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THE GRÖNDALSFJELL GABBRO

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Royal School of Mines

1973

Söndre Gröndalsfjell (looking west).

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The Author would like to express his gratitude for the hospitality extended to the field party by Elkem Skorovas Gruber A/S, at whose invitation the mapping was undertaken.Thanks are also due to Mr. A. Thompson of the Geochemistry Department for his assistance in the analytical work, and to Mr. W.Diver and Mr. B. Foster for their assistance with the photomicrographs. I am above all indebted to my supervisor, Dr. C. Halls, for his invaluable help and advice, both in the field and during the follow-up work at college.

CONTENTS

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Stereograms:

All stereograms are equal-area, lower hemisphere projections.

Abbreviations:

P.P.L. : plane polarised light.

C.N. : crossed nicols.

1. INTRODUCTION

During the Summer of 1972 a party of students from Imperial College, under the supervision of Dr. C. Halls, visited the Skorovas Pyrite Mine at the invitation of Elkem Skorovas Gruber A/S. Whereas the previous year's party had concentrated on the area around the mountain of Skorovasklumpen, to the north of the mine, this party was to carry out detailed geological mapping of the area to the south and west of the mine.

1.1 Geography and Physiography

The Skorovas Pyrite Mine is situated some 30 km. from the Swedish border in the upper Namdalen Valley in Central Norway, just southwest of the lake known as Tunnsjöen, and about 260 km. north of Trondheim.

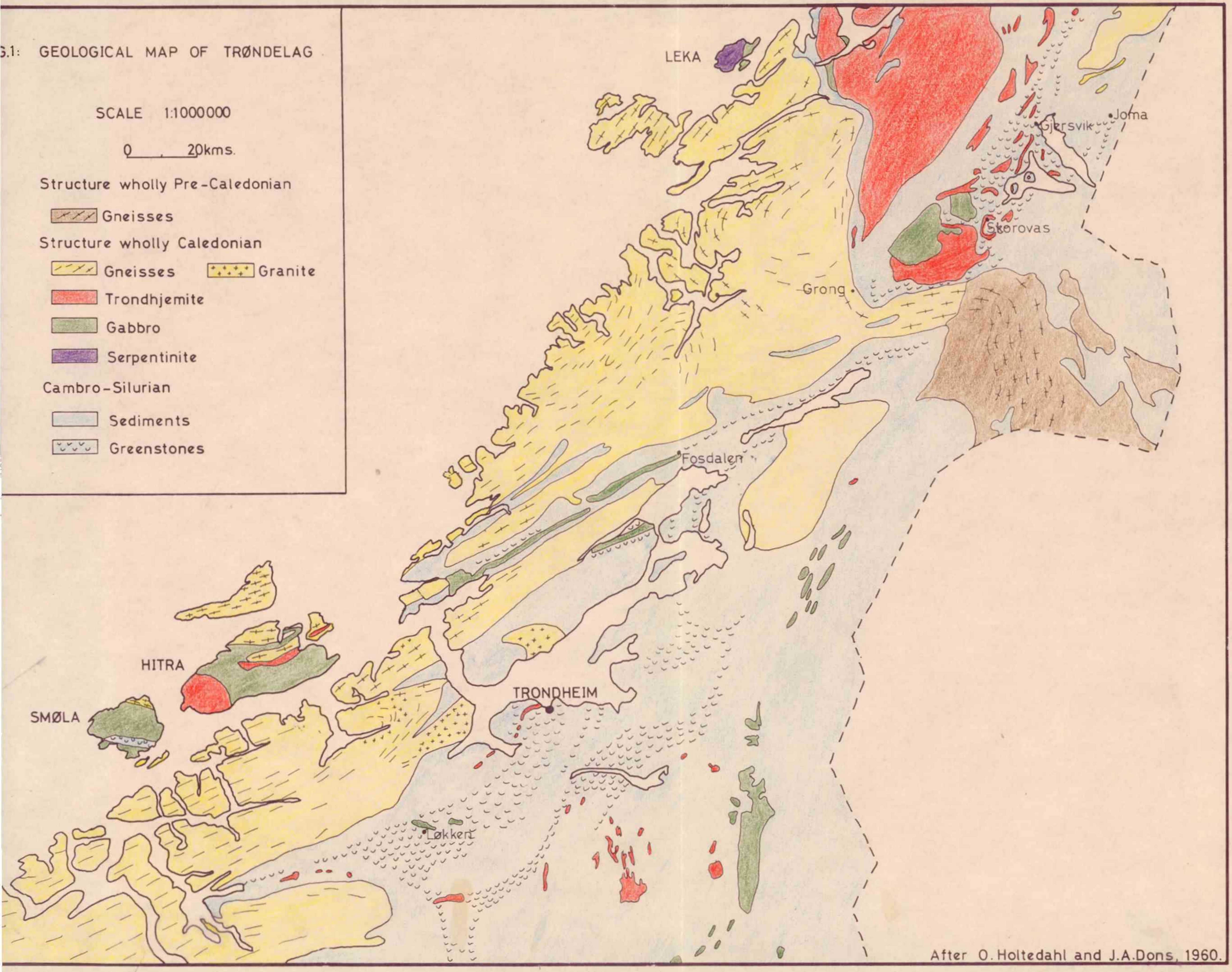
The mining village itself is situated 450 m. above sea level, in the floor of a narrow valley running approximately east-west, bounded to the north by Skorovasklumpen (900 m.), and to the south by Grubefjell (880 m.). At its western end the valley curves northward around the foot of Söndre Gröndalsfjell (950 m.), which is separated from Grubefjell by a wide pass.

Exposure is on the whole excellent. Below about 500 m. it is reduced by the presence of large areas of drift, birch scrub and moss, but above this height exposure rapidly increases until, on the top of Söndre Gröndalsfjell, it is almost total, with the relationships between different lithologies often made clearer by weathering.

1.2 The Mapping Area

The area mapped by the Author centred on the northeastern flank of a large basic intrusion, which comprises most of the mountain known as Gröndalsfjell. This area is only a small part of a large intrusive body some 8 km. across. Hence the term "Gröndalsfjell Gabbro" will refer only to that portion of the Gabbro actually mapped, and lying within the marginal fault.

The intrusive history of this body is complex, and its understanding is rendered all the more difficult by deformation and tectonic dislocation upon which are superimposed the effects of low-grade regional metamorphism.


G.1: GEOLOGICAL MAP OF TRØNDELAG
SCALE 1:1000000
0 20kms.
Structure wholly Pre-Caledonian
Gneisses
Structure wholly Caledonian
Gneisses
Granite
Trondhjemite
Gabbro
Serpentinite
Cambro-Silurian
Sediments
Greenstones
LEKA
Joma
Gjersvik
Skorovas
Grong
Fosdalen
HITRA
SMØLA
TRONDHEIM
Løkken
After O. Holtedahl and J.A. Dons, 1960.

2. REGIONAL GEOLOGY

The Lower Palaeozoic rocks of the Trondheim Synclinorium terminate against an arcuate ridge of Pre-Cambrian granitic gneisses known as the "Grong Culmination". This feature runs from west to east and then southeast across the trend of the main Caledonian fold belt, and separates the main outcrop of Cambro-Silurian rocks into two parts (Figs. 1 and 2). To the south the rocks form a pair of narrow synclines known as the Snåsa and Verdal Synclines. These two structures are separated initially by the Tømmerås Anticline, but merge southwestwards to form the Trondheim Synclinorium (Fig. 2). To the north the rocks continue as a series of thrust nappes. The area was first mapped by Steinar Foslie in the years 1922 to 1943. As a result of Foslie's work, Oftedahl (1956) divided the area into two principal tectonic units: the Olden Nappe, outcropping in the centre of the Grong Culmination, and the overlying Seve Nappe.

2.1 The Olden Nappe

The Olden Nappe consists of Pre-Cambrian gneissic rocks overlain by small remnants of a Cambro-Silurian series. Over this series are thrust the rocks of the Seve Nappe.

2.2 The Seve Nappe

The Seve Nappe comprises both fine and coarse-grained granitic rocks overlain both in the northeast and the south-west by a series of Cambro-Silurian metamorphosed volcanic and sedimentary rocks. The southwestern series form the Snåsa

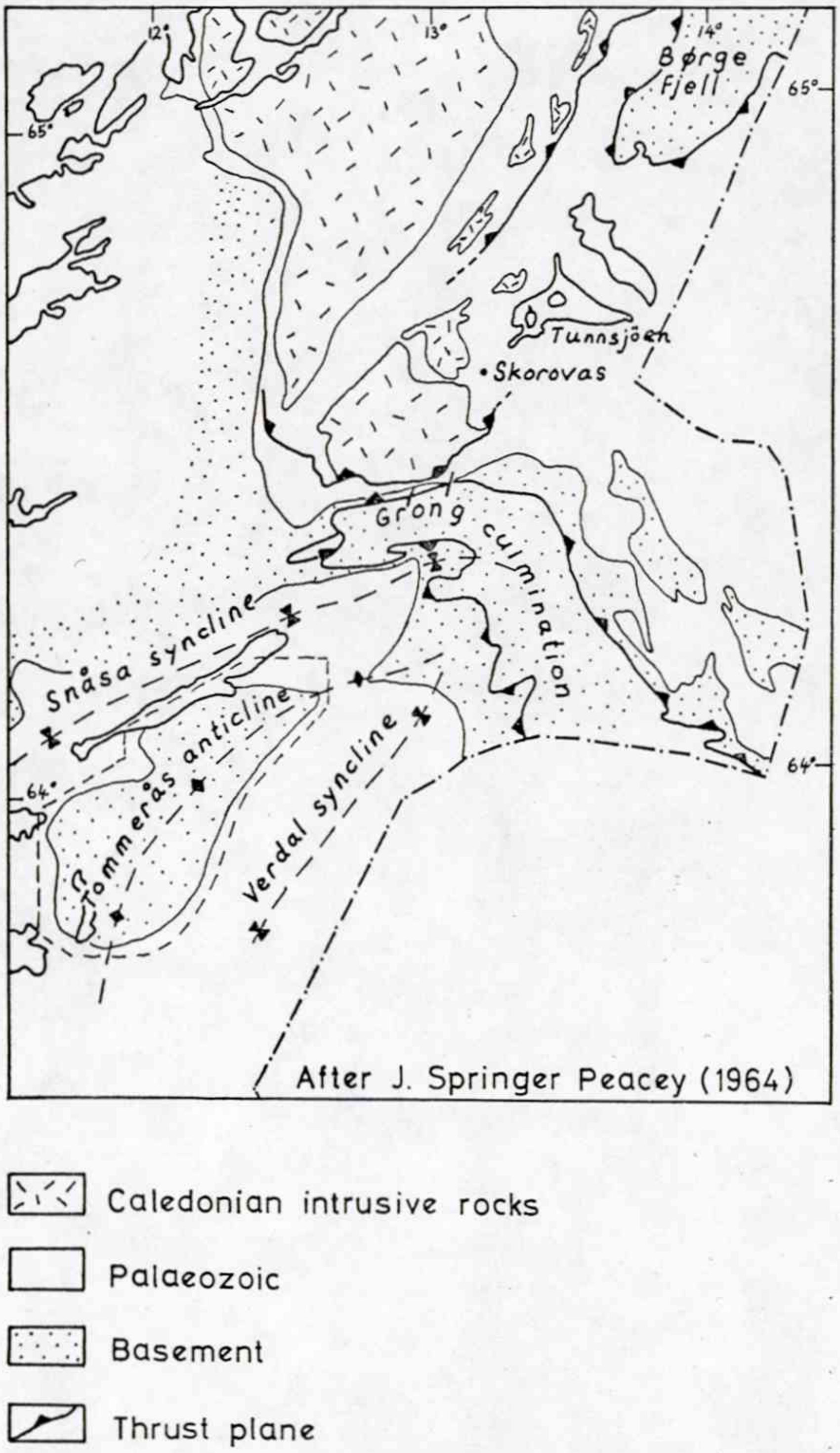


Fig.2 Simplified geological map of the Grong region.

and Verdal Synclines mentioned above. Northeast of the Grong Culmination the Seve Nappe has been divided into two parts: the Western Nappe and the Eastern Nappes.

2.2.1 The Western Nappe

The Western Nappe was first discovered to the north of the Grong region by Strand (1953). It consists of a series of high-grade metamorphic rocks developed over more than 100 km.. The southerly continuation of this Nappe is uncertain due to the boundary having been obliterated by metamorphism.

2.2.2 The Eastern Nappes

The Eastern Nappes consist of several units of low-grade metamorphic rocks (greenschist facies). The best-defined unit is the Gjersvik Nappe, which consists of greenschists intruded by gabbroic and granitic bodies. The Gröndalsfjell Gabbro with its envelope of metavolcanic rocks forms a major part of the lithologies comprising the Gjersvik Nappe in the Skorovas Region. There is also a further group of gabbroic and granitic rocks which may either be part of the Gjersvik Nappe or the Western Nappe. On the eastern flank of the Gjersvik Nappe a series of supracrustal rocks occurs which seems to represent at least two local nappes.

2.3 Stratigraphy

Foslie mapped the rocks at Skorovas as lying within the Støren Group (Lower Ordovician). Definite stratigraphical correlation is rendered difficult, however, by the lack of fossil evidence, the scarcity of reliable marker horizons, the structural complexity of the area, and metamorphism.

2.4 Tectonic History of the Area

According to Oftedahl (1956), at least two major tectonic phases may be distinguished: the thrusting of the nappes probably occured during the first phase, whilst the second phase consisted of folding, thrusting, metasomatism and doming of the anticlinal areas. The relative chronology of these tectonic, metamorphic and metasomatic events is, however, open to discussion (Gale and Roberts 1972), and must be critically evaluated in the light of revised tectonic concepts and detailed work on a local scale.

3. LOCAL GEOLOGY

The Gröndalsfjell Gabbro is bounded to the northeast by a thick sequence of greenstones, which was mapped by the 1971 party as belonging to the "Upper Unit". To the east, the Gabbro is bounded by an area of trondhjemite (for definition see 3.5), meta-gabbro, talc schists and greenstones. This area has been broadly termed the "Intrusive Zone" and is discussed in greater detail by R. Horsley (Field Report 1972, in preparation). Only a brief description of the lithologies is given here.

3.1 Upper Unit Greenstones

The Upper Unit Greenstones consist of a series of basic meta-volcanics, and are characterised by their more massive appearence compared to the other more schistose rocks in the area (Hirsinger 1971).

Several types of rock occur, the most common being a fairly massive, fine-grained greenstone containing abundant knots, veins and lenses of epidote. The lenses may be up to 60 cm. in length and up to 10 cm. thick; they have frequently been stretched and boudined to a marked degree and are consequently traversed by small fractures (Fig 3).

Short, discontinuous feldspathic bands also occur. These may be primary igneous concentrations of phenocrysts, or they may be porphyroblasts produced by metamorphism. Since the area has undergone at least two major periods of deformation, the Author favours the latter view, particularly since the abundance of epidote indicates that extensive mass transfer has taken place.

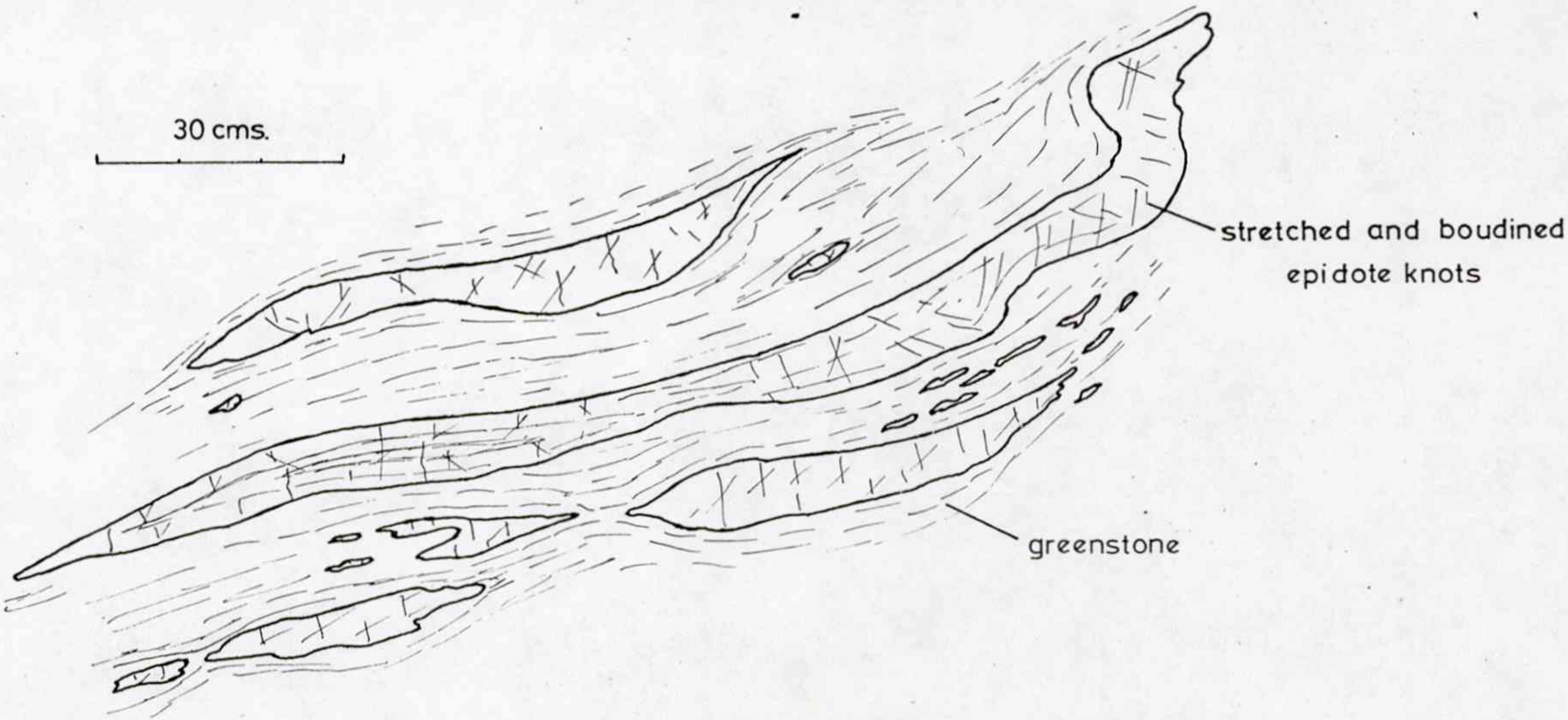


Fig.3 Epidote knots in amphibolitic Upper Unit Greenstones.

Well-defined amygdales, up to 0.2 cm. across, are common in these rocks, and occur in bands up to a metre or so thick. They are frequently infilled by radial growths of quartz, epidote or calcite, which has often been either partly or wholly removed by weathering.

The rocks are often heavily charged with pyrite, which occurs as small cubes in pyritic bands up to a centimetre across.

3.2 Greenstones of the Intrusive Zone

The greenstones of the Intrusive Zone consist of a thick series of basic lavas with small amounts of keratophyric material (mapped as felsite) occuring as separate intercalated flows, or as minor intrusions . The rocks may either be massive, or else display an S1 schistosity (see 7.1). Agglomeratic bands are also occasionally present. The lavas may be porphyritic, with plagioclase phenocrysts, or amygdaloidal, with the amygdales infilled by quartz or calcite, or, more rarely, chlorite or epidote. These amygdales may be slightly deformed in some areas.

Mineralogically, these greenstones consist of fine-grained quartz, chlorite, albite and epidote, with occasional plagioclase phenocrysts. Unlike the feldspars in the Upper Unit Greenstones, which have the porphyroblastic appearence described above, the feldspars in the greenstones of the Intrusive Zone may be zoned, ranging from An.11% in the cores to An.32% on the rims.

3.3 Meta-Gabbro

The meta-gabbro is a dark green, medium to coarse-grained rock consisting of epidote and plagioclase in a matrix of chlorite and amphibole. An S1 schistosity is sometimes present. No original mineralogy remains: the typical meta-gabbro consists, in order of decreasing abundance, of epidote, chlorite, quartz and iron oxide; leucoxene is occasionally present as an alteration product of ilmenite. The quartz is present in varying amounts, and has been produced either by metamorphism, or where it is spacially related to the trondhjemite, by introduction. The most distinctive feature of the meta-gabbro is the net-veining by acid material. Pegmatitic patches are common in the meta-gabbro to the north of the Dausjöen. Elongate patches of amphibolite, usually net-veined, are sometimes present in the meta-gabbro.

3.4 Talc Schists

Where shearing of the meta-gabbro has taken place, long linear features, containing small amounts of talc schist, may occur. These features may be up to several hundreds of metres long. The attitude of the talc schist bands varies from a steep northerly dip to almost horizontal.

3.5 Trondhjemite

The word "trondhjemite" is used here according to the definition given by Goldschmidt (1916), i.e. a granodiorite in which alkali-feldspar is completely, or almost completely, suppressed.

The trondhjemite is a whitish, schistose rock consisting of roughly equal amounts of felsic and mafic minerals. Although usually coarse-grained, a fine-grained, highly crushed variety also occurs. Microscopic examination of the quartz indicates that this rock has been heavily internally deformed. The outstanding textural feature of the rock is a planar flattening of these quartzes, probably due to F1 folding (see 7.1). The outstanding mineralogical feature is the high degree of alteration suffered by the feldspar; this consists of albite showing various stages of breakdown to clinozoisite, sericite, calcite and epidote. Calcite also occurs as small grains within recrystallised quartz, and as small veinlets. Fine-grained chlorite also occurs, and appears to pseudomorph primary amphibole. The trondhjemite frequently contains xenoliths of meta-gabbro.

