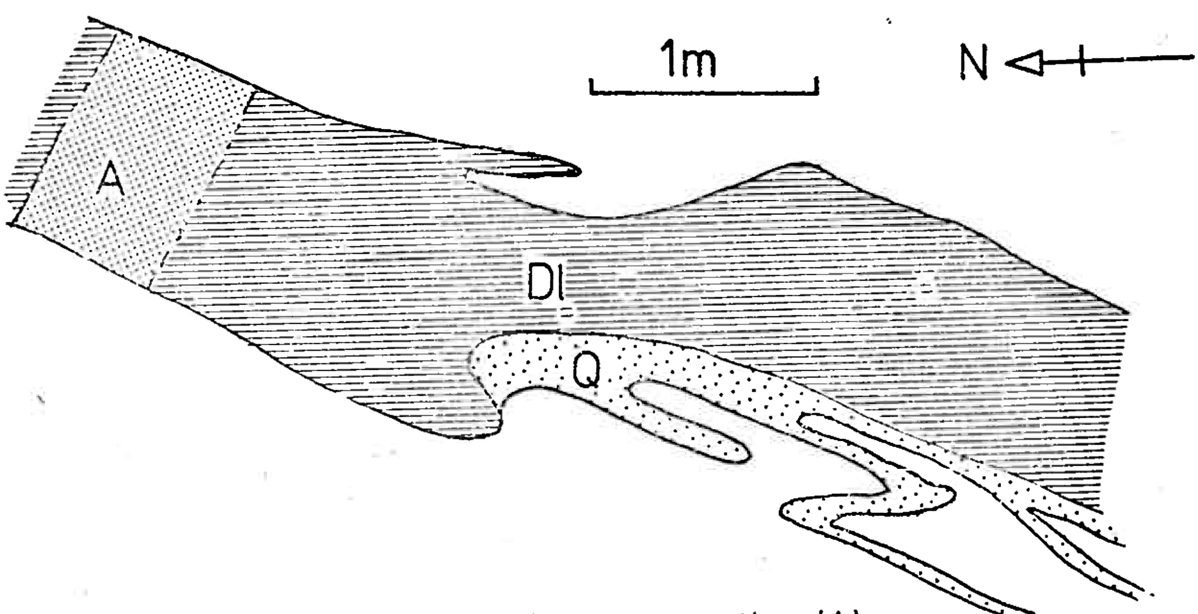


Fig. 25 Large amphibole-rich segregation (A) in dolerite dyke at (-11700,71260). Segregations of quartz (Q), possibly tectonised, occur at dyke-diorite interface.

3.1.5. (b) Trondhjemite Dykes

Trondhjemite is the commonest minor intrusive phase within the Grøndalsfjell igneous complex. It occurs within both the greenstone hornfels and the major intrusive phases. At least two generations of trondhjemite intrusions are recognisable in the field.

The dykes are commonly 1 or 2 m. in width but may reach 75 m. at (-14400, 69270). They usually extend for at least 10 m., occasionally reaching lengths of over a kilometre to the east of Grøndalselva (Fig. 27).

The dykes usually dip steeply northwards although a few dip shallowly or to the south (Fig. 28). They may be displaced by up to 1 m. by small fractures (Fig. 29) and are often shear-folded (Figs. 30, 31 and 32). Parallel sets of dykes may possibly represent f 1 isoclinal folding (Fig. 33) although no F1 fold closures were seen in Grøndalen.

The trondhjemite weathers to a distinct whitish colour and supports the growth of a light green-yellow lichen (Rhizocarpon geographicum). It is composed predominantly of quartz and saussuritised feldspar but rarely chlorite replacing biotite occurs as bands in the trondhjemite. Xenoliths of angular gabbro or greenstone rafts up to 20 m. across occur locally in the larger dykes (Fig. 27).

Segregations of quartz into knots and stringers up to 5 cm. in width are common. Similarly, knots composed of epidote and minor pyrite occur towards the centres of some dykes.

The trondhjemite dykes are usually fine grained with only occasional segregations of large feldspar laths and rare muscovite layers into the centre of the dyke. A pegmatitic phase is also present within

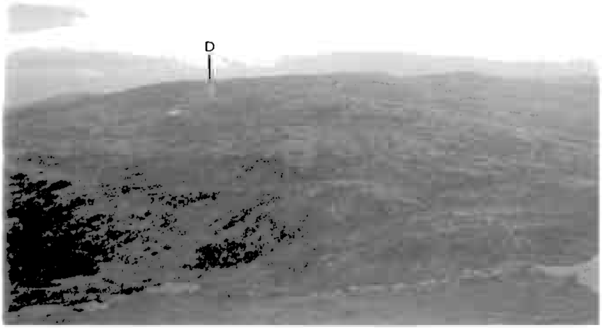


Figure 27. View east from Kurfjellet across Grondalselva to Sondre Grondalsfjell. Careful inspection reveals parallel Trondhjemite dykes including one with a large diorite raft at (D).

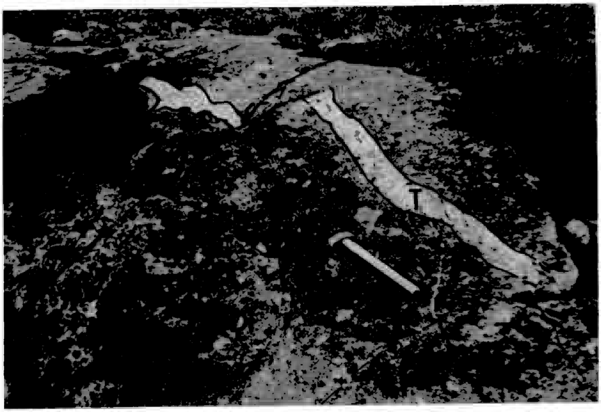


Figure 28. Gabbro raft (G) in diorite (Di) containing a Trondhjemite dyke (T) displaced by a small fracture. At (-14460, 69940).

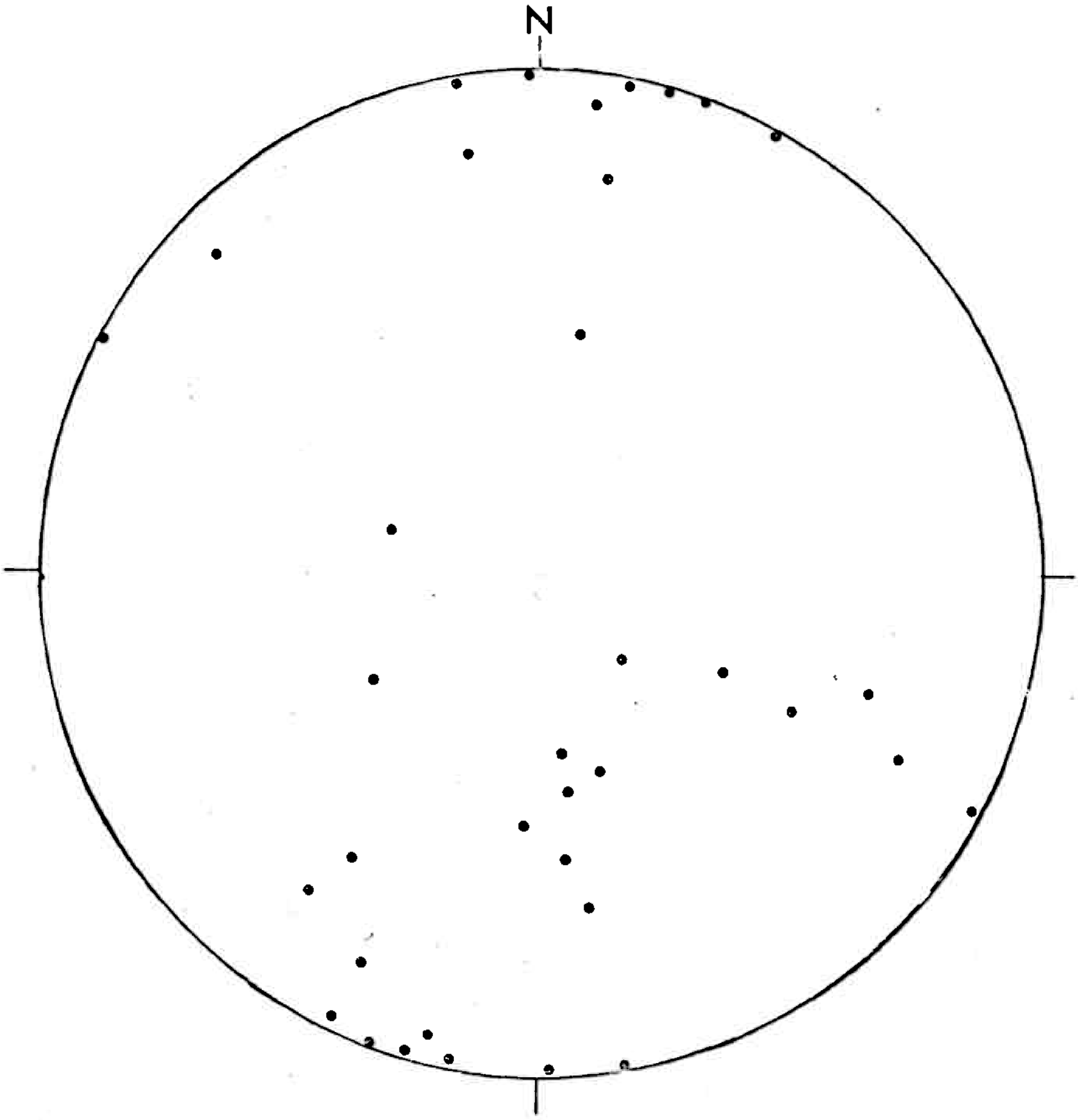


Fig. 28 Stereoplot of trondhjemite dykes in the Gröndalsfjell igneous complex, Gröndalen.

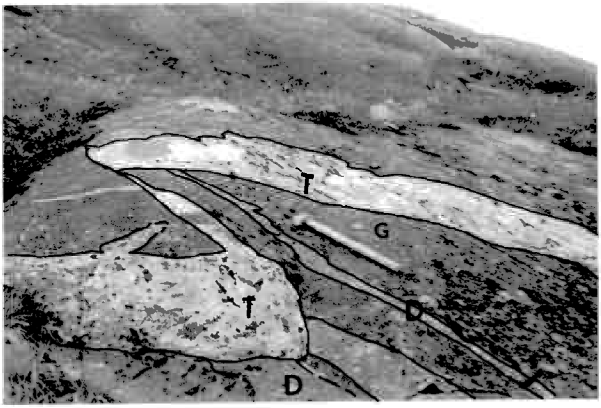


Figure 30. Shear folded Trondhjemite dyke (T) displacing dolerite dykes (D) in a gabbro raft at (-14530, 45950).

Figure 31. Trondhjemite dyke (T) in gabbro (G) that has either been shear folded or intruded along fracture planes.

Figure 32. Trondhjemite veins (T) in gabbro (G) with an apparent en echelon attitude at (-14470,69930).

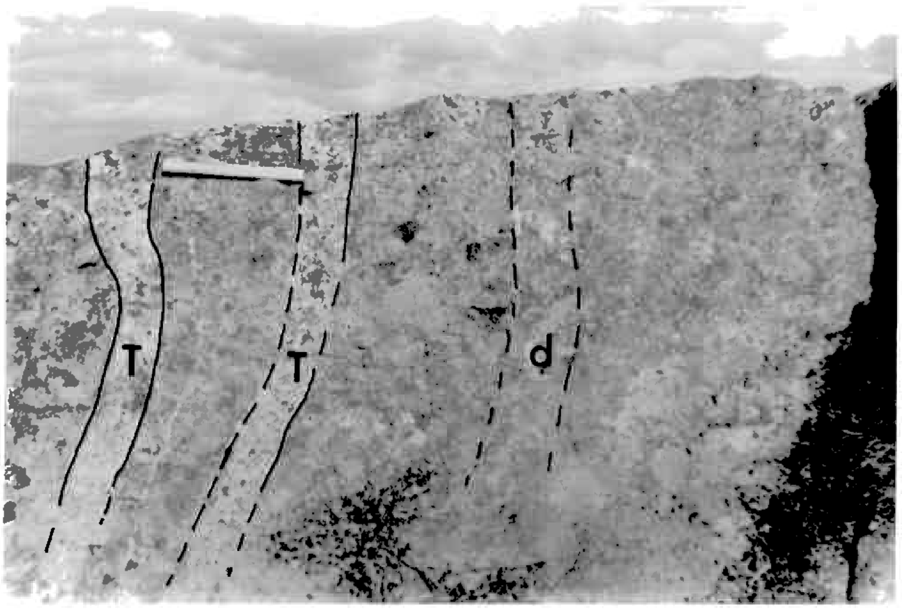


Figure 33. Parallel Trondhjemite dykes with a dolerite dyke (d) in diorite.

diorites in the northeast of the study area.

The pegmatites strike approximately northeast-southwesterly and dip steeply to the north. They are usually about 2 m. wide and can be traced for up to 150 m.

Within the matrix of quartz and saussuritised plagioclase, euhedral crystals of muscovite up to 3 cm. in length are present. These crystals occasionally have a slight bluish tinge in hand specimen, suggesting they are possibly lithium rich. Columnar amphibole, probably actinolite, euhedral epidote and a pink garnet are also present.

3.1.5. (c) Deuteric Veins and Dykes

Veins of fine-grained quartz-albite-epidote occur frequently throughout the study area. Commonly they are irregular features, not normally traceable over more than 1 m. and usually they are less than 1 cm. thick. They are most abundant within the diorite that has undergone the severest saussuritisation.

Occasionally these veins have a sub-parallel orientation, striking typically northeast-southwesterly. The only dip measurement taken was 29°N, strike 229°.

In thin section the veins are seen to comprise clinozoisite, epidote, albite and quartz with occasional chlorite. They have diffuse boundaries with the host rock indicating their deuteric mode of origin.

Dykes composed of this material also occur in Grøndalen. These are between 6 cm. and 12 cm. thick and usually occupy late stage fractures (Chapt. 4). These dykes are also found as separate intrusive phases at the edges of large trondhjemite dykes at (-13670, 69470). Here two generations, each about 10 cm. thick, are found on the footwall side of the trondhjemite, but do not occur on the hanging wall. A coarse dyke occurs in a gabbro raft at (-12830, 71600) striking 95°. Epidote crystals 7 to 8 mm. in length are present in a fine-grained acidic groundmass and segregations of quartz are common, particularly to the centre of the dykes.

The dykes are considered to represent the last stage of intrusion in the complex, taking place along tensional fractures and other pre-existing anisotropies such as dyke/country-rock contacts.

3.1.5. (d) Quartz Veins

Irregular quartz veins, lenses and knots are common in both the intrusive and extrusive rocks of the Grøndalsfjell complex. Occasional thick veins, striking approximately north-south and dipping moderately to the north occur around eg. (-11770, 71100) where stringers and lenses of coarse-grained pyrite are contained within a highly sheared vein.

3.2. The Lithologies Beneath the Thrust Horizon

The lithologies occurring structurally beneath the klippe of the Grøndalsfjell complex outcrop to the west and south of the study area. This suite comprises an arcuate belt of schistose greenstones lying beneath the thrust horizon. The greenstones make a fairly sharp contact with a sheared trondhjemite to the south. Further to the south, the trondhjemite is gradational into a quartz gabbro rock, all the contacts trending approximately parallel to the trace of the thrust plane.

3.2.1. The Schistose Greenstone

The schistose greenstone belt is structurally thickest in the west, where it extends for several kilometres beyond the mapping area. It thins out southwards to a thickness of less than one kilometre and reaches a thickness of a few hundred metres in the southeast.

The greenstones have a well developed planar schistosity which is concordant with the thrust plane and is probably the result of high strain along this plane. The dip of the schistosity varies from 30° to 70° but is commonly 40° to 50° (Fig. 34). The observed variations in dip may be due to late shear folding having been superimposed near-ioaxially with primary axial planar schistosity (Chapt. 4). Such shear folds of minor amplitude commonly occur (Fig. 35).

The dominant greenstone lithology is a fine-grained, grey-green, basic to andesitic sheared extrusive. The planar fabric is evident in hand specimen by segregation of mafic and felsic minerals into very fine bands. Epidote and amphibole rich knots and quartz-feldspar veins may also be present, concordant with schistosity. Rust zones, representing sulfidic mineralisation, may be concordant or discordant with schistosity (Chapt. 5).

A schistose greenstone with a very pitted surface is present on the eastern shore of Grøndalsvatn. These pits probably represent preferential solution of carbonate of tectonic segregational origin. Within these pits, clusters of actinolite occur, orientated at right angles to the pit walls.

Within the schistose greenstones more massive greenstone horizons occur, often up to 2 metres thick and extending up to 20 metres. (Fig. 36).

