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Sammendrag

A Petrological and Structural Analysis of an Area East of Lökken, Sör Tröndelag, Norway

by S J Jenkins

Derby Lonsdale College of Higher Education
1983.

CONTENTS

NOTE REGARDING ABBREVIATIONS IN THE TEXT

All rock specimens are referred to by their specimen number and not their location number.

The following mineral abbreviations are used:

An	Anorthite
Cc	Calcite
Cord	Cordierite
Ct	Chloritoid
Gt	Garnet
K'spar	Potassium Feldspar
Ms	Muscovite
Qz	Quartz
Ru	Rutile
Sill	Silliminite
Sph	Sphene
Staur	Staurolite
Zo	Zoisite

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ABSTRACT

A structural and petrological analysis of the Lower Ordovician sediments and greenstone igneous rocks 10km west of Lökken, Sör Tröndelag, Norway, revealed a structurally complex regionally metamorphosed terrain. These rocks are part of the Lower Hovin Group belonging to the Trondheim Super Group.

The terrain mapped represents the chlorite zone of a Barrovian metamorphic sequence. By working from previous researchers experimental synthesis a schreinemaker bundle was constructed. From this the metamorphic grade was estimated to vary between 450° - 550°C at XCO_2 0.01 - 0.2 at a pressure of 5 Kbars.

Stereographic analysis and way-up evidence were used to establilish the structure. The sequence represents the inverted refolded limb of an F_1 nappe structure closing just to the north of the mapped area.

ACKNOWLEDGEMENTS

I owe many thanks to the Orkla Gruba for thier hospitality, in particular to Goodman Grammeltvedt and Tor Greene. I am also endebted to Dr P Ryan, Mr J E Matthews and Dr N F C Hudson for their help and encouragement.

INTRODUCTION

This study is an attempt to provide a petrological and structural analysis of an area of Lower Palaeozoic greenschists outcropping 10km west of Lökken, Sör Tröndelag, Norway.

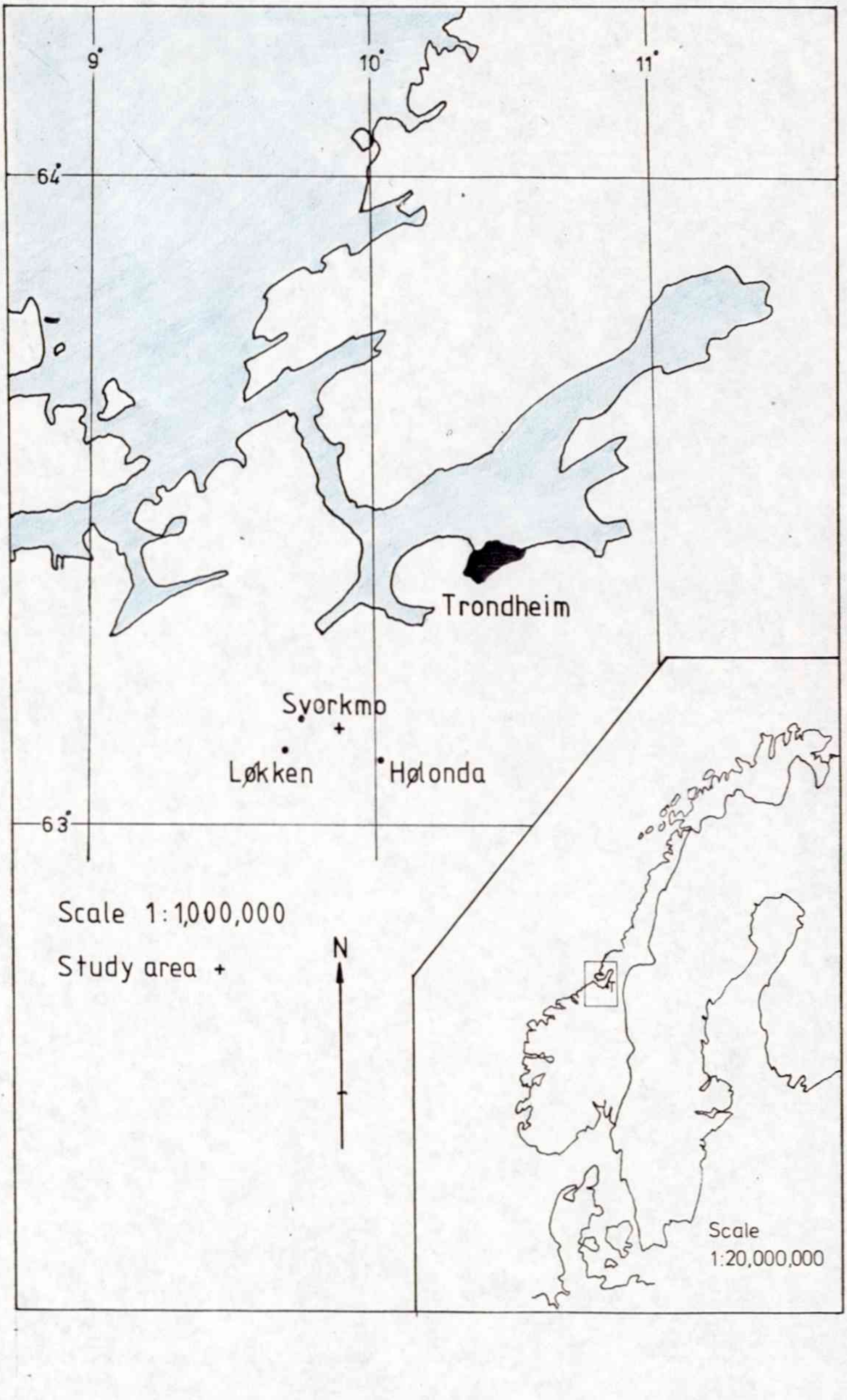
The rocks studied are mainly sediments which make up part of the Lower Hovin Group (Vogt 1945) also known as the Kronkstad Group (Chaloupsky 1970) forming part of the Trondheim Supergroup. They are situated within the Storen Nappe, part of the Trondheim Nappe complex (Greene and Roberts 1980) on the Svørkmo antiform (Rutter, Chaplow and Matthews 1967).

Interpretation of the stratigraphy has undergone a number of changes. Vogt (1945) suggested the Lower Hovin to be Llanvirnian to early Ashgillian, Chaloupsky (1970) suggested Arenigian to Llandeillian and Ryan et al (1980) using the evidence of the profuse graptolite fauna of the Lo and Bogo formations suggested mid-Arenig to mid-Llanvirn.

The Lower Hovin sediments rest on the ocean-floor tholeiites of the Storen Group (Greene and Roberts 1980) which represent part of a fragmented ophiolite of Cambrian to Lower Arenig age (Greene and Roberts 1980) obducted in pre-mid Arenig time (Greene and Roberts 1980). The Lower Hovin Group sediments represent the erosional detritus from the Storen Group just to the South and with increasing age these sediments show an increasing bipolar provenance with acid and basic fragments many of metamorphic origin of continental derivation (Greene and Roberts 1980). Greene and Roberts (1980) suggest that the Lower Hovin and Upper Hovin are of back-arc derivation sited within the Caledonian Iapetus Ocean.

