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Tittel

The Geology of an Area of Molybenum Mineralisation within the Norwegian Caledonides - Fremstfjell, Grong District, N Trøndelag

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Geologi Boring		Fremstfjell Smaltjern Cyprostjern

Råstoffgruppe	Råstofftype
Malm/metall	Cu,Mo

Sammendrag, innholdsfortegnelse eller innholdsbeskrivelse

BSc & BSc (Hons) Degree in Geology at Dept of Geology, Portsmouth Polytecni

Hensikten med avhandlingen var å avklare omfang og type Mo-mineralisering i Femstfjell.
Mineraliseringen finnes innen en intrusiv leucotrondhjemitt og granodiorit, sammen med grønnsteiner av Gjersviktypen. Det er en porfyr mineralisering av calk-alkaline type. Molybdenitten finne disseminert i et uregelmessig stockverk av kvarts og kvarts/py årer og som smurt ut på sprekkeplan.
Mineralisering i to faser og eksisterer i en serie nedforkastede blokker som tynner mot øst og utvider seg mot nord. Innen det modellområdet som er undersøkt er beregnet 8700 tonn Mo ved 0,05% Mo.

PORTSMOUTH POLYTECHNIC

DEPARTMENT OF GEOLOGY

THE GEOLOGY OF AN AREA OF MOLYBDENUM MINERALISATION
WITHIN THE NORWEGIAN CALEDONIDES - FREMSTFJELL,
GRONG DISTRICT, N TRONDELAG

Name: R N HOCKING

Course: BSc & BSc (Hons) CNAA Degree in Geology

Year: III (1982)

THE GEOLOGY OF AN AREA OF MOLYBDENUM MINERALISATION WITHIN THE NORWEGIAN CALEDONIDES, FREMSTFJELL, GRONG DISTRICT NORD-TRØNDELAG

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1982

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ABSTRACT

The aim of the project was to determine the extent and type of molybdenum mineralisation at Fremstfjell, near Grong, Nord-Trøndelag on behalf of Grong Gruber A/S. Using this information the possibilities for an ore body were then to be considered.

The author has concluded that the mineralisation occurs with the intrusive leucotrondhjemite and granodiorite associated with the Middle Greenstones of the Gjersvik Group and that it is a calc-alkaline porphyry-type mineralisation of the subduction-related variety. The molybdenum occurs as disseminated molybdenite in a discontinuous stockwork of quartz and quartz/pyrite veins and as dry 'paint' along joint planes and fractures in the host rocks, these veins showing no preferred orientations, as such. Two major phases of molybdenisation existed produced by hydrothermal solutions intruding the igneous rocks and enclaves of the greenstone cover, but rarely in the meta-volcanic allochthon.

Information obtained from boreholes indicated an ore body at depths from 0-70 m composed of a series of downfaulted blocks that dip and broaden towards the north, thinning eastwards - the western extent of which was not determined. The area contained within the model proposed would produce 8,700 tonnes of molybdenum at 0.05% concentrations of the element, although the ore body extended beyond the area covered in this model.

CHAPTER 1

INTRODUCTION AND STRATIGRAPHY

INTRODUCTION

Grong is situated approximately 150 km North-East of Trondheim (Figure 1), Nord-Trøndelag. It lies in a large valley at the convergence of the Sanddøla and Namsen rivers, the latter being the principal river in the district. It is surrounded by steeply rising mountains attaining a maximum height of 1160 m in the North.

The field area, 25 km east of Grong, is set in the mountainous terrain of the Caledonides. The Sanddøla occurs along the southern contact of the Caledonides with the Precambrian of the Grong Culmination, 5 km to the south.

TOPOGRAPHY AND VEGETATION

The area under investigation lies at a height of 640 to 690 m, above the tree line, and exhibits typically post-glacial topography (Photographs 1 and 2). The ground is generally smooth with well-rounded peaks to the higher areas and post-glacial lakes in the depressions. Frost action has emphasised jointing, producing a tabular appearance to the rocks, which occasionally show evidence of ice gouging. They are deeply weathered often with zones of rusting when mineralised.

The vegetation is generally sparse and tundra-like with about 30-40% rock exposure and thin soils. Mosses and heather predominate, which support reindeer, and often patches of dwarf birch.

In the lower areas marshes occur containing sphagnum mosses and rushes. Little other vegetation exists apart from the occasional occurrence of Lychnis alpina (the "Northern Copper Flower") which thrives on cupriferous soils.

Photograph 1: View west across Cyprustjern showing the general topography.

Photograph 2: View southeast across the field area from southwest of Kortjern.

Photograph 3: View southeast from the triangulation point showing the more barren Grong Culmination to the south.

REGIONAL GEOLOGY AND STRATIGRAPHY

Caledonian rocks extend for almost the entire length of Norway, except for the southern tip which is composed of Precambrian rocks (Figure 1).

The Grong district (Plate 1) forms a large depression within the Norwegian Caledonides between two Precambrian massifs, Børgefjell to the north and the Grong culmination (Photograph 3) bordering the southern part. It is composed of great thicknesses of eugeosynclinal deposits of assumed Precambrian to Silurian age that can be divided into three main tectonostratigraphical units (after Kollung 1979) (Table 1); an eastern and lower, a central, and a western and upper complex. The Eastern Complex consists of the Seve Nappe of probable Precambrian (? to Cambrian) age, and a lower Køli Nappe overlying it with Ordovician and Silurian rocks. The Central Complex composed of the Rantser Nappe is thought to be inverted and of Cambrian to Silurian age. The Western Complex is inverted and comprises the Ordovician Limingen Nappe and the overlying Helgeland Nappe consisting of rocks of assumed Precambrian (? to Cambrian) age. The field area lies essentially within this latter complex.

STRATIGRAPHY OF THE WESTERN COMPLEX

Three groups in an inverted position constitute the Western complex; the Namsen group, Gjersvik group and the Limingen group (Table (ii).)

NAMSEN GROUP

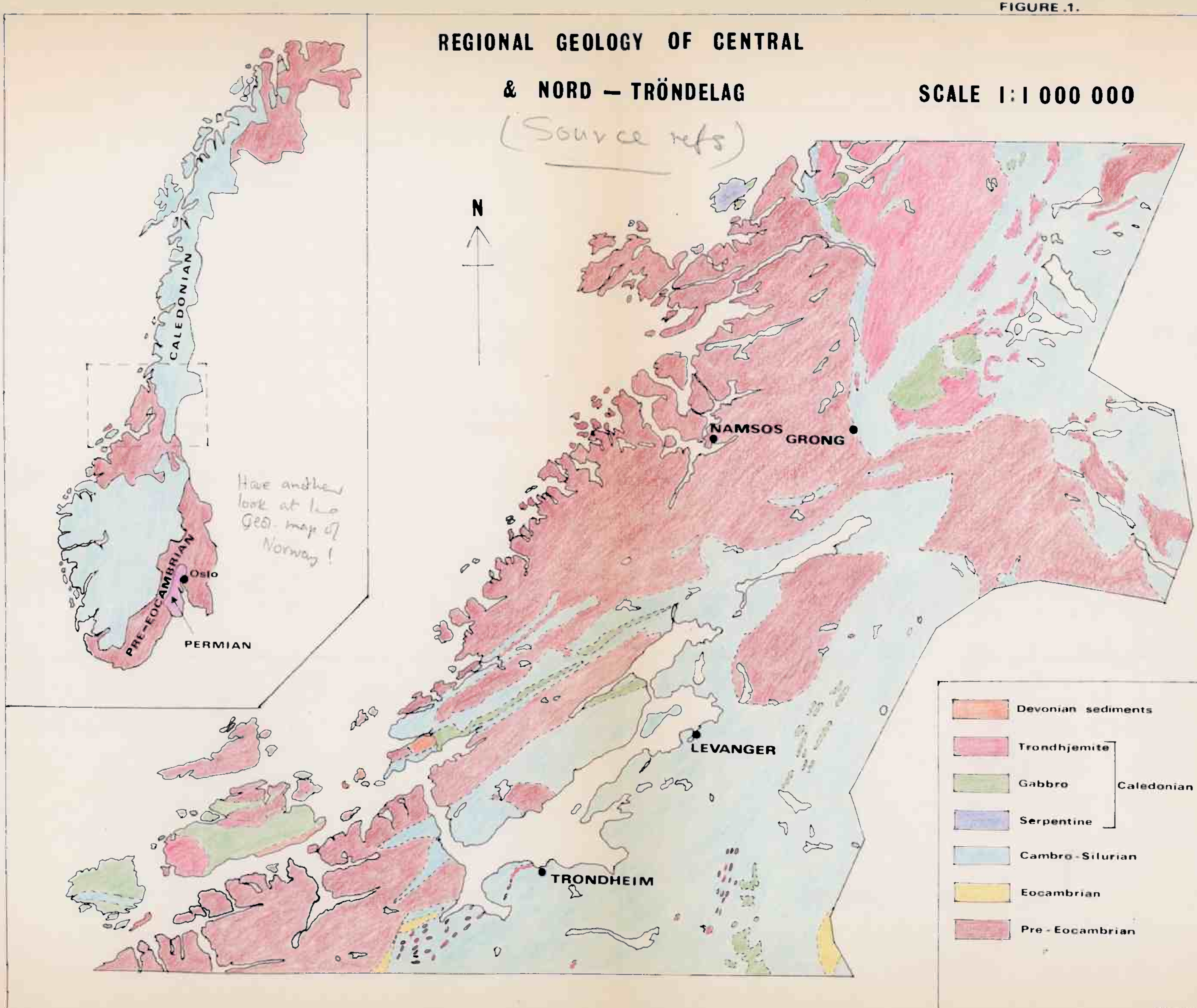
This particular group lies within the Helgeland Nappe. It is composed of garnet mica schists, limestones, and amphibolites in the north at Steinfjell. These rocks have undergone a lower amphibolite facies metamorphism, the grade increasing to the south producing gneissic rocks in the Tromsfjell-Tunnsjødal area which have in turn been heavily intruded by granodiorite.

FIGURE .1.

REGIONAL GEOLOGY OF CENTRAL & NORD – TRÖNDELAG

SCALE 1 : 1 000 000

(Source refs)



WESTERN COMPLEX	HELGELAND NAPPE	Namsen Group
	LIMINGEN NAPPE	Gjersvik Group
		Limingen Group
CENTRAL COMPLEX	RANTSER NAPPE	Røyrvik Group
		Huddingsdalen Group
EASTERN COMPLEX	LOWER KOLI NAPPE	Renselvann Group
		Nordli Group
	SEVE NAPPE	Hartkjølen Group
		Daergafjell Group
BASEMENT		

Table (i); Stratigraphical units of the Norwegian Caledonides in the Grong district (after Kollung 1979).

In the Grong area the group is only thinly represented by high grade mica schists containing garnet and kyanite. This is the Namsen formation of Gale (1975).

GJERSVIK GROUP

The Gjersvik group contains most of the mineralisation of the district. It is divided into six fairly distinct units. However, in no area do all six occur together.

The units consist predominantly of volcanic rocks, with large masses of intrusives. Basic volcanics (now greenstones and amphibolites) are the most widespread, but abundant acid and some intermediate volcanics are also present.

Metamorphism increases to the south and west at increasing stratigraphical depths. In the Steinfjell-Gjersvik area units (2) and (3) (Table (ii)) are probably hornblende rocks within the garnet zone, whereas units (4), (5) and (6) lie in the biotite with transitions to the chlorite zone. In the southern part of the district (2) and (3) are not present, however, the increase of grade is evident from Unit (4) which, south of Tunnsjødal is in the garnet zone. The volcanics of the Grong area probably lying in the amphibolite facies.

Unit 1 - Banded Hornblende Gneiss

It occurs from west of Tromsvann southwards to Grøndalen. The rock exhibits a well-developed foliation enhanced by alternating bands of melanocratic amphibolite to a more leucocratic quartz-dioritic material also containing hornblende. This gneissic lithology could represent metamorphosed volcanics in which case the banding could indicate original tuffs.

Unit 2 - Banded Amphibolite

This banded amphibolite is continuous from the northern end of the district to south of Lille Tromselv. It is probably a product of recrystallisation as there is no apparent evidence for any intrusive origin.

8. Cacl-phyllite/sandstone, often conglomeratic. 7. Polymict greenstone conglomerate. 6. Banded calc-phyllite/sandstone or siltstone. 5. Highly calcareous arkose, partly conglomeratic. 4. (Calcareous) arkose, partly conglomeratic. 3. Calc-phyllite, sandstone, siltstone, often banded local greenstone, greenschist. 2. Highly calcareous conglomerate. 1. Polymict conglomerate, local limestone.	LIMINGEN GROUP (Middle (?) and Upper (?) Ordovician)
6. Younger Greenstone. Mostly Mg/Ca-rich lavas. Minor tuffs and agglomerates. Keratophyres. 5. Middle Greenstone. Mostly Fe-rich lavas. Minor tuffs and agglomerates. Keratophyres. Between Limingen and Ingulsvann with phyllite, sandstone, siltstone. Finnbu formation in Sanddøla - tuffs, phyllite, hornblende porphyroblasts, schists, quartzite, limestone. 4. Older Greenstone. Amphibolitic towards south. Mostly tuffs, minor lavas, local agglomerates. Keratophyres. 3. Homogeneous amphibolitic greenstone. 2. Banded amphibolite. 1. Banded Hornblende Gneiss.	GJERSVIK GROUP (Lower (?) Ordovician)
Mica Schist or Gneiss, with limestone and amphibolite.	NAMSEN GROUP ((?) Pre-cambrian)

Table (ii): Stratigraphy of the Western Complex (after Kollung 1979).

Unit 3 - Homogeneous Amphibolitic Greenstone

This unit occurs from north of Bjorkvann to Tromsfjell. In the southern portion, near Tromsdal, it is highly deformed producing large isoclinal folds. It has a diffuse boundary with unit (4), but a sharper contact with (2) indicating a volcanic origin.

Unit 4 - Older Greenstones

These greenstones are continuous over great distances. They are actinolite-rich and possess three varieties of banding:

i) Leucocratic bands of plagioclase ± quartz,

ii) Green bands of epidote ± chlorite,

iii) Melanocratic bands which are hornblendiferous.

They may represent tuffaceous deposits.

Keratophyres are fairly abundant in this unit. These are micaceous and may have initially been tuffs. One particular horizon, up to 500m thick, appears to be the youngest member of the Older Greenstones as it is in contact with the Middle Greenstones.

Unit 5 - Middle Greenstones

Unit 5 is the thickest of the Gjersvik Group. The main northwest outcrop is continuous southwards to Nesadalen where it is intruded by a large trondhjemite in the field area. To the southeast three greenstone units within the Limingen group could be correlatives of this particular unit.

The main constituents are lavas of basaltic to andesitic composition. These are fine grained, massive to schistose rocks commonly incorporating amygdaloidal and porphyritic textures with plagioclase and amphibole phenocrysts. Epidote-rich segregations are numerous and generally small although larger examples occur occasionally, possibly representing original pillow structures. However, good pillows are rare.

Tuffs are the major constituent in the field area and its immediate vicinity (Gale 1975). However, they are subordinate to lavas in the lower Sanddøla.

In the northern parts of the district the metamorphic grade lies in the chloritic zone of the greenschist facies with transitions to the biotite zone. To the south, in the Sanddøla the grade is undetermined.

The mineralogy of this unit is essentially plagioclase (secondary albite); chlorite and epidote with actinolite, quartz, biotite, calcite and stilpnomelane as accessories. The rocks show a high content of opaques especially with respect to magnetite and pyrite, often accounting for as much as 10% of the rocks composition.

Keratophyres are abundant in the northwest, but secondary in south/east trending belts. They contain plagioclase quartz, muscovite, chlorite and pyrite. Darker green chloritic varieties exist which may be transitions to the quartz-rich greenstones. Their origin is difficult to determine, their extensive thicknesses could indicate derivation from pyroclastics plus locally they can appear agglomeratic.