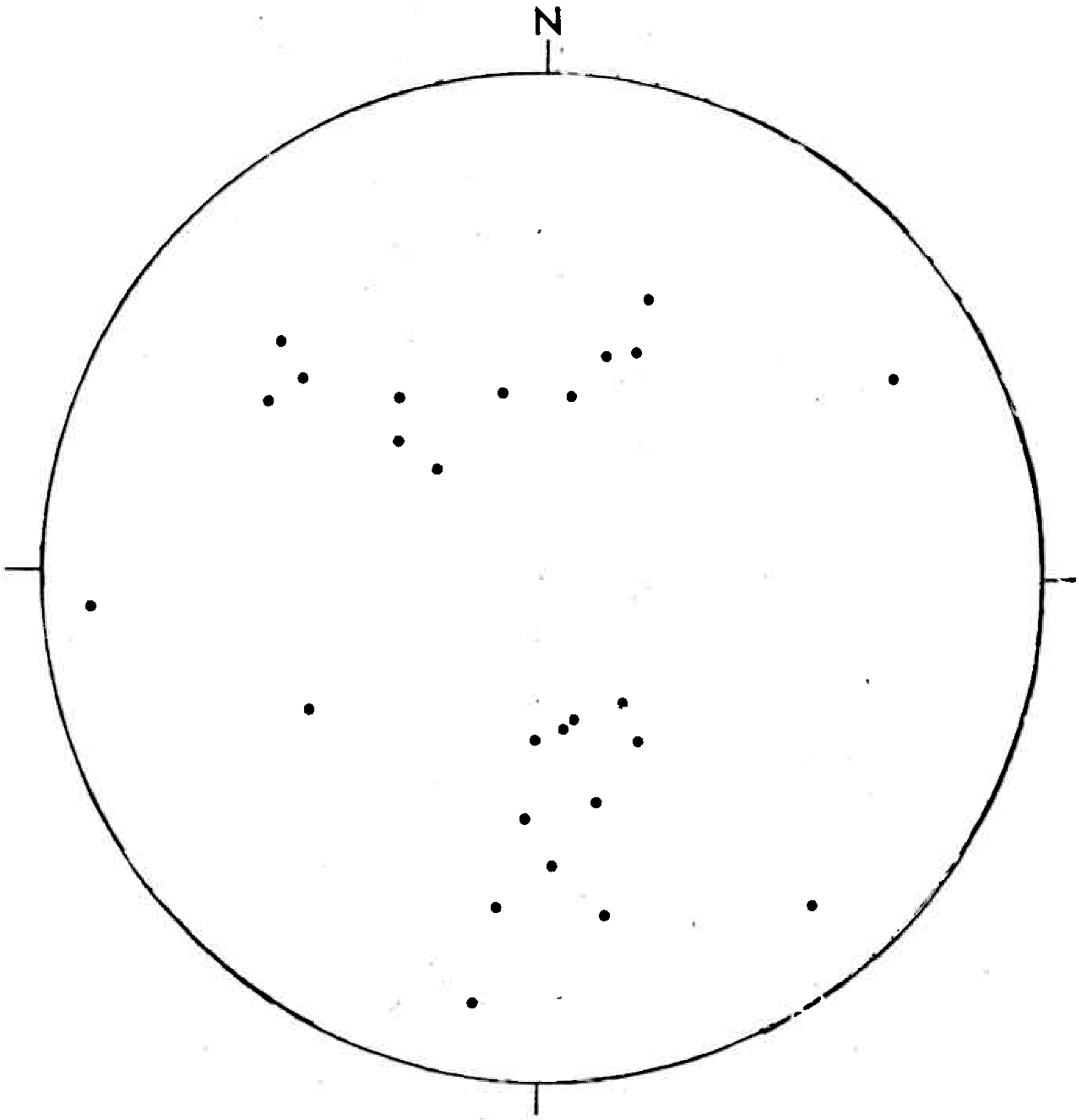


Fig. 34 Stereoplot of schistosity planes in greenstone schists.

Figure 35. Minor folds of schistosity in greenstone at (-12380, 68770).

Figure 36. Massive horizon (M), possibly a dyke within schistose volcanics, west of Grondalsvatn.

These are usually concordant with the schistosity but occasionally cut it at low angles. These may repr esent mafic dykes.

The more acidic volcanics, including acidic tuffs at eg. (-15070, 71750) occur as light weathering massive bands within the schistose greenstones. Similarly, rust zones may be included in these massive acidic bands. Locally, thin chert rich horizons, usually associated with magnetite, are present in the greenstone schists at eg. (-14950, 71750) These bands, representative of volcanic exhalative mineralisation, average a few centimetres in thickness. All the more massive bands are more competent than the enclosing schists and are frequently boudinaged (Fig. 37).

The penetrative schistosity has destroyed any primary extrusive textures although possible relict pillows, outlined by curvilinear epidote veining were found at (-12860, 69050) and banded acidic volcanics occur at (-15600, 71370).

In thin section the primary mineralogy is seen to have been completely replaced by minerals of the greenschist facies. The groundmass is composed of abundant albite and actinolite which has frequently crystallised into orientated layers. Disseminations and stringers of euhedral pyrite, often altered to haematite and limonite are common (Fig. 38).

The more massive greenstone horizons similarly possess a greenschist facies mineralogy. In thin section porphyroblasts of green hornblende are seen to give the rock a weak planar fabric (Fig. 39).

Knots, composed of an iron rich epidote core, rimmed by iron deficient epidote and finally clinozoisite with pyrite, may represent

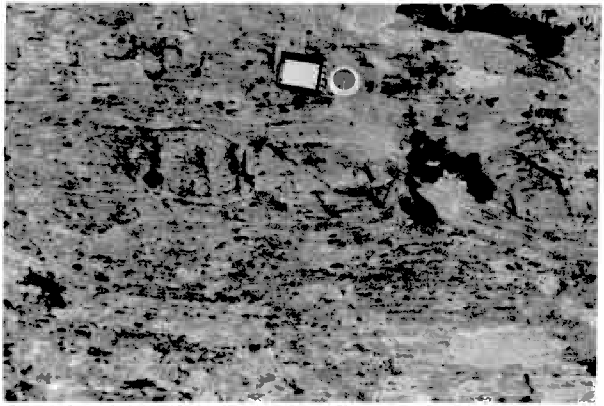


Figure 37. Boudinaging of a more competent band within schistose volcanics, west of [illegible].

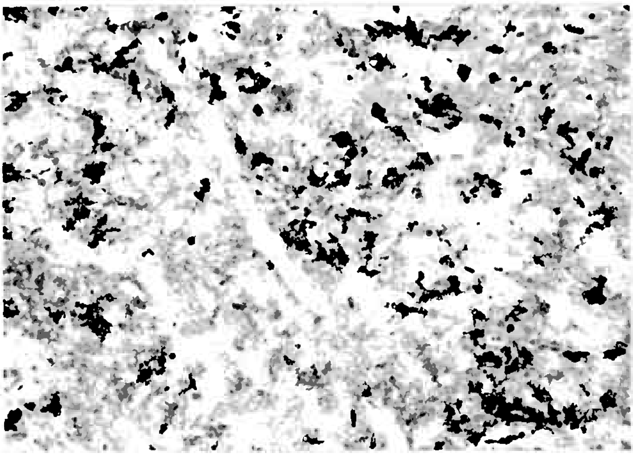


Figure 38a. Clinozoisite vein in greenstone schist, west of Grondalsvatn.

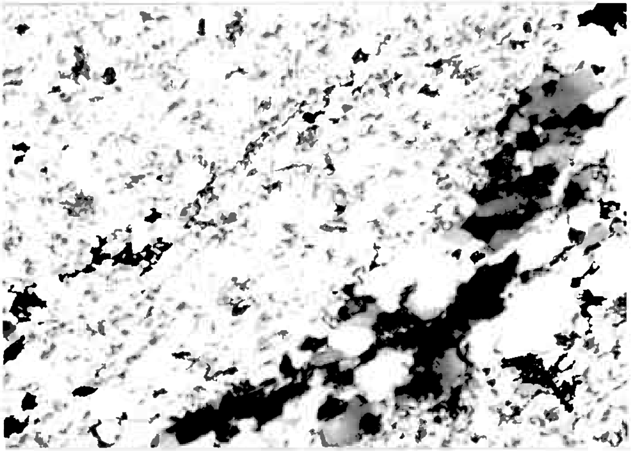


Figure 38b. Sheared [illegible] [illegible] [illegible] clinozoisite veins.

Figure 39. [illegible] [illegible] [illegible] planar fabric displayed by sub-parallel orientation of hornblende crystals [illegible] ([illegible], [illegible]).

original amygdales.

3.2.2. The Trondhjemite

The trondhjemite, as a major intrusive phase weathers to a light-grey colour, similar to the trondhjemite of the Grøndalsfjell complex, and supports the growth of the lichen Rhizocarpon geographicum. It is a coarse, phaneritic, hard rock composed essentially of conspicuous knots and stringers of bluish-coloured quartz in a matrix of saussuritised feldspar, quartz and minor ferromagnesian minerals.

A crude, planar fabric or tabulation is apparent in the trondhjemite, this being roughly concordant with the greenstone schistosity and the thrust plane orientation (Fig. 40), suggesting these fabrics were imposed by tectonism related to the form of the klippe. The knots of quartz, occasionally having diameters of up to 4 cm. by 1 cm. occur frequently, concordant with the crude schistosity. Spindle-shaped xenolithic-like bodies, reaching a maximum length of .5 m. are orientated along the crude schistosity planes at (-12700, 68150) and (-12830, 68170). These are apparently composed of fine-grained chlorite, epidote and quartz and may represent greenstone xenoliths.

Pitted zones are present locally in the trondhjemite, for example at (11550, 68260). These pits are the result of preferential weathering of knots of carbonate-chlorite rich material, again orientated along the crude schistosity. These knots are lighter in colour and softer than the previously described xenoliths.

In thin section plagioclase, possibly oligoclase is seen to be the major component of the trondhjemite mineralogy. Saussuritisation

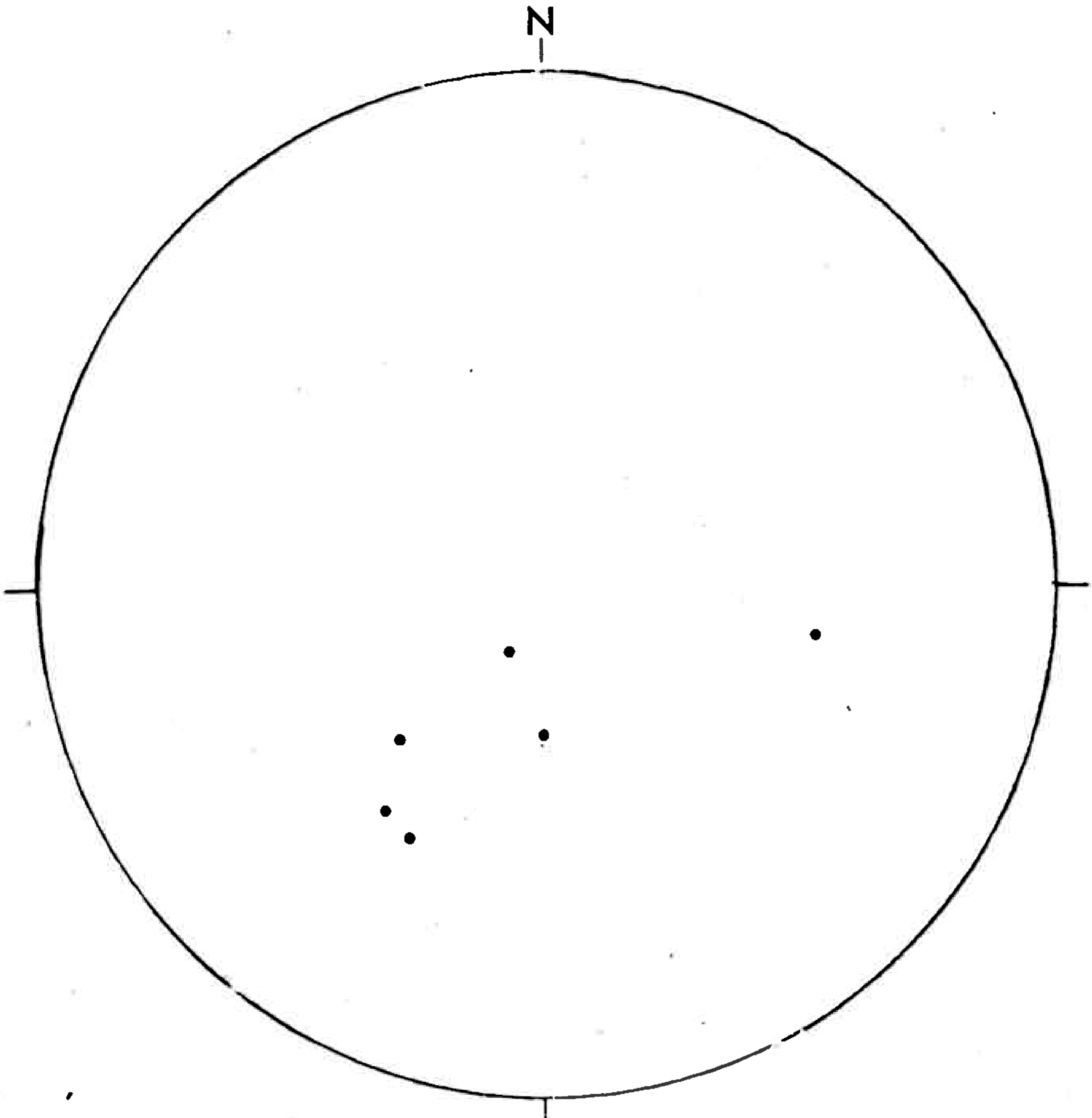


Fig. 40 Stereoplot of schistosity in the Trondhjemite and Quartz Gabbro.

Figure 41.a. Schistose Trondhjemite with quartz, sericitised feldspar and clinozoisite.

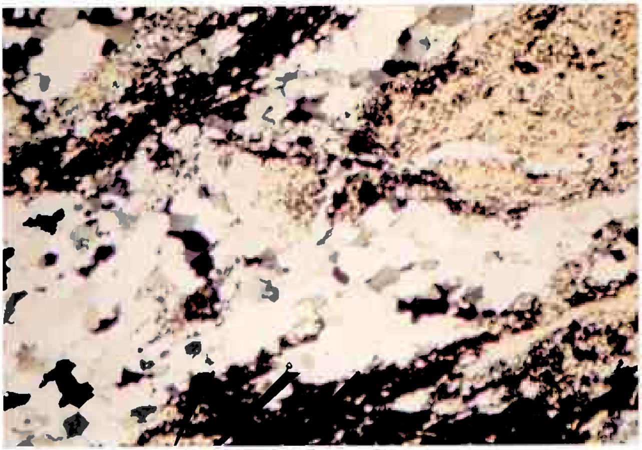


Figure 41.b. A more schistose sample of the same lithology.

to varying degrees has effected the plagioclase laths, proceding from the core outwards until occasionally only relict laths are visible. The alteration products are epidote, clinozoisite, chlorite and possibly actinolite with quartz.

Quartz comprises about 35% of the rock, either forming interstitial to the feldspar laths or as stringers, grains being anhedral and sheared (Fig. 41).

Chlorite is present in subhedral crystals but is often altered to epidote, especially along the cleavage planes. Magnetite is present as an accessory.

A raft-like area of dioritic material is pres ent around (-11900, 67450). This is in fact an area of mafic trondhjemite. The "raft" has dimensions of about 500 m. by 200 m. and has gradational contacts with the surrounding trondhjemite.

3.2.3. The Quartz Gabbro

The quartz gabbro is a coarse, dense rock which weathers a dark-grey colour. Blue quartz crystals or aggregates, up to 3 - 4 km. in diameter are visible particularly well on the weathered surfaces. The quartz, probably of metamorphic origin, is set in a groundmass of ferromagnesian minerals and saussuritised plagioclase. Magnetite and pyrite are present as disseminations.

A very crude planar fabric is apparent, stringers of blue quartz reaching 1 cm. in length often occurring parallel to this.

To the south, the quartz gabbro passes gradationally into a more felsic rock. The contact again appears roughly parallel with the trace of the major thrust. Time did not permit the mapping of this contact over more than a few hundred metres but examination of aerial photographs of the area enable both the northern contact with trondhjemite and the southern contact with an unknown lithology to be extended for about a kilometre (Fig.51).

3.2.4. Minor Intrusive Phases

3.2.4. (a) Basic Dykes

Several types of basic dykes are recognisable in the lithologies beneath the thrust plane. Doleritic intrusions, with a similar appearance to those intrusions in the Grøndalsfjell complex comprise the most abundant minor intrusive phase (Figs. 42 and 43) but they occur less frequently in the rocks beneath the thrust plane than above, in the Grøndalsfjell complex. The massive horizons that cross-cut the schistosity in the greenstones are probably doleritic dykes.

A dark green doleritic porphyry dyke, striking 91° and dipping steeply northward, occurs at (- 13850, 68100). Thin section reveals this to be composed of amphibole phenocrysts up to 2 cm. in length in a fine-grained groundmass of epidote, clinozoisite, chlorite, quartz and albite (Fig. 44). The phenocrysts display relict zoning, are schillerized and rimmed by chlorite and magnetite. Stringers and disseminations of pyrite are common. Quartz, epidote and albite form knot-like intergrowths which may represent relict vesicles or amygdales.