4. THE GRÖNDALSFJELL GABBRO

All the evidence suggests that the intrusion of layered gabbro was the earliest plutonic event in the evolution of the Gröndalsfjell Gabbro-Diorite complex. Essentially, this complex consists of large, xenolith-like bodies of layered gabbro in a later dioritic matrix. Intrusive across these two principal phases are a set of basic "black dykes" and a set of trondhjemite dykes (Fig.4). A likely chronology of intrusive events in the Gabbro is as follows:

a) intrusion of the layered gabbro,

b) production of the diorite matrix by alteration of the gabbro and/or intrusion,

c) intrusion of the black dykes,

d) intrusion of the trondhjemite dykes.

4.1 Layered Gabbro

The layered gabbro is a coarse-grained rock occuring as distinct bodies up to 50 m. across. Weathering produces a dark brown rock with a very rough, pitted surface, the olivines having weathered out from in between the more resistant feldspars. The rock exhibits a well-developed rhythmic layering resulting from a variation in the proportion of feldspars to ferromagnesian minerals. Individual layered units may be up to several metres thick, but are usually not more than 30 cm. thick (Fig.5). Flowage or "fluxion" phenomema are common, and vary in size from a few centimetres to features more than a metre across (Figs.6 and 6a). These may possibly represent

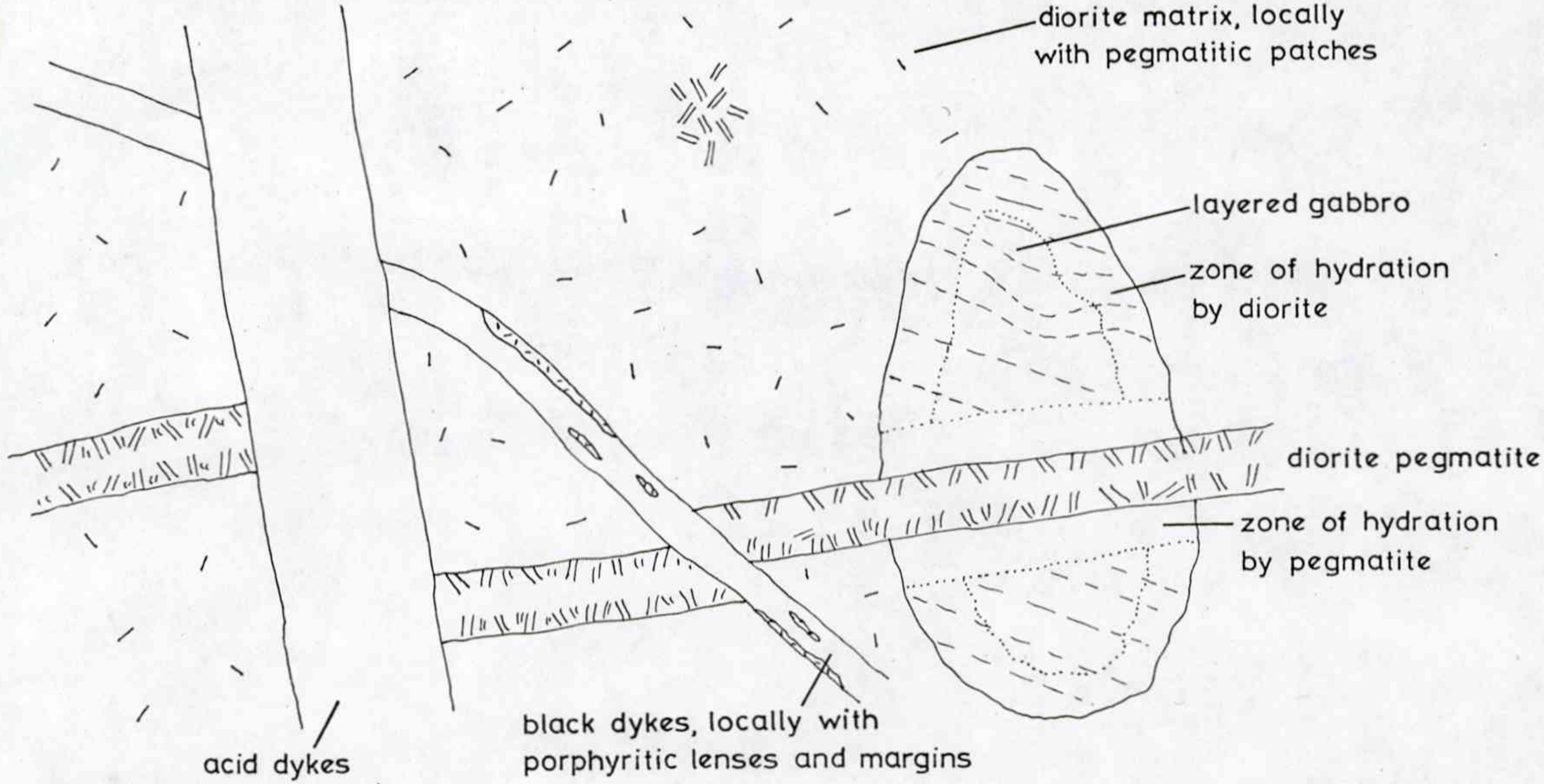


Fig.4 The Principal Phases of the Gabbro.

Fig.4a: Layered gabbro (G) in the diorite matrix (D) around (71,400; 8,550).

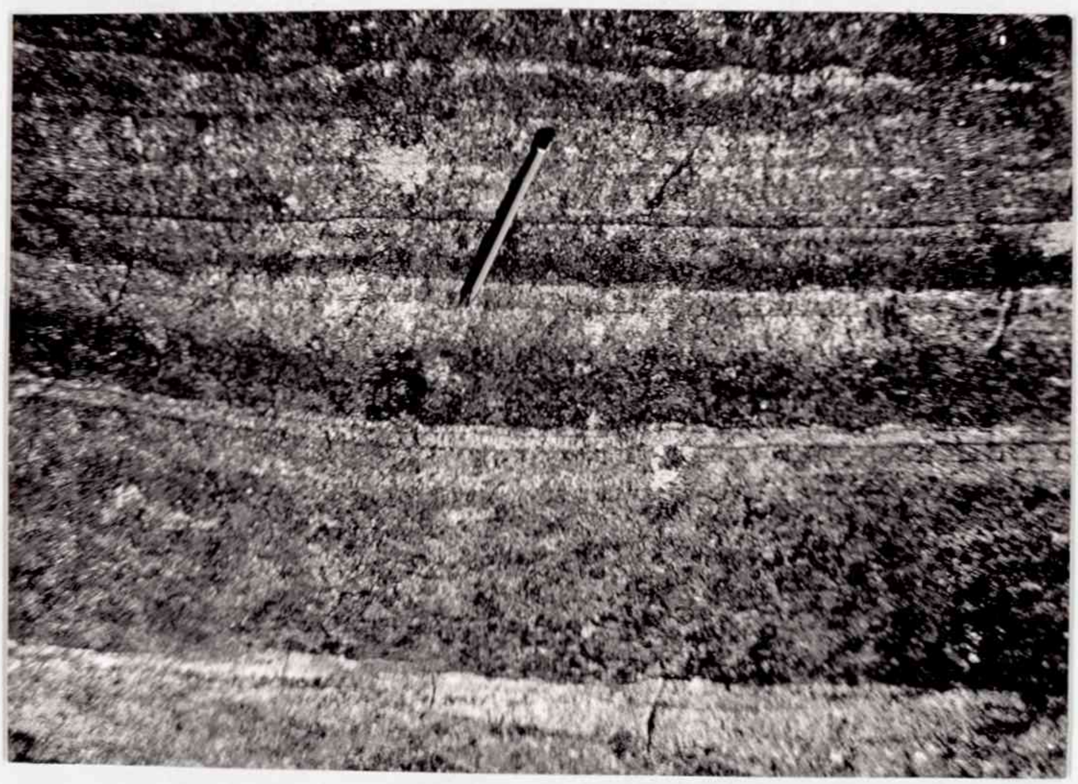
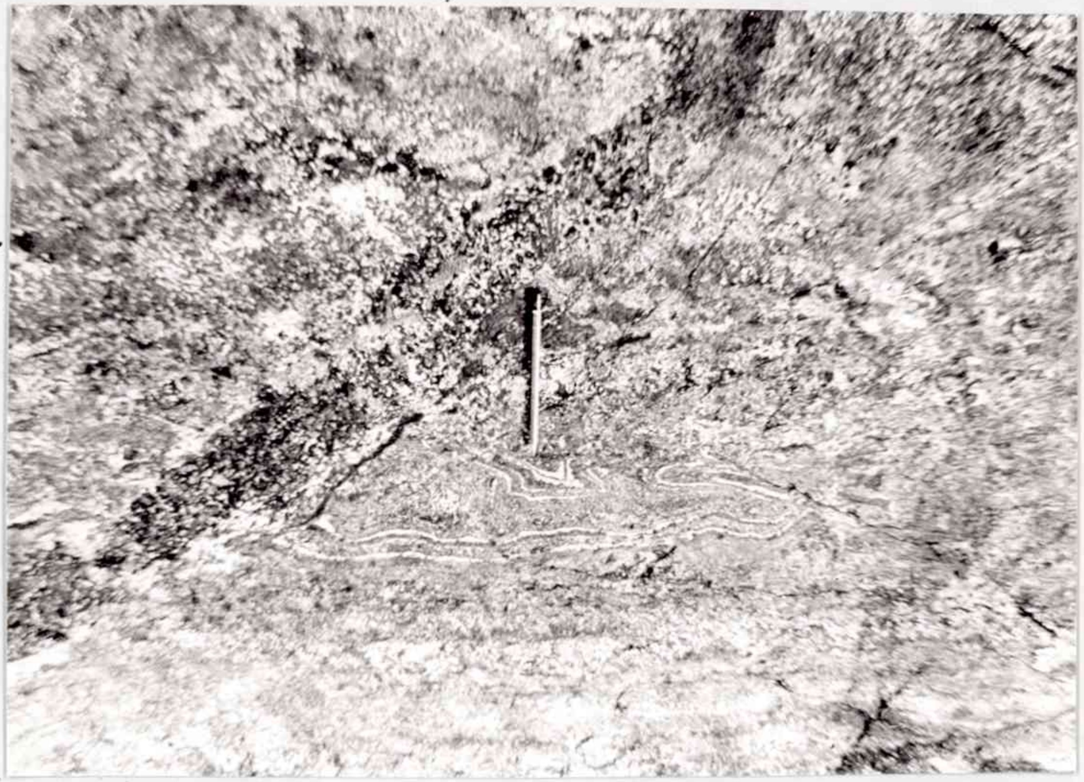
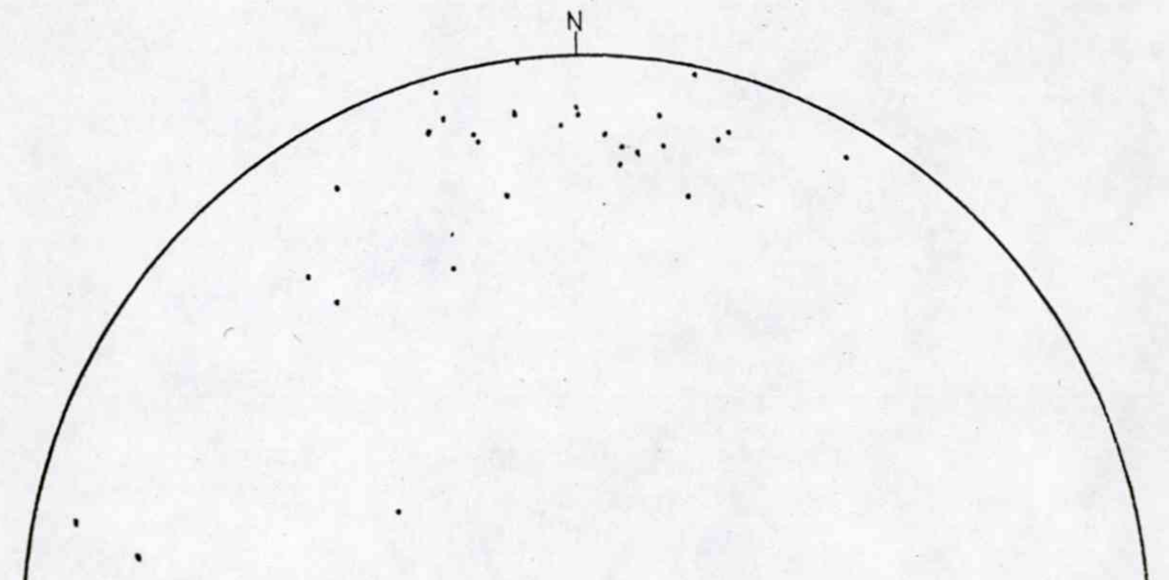


Fig.5: Rhythmic layering in the layered gabbro at (71,540; 9,175).



Figs.6 and 6a: Fluxion phenomena in layered gabbro at (71,400; 8,550) and (71,540; 9,175) respectively. 6a shows a pegmatite vein.



POLES TO LAYERING
30 POINTS PLOTTED

Fig.7

slump structures (Wadsworth 1973). The attitude of the layering is always either vertical or sub-vertical, indicating a post-cumulus displacement (Fig.7), as suggested by Mason (1971) in the case of the Sulitjelma Gabbro in Northern Norway.

The gabbro varies in composition from a troctolite, through a troctolitic gabbro, to a hypersthene gabbro. Each of these principal lithologies is described below, though there is a gradational change between each one. The plagioclase in the thin sections examined was bytownite, varying from An.79% to An.83%. A list of thin sections and their corresponding grid references is given in Appendix 2.

4.1.1 Troctolite

The troctolite consists almost entirely of olivine and plagioclase. The olivine occurs as anhedral grains and has been partly serpentinised. The serpentine occurs as "veins" along cracks in the olivines, with separation of magnetite at the centres of the veins. Expansion resulting from compositional changes during serpentinisation has caused extensive shattering of the surrounding intercumulus plagioclase, with fractures radiating outwards from the olivine nuclei. Many of the olivines are rimmed by magnetite and one or more generations of orthopyroxene, with an outer rim of hornblende-spinel simplectite resulting from reaction between olivine and plagioclase during crystallisation (Fig.8).

4.1.2 Troctolitic Gabbro

The olivines in the troctolitic gabbro are much more serpentinised than those in the troctolite. The serpentine

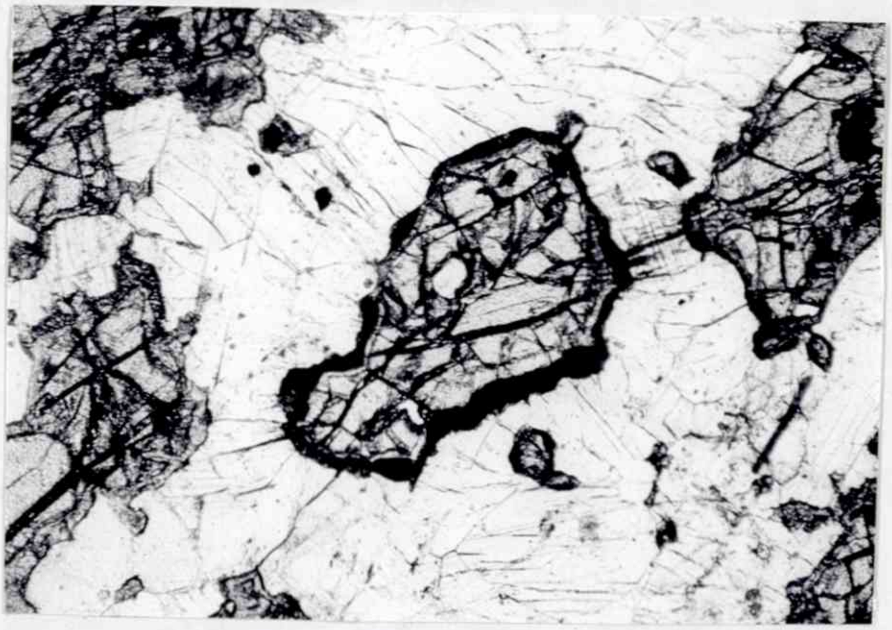


Fig.8: Olivine in troctolite rimmed by orthopyroxene and hornblende-spinel (dark). X 2.5, P.P.L.

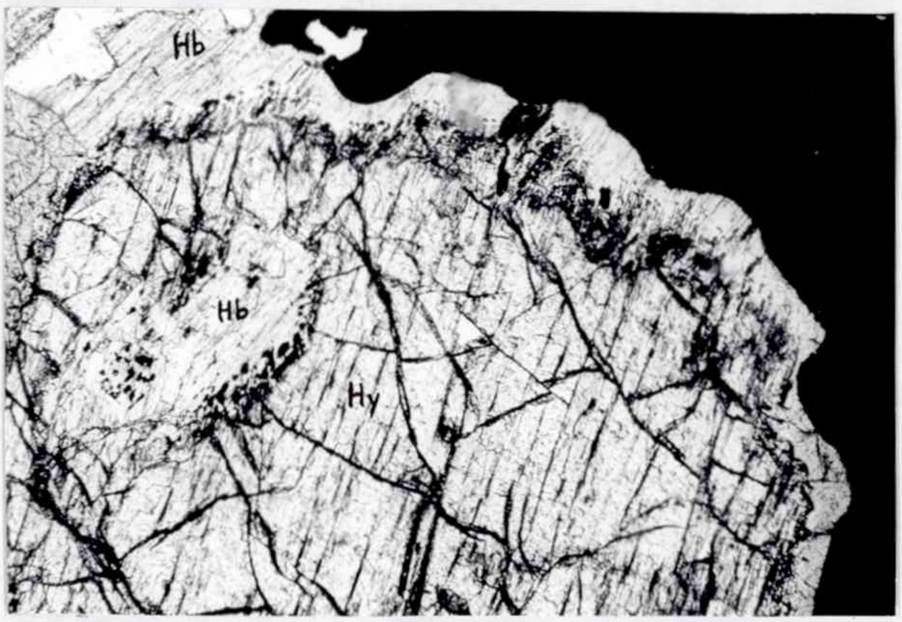


Fig.9: Hypersthene (Hy) with inclusion and rim of hornblende (Hb); iron oxide grows outwards from the hypersthene into the hornblende as well as forming interstitial areas (top right). X 6.3, P.P.L..

veins are wider and more numerous, with much more separation of magnetite; there is also much more of the latter around the grain boundaries of the olivines. The reaction rims of orthopyroxene and hornblende-spinel are also wider. Small remnants of olivine grains and their reaction rims are present within some of the larger plagioclases. Orthopyroxene (hypersthene) and clinopyroxene (augite) are present in increased amounts as large subhedral crystals and begin to enclose plagioclase in subophitic intergrowth. Augite is the more abundant pyroxene and frequently rims the olivines instead of hypersthene.

4.1.3 Hypersthene Gabbro

The hypersthene gabbro consists of subhedral augite, hypersthene and secondary hornblende in a matrix of plagioclase. The augite is often twinned and occasionally schillerised. It may also contain Stillwater-type exsolution lamellae of hypersthene.

Hypersthene may enclose a little plagioclase in ophitic intergrowth. Many of the crystals have rims and inclusions of hornblende, with iron oxide growing outwards from the hypersthene into the hornblende (Fig.9). In places hypersthene also contains what appear to be exsolution "blebs" of iron oxide. The latter may also occur as interstitial grains, but is more often present as small grains associated with hornblende, which occurs as an alteration product of pyroxene.

A few of the larger plagioclases exhibit a vague zoning.

4.1.4 Fine-grained Gabbro

A few of the larger bodies of layered gabbro contain patches of a distinctive dark, finer-grained rock which weathers to an ochreous yellow or rusty brown colour; this was observed at (72,480; 9,600), (72,320; 9,650), (72,150; 9,900) and (72,500; 9,980). This colour is due to a relatively high content of oxide and sulphide minerals (see section 5).

The rock consists of a few large, heavily altered olivines in a matrix of plagioclase, altered pyroxene and opaque minerals. The olivines have suffered extensive serpentinisation, with the separation of a large amount of magnetite. Wide rims of the latter, orthopyroxene and hornblende-spinel symplectite also occur. A few small plagioclases near olivine grains are also surrounded by such rims, and probably represent completely altered olivines. As with the troctolitic gabbro, serpentinisation has caused extensive shattering of the surrounding plagioclase.

Plagioclase occurs as small anhedral grains, with a few large subhedral crystals, some of which show a vague zoning.

The orthopyroxene is hypersthene, and is extensively altered to hornblende; it is mainly present as small subhedral crystals in the matrix. A few large crystals do occur, however, and these are surrounded by large areas of hornblende; some of these crystals enclose laths of plagioclase.

Magnetite occurs principally as veins growing outwards from the serpentinised olivines to become large areas enclosed by hypersthene or hornblende. The interstitial opaque mineral (probably titaniferrous magnetite or ilmenite) is extensively altered to sphene.

4.1.5 Alteration of the Gabbro

The layered gabbro may be altered in several ways: by the diorite matrix, by pegmatites, by black dykes and by trondhjemite dykes. The alteration products differ in chemistry and in the degree of hydration suffered by the gabbro.

Where the layered gabbro is in contact with the diorite a zone of hydration is produced which is commonly more than a metre across in the larger bodies. The rock is often hydrated in a spheroidal manner (Fig.10). The contact is fairly sharp between gabbro and diorite, but gradational between altered and unaltered gabbro. The texture of the latter is perfectly preserved in the hydrated phase: the rock still retains its rough, weathered surface but instead of the original dark brown colour is altered to a dark green. A relict cumulate texture can be seen in thin section, and the layering and fluxion phenomena continue undisturbed between the unaltered and hydrated phases (Fig.11). All this suggests that alteration and metasomatism of the gabbro in situ has taken place. This could have occured before, during or after the tilting of the primary layering of the early gabbro magma chamber.