The rocks of the Hovin Group are structurally complicated by two phases of folding and a possible third minor deformation. The rocks in the mapped area display this well with some sedimentary structure and

Fig.1.1 Location of study area.



good cleavage. They have also been regionally metamorphosed in a Barrovian type sequence.

The rocks are well exposed in road cuttings along the Svorkmo to Holonda Road and along the margins of lakes. In addition many isolated outcrops were located in the forest. Aerial photographs were used to help locate outcrops and fault lines. Recently published 1:5000 NGO topographic maps of the area were found useful as field slips.

II

PETROGRAPHY OF THE ROCK UNITS

Greenstone conglomerates and grits

Both conglomerates and grits consist mainly of matrix supported 'floating clasts' within a sandy matrix ~~of ten~~ containing large bands and lenses of sand and silt with no rudacious clasts. As a result, defining the geological boundaries of these units was problematical.

For field purposes the following classification was used:

conglomerate	>1cm	- long axis
grit	<1cm> 2mm	- long axis
sandstone	<2mm but easily visible clasts	
siltstone	finer material	

The clasts are a mixture of rounded and angular fragments stretched or flattened. The most competent clasts such as jaspar show brittle failure due to deformation (Plate 2.1).

The conglomerates and grits often show a scoured base and graded bedding. This gives good way-up evidence and are indicative of a high energy enviroment with debris flows and plane bed lamination (Plate 2.2).

The rudite clasts consist of greenstone, occasionally whole pillows, jaspar and ore minerals and with increasing distance from the Storen Group, quartzite, limestone, acid igneous and basic igneous clasts increase in proportion. This is strong evidence for a bipolar provenance.

In thin section it was interesting to note that many basic clasts considered in hand specimen to be derived from the Storen Group are in fact quite large nodules of pure epidote up to 2cm in long axis. It is interesting to consider whether these clasts could have been primary

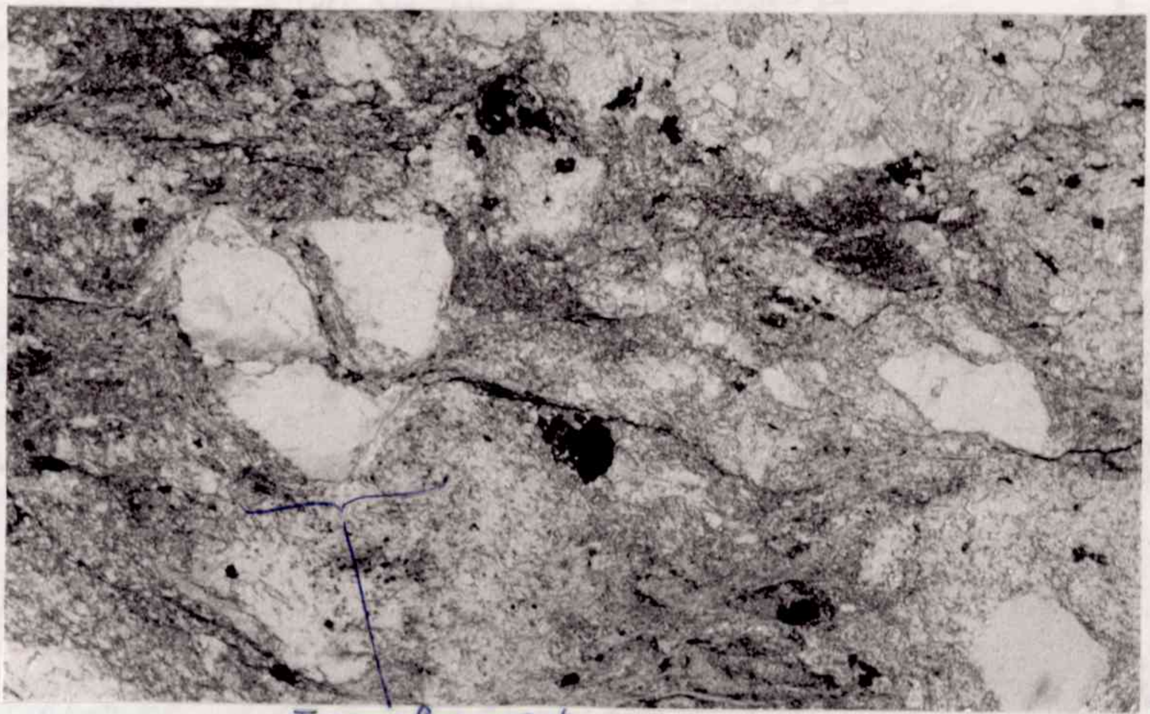


Plate 2.I Grit No. 82.The large jasper fragment shows brittle failure.

Plate 2.2 Conglomerate/sandstone boundary. The conglomerate shows a scoured base demonstrating an inverted sequence.

epidote derived from the pillow lavas or whether such large clasts require a metamorphic origin. Could they have been derived from a continental provenence like the acid fragments?

The grits are of similar composition to the conglomerates varying slightly in amounts of plagioclase, quartz, calcite and epidote. The plagioclase compositions range An_5 - An_{11}. One grit contains very large poikiloblastic plagioclase clasts with inclusions of sericite and epidote. Clasts of epidote are Fe rich showing third order polarization colours. In two thin sections epidote only occurs in the matrix and is hard to resolve under the microscope. One grit also dipslays tourmaline within a clast of schist. Most of the thin sections show sphene except one. Rutile however, is present in this specimen due to a variation in XCO_2 (ref. page 31).

The matrix is made up of quartz, sericite and chlorite, often wrapped around the clasts as S_1 and S_2 fabrics forming pressure shadows. (Plate 2.1).

Sandstone and Siltstones

These rocks are dark green to grey and can be hard to distinguish from the greenstone lavas in the field. It is necessary to examine the weathered surface where their sedimentary structures are well displayed, giving good way-up evidence (Plate 2.3).

These rocks are dominated by quartz but they also contain epidote. The epidotes are mainly Fe rich showing third order colours. These are mainly the larger grains and could be detrital. The smaller grains in specimen No. 144 and No. 141 are clinozoisite showing low order polarization colours often with anomolous blue. These grains often show zoning formed by two episodes of growth. All these rocks contain one or two micas either biotite, chlorite or sericite. Chlorite is less abundant in the north with the incoming biotite. Biotite makes an early appearance in the psamites but does not appear in the adjacent pelites. Sphene and magnetite are also common constituents of these rocks.