An andesitic porphyry intrusive is present at (-12830, 68170). This is a medium to light grey-green rock with conspicuous amphibole phenocrysts up to 4 mm. in length set in a finer matrix. Knots of

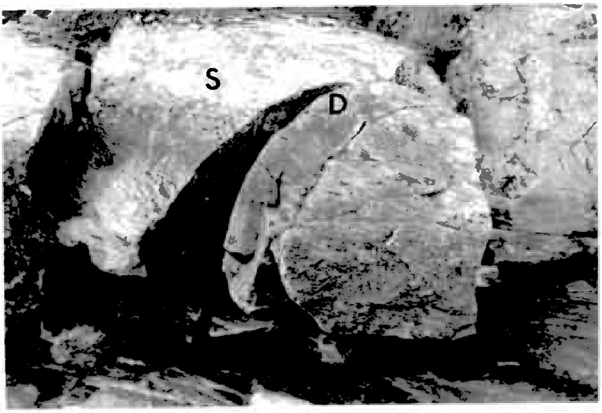


Figure 42. Mechanical weathering causing splitting along the contact of a doleritic dyke (D) with schistose trondhjemite (S) at (-17573, 68120).

Figure 43. Tectonised (?) doleritic dyke in sheared Trondhjemite (S) at ([illegible], [illegible]).

Figure 44. Amphibole, possibly actinolite, phenocrysts displaying relict pyroxene cleavage and [illegible] inclusions. Overgrowths of chlorite occur in the tectonic [illegible] zones of the crystal at (-[illegible], [illegible]).

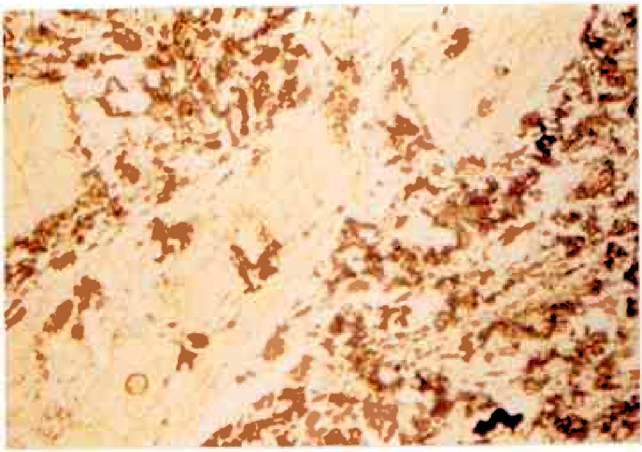


Figure 45. Amphibole phenocrysts in basic dyke at (-[illegible], [illegible]).

euhedral pyrite with quartz filling tectonic shadow zones around the pyrite occur commonly in this dyke.

In thin section, amphibole phenocrysts, possibly actinolite, are observed to replace pyroxene, relict pyroxene cleavage being locally inherited by the amphibole. In turn clinozoisite, chlorite and possible epidote replace the phenocrysts, the margins of which are strongly corroded (Fig. 45).

The matrix has been totally altered; a few lath-shaped aggregates of clinozoisite, albite, chlorite and quartz may represent original feldspar laths.

3.2.4. (b) Quartz and Epidote Veins

Quartz and epidote veins are universally abundant in all major lithologies. In the greenstones the quartz often follows the strike of the schistosity but is irregular in all other lithologies. Epidote-quartz-albite veins and knots similarly occur irregularly throughout lithologies beneath the klippe.

4. STRUCTURAL GEOLOGY

4.1. Tectonic History of the Skorovas Region

Previous work, from Foslie (1922-1927) to Halls et al (1971 - 1977) has led to the recognition of the following sequence:

(i) Intrusion of massifs into the volcanic stratigraphy.

(ii) The main tectonic phase, during the Caledonain orogeny comprising:

(a) Creation of tight (F1) isoclinal folds and primary axial planar schistosity.

(b) Emplacement of the Gjersvik nappe.

(c) Minor thrusting within the Gjersvik nappe between the plutons and volcanics, arising due to major differences in competence.

(iii) Local open folding along near rectilinear axes producing broad dome and basin structures probably related to the equilibration between the basement and its nappe load after nappe emplacement. Associated with this, re-activation of previously established fractures and thrusts is thought to have resulted in shear-folding of the F1 schistosity within the extrusives, particularly in the vicinity of contacts with the larger intrusive masses.

The presence of large intrusive bodies within the volcanics is an important structural factor, since they have led to the development of strongly heterogeneous stress fields in the Skorovas area, due to their much greater competence under deformation.

4.2. The Structure of Gröndalen

Structural information is fairly sparse in the Grøndalen area. Recordable information is most abundant in the greenstone schists beneath the thrust plane, but poor exposure in this area hinders any serious attempt of structural mapping.

4.2.1. Structure of the Gröndalsfjell Igneous Complex

Any intrusive structures within the complex are difficult to ascertain because of the diffuse nature of the contacts, making accurate determination of dip impossible. However, considering the effect of topographic change on contact trends, one can infer that the dips of the contacts are generally steep.

Examination of the 1:25000 geological map of the Grøndalsfjell complex shows that the outcrop pattern of the lithologies in Grøndalen is approximately symmetrical with the outcrop patterns in the east of the complex, with the line of symmetry running north-south through the centre of the complex. The core and oldest part of the intrusive body is the gabbro raft belt. The outer margins comprise the hornfelsed greenstones and belts of greenstone xenoliths in diorite.

One can suggest that the Gróndalsfjell massif represents an inverted, multi-sequential intrusive complex, probably originally lying at a relatively deep position within the Gjersvik nappe (Sections 1, 2, 3 and 4; Figs. 46 and 6).

At the eastern thrust margin of the complex, exhalative horizons are seen to traverse the thrust with displacements in the order of tens of metres (Ferriday (1977) personal comm.) This and the similarity of

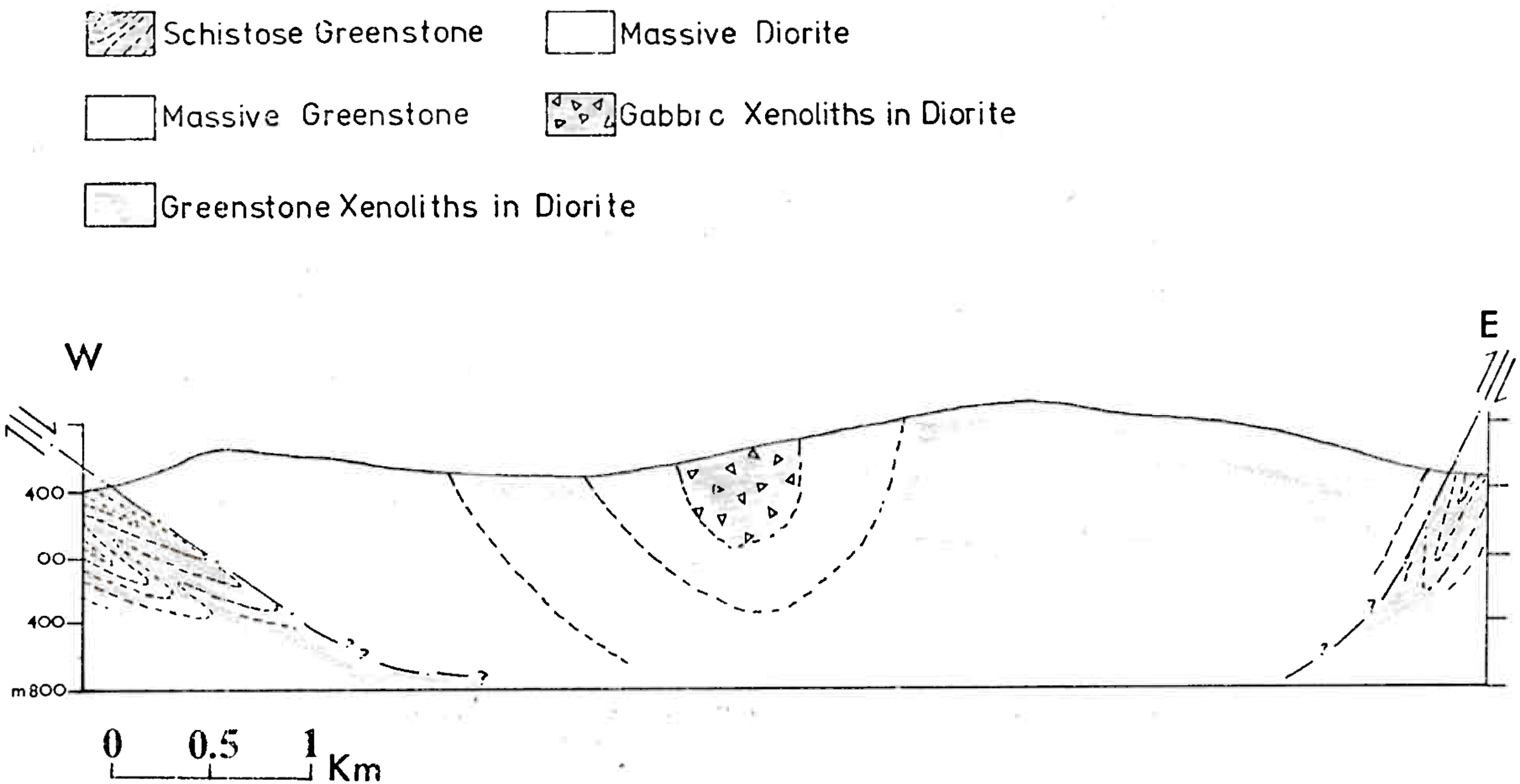


Fig.46 Generalised section E-W through the Gröndalsfjell complex.

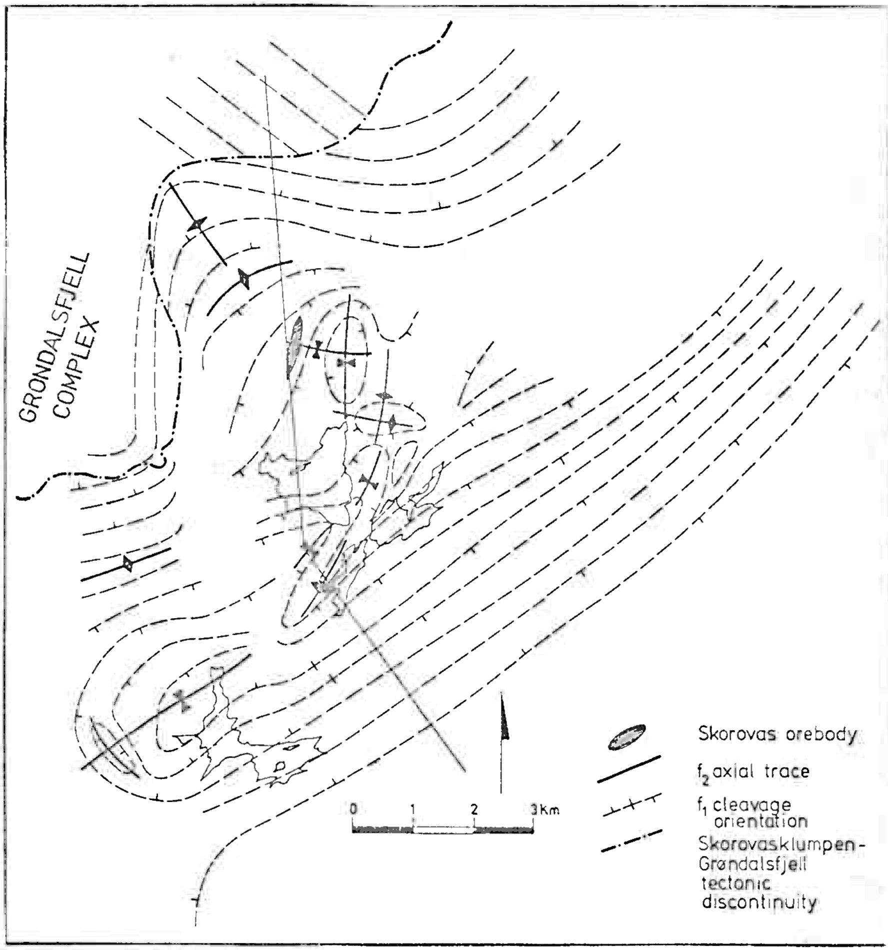


Fig. 47 Synoptic map of the principle structural trends in the Skorovas region showing the principle structural trends and the eastern boundary of the Gröndalsfjell tectonic discontinuity.
From Halls et al (1977).

greenstone mineralogies above and below the thrust suggests displacement to have been relatively small, or imbricate fracturing to have taken place in the greenstones outside the complex, resulting in similarly small nett displacements of the order of 1 km. The direction of thrusting is believed to have been generally from the west, since the major basement occurs to the east.

The present depth of the Grøndalsfjell complex is unknown. However, a vertical thickness of over 1000 m. is exposed in Grøndalen.

4.2.2. The Thrust Horizon

The thrust horizon in Grøndalen can be traced by conspicuous changes in topography and vegetation (Figs. 48 and 49). A sheet of trondhjemite, varying in thickness from 15 cm. to 1 m., dipping 45^{o} - 60^{o} northwards and having the thrust plane as its lower contact is present in south-east Grøndalen. This was seen at (-10680, 67790) and (-11400, 68830). The trondhjemite was not present to the west of Grøndalen or to the north of Grøndalsvatn. Abundant epidote veining occurs within 1 m. above and below the thrust. At (-14950, 70880) abundant quartz veins, up to 15 cm. thick occur in the hornfelsed greenstones above the thrust plane. The veins are orientated roughly parallel with the strike of the schistosity of the greenstones beneath the thrust plane and in cross section these veins exhibit well developed shear folds.

The dip of the thrust plane varies from 60^{o} to 30^{o} (Fig. 50) and it is locally imbricate, particularly in the northwest of the mapping area and also possibly to the north of Grøndalsvatn. Similarly, imbricate

Figure 48. View of Spinshmulen showing thrust and lithologies.

Figure 49. View of thrust on west side of Murfjellet; M- massive greenstone thrust over schistose greenstone (S).

thrusting may well have taken place within the schistose greenstones in the south of the area. The locally imbricate nature of the thrust is readily observable from aerial photographs of Grøndalen (Fig. 51)

The thrust horizon is suspected to have a saucer-like form beneath the Grøndalsfjell complex (Fig. 46).

4.2.3. Structure of the Igneous Units Beneath the Thrust Horizon

Very little is known about the intrusive structure of the igneous suite beneath the thrust. However, the dips of the contacts between lithologies are suspected to be steep.

4.2.4. Mode of Intrusion and Mechanism of Emplacement of the Grøndalsfjell Igneous Complex

Field evidence suggests the Grøndalsfjell plutons to have been intruded fairly passively, with only minor evidence of possibly more forceful intrusion, such as the veining of greenstone by diorite. However the intrusive - country rock contracts have largely been obscured by the thrust horizon. The passive nature of intrusion indicates that there was not a great deal of resistance to the incoming magma implying that the magma did not have to exert a large amount of force to secure an entry (Speedyman, 1971). Thus the intrusion was of a permissive nature.

Pirsson (1914) described permissive intrusion as one in which the magma is intruded into low-pressure regions created by some force other than that exerted by the incoming magma. Dietrich (1954) indicated that such a force could be tectonic, the magma flowing into low-pressure regions created by tectonic stresses.

The intrusion of the Grøndalsfjell complex probably occurred before the emplacement of the Gjersvik nappe since it was probably major competence differences between major plutonic bodies and the surrounding volcanic or sedimentary formation that induced thrusting within the nappe, resulting in the emplacement of the Grøndalsfjell complex as a klippe.

Examination of the geological maps of the Grøndalsfjell thrust contacts shows that the primary lithologies as well as the schistosity traces curve around the thrust trace, suggesting the schistosity and volcano-stratigraphy to be concordant or subcordant. This curving of lithologies and schistosities around the Grøndalsfjell massif was used by Halls et al (1977) to demonstrate the presence of a tectonic discontinuity at the thrust boundary (Fig. 47). This discontinuity formed as a result of the previously mentioned gross competence differences between the Grøndalsfjell klippe and the surrounding extrusives during nappe emplacement, the extrusives having behaved in a plastic manner, with "moulding" of the volcano-stratigraphy around the klippe.

To the south of Grøndalen the trondhjemite and gabbro lithologies, together with their poorly developed schistosities, also trend sub-parallel to the thrust trace. These relatively massive units form the margin of a large plutonic complex to the southwest of Grøndalen (Foslie, 1927). That this complex should also be affected by the klippe, if only at its borders, demonstrates the importance of the tectonic discontinuity.

The curvilinear nature of the trace of the thrust horizon may

Figure 50. View of thrust in [illegible] at (-14190, 7[illegible]50).

also however be the result in part of subsequent folding of the klippe on its margins; the large hornfelsed greenstone apophysis to the west of Grøndalselva is surrounded almost symetrically by a greenstone xenolithic belt. The thrust horizon also curves around this greenstone unit which may represent the axial trace of a synform or antiform. There is no direct field evidence to support this theory however.