The gabbro has also suffered hydration in the vicinity of pegmatite veins (Fig.12). Around the smaller veins the zone of hydration is thin, and consists mostly of light green flakey amphibole; at (71,400; 8,550), for example, around a pegmatite 15 cm. wide, the zone of hydration was about 5 cm. wide. Around larger pegmatites or pegmatitic zones the zone of hydration may be up to a metre or so across, and here the hydration is similar to that produced by the diorite matrix. The hydrated olivine-bearing gabbro around the wider pegmatitic zones has a reddish-

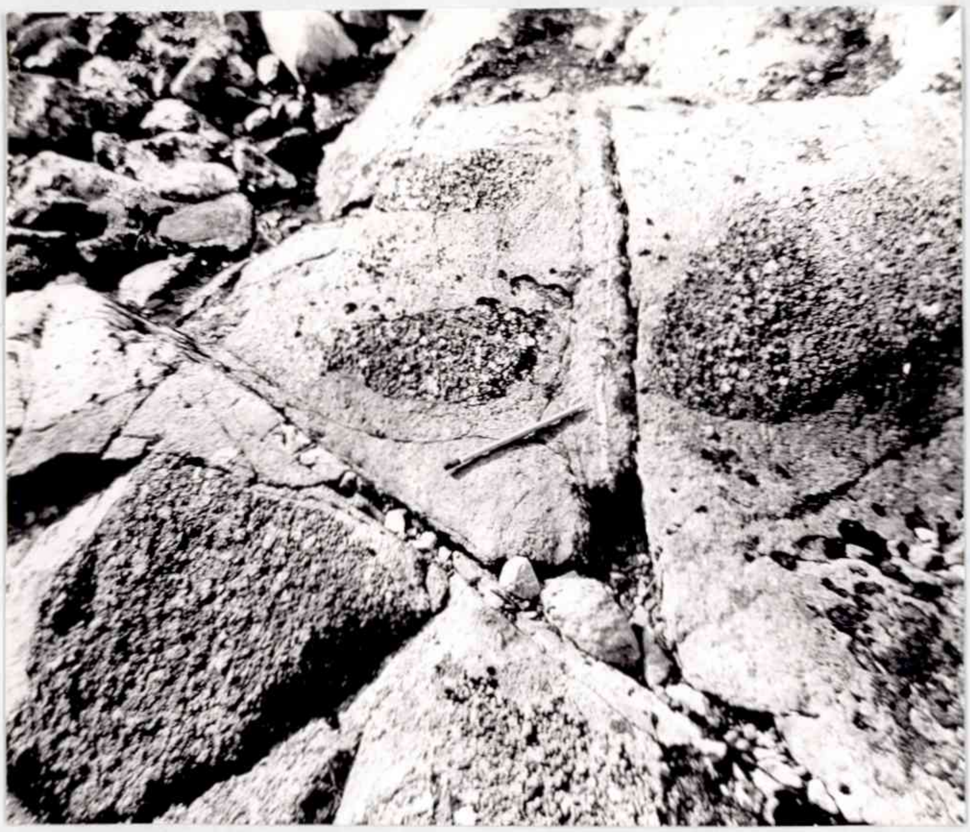


Fig. 10: Spheroidal hydration of layered gabbro at (71,430; 8,670).

Fig. 11: In-situ metasomatism of layered gabbro (G) to give hydrated gabbro (H) at (71,220; 9,350); the lines of fluxion continue undisturbed between the two facies.

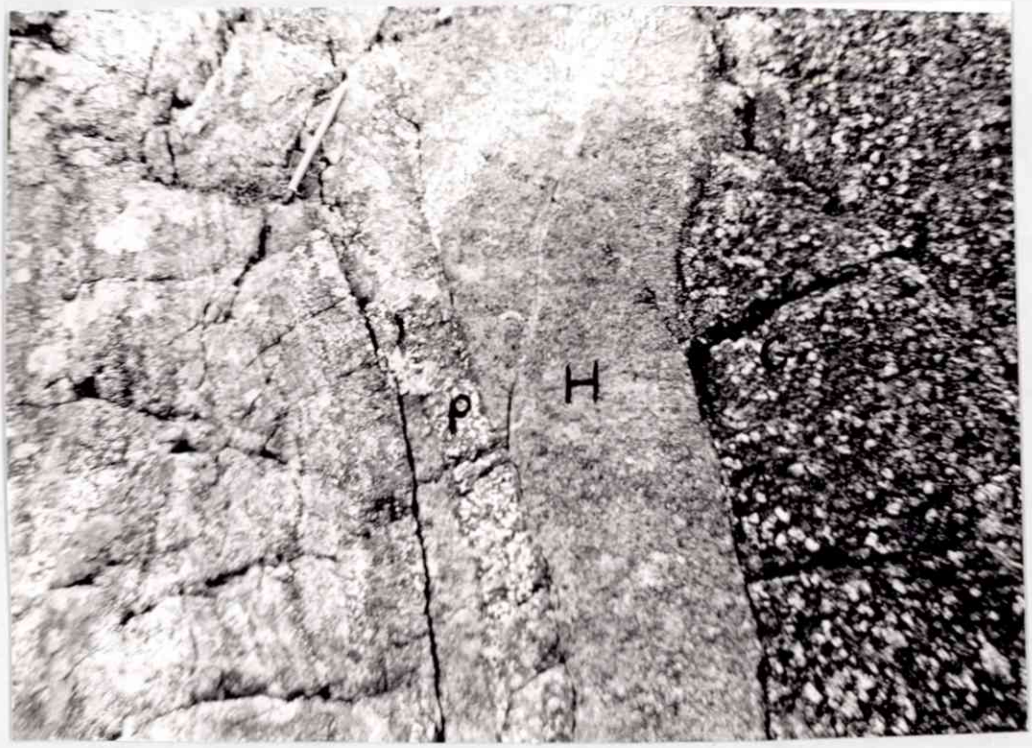


Fig.12: Hydration of layered gabbro (G) by pegmatite (P) to give hydrated, iron-stained gabbro (H), at (71,430; 8,670).

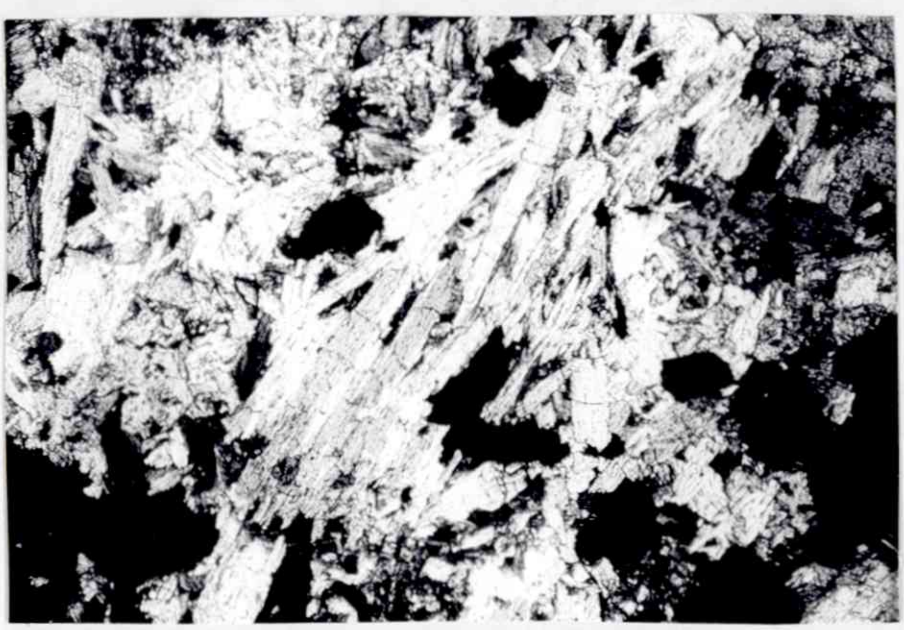


Fig.13: Ferro-actinolite, iron oxide (dark) and saussuritised plagioclase (top right) in hydrated gabbro. X 2.5, C.N.

brown colour, presumably due to iron oxide derived from the olivine.

Mineralogically, the main alteration product in the hydrated gabbro is saussuritised plagioclase, consisting of dense, fine-grained masses of epidote, clinozoisite and chlorite; relict albite twinning is present in places. Epidote mostly occurs as fine-grained masses rimmed by chlorite, though some small grains are present. The degree of saussuritisation increases sharply across the zone of hydration. Pyroxene is converted to ferro-actinolite, which occurs as large prismatic crystals, sometimes twinned (Fig.13); more rarely pyroxene is altered to small fibrous patches of uralite.

The diorite matrix sometimes contains patches of a coarse, even-grained rock, somewhat darker than the normal diorite. This was found in several places, the best example being at (71,900; 8,700). In thin section this rock is seen to consist of irregular areas of subhedral ferro-actinolite, often showing twinning, in a plagioclase matrix showing varying degrees of saussuritisation. Many of the plagioclases are zoned, and where this occurs saussuritisation has proceeded outwards from the more calcic core. Large amounts of iron oxide are present, mostly occuring at the grain boundaries of the ferro-actinolite, but also as inclusions within the latter. Laths of plagioclase may be enclosed by ferro-actinolite, suggesting a relict ophitic texture. A few areas of finer-grained ferro-actinolite, plagioclase and iron oxide are also present. It is possible that this rock type represents layered gabbro which has been almost completely metasomatised.

In a less altered variety of this rock, as, for example, at (70,200; 8,750), large pyroxenes are present. The clinopyroxene has been almost completely converted to uralite. The orthopyroxene has suffered less alteration and well-defined subhedral crystals are present; it is always at least partly uralitised, but the original interference colours, extinction angle and pale green to pink pleochroism, characteristic of hypersthene, can still be seen.

4.2 The Diorite Matrix

The diorite matrix consists essentially of a hornblende-plagioclase rock comprising four distinct phases: a pegmatitic, a coarse-grained, a medium-grained and a fine-grained phase. Of these the coarse-grained phase is by far the most abundant. In describing these grain sizes the different terms have been used in a comparative sense only, in order to distinguish between the different phases. Strictly speaking, the medium-grained phase, with minerals identifiable with the naked eye, would normally be described as coarse-grained, whilst the fine-grained phase, with separate grains, but not minerals, discernable with the naked eye, would normally be described as medium-grained.

The relationships between the different phases of the diorite vary: coarse-grained diorite may pass into pegmatitic diorite, and this in turn may pass into pegmatite veins. Gradational changes between coarse, medium and fine-grained diorite also occur. Medium-grained diorite, however, may contain xenoliths of coarse-grained material, whilst fine-grained diorite frequently occurs as veins or small dykes cross-cutting

Fig. 14: Fine-grained diorite (F) cutting xenoliths of coarse-grained material (C) in a medium-grained matrix (M), at (72,780; 8,680).

Fig. 15: Medium-grained diorite (M) containing xenoliths of coarse-grained material (C) showing "layering", at (72,500; 9,030)

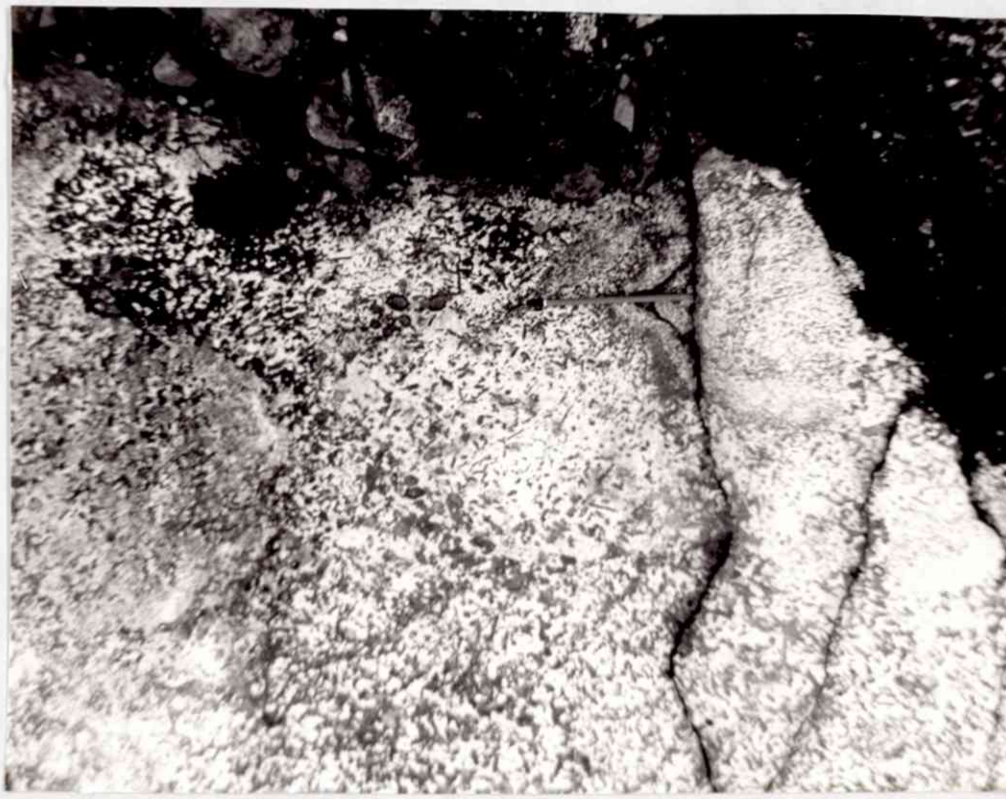


Fig.16: "Layering" in pegmatitic diorite at (72,850; 8,600).

Fig.17: Diorite containing streaks of feldspathic material at (71,220; 9,350).

the other phases (Fig.14). A few patches of flaser diorite occur in the coarse-grained phase, especially in the area south-southwest of Snauskallen.

Layering occurs both in the coarse-grained and in the pegmatitic phases of the diorite. In the coarse-grained material this was observed at (72,500; 9,030), in xenoliths within medium-grained diorite (Fig.15). In the pegmatitic diorite layering was observed at (72,850; 8,600), and dipping 15 degrees in the direction 127 degrees. In both cases the layering consisted of alternating bands of amphibolitic and feldspathic material. In the pegmatitic diorite the effect is similar to graded bedding, with the amphiboles showing a well-developed igneous lamination (Fig.16). In view of the shallow dip the layering observed in the pegmatitic phase is unlikely to be a feature inherited from the layered gabbro, but rather due to fluxing.

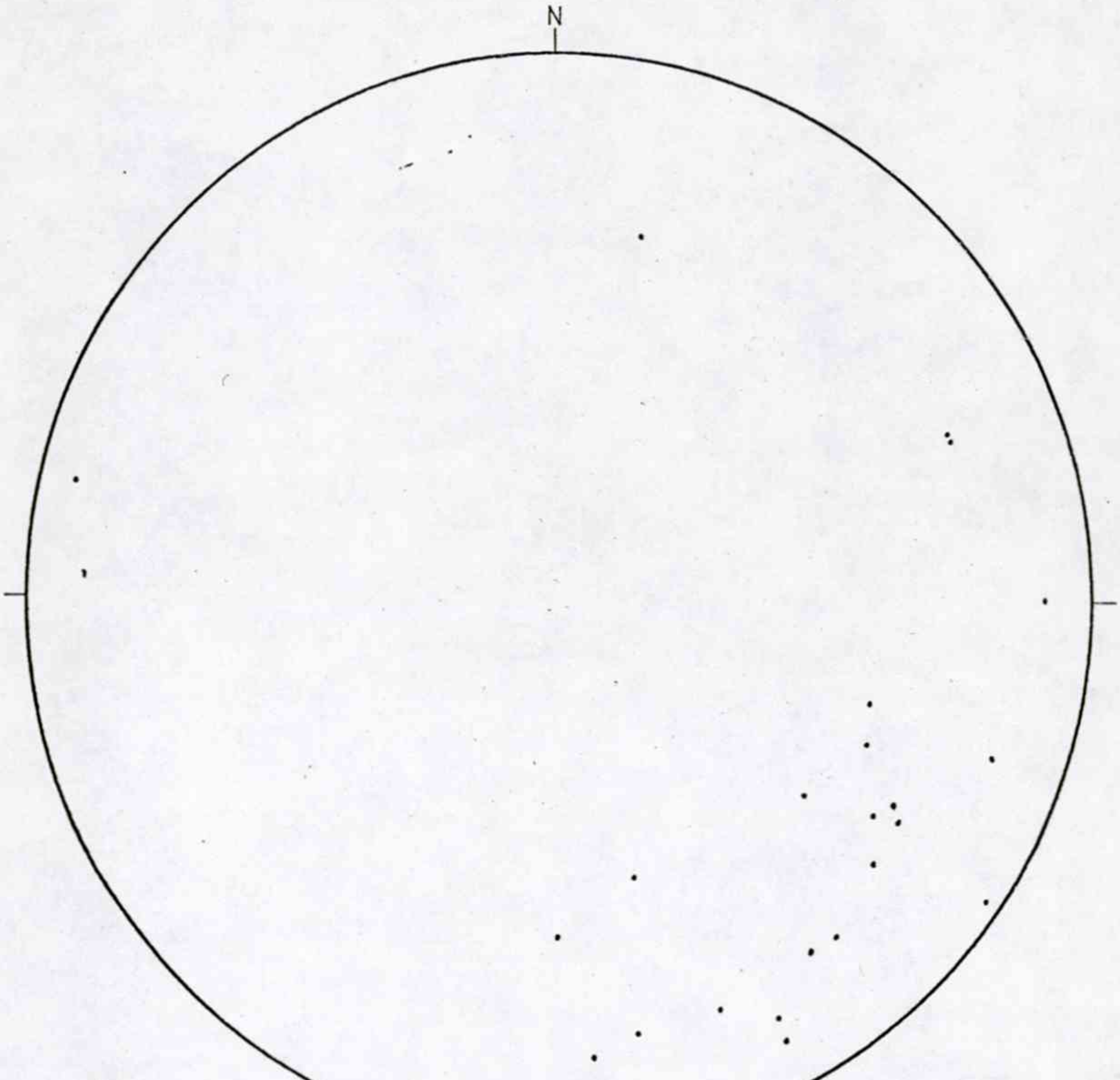
A more feldspathic variety of the diorite occurs in the vicinity of some of the trondhjemite dykes, and may intrude, and to some degree alter the normal diorite. It is possible that this material has resulted from contamination and mobilisation of the normal diorite by trondhjemitic material. A similar phenomenon may also occur, however, where no trondhjemite dykes are present in the area. Here the feldspathic diorite occurs as long streaks (Fig.17). The boundaries of these streaks are vague, the surrounding diorite being partly altered; where the streaks cross one another, larger amounts of feldspathic material are present. This material may have resulted from deuteric activity at a late stage, when the diorite had almost solidified. If such is the case, then the deuteric material might be expected to form veins, and since the diorite would not quite have solidified these veins would have vague boundaries, giving a "streaky" appearance.

4.2.1 Diorite Pegmatite

The pegmatitic phase of the diorite occurs in several different ways: as discrete veins, as small patches a few tens of centimetres across, and as pegmatite zones up to several metres across; in addition to these, much of the normal diorite matrix is sufficiently coarse-grained to be termed pegmatitic, especially in the northern part of the mapping area. The smaller veins are rarely more than 30 cm. across, and are discontinuous features extending only over a few metres of strike length. The wider veins, however, may be traced for several tens of metres, or even further in some cases, as, for example, around (71,400; 8,550).

Sets of veins, sub-parallel to one and other, are common. The general trend is approximately northeast-southwest, with northwesterly dips of between 40 degrees and vertical (Fig.18). The veins are characterised by the growth of large prismatic amphiboles perpendicular to the vein margins, suggesting dilational opening. Zoning is present in some of the veins and consists of alternating bands of amphibole-rich and more feldspathic material (Fig.19).

The pegmatite zones consist of patches of parallel pegmatitic bands, and exhibit features similar to those found in the veins, though the amphiboles are not so well-developed.



POLES TO PEGMATITES
23 POINTS PLOTTED

Fig.18

Fig.19: Zoning in pegmatite cutting coarse-grained diorite at (73,950; 9,980).

Fig.20: Fluxing in pegmatitic diorite at (71,425; 8,670).

Fig.21: Appinitic facies of the diorite at (71,400; 8,550).

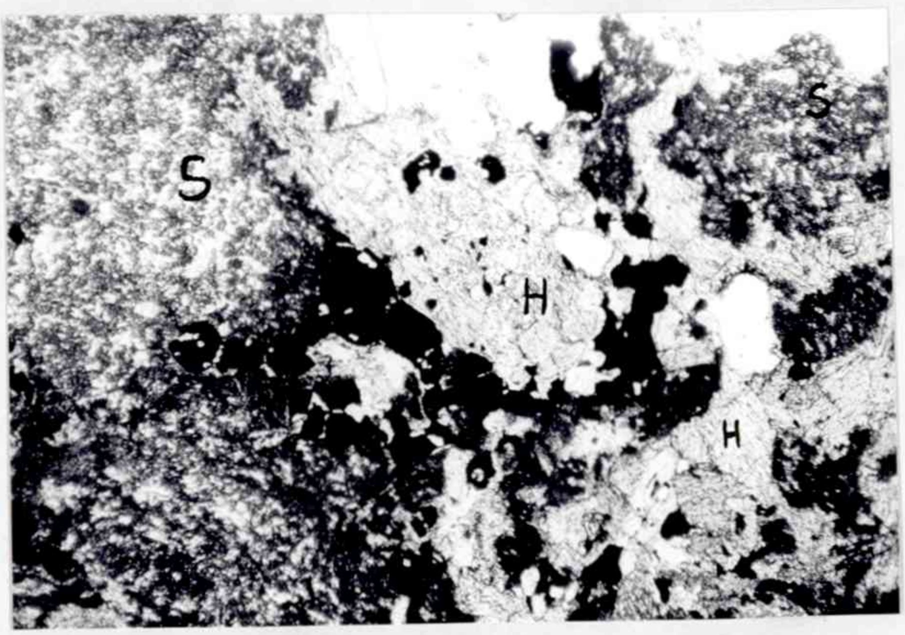


Fig.22: Hornblende (H) in diorite rimmed by iron oxide (dark); the plagioclase has been completely converted to saussurite (S). X 2.5, P.P.L.