Thin beds of quartz-rich cherts containing magnetite or haematite are often associated with the acid volcanics. Other sediments are only seen in the northeast belt of the greenstone within the Limingen Group. At Ingulsvann part of the unit consists of phyllites, metasiltstones or dark green sandstones.

Finnbu Formation

This is a local, but thickly developed unit between Bergfoss and Trangen, in the Sanddøla, just south of the field area. It is a tuffitic/sedimentary sequence up to 1000m thick and stratigraphically situated between the Middle Greenstone and the Røyrvik group. The major lithologies of this formation are greenschists, calcareous schists, phyllites, thin lavas, keratophyres, quartzites and a persistent limestone. Many of the rocks characteristically containing hornblende porphyroblasts.

Unit 6 - Younger Greenstones

Generally, this unit is in direct contact with the Limingen Group, however, in the northwest it is infolded with middle greenstone.

It is more leucocratic and coarser grained that unit (5) with a weak penetrative cleavage. It has much calcite with little or no magnetite or pyrite and very little quartz or stilpnomelane. Basaltic lava is dominant, commonly showing pillow structures with epidote segregations. Locally, basic tuffs, agglomerates and extrusive keratophyres occur.

Amphibolites Near Grong

West of the basement anticline at Trangen the volcanics of the Gjersvik Group are at their highest metamorphic grade (amphibolite facies). Whilst approaching the anticline from the east the Middle Greenstones become thinner, whereas, the Older Greenstones thicken. Thus most of the amphibolites belong to unit (4). Near their base a distinctive calcite-rich unit containing hornblende porphyroblasts occurs. This may be a continuation of the Finnbu formation.

Intrusives

The volcanics of the Gjersvik Group have been intruded by a variety of plutonic rocks; mainly acidic or basic in nature. Most of these intrusions were emplaced earlier than or contemperaneously with the first deformative phase as they often exhibit a foliation parallel to the schistosity of the older rocks.

Three provinces can be defined:

(i) Northwest Province

This area contains medium/fine grained granodiorites and metagabbros/diorites in units (1) to (4). The granodiorites are pinkish in colour and possess microcline (secondary to sodic plagioclase).

These intrusions take the form of concordant sheets, some of great size. The granodiorites also penetrate the metagabbros thus the former are the youngest intrusive rocks.

(ii) Northeast Province

Trondhjemites (oligoclase-andesine rich granodiorites) and metagabbros/diorites, often in close association form the main intrusives within the greenstones.

The trondhjemites are light grey, medium to coarse grained rocks with quartz aggregates. Most are strongly acidic. The metagabbros/diorites are more fine grained, similar to the greenstones, as they were intruded at shallower depths. Generally, the intrusions, taking the form of sub-concordant 'plate-like' bodies.

(iii) Southern Province

The southern province is composed of two massifs, the Grøndalsfjell massif and Heimdalshaugen Gabbro (basic in the north, but more acidic in the south and east). They have been dated as 433 ± 10 my. (A. Råheim et al 1979.)

The composition of the Grondalsfjell massif varies from olivine gabbro (troctolite) to hypersthene gabbro. Most of the intrusions are however, altered to hornblende gabbro or diorite.

The acidic rocks of the large, southern massif, are trondhjemites similar to those in the northeastern province.

LIMINGEN GROUP

This final group of the Western Complex comprises sediments deposited under relatively unstable conditions. They include calc-phyllites, metasandstones, siltstones, arkoses and conglomerates. Strong banding is characteristic of these rocks except the conglomerates, which contain boulders and pebbles of the underlying Gjersvik Group. However, graded bedding can be seen with crossbedding in the arkoses.

The metamorphic grade exhibited by this group is the lowest found in the Grong district, namely the chloritic zone of the greenschist facies. Although, near Grong the metamorphism is distinctly higher with the occurence of biotite.

The Limingen group is subdivided into eight units that can be seen in Table (ii).

MINERALISATION

The Grong district has a large number of ore occurrences, though most of them are of minor importance. The largest, Joma, is situated in the Røyrvik Group whilstthe other three major deposits; Skorovas, Gjersvik and Skiftesmyr lie within the Gjersvik Group.

The mineralisation occurs within three major associations: volcanic, intrusive and sedimentary. The volcanic one is by far the most important. The deposits are mainly stratiform, probably syngenetic, originating from volcanic exhalations producing chemical sediments.

The majority of mineralisation is in the Gjersvik Group, associated with acidic, keratophyric tuffs and lavas, agglomerates, and jasper or magnetitic cherts. Other mineralisation, including those in the Røyrvik group have no association with acid volcanics.

The volcanic associations of the Gjersvik Group produce lead/zinc, iron and copper mineralisation with the formation of pyrite, pyrrhotite, magnetite, chalcopyrite, sphene, galena and occasionally bornite and tetrahedrite. A similar mineralogy is produced in the intrusive associations with pentlandite in the more basic rocks. The acidic intrusives in or around the trondhjemites in the Gaizervann/Sanddøla area contain molybdenite in quartz veins with frequent pyrite and chalcopyrite.

SUMMARY OF THE GJERSVIK GROUP

The six units of the Gjersvik Group are clearly metamophased basic and intermediate volcanic tuffs and lavas with associated keratophyric and sedimentary horizons. They contain deposits of exhalative copper, lead and zinc mineralisation.

Into this volcano-sedimentary allochthon igneous complexes have been intruded. The main phase of emplacement occurring approximately 433 ± 10 my ago. These intrusions took the form of generally, concordant lens-shaped bodies in a basic to acidic sequence. Associated mineralisation included copper with molybdenum to a minor extent.

Thus, overall this petrological association is of a calc-alkaline variety typical of most porphyry deposits of the world.

Are these own obs. or taken from literature. Ev. refs ?

STRUCTURAL GEOLOGY

FOLDS

Throughout the district the general trend of the strike is northeast/ southwest with dips towards the northwest.

Early Folds (F1)

The early folds are of the tight to isoclinal variety, the main schistosity being developed parallel to their axes. Associated with them are mineral lineations, boudinage and stretched pebbles in the case of the conglomerates. Their trends vary from northeast/southwest in the central area to north/south to northwest/southeast in the western and eastern regions.

Late Folds

These folds which deform the regional schistosity are of a variety of styles and trends.

The most common folds (F2) are small scale, open to tight forms varying from a symmetrical to highly asymmetrical geometry. The axial planes exhibit moderate to steep dips mostly trending northeast/southwest.

Later (F3) folds are less common. They range from gentle to open folds with vertical axial planes. In the Sanddøla/Grong area, in particular, the axial trends are northwest/southeast and can occasionally be seen to fold the (F2) axes. These (F3) folds are themselves folded and can be seen to be overturned in some cases.

THRUSTS

The Seve Nappe is the lowest of the five major thrusts. It separates the crystalline precambrian basement from the younger allochthonous cover. This basement is separated from the Namsen Group near Grong by a mylonite zone, but further west there is little or no tectonisation and in the north the contact between the Børgefjell massif and overlying rocks is only moderately to weakly tectonised.

The next thrust in the stratigraphical sequence is the lower Koli Nappe containing Ordovician and Silurian rocks, with only minor tectonisation occurring. However, in the overlying Rantser Nappe extensive thrusting is apparent in the north and east with mylonisation of the Huddingsvann Limestone.

The rocks of the field area form part of the Limingen and Gjersvik Groups which both belong to the Limingen Nappe. Minor mylonisation is seen at the contact with the Rantser Nappe with minor thrusting occurring throughout, associated with the emplacement of the intrusives.

The highest thrusting in the stratigraphical sequence is represented by the Helgeland Nappe of the Western Complex, although it's nappe characteristics are somewhat indistinct.

FAULTS

Most parts of the region seem to be little influenced by late high-angle faulting, but large fractures of different trends are common. In many areas east/west fractures predominate, the majority, showing little or no tectonisation with small displacements.

The area most influenced by faulting lies between Skorovas and the Sanddøla river. These faults generally exhibit a north and northeast trend with varying displacements from a few to hundreds of metres. Some faults in the Sanddøla area show displacements in the order of 100m and one along the trondhjemite border is estimated at 1000m (Gale 1975).

CHAPTER 2

GEOLOGY AND PETROGRAPHICAL STUDY OF THE FIELD AREA

GEOLOGY OF THE FIELD AREA

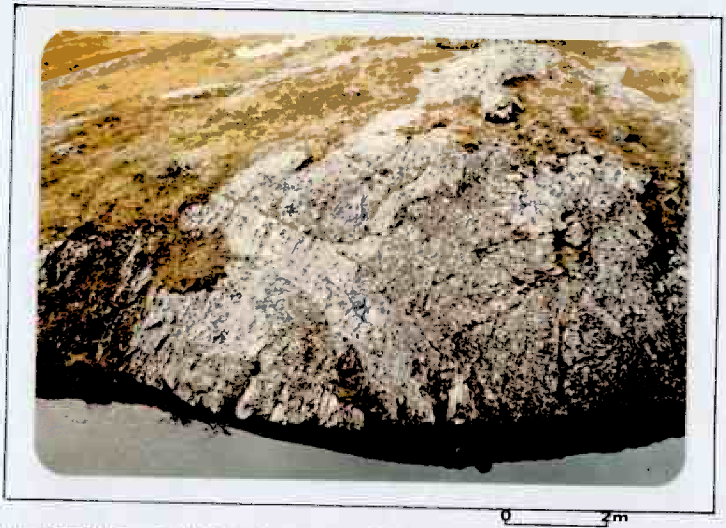
The eastern and north-eastern margins of the field area are bounded by the greenstones (plate 2) belonging to Unit 5 of the Gjersvik Group. The lithology is fine grained, greyish-green in colour and exhibits narrow banding and a mottled appearance indicative of sedimentary volcanic tuffs and lavas although no apparent pillow structures exist. Originally they may have been of an andesitic/basaltic composition that have since undergone a greenschist facies metamorphism. These greenstones are generally schistose occasionally possessing a more porphyritic texture with feldspar/amphibole phenocrysts and epidote segregations. However, east of Kortjern the greenstones are represented by meta-sediments (photograph 4). They show distinct bedding, trending at 155^{o}, with a cleavage developed in the softer material. Due to their differential weathering it appears they were originally composed of interbedded calcareous sediments/mudstones with finer siliceous material, possibly cherts.

Into this volcano-sedimentary cover granodiorite was intruded producing an irregular, often interdigitating contact (photograph 5). The granodiorite is generally mesocratic and blocky in appearance. It is composed of abundant plagioclase (often pinkish in colour) and quartz with darker minerals to a lesser extent. However, it varies considerably across the area, in some instances it resembles a true granodiorite whilst in others it is darker, containing large milky feldspars. Between Småltjern and Nedrebekken this rock has undergone propyllitic alteration - veins of bright green epidote and quartz are present with frequent large clots of chloritic material.

Along the greenstone/granodiorite contact mixing of these lithdogies has occurred producing a greyish 'hybrid' rock, although no thermal alteration of the greenstone is apparent. The intrusive granodiorite often dykes into the meta-volcanics (photograph 6) with the greenstone forming enclaves within it,

Photograph 4: Metamorphosed calcareous sediments/mudstones and cherts east of Kortjern.

Photograph 5: Massive, schistose greenstones overlying the paler, intrusive granodiorite east of borehole 9.



Photograph 6: A bifurcating granodiorite dyke in massive greenstone.

Photograph 7: Leucocratic quartzo-feldspathic veins cutting the coarse gabbroic xenoliths south of Kroktjern.

usually some distance from the contact. These xenoliths tend to outcrop as elongate sheets generally with the grey 'hybrid' rock bordering them. They appear similar to the massive greenstone cover, but are more altered and mineralised, losing most of their banded and mottled textures. Nearly all of these sheet-like bodies possess an east/west trend and have lengths of approximately 10-30m at the surface.

Also contained in the granodiorites are gabbroic xenoliths. These occur in a belt trending north/south from west of Kortjern to south of Småltjern, and again just north-west of the triangulation point. The outcrops occur as angular to rounded blocks ranging from 1 to 10m in diameter. They are composed of amphibole and feldspathic material (often highly epidotised) producing a coarse gabbroic texture, patches often become pegmatitic. Mixed contacts occur, similar to the greenstone xenoliths, but these enclaves may be intruded by leucocratic quartzo-feldspathic veins upto 20 cm wide (photograph 7). The origin of these blocks is not fully understood. However, the present author considers that they were derived from the main gabbroic intrusion to the west of the area (plate 1) in which case the granodiorite is younger than the proposed 433 million years given to the gabbro by Råheim et al (1979).

Younger still, and intruding the granodiorite is the leucotrondhjemite It predominates in the central section of the field area with thinner east/west trending sheets to the south of the triangulation point and north of Småltjern, near borehole 1. It is a more leucrocratic rock, composed of essentially quartzo-feldspathic material with no apparent mafics, but carries the bulk of the mineralisation. In most cases it possesses a fine granitic texture, but frequently becomes schistose. In trench 3 the textures indicate a more metasomatic origin producing a lensoid appearance to the rock (photograph 8). Propyllitic alteration is less well developed than the granodiorite, only intermittent epidote veins are present. The rock exhibits three sets of joints, as in most granitic rocks, typical orientations being:

i) Striking 100° dipping 90°

ii) " 043° " 85° E

iii) " 355° " 43° W

The leucotrondhjemite exhibits similar interdigitating contacts with both the greenstones (photograph 10) and the granodiorite, this material also veining the greenstone. However, there is no evidence for a reaction at the contacts, unlike the granodiorites. Only enclaves of the meta-volcanic material are apparent, the gabbroic blocks being almost entirely restricted to the earlier intrusion. These greenstone xenoliths are similar to those in the granodiorite, but the more leucocratic material appears to actually invade them producing veins of approximately 10 cm in width (photograph 9).

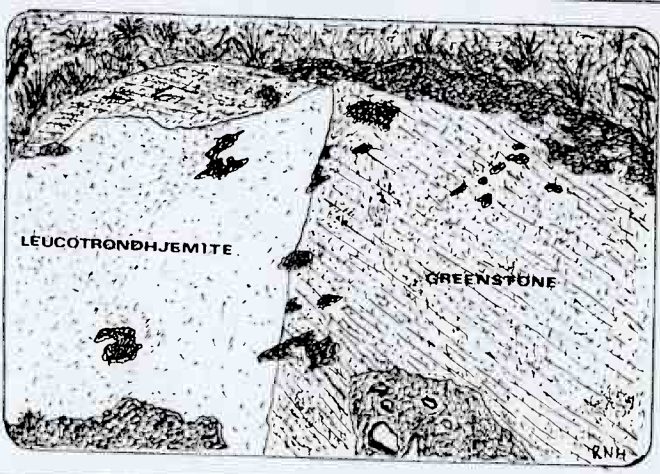
The youngest igneous activity in the field area is displayed by a series of dykes or sills. They generally exhibit an east/west trend, concordant with the intrusives foliations. Two varieties of dykes occur. The first group is composed of a fine-grained greenstone, more soft and fissile than the massive allochthonous meta-volcanics. They are composed of basically epidote and chlorite now, but were probably of a doleritic composition initially. Most of the outcrops are 1·5 m wide, but not laterally extensive, often occurring broken and boudinaged. This type of deformation they have undergone indicates their emplacement prior to the development of the foliation within the area.

The second group of dykes are subordinate to the meta-dolerites. These are composed of a more melanocratic, dioritic material with small euhedral, feldspar phenocrysts set in a chlorite/epidote groundmass. They are more massive and resistant than the first group, exhibiting jointing in some instances, but no foliation is apparent. Thus, they may have been intruded at a later date, post-foliation, as they do not necessarily follow the east/west trend and occasionally appear to be more structurally controlled.

Photograph 8: Lensoid leucotrondhjemite with streaked out greenstone xenoliths in trench 3.

Photograph 9: Leucotrondhjemite veining a pyritised greenstone xenolith in trench 6.