4.2.5. Late Stage Fractures

High angle, late-stage fractures and faults strike dominantly northeast-southwest across Grøndalen. These features are easily recognisable on contour maps or aerial photographs as distinct gulleys, up to 30 m. in width, that control the drainage in the Grøndalselva catchment area. A map of the fractures and other geological information obtainable from aerial photographs is given in Fig. 51.

Outcrop patterns suggest small, localised displacements in the order of 1 - 10 m. have occurred along some of these fractures while brecciated diorite-greenstone rock occurs at (-13670, 69420) in a gulley marking one of the fractures.

Rose diagrams for the fractures shown in Fig. 51 are given for fractures above and below the thrust in Figs. 52 and 53 respectively. Above the thrust plane a dominant set of orthogonal fractures occurs, the major trend being northeast - southwest. This set of fractures is also present in the lithologies beneath the thrust horizon where an additional set of orthogonal fractures are present, with major north - south trends.

The formation of the features postdates both the emplacement

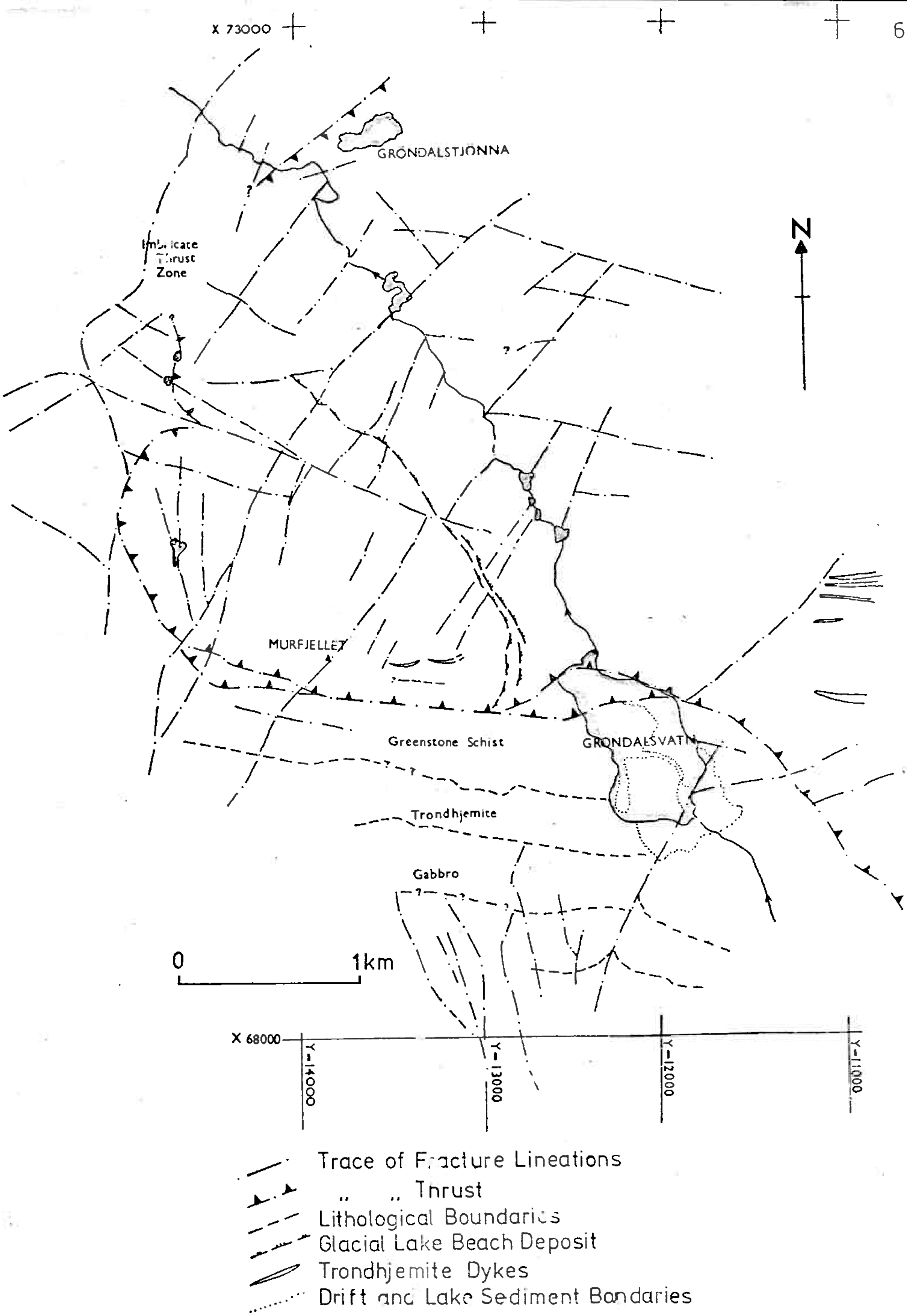


Fig.51 Major fractures and lithologies as recognised on aerial photographs of Gröndalen.

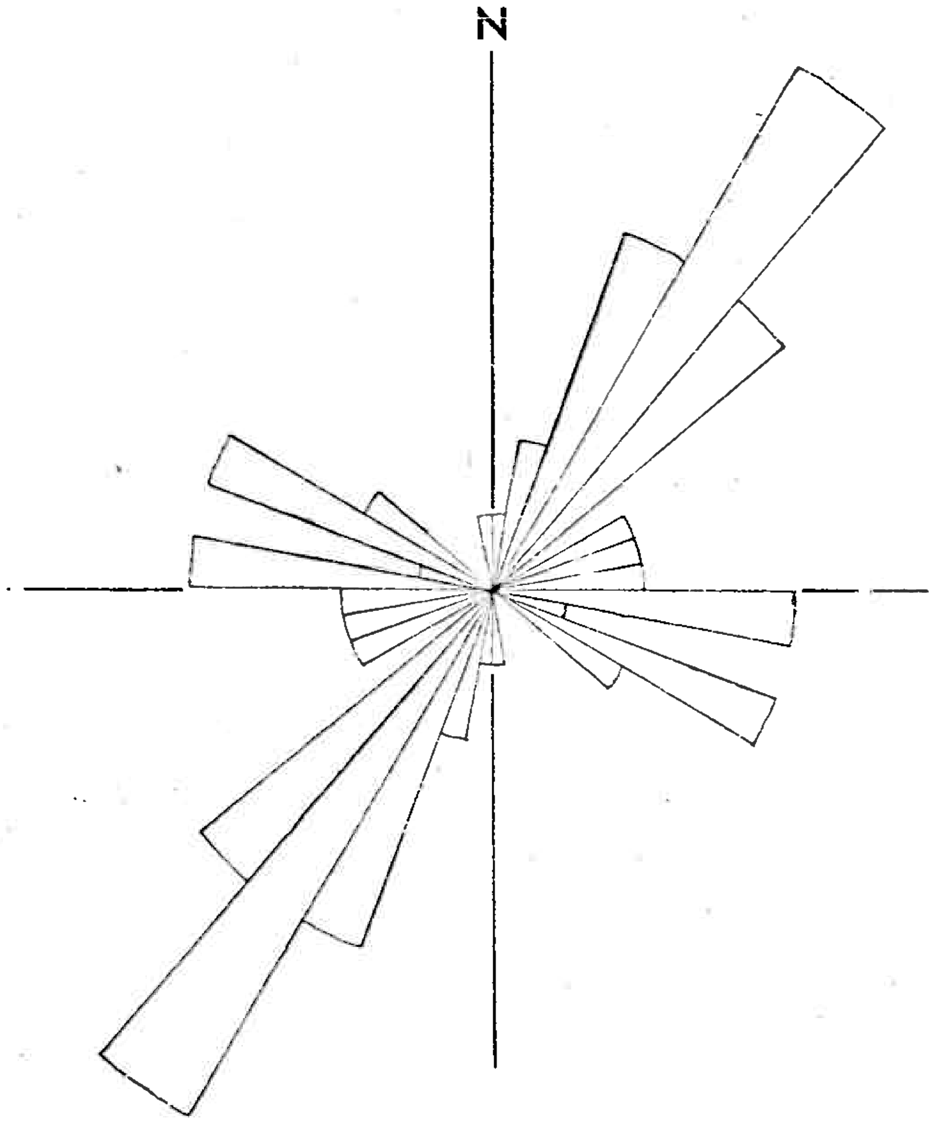


Fig.52 Rose diagram of fractures occuring above the thrust horizon in Gröndalen. Fractures traced from aerial photographs.

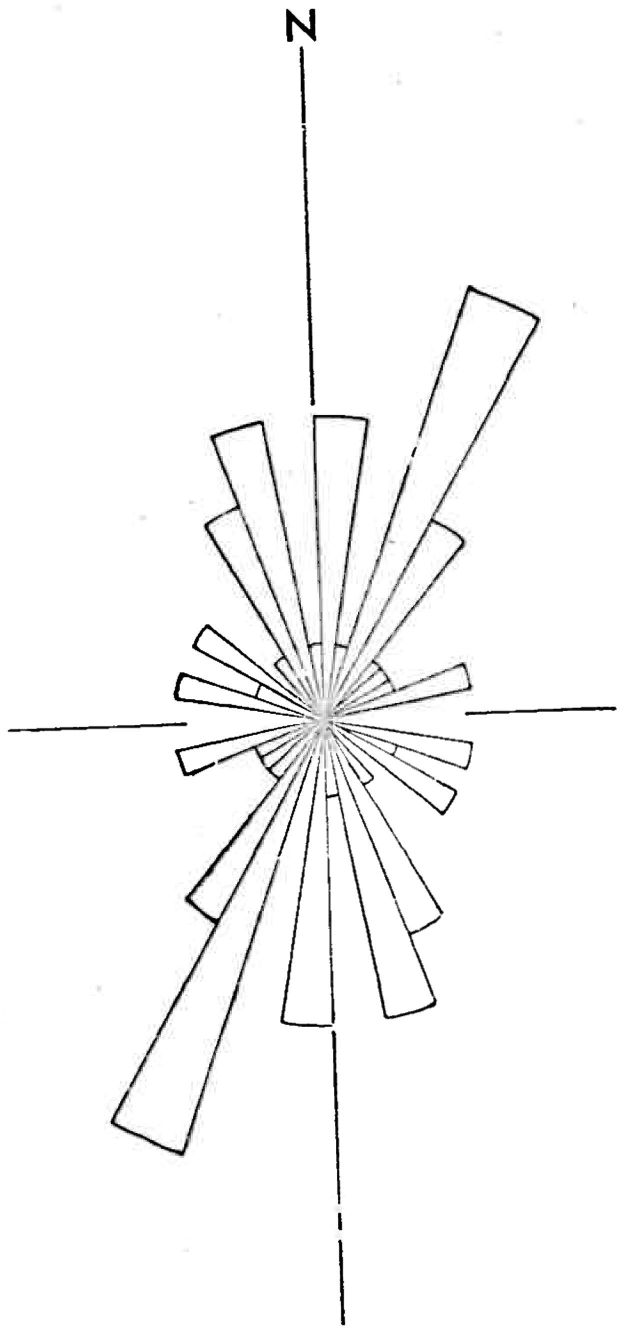


Fig.53 Rose diagram of fractures occuring beneath the thrust horizon in Gröndalen. Fractures traced from aerial photographs.

of the klippe and the final folding phase. Fractures of this type are common throughout the Skorovas region. "In all probability they can be attributed to the final stages of tectonism, but the influence of later events, such as basement reactivation during Mesozoic rifting cannot be discounted". (Halls et al, 1977).

The north-south trending fractures in the plutonic rocks to the south of the thrust horizon may possibly be the result of the emplacement of the klippe; the extrusives and margins of the plutonic massif developed a planar fabric and deformed plastically around the margins of the klippe. The rocks distal to the thrust and deeper within the large intrusive body may have responded merely by fracturing.

5. ECONOMIC MINERALOGY OF GRÖNDALEN

Two types of mineralisation occur in the Grongfelt Region:

(i) Cumulus ores of magmatic origin within the plutonic members of igneous complexes.

(ii) Massive base-metal bearing sulfides produced at the volcanic level.

Both ore types occur within the Skorovas region; sub-economic quantities of chalcopyrite-pentlandite bearing cumulus ore are present at Lillefjellklumpen, to the north of Skorovas (Johnson - Høst, 1932; Palmer, 1972) and the volcanic ores are represented by the Skorovas orebody itself and peripheral exhalative mineralisation.

5.1. Mineralisation within the Gröndalsfjell Igneous Complex

5.1.1. The Massive Greenstones

Within the massive hornfelsed volcanics, rust zones are commonly observed. These zones are often associated with the more acidic horizons with the volcanics at for instance (-14250, 70320). At the outcrop level the sulfides have been highly oxidised and commonly weathered out to produce a leached lithology with cubic voids representing former pyrite crystals.

A pyritic-magnetite rust zone, striking approximately 110° and extending intermittantly over about 100 m., is present at (-13220, 70260) in a shallow gulley. Abundant euhedral pyrite crystals, up to .5 cm in diameter occur in acidic to basic greenstones containing knots of blue quartz.

In polished section pyrite, occurring as disseminations and knots up to 2 cm. in diameter is seen to be the major form of mineralisation. Chalcopyrite and pyrrhotite, which is often highly altered to marcasite-pyrite occurs as replacements and veinlets within pyrite (Fig. 54).

Compass deflections around (-10450, 69740) indicate a magnetic anomaly although only minor sulfide dissemination was recognised at this locality. However this and the nearby presence of the Red Alpine Catchfly (Viscaria alpina), an indicator plant for copper-rich soils (Vogt, 1942; Brooks, 1972), may well indicate possible sub-surface mineralisation.

Sulfidic mineralisation also occurs within greenstones of the xenolithic belts at, for instance (-14270, 70900) where the mineralization extends into the surrounding diorite, suggesting either total localised digestion of the xenolith or remobilisation of the ore minerals. A relatively large showing of mineralisation, extending 10 m by 20 m occurs in the Grøndalselva at (-12430, 69260) only fifty or so metres from the thrust horizon. This showing was only seen above water level for two weeks when the Grøndalselva was in abnormally low flow.

Pyrite, pyrrhotite and chalcopyrite are the dominant ore minerals, occurring in varying proportions in massive, disseminated and veinlet form. In polished section pyrrhotite, commonly altered to marcasite-pyrite, is observed to be the dominant mineral in the massive ore, forming ophitic and sub-ophitic intergrowths with pyrite (Fig 55). Pyrrhotite also occurs as veins in pyrite (Fig 56) and shows occasional possible annealment textures. Chalcopyrite occasionally replaces the pyrrhotite as well as forming as a separate phase within the silicate

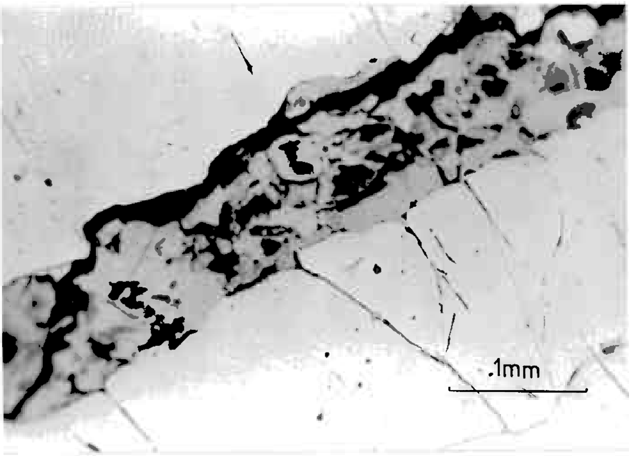


Figure 54. Vein of pyrrhotite and chalcopyrite in pyrite in hornfelsed greenstone at (-15220, 70260).

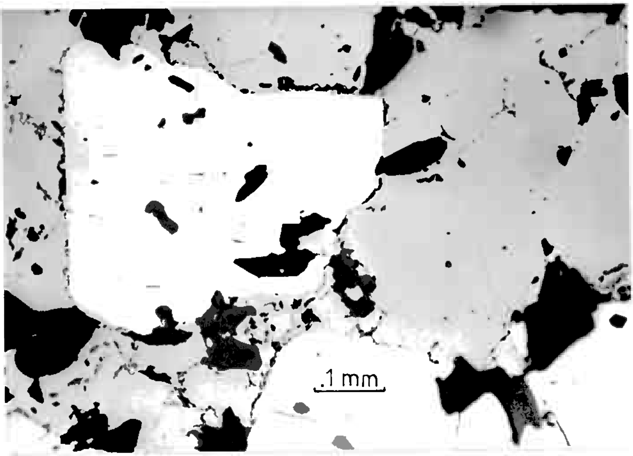


Figure 55. Ophitic pyrite in pyrrhotite at above location.

matrix. Complex magnetite-ilmenite-sphene intergrowths are present as disseminations. Pyrite also forms complex intergrowths with graphite which is probably the metamorphic derivative of carbon produced in the process of reduction of exhaled iron hydrosols to iron oxides and sulphides by decaying organic matter in environments of limited circulation on the sea floor.