Fluxion phenomena, similar to those observed in the layered gabbro, also occur (Fig.20).

The small pegmatite patches are characterised by the growth of large euhedral amphiboles of about the same size as those occuring in the pegmatite veins; here however, both prisms and cross-sections are present (Fig.21). A typical feature of these amphiboles is the partial corrosion of the cores. This phenomenon has been recognised by several authors (e.g. Wells and Bishop 1955), the facies being termed "appinitic" by Bailey (1916). The origin of this facies, and of the pegmatitic diorite is discussed in 4.2.3.

4.2.2 Mineralogy

In thin section the diorite is seen to consist of dark green hornblende and varying amounts of iron oxide in a matrix of completely saussuritised plagioclase, with relict albite twinning and subophitic intergrowth occasionally visible.

In the coarse-grained phase, unlike the pegmatitic phase, the hornblende is only subhedral, becoming more anhedral in the medium and fine-grained phases. This mineral is commonly twinned and schillerised; a few crystals show zoning,,and these consist of a pale green core and margin with a thin zone of darker green, presumably more iron-rich, in between.

Many of the hornblende crystals are altered to chlorite and iron oxide, the latter being deposited along cleavage cracks and fractures, and around the peripheries of the crystals (Fig.22). The chloritic material penetrates the hornblende in a manner suggesting hydration and replacement, the junctions between the original mineral and the chlorite being irregular and serrated; where this occurs the hornblende may show a "bleached" appearence. Where chloritisation has taken place to a greater degree, those parts of the crystal between the larger cracks have been filled with an almost isotropic aggregate of pale green chlorite flakes. A few grains of epidote occur associated with the chlorite.

Iron oxide occurs in two ways: as a partly resorbed inter-cumulus phase consisting of corroded patches or cubes, or as rims around the hornblende; it is commonly altered to sphene.

At (71,500; 9,275), on the northeast margin of the Gabbro near Snauskallen, the diorite pegmatite passes into a rock consisting of subhedral hornblende, a pinkish orange feldspar, possibly orthoclase, and accessory quartz. The quartz and feldspar may form a graphic intergrowth.

Also in this area, but nearer to the marginal fault, there occurs a hybrid rock, apparently derived from both dioritic material and country rock. It consists of large, primary, subhedral hornblendes and secondary actinolite in a dense, fine-grained matrix of epidote and clinozoisite. Epidote also occurs as veinlets along the amphibole cleavage, and as small, dispersed grains. Small grains of iron oxide also occur, mostly associated with amphibole.

4.2.3 Origin of the Diorite

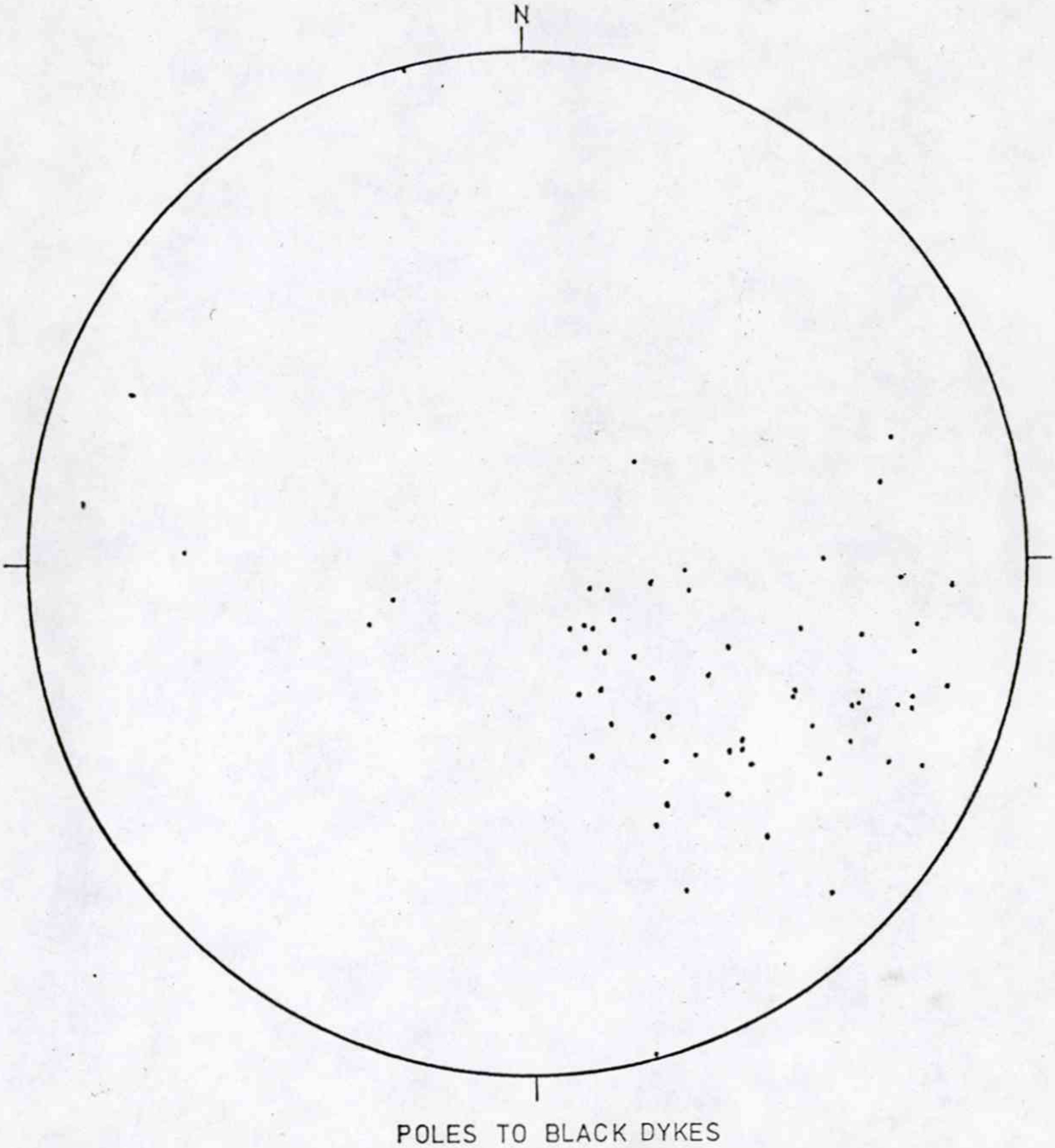
The occurence of ophitic and subophitic intergrowths of saussuritised plagioclase and hornblende in both metasomatised gabbro and diorite indicates that the latter was produced, at least in part, by metasomatism of the gabbro, and is not wholly an intrusive body. This is also borne out by the geochemistry of the rocks, particularly by the trace element distribution (see section 6).

To account for the different phases observed in the diorite is more difficult. Certainly, the pegmatitic and the appinitic phases appear to be due to deuteric activity at a late stage in the evolution of the diorite. The medium and fine-grained phases, however, are clearly later than the coarse-grained and pegmatitic phases. They may either represent metasomatism of a different rock type, or perhaps more likely, a finer-grained, more mobile stage in the crystallisation of the diorite.

In considering the change from gabbro to diorite, it is clear that the mobility of water was the most important factor influencing this process. This is reflected by the abundance of fluxion phenomena and pegmatite veins, and by the fact that the principal change involved in the transformation is the saussuritisation of plagioclase and the hydration of pyroxenes to form amphiboles.

4.3 Black Dykes

The black dykes consist of a dark, fine to medium-grained rock with an amphibolitic "sparkle" on freshly broken surfaces. They are short, discontinuous features, the strike length depending on the width of the dyke. The largest are about 15 cm. wide and are usually pinched out over distances greater than about 20 m.. Small sinistral displacements are common on either side, and are of the same order as the width of the dyke. The dykes follow a general northeast-southwest trend, with varying dips to the northwest, though a few dip to the southeast (Fig.23). Some of the dykes display a fine foliation



POLES TO BLACK DYKES
65 POINTS PLOTTED

Fig.23

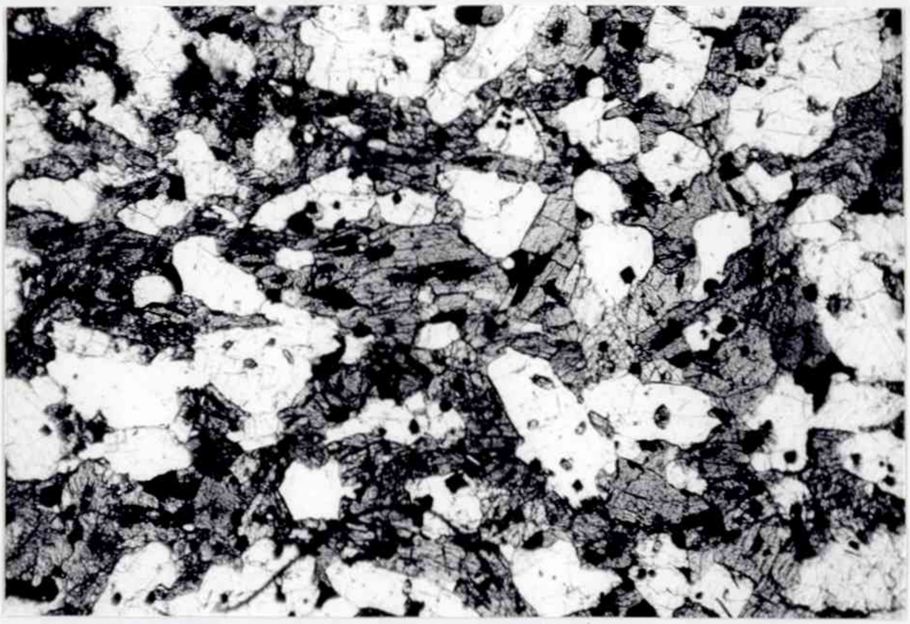


Fig.24: Plagioclase (white) and schillerised hornblende in black dyke. X 2.5, P.P.L.

Fig.25: Black dyke with porphyritic margin cutting hydrated layered gabbro at (71,430; 8,670).

perpendicular to the margins. They are frequently offset by joints of varying size. Thin sub-parallel "stringers" may accompany the larger dykes. Chilled margins and inclusions of country rock (usually diorite) are rare. At least two generations of black dykes can be distinguished in the field on the basis of cross-cutting relationships, with the earlier set showing the characteristic sinistral displacement.

4.3.1 Mineralogy

The black dykes consist of subhedral plagioclase with interstitial hornblende and iron oxide, and are distinguished by their primary appearence compared with other rock types in the area. The plagioclase is unaltered bytownite or labradorite, varying between An.62% and An.79%, and averaging about An.70%. A few of the crystals are slightly clouded. The rock also contains a few plagioclase phenocrysts up to 3 mm. long. These have been completely saussuritised to clinozoisite and a few small grains of epidote.

The hornblende is sometimes subhedral, though more often interstitial. Twinning and schillerisation are common (Fig.24).

Iron oxide is abundant, and mostly occurs at the grain boundaries of the hornblende.

The black dykes also exhibit a porphyritic facies, which occurs as lenses within the dykes, and at the margins (Fig.25). The contacts between the porphyritic and the aphyric facies are sharp and unchilled, neither seeming to have been altered by the other. The phenocrysts consist of large plagioclases up to 7 mm. long; these have been almost completely altered to clinozoisite, though some relict pericline and albite twinning is still visible. The hornblende crystals are slightly larger and better-formed than those in the aphyric facies. No iron oxide is present. The porphyritic facies is confined only to those dykes on top of the main gabbro mass, and is not found on the lower slopes.

Taking into account the composition of the plagioclase, and the presence of hornblende as the only ferromagnesian mineral, the black dykes may be tentatively classified as hornblende-dolerite. Due to the rarity of hornblende in dolerites generally, it is possible that this mineral is secondary after a primary pyroxene; there is no textural evidence, however, to suggest that the hornblende is anything but primary.

4.4 Micronorite Dykes

In the field, the micronorite dykes were mapped as "amphibolitic" black dykes, on account of their dark green colour. They were only observed in one place, however, this being in the face of a small cliff on the northeastern flank of the Gabbro, at (71,740; 8,860). They are features with moderate dips and follow the same trend as the black dykes. Most of the physical features displayed by the latter are present: the rock may or may not be porphyritic, a few inclusions of country rock are present, and a well-developed foliation is visible.

4.4.1 Mineralogy

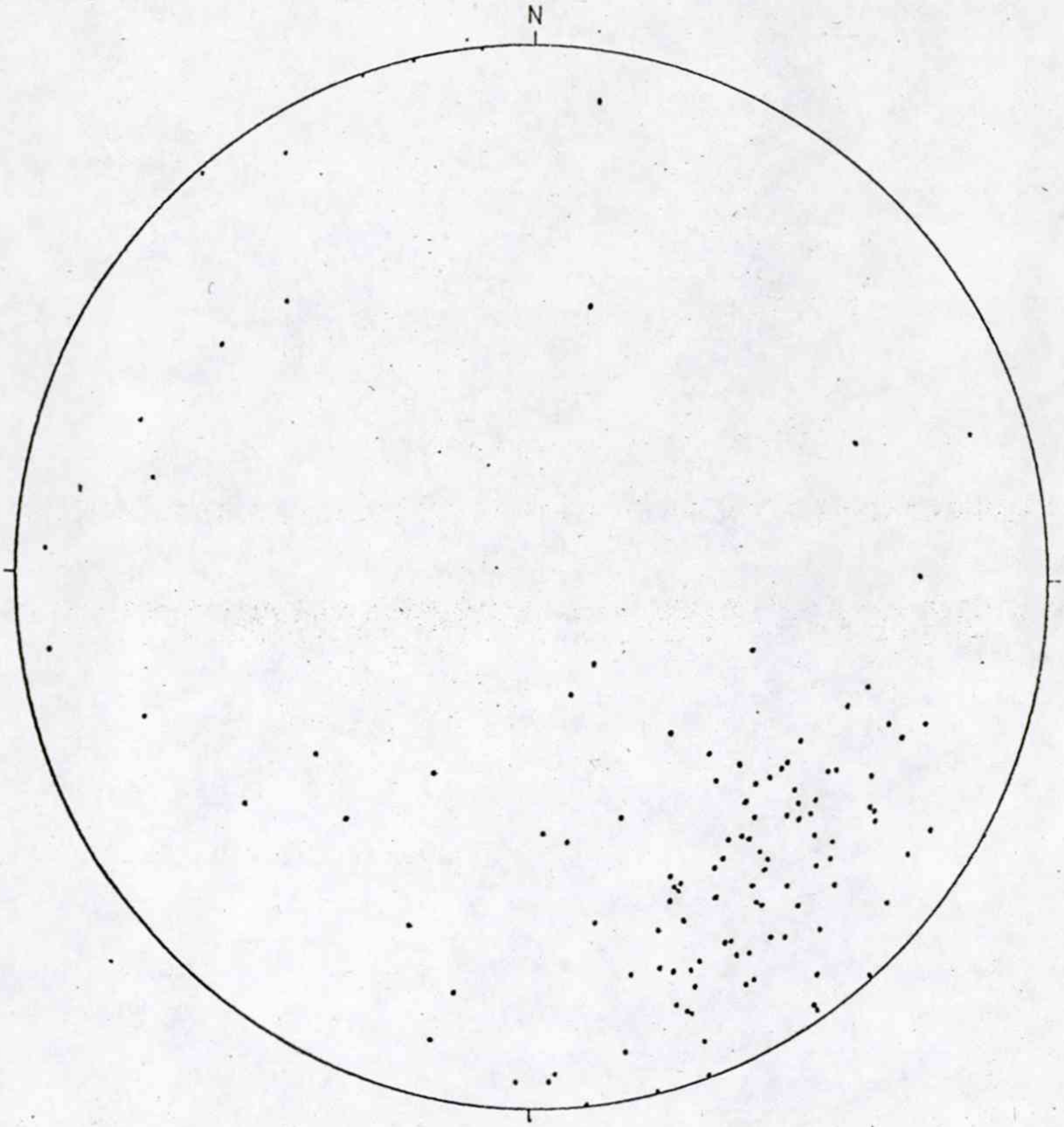
The micronorite dykes consist of small, corroded, subhedral crystals of hypersthene, often twinned, in a dense, fine-grained matrix of chlorite and clinozoisite, with a few small grains of epidote also present. The clinozoisite presumably represents completely saussuritised plagioclase, and pseudomorphs the latter in the porphyritic facies. The hypersthene is extensively replaced and pseudomorphed by chlorite. Iron oxide occurs either as rims around the hypersthene or associated with the replacing chlorite.

4.5 Trondhjemite Dykes

The trondhjemite dykes vary in appearance from greyish white in the more felsic rock to creamy white or pink in the more mafic varieties.

The latter material is confined to the marginal fractures of the Gabbro, where it occurs as sheet-like masses up to several hundred metres long. The more felsic material occurs as dykes up to 2 m. across. Unlike the black dykes and pegmatites, the trondhjemite dykes are much more persistant features, the widest ones continuing for distances of up to 1½ km.. The general trend is northeast-southwest, though a few trend more to a north-south direction. The dips are generally steep (between 50 and 75 degrees), and to the northwest, though a few dip to the southeast (Fig.26). In general the trondhjemite dykes show roughly the same attitude as unfilled fractures, and indeed most are merely partial infillings of the latter by trondhjemite. Displacements are rare, and where these occur they are dextral, and of the same order as the width of the dyke (Fig.27).

A few of the smaller dykes have been tectonised: they may



POLES TO TRONDHJEMITE DYKES
117 POINTS PLOTTED

Fig.26

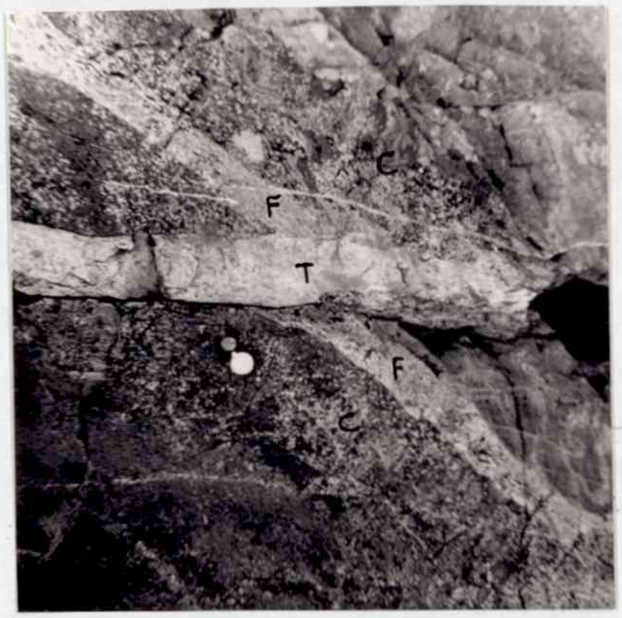


Fig.27: Trondhjemite dyke (T) cutting fine-grained (F) and coarse-grained diorite (C) at (73,280; 8,570).

Fig.28: Rotated trondhjemite dyke cutting coarse-grained diorite at (72,900; 8,500).

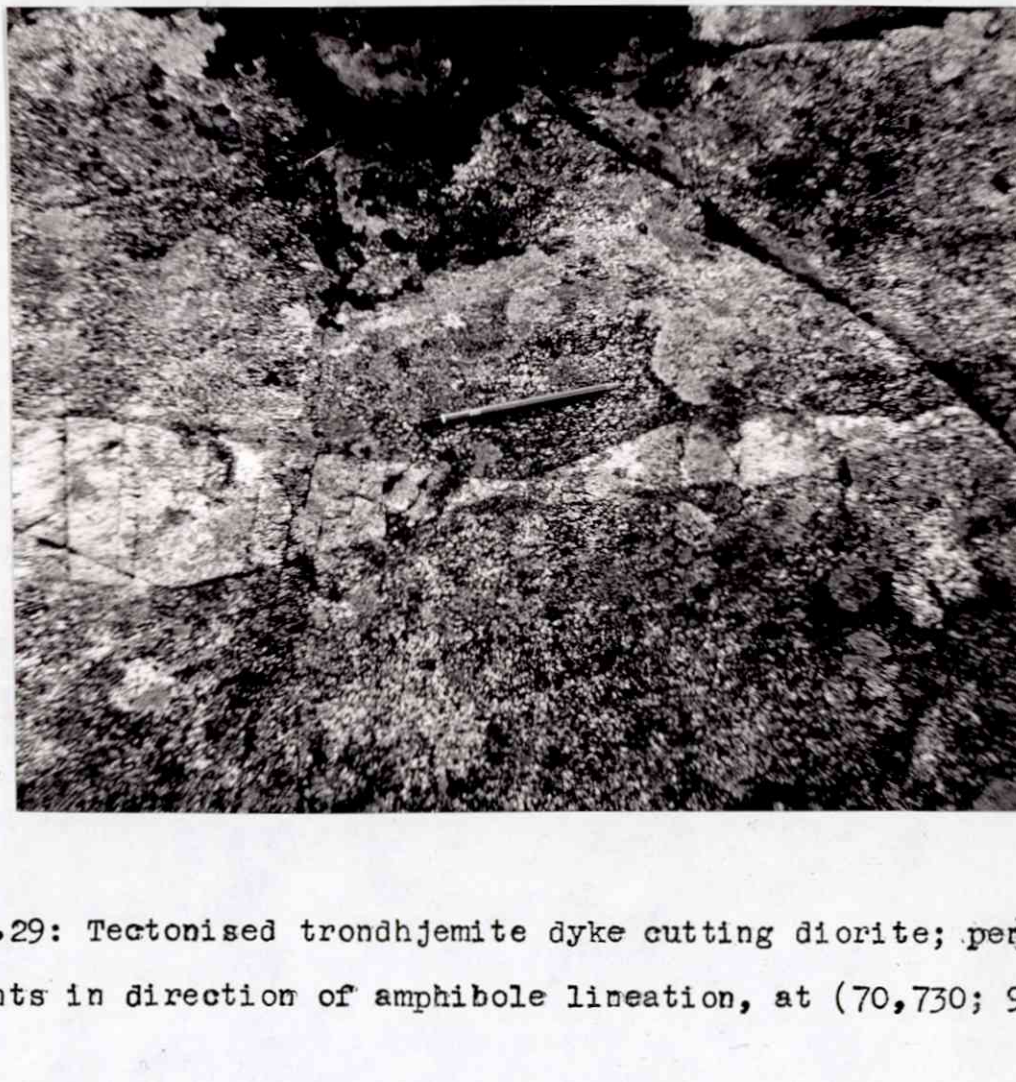


Fig.29: Tectonised trondhjemite dyke cutting diorite; pencil points in direction of amphibole lineation, at (70,730; 9,150).