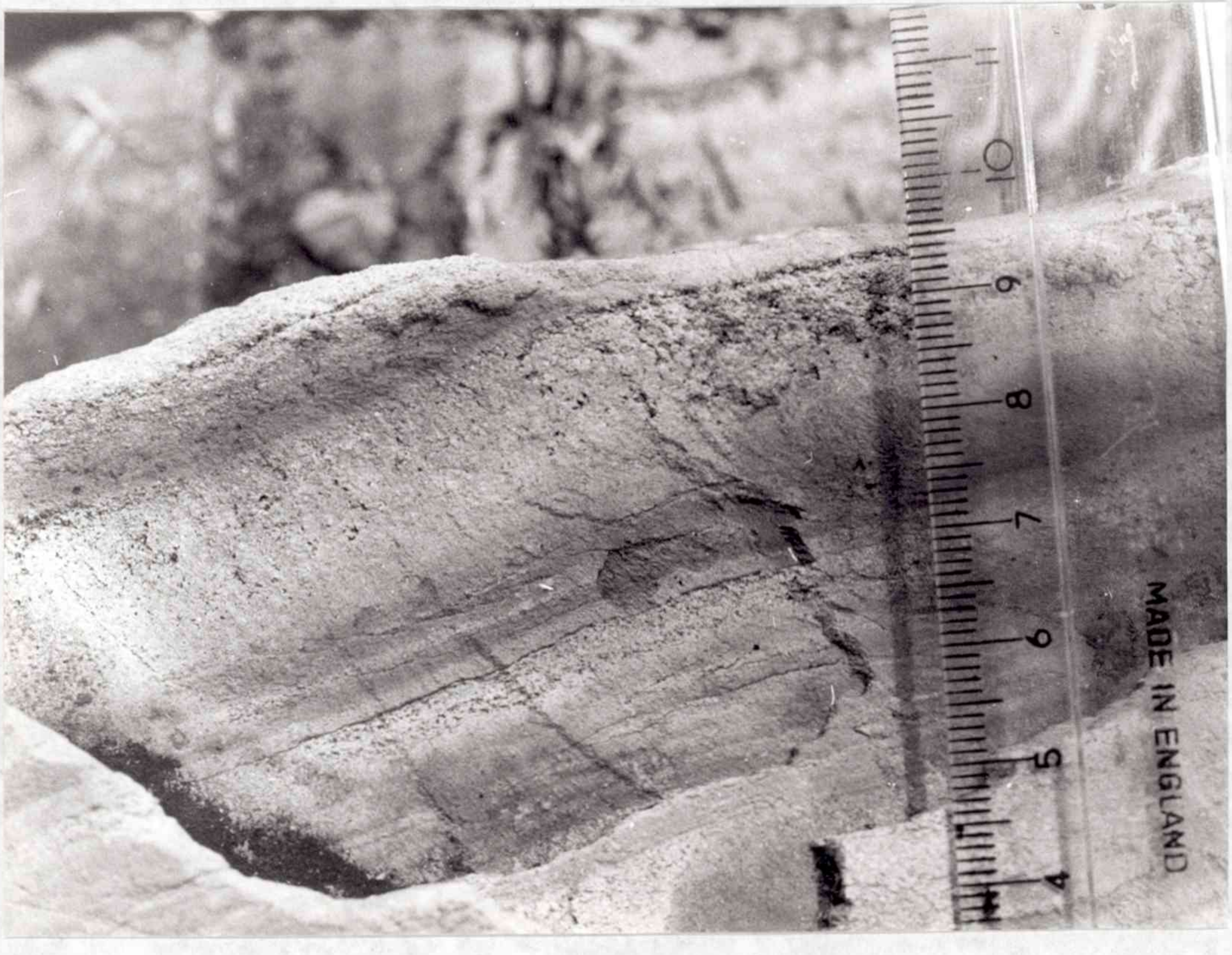


Plate No. 2.3
Graded bedding in the sandstone demonstrating an inverted sequence.

Pelites and Semi Pelites

Interbedded with the sands and silts are bands of chlorite and muscovite rich pelites. These units are strongly cleaved into paper thin flakes crumbling easily making collection difficult. In several locations the semi-pelitic rocks are competant. Specimen No. 91 is a calcareous, chloritic, muscovite, quartz schist and Specimen No. 133 is a chloritoid schist. In thin section the later shows small rosettes and hour glass structures of chloritoid set in a muscovite rich matrix (Plate 2.4).

In the North of the mapped area north of the Hölonda porphyrites, pelites become more dominant, however towards Lake Rörtj the lithology returns to sands and grits.

Along the road cutting between Lakes Bakktj and Steingruvtj a small slate quarry provides good exposure of a well cleaved slate. This is reported to have produced graptolites, however none were found by the author.

Black Shales

In contact with the Hölonda porphyrites black shales are exposed. These shales are cleaved to very thin laminations and are extremely incompetent. Their black colour is probably due to a high graphite content.

Limestone

In the north east of the area, thin bands of limestone are exposed. These thicken rapidly to the east where they are exposed along a forest track on the eastern limit of the map.

The limestones are white crystalline limestones and darker, slightly pelitic limestones containing muscovite and chlorite. They are recrystallized in the west but towards the east they show more of their original structures. One exposure on the forest track is pock