The host rock to the mineralisation is a highly altered acidic greenstone containing chert-rich horizons and irregular veins of diorite. It comprises saussuntised feldspar, quartz, chlorite, epidote and both non-ferroan and ferroan zoisite. A gossan, up to 5 cm. thick is locally present

5.1.2. The Gabbro

Magnetic anomalies, that noticeably deflect compass bearings, are present around (-10450, 69740) and (-11650, 70690) where outcrops of coarse, green gabbro and red-brown gabbro as xenoliths in green gabbro occur respectively (Chapt. 3.1.1). In hand specimen both rock types evidently contain magnetite; the red-brown gabbro in polished and thin sections is seen to contain abundant magnetite veinlets exsolved from serpentinised olivines (Fig.10). In addition, minor amounts of pyrite, chalcopyrite, pyrrhotite and magnetite are present as disseminations. The ore minerals in the red-brown gabbro show no evidence of being formed by a cumulate process.

Euhedral magnetite crystals up to 2 cm. in diameter occur to the south of Middagshaugen at (-12680, 72250). The magnetite may have been remobilised on the emplacement of the diorite.

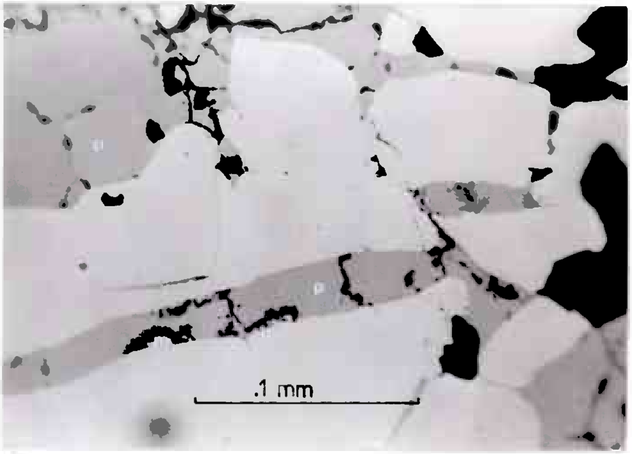


Figure 56. Vein of pyrrhotite (p) altering to marcasite (m) in pyrite at (-12430, 69760)

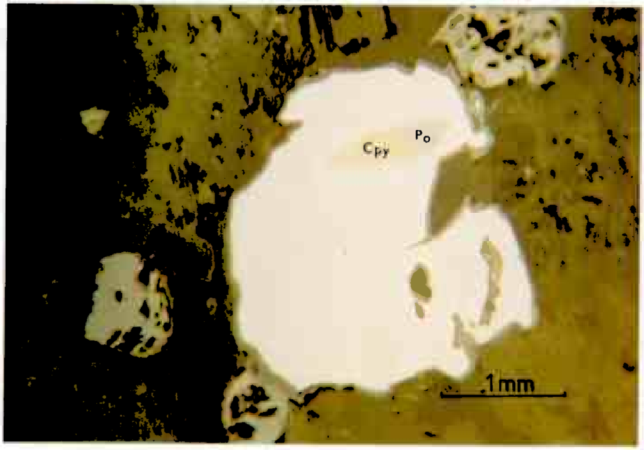


Figure 57. Anhedral pyrite with inclusions of chalcopyrite (cpy) and pyrrhotite (po) in diorite.

Disseminations of sulfidic mineralisation, of pyrite or pyrrhotite are recognisable in all gabbroic lithologies. These are probably usually of cumulus origin, similar to the mineralisation in the gabbro in the eastern part of the Grøndalsfjell complex. (Walker, 1972)

5.1.3. The Diorites

Minor disseminations of sulfidic mineralisation are present in all dioritic lithologies, particularly in the more basic rock-types. Similarly, disseminations of magnetite are common in all lithologies.

Pyrite is the most common sulfide mineral although chalcopyrite is present at (-11800,69500) and possibly pyrrhotite at (-12670, 70040). In polished section the pyrite is seen to occur as euhedral or subhedral crystals (Fig 57). Clinozoisite and quartz occasionally infill tectonic shadow zones around these grains, dating them as pre-tectonic. Inclusions of silicate material are common in the pyrite while minor amounts of replacement by pyrrhotite and chalcopyrite occurs. Magnetite occurs as an intercumulus phase, as complex intergrowths with ilmenite or mag-ilmenite, and with a silicate phase, possibly sphene.

5.1.4. Minor Intrusives

Disseminations of pyrite, magnetite and possibly pyrrhotite occur in the basic dykes. The magnetite occurs either as subhedral crystals (Fig. 58) or as complex intergrowths with ilmenite and sphene. Occasionally the dykes noticeably magnetic at, for instance (-12010, 71180).

Trondhjemite may contain minor stringers of presumably

Figure 58a. Subhedral magnetite in basic dyke.

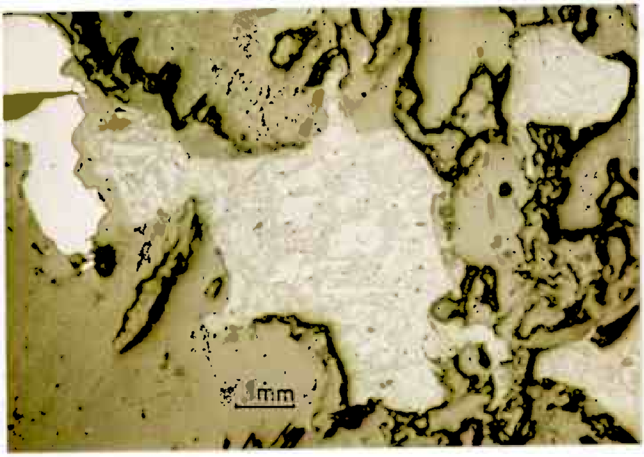


Figure 58b. Complex magnetite-ilmenite-sphene intergrowth in basic dyke.

remobilised pyrite and pyrite may also be found as segregations within epidote rich veins at for instance (-12830, 71600) within a doleritic dyke.

A quartz vein, containing abundant euhedral pyrite as stringers, knots and lenses, that are up to 1.5 cm and orientated along the altitude of the vein, occurs at (-11770, 71100).

5.2. Mineralisation Within the Lithologies Beneath the Thrust Horizon

5.2.1. The Schistose Greenstones

Disseminations and stringers of pyrite are common within the schistose greenstones. Rust zones, up to 20 m. in length and 2 m. in width, often concordant with the trace of the schistosity or cutting it at low angles occur commonly within this lithology. These rust zones are frequently associated with acidic bands but may also occur within the andesitic to basic volcanics.

Rust zones, at eg. near Spissknulen (-9800,67540), with typical dimensions of 10 m. in length and 1 m. in width, are common. Pyrite is the most common form of mineralisation, occurring either as subbedral to euhedral crystals, commonly with corroded faces and minor replacement by pyrrhotite, or as complex intergrowths with a silicate phase (Fig. 59). Minor disseminations of anhedral magnetite are also present.

Oftedahl (1958) described a showing of base-metal mineralisation within schistose volcanics at (-14300, 72830), this prospect having been previously investigated by Foslie (1919).

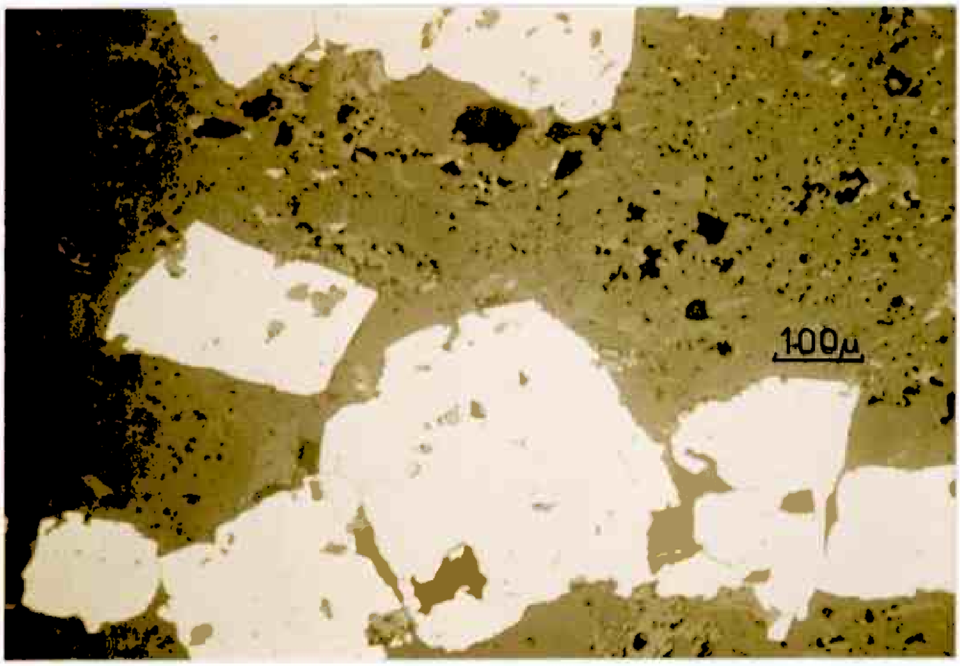


Figure 59.a. Euhedral pyrite in schistose greenstones at (-9800,67540).

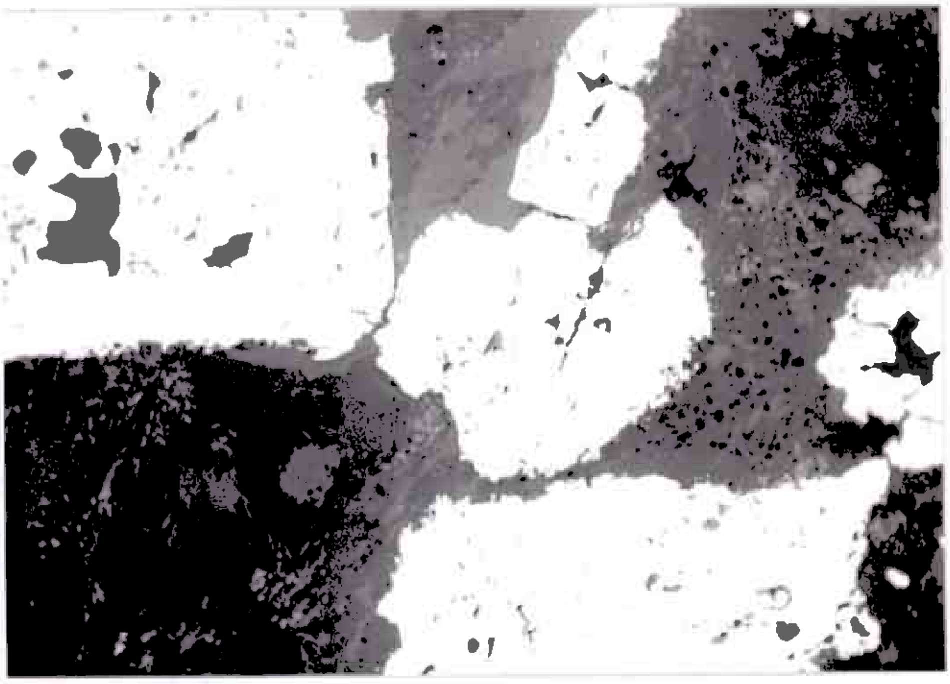


Figure 59.b. Pyrite with corroded edges in schistose greenstone at (-9800,67540).

Exposure in the vicinity of the prospect is poor, the land being heavily forested by Scots pine. However, immediately around the prospect the tree density is noticeably lower, probably due to heavy-metal poisoning of the soils (Bølviken and Lag, 1977).

The prospect may be divided into two sites, a northeastern and southwestern, separated by about 30 m. of marshy ground.

Mineralisation in the northwestern site is largely confined to a schistose basic volcanic lithology that has been veined irregularly by quartz. The mineralised zone strikes 113° and dips between 60°N and sub-vertical, being apparently on the limb of a fold and averaging .5 m. in thickness.

Pyrrhotite is the dominant ore mineral, occurring locally as knots, up to 2 cm. in diameter, stringers and disseminations. In thin section it is seen to contain pyrite as ophitic and subophitic intergrowths. Chalcopyrite, magnetite and sphalerite replace the pyrrhotite which is altered along crystal margins and fractures to marcasite. Sphalerite also occurs in veinlets through the pyrrhotite. Silicate inclusions are common in the grains, which occasionally show well-developed tri-cuspate annealment textures.

Pyrite occurs as anhedral to euhedral crystals, usually rimmed by pyrrhotite. Chalcopyrite and pyrite also occur within the silicate matrix as disseminations parallel to schistosity

The footwall comprises a schistose andesitic to basic volcanic rock containing minor stringers of pyrrhotite and pyrite. The hanging wall comprises a similar lithology but is more massive and displays boudinaging of epidote-rich veins (Chapt. 3.2. , description of more massive greenstone lithologies within the schists).

The southwesterly site comprises pyrite-sphalerite mineralisation within a schistose acidic volcanic lithology. A minor fold in the schistosity plunges 46° to 245°.

The ore mineralogy is comprised of approximately equal amounts of pyrite and sphalerite with minor magnetite. Minor chalcopyrite occurs as inclusions in the sphalerite, intergranular between pyrite crystals and as disseminations within the silicate matrix.

The sphalerite occurs as ophitic and sub-ophitic intergrowths with pyrite. It has a reflectance of about 20 and whitish internal reflections, suggesting a particularly low iron content within the sphalerite (Ramdohr, 1969).

To the west of the area mapped, a single traverse from the E57 to the SSW of Lillefjelldomma revealed a haematite-magnetite schist within the extrusives, 2.5 km. southwest of Vestre Lillefjellet, 400 m. due east of trig. point 625. Within one outcrop the lithology varied according to the relative abundance of haematite and magnetite. In the haematite rich schist,orientated layers of flaky haematite in a silicate matrix give the rock a well developed schistosity (Fig. 60). Grains of pinkish-grey magnetite occur within the haematite layers. The pink colour may represent high contents of manganese within the magnetite (O'Leary, 1973) or alternatively, high contents of titanium (Ramdohr, 1969). In the magnetite-rich schists, grey-coloured magnetite crystals, having abundant silicate inclusions occur. These schists contain well twinned haematite crystals (Fig. 61). These lithologies probably represent peripheral exhalative-sedimentary mineralisation within the volcanic sequence.

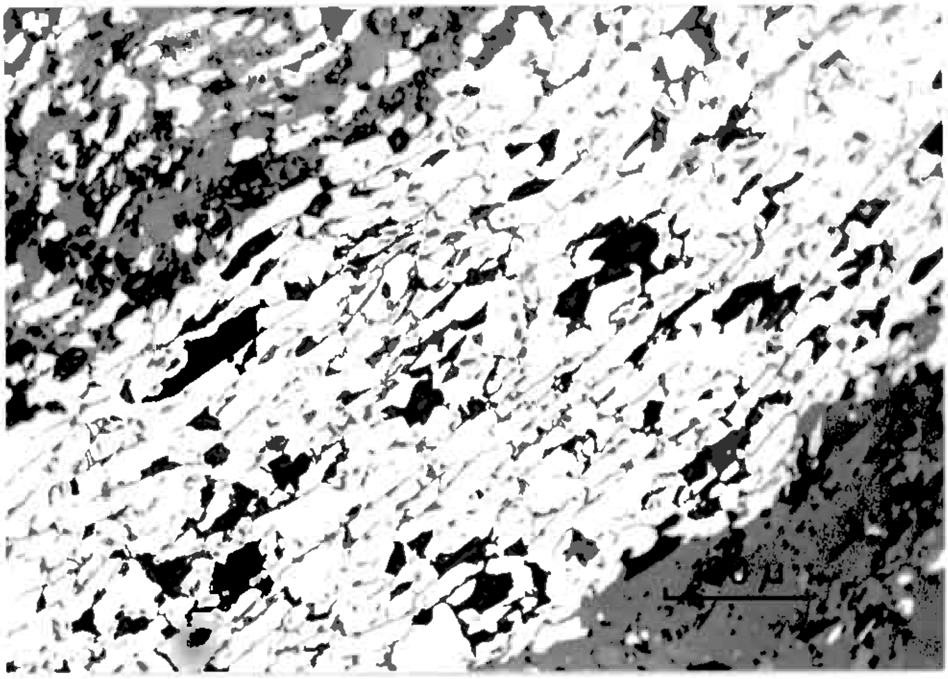


Figure 60. Haematite schist.