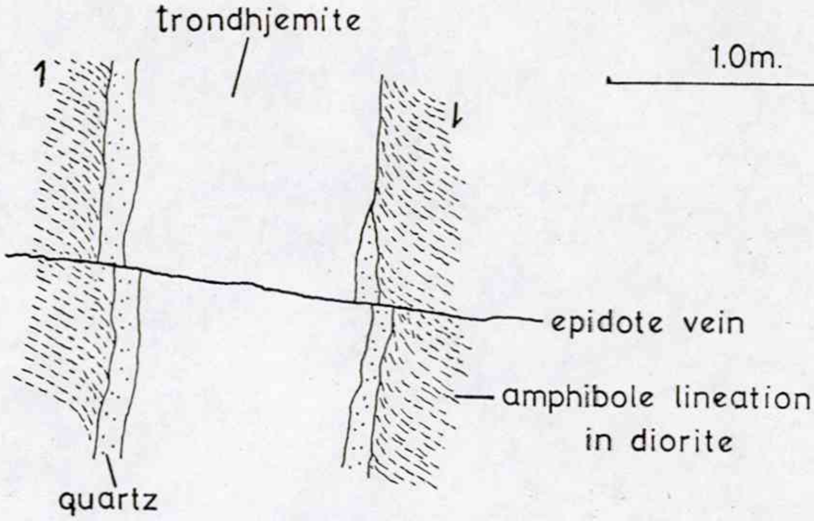


Fig.30: Trondhjemite dyke with quartz margins at (72,850; 8,600).

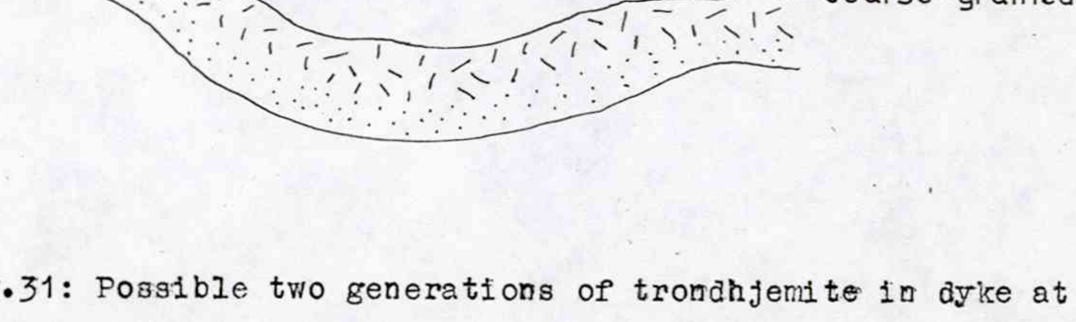


Fig.31: Possible two generations of trondhjemite in dyke at (70,620; 8,630).

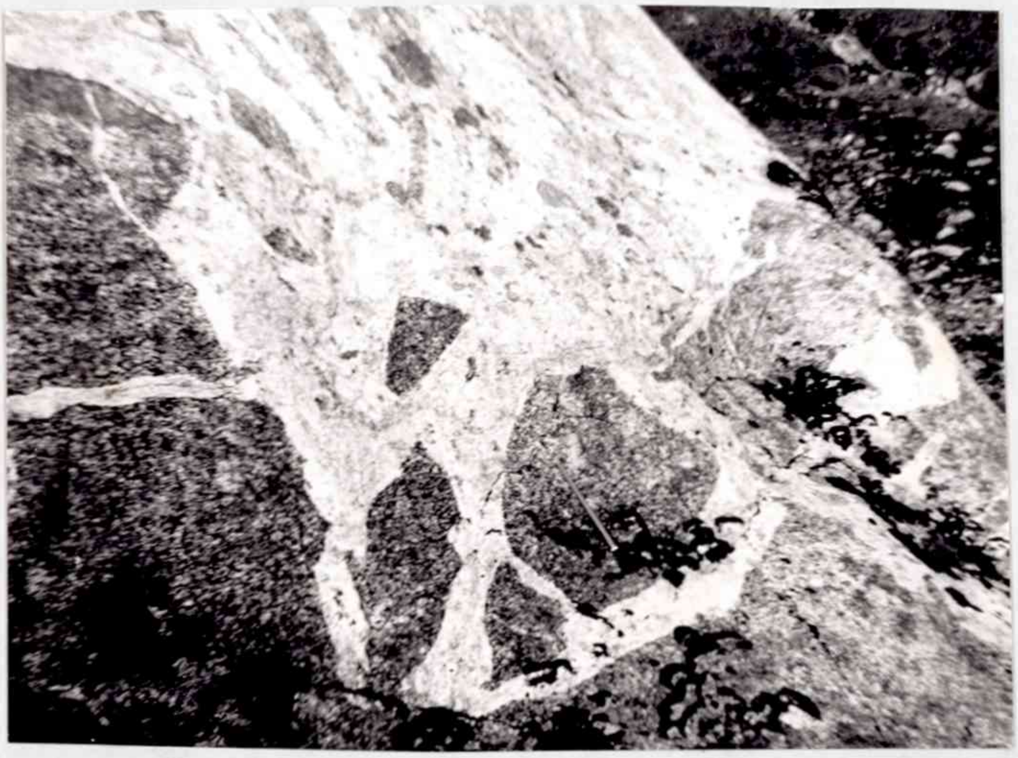


Fig.32: Xenoliths of coarse-grained diorite in trondhjemite at (71,450; 9,000).

Fig.33: Xenoliths of amphibolitic Upper Unit greenstones in trondhjemite at (70,690; 8,000).

be rotated (Fig.28), or displaced by small joints. Wherever tectonism has occured, or the dykes have caused displacement, a noticeable foliation of the country rock is developed in the immediate vicinity of the dyke. In one case a small dyke showed a boudined appearance (Fig.29); the boudins were rather angular in shape, however, and no deflection of the foliation in the surrounding diorite could be observed. It is possible, therefore, that this dyke was merely displaced by a sub-parallel joint.

Thin quartz veins may occur at the margins of, or run sub-parallel to, the dykes (Fig.30).

In one case, two generations of trondhjemitic material seem to have been intruded (Fig.31). The finer-grained material is unlikely to be merely a chilled margin, since the trondhjemite is not chilled around the diorite xenolith; also, the contact between coarse and finer-grained diorite is fairly sharp.

The larger dykes may contain xenoliths of diorite or greenstone. Xenoliths of diorite have behaved in a fairly competent manner (Fig.32), whilst those of greenstone appear to have undergone a more plastic deformation, together with partial melting (Fig.33).

4.5.1 Mineralogy

The typical trondhjemite is a foliated quartz-feldspar rock, with the feldspar occuring as porphyroclasts. These are well-developed and may be subhedral. Almost all the feldspar is plagioclase; the composition is difficult to determine but the small extinction angle (0-10 degrees) suggests oligoclase. Some of the plagioclases are heavily sericitised, with sericitisation proceeding most often from the cores outwards

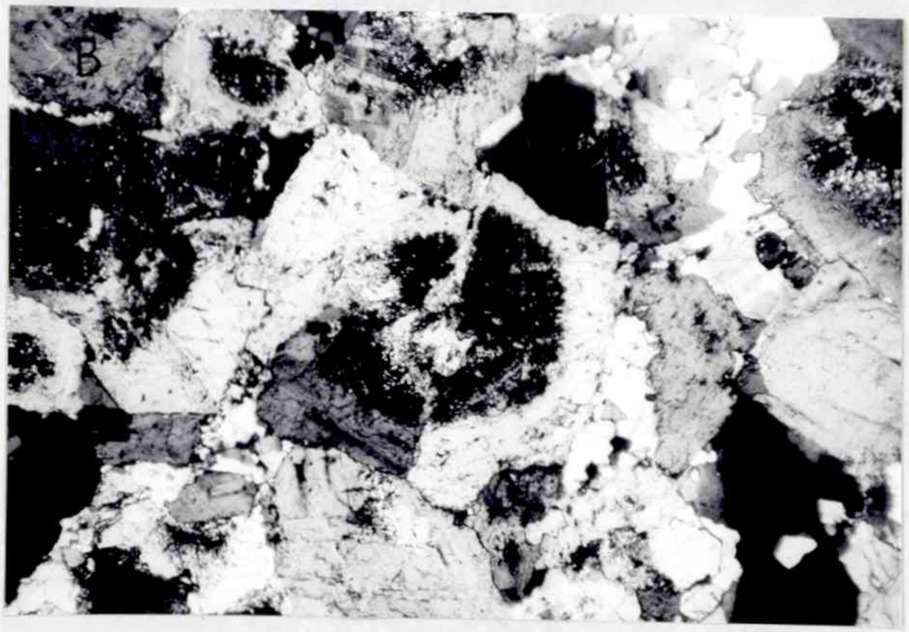


Fig.34: Corroded plagioclases in a matrix of sericite, biotite (B) and fine-grained recrystallised quartz; the centre plagioclase crystal shows Carlsbad twinning. X 6.3, C.N.

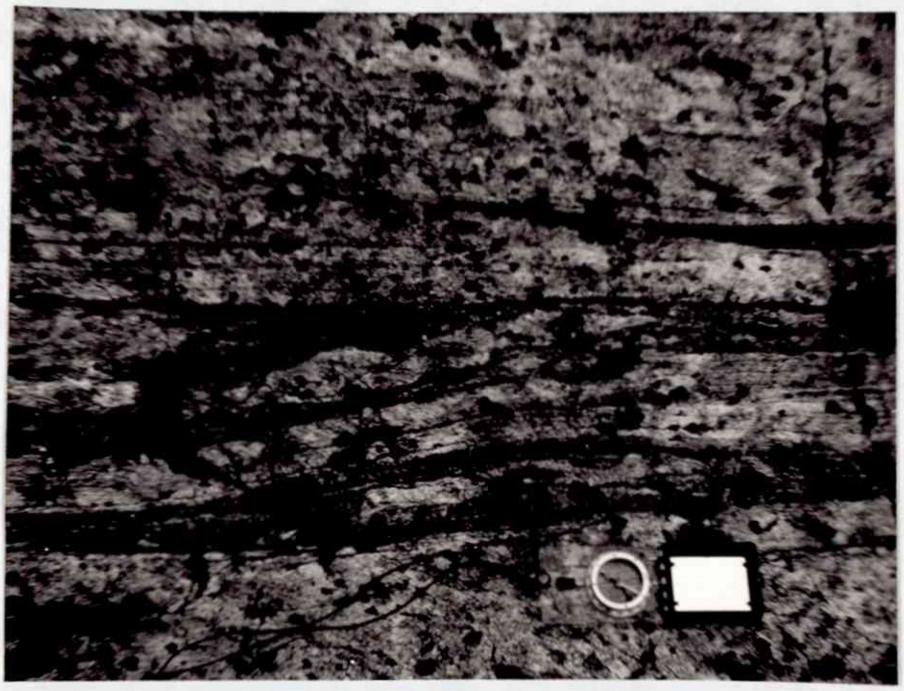


Fig.34a: Mylonite at (72,380; 8,800).

(Fig.34); a vague zoning may be present. The matrix is principally composed of fine-grained quartz, with fibrous shreds and masses of biotite and sericite, the latter mostly occuring around the plagioclase phenoclasts.

In the more tectonised varieties of trondhjemite the feldspars are much more heavily coroded and the matrix has a finer-grained, more "ground-up" appearance, with biotite proxied by brown iron oxide.

The more mafic trondhjemite occuring in the marginal fault system varies from creamy white to pink in colour, the latter being possibly due to the abundance of iron in the feldspars of this facies. The rock consists of quartz, subhedral plagioclase and a little microcline, with interstitial ferromagnesian minerals. The plagioclase is unaltered, but in the rock examined no crystal sections were found which enabled it to be determined conclusively; however, the characteristically low extinction angles suggest oligoclase, as in the more felsic trondhjemite. The principal ferromagnesian mineral is hornblende, which is often rimmed by iron oxide. A few large, heavily uralitised subhedral crystals of hypersthene are also present; these crystals commonly have rims of hornblende, biotite, uralite or iron oxide.

4.5.2 Mylonite

Mylonitisation of the trondhjemite may occur, principally within the marginal fault system, though one small patch of mylonite was found in a trondhjemite dyke on the northern flank of the Gabbro, at (72,150; 8,850). The type of mylonite produced obviously depends on the composition of the original trondhjemite. At the locality cited above, the trondhjemite is the typical greyish white material, and the mylonite consists of irregular bands of grey and brown material. The pink trondhjemite in the marginal fault system has been altered to a pinkish mylonite, whilst the mylonite derived from the creamy white trondhjemite consists of irregular bands of white and green material. In this case the green bands are chlorite and epidote-rich, consisting of fibrous masses of chlorite with large shattered grains of epidote; a little fine-grained quartz and heavily sericitised feldspar is present. The white bands consist of slightly coarser-grained quartz and completely sericitised feldspar, with a few small grains of epidote. The feldspar exhibits a well-developed augen texture, and a few schlieren of coarse-grained quartz are present. Opaque minerals have been altered to sphene.

4.6 Xenoliths

Xenoliths of country rock, up to several metres across, are abundant in the diorite matrix, and consist for the most part of material closely resembling the Upper Unit greenstones, though rather more amphibolitic in places. The typical xenolithic material is composed of fine-grained quartz, sodic plagioclase and epidote, with interstitial biotite. Texturally, there is a close resemblance to the black dykes. Veins of coarse-grained epidote are abundant, together with long streaks of fibrous chlorite and associated iron oxide. Larger areas of iron oxide also accur at the centres of epidote veins, as small scattered grains or in association with biotite (Fig.35).

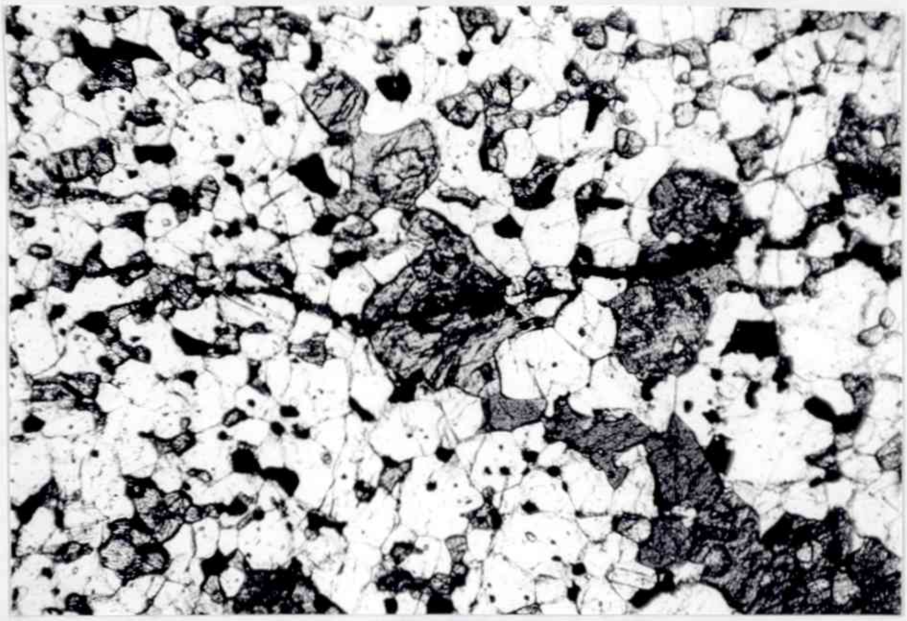


Fig.35: Greenstone xenolith consisting of hornblende (centre, light grey), epidote (dark grey), iron oxide (dark) and quartz/ plagioclase (white). X 2.5, P.P.L.

Fig.36: Elongated greenstone xenoliths in matrix of coarse-graine diorite; pencil lies along direction of amphibole lineation, at (72,780; 8,680).

The smaller xenoliths are often elongated in the same direction as the foliation in the diorite (Fig.36).

Around Snauskallen, near the marginal fault, the interaction between diorite and xenolithic material has produced a migmatitic effect. Near the margins of the xenoliths, large porphyroblasts of subhedral plagioclase up to several millimetres long begin to appear in and around dark amphibolitic veins. These veins become more feldspathic towards the diorite matrix, until they grade into the latter. Around some of the smaller xenoliths the diorite becomes richer in quartz and feldspar.

One xenolith examined, about 300 m. west of the marginal fault, at (72,780; 8,680), consisted of a coarse-grained, mottled, pinkish-grey rock composed of heavily altered oligoclase, with some microcline and hornblende, in a matrix of finer-grained quartz. The rock has a foliated, ground-up appearance in thin section, and may possibly represent an inclusion of granodiorite, though where this material could have come from is difficult to say, since the nearest known outcrop of granodiorite is several kilometres away.

5. MINERALISATION

5.1 Layered Gabbro

Mineralisation in the layered gabbro is sparse, and appreciable amounts are principally confined to a few isolated patches which weather to a rusty brown or ochreous yellow colour (for grid references see 4.1.4).

Pyrrhotite is the principal ore mineral, and occurs as thin pyrrhotite-rich pods up to 1 cm. long, or as elongate grains disseminated throughout the rock. Both pods and grains are orientated parallel to the layering. In polished section the pyrrhotite is seen to form large, irregular grains with cuspate boundaries. The larger grains may consist of an aggregate of smaller grains with straight boundaries (Fig.37). Lamellar twinning is common. Cracks traverse some of the grains, whilst shearing is also evident, indicating a post-depositional deformation. In weathered gabbro pyrrhotite is rimmed by successive generations of limonite, which also occurs along cracks and cleavage planes.

Pyrrhotite may be replaced at the rims by a few small areas of chalcopyrite, the junction between the two minerals being curved and having low relief. Small laths of secondary marcasite also occur at or near the rims.

Magnetite, like pyrrhotite, is an intercumulus phase, and occurs as interstitial grains in the same way. It also occurs as rims around some of the pyrrhotite grains, and as a separation product resulting from serpentinisation of the olivines. A well-developed octahedral cleavage is present.

Ilmenite is present in small amounts as rims around grains

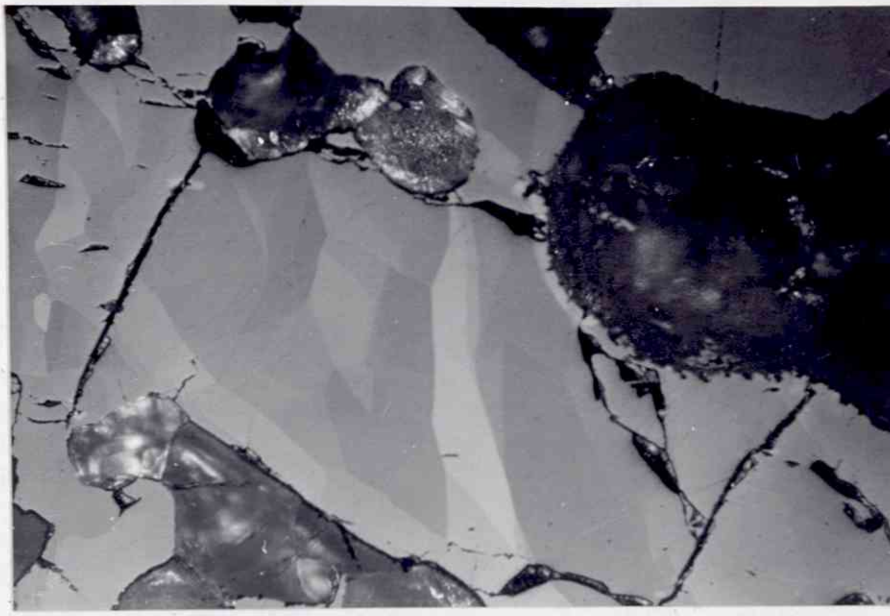


Fig.37: Composite pyrrhotite grain in layered gabbro. X 6.3, C.N.