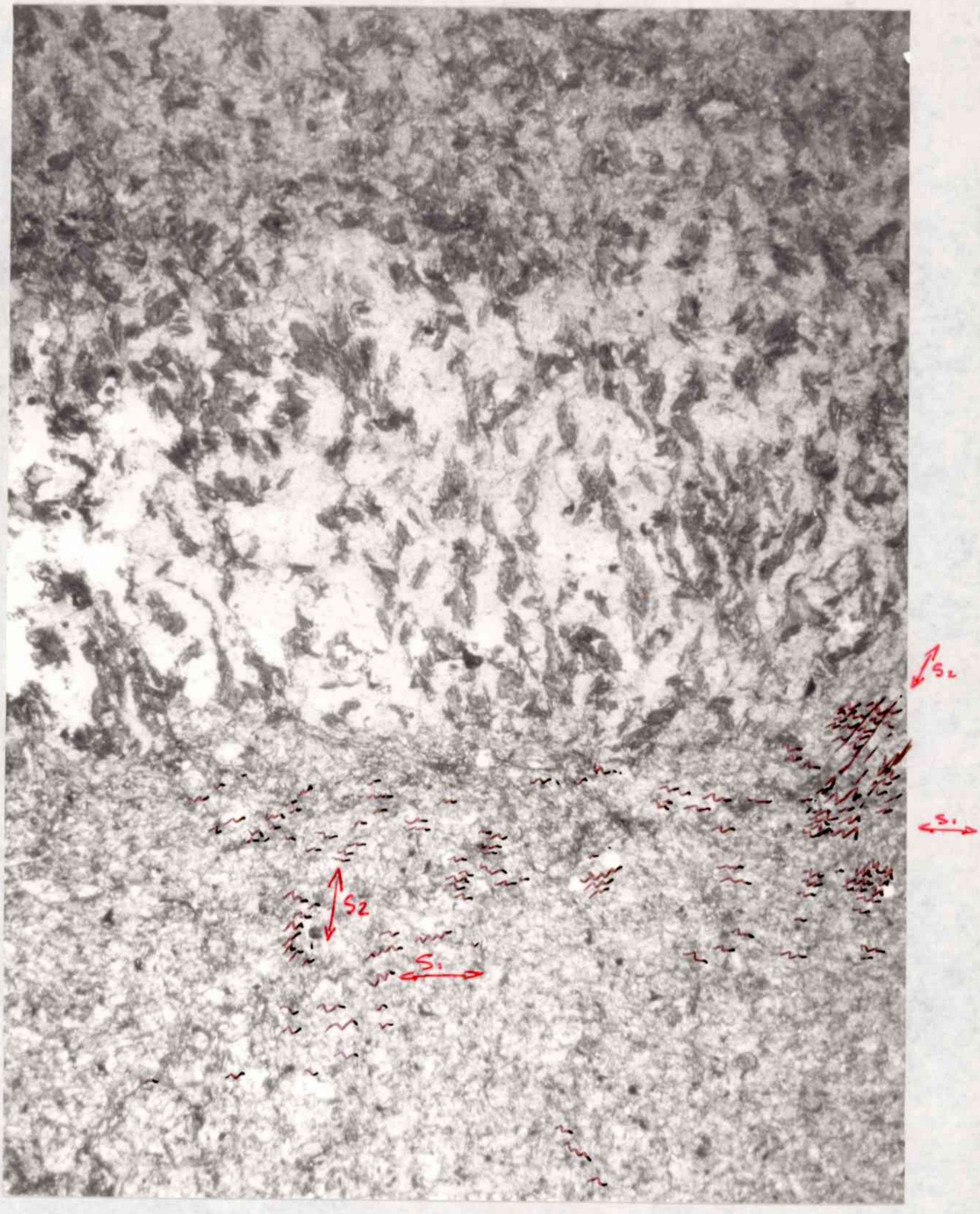


Plate No.2.4 Chloritoid schist. The chloritoid crystals show bow-tie structures aligned with F_2 and S_2 orientations. Plane Polarised light.

marked with limonite filled fossil casts. They are almost unrecognisable but with a little imagination gastropods or brachiopods could be identified.

Greenstone Lavas

There are several outcrops of greenstone throughout the area. The most continuous band is exposed at the Lake Bakktj road cutting. None of these lavas show pillows like their counterparts in the Storen Group.

The greenstones in the field are massive only occasionally displaying a cleavage and usually forming large outcrops. They are often seamed with veins of calcite, epidote and quartz. In thin section the mineralogy is quartz, calcite, plagioclase, epidote chlorite, actinolite, sphene and magnetite. The plagioclase is An_7 and the epidote shows third order polarization colours.

Most horizons do not show a particularly large lateral extent and probably represent fairly small localized lava flows.

Several outcrops of a thin prophyritic greenstone 2 meters thick were located near Lake Bukkuvatnet. In thin section the 'phenocrysts' are calcite and look very similar to the amygdales in the amygdaloid greenstone described by Chaloupsky (1970), from 1km south east of Jonland. The rock is however more acid than the greenstone previously described containing significantly more quartz and less epidote.

Holonda Porphyrites

Two distinctly different units were mapped. They represent laterally continuous intrustions of basite and andesite. Both units are porphyritic, heavily altered and deformed. Both units show baked margins on both sides. In the field the country rock is brittle and hard but shows little evidence of thermal metamorphism in thin section other than unusually large amounts of Fe oxides which may be wall rock alteration and the possible growth of a small amount of biotite.

Vogt (1945) suggested the two porphyrites to be, the 'Berg' type rich in plagioclase phenocrysts, and the 'Almas' type more basic and abundant in phenocrysts of albite and pyroxene.

The andesite porphyrite in the area mapped shows large, often flattened phenocrysts of plagioclase aligned in a planar fabric in a matrix of chlorite epidote, quartz, biotite, actinolite and albite. The phenocrysts which appear distinct in hand specimen are poikiloblastic albite, of composition An_{10} , which is only recognisable by its ability to go into extinction en-mass behind inclusions of epidote, actinolite and quartz.

The basic porphyrite shows in hand specimen and thin section, large actinolites of several compositions some psudomorphing earlier phenocrysts, probably the pyroxenes described by Vogt, and some fresh porphyroblasts. A ground-mass of quartz, plagioclase (An_{13}), epidote, chlorite, sphene and biotite is wrapped around the actinolite crystals in a strong fabric leaving pronounced pressure shadows (Plate 2.5).

Plate 2,5 Basic porphyrite. Large actinolite crystals are wrapped around by a strong fabric developing pressure shadows. PPL

III

METAMORPHISM

The rocks have been described petrographically in the previous chapter. Their mineralogy and textures show that they have all undergone regional metamorphism. In this chapter it is proposed to examine the nature of this regional metamorphism. Sixteen rocks of varying lithology and grade from the mapped area were examined in thin section to establish the mineral assemblages. A list of mineral assemblages is given in the table Fig. 3.1. The locations of these assemblages are given on the location map Fig. 3.2. Rock types are also included in this table.

The mineralogy of the rocks in the area mapped and the area to the north mapped by C A R Robin indicate that the metamorphic grade increases towards the north.

Petrology

Pelites and Psamites

In hand specimen muscovite and chlorite were common constituents of all the pelites. Only one pelite specimen was examined in thin section (Specimen No. 133). This rock has the assemblage chloritoid, chlorite, muscovite and quartz which, according to A Miyashiro (1973) only occurs in rocks with a high alumina content and a high Fe^{2+}/Mg ratio. He also suggests that it occurs in the low temperature parts of regionally metamorphosed terrains such as the chlorite zone.

Pelites to the north in the area mapped by C A R Robin all contain biotite with the assemblage biotite - muscovite - quartz being typical, showing an increase in grade to the biotite zone.