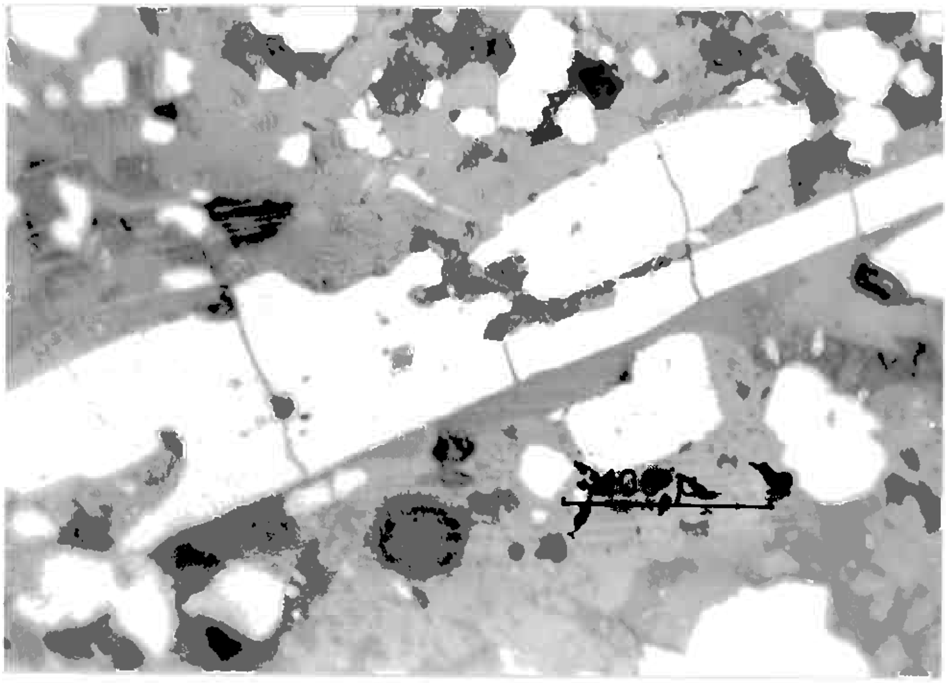


Figure 6I. Magnetite lath with twinned haematite in greenstone schist.

5.2.2. Mineralisation within the Intrusive Lithologies

The trondhjemite contains only sparsely disseminated pyrite or pyrite-magnetite mineralisation; the quartz-eye gabbro (silicified gabbro) similarly only contains minor amounts of disseminated pyrite, magnetite and possibly pyrrhotite (Fig.62).

The minor intrusive phases contain only stringers and disseminations of pyrite and pyrrhotite with magnetite.

5.3. Mineralisation and Metamorphism

Within the Grøndalsfjell intrusive complex, the origin of mineralisation is at least partly magmatic, as indicated by the presence of cumulate magnetite. The magnetite occurring in the form of complex magnetite-ilmenite-sphene intergrowths may be the result of one or more generations of ilmenite exolving from the magnetite during slow cooling (Ramdohr, 1969). However this does not explain the presence of the intergrowths with the volcanic lithologies so there may well be a metamorphic origin to these phases.

Euhedral pyrite, occurring as stringers in many of the lithologies both above and below the thrust horizon suggests that remobilisation of the pyrite has occurred, as does the presence of pyrite as segregations within late-stage deuteric epidote-rich veins. However the presence of mutual impaction boundaries on some of the crystals indicates that some of the pyrite was deformed in a brittle cataclastic manner by either the tectonic event that produced the F1isoclinal folds or the thrusting.

The pyritic and pyrrhotitic copper-zinc bearing mineralisation in the volcanics may also have been remobilised from its original

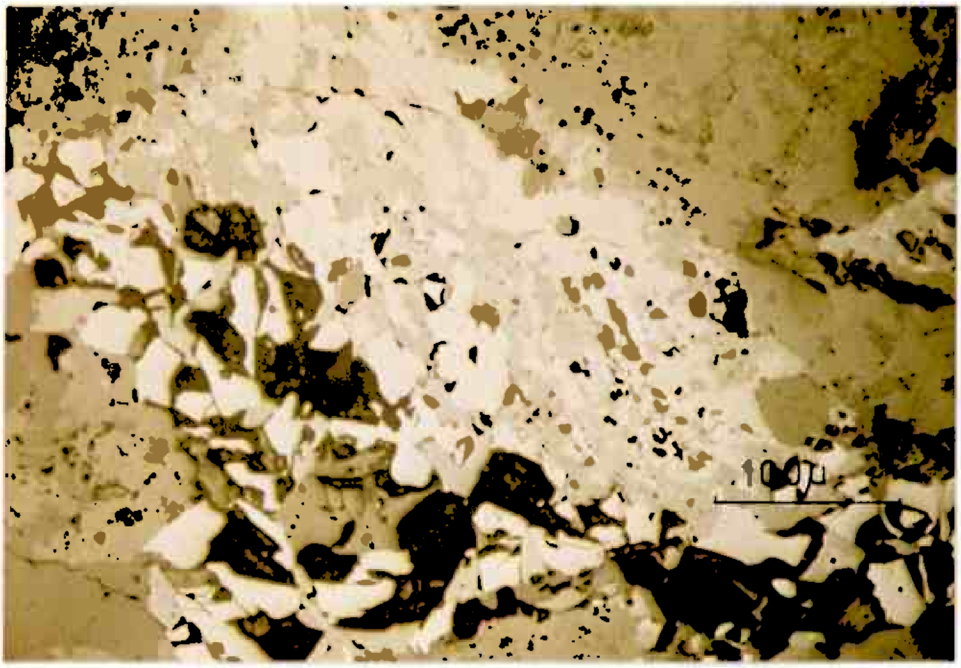


Figure 62. Complex magnetite-ilmenite-silicate intergrowth in silica gabbro.

stratiform, vulcanogenic position; the strike of the rust zones in the greenstone schists is usually parallel to the trace of the schistosity. This may represent remobilisation and redeposition of the sulfides in a saddle-reef type attitude, being concordant with schistosity. More probably however, the sulfides are in a stratabound attitude since the original volcanic stratigraphy has deformed plastically around the klippe and has developed schistosity sub-parallel to the original stratigraphy.

5.4. Geochemical Analyses

Electron probe analyses were made of samples from the prospect discovered by Foslie at (-14320, 72820) and the ore showing in the Grøndalselva at (-12440, 69220).

(i) SPECIMEN KI 63, location: (-14320, 72820)

Mineral : pyrite

Element	% Detection Limit	% Element
Mg	0.108	0.0000
Ca	.096	0.0000
Ti	.106	0.0000
Cr	.128	0.0000
Mn	.144	0.0000
Fe	.618	46.5382
S	.421	53.9840
Ba	.279	0.000

Mineral : pyrrhotite

Element	% Detection Limit	% Element
Mg	0.105	0.0000
Ca	.093	0.0000
Ti	.107	0.0000
Cr	.131	0.0000
Mn	.146	0.0000
Fe	.709	60.9564
S	.362	38.9538
Ba	.282	0.0000

(ii) SPECIMEN KI 66, location : (-14320, 72820)

Mineral : pyrrhotite

Element	Detection limit	% Element
S	0.343	35.3531
Ca	.097	0.0000
Ti	.109	0.0000
Cr	.137	0.0000
Mn	.151	0.0000
Fe	.538	31.1630
Co	.294	0.0000
Ni	.237	0.0000
Cu	.819	35.1362
Zn	.406	0.0000

Mineral: sphalerite

Element	% Detection limit	% Element
S	0.229	32.2172
Ca	.070	0.0000
To	.079	0.0000
Cr	.098	0.0000
Mn	.109	0.0000
Fe	.137	0.7789
Co	.149	0.0000
Ni	.176	0.0000
Cu	.225	0.0000
Zn	.971	71.2734

A trace of cadmium was also detected in the sphalerite.

(iii) SPECIMEN KI 49 (iii), location: (-12440, 69220)

Mineral : pyrite

Element	% Detection limit	% Element
S	0.424	54.3280
Ca	.096	0.0000
Ti	.106	0.0000
Cr	.127	0.0000
Mn	.145	0.0000
Fe	.619	46.5870
Co	.325	0.7086
Ni	.219	0.0000
Cu	.276	0.0000
Zn	.387	0.0000

Note the presence of a small amount of cobalt within the pyrite.

Mineral : pyrrhotite

Element	% Detection limit	% Element
S	0.363	38.8815
Ca	.094	0.0000
Ti	.107	0.0000
Cr	.134	0.0000
Mn	.148	0.0000
Fe	.710	60.7788
Co	.354	0.0000
Ni	.227	0.0000
Cu	.286	0.0000
Zn	.400	0.0000

The presence of low-iron sphalerite was confirmed at the prospect north-west of Grøndalstjønna.The values of zinc are anomalously high however, partially due to miscalibration on the probe; the values for the other elements are within the standards.

6 CONCLUSION AND ECONOMIC POTENTIAL OF GRØNDALEN

The major component of the Grøndalsfjell intrusive complex, the dioritic phase, has been recognised as being later than both the cumulate form of mineralisation and the exhalative-type mineralisation; it does not constitute an economic target for metallic orebodies.

(a) Cumulate mineralisation

This is best developed in the gabbroic phases of the Grøndalsfjell intrusive complex and at this level of exposure mineralisation is present only in sub-economic quantities; no pentlandite or platinum phases were recognised. Since the intrusive body is overturned, the gabbro is expected to pass into diorite at depth and in conclusion, mineralisation is unlikely to occur in economic quantities beneath the surface. However there is a lot of 'depth' in which unsuspected things could happen.

(b) Exhalative mineralisation

The economically interesting areas were defined:-

1. The greenstone xenolith zone, occurring to the south of Grøndalen and above the thrust horizon. Here mineralization within the xenoliths, present in the Grøndalselva as copper-bearing pyrrhotite ore may be connected somehow to the magnetic anomaly present around the greenstone raft at (-11170, 19500) where the presence of the copper indicator Viscaria alpina has been noted.

Certainly the extension of the xenolithic belt to the west of Grøndalselva passes through the mineralised area and the brown mica diorite into this anomalous zone. Whether this represents any real, rather than apparent, connection is unknown but geophysical methods such as resistivity, electromagnetic and V.L.F. techniques may be able to ascertain this.

2. S. Foslie's (1919) prospect, first described in a publication by Oftedahl (1958) occurring below the thrust horizon to the west of Grøndalstjonna at (-14320, 72830). At the surface, zinc mineralisation as sphalerite is the dominant ore mineral but at depth this may change into a copper-rich facies. Re-trenching in order to ascertain the structure and continuation of the mineralisation zone at depth may prove valuable since low exposure hinders realistic evaluation of the prospect.

3. Exhalite showings to the south west of Lillefjellet. Due to lack of time, little work was undertaken in this area, but the single traverse did reveal haematite and magnetite-rich schists. Geophysical work may indicate sub-surface base metal horizons.

4. Mineralisation to the south east of Lillefjellet. Here within the schist are numerous small showings of exhalite type mineralisation within lavas and pyroclastics. At depth there may be a connection of these showings.

7. COMPARISON BETWEEN THE GRÖNDALSFJELL INTRUSIVE COMPLEX AND OTHER SELECTED MAFIC INTRUSIVE COMPLEXES IN THE GREENSTONE BELTS OF NORWAY

A comparision between the Grøndalsfjell igneous complex and other complexes is made on the basis of the following features:

(i) The nature of the relationship between the plutonic body and the country-rocks.

(ii) The nature of the intrusive lithologies, their intrusive form and their ore mineralisation.

(iii) The structure of the igneous complex.

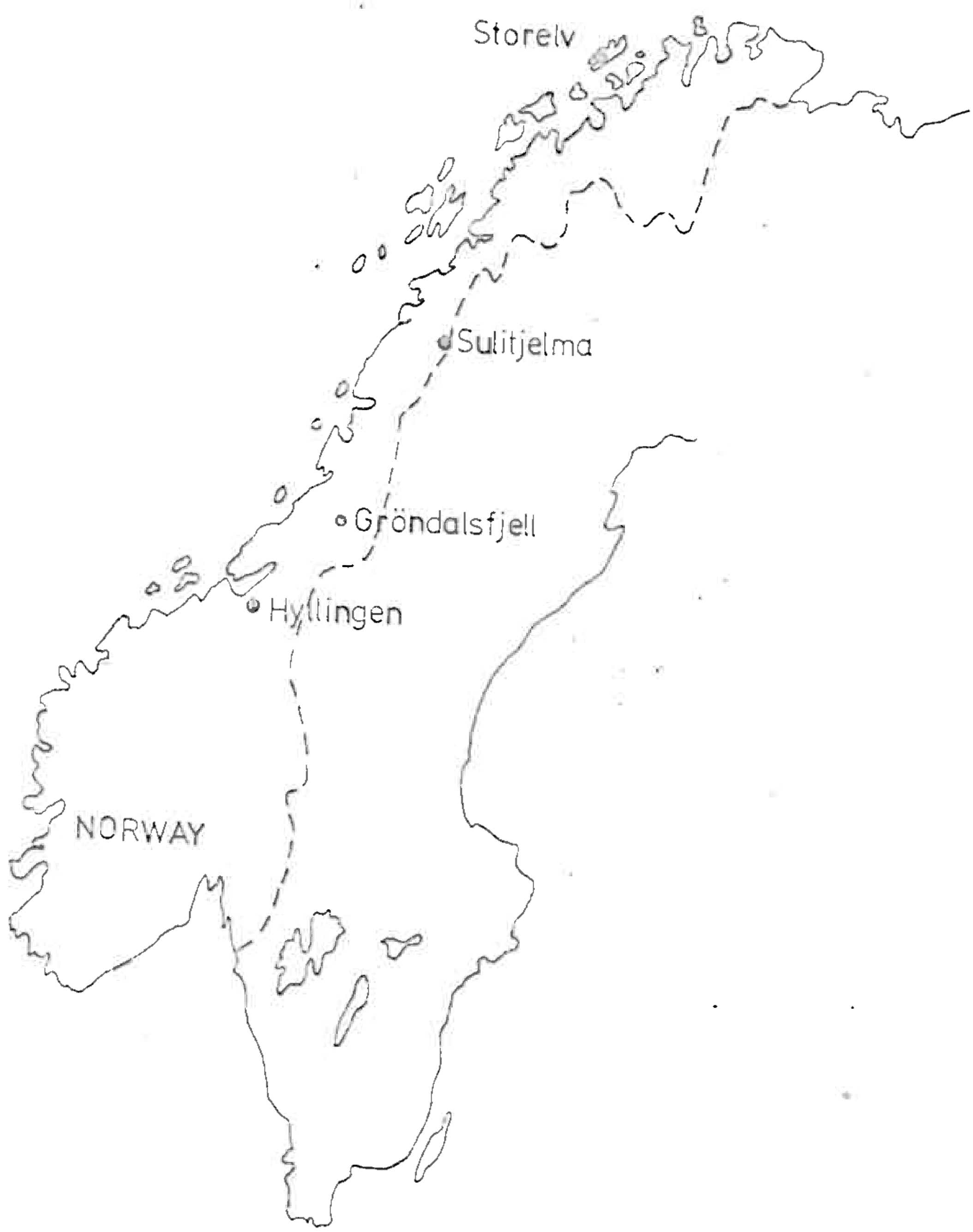


Fig. 63 Location map of gabbroic complexes referred to in text.

7. A. COMPARISON WITH THE SULITJELMA GABBRO COMPLEX

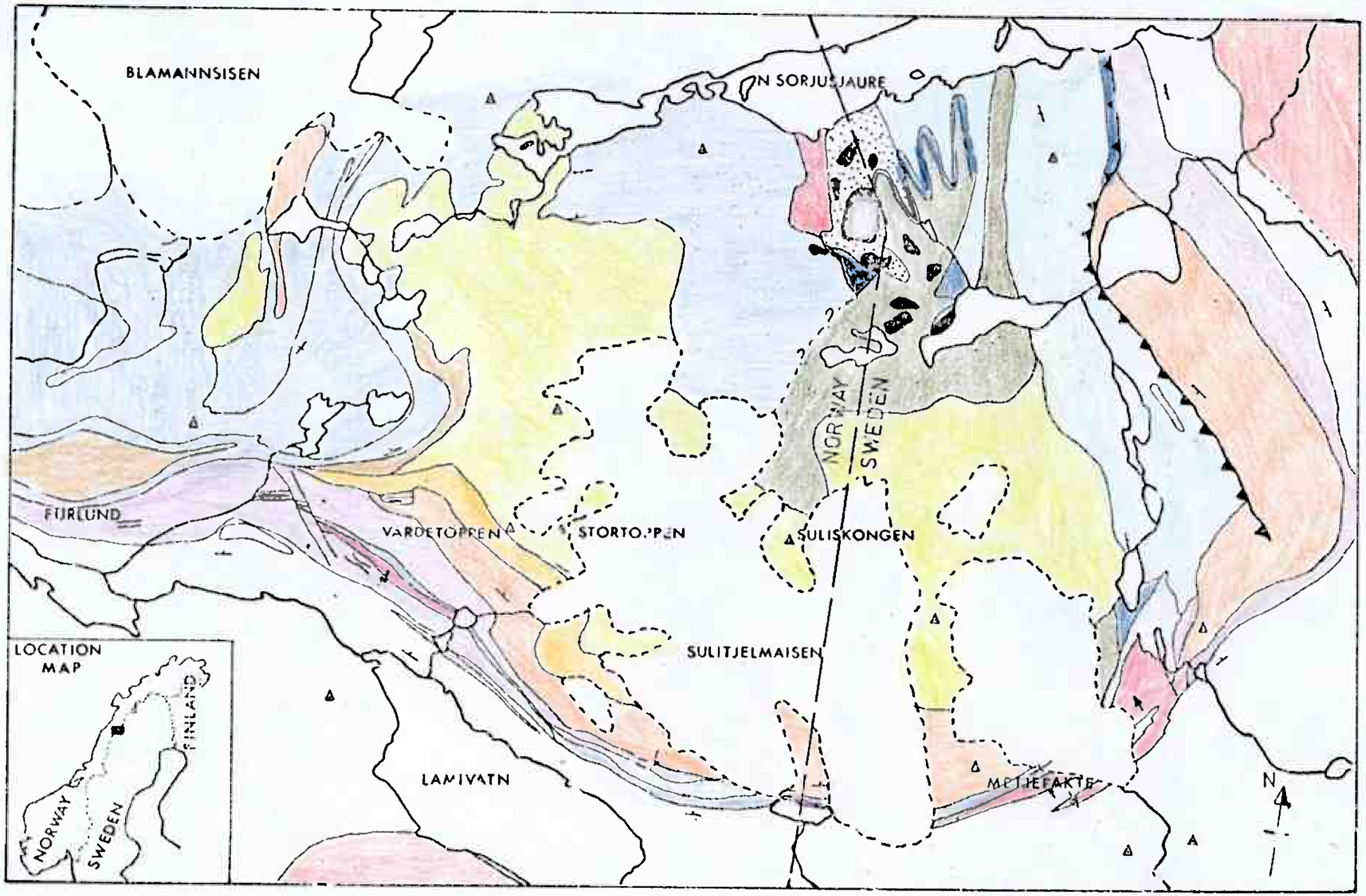
The Sulitjelma gabbro of Nordland complex forms the peaks of the Sulitjelma mountains on the Norwegian-Swedish border. The gabbro outcrops over an area of about 13 km. east-west by 10 km. north-south (Figs. 63 and 64).