Photograph 10: Interdigitating greenstone/leucotrondhjemite contact.



STRUCTURAL GEOLOGY

Most of the lithologies contain a crude foliation, the greenstones showing a somewhat stronger cleavage. It's general strike throughout the intrusives is in an east/west direction dipping northwards between 50° and 70°. Thus, the development of this foliation appears to have been a relatively late event affecting all of the rocks. However, the meta-dolerite dykes frequently possess a cleavage, although somewhat weaker, in different orientations to the general strike. In some cases the dyke's cleavage is not apparent in the surrounding rocks (photograph 11) this being due to the meta-dolerite's higher suceptibility to deformation. Therefore, there could be two phases of foliation development, the latter phase being weaker, only affecting the softer dykes.

Faults

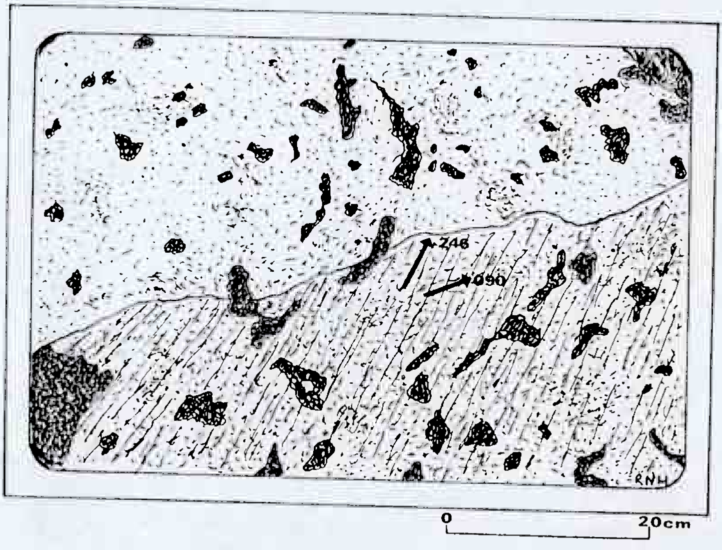
Faults are somewhat difficult to detect in the field. However, with the aid of aerial photograph interpretation the area appears to have undergone intense deformation.

The most prominent features are the so-called Nedrebekken and Småltjern shear zones that follow an east-north-east trend (photographs 12, 13 and 14). Thelatter is obscured by water, However, Nedrebekken is easily examined. The rocks in this vicinity exhibit a strong foliation. They are deeply weathered and fractured, often showing rusting when pyrite is present. However, there appears to be little evidence of any lateral movement, vertical displacement being undetectable even in borehole 2 which passes beneath this zone.

Two sets of major faults are apparent. The first set runs approximately parallel to the two shear zones and intersects the second set, which has a trend of about 155° (plate 2). They seem to be dextral tear faults, some exhibiting lateral displacements of upto 100 m, particularly those trending at 155°. Their most notable effect on the lithology is to displace the leucotrondhjemite body in a 'stepped' manner from north to south.

Other, more minor, faults exist in varying orientations, but their

Photograph 11: Contact between the granodiorite and a meta-dolerite dyke exhibiting a terminated cleavage.



effect on the geology at the surface, is virtually negligible. However, in some cases vertical displacements could occur.

Folds

Within the intrusives folding of the foliation was not observed. However, the greenstone cover does show such deformation. In general, the greenstones' foliation appears to be folded around the igneous rocks. In the north of the area a relatively tight fold is apparent near Kortjern where the greenstone tongues into the granodiorite, to the south the folds become more open, following the contact.

Considering the greenstone is older than the intrusives, this folding of the foliation must have been developed as a result of the emplacement of these igneous bodies, the foliation being present in the meta-volcanics prior to the emplacements.

Photograph 12: View east along the Småltjern shear zone.

Photograph 13: Fracturing and foliation developed in the Nedrebekken shear zone.

Photograph 14: View north along trench 5 into the shattered Nedrebekken shear zone.

MINERALISATION

Pyrite

Pyrite is generally abundant throughout the field area. However, it predominates in veins and disseminations in the older greenstone cover, up to approximately 10% in some instances, where it appears to be the only significant mineralisation.

Within the intrusives it is present in lower concentrations again occurring as fine disseminations and in younger hydrothermal veins. In this respect there appears to be two phases of pyrite mineralisation. The older of these two phases incorporates molybdenite/pyrite.quartz veins, with a younger purely quartz/pyrite association. The xenoliths of greenstone showing marked concentrations of the mineral (photograph 15).

Molybdenite

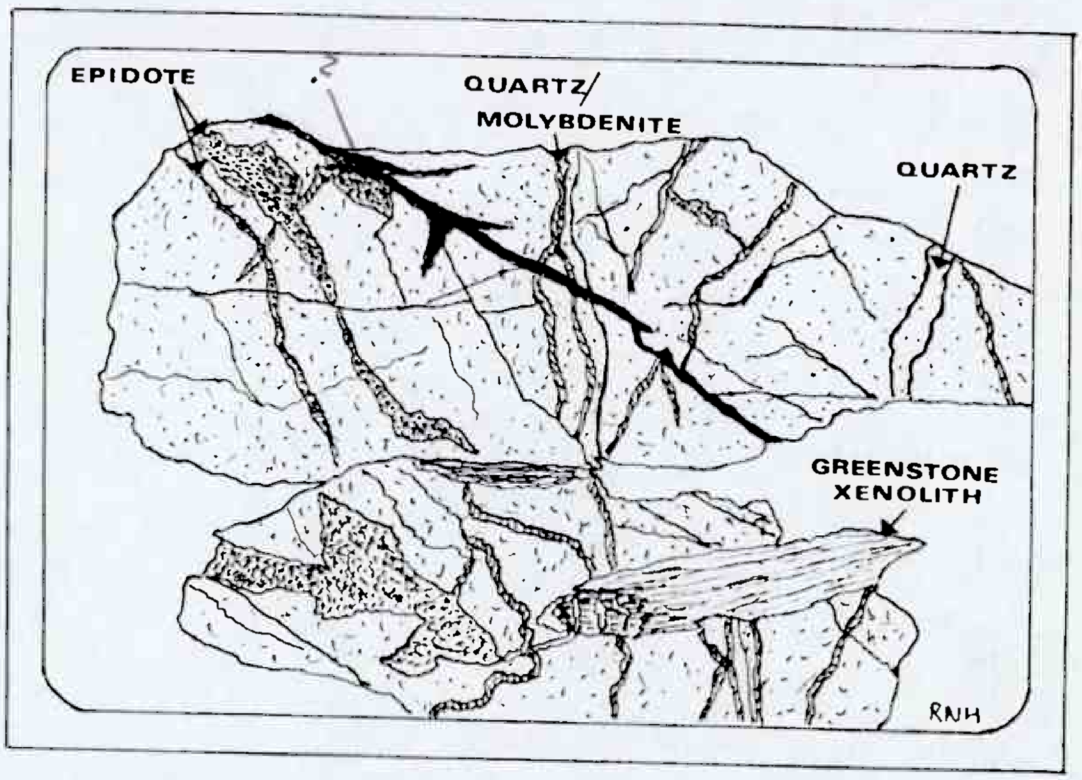
The molybdenite is contained within the intrusive rocks, mainly in the leucotrondhjemite. It is absent in the greenstone cover, but may occasionally be present within enclaves of this material. It occurs (as molybdenite) in veins and more rarely as flakes and disseminations throughout the rocks.

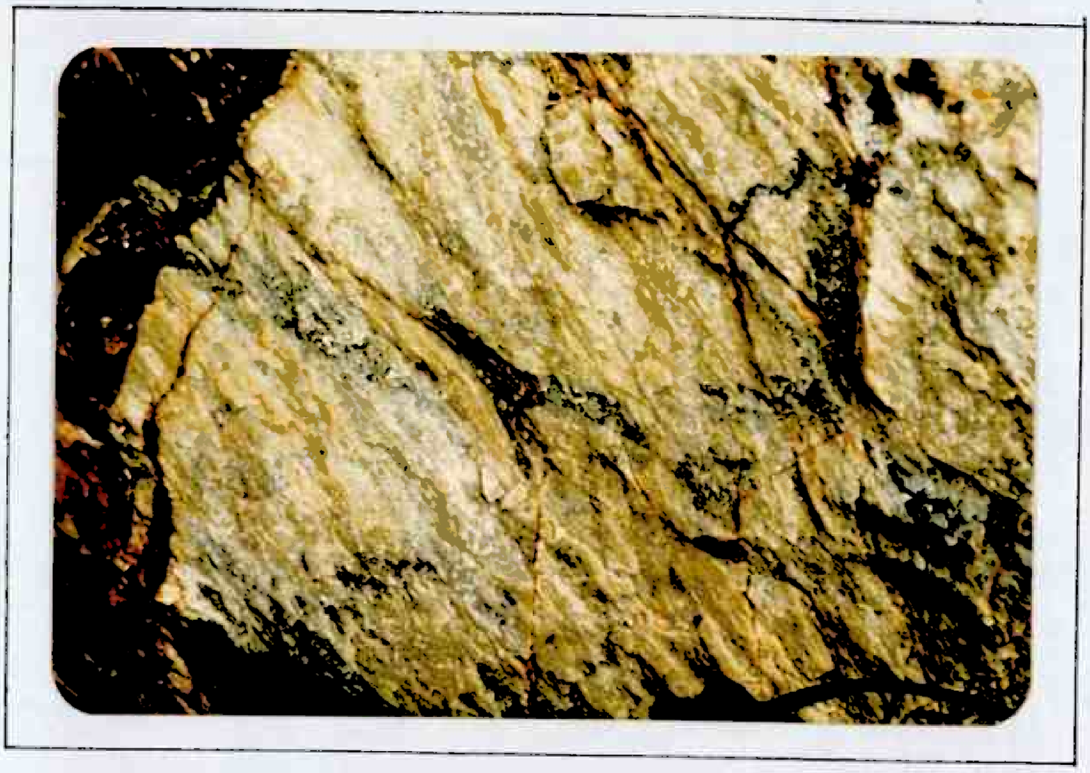
Information gleaned from the boreholes and trenches throughout the area indicates at least two main phases of molybdenisation. The first phase occurred prior to the pyrite mineralisation (photograph 16) and consisted of a quartz/molybdenite association. This initial hydrothermal material is seen as fine cross-cutting veinlets of random orientation (photograph 17). They appear to have been introduced prior to the development of the foliation as the veins can be seen to be streaked out along the planar fabric (photograph 18). The second phase, comprising molybdenite/pyrite/quartz mineralisation, again occurs as fine veins. This stage, however, occurred after the development of the rocks' foliation (photograph 18). A possible third phase is also apparent. In this case molybdenisation occurred after the development of the joints within the igneous rocks, and fractures in some of the greenstones. Molybdenite exists as dry "paint" along the surfaces of such features, up to approximately 4 mm thick.

Photograph 15: Highly pyritised greenstone xenolith in leucotrondhjemite (trench 3).

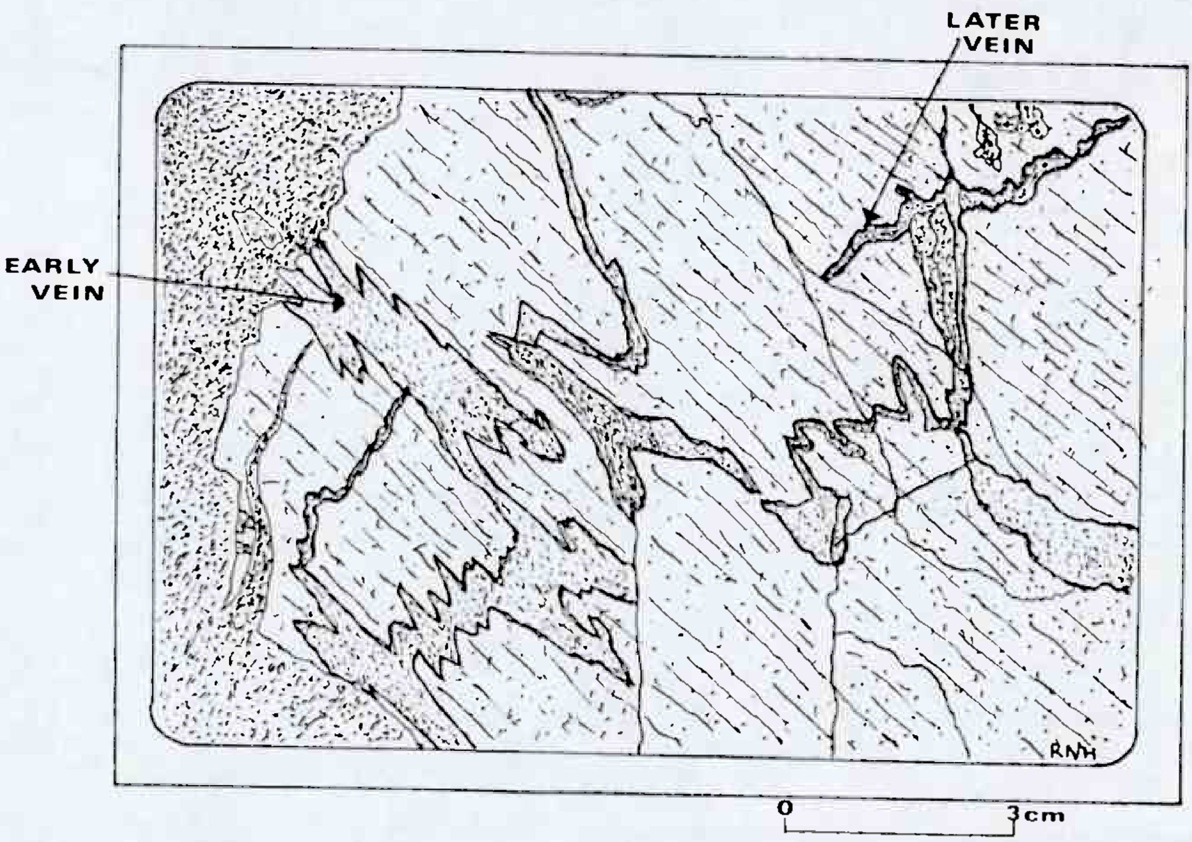
Photograph 16: Younger pyritic vein cross-cutting an older quartz/ molybdenite one in borehole 2.

Photograph 17: Early quartz/molybdenite veins in a loose block of leucotrondhjemite from trench 3.





Photograph 18: Quartz/molybdenite veins, pre-foliation, streaked out and cut by younger, post-foliation, quartz/molybdenite/pyrite veins in trench 6.



Chalcopyrite

The occurrence of copper in this area is limited. Chalcopyrite and secondary copper minerals are only seen in some of the boreholes and on the surface near Småltjern as disseminations. However, using geobotanical methods the copper can be detected and its distribution plotted:

Distribution of Lychnis alpina

Lychnis alpina (*Viscaria alpina*) commonly known as the 'Red Alpine Catchfly' or 'Alpine Campion' is generally found in the Alps, Pyrenees and in subartic Europe, West Asia and North America, reaching 73° 10'N in East Greenland. It occurs up to an altitude of about 1000 m in alpine moor-type conditions. The plant frequently grows on serpentine and primary siliceous rocks with an unusually high content of the base metals, particularly copper, zinc and nickel, hence it's alternative common name 'Northern Copper Flower'.

L.alpina (photograph 19) belongs to the carophyllaceae (campion family). It is a perennial tufted herb that stands erect (5-15 cm). Oblong-lanceolate or linear leaves occur in pairs, usually 1-6 pairs, on the flowering stem. The flowers are 6-12 mm in diameter composed of crowded florets which are pinkish-rose coloured.

In certain parts of the field area these plants are relatively abundant. By plotting their locations (figure 2) it was hoped to indicate the distribution of copper. The plants seem to be concentrated along the two shear zones (Småltjern and Nedrebekken) and generally to the north of the molybdenum mineralisation where there ~~is~~ are abundant water and bogs concentrating the copper.