The psamitic rocks collected commonly have the assemblage chlorite-quartz indicative of the chlorite zone. Three of these rocks also contain biotite, Specimens No. 144, No. 141 and No. 34. These

Mineral assemblages. Fig. 3.1

Spec. N°.	Loc. N°.	Qz	Plag	Cc	Zo	Chl	Chld	Sph	Ru	Mag	Biot	Ms	Tour	Act		Rock name
28	14	×	×		×	×		×			×			×		Holanda Andesite Porphyry
34	33	×			×					×	×					Biotite Sandstone
36	112g	×	×	×	×	×		×		×				×		Greenstone Lava
39	158	×	×		×	×		×				×				Quartz Feldspathic Siltstone
42	262	×	×	×	×	×		×					×			Quartz Feldspathic Calcarious Grit
44	362	×	×		×	×				×		×				Quartz Feldspathic Sandstone
82	433	×	×	×	×	×		×				×				Quartz Calcarious Grit
83	425	×	×	×	×	×						×				Porphyritic Greenstone Lava
86	574	×	×	×	×	×		×				×				Conglomerate
91	594	×		×		×						×				Calcarious Chloritic Muscovite Quartz Schist
92	597	×	×	×	×	×			×	×						Quartz Feldspathic Calcarious Grit
96	632	×	×		×	×		×			×			×		Basic Porphyry
128	642			×		×						×				Crystalline Limestone
133	698	×				×	×					×				Chloritoid Schist
141	747	×			×						×	×				Biotite Siltstone
144	807	×			×			×			×					Biotite Siltstone

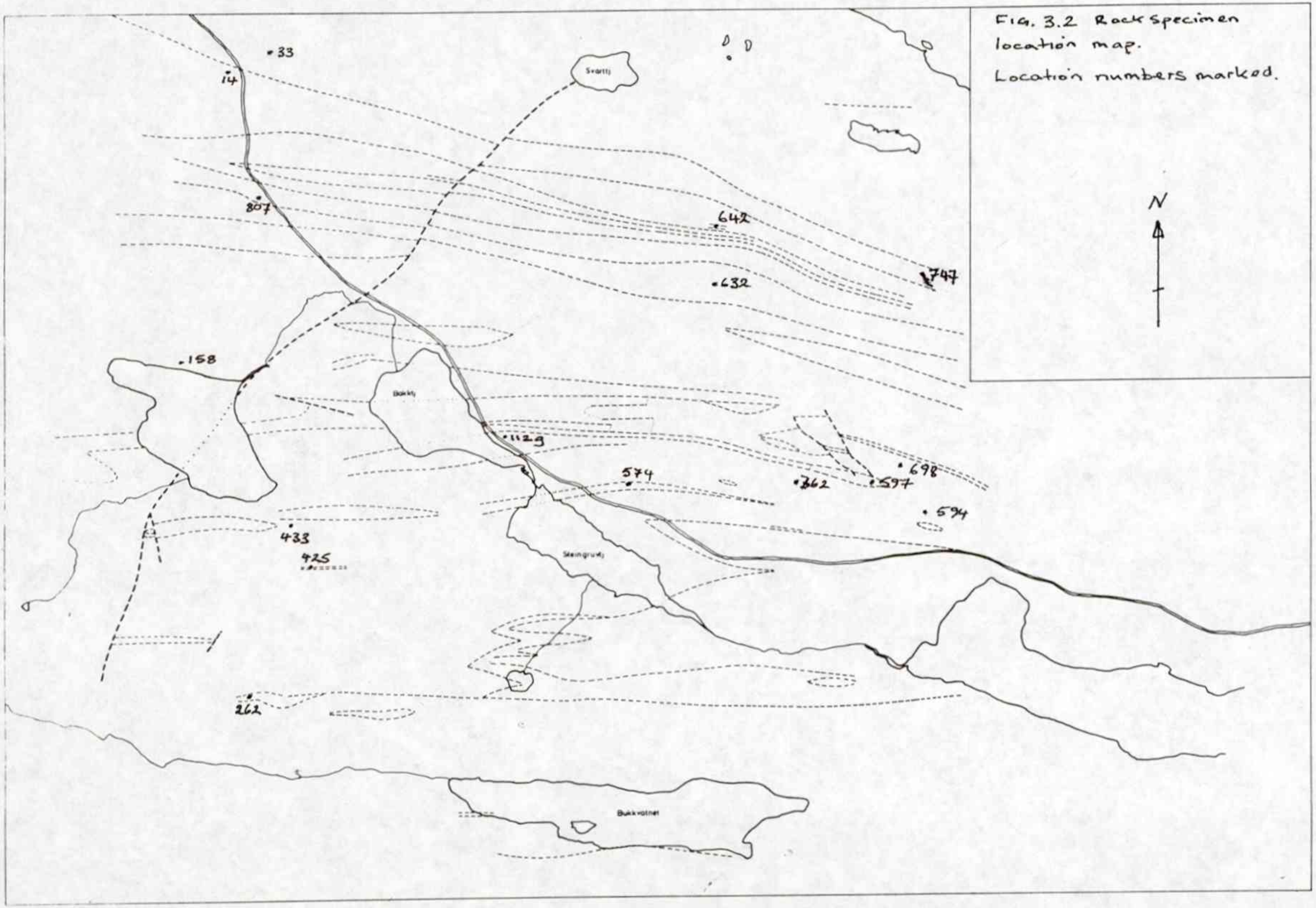


FIG. 3.2 Rock Specimen location map.
Location numbers marked.

rocks are all very silicious only one of them containing another mica, No. 141 contains sericite. The occurance here of biotite in psamites adjacent to chlorite pelites devoid of biotite is similar according to Miyashiro to the metagraywackes in the Scottish Highlands. Epidote occurs in all the psamites; Fe rich epidote. In specimen No. 141 and No. 144, clinozoisite occurs. The plagioclase is all albitic, An_{5-11} typical of the greenschist facies. Specimen Nos. 42, 82, 86 and 82 all show the assemblage epidote - albite - calcite - chlorite which is also typical of the greenschist facies. Most of these rocks also contain sphene but contained the assemblage rutile - calcite - quartz which is the result of a variation in vapour pressure, which will be discussed later in more detail (ref. page 31).

Metabasites and calc schists

Assemblages typical of the greenschist facies were found. The assemblage actinolite - chlorite - albite - epidote was found in both the greenstone No. 36 and the basic porphyrite No. 96. Epidote, calcite and quartz formed numerous veins in this rock. Sphene is also a common constituent. The basic porphyrite displays large actinolite grains of a wide range of composition showing grains of low polarization and high polarization colours, psudomorphing earlier minerals (ref. page 17). This rock also contains quartz, biotie and sphene. Specimen No. 83 referred to as the porphyritic greenstone shows the mineral assemblage chlorite - albite - epidote which Miyashiro states is typical of the greenshcist facies.

Several of the rocks to the north collected by C A R Robin display assemblages typical of the epidote amphibolite facies. This represents a considerable increase in grade. Specimen No. 165 and No. 175 contain albite - epidote - blue-green hornblende which is indicative of the epidote amphibolite facies. Specimen No. 149 contains blue-green hornblende but not albite and epidote.

Phase relations and estimation of conditions of metamorphism

Pelites and psamites

In the pelites the only really useful assemblage is chloritoid - chlorite - quartz - muscovite. This is plotted on the PT grid, Fig. 3.3, taken from Grieve and Fawcett (1974). This work is based on FASH part of the KFMASH model pelite system. Their work is based partly on the experimental synthesis by Schreyer (1965). This system is restricted to $PH_2O = P_{total}$ and FO_2 conditions near the QFM or NNO buffers which, as we will see later, is not far from the situation in the rocks examined. The chloritoid - quartz assemblage restricts the metamorphism to approximately 400-550°C at 2-6 Kbars.