7. A.(i) Relationship of the gabbro complex with the country rocks

The Sulitjelma gabbro makes sharp contacts with the country rocks which have been hornselsed over a zone about 30 m. wide. Veins of gabbro, not usually coarser than the main gabbro mass, extend into the country rocks. In addition larger apophyses of gabbro run out from the main mass for a kilometre or more. Some apophyses are sill-like bodies, cross-cutting the country rocks. Similarly screens of country-rock extend into the gabbro.

In contrast the Gróndalsfjell plutonics make far more diffuse contacts with the country rocks. This contact however has been largely obscured by the thrust horizon. Where present however, veins of dioritic material extending into the greenstones are similarly noticeably as coarsely crystalline as the main mass and thus a chilled margin facies appears absent in both areas. The conspicuous country-rock xenolith zones present in Gróndalsfjell are absent in Sulitjelma. Apophyses of diorite, extend nearly 1 km. into the country rock in the west of Grøndalen where they are cut off by the thrust horizon. Screens of country rock extend about 1 km. into the diorite and are largely hornfelsed in contrast to the relatively narrow hornfels zone at Sulitjelma.

A tectonic contact is made by the gabbro in the southwest, marked by a tectonic melange of gabbro and amphibolite ("flaser gabbro"). At


BLAMANNSISEN
N SORJUSJAURE
NORWAY
SWEDEN
FURLUND
VARDETOPPEN
SULISKONGEN
SULITJELMAISEN
LAMIVATN
LOCATION MAP
NORWAY
SWEDEN
FINLAND
N

- GRANITE GNEISS
- STADDAJAURE SCHIST
- SORJUS MARBLE
- SORJUS PHYLLITE
- PILLOW LAVA — OTERVATN VOLCANIC SERIES
- UNDIFF. VOLCANICS — OTERVATN VOLCANIC SERIES
- METJEPAKTE SILL COMPLEX.
- FURLUND GROUP
- SJONSTÅ GROUP
- FURULUND GRANITE
- SULITJELMA GABBRO
- FLASER GABBRO
- HAMMEREN ULTRAMAFICS AMPHIBOLITE/ SERPENTINITE

- LATE THRUST
- EARLY SLIDE
- GEOLOGICAL BOUNDARY
- STRIKE AND DIP
- MOUNTAIN PEAK
- GLACIER MARGIN
- DIRECTION OF YOUNGING

SCALE

0 5km

Key to fig 64

the present level of exposure, the Grøndalsfjell complex of course, makes a tectonic contact on all sides.

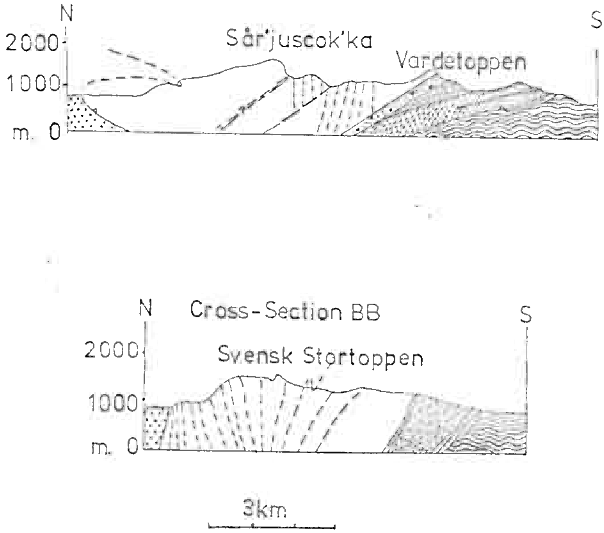
Sulitjelma displays cross-cutting relationships with the country rock and in the northeast corner of the complex there are igneous breccias composed of hornfelsed fragments of country rocks and more rarely gabbro in a leucocratic igneous matrix of varied composition,thought by Mason (1970) to be a result of partial melting of the country rock.

The sub-parallelism of acidic volcanic bands within the screen of hornfelsed greenstones to the dioriteapophyses in the Grøndalsfjell complex, may suggest a more concordant intrusion. No breccias are found in Grøndalsfjell. The discordant nature of the igneous body within country rock at Sulitjelma may suggest a slightly more foneful intrusion when compared to the intrusion of the Grøndalsfjell plutons.

(ii) Nature and form of the intrusive rocks

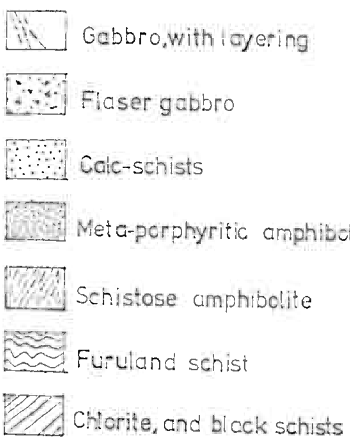
Three facies of unaltered gabbro were recognised by Mason (1970). These are massive olivine gabbro,rhythmic layered olivine gabbro and biotite-bearing ferrogabbro. Also a small body of granite, the Furulund granite occurs to the west of Sulitjelmaisen. The Furulund granite locally veins gabbro and thus is thought to be later than the gabbro although it is likely that both belong to the same episode of intrusive activity. A granite facies is not developed at Grøndalsfjell, the more acidic phase being represented by trondhjemite (relatively K deficient).

Grondalsfjell in comparison has more numerous lithologies: there are two distinct forms of olivine gabbro, layered and massive



Vertical scale=horizontal scale

Fig. 65 Cross-section through the Sulitjelma gabbro.



as well as hypersthene gabbro, norite and troctolite (recognised by Walker 1972). Various diorite facies occur as well as basic and trondhjemitic minor intrusive phases.

The layering at Sulitjelma is similar to that at Grøndalen in both mineralogy and the fact that both are steeply dipping. Fluxion phenomena recognised in the layering of both massifs and the layering in both is suspected to have been formed by gravity settling in the presence of convection currents according to the "Skaergard model". Assuming this model is correct, it is deduced that the present steep attitude of rythmic layering is due to post-cumulus displacement.

The gabbros from Sulitjelma and the Grøndalsfjell gabbros and much of the diorites are cumulates. Sub-economic deposits of pyrrhotite as a intercumulus phase are present in both areas.

7. A. (iii) Structure of the Igneous Complex

Sections showing the structure of the Sulitjelma intrusive complex are given in Fig. 65 . Mason (1970) used the attitude of the rythmic layering as evidence for deformations of the gabbro. In the zone of layered gabbro running east-west across the complex the layers dip generally steeply northwards in the southern part of the zone, vertically in the middle parts and steeply dipping in the northern part. Mason tentatively suggested that this indicates that the gabbro is folded locally into a syncline but lies on the northward dipping limb of a complex structural depression whose centre lies further north. The axial trace of the syncline runs east-west across Duoldagabjavlrek and folds both the Furulund granite and gabbro. The absence of cryptic layering, as an indicator of relative age means that the structure is only tentative.

7. B. COMPARISON WITH THE STORELV GABBRO

The Storelv Gabbro is a large sheet of dominantly gabbroic rocks that occur in Sørøy, Finmark. The complex can be traced for some 40 km. along strike and reaches a maximum thickness of 3 km. (Figs. 63 and 66). The body has been considerably deformed, with many of the variations in thickness due to tectonic extension.

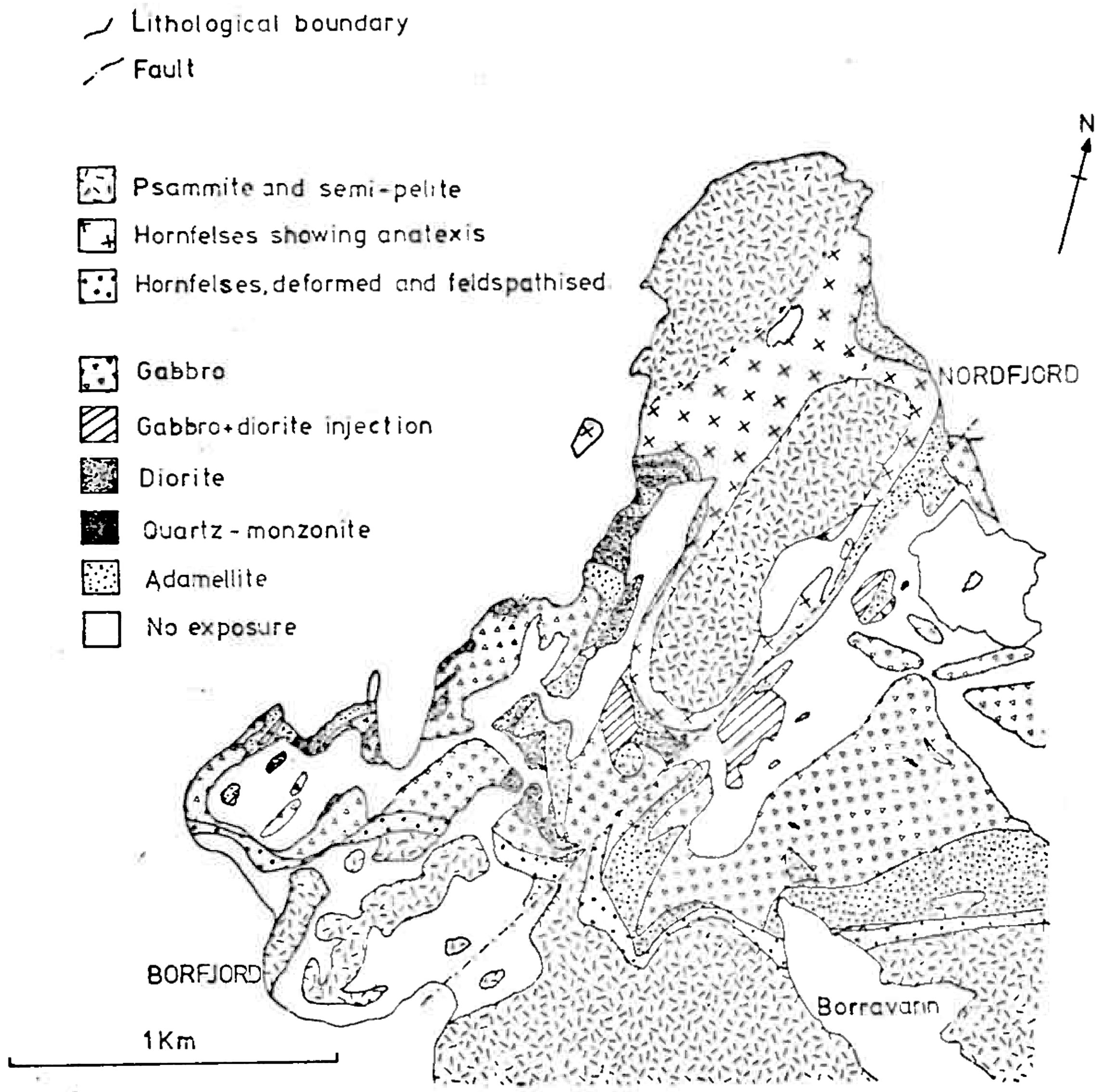
7. B. (i) Relationship of the Gabbro Complex with the Country-Rocks

The Storelv Gabbro makes fairly diffuse contacts with the country rock; extensive rafts of limestone and calc-silicate rocks are found within the gabbro. These are members of the Klubben psammite and Storelv Schist groups. In the southwest, rafts of hornfelsed graphite-schists also occur, indicating the presence of the Falkenes Marble and Aafjord Pelite Groups.

The the west of Sandofjord, a think sheet of foliated gabbro, approximately 50 m. thick, follows closely the axial plane of a major F1 recumbent syncline. This sheet of gabbro represents either an apophyse of the Storelv Gabbro or a thin sheet of the same age parallel to the main body.

Over much of its outcrop, the Storelv. gabbro appears to lack well developed contact metamorphic effects, and over large tracks the country rocks apparently persist to the contact of the gabbro, which is often highly foliated due to post-emplacement deformation. Occasionally well developed hornfels do occur at the gabbro contact, though, in contrast to Grøndalsfjell, more typically hornfelsed rocks are found as lenses within apparently normally foliated lenses. The hornfels occur along

GEOLOGICAL MAP OF THE BORFJORD AREA.



the southwestern outcrop of the Storelv Gabbro and in the northern part of the Seines peninsula in the Børfjord area where the hornfels are locally highly foliated. In thin section the rocks have a granoblastic hornfels structure with preservation of F1 fold structures. These features are absent in Grøndalsfjell where nearly all primary tectures have been obliterated and intrusion occurred before the F one folding developed.

In contrast to the Grøndalsfjell complex, partial melting resulting from anatexis is abundant. These anatectic veins vary in form and make diffuse to sharp contacts with the hornfelsed country rock.

The metasedimentary rafts within the Storelv Gabbro also contain abundantly preserved F1 minor folds with granoblastic textures superimposed upon them. Anatectic veins are also common within these rafts.

(ii) Nature and form of the intrusive rocks

The Storelv Gabbro is an intrusive complex comprising gabbro with subordinate ultramafic varieties and sheets of diorite, monzonite and adamellite. The latter two phases are absent from the Grøndalsfjell complex, with trondhjemite occurring in their place. As in the Grøndalsfjell complex however, the intrusive relationships are well preserved. Similarly, abundant metasomatic activity accompanied the later members of the igneous sequence.

At both Grøndalsfjell and Storelv, the gabbro was the earliest intrusive phase, followed by diorite (although two generations of gabbroic intrusion are possibly present in the Grøndalsfjell complex). The

Storelv gabbro and diorite both contain metasedimentary rafts, whereas only the latter contain country rock rafts at Grøndalsfjell.

The gabbro and diorite at Storelv both have identical structural and metamorphic histories which leads Sturt and Taylor (1972) to suggest that "there was probably no great time span between their successive emplacements" although they were deformed and metamorphosed prior to the emplacement of the sheets of quartz-monzonite and adamellite. At Grøndalsfjell the gabbro and diorite have similar metamorphic histories (although the gabbro is serpentinised) but neither display any obvious F1 deformation fabrics.

The gabbro at Storelv shows considerable variation, but is usually a melanogabbro with small lenses and discontinuous sheets of peridotite and troctolite, though a more leucocratic facies may be locally extensive. No layering is evident. The original igneous mineralogy and fabric are nowhere perfectly preserved in the Storelv Gabbro and this is largely true of the Grøndalsfjell complex although local areas of blue-diorite represent relatively fresh zones.

The eastern outcrop of the Storelv Gabbro is extensively deformed although zones of highly schistose material, developed late in the S1 stage, are found throughout the complex. In contrast, the Grøndalsfjell complex has only locally developed mylonitic or brecciated lithology and has nowhere developed a schistosity. Basic dykes in the Storelv Gabbro are deformed by F2; this is possibly also true of the basic dykes of the Grøndalsfjell complex.