Photograph 19: Lychnis alpina

Figure.2. DISTRIBUTION OF Lychnis alpina L. THROUGHOUT THE FIELD AREA

(‡ denotes approximately 3 plants)

PETROGRAPHICAL STUDY

GRANODIORITE (Figure 3)

An approximate modal analysis of this rock produces a content of:

Feldspar	-	57%
Epidote	-	25%
Quartz	-	7%
Chlorite	-	5%
White Mica	-	3%
Sphene	-	3%
Carbonate	-	less than 1%.

Solitary crystal of Allanite.

Based how many sections
How many points ?

The feldspars are very patchy and "dusty" towards their centres, often showing zoning of alteration products, in particular sericite. The crystals are often idiomorphic, predominantly of an oligoclase/andesine composition with little or no potash feldspar.

The epidote appears to be pistacite. It is generally anhedral occurring as a secondary alteration product of the decomposition of feldspar. It frequently exists both enclosing and enclosed within the feldspar. Small veinlets of this mineral also occur, but these are probably a result of a later stage epidotisation.

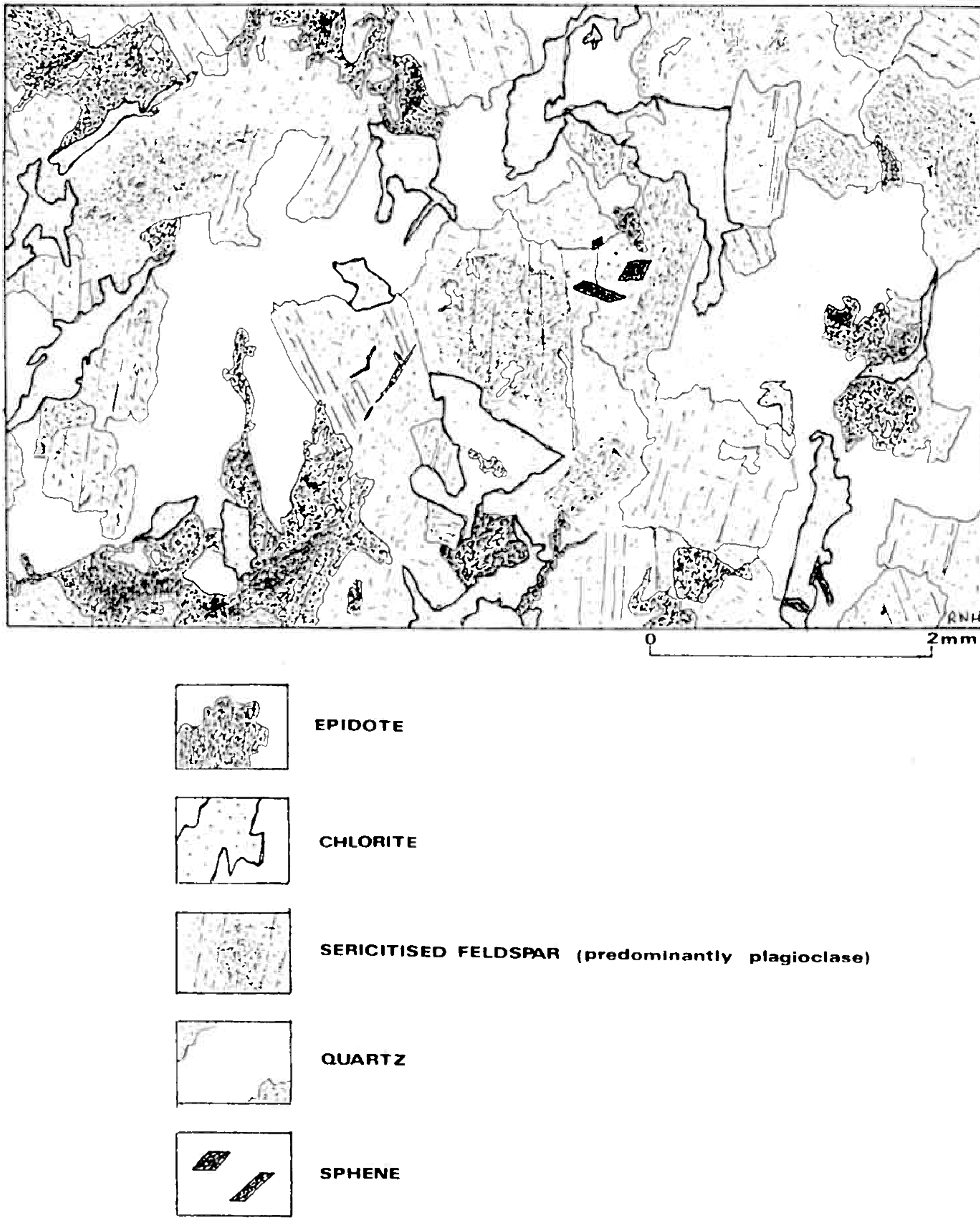
Surrounding the feldspars and epidote, producing an overall hypidiomorphic texture to the section, is a finer groundmass of later consolidated massive quartz and feldspar, possibly orthoclase with inclusions of the white mica and lath-shaped chlorite crystals. Occasionally a carbonate is present which may result from propyllitic alteration rather than being a primary constituent. The sphene, contained in both this finer material and in the feldspars occurs as euhedral 'envelope' shaped crystals often exhibiting twinning and may have been formed by a late stage titaniferous mineralisation.

The handspecimens are generally mesocratic, the dark constituents represented by chlorite and epidote. There are no apparent mafic members such as biotite or amphibole, normally associated with granodiorites, including ore minerals. Thus, this rock could be termed a "Biotite-free granodiorite".

LEUCOTRONDHJEMITE (Figure 4)

This rock, similar to the mesocratic granodiorite, contains no apparent ferro-magnesium minerals. The only evidence for the presence of iron is in

Figure 3
GRANODIORITE



pyrite which may result from a later mineralisation as it is predominantly found in veins. It is composed of approximately:

Feldspar	-	49%
Quartz	-	22%
Epidote	-	13%
White mica	-	13%
Pyrite	-	2%
Chlorite) Sphene)	-	1%

The feldspars are less euhedral than in the previous variety. They show a greater degree of sericitisation often becoming completely replaced by the white mica. Due to this state of alteration their composition is not easily determined, however, most crystals exhibit ghost lamellar twinning, some 'fresh' fragments indicating an oligoclase/andesine composition.

The epidote is again of the pistacite variety resulting from the decomposition of the feldspars. However, perhaps more commonly, it occurs in secondary veins similar to the pyrite.

The groundmass, composed of mainly quartz, white mica and a very small proportion of chlorite, shows more of a linear fabric. The fused quartz grains appear to be elongate with the lath-shaped white mica almost "flowing" around the feldspar and epidote crystals. Again some orthoclase may be present, but if so it is subordinate. The sphene may have formed slightly earlier than in the granodiorite as the few crystals that occur are generally anhedral.

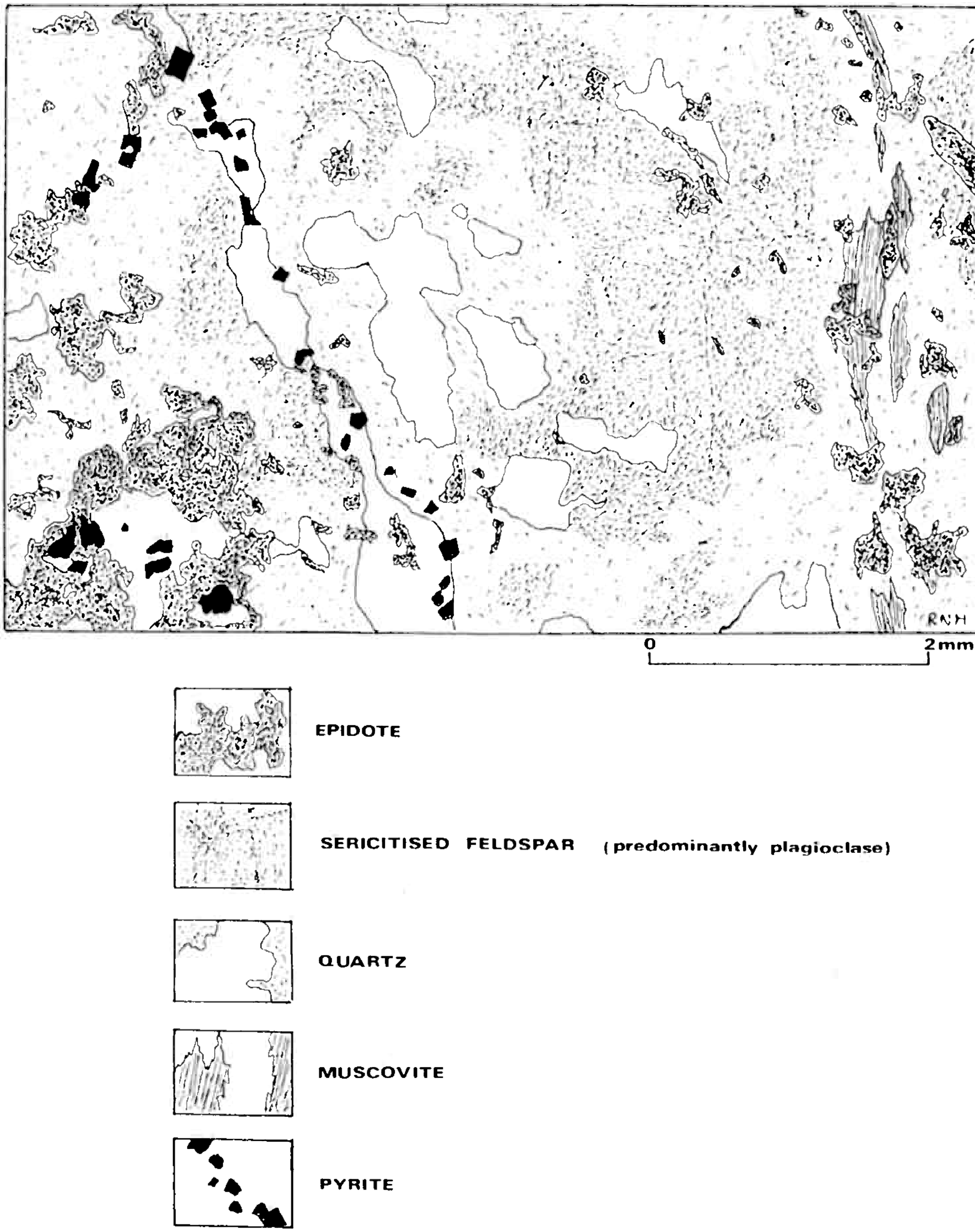
The handspecimen is pale pink in colour due to the feldspars, despite them having a sodic nature. Very few dark constituents are apparent, thus this rock could be termed a leucocratic granodiorite or, perhaps better still, leucotrondhjemite. Although this latter classification usually requires biotite, trondhjemites are generally lacking in potassium-rich feldspars as they are supressed by the more sodic varieties. (Johannsen 1932). Therefore, this phenomenon may explain the higher white mica content of this particular rock.

GREENSTONE (Figure 5)

The specimen of greenstone examined comes from within borehole 2 (see core analysis) and is therefore relatively 'fresh' and unaltered. Crude modal analysis shows it to contain:

Figure 4

LEUCOTRONDHJEMITE



Chlorite	-	26%
Epidote	-	25%
Amphibole	-	15%
Feldspar	-	16%
Pyrite	-	8%
Quartz	-	6%
White mica	-	4%

Epidote, of the pistacite variety, generally occurs as large subhedral 'clots' and also in small veinlets throughout the rock. Associated with the amorphous crystals in chlorite. These two minerals are often intergrown with chlorite occasionally rimming the epidote as a result of it's decomposition. Hence, they both occur in approximately the same proportions.

The amphibole occurs as concentrations of subhedral to anhedral crystals. It is pale green in colour and appears to be actinolite, frequently intergrown with the epidote.

The groundmass is composed mainly of fine grained quartz, white mica and feldspar, both plagioclase (oligoclase/andesine) and potash-feldspar. The presence of the mica produces a linear fabric to this assemblage. Epidote and chlorite are again present still bearing a similar relationship to one another, this finer material being almost devoid of actinolite.

Throughout the rock small veins of pyrite occur. The crystals are usually euhedral and appear to have been developed after the rock crystallised. These veins, along with those of later formed epidote, produce a mottled appearance to the rock.

Originally the greenstone may have been an andesitic volcanic tuff or lava, although no microscopic structures indicating this are apparent, and has since undergone a greenschist facies metamorphism.

META-DOLERITE (Figure 6)

This rock outcrops as dyke-like bodies in the field and exhibits a greenstone composition of approximately:

Epidote	-	45%
Chlorite	-	30%
White mica	-	18%
Feldspar	-	3%
Pyrite	-	1%
Quartz	-	3%
Tremolite	less than	1%