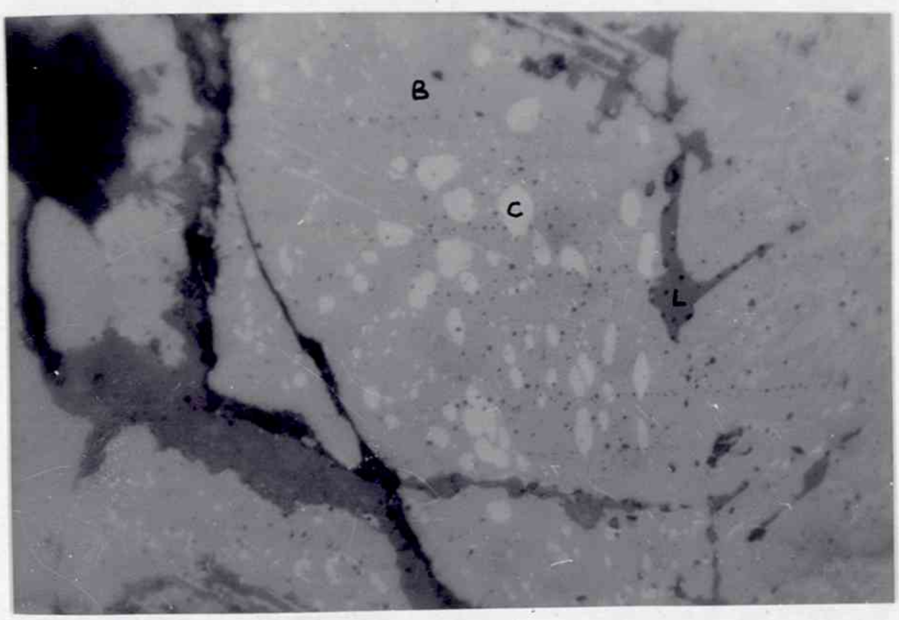


Fig.38: Bornite (B), exsolved chalcocite (C) and replacing limonite (L) in slightly weathered pegmatitic diorite. X 60, P.P.

of magnetite, or as exsolution lamellae along the (111) cleavage of the latter.

5.2 Diorite

Like the layered gabbro, the diorite is poorly mineralised, and what mineralisation there is is largely restricted to the coarse-grained or pegmatitic phases. Small, scattered grains of magnetite are common in all phases, however.

Mineralisation in the pegmatitic diorite consists of a few small areas, up to 2 mm. across, of magnetite, pyrite, chalcopyrite, bornite and chalcocite, in order of decreasing abundance. Magnetite and pyrite occur as large irregular grains rimmed by limonite. Chalcopyrite usually occurs in association with pyrite. Bornite occurs in a similar manner, and frequently contains exsolved blebs of chalcocite (Fig.38); the latter also forms blebs along the cleavage of the bornite. All the above minerals are replaced to a certain extent by limonite.

5.3 Black Dykes

Only one black dyke, at (71,400; 8,550), showed any noticeable amount of mineralisation, and this consisted of small, scattered cubes of pyrite. Magnetite is common as an interstitial phase, however.

6. GEOCHEMISTRY

6.1 Major Elements

The behaviour of the major elements is rather irregular. Unfortunately, time did not permit a large number of analyses to be made; had this been possible, a more regular pattern might have emerged.

Ratios of the oxides of geochemically related major elements have often proved usefull in understanding the evolution of various igneous rocks. When some of these ratios, such as Na_2O : CaO and (Na_2O + K_2O) : (CaO + MgO), were determined, however, they proved to be unhelpfull, and rather to confuse the issue. For this reason they have not been included.

6.1.1 Sodium, Potassium

The amount of sodium and potassium in the layered gabbro is characteristically low. Since these elements are highly mobile, however, the amount of total alkalis (Na_2O + K_2O) is noticeably greater in the later rocks. Petrologically, this trend is reflected by the increasing saussuritisation of the plagioclase, and, in the case of sodium, by the abundance of hornblende in the diorite, particularly in the pegmatitic phase. The highest total alkali content of 3.63% occurs in the greenstone xenolith W8. This is several percent below the average for spilitic greenstones, however; as has been observed in 4.7, there is a marked increase in feldspar content towards the margins of xenoliths, and this may reflect the diffusion of sodium and potassium away from the xenoliths towards the more

%	W1	W2	W3	W4	W5	W6	W7	W8
Na_2O	1.25	1.90	2.12	2.35	2.24	2.34	2.15	2.83
K_2O	0.16	0.10	0.37	0.20	0.54	0.39	0.22	0.80
CaO	11.39	12.52	11.03	10.42	10.48	11.04	12.35	10.53
MgO	13.21	9.10	7.17	6.47	9.23	12.10	8.74	11.51
ΣFe_2O_3	8.48	7.44	14.80	10.17	13.23	12.03	12.15	11.60
MnO	0.12	0.15	0.18	0.20	0.16	0.18	0.16	0.20
p.p.m.								
Ni	303	129	81	75	140	152	115	42
Cr	275	499	233	250	280	230	224	84
Co	194	190	195	180	188	152	193	168
Cu	55	37	50	34	72	153	109	77

W1: troctolite.

W2, W3: metasomatised gabbro.

W4: coarse-grained diorite.

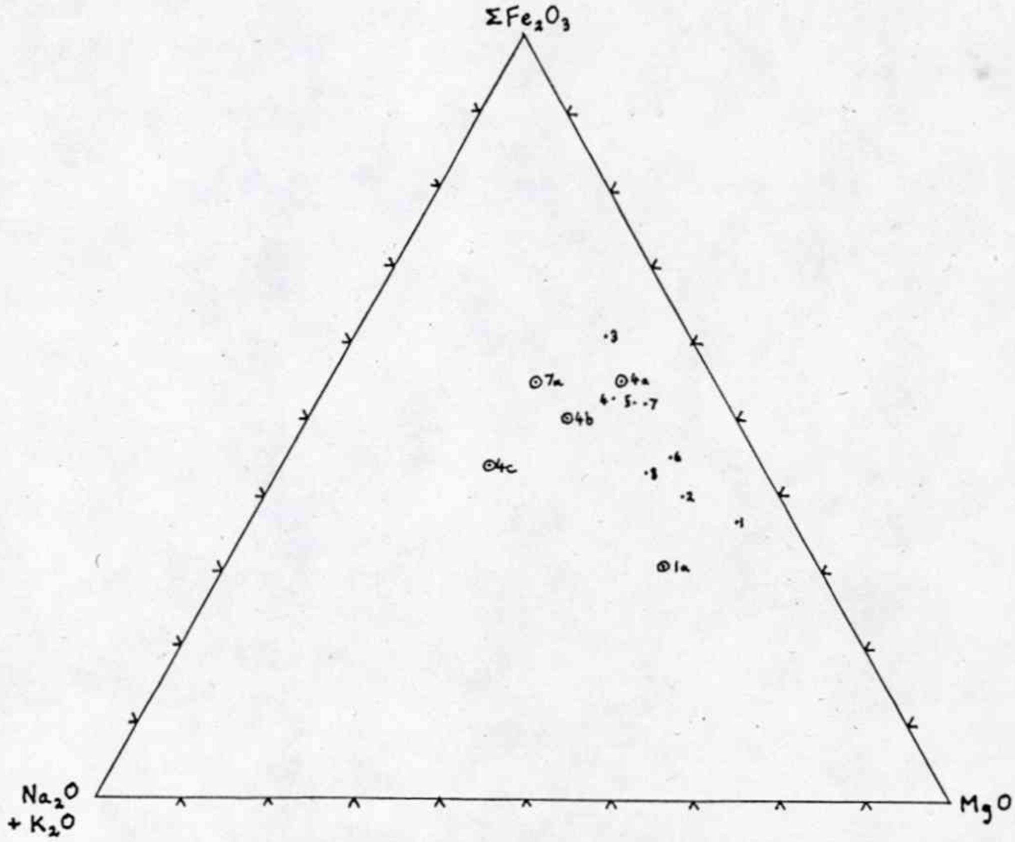
W5: pegmatitic diorite.

W6: pegmatite vein.

W7: black dyke.

W8: greenstone xenolith.

Fig.39: Analyses of principal rock types in the Gröndalsfjell Gabbro.



1a: troctolite, Belhelvie, Aberdeenshire.

4a: epidiorite, Argyll.

4b: meladiorite, Cortland Series, New York.

4c: intrusive diorite, mean of 70 analyses (Daly).

7a: hornblende dolerite, Fort Montgomery, New York.

Fig.40: FMA diagram of Gröndalsfjell and comparable rocks.

feldspathic diorite.

Although it has been stated above that alkalis are concentrated in the later rocks, the black dykes are an exception, since they represent a later intrusion of more basic material.

When the principal rock types in the Gröndalsfjell Gabbro are compared with corresponding unmetamorphosed rocks from other parts of the world (Fig.40) it is found that they are noticeably depleted in alkalis. Since metamorphism in the Gabbro is fairly limited when compared to other rocks in the area, it is possible that, to a certain extent, diffusion of alkalis away from the Gabbro into rocks of higher metamorphic grade occured as a result of metamorphism.

6.1.2 Calcium

The behaviour of calcium is much more erratic than that of sodium or potassium. This is manifested both in magmatic differentiation and in metamorphism. In very early differentiates such as dunites and peridotites, the calcium content is very low; as the content of calcic plagioclase increases, however, so does the calcium content, and a maximum is reached during the initial steps of the main stage of differentiation, as, for example, in gabbros and anorthosites. In later differentiates, however, such as diorites and granodiorites, the calcium content progressively decreases; calcium content increases, however, in rocks of higher grade, such as amphibolites (Hyndman 1972).

One of the most important aspects of the behaviour of of calcium in the Gröndalsfjell Gabbro is its possible mobility during saussuritisation of the plagioclase. In the layered gabbro the plagioclase is almost unaltered; in the hydrated and metasomatised varieties, however, it is completely replaced by clinozoisite and epidote. The alteration of pyroxene to amphibole has proceede concurrently with saussuritisation.

A feature common to all the rocks analysed, apart from the unaltered troctolite, is their greater calcium content compared with the corresponding unaltered rocks:

W1 (troctolite) 11.39% W1a (troctolite, Belhelvie) 11.41% CaO
W4 (diorite) 10.42% W4a (epidiorite, Argyll) 9.30%
W4b (meladiorite, New York) 9.57%
W4c (diorite, Daly's average) 6.63%
W7 (black dyke) 12.35% W7a (hornblende dolerite) 7.53%

It is possible, therefore, that corresponding to the alkali depletion suggested above, an introduction of calcium has taken place. Certainly, extensive mass transfer has occured in the rocks of the area, as demonstrated by the abundance of epidote knots and veins. It would seem, therefore, that calcium has been a very mobile element during metamorphism.

6.1.3 Magnesium

In the earlier phases of the Gabbro there is a progressive decrease in magnesium content with increasing metasomatism of the gabbro proper, and this is reflected by the disappearance of early-formed minerals such as olivine and pyroxene. The lowest magnesium content occurs in the normal coarse-grained diorite.

Higher values, however, occur in the diorite pegmatite and the greenstone xenolith W8. In the case of the pegmatite, this is perhaps contrary to what might be expected. Eskola (1914), pointed out that magnesium may be highly mobile in metasomatic processes. If, as has been suggested, the diorite and its pegmatitic phases resulted from metasomatism of the gabbro, then it is conceivable that magnesium originally derived from layered gabbro was locally incorporated by the pegmatite into the hornblende lattice. Such an idea might also explain the high magnesium content in the greenstone xenolith, with magnesium entering the chlorite and biotite lattices. Alternatively, the ferromagnesian minerals in the original lava from which the greenstones were probably derived may have provided the magnesium; this is unlikely, however, since this element would have been lost at a very early stage in metamorphism.

Magnesium is also rather high in the more basic black dykes, presumably due to a more magnesium-rich hornblende.

Overall, the principal rock types analysed contain more magnesium than the unaltered comparisons (Fig.40). It is possible, however, that this is more a reflection of the composition of the original magma than due to metasomatic processes.

6.1.4 Iron

Since iron oxide is ubiquitous in all the rocks of the Gabbro, interpretation of the analyses is difficult. In thin section, however, much of the iron oxide seems to be associated with the conversion of primary pyroxene in the layered gabbro, to actinolite in the metasomatised gabbro, and to hornblende in the diorite; the formation of chlorite and epidote also requires iron. Hence, apart from the seemingly anomalous value for W3, the iron content appears to be greater in the later rock types, which is what might be expected. This phenomenon is well-displayed in the pegmatitic phases of the diorite, where iron has presumably entered into the hornblende lattice in greater amounts; chlorite and epidote are also more abundant here.

6.2 Minor Elements

Whereas considerable information is available concerning minor element distribution in igneous rocks, comparatively little work has been done on metamorphic rocks. Shaw (1954), however, showed that a rock may retain the primary distribution pattern of minor elements even after intense metamorphism. At low grades of metamorphism, no detectable change in minor element concentration is produced, unless movement of solutions has occured during the metamorphic processes. At higher grades of metamorphism there may be some redistribution of minor elements among newly-formed minerals, but here again the overall concentration is not affected unless solutions have been active.

The principals outlined above help to confirm the mode of origin for the diorite already suggested. If the diorite had been intruded as a separate magma, one would expect a considerably lower concentration of such elements as nickel, chromium, cobalt and copper than is found in the layered gabbro. Broadly speaking, however, this is not the case. The highest value for chromium, for instance, is found in gabbro which has been almost completely metasomatised. Irregularities in the analyses may be partly explained by local variations in the composition of the original gabbro, whilst the presence of diorite pegmatite indicates that at least some mobility of minor elements (i.e. heavy metals with low site preference in the common silicates) was associated with deuteric activity in the late stages of consolidation.

6.2.1 Manganese

The principal feature displayed by manganese is its increasing concentration as the gabbro is metasomatised to form diorite. Rankama and Sahama (1968) have observed that the dark silicate minerals which contain hydroxyl groups in their structures are the highest in manganese; hornblende, for instance, may contain up to 0.3% MnO. This increase in manganese, therefore, may be due to the increasing abundance of hornblende as the gabbro is metasomatised.

Daly (1933) quotes an average of 0.13% MnO for intrusive diorites, excluding quartz diorites, whilst if the latter are included this value falls to 0.09%. The values obtained in the Gröndalsfjell diorite, however, are considerably larger, and this again indicates a metasomatic rather than intrusive origin for the diorite.

6.2.2 Nickel, Cobalt

Nickel and cobalt may be conveniently considered together on account of their geochemical affinity. The analyses show that nickel is enriched in the more basic rocks, while cobalt is more evenly distributed.

In igneous rocks the nickel and cobalt contents, and the Co : Ni ratios are highest in the ferromagnesian minerals pryoxene and olivine, especially the latter. Nickel tends to increase with increasing magnesium content, and decrease with increasing iron content. This is due to the similarity in ionic radius between nickel and magnesium, and the disimilarity between nickel and ferrous iron:(Rankama and Sahama 1968): Mg : 0.78Å; Ni : 0.78Å; Co : 0.82Å; Fe : 0.83Å.

Rock	ppm Ni	ppm Co	Co : Ni
1. troctolite	303	194	0.64
2. metasomatised gabbro	129	190	1.47
3. " "	81	195	2.41
4. diorite	75	180	2.40
5. pegmatitic diorite	140	188	1.34
6. pegmatite vein	152	152	1.00
7. black dyke	115	193	1.68
8. greenstone xenolith	75	180	2.40

Taking the Co : Ni ratios, it is evident that, apart from the diorite pegmatite, cobalt greatly increases at the expense of nickel in the less basic rocks. Early researchers attributed this to the similarity in ionic radius between the divalent cobalt ion and the ferrous ion. Later work, however (e.g. Rankama and Sahama), indicated that it is very unlikely that ionic radii controll the Co : Ni ratios and the introduction of these elements into the structure of ferromagnesian minerals. It is probable that cobalt and nickel will enter any ferromagnesian structure formed at a certain moment in crystallisation, and that other factors, not yet understood, are responsible for the variation in Co : Ni ratios in igneous rocks (Landergren 1948)

Whatever the reason, however, nickel has been progressively depleted, and the Co : Ni ratio increased as metasomatism of the gabbro has proceeded, with the lowest nickel and highest Co : Ni values occuring in the diorite. Presumably, the reason for the decrease in nickel content is that as olivine and pyroxene disappear, nickel can still substitute for magnesium (and less so for iron) in the hornblende lattice, but not for calcium.

As with the other minor elements determined, nickel and cobalt are present in much greater amounts in the Gröndalsfjell diorite than in intrusive diorites, the averages in the latter being 40 and 32 parts per million respectively.

6.2.3 Chromium

Chromium is characterised by a high crystal field site preference, and in a normal differentiation sequence is concentrated in the early-formed rocks; besides forming chromite and chrome-spinel, chromium is also concentrated in the early-formed pyroxenes. Apart from a high value in the metasomatised gabbro W2 however, the behaviour of chromium in the Gröndalsfjell Gabbro is rather erratic. If one assumes a metasomatic origin for the diorite, then this can be explained by the fact that hornblende can quite easily inherit large amounts of chromium from earlier-formed minerals, since this metal can substitute for ferric iron and aluminium in the hornblende lattice; any excess chromium could be taken up by magnetite or ilmenomagnetite (Rankama and Sahama). Goldschmidt quotes an average chromium content in diorite of 68 parts per million, considerably less than that found in the Gröndalsfjell diorite.

6.2.4 Copper

Copper shows a rather irregular distribution in the analyses. The metal is chiefly present in igneous rocks as the cuprous ion, which has an ionic radius close to that of sodium and calcium. It would seem at first, therefore, that copper should substitute for these two elements. This is not the case, however, since the cuprous ion forms bonds of low ionic character. This helps to explain the irregular distribution of copper in igneous rocks generally. Another factor is the chalcophile nature of copper, so that it is concentrated in the suphide rather than in the silicate phases.

It is also possible for the cupric ion to substitute to a very limited degree for ferrous iron where there is insufficient sulphur present for the formation of a discrete sulphide phase.

In discussing the mineralisation of the area it has already been noted that small amounts of chalcopyrite are present in the layered gabbro. Larger amounts of copper sulphides are present in the diorite pegmatite, and this may be due to remobilisation and concentration of earlier sulphides during metasomatism of the gabbro.

The black dyke analysed also showed a high copper content, and this is possibly due to the fact that a few of the black dykes contain pyrite, with which the copper could be associated.

6.2.5 Conclusions

Abnormally high amounts of the transition metals chromium, nickel, cobalt, copper and manganese in the dioritic facies points to a directly metasomatic origin, at least in part, for the diorite by metasomatism of the original gabbro.

7. STRUCTURAL GEOLOGY

The work of the 1971 field party indicates a polyphase history of deformation in the region. The earliest recognisable period of deformation has produced a penetrative recrystallisation and schistosity in the supracrustal rocks and associated intrusives, and has been given the notation F1 for convenience. Field evidence and petrographic studies have shown that later folding and a limited degree of recrystallisation are superimposed on this earliest deformation, so that three distinctly separate periods of deformation can be recognised i.e. F1, F2 and F3 (see also Nicholson 1971).

7.1 Folding

Although folds are abundant in the surrounding rocks, they are almost absent in the Gabbro. Here, only a few instances of folding were observed, two being in greenstone xenoliths (Fig.41) on the northern margin of the Gabbro. These were F1-type features, with the axial plane cleavage infilled by epidote. If these features really represent F1 folds, then this would mean that the Gabbro was intruded after the F1 folding. In the north of the area, near the marginal fault, some of the diorite pegmatite veins exhibit what appear to be F2-type folds (Fig.42). That considerable strain was involved in the production of these folds is indicated by the well-developed hinge-thickening and limb-thinning of these features. Some folds show a slight rotation of the amphiboles towards the axial plane.

In the greenstones around the northeast margin of the Gabbro, the only structural feature to show any significant trend from

Fig.41: Greenstone xenolith (G) in coarse-grained diorite (D) at (72,780; 8,680); xenolith shows a possible F1 fold, the left-hand limb having been sheared off.