Irregular sheets of diorite intrude the Storelv gabbro and contain angular xenoliths with marked net-vein contacts. At Grøndalsfjell

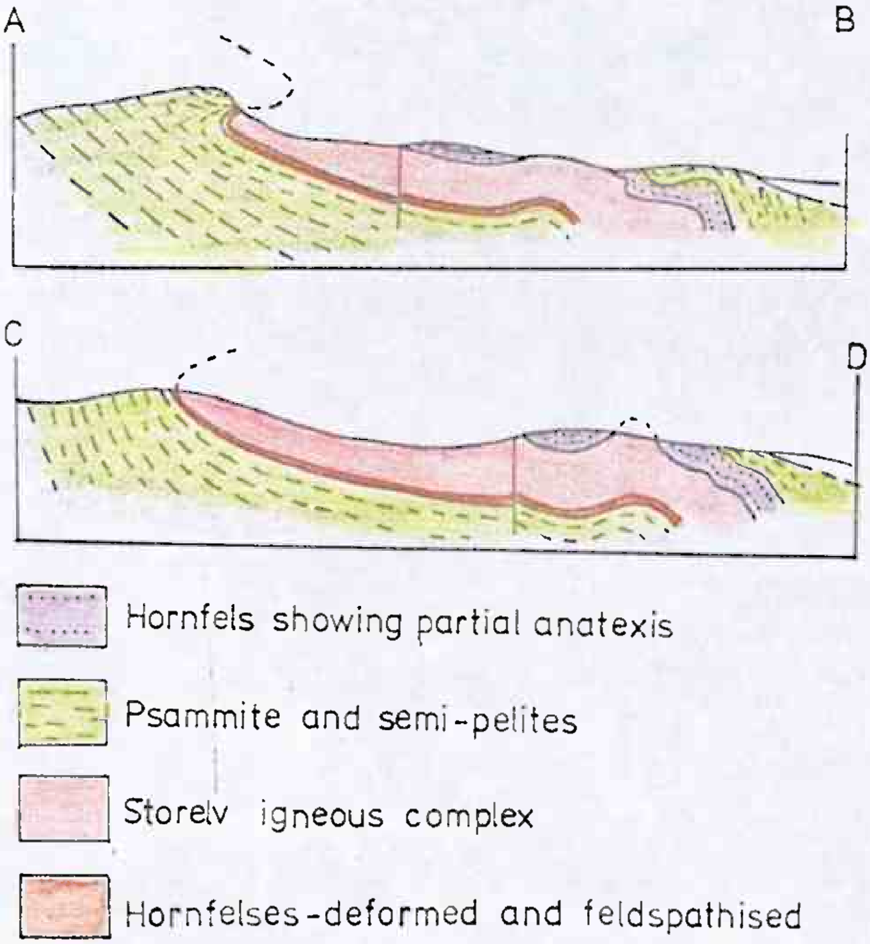


Fig. 67 Geological cross-sections of the Börfjord area
From Sturt and Taylor 1972

however one major dioritic phase (with local chemical variations) intruded the gabbros. Subsequent deuteric alteration and regional metamorphism has altered the primary mineralogy of the diorite but the igneous fabric is often largely retained. This is in contrast to the Storelv diorite where a metamorphic fabric and mineral assemblage is present.

The monzonites and adamellites, not present in the Grøndalsfjell complex form sheets containing diorite and gabbro as xenoliths.

The effect of the main second period of deformation had a much greater effect on the Storelv Gabbro than the Grøndalsfjell intrusive complex; the former suffered intense internal deformation and developed a new foliation and boundinaging of the acidic sheets occurred. The latter only deformed locally.

7. B.(iii) The Structure of the Igneous Complex

The Storelu Gabbro was emplaced into structures already produced by F1 deformation. In comparision the Grøndalsfjell complex was intruded probably pre-F1. The structure of the Storelu intrusive complex is described by Fig.67 .

7. C. COMPARISON OF THE GRÖNDALSFJELL COMPLEX WITH THE HYLLINGEN COMPLEX

The Hyllingen gabbro complex lies in the Haltdalen district in Sør-Trøndelag (Figs. 63 and 68) and forms the southern part of the Fongen gabbro massif which extends northwards from Haltdalen for about 40 km., having a width of 5 - 10 km.

(i) Relationship with the country rocks

The Hyllingen gabbro complex is intruded into Palaeozoic meta-sediments and metavolcanics which were folded and metamorphosed during the Caledonian orogeny. Hornfelsing of the country rocks (the Støren group and Gula schist group) occurred on the intrusion of the gabbro.

(ii) The intrusive relationships

The greater part of the Hyllingen gabbro complex is made up of olivine gabbros and norites; transitions between these two exist depending on the relative abundance of clinopyroxene and orthopyroxene whereas diorite forms the major igneous phase in the Grøndalsfjell complex.

Ultrabasics (olivine-serpentine-tremolite rocks) occur as small knolls adjacent to the main gabbro massif to the west of Skjelapynten and at Holtsjøhøgda (Fig. 69). These rocks may be described as pyroxenites and olivine-bearing serpentinites: they grade marginally into olivine-bearing tremolite rocks. Magnetite, ilmenite, chromite and pentlandite-bearing pyrrhotite comprise the ore mineralogy. Lateral variations amongst the more mafic constituents, to produce distinct zones, are not recognised at Grøndalsfjell. No pentlandite or

HYLLINGEN GABBRO COMPLEX.

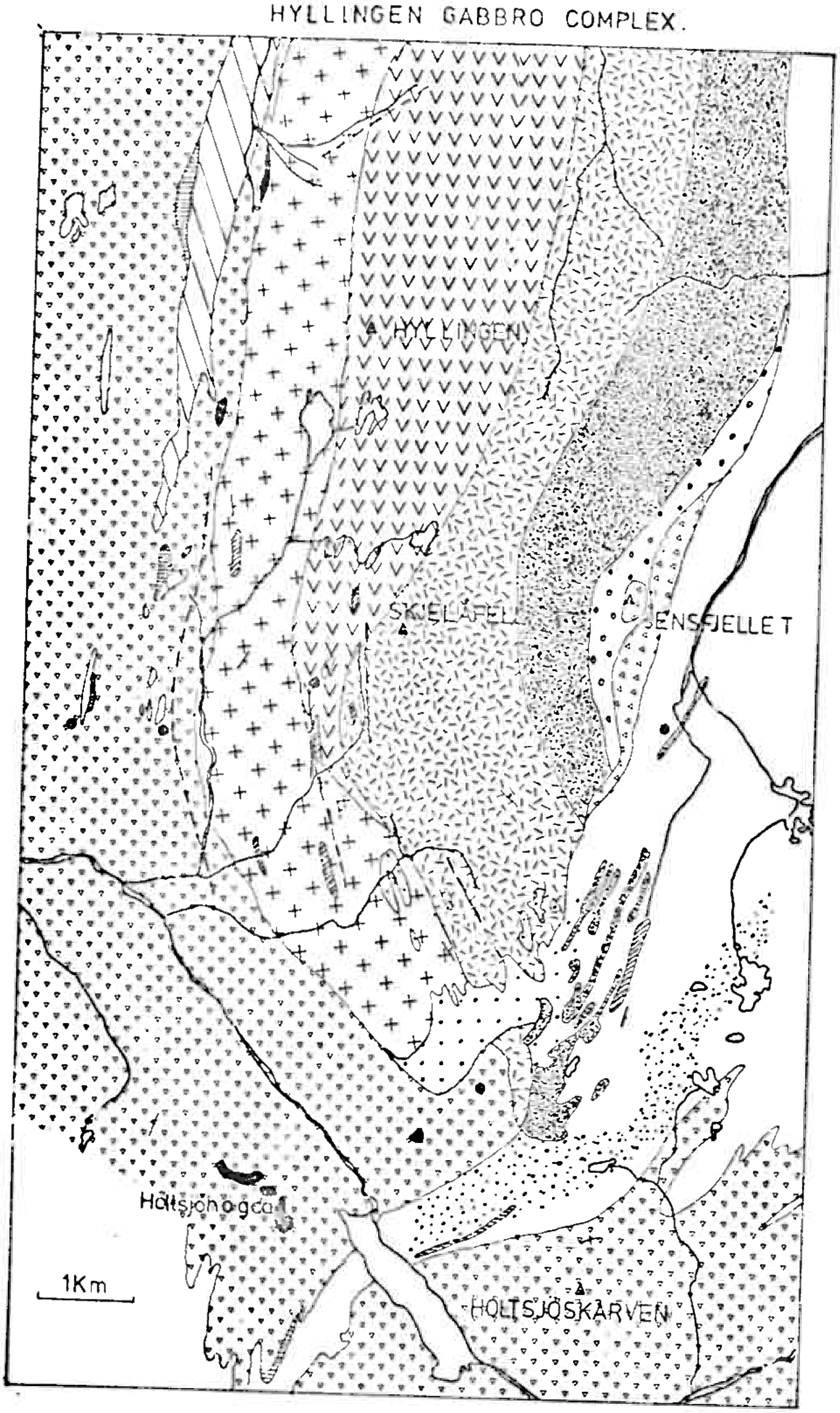


Fig. 68 Geological map of the Hyllingen gabbro complex. From Nilsen 1973. Key as Fig. 69

or chromite has been recognised at Grøndalsfjell.

The western part of the main gabbro complex at Hyllingen comprises peridotite layers alternating with more feldspathic olivine gabbros and norites. This is not present at Grøndalsfjell; many ultramafic-mafic relationships have probably been obscured by the intrusion of the diorite to produce isolated rafts of gabbroic material.

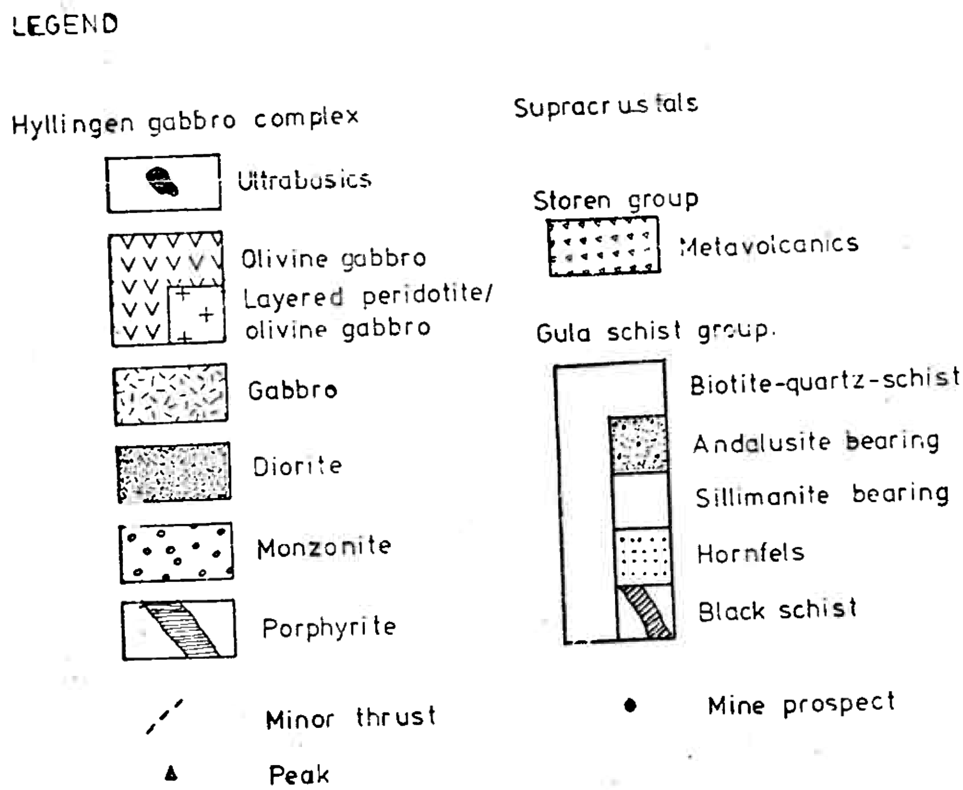
The peridotites grade into olivine-gabbros by an increase in plagioclase content. An abrupt change from peridotite to olivine-gabbros occurs in the layered sequence however. Magnetite and ilmenite are more abundant than in Grøndalsfjell and pyrrhotite is also present emphasising the intimate correlation between ore mineralisation and the more mafic components of the massif.

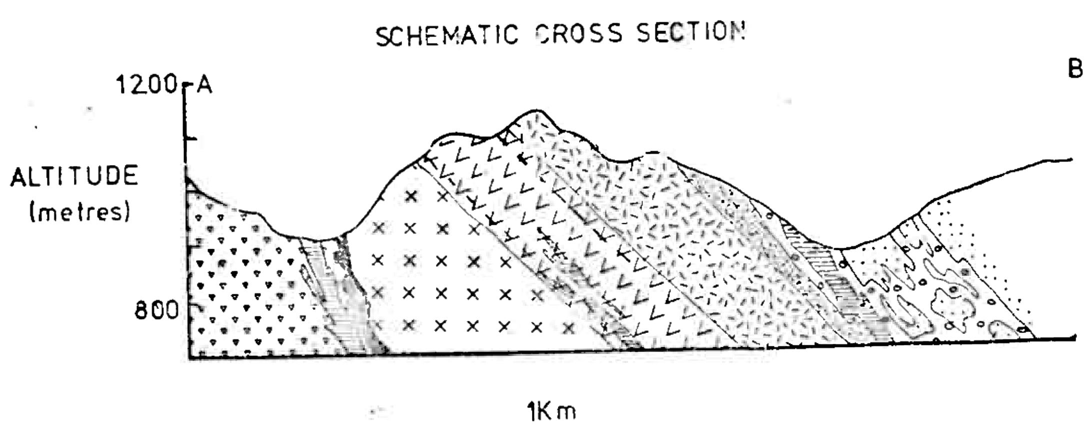
Gradational contacts of peridotites are also made with olivine-free pyroxene gabbro which itself grades eastwards into hornblende diorite; the diorite grades eastwards into monzonites. At Grøndalsfjell the dioritic phase is more abundant whilst the monzonite is absent.

Swarms of medium to fine-grained leucocratic quartz-monzonite rocks, with the same order of thickness as many of the trondhjemite dykes at Grøndalsfjell (0.5 - 2 m.), encompass the eastern border of the Hyllingen complex, intersecting the hornfels and schists as sills.

(iii) <u>Structure of the Complex</u>

The complex has a well developed foliation that appears as a sheet-like fracture system which is specially prominent among the olivine gabbros and the peridotites. The sheets are from a few cm. to several metres in thickness and these commonly have transitions


LEGEND
Hyllingen gabbro complex
Ultrabasics
Olivine gabbro
Layered peridotite/ olivine gabbro
Gabbro
Diorite
Monzonite
Porphyrite
Minor thrust
Peak
Supracrustals
Storen group
Metavolcanics
Gula schist group.
Biotite-quartz-schist
Andalusite bearing
Sillimanite bearing
Hornfels
Black schist
Mine prospect


SCHEMATIC CROSS SECTION
1200
A
B
ALTITUDE
(metres)
800
1Km

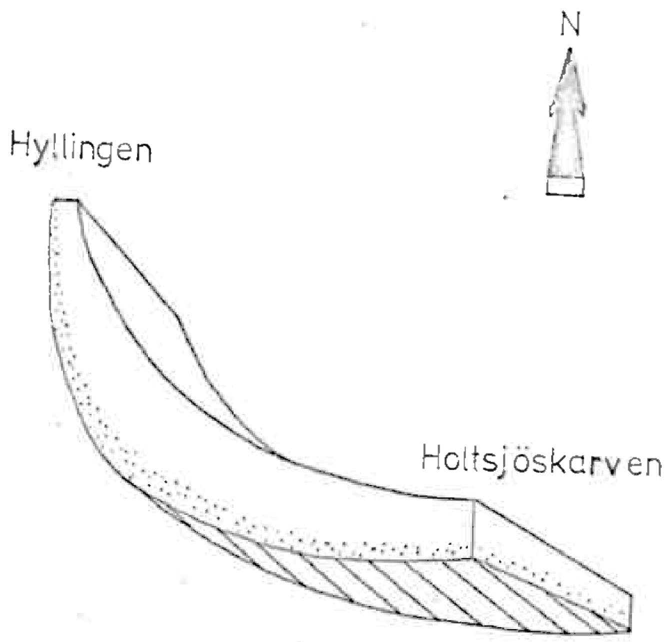


Fig.70 Schematic outline of the flexed sheet structure of the Hyllingen complex. From Nilsen (1973)

into massive rocks without any planar fabric.

The fracturing is in fact well developed foliation; the fracture pattern is thus related to the flow pattern that produced the foliation (Nilsen, 1973).

The flat-lying shear zones (Fig. 69) trend parallel to the foliation planes, these being occupied by thin horizons of flaser gabbro. In Grøndalsfjell a thin zone of flaser gabbro (0.5 m. in diameter) is recorded in a gabbro xenolith within diorite. Various pegmatites occur adjacent to the shear zones at Hyllingen. Strain is assumed to have acted parallel to foliation planes in the complex, thus producing the flaser gabbro. Pegmatite formation must have taken place before the occurrence of brittle fracture.

The layered gabbro rafts have no noticeable well developed fracture system. The trondhjemite pegmatites however are thought to have been intruded before the fracturing of the complex.

The general structure of the Hyllingen complex seems to be a flexed sheet, lying conformable with the enclosing supracrustals. A thickness of 3 km. is estimated, but a thinning of the sheet to the south is recognisable and a concave-convex form is suspected (Fig. 70).

The Hyllingen gabbro complex has petrological layering; gravity layering of both cryptic and rythmic types are present whereas only rythmic layering has been recognised in the Grøndalsfjell complex.

7.D. SUMMARY.

The Grondalsfjell igneous complex has tectonic boundaries with the underlying, older lithologies. This may obscure many primary igneous structures and make obvious comparisons with other igneous complexes difficult to draw.

However the Grondalsfjell igneous complex has a more abundant dioritic component than the other igneous complexes described. There is also an abscence of granitic rock types suggesting the Grondalsfjell complex is relatively K- deficient.

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