Muscovite - calcite - quartz, Sphene, Sphene-plagioclase and zioste are all useful assemblages in the psamites, giving a tight control on temperature and PCO_2 which will be dealt with later. The muscovite - calcite - quartz stability is plotted on a PT grid, Fig. 3.4, which is taken from D Hewitt (1973). Synthetic starting materials were used at $PCO_2 + PH_2O - P_{total}$. This restricts the assemblages discussed to 2-8 Kbars at 400 - 600°C.

Metabasites and calc schists

The calc schist contains the assemblage muscovite - calcite - quartz which is useful as discussed in the above section. This assemblage was also found in the porphyritic greenstone. All the metabasites contain epidote and most, the assemblage sphene - plagioclase, which are very useful for plotting temperature and PCO_2 conditions which will be dealt with later. The plagioclase ranges from $An_7 - An_{13}$.

It was found that none of these assemblages lend themselves to plotting the pressure. However, the assemblage blue-green hornblende - epidote - albite found just to the north slightly higher in the sequence, can be used to estimate the pressure at approximately 5-6 Kbars in the Lower epidote amphibolite facies according to A

Fig. 3.3

PT grid for Chloritoid + Quartz stability. (Grieve + Fawcett 1974)

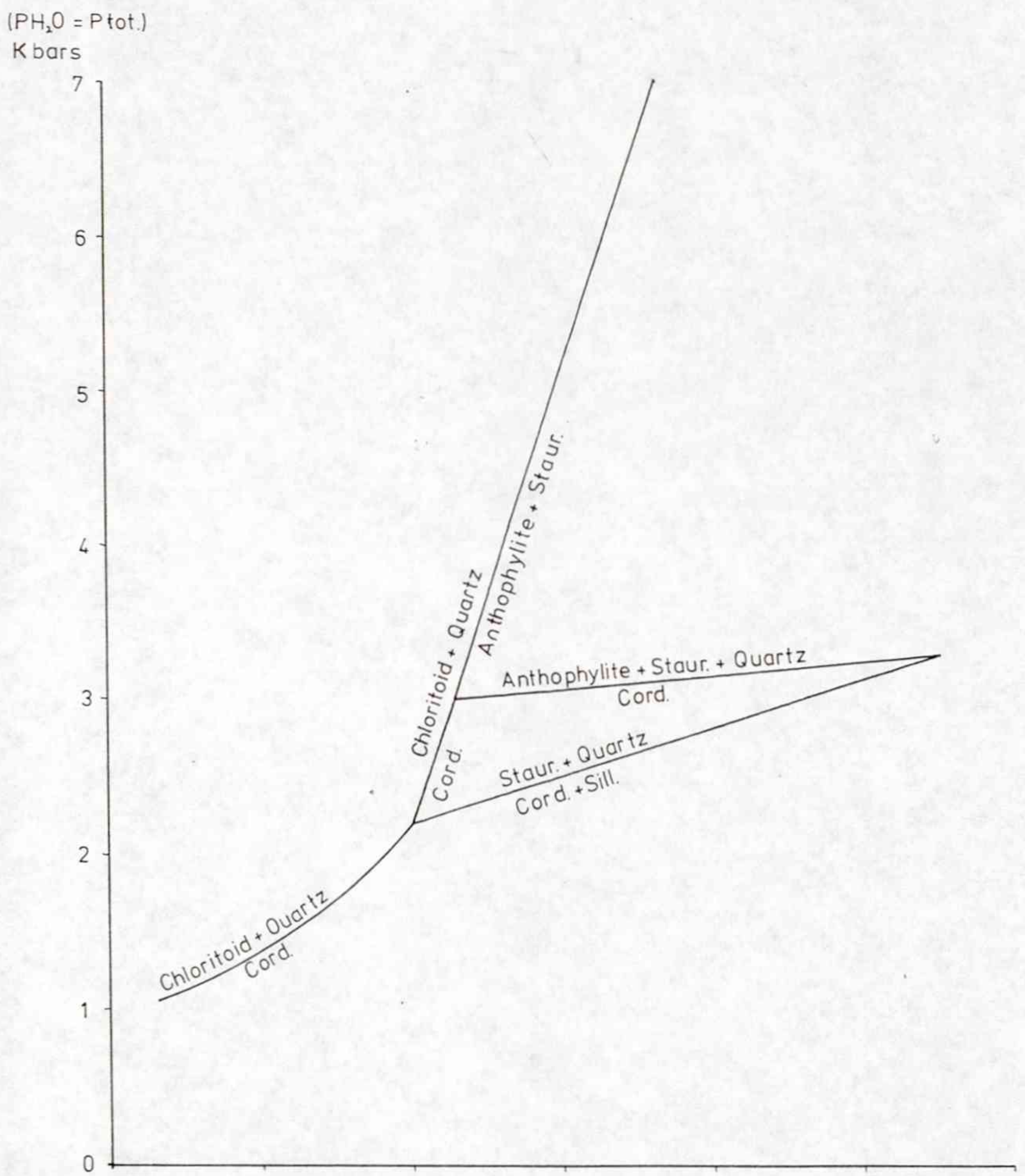
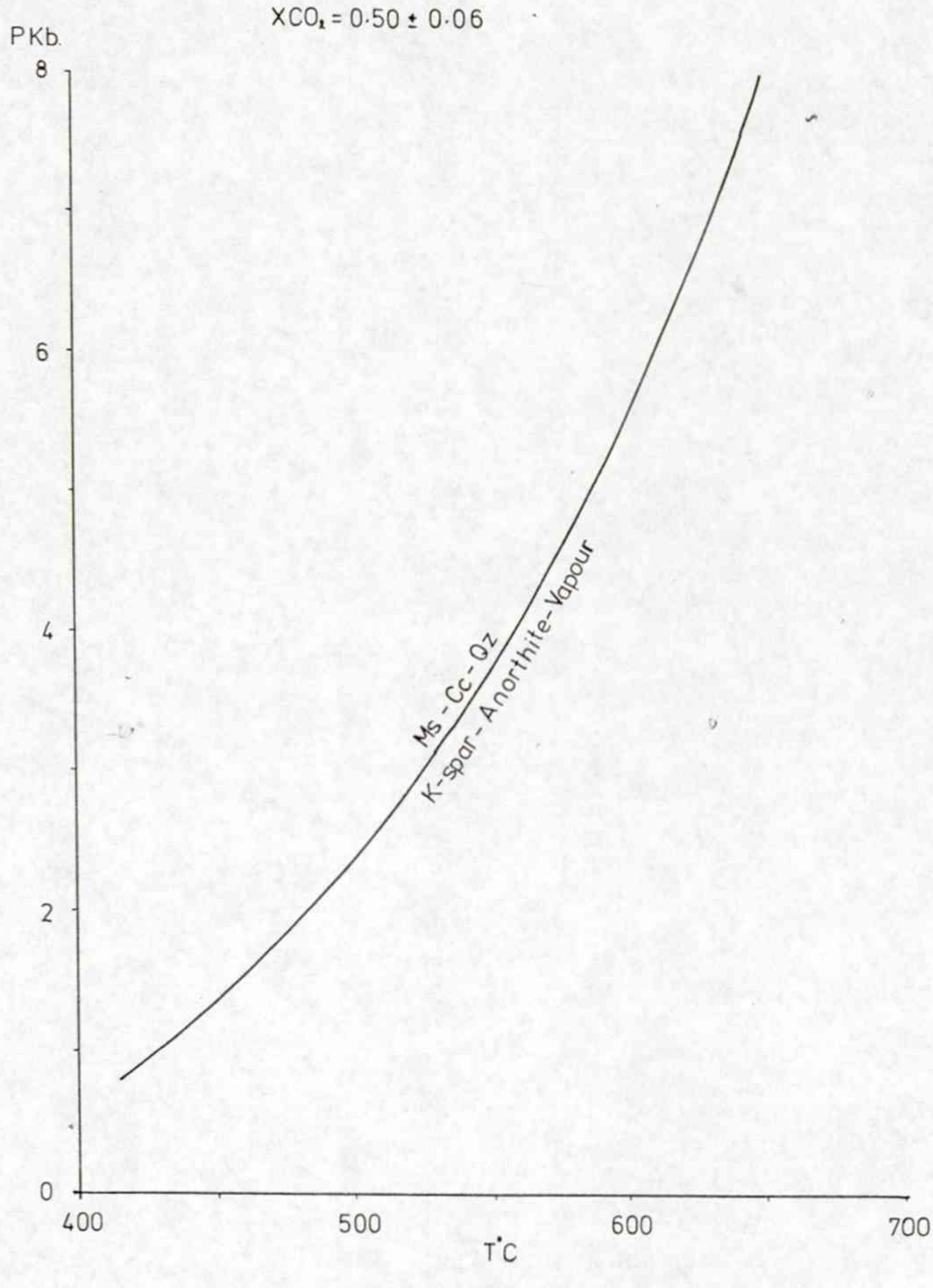