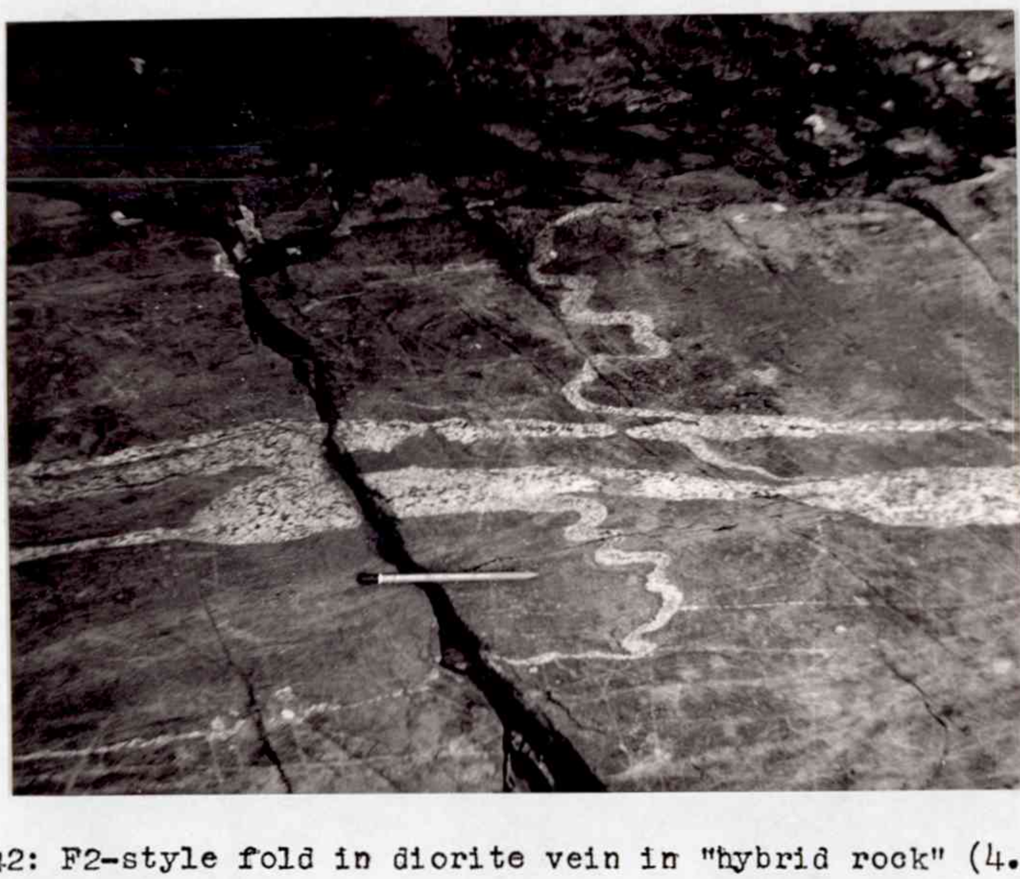
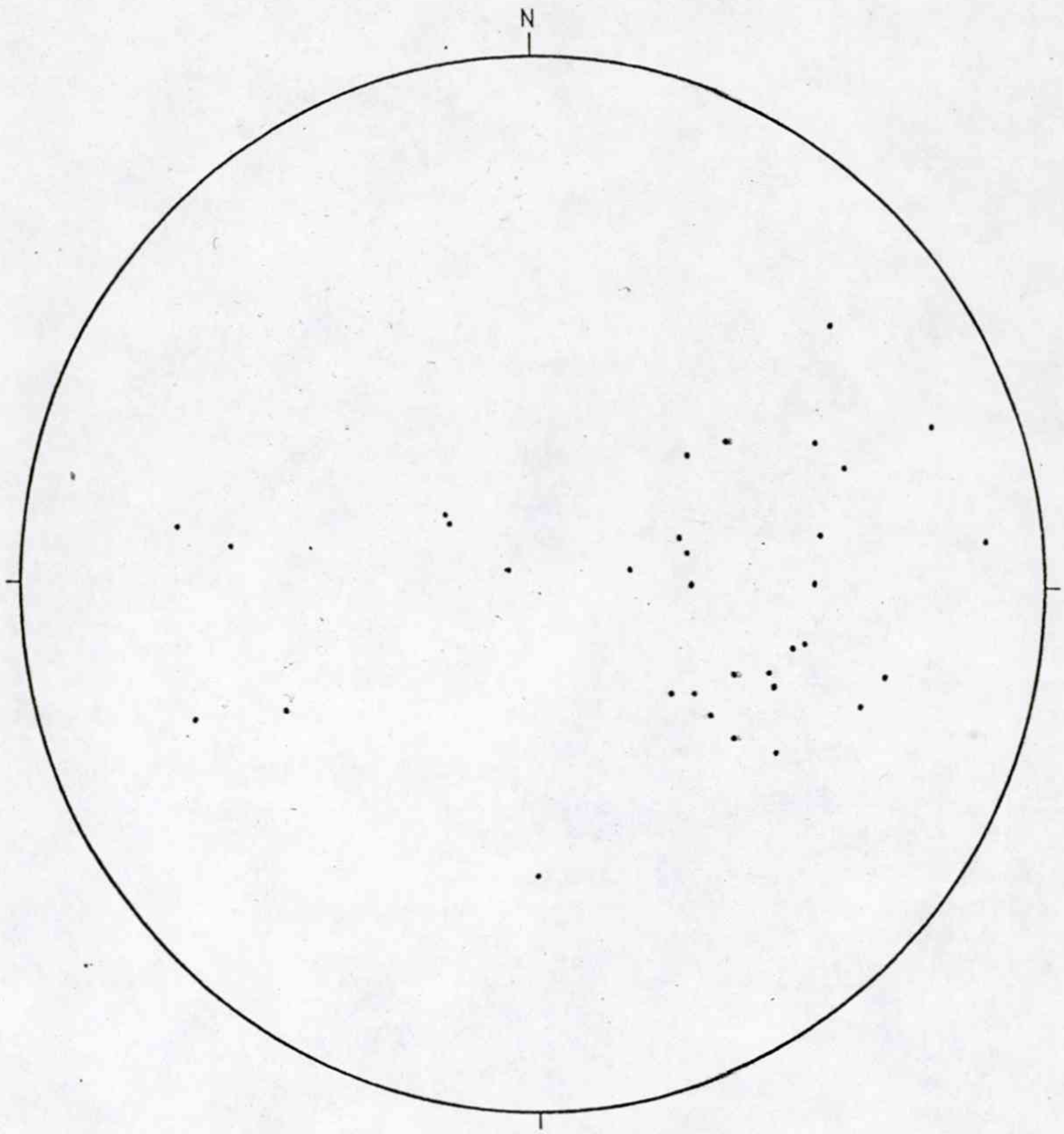
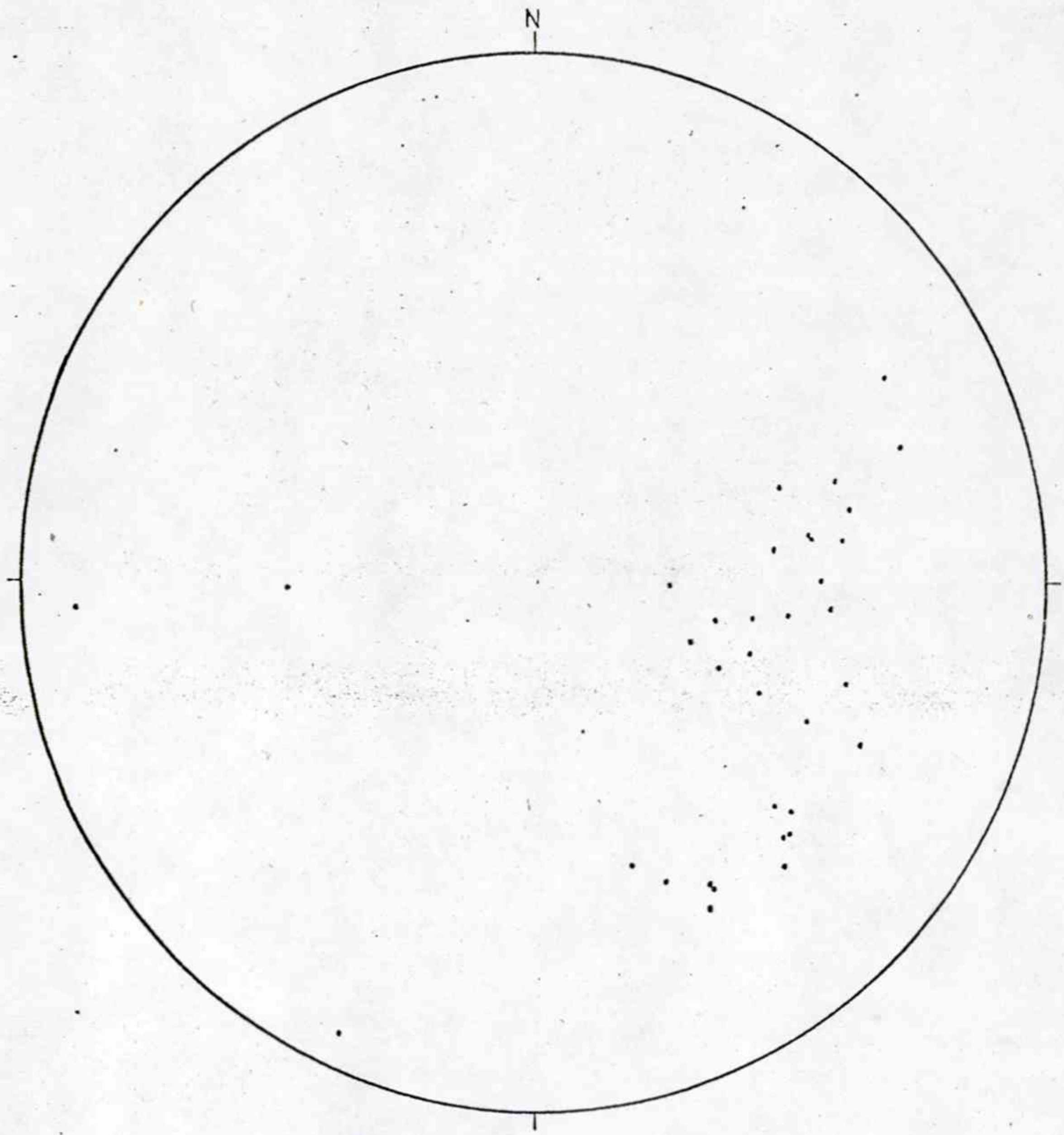


Fig.42: F2-style fold in diorite vein in "hybrid rock" (4.2.2) at (73,280; 8,570).



POLES TO S1 SCHISTOSITY
34 POINTS PLOTTED

Fig.43



POLES TO FRACTURE PLANES
34 POINTS PLOTTED

Fig.44

the measurements made is S1, which has an east-northeast - south-southwest trend (Fig.43).

7.2 Mineral Lineation

The amphiboles in the diorite sometimes exhibit a lineation, the trend of which varies irregularly. This feature is best-developed in the areas mapped as "flaser diorite". Small greenstone xenoliths may also be elongated in the same direction. The lineation may be displaced by small amounts along joints or fractures.

7.3 Fracturing

Fracturing in the Gabbro finds expression as joints or fractures, with little evidence of displacement. Whereas other more incompetant rocks in the area have undergone a more plastic deformation, such as the greenstones, the Gabbro has behaved in a much more competant manner. The extensive development of fractur fractures and trondhjemite dykes is therefore not found in the surrounding rocks, though a few large fractures with a similar trend do exist.

The general attitude and distribution of the fractures suggests a conjugate fracture system. The principal development of fractures, however, is in a northeast-southwest direction (Fig4 indicating that there was a greater component of tensile stress at right angles to this direction.

The fact that the diorite pegmatites, black dykes, trondhjemite dykes and fractures all have the same general attitude, and that many of the trondhjemite dykes are merely partial infillings of fractures, suggests that the same system of earthmovements was responsible for all these features.

Small joints are common in the Gabbro, particularly on the northern flanks, and are frequently infilled by epidote. These generally follow the same trend as the fractures, though they do offset a few of the latter.

It is clear that fracturing and infilling by dyke material took place at a late stage in the structural history of the Gabbro, whilst jointing and associated epidote veining were even later.

7.4 The Marginal Fault System

The nature of the marginal fault system varies: in the north of the mapping area one large, single fracture is present; further south, however, this developes into a complex fault zone, and is an imbricate feature. The dip is between 40 and 60 degrees to the west. To the south, however, in the area mapped by R. D. Scott, this feature either has an almost horizontal attitude, or else dips very gently to the west. Hence it is possible that the main marginal fault is not a fault at all, but a folded thrust plane, with the Gabbro having originally been thrust from a westerly direction.

7.5 Conclusions

The essentially massive and undeformed character of large areas of the main Gabbro mass contrasts strongly with the highly deformed and schistose character of the surrounding rocks to the east and northeast. Fracture cleavage affects the major part of the fresh layered gabbro, and despite alteration associated with this, penetrative deformation and recrystallisation under the influence of tensile stress has not occured. The gabbro-diorite mass can therefore be regarded tectonically as a body which contrasts strongly with its more yielding envelope.

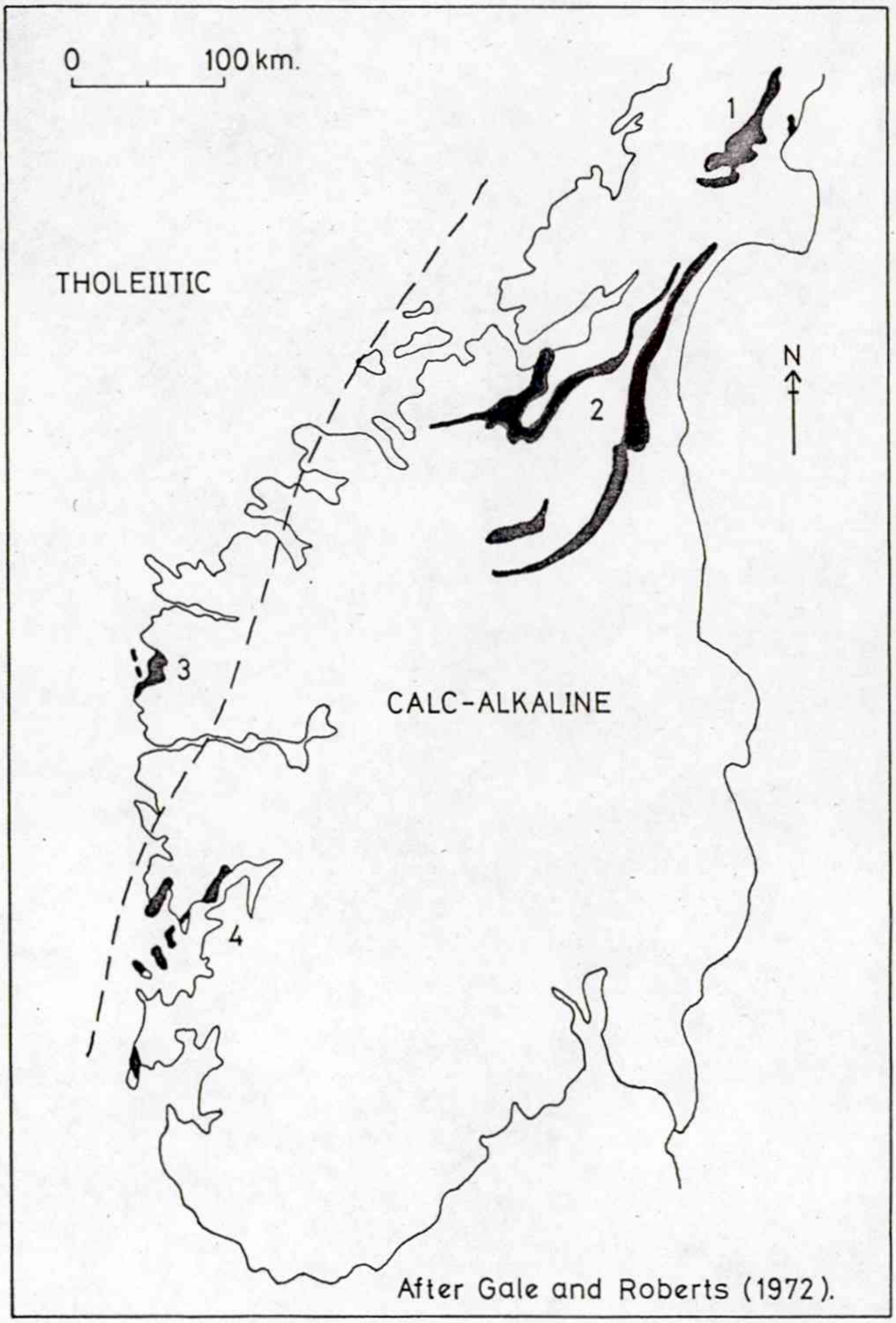


Fig.48: Location of main areas of Upper Cambrian - Lower Ordovician basaltic/andesitic volcanics in Southern Norway. 1: Grong region, 2: Trondheim region, 3: Solund region, 4: Bømlo-Hardanger region.

8. THE ORIGIN AND EMPLACEMENT OF THE GABBRO

8.1 Suggested Model

Greenstone belts of the Central Norwegian Caledonides, together with their associated gabbros and sulphide orebodies, have been identified as an ophialite sequence representing the location of a suture developed during the Caledonian collision orogeny (Dewey 1969). ?

This simple approach has been modified by Nicholson (1971), who demonstrates the essentially Scandinavian rather than American character, and the coherence of, the Pre-Cambrian basement underlying the Scandinavian Peninsula. Nicholson also suggests that the original site of any suture must have lain some distance off the present-day Norwegian coastline. The volcanic-intrusive rocks of the former Caledonian oceanic lithosphere, together with their associated sediments, would have been thrust eastwards over the basement provided by the Scandinavian continent, during the later phases of the orogeny.

Wilson (1966), Dewey (1969) and Gale and Roberts (1972) suggest that the extensive development of lower Palaeozoic greenstones in Southern Norway is related to the evolution of an island arc system following the closing of the proto-Atlantic ocean in late Cambrian/early Ordovician times. Analyses quoted by Gale and Roberts are said to show a lateral variation from calc-alkaline volcanism in the east to tholeiitic volcanism in the west (Fig.48). Recent work indicates a change from tholeiitic, through calc-alkaline, to alkaline volcanism in moving across island arcs towards continents, according to the depth of magma

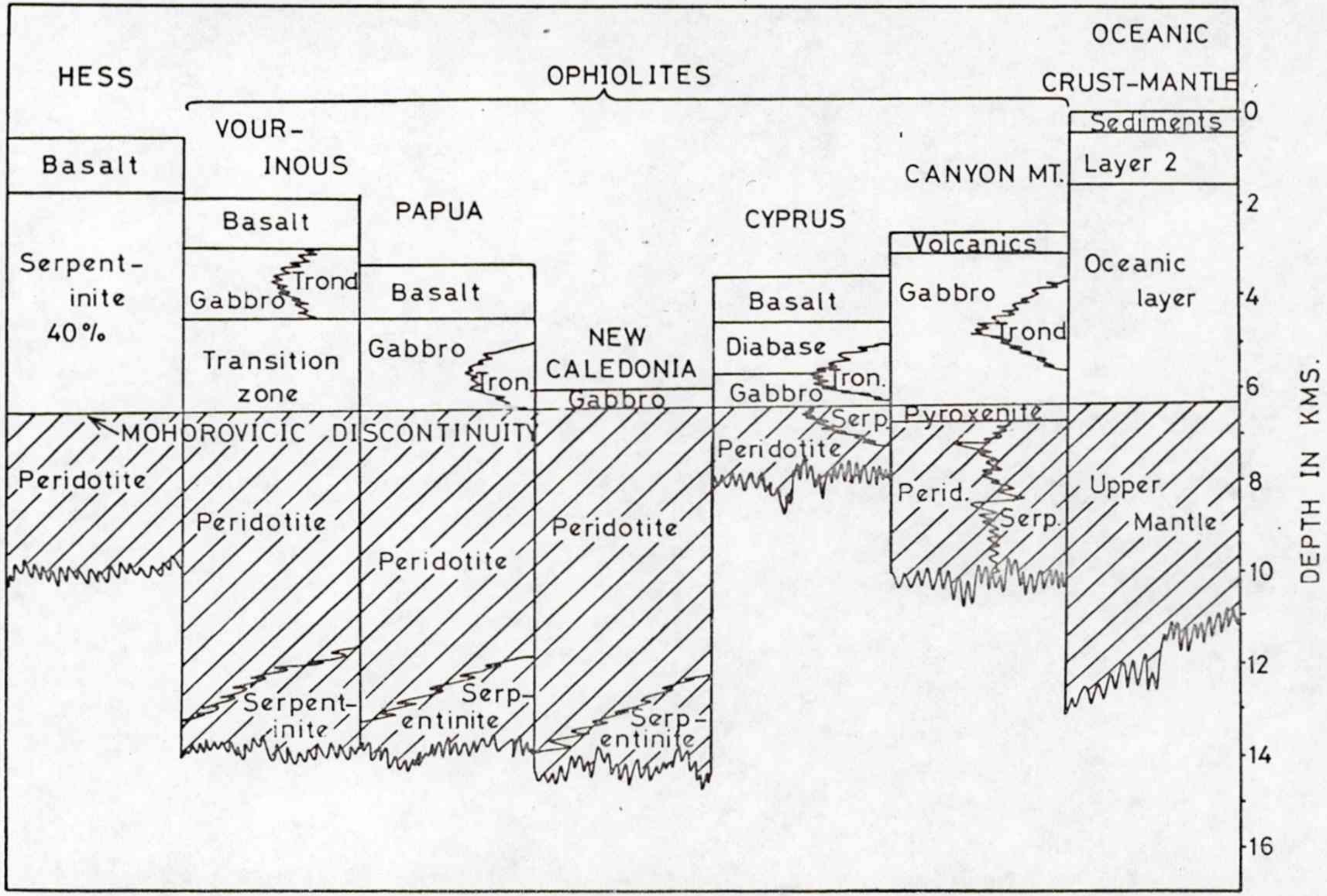


FIG.45 Comparison of igneous units from various ophiolite masses with the geophysical estimate of oceanic crustal layers.

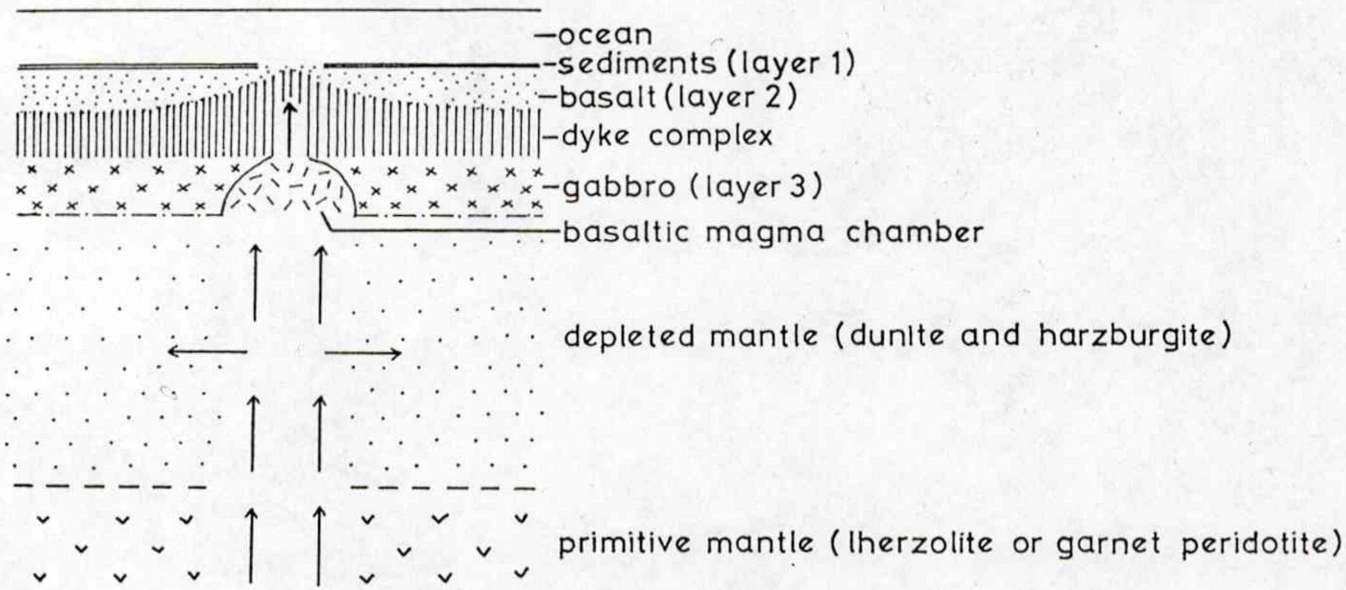


Fig.46: Upper 25 km. of oceanic crust and upper mantle at a mid-ocean rise (after Sillitoe 1972).

generation along a subduction zone (Kuno 1966).