Figure 5
GREENSTONE

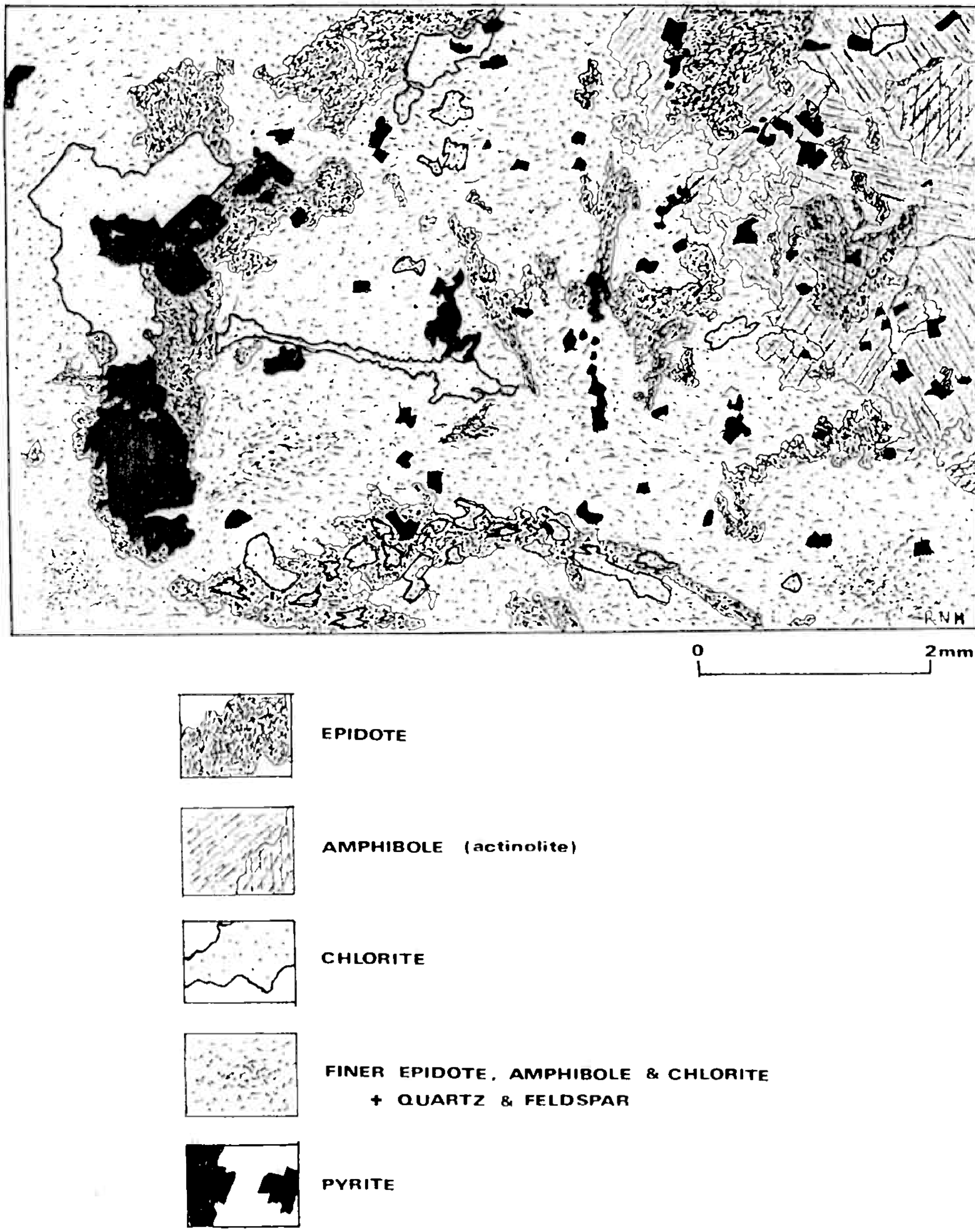
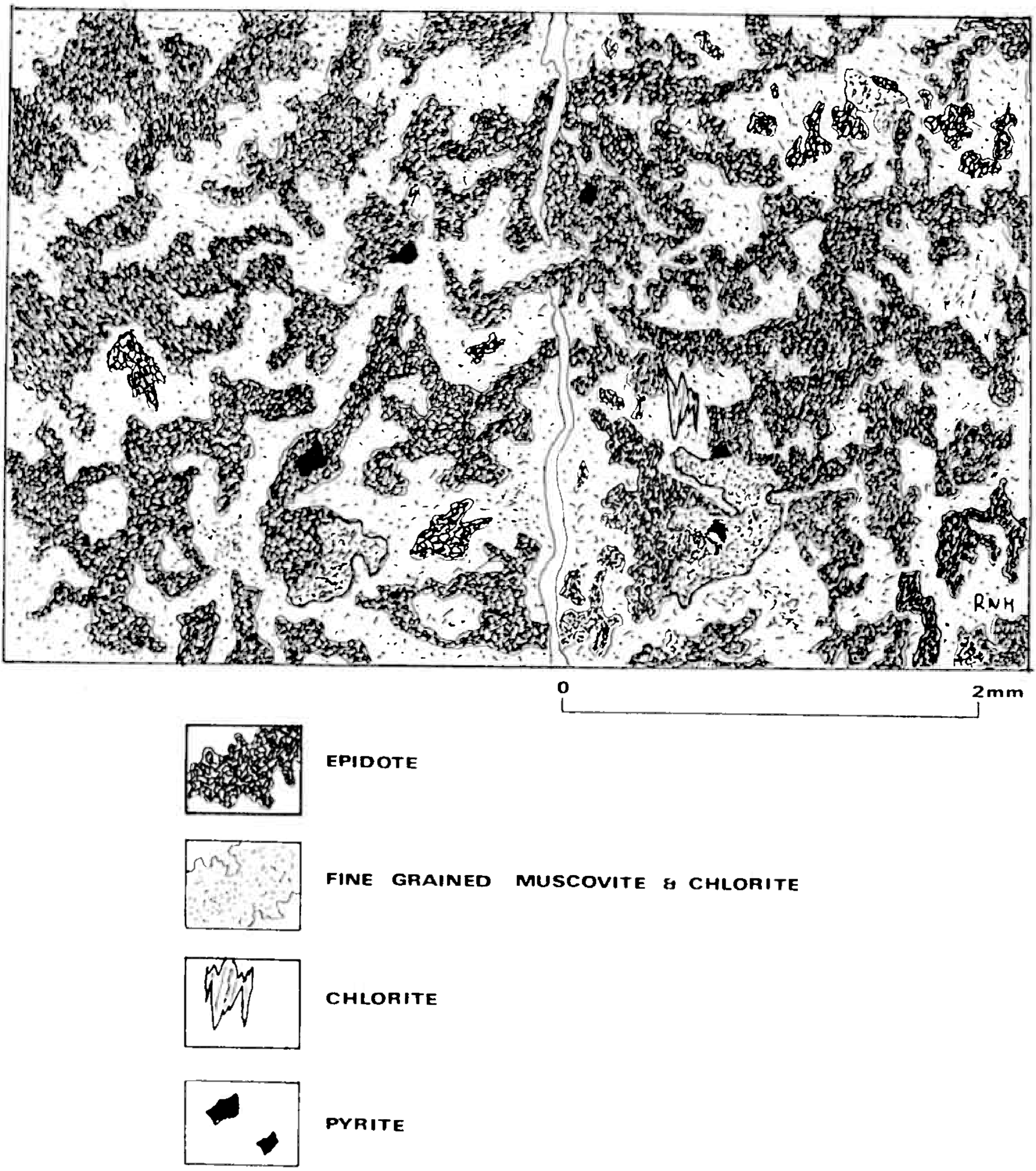


Figure 6

META – DOLERITE



The epidote, again pistacite, occurs as randomly distributed anhedral crystals. Their shape may be attributed to the original fine ophitic texture of the dolerite. Occasionally they include cubic pyrite with haematite fringing but not to the same extent as the previous greenstone.

The groundmass has a very fine linear, schistose fabric produced by fibrous chlorite, amphibole (possibly tremolite) and white mica with quartz. Occasionally larger crystals of the chlorite and unidentified, sericitised feldspathic material are present. Small "pockets" composed of quartz, pyrite and epidote are also apparent.

In the field and handspecimens this appears as a very fine grained, pale green rock. No crystals are visible to the naked eye apart from the occasional pyrite cube. However, in thin sections this rock exhibits a truly recrystallised texture, the mineralogy indicating a greenschist facies metamorphism.

DIORITE (Figure 7)

Again, this rock type outcrops as dyke-like bodies in the field. It contains:

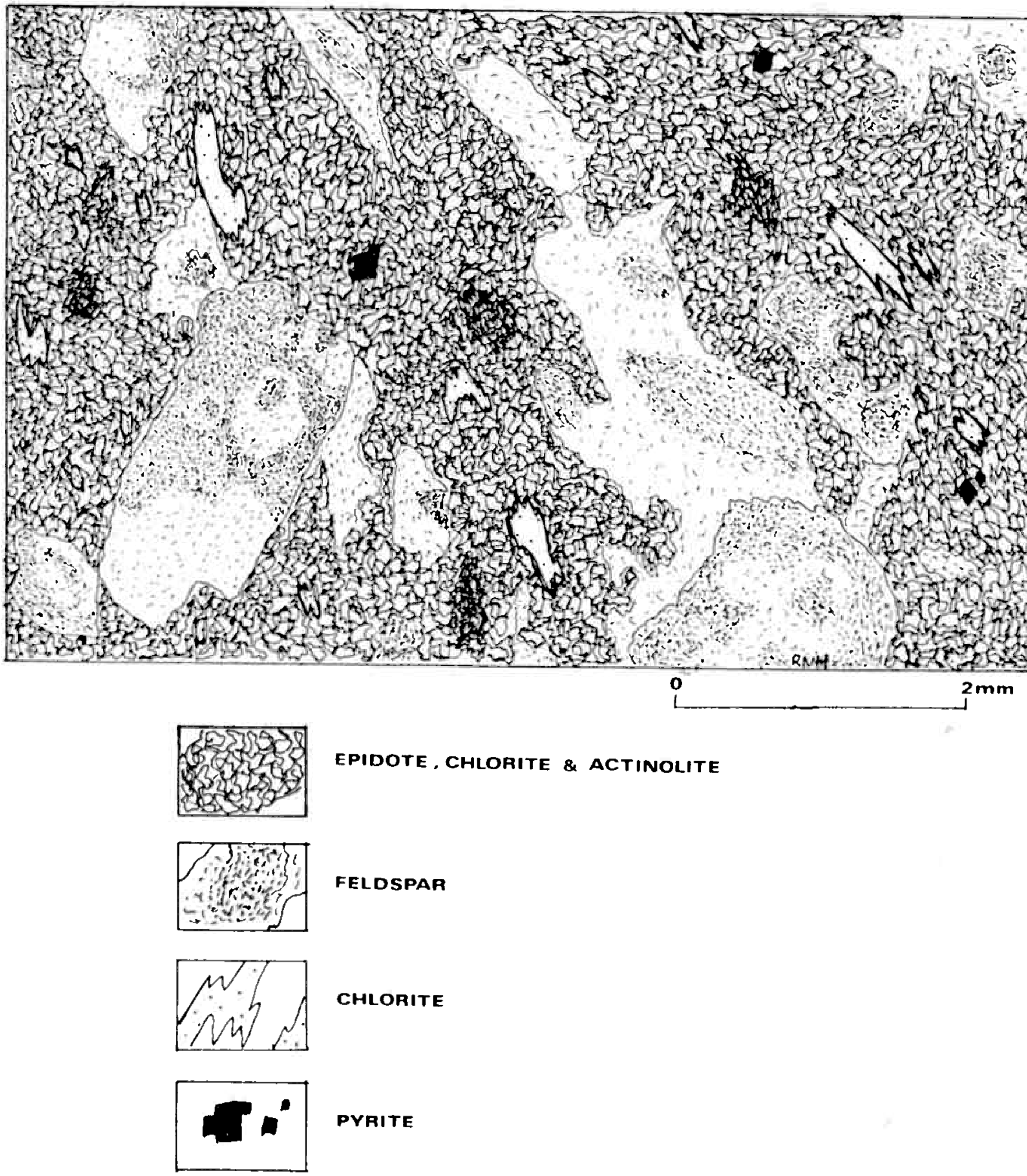
Chlorite	-	33%
Feldspar	-	27%
Epidote	-	25%
Quartz	-	14%
Pyrite)		
Amphibole)	-	1%
Carbonate)		

The feldspar occurs as euhedral, tabular phenocrysts upto 2 mm in length. They appear "dusty" and highly altered, mainly to sericite and epidote, often showing a faint zonation. Due to the state of deterioration their composition is difficult to discern. Even though some exhibit ghost lamellar twinning attempts to determine the An% were futile. In some cases these phenocrysts show a degree of alignment indicative of their intrusive origin.

The groundmass is much finer, possessing a linear fabric, and composed of chlorite laths and patches with later consolidated interstitial quartz and fine grained epidote. Also contained in this material is relatively "fresh" plagioclase of an oligoclase/andesine nature plus minor pyrite, amphibole and carbonate.

Figure 7

DIORITE



The handspecimen is generally melanocratic due to the chlorite/epidote content, with the prominant feldspars producing an igneous porphyritic texture. However, the thin section indicates more of a hypidiomorphic texture.

METAGABBRO (Figure 8)

This material occurs mainly as xenoliths within the granodiorite. It's approximate composition being:

Amphibole	-	42%
Chlorite	-	20%
Epidote	-	19%
Feldspar	-	10%
Pyrite	-	6%
Sphene	-	3%

The amphibole predominates throughout the more basic section of this rock. It appears to be of an Actinolite/Tremolite composition. The crystals are subhedral/anhedral often showing both prismatic and basal cleavages. This particular mineral probably represents the alteration of original pyroxene contained in this rock.

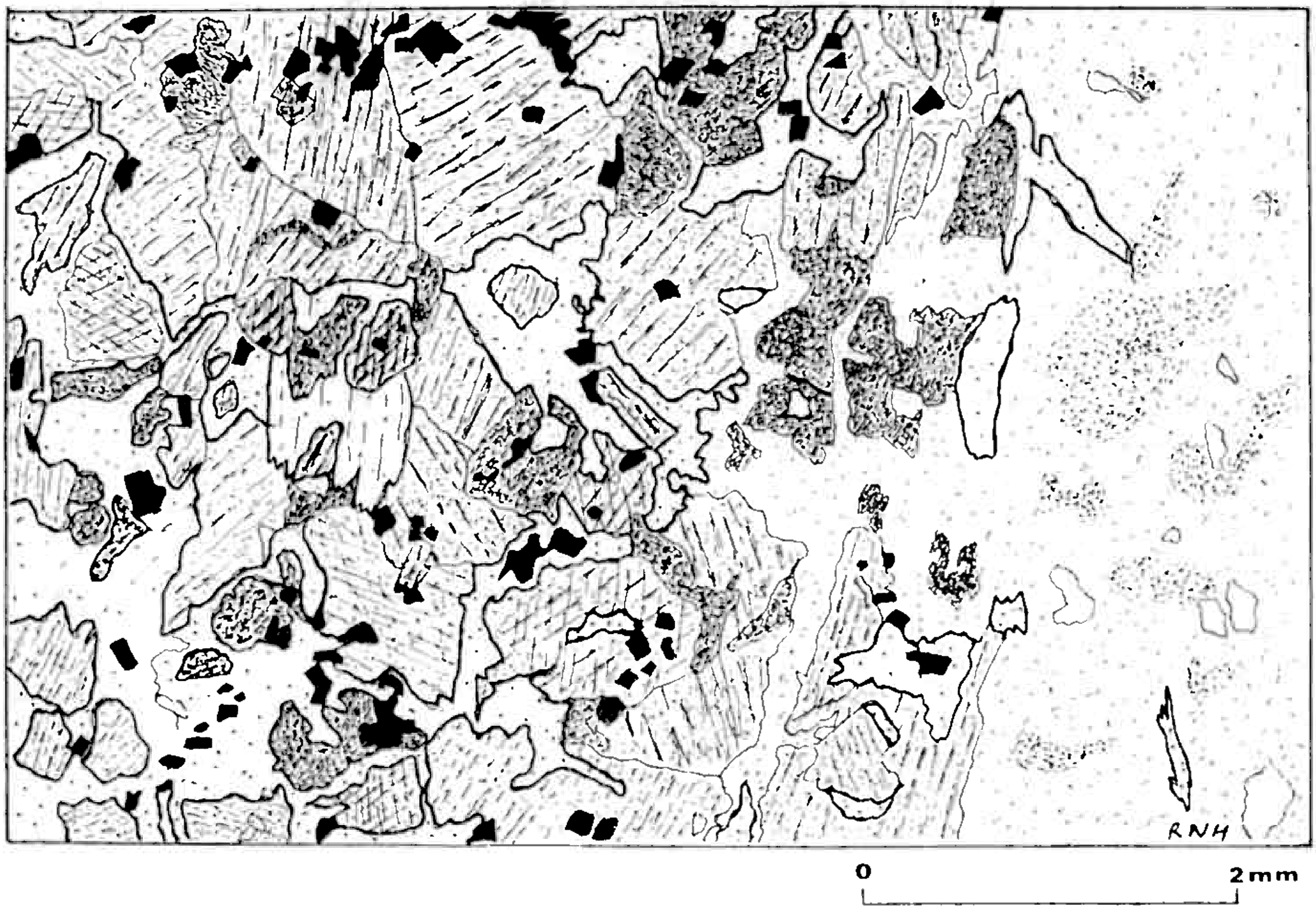
Interstitially between the amphibole crystals, chlorite with lath-shaped and amorphous habits is present, often with cubic pyrite and minor sphene. Similarly with the epidote, which can be seen to be a secondary alteration product of the original feldspar. In some instances, this feldspar which was of a plagioclase composition exhibits preferential replacement by epidote (pistacite) along the lamellar twins.

Veining this grabbroic material are more acidic fractions composed of mainly orthoclase, plagioclase (oligoclase) and quartz with some chlorite. The most unusual phenomenon associated with these veins is that on staining for their feldspar content orthoclase predominates along the contact followed by a zone of quartz/albite giving way to a more calcic plagioclase towards the centre. These veins are a later feature, possibly originating from the granodiorite.

Due to their present mineralogy, consisting of predominantly amphibole as opposed to pyroxene, these rocks can be best described as metagabbros. The metamorphism probably being a result of thermal action by the granodiorite on these xenoliths.

Figure 8

METAGABBRO / QUARTZO – FELDSPATHIC VEIN



AMPHIBOLE (actinolite/tremolite)

EPIDOTE

CHLORITE

SERICITISED FELDSPAR

QUARTZ

PYRITE

Mo is chalcophile
also.

CHAPTER 3

GEOCHEMISTRY AND MOLYBDENUM DEPOSITS

THE GEOCHEMISTRY OF MOLYBDENUM

Molybdenum (atomic no 42) belongs to group VI of the periodic table. Chemically it occurs in valences +4, +5 and +6, however, in nature only the +4 and +6 valences are important. Of these two, +4 is characteristic of endogenous settings whilst +6 of exogenous environments. It has seven stable isotopes (Table (iii)) although ^{100}Mo may possibly be radioactive, acting as a β-transmitter producing ^{100}Te.

In group VI the trends of increasing ionic radii from the top to bottom of the group and the decrease of ionic radii within each period (moving from left to right) are not apparent. Thus, Mo, W and Nb exhibit similar ionic radii with a valence of +4; the radii of Mo and W also being similar in the +6 state.

Molybdenum occurs in several minerals within the earth's crust (Table (iv)), however, the only independently occurring mineral of any importance in the endogenous environment is molybdenite. Other molybdenum sulphide complexes exist, but the remainder of the magmatically originated molybdenum is found in mutual substitutions with other elements in crystalline mineral structures.

Considering radii and ionic charges, there are several ions which should in principle be able to substitute for Mo^{4+} in molybdenite, namely Ti^{4+}, Cr^{3+}, Nb^{4+}, Ta^{5+}, Sn^{4+}, V^{4+}, Zr^{4+}, Fe^{3+} and W^{4+}. Nevertheless, the peculiar trigonal arrangement with 6-coordination of Mo^{4+} in this sulphide determines that only Re^{4+} and W^{4+} satisfy the conditions, and that tungsten's high oxygen affinity tends to exclude it from the combination with sulphur. It is due to this that rhenium is the only foreign element substituting in molybdenite. Molybdenum is rarely found in other minerals, although it is concentrated in the lithosphere by magnetite (up to 400 ppm in rare cases) and may substitute for Ti^{4+} in titaniferous minerals. Only a few occurrences of the element entering the

^{92}Mo	-	15.86%
^{94}Mo	-	9.12%
^{95}Mo	-	15.70%
^{96}Mo	-	16.50%
^{97}Mo	-	9.45%
^{98}Mo	-	23.75%
^{100}Mo	-	9.62%

Table (iii): The seven stable isotopes of molybedenum and their abundances in the earth.

Jordisite	-	$Mo\ S_2$
Molybdenite	-	$Mo\ S_2$
Molybdite	-	$Mo\ O_3$
Lindgrenite	-	$Ca_3\ (Mo\ O_4)_2\ (OH)_2$
Powellite	-	$Ca\ Mo\ O_4$
Wulfenite	-	$Pb\ Mo\ O_4$
Koechlinite	-	$(Bi\ O)_2\ Mo\ O_4$
Ferrimolybdite	-	$Fe\ (Mo\ O_4)_3 .\ 7H_2O$
Ilsemannite	-	$Mo_3O_8 .\ n\ H_2O$?

Table (iv): The main mineralogical occurrences of Molybdenum.

Mo in Scheelite

$Ca\ (W, Mo)\ O_4$

silicate phases in igneous rocks have been reported. One such case is the molybdo-sodalite of Vesuvius.

Molybdenum in Meteorites and Igneous Rocks

Meteorites show appreciable concentrations in the metallic and somewhat less in the sulphide phases indicating a siderophile and thiophile nature to the element. However, in the earth's crust molybdenum is purely lithophile.

Igneous rocks, generally, exhibit approximately 15 ppm molybdenum with 3 ppm in the more basic varieties (G. Von Hevesey and R. Hobby in Goldschmidt (1958)). the greatest concentrations corresponding to biotite, hornblende and accessory minerals. Nevertheless, their contribution to the total molybdenum is minor due to the low percentages of these minerals in the rocks. On the other hand, in spite of their low concentration of molybdenum, feldspars store more than 50% of the total molybdenum, quartz and muscovite being practically void of the element.

Tin, tungsten, molybdenum, and, to a lesser extent, bismuth commonly occur together, but usually one metal is more abundant in a deposit or zone of a deposit. The geochemical distribution of these elements in igneous rocks is characterised by a preference for the late products of magmatic fractionation, thus they tend to be associated with more alkaline/acidic rocks and pneumatolytic events. Molybdenum, in particular, has a greater mobility thus there may be a "transfer" of the element from more basic and intermediate intrusive members into the more acidic final crystallisation. The molybdenum is generally removed by halogen vapours, in particular fluorine and chlorine, and by water during crystallisation, therefore, due to its high mobility the concentration of molybdenum in an intrusive rock may not necessarily represent the true contents of the original magma (Haffty and Noble 1972). Alternatively, post-magmatic alteration (albitisation, chloritisation, silicification, etc) which greatly adjusts the molybdenum content of the rock, removes the element. This leaching process, if followed by a concentration phase, could possibly be sufficient for generating molybdenum deposits and enriched magmas (Korshinskiy and Tauson in Oyarzun, 1978).

In the pneumatolytic stage the migration of molybdenum is only feasible above 373° (critical temperature of water) and low pH. Upon cooling, the halides tend to react with the water and are hydrolysed. The formation of other minerals that "remove" fluorine and chlorine from the gaseous phase will cause precipitation of molybdenum, similarly a high concentration of S^{-} ions which will deposit molybdenite.

Molybdenum Weathering and Sedimentation

In the zone of weathering the only important primary molybdates of divalent metals are powellite and wulfenite the latter often occurring in the oxidation zone of lead deposits. These secondary compounds, including ilsemannite, are frequently the only indication of the presence of molybdenum.

The bulk of molybdenum from primary igneous rocks goes through a solute phase before precipitation. This takes place in hydrosylate and perhaps still more obviously in oxidate sediments, especially where Mn III or IV is being precipitated. Goldschmidt (1958) noted conspicuous amounts of molybdenum in manganiferous oxides in zones of oxidation.

Under strongly oxidising conditions in the sedimentary cycle molybdenum as the molybdate ion becomes mobile and may migrate with vanadium in sediments. Under strongly reducing conditions molybdenum is precipitated presumably as molybdenite, as in the case of the Kupferschiefer (Mansfeld, Germany) where its concentration varies from 10-1500 ppm.

TYPES OF MOLYBDENUM DEPOSITS

Molybdenum deposits throughout the world can be broadly classified under five categories (Jensen and Bateman 1979):

i) The first class includes the porphyry or disseminated deposits, including stockworks and breccia pipes. Two further divisions of this category can be made on the basisof their geotectonic setting - subduction-related and rift-related deposits (Sillitoe R.H. (1980)). Such deposits are characterised by molybdenite occurring alone or with quartz and/or pyrite in fractures and open spaces of stockworks and breccias. The molybdenite is fine grained, generally less than one millimetre across and in many cases not seen with the hand lens. Examples of this type of deposit include Climax, Colarado; Urad-Henderson, Colarado; Bingham, Utah and numerous porphyry copper-molybdenum deposits.

ii) This group of deposits incorporates the contact-metasomatic varieties. Usually, a granitic-like body is intruded into a sedimentary cover producing contact metamorphism. Skarns are developed along its contact often with the metasomatic formation of molybdenite. This mode of formation is relatively common throughout the world occurring in areas such as: Pine Creek, California; Helvetia, Arizona; Knaben, Norway; North-Eastern Caucasus, Russia; China; and Azegour, Morocco.

iii) The third category is purely of the stockwork/quartz veining type of molybdenisation. Here, the molybdenite occurs in massive quartz veins in a stockwork of discontinuous veinlets and disseminated flakes. Such mineralisation is pneumatolytic, and generally occurs in fractured zones or along joints in the host rocks. The Questa Molybdenum Mine in New Mexico is perhaps the best known example of this type of deposit, as well as possessing a porphyry type molybdenum-bearing intrusion.

iv) This group includes pegmatites and aplitic dykes which contain the molybdenum mineralisation, again as molybdenite flakes and disseminations.

Few examples of this type exist. Those that have been studied in detail occur mainly in Canada: Most Mine, Quebec; Val d'Or and Preissac, Quebec.

v) This final category is of a sedimentary nature and includes bedded molybdenum minerals in sandstone-type uraniferous deposits. Significant amounts of the exogeneous minerals jordisite and ilsemannite can be present (up to more than 0.5%). The origin of the molybdenum is not fully understood, but it is probably the result of molybdenum becoming concentrated in shales commonly associated with carbon. Leaching of the metal ion along with the uranyl ion results is the occurrence of both together.

Such deposits are relatively common in Utah, Colarado, Arizona, New Mexico, Wyoming, South Dakota and Texas.

CHAPTER 4

BOREHOLE DESCRIPTION

SITING OF BOREHOLES

After an induced polarisation survey of the area in 1980 a major anomaly was detected, contained within the hill surrounding the triangulation point at grid reference (040200 715322) (plate 2). The data indicated an elongate zone trending east/west for approximately 1400 m with a maximum breadth of about 350 m. The highest readings obtained were in the order of 14 to 15%. Few other anomalies occurred apart from minor ones to the north and west.

The contours derived from the survey showed a dip to the north for the mineralisation comparable with the general structural dips of the area.

Using this data and information derived from earlier fieldwork by Gale in 1973 and 1974, Voke's 1979 and Ryan in 1980 (regarding the surface outcrops of molybdenum) sites for nine boreholes were chosen. The first borehole was situated over a minor anomaly west of Småltjern the second just north of Nedrebekken to determine the extent of the mineralisation's dip. Boreholes 3,4,5 and 6 were positioned in a line trending north/south across the major anomaly to produce a cross-section (plate 3, photograph 20), similarly holes 7 and 8 (Figure 9) further east. Finally, borehole 9 was positioned near the greenstone/granodiorite boundary to determine the eastwards extension of the mineralisation. Due to the structural dips of 50 to 70° north the holes were drilled at an angle of 58.5° to the south so as to intersect the planar structures at high angles.

Photograph 20: View north from borehole 4 along the profile through holes 5 and 6.

CORE ANALYSIS

Borehole 1

Borehole 1 attained a depth of 99.40 m towards the Småltjern shear zone.

The predominant lithology throughout the hole is of a mesocratic, porphyritic granodiorite containing euhedral crystals of feldspar. In some cases this rock becomes more leucocratic with the disappearance of the phenocrysts.

Propyllitic alteration is apparent throughout with silicification producing an almost schistose rock. Veins of brecciated epidotised/albitised material frequently occur (photograph 21) with massive barren quartz veins sometimes containing patches of bottle-green chlorite.

The first ten metres possess a relatively high molybdenite concentration (photograph 22). The mineral occurs as 'paint' on dry fractures and joint planes as well as disseminations in quartz veins. Throughout the rest of the hole the molybdenisation is generally weak. Occasionally the dry 'paint' occurs, particularly towards the end of the core with intermittent quartz/molybdenum veins. The veins within this hole appear to be flat lying ($18^{\circ}/20^{\circ}$ to the side of the core), although their direction is unknown. Disseminated within the lithology is pyrite and some cholcopyrite, particularly in the few greenstone dykes which have little other mineralisation.

Borehole 2

A more leucocratic granodiorite/leucotrondhjemite occurs throughout the 91 m of this hole. It has no porphyritic feldspars as in borehole 1 and is generally more silicified and often schistose. Greenstone dykes do occur but they are subordinate to the greenstone xenoliths which appear either mottled or bearing a pseudo-gabbroic texture, and may have originally been gabbroic blocks. Another variety exhibits brecciation (photograph 23) with a silicified matrix possibly representing a meta-agglomerate.

Photograph 21: Brecciated epidotised/albitised material in borehole 1 at approximately 80m.

Photograph 22: Borehole 1, Box 1 - moderate to high molybdenisation in the first 10 metres of this hole.

?

The degree of molybdenisation decreases from the top to the bottom of the hole. The first 10 metres are generally high becoming more moderate towards the 20 m depth and weak thereafter. The greenstones show a weak molybdenum mineralisation, the molybdenite occurring mainly in the silicified zones. Pyrite is again abundant, especially in the greenstones and appears to be later than the molybdenisation (photograph 16).

Borehole 3

Borehole 3 shows three main lithologies. The first variety is the banded and mottled greenstone and meta-dolerite dykes, there are no apparent pseudo-gabbroic textures and thus probably represent meta-volcanics. Again they occur as rafts or enclaves in the more predominant leucotrondhjemites/ granodiorites. The leucotrondhjemites are similar to those in borehole 2 and carry the bulk of the mineralisation. The third group are the granodiorites that appear mesocratic with feldspar phenocrysts and are subordinate to the leucotrondhjemites.

The greenstones are highly pyritised, but only contain very weak molybdenite, if any at all, similarly the darker granodiorites. A weak zone of mineralisation occurs in the leucotrondhjemite from 10 to 40 m with higher concentrations from 57-84 metres. Below 84 m the hole is barren of molybdenum.

Borehole 4

This borehole attains a maximum depth of 202.80 m. The lithologies are similar to the previous hole, but the mesocratic granodiorite is not represented and the greenstones exhibit pseudo-gabbroic patches.

The first 124 m are predominantly composed of the pale pink/grey/green leucotrondhjemite with minor greenstones. The whole of this section, overall, shows a moderate to high molybdenum mineralisation and associated pyritisation. From 124 to 185.50 m greenstones are dominant with little or no molybdenite, but rich in pyrite and some chalcopyrite. Below this a second zone of moderate/high mineralisation occurs within more leucotrondhjemite.

Photograph 23: Brecciated greenstone, possibly a meta-agglomerate in borehole 2 at 68.49m.

Photograph 24; High intensity quartz/molybdenite stockwork at 166.10m in borehole 6.

Borehole 5

Borehole 5 the deepest of the 9 holes, displays similar rocks to borehole 3. However, they seem to show a greater propyllitic alteration and schistosity with fracturing and brecciation from 19.90 to 33 m which may represent the Nedrebekken shear zone.

The major molybdenisation occurs from 33m to approximately 150 m although above this intermittent zones of medium/high mineralisation exists with minor copper. From 150 to 240 m, although there is some weak molybdenisation, the zone is generally barren and correlates with that of borehole 4. Below this point the hole ends in a lower medium/high intensity zone at 267 m.

Borehole 6

Again, leucotrondhjemite, greenstones and granodiorite are represented in this hole, the former predominating. Similar alteration products to borehole 5 are also present with what may be hydrothermal brecciation and carbonatisation.

Molybdenum mineralisation occurs throughout the 196.92 metres of the core in varying intensities. Twenty metre sections showing high concentrations of moly occur from 10 to 30 m and 50 to approximately 70 m before a weaker zone is observed. This latter section ends at 137 m and below it more medium/ high intensity mineralisation is apparent, particularly from 166.10 m to 170 m (photograph 24) where there is a stockwork of quartz/molybdenite veins.

Borehole 7

Further east from the 4 previous holes, borehole 7 still contains the three main lithologies. In the top half of the core meso-granodiorite is abundant with finer bands of greenstone and leucotronhjemite which may indicate an interfingering contact. Towards the base, leucotrondhejemite predominates.

The main mineralisation, although only weak/medium, occurs from approximately 80 m to 140 m, concentrated mainly in the leucotrondhejemite. Pyrite is common throughout with a few occurrences of chalcopyrite.

Borehole 8

Borehole 8 contains basically darkish grey/green, mottled and banded varieties of the greenstone with interbanded leucotrondhjemite and granodiorite.

The mineralisation lies within the leucotrondhjemite below the greenstone. Again it is generally weak/medium intensity and forms a relatively narrow zone down to a depth of 101m. Below this point the rock is barren apart from some mineralisation in the granodiorite towards the end of the hole at 150 m.

Borehole 9

This hole lies near the contact between granodiorite and greenstone, thus the latter tends to predominate in the core. It does, however, vary considerably from a greenish/grey banded and mottled variety to a more porphyritic type of meta-volcanic rock. Only a few minor occurrences of the granodiorite exist.

The mineralisation is stronger than in boreholes 7 and 8. Pyrite is abundant, up to approximately 10% in some instances, with minor chalcopyrite. The molybdenite occurs in a zone from about 33 m to 105 m varying from weak to high concentrations, the more intense molybdenisation occurring in the granodiorite from 54-62 m.

INTERPRETATION OF BOREHOLE DATA

The data from only 9 holes limits the extent of interpretation of the mineralisation. However, it is possible to devise two hypothetical models for the existence of a body of mineralisation in the eastern part of the anomaly using data obtained from boreholes 3 to 9 inclusive.

Model 1

The cross-section through the widest part of the anomaly, incorporating boreholes 3,4,5 and 6 (plate 3), indicates a major zone of mineralisation. The upper extent of this zone is limited by the topographical surface, but its base dips at an angle of approximately 27° to the north. As the mineralisation is traced northwards its thickness increases from about 80 m in borehole 3 to about 196 m in borehole 6, although the zone was not bottomed in this last hole. Beneath this so-called 'Upper Zone' an area essentially barren of molybdenum occurs with a minor, 'Lower Zone' of mineralisation below, indicated by boreholes 4 and 5, the extent of which is indeterminable.

To the east, the cross-section obtained from boreholes 7 and 8 (figure 9) shows that the mineralisation is far more limited in extent.

Only a narrow zone of approximately 60 m at depths varying from 35-70 m occurs. In this first model the narrow band is taken to be approximately horizontal in the north/south plane, unlike the dipping Upper Zone of the previous section.

The third cross-section (figure 10), produced by connecting holes 3, 7 and 9 shows the east/west extension of the ore body in this area. In borehole 3 the relatively shallow lying Upper Zone is only about 75 m thick, comparable with the mineralisation's extent in boreholes 7 and 9. Thus, the ore body can be drawn between each of the holes.

The first model (figure 11) derived from this data is of a continuous ore body throughout these seven holes. If this is the case, the mineralisation would show a dip to the north along the line of holes 3, 4, 5 and 6 gradually flattening and becoming thinner towards the east. Along the east/west line a

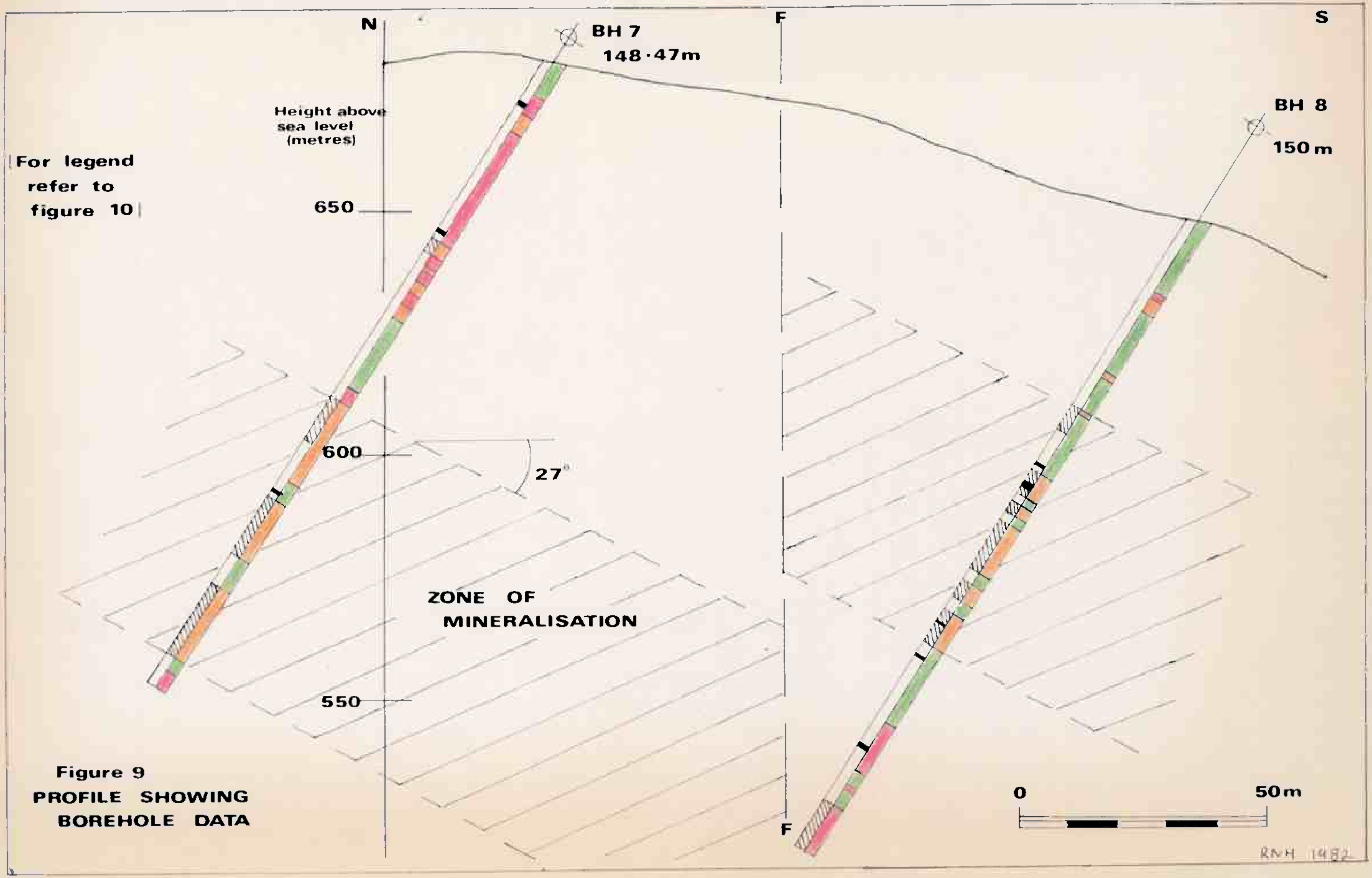
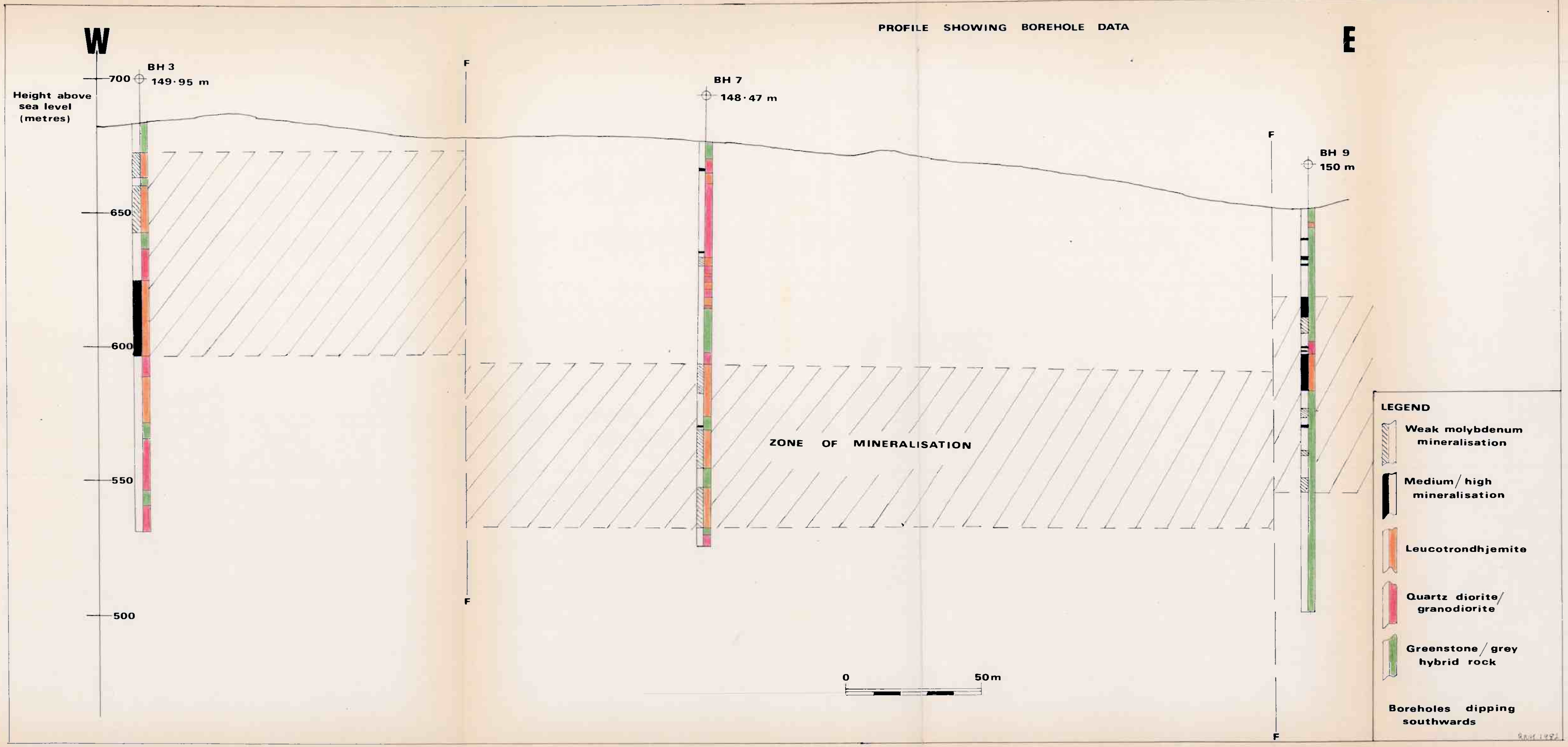


Figure 9
PROFILE SHOWING
BOREHOLE DATA

Figure 10



PROFILE SHOWING BOREHOLE DATA
W
E
Height above sea level (metres)
700
650
600
550
500
BH 3
149·95 m
BH 7
148·47 m
BH 9
150 m
F
F
F
F
ZONE OF MINERALISATION
0
50m
LEGEND
Weak molybdenum mineralisation
Medium/ high mineralisation
Leucotrondhjemite
Quartz diorite/ granodiorite
Greenstone/ grey hybrid rock
Boreholes dipping southwards

broad asymmetrical saucer shaped profile occurs, the line between holes 7 and 8 being the plane of maximum curvature.

Model 2

In this second model (figure 12) the section through boreholes 3-6 is again the same as for the first. However, the cross-sections through 7, 8 and 3, 7 and 9 are somewhat modified.

Assuming that the dip of the base of the mineralisation (27°N) remains constant from the west to east. Then, the section through 7 and 8, instead of showing a flat-lying zone as in model 1, shows a dipping, faulted zone.

The aerial photographs indicate three intersecting lineations, which may be faults, just to the south of borehole 8 along the line with borehole 7. The more minor of these features, trending approximately SSW would also displace borehole 7 with respect to borehole 3. To maintain the overall dip of the mineralisation at 27° N borehole 7 would have been displaced approximately 75 m to the south with respect to borehole 8. Further east a more major fault occurs just west of borehole 9. This appears to have been more of a tear fault with a slight vertical displacement of borehole 9 with respect to borehole 8. However, along this line the mineralisation contained in borehole 7 shows greater displacement when compared with borehole 9.

In conclusion, this second model shows a northerly dipping ore body with a central down-faulted block that has been displaced approximately 75 m. The zone gradually thickening towards the north and west.

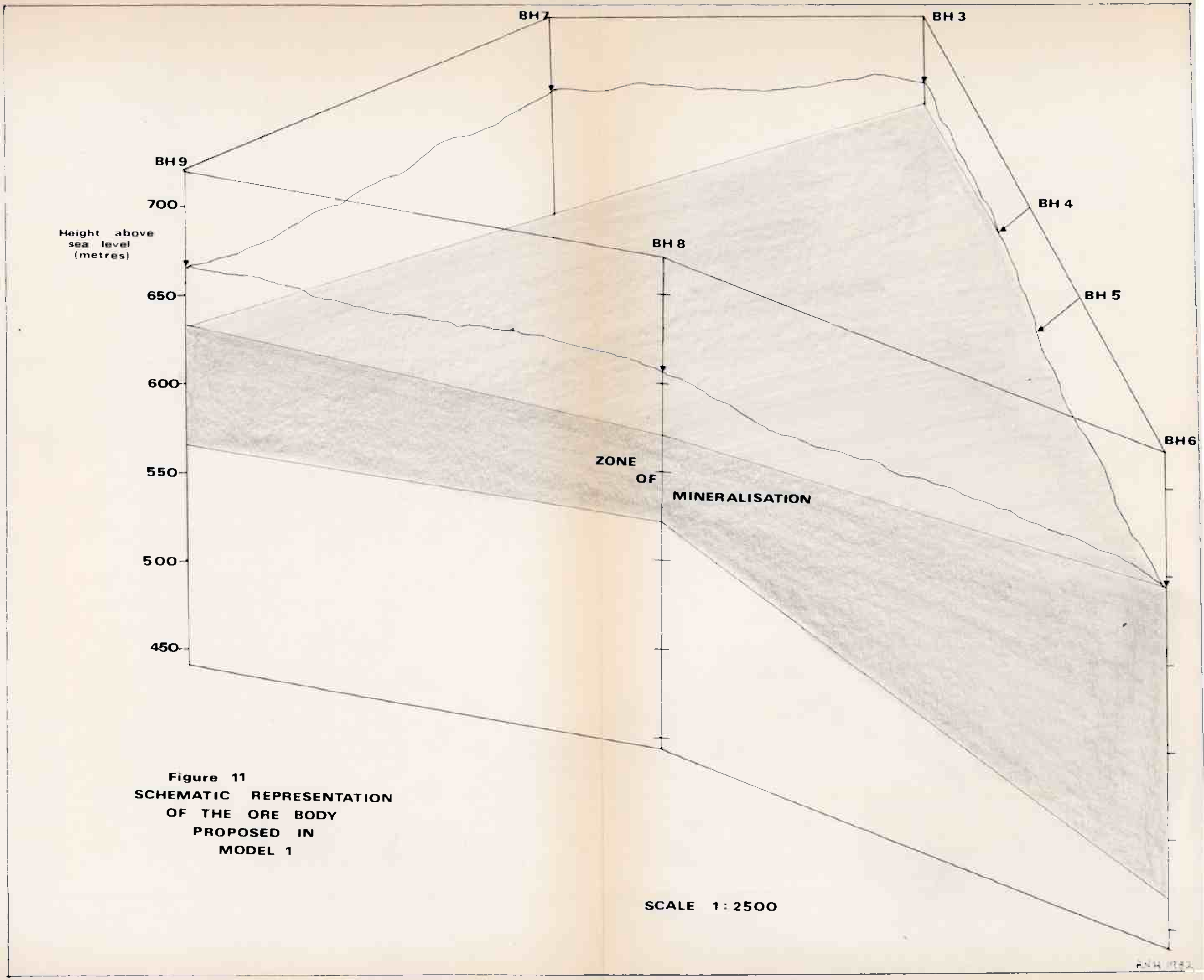


Figure 11
SCHEMATIC REPRESENTATION OF THE ORE BODY PROPOSED IN MODEL 1

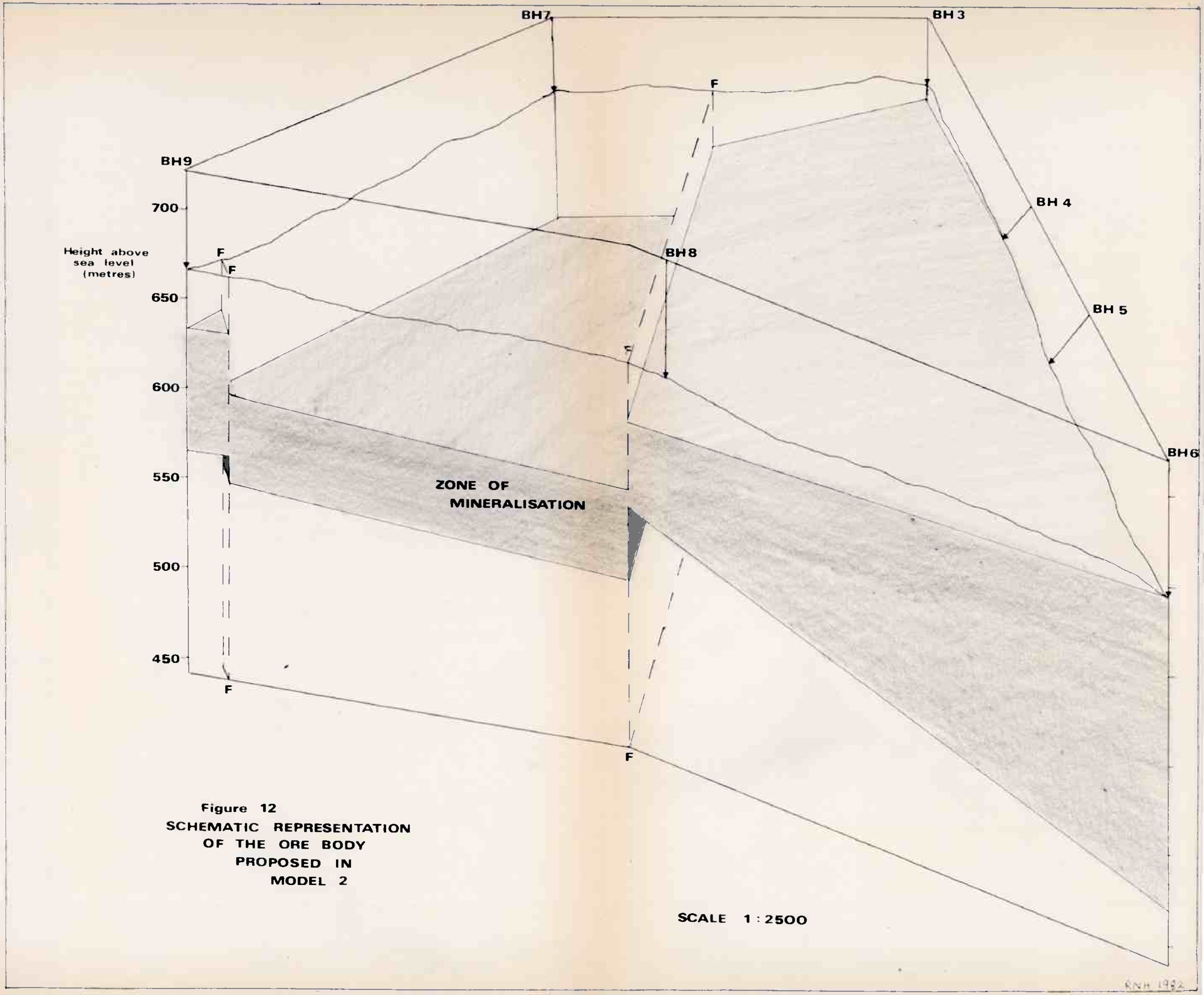


Figure 12
SCHEMATIC REPRESENTATION OF THE ORE BODY PROPOSED IN MODEL 2

CHAPTER 5

CONCLUSION

ECONOMIC IMPLICATIONS

This is a calc-alkaline porphyry deposit of the subduction-related variety. Although no true porphyry is present and the distribution of L. alpina does not indicate a copper-rich zone of any significance.

The molybdenum mineralisation appears to be similar to the Questa Molybdenum Deposit of New Mexico (Carpenter R.H., 1968) though on a much smaller scale. The molybdenite occurring as fine disseminations in a stockwork of discontinuous quartz veins (photograph 25). The spacing between these veins varies considerably and in general they show little or no preferred orientation.

The author considers that with the limited borehole data from holes 3 to 9 the second of the two models for the ore body should be proposed. The correlation between the holes and the geometry of the mineralised zones within these cores appear to fit model 2 more successfully. Therefore, the ore body is formed of a series of faulted blocks which dip and broaden northwards, thinning towards the east. Assuming this model contains approximately 6.2 million cubic metres and that the average density of the rocks is 2.8 tonnes per cubic metre with a molybdenum content of about 0.05%, then a pay of approximately 8,700 tonnes of molybdenum exists. However, the western and northern extents of the mineralisation are not known and the pay will be considerably larger over the whole area.

Considering Tauson's and Recharskiy's observations in Oyarzun J. (1978), whereby molybdenum tends to be concentrated in the peripheries of an intrusion due to it's high mobility, three major questions are left unanswered:

i) Does the molybdenum become less concentrated at depth?

ii) Assuming that the ceiling of the intrusives has been removed, then has the area been too deeply eroded removing the bulk of the mineralisation?

iii) Does the molybdenum occur in higher concentrations in the roof of the intrusives directly below the greenstone?

Photograph 25: Discontinuous stockwork of quartz veins, some bearing molybdenite, on the surface of a leucotrondhjemite outcrop.

SUGGESTIONS FOR FURTHER WORK

The most important work in the future is to determine the full extent of the ore body and to attempt to prove the theory of its faulting proposed in this report. Therefore, the author would recommend:

i) Further boreholes west of profile 3, 4, 5 and 6 with associated mapping to find the westward extension of the mineralisation.

ii) The siting of new boreholes through the greenstone north of Cyprustjern to determine the extent of the dipping and broadening ore body, and to try to answer question (iii) posed previously.

iii) A set of boreholes to produce more accurate cross-sections between 3, 7 and 9, and, 7 and 8 to test the proposed model.

iv) An extension be made to holes 4, 5 and 6 to attempt to show the extent of the lower zone of mineralisation noted in holes 4 and 5.

v) Continued evaluation of other molybdenum anomalies and showings in the peripheral zones of the intrusive complex according to the theory that molybdenum becomes concentrated in the intrusive's margins.

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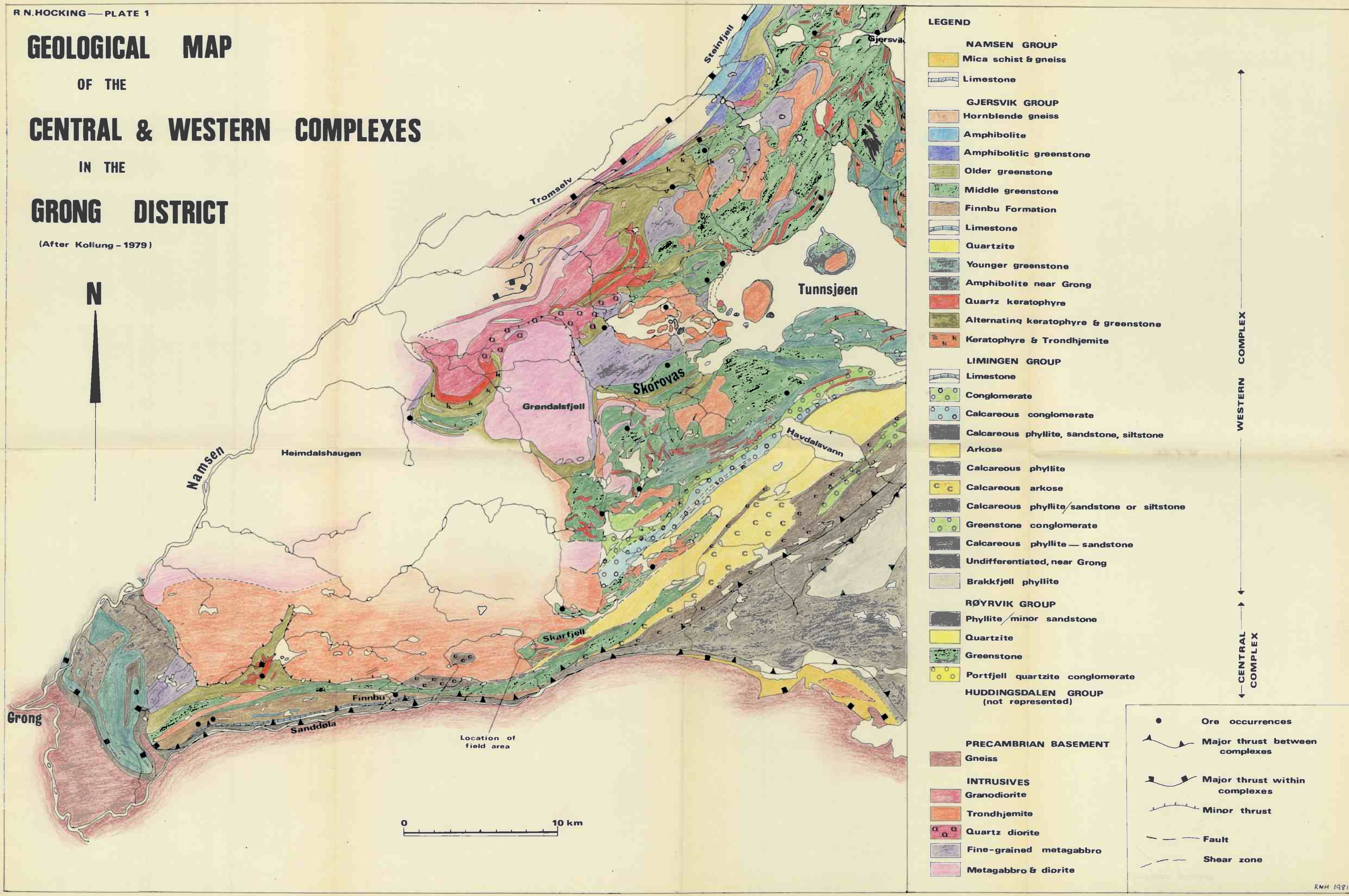
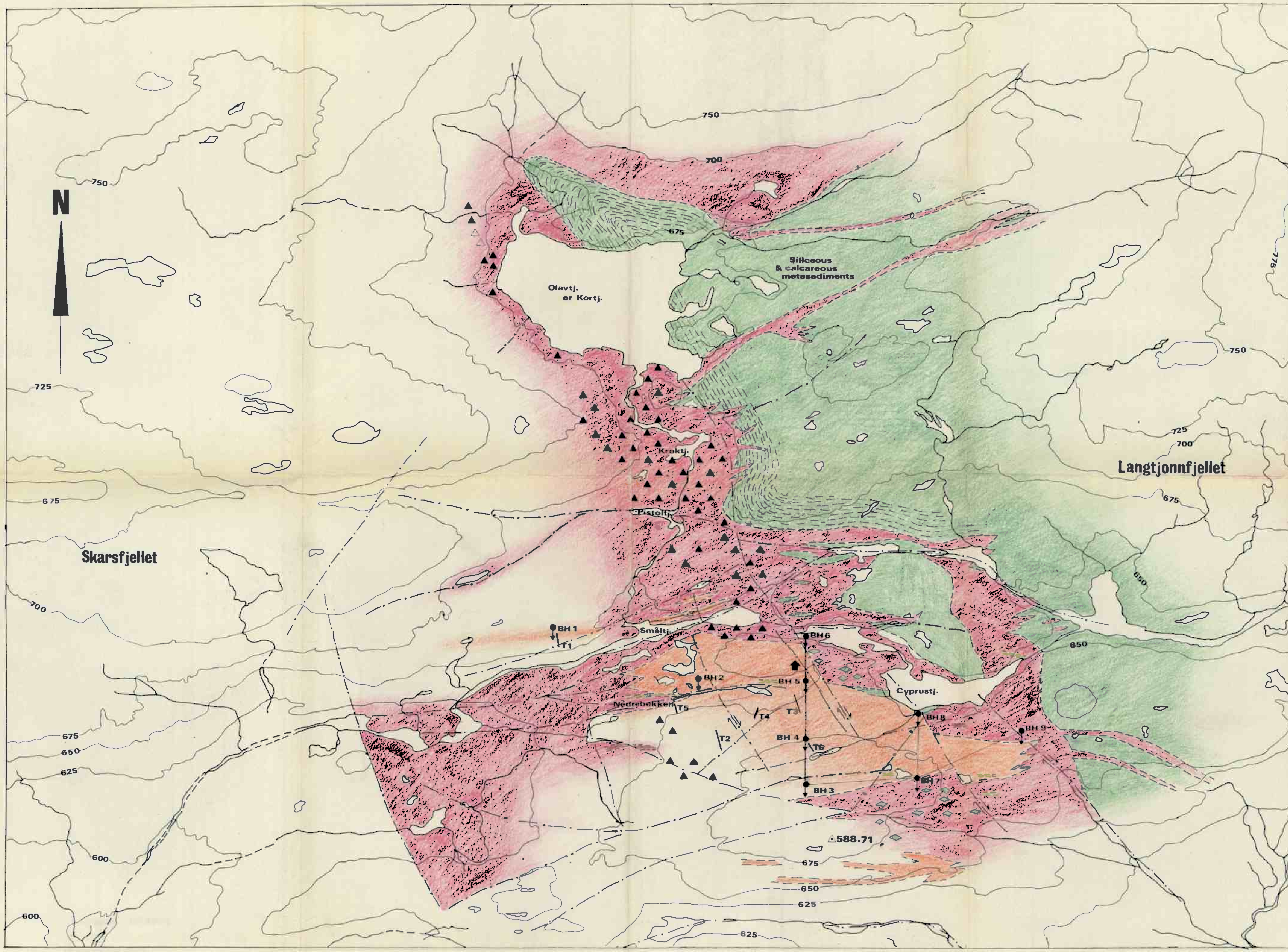

R.N. HOCKING — PLATE 1
GEOLOGICAL MAP
OF THE
CENTRAL & WESTERN COMPLEXES
IN THE
GRONG DISTRICT
(After Kollung - 1979)
N
Steinfjell
Gjersvik
Tromselv
Tunnsjøen
Skorovas
Grøndalsfjell
Heimdalshaugen
Namsen
Havdalsvann
Skarfjell
Finnbu
Sanddøla
Grong
Location of field area
0
10 km
LEGEND
NAMSEN GROUP
Mica schist & gneiss
Limestone
GJERSVIK GROUP
Hornblende gneiss
Amphibolite
Amphibolitic greenstone
Older greenstone
Middle greenstone
Finnbu Formation
Limestone
Quartzite
Younger greenstone
Amphibolite near Grong
Quartz keratophyre
Alternating keratophyre & greenstone
Keratophyre & Trondhjemite
LIMINGEN GROUP
Limestone
Conglomerate
Calcareous conglomerate
Calcareous phyllite, sandstone, siltstone
Arkose
Calcareous phyllite
Calcareous arkose
Calcareous phyllite/sandstone or siltstone
Greenstone conglomerate
Calcareous phyllite — sandstone
Undifferentiated, near Grong
Brakkfjell phyllite
RØYRVIK GROUP
Phyllite/minor sandstone
Quartzite
Greenstone
Portfjell quartzite conglomerate
HUDDINGSDALEN GROUP
(not represented)
WESTERN COMPLEX
CENTRAL COMPLEX
PRECAMBRIAN BASEMENT
Gneiss
INTRUSIVES
Granodiorite
Trondhjemite
Quartz diorite
Fine-grained metagabbro
Metagabbro & diorite
Ore occurrences
Major thrust between complexes
Major thrust within complexes
Minor thrust
Fault
Shear zone
RNH 1981

R N HOCKING — PLATE .2.

GEOLOGY OF THE FIELD AREA

COMPILED BY
M J RYAN
A I R MOHAMMED
& R N HOCKING
(1981)



LEGEND

- Granodiorite / Quartz diorite
- Leucotrondhjemite
- Greenstone (foliation indicated)
- Meta-dolerite
- Diorite
- Metagabbro xenoliths
- Greenstone xenoliths
- Faults (derived from fieldwork and aerial interpretation)
- BH Borehole (with direction of plunge indicated)
- T Trench

0 500m

RNH 1982

R.N.HOCKING — PLATE 3

PROFILE SHOWING CORRELATION OF BOREHOLE DATA