Fig. 3.4 PT grid for Muscovite - Calcite - Quartz stability (Hewitt 1973)



Miyashiro (1973), Fig. 3.5. Since the rocks just to the south can be assumed to be slightly lower in grade actinolite being the only amphibole not hornblende. It is therefore reasonable to suggest that the pressure of metamorphism was approximately 5 Kbars.

The assembalges discussed can be represented in two projections $TiO_2 - CaO - Al_2O_3$ and $K_2O - CaO - Al_2O_3$, Fig. 3.6. Fig. 3.7 shows the compatibility diagrams with the rock specimen numbers marked on to illustrate the compositions present.

The reactions involving sphene - rutile - zoisite - anorthite - calcite - vapour are related by an invariant point. These are presented on Schreinemaker analysis 'A' Fig. 3.8. The reactions involving muscovite - ziosite - anorthite - calcite - vapour and a possible K phase potassium feldspar are also related by an invariant point. These are presented on the Schreinemaker analysis 'B', also on Fig. 3.8. Compatibility diagrams showing the stable phases included. Both these invariant points have a common reaction:

$$\text{ziosite} \rightleftharpoons \text{anorthite} + \text{calcite.}$$

This allows both invariant points to be related. The different facies are numbered 1-8. The four compatibility diagrams with rock specimen numbers fit with facies 1, 2 and 3. One assemblage fits the facies 1. This being the rutile bearing rock. The rocks belonging to facies 2 are common to facies 3 aswell. Some of these assemblages also contain plagioclase. The reaction:

$$\text{rutile} + \text{ziosite} \rightleftharpoons \text{sphene} + \text{anorthite} + H_2O$$

is a continuous reaction with the calcium content of the plagiocloase increasing with temperature. Therefore it is likely that this reaction will have taken place to a certain degree. Graphically this can be displayed by bringing the invariant point down in temperature. The rock specimens in this category have been put in brackets in the diagram. Three assemblages are restricted to facies 3 by the assemblage muscovite - zoisite - calcite.

With reference to experimental data the Schreinemaker bundles can be plotted onto a T-X grid, Fig. 3.9. The

$$\text{rutile} + \text{calcite} \rightleftharpoons \text{sphene}$$

Fig. 3.5 Temperature & pressure of metamorphic facies (simplified).

Fig. 3.6 Compatibility diagrams for $TiO_2 - CaO - Al_2O_3$ & $K_2O - CaO - Al_2O_3$

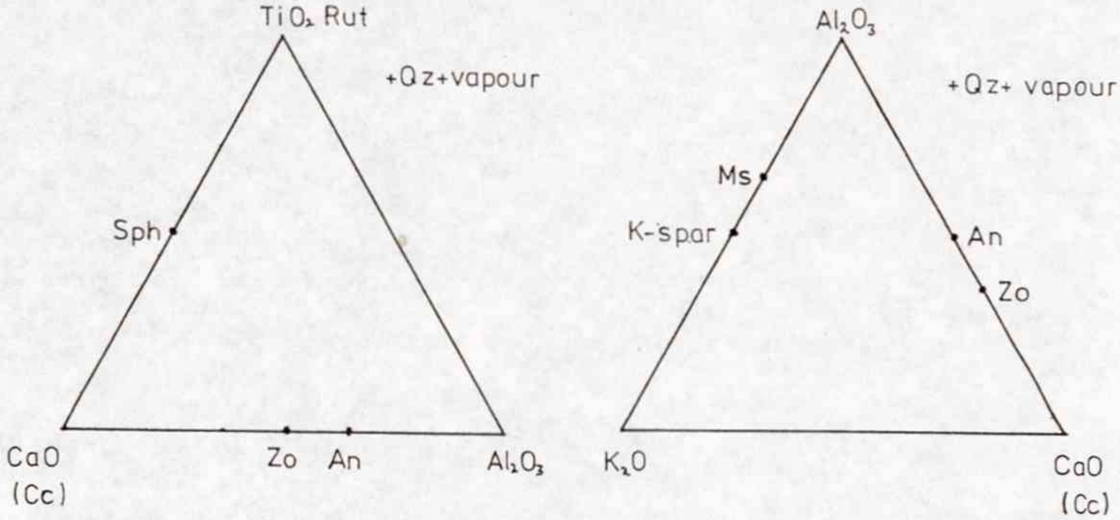


Fig. 3.7 Compatibility diagrams with mineral assemblages

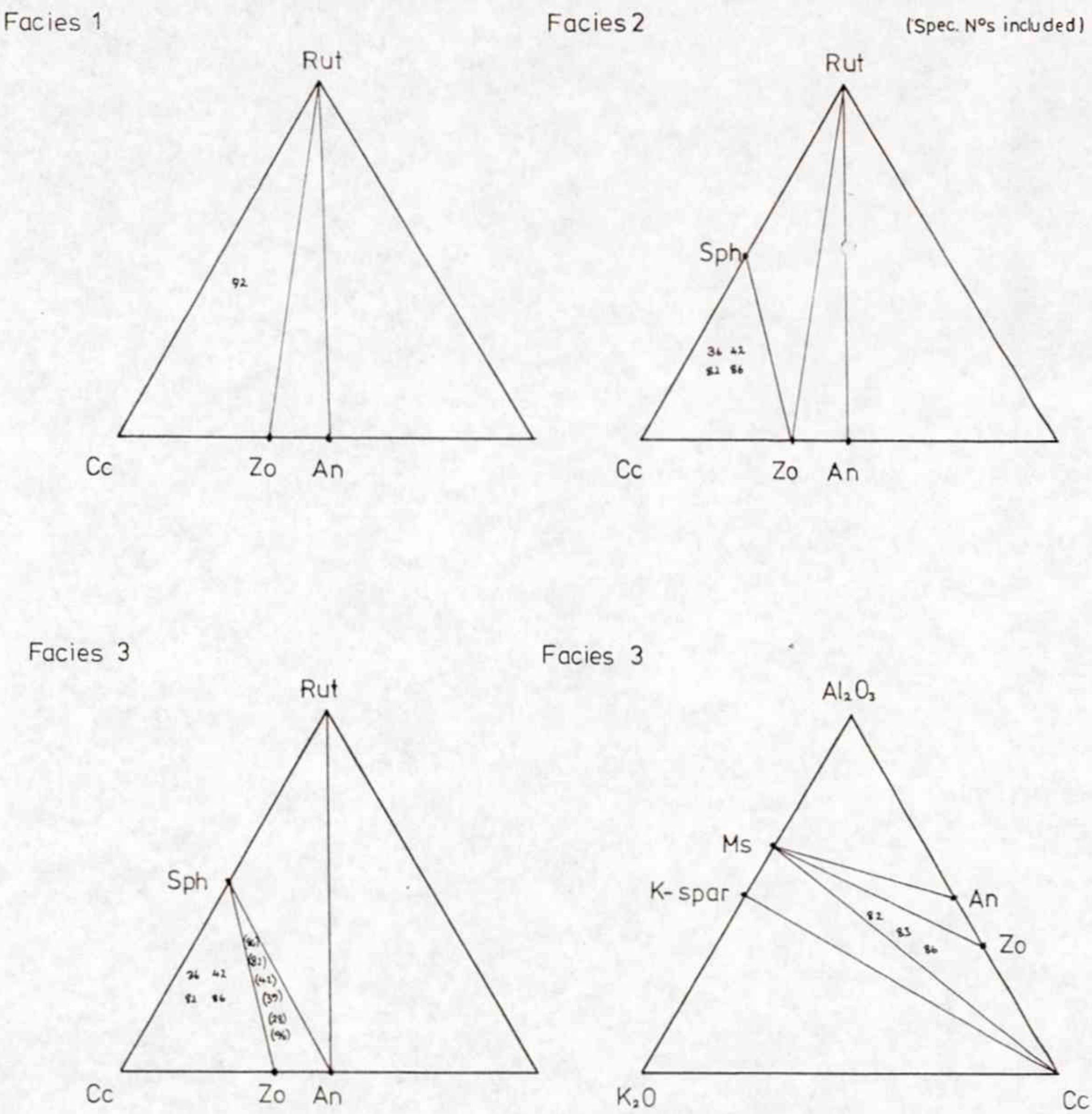
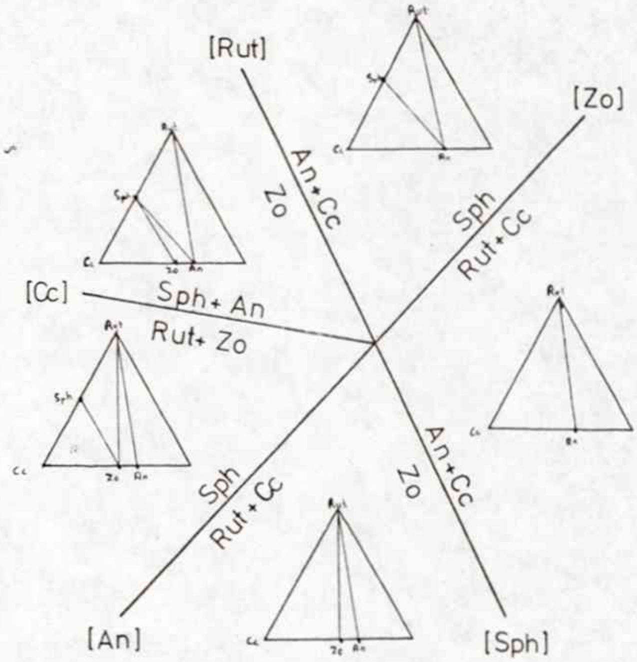


Fig. 3.8 Schreinemakers analyses with compatibility diagrams.

Analysis A $TiO_2-CaO-Al_2O_3$



Analysis B $K_2O-CaO-Al_2O_3$ (+Qz + vapour for A & B)

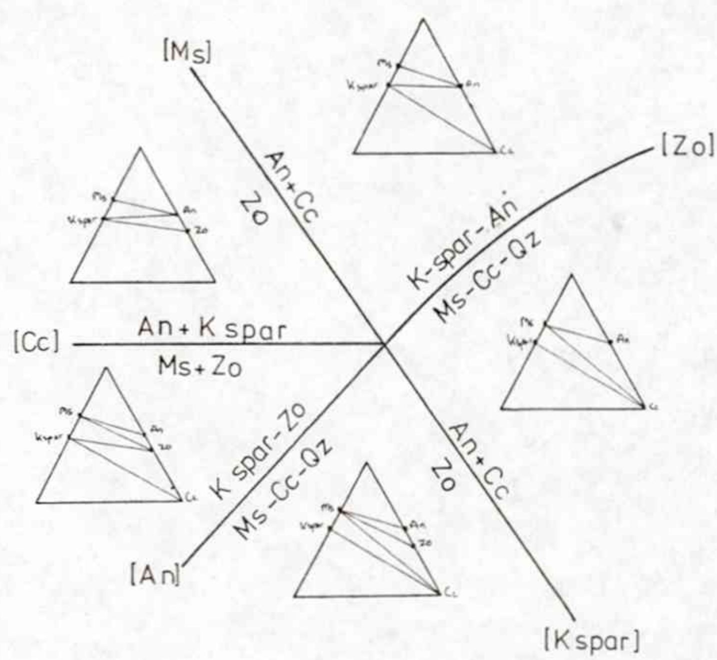