The above model for the evolution of the Scandenavian-Caledonian orogen involves the consumpsion of oceanic lithosphere along a southeasterly-dipping subduction zone during the closing of the proto-Atlantic ocean. Partial melting of subducted lithosphere gave rise to the development of an island arc system, with the formation of a back-arc marginal ocean basin. The bulk of the Cambro-Silurian sedimentary/volcanic sequence may therefore have accumulated in a basin of this type.

If, from the comparisons presented in the following pages, the Gröndalsfjell Gabbro is considered as layer 3 oceanic crust in an ophiolitic suite, and if the above model is accepted, then it is possible that the Gabbro was emplaced in its present position as part of an ophiolite complex generated in a back-arc basin by the mechanism outlined in 8.3.

But Gabbro shows thrust contact to Greenstones below.

8.2 General Features of Ophiolites

Ancient sites of plate consumption are believed to be marked by linear belts of ophiolites lying along boundaries of lithospheric plates. A striking feature of the geological map of Nord Trøndelag (Fig.1) is the linearity displayed by many of the outcrops, especially the gabbroic rocks.

Well-developed ophiolite sequences generally consists of a number of distinctive lithological units. Ideally, three layers of oceanic crust pass downwards through a transition zone into an ultramafic assemblage probably representing upper mantle material (Fig.46).

Layer 1 of the oceanic crust consists of thin sequences of chert, shale and limestone, often with a metal-rich base. The haematite or magnetite-bearing chert or "jaspis" found at Skorovas may possibly be a partial equivalent of these ferruginous layer 1 sediments.

Beneath layer 1 are the dominantly extrusive basalts of layer 2. These are essentially tholeiitic in composition, with some hyaloclastite and alkali basalt. These rocks are commonly pillowed and spilitised. Pillow structures are difficult to identify at Skorovas due to the deformation suffered by the rocks. Spilitisation is apparent, however.

The rocks of layer 2 pass downwards into layer 3. The latter consists of cumulate, and sometimes foliated, gabbroic rocks. Diorites and trondhjemites may occur as discrete intrusive bodies in, or as diffuse facies of, the gabbro. The relatioship between gabbro and the overlying layer 2 basalts varies from intrusive to unconformable. The relationship between gabbro and diorite on Gröndalsfjell has already been discussed in 4.2.3.

There is frequently, though not necessarily, a transitional sheeted complex between layers 2 and 3, consisting of swarms of dolerite dykes. These dykes intrude both the lower parts of layer 2 and the upper parts of layer 3, whilst the central portion of the sheeted complex may consist entirely of dykes. It is thought that these features represent the feeders to the layer 2 basalts. This dyke complex may be represented on Gröndalsfjell by the extensive development of black dykes.

Beneath layer 3 are the ultramafic rocks of the upper mantle. These consist of varying proportions of dunite, harzburgite and lherzolite. When tectonically emplaced, these may be strongly banded, foliated and tightly folded.

The complex transition zone between the upper mantle and layer 3 is known as the Mohoroviçic Discontinuity or "Moho". This is characterised by cumulate and interlayering and intrusive relationships between the basic and ultrabasic rocks (Reinhardt 1969, Dewey and Bird 1971).

Ultramafic rocks of ophiolitic affinity are absent in the Skorovas region, but to the east of the marginal fault system the meta-gabbro contains patches of talc schist and amphibolite which may possibly represent metamorphosed peridotite incorporated in gabbro as a subduction mélange (see below).

In addition to, the features described above, it is interestin to note, in connection with the marginal fault system of the Gabbro, that faulted or thrust contacts between major units are common in ophiolites (Penrose Field Conference 1972).

Metamorphic effects in and around ophiolite complexes are many and varied, and are probably due to processes taking place during both genesis and tectonic emplacement. Many of the complex internal igneous, structural and metamorphic relationships, howeve are probably related to genesis, and not to processes operating in the orogenic belts in which ophiolites are finally emplaced (Dewey and Bird). These effects may include thermal and hydrothermal alteration at the site of origin, amphibolite to blueschis facies metamorphism due to subduction, and regional thermal metamorphism (Miyashiro 1972). The latter may result from high heatflow at the mid-ocean ridge before the oceanic crust moves down the cooler flanks, or else may be due to high-temperature metamorphism in an island arc environment. As mentioned above, spilitisation of layer 2 basalts is another feature of ridge metamorphism, and is possibly due either to reaction between tholeiitic lava and sea water, or to post-cooling hydrothermal

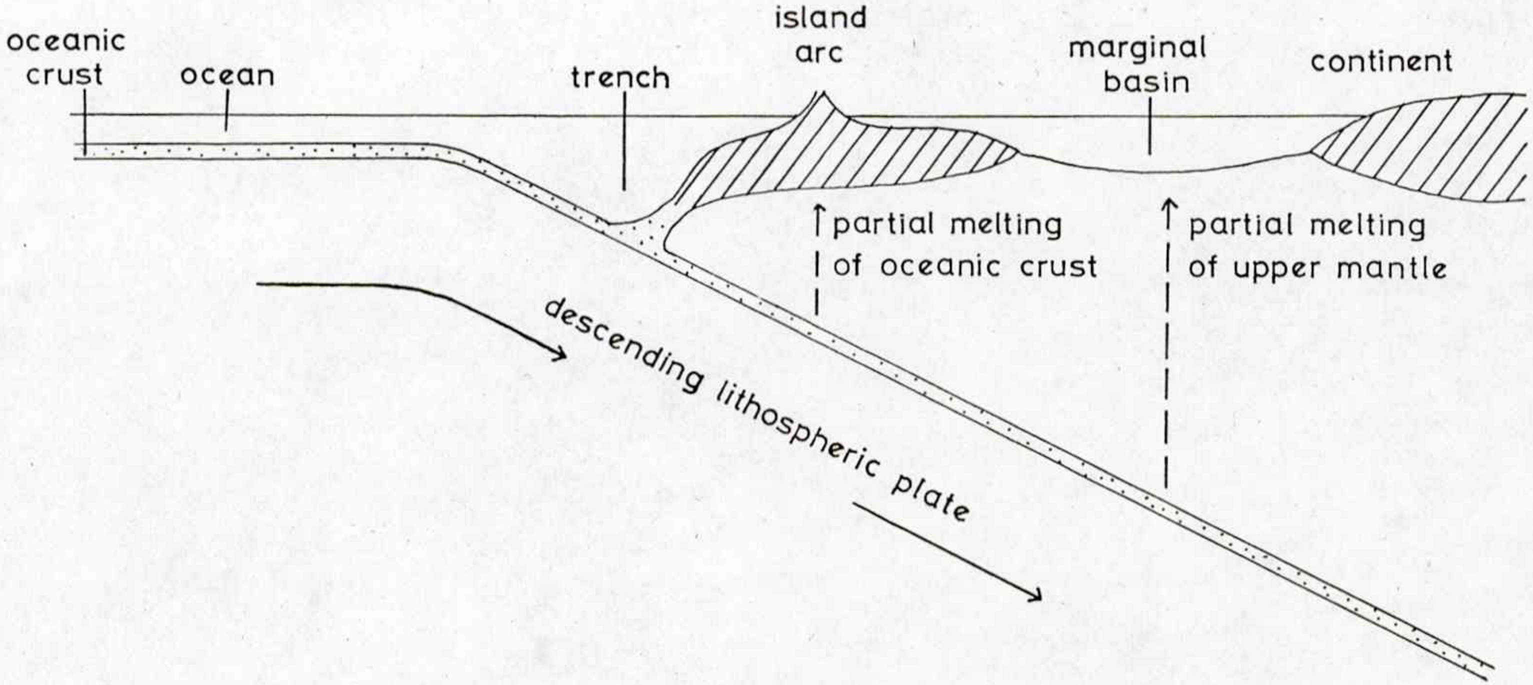


Fig.47: Possible mechanisms for ophiolite emplacement.

alteration. According to some authors, spilites may be crystallisation products of primary magmatic differentiation (e.g. Battey 1956); the unlikelyhood of a spilitic magma has been confirmed experimentally, however, by Yoder and Tilley (1962) and Yoder (1967).

8.3 Origin and Emplacement of Ophiolites

From work on known ophiolite complexes throughout the world, from drilling and dredging on mid-ocean ridges, and from geophysical data, it is now generally believed that ophiolites are fragments of oceanic crust and upper mantle tectonically emplaced in orogenic belts.

Kay and others (1970) envisage the partial melting of primitive upper mantle material (lherzolite or garnet peridotite) beneath the ridge axis. This melting yields a tholeiitic liquid at a depth of between 25 and 30 km.. This leaves a depleted residu consisting essentially of olivine and orthopyroxene (dunite and harzburgite). The tholeiitic liquid ascends to form a magma chamber, with the resulting crystallisation of gabbro and the formation of a cumulus texture. This magma gives rise to a dolerit dyke swarm which feeds the overlying layer 2 basalts.

The oceanic lithosphere is then transported away from the ridge by sea-floor spreading, until it is thrust beneath island arcs or continental margins along subduction zones (Fig.47). In this connection, it is difficult, according to Dewey and Bird, to account for sheeted dyke complexes except by a sea-floor spreading mechanism. During subduction, material may be torn from the descending plate and tectonically emplaced behind or beneath trenches, giving rise to ophiolites. It is possible that ophiolite may also be emplaced by overthrusting or "obduction" of slices of oceanic lithosphere onto the edges of island arcs or continents. This might be due to the collision of a continent with a subduction zone dipping away from it. If the above model is accepted, however, this could not have occured, since the proposed subduction zone would have dipped to the southeast i.e. towards the Scandinavian continent.

Ophiolites may also be generated in marginal ocean basins. Here, slow, diffuse spreading involves the movement of island arcs away from continental margins. Diapirs of mantle material are generated in a zone of mantle instability above a descending plate, and undergo partial melting to yield a basaltic liquid which is alkaline at depth and tholeiitic at shallower levels (Kuno).

8.4 Metallogeny of Ophiolites

Metallogeny in ophiolites is manifested in three principal ways:

1) alpine-type podiform chromite deposits associated with basic and ultrabasic rocks,
2) magmatic copper-nickel sulphide deposits associated with basic rocks,
3) massive copper and zinc-bearing pyrite orebodies associated with hydrothermal activity.

These types are numbered in chronological order, with pH_2O increasing from (1) to (3).

The original geometry of these bodies may be strongly modified by structural mechanisms operating during tectonic emplacement.

With regard to the mode of formation of the massive pyrite orebodies, Sillitoe (1972) suggests that metal-bearing hydrothermal fluids are released during the final stages of crystallisation in the magma chambers underlying the layer 2 basalts; these magma chambers are represented in ophiolites by gabbro complexes. The massive sulphide orebody at Skorovas, therefore, may owe its origin to hydrothermal fluids derived from the Gröndalsfjell Gabbro. Sillitoe also states that metals could be released from layers 2 and 3 during metamorphism beneath the ocean floor, or during leaching by hydrothermal fluids or heated sea water. The Gröndalsfjell Gabbro is certainly poor in copper when compared with similar rocks, so that it is possible that a certain amount of leaching has taken place.

These deposits are subsequently transported away from their site of origin at or near the mid-ocean ridge by sea-floor spreading. Sillitoe suggests that only a minority are incorporated into island arcs or continental margins, but that most are subducted. During subduction, some of these deposits may be incorporated into continental crust as parts of slices of oceanic lithosphere (ophiolites).

Massive sulphide deposits may also be associated with calc-alkaline volcanism along island arcs or continental margins which have been, and may still be, underlain by subduction zones. Such deposits appear to be richer in lead, zinc, silver and barium than those associated with ophiolites. In this connection, silver and barium minerals have not been found at Skorovas, whilst lead (present as galena) is only present in subordinate amounts (Gjelsvik 1960).

9. CONCLUDING STATEMENT

As stated in the introduction, the mountain of Gröndalsfjell comprises a large gabbroic mass about 8 km. across. Further to the southwest, and probably part of the same mass (the two outcrops are separated by drift) is a much larger gabbroic body several tens of kilometres across, and centred on the imposing mountain known as Heimdalshaugen. There are also numerous small gabbroic and dioritic bodies in the immediate vicinity of Skorovas, one of which, on Lillefjellklumpen, contains the massive pyrrhotite body examined by Q. G. Palmer in 1971. Small areas of disseminated pyrrhotite mineralisation also occur on Gröndalsfjell.

These basic intrusives have still to be examined in detail. Such examination, in addition to yielding much information concerning the intrusive and metamorphic history, and the geological evolution of, the area, might also prove rewarding from an economic point of view. The Author hopes, therefore, that this preliminary investigation will stimulate further research in the area, and prove helpfull to those who undertake such work.

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APPENDIX 1: ANALYTICAL PROCEDURE

1) The bulk sample is hand crushed to -20 mesh (710 microns), and then crushed further to -100 mesh (142 microns), a representative sample being obtained by the "quartering" method.
2) A sample of 400 milligrams is weighed out and placed in a polythene beaker.
3) 5 millilitres of deionised water is added to wet the sample.
4) The following acids are then added to reduce the sample:
   2 ml. of concentrated nitric acid (HNO_3),
   3 ml. of perchloric acid ($HClO_4$),
   7-10 ml. of hydroflucric acid (HF).
5) The samples are then evaporated to dryness by leaving overnight on a thermostatically-controlled hotplate.
6) The residue is dissolved in 10 ml. of 2M hydrochloric acid, a roughly equal amount of deionised water added, and warmed.
7) The solutions are then transfered to 100 ml. flasks and made up to volume with deionised water.

For soda and potash a preventative interference agent is added, consisting of a mixture of ammonium carbonate ($(NH_4)_2CO_3$) and ammonium hydroxide (NH_4OH). A few millilitres of this is added to a suitable aliguot and the sample is diluted to a second stock solution.

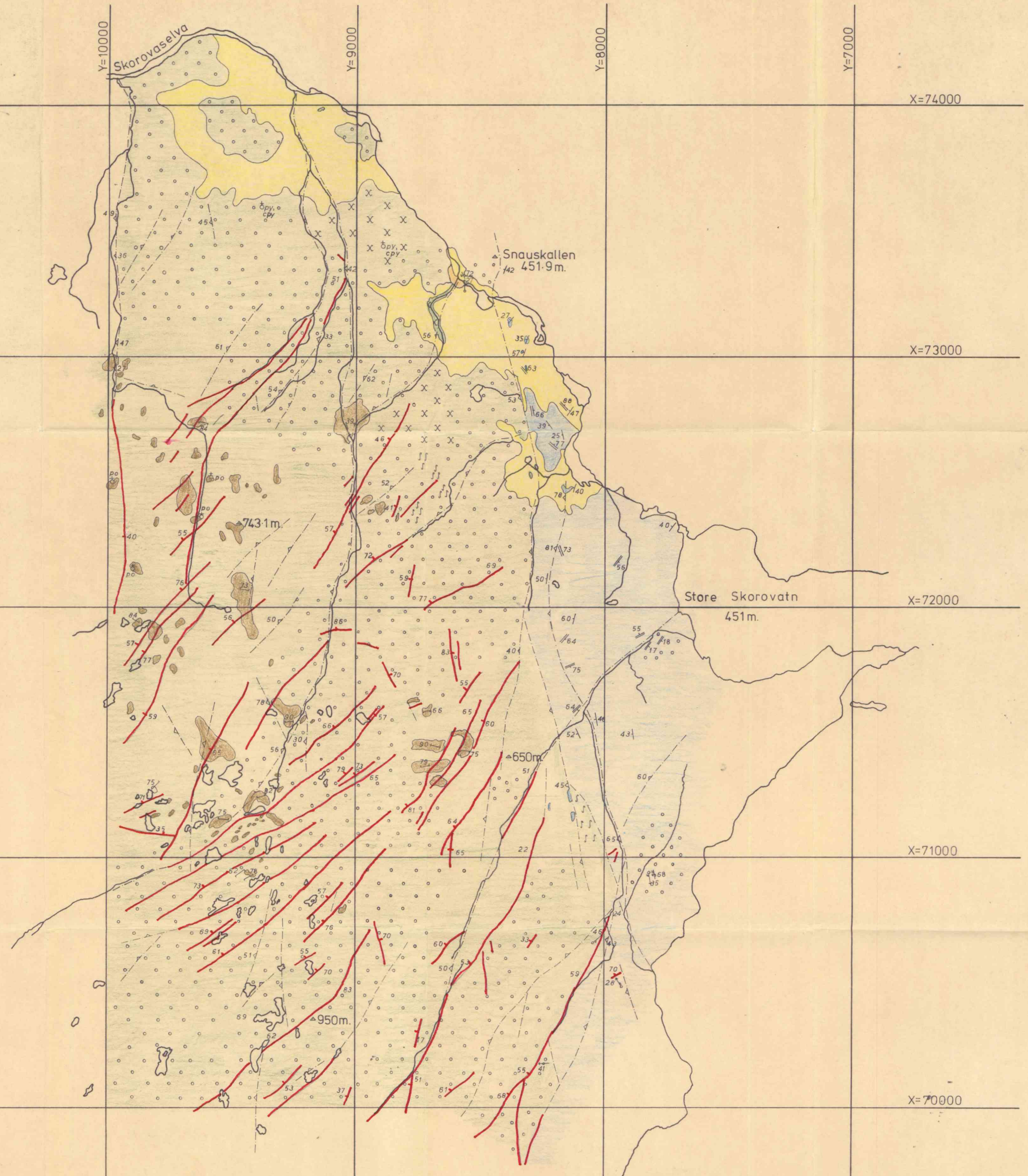
For the oxides of calcium, magnesium and iron (total Fe_2O_3), the interference addative is a lanthanide reagent (La_2O_3).

The samples were analysed using the Pye-Unicam SP90 atomic absorption spectrophotometer. Accuracy was checked by the introduction of known standards; discrepancies proved negligible, however.

APPENDIX 2: SAMPLE LOCATIONS

Thin section number	Mentioned in section	Y coordinate	X Coordinate
G21a troctolite	4.1.1		
G21b troctolitic gabbro	4.1.2		
G8c hypersthene gabbro	4.1.3		
PW113d metasomatised gabbro	4.1.5	72,730	9,630
PW 154a " "	"	71,900	8,700
PW 128 " "	"	70,200	8,750
PW 217 fine-grained gabbro	4.1.4	72,500	9,980
PW 85b medium-grained diorite	4.2	72,740	8,840
PW 85c fine-grained diorite	"	"	"
PW 104 hybrid rock	4.2.2	73,280	8,570
PW 156 black dyke	4.3	71,780	8,750
PW 38b porphyritic black dyke	"	71,400	8,550
PW 157f micronorite dyke	4.4	71,740	8,860
G6 trondhjemite dyke	4.5		
G1A " "	"		
PW 23 " "	"	70,950	8,300
PW 18 " "	"	71,030	7,940
PW 151 mylonite	4.5.2	72,150	8,850
PW 46 xenolith (lava)	4.6	71,500	9,100
PW 81 " (granodiorite)	"	72,780	8,680

Polished section number	Mentioned in section	Y coordinate	X coordinate
G30 pyrrhotite-bearing gabbro	5.1		
PW114 " " "	"	72,480	9,600
PW113a brown weathered gabbro	"	72,730	9,630
PW 115 " " "	"	72,320	9,650
PW 215 " " "	"	72,150	9,900
PW 79 coarse-grained diorite	5.2	72,750	9,020
PW 108 diorite pegmatite	"	73,425	8,730
PW 108b " "	"	"	"
PW 38c black dyke	5.3	71,400	8,550
Analytical sample number			
W1 troctolite	6.		
W2 metasomatised gabbro	"	73,425	8,730
W3 " "	"	72,500	9,100
W4 coarse-grained diorite	"	70,200	8,750
W5 pegmatitic diorite	"	73,425	8,730
W6 pegmatite vein	"	71,400	8,550
W7 black dyke	"	73,430	8,720
W8 greenstone xenolith	"	69,970	8,480



GEOLOGICAL MAP OF SÖNDRE GRÖNDALSFJELL

N

SCALE 1:10000

0·5 0 0·5 1km.

LEGEND

- Layered gabbro
- Diorite and metasomatised gabbro
- Inclusions of country rock
- Greenstones
- Calc schists
- Quartz diorite
- Diorite pegmatite
- Flaser diorite
- Trondhjemite dykes
- Drift

- Undifferentiated fold axis
- F_1 fold axis
- F_2 fold axis
- Quartz rod
- Axial plane of undifferentiated fold
- F_1 axial plane
- F_2 axial plane
- Layering
- Penetrative schistosity S_1
- Fracture cleavage S_2
- Flattening direction
- Fault

Mineralisation:
- py pyrite
- po pyrrhotite
- cpy chalcopyrite

P.T. WALKER R.S.M. 1972

Antall	Gjenstand	Nr.	Material	Anmerk.
	GEOLOGICAL MAP			Målestokk / Tegn. / Trac. / Kfr.
				Erstatning for:
Dato	ELKEM A/S SKOROVAS GRUBER			P.T. WALKER.
Forandr.				Erstattet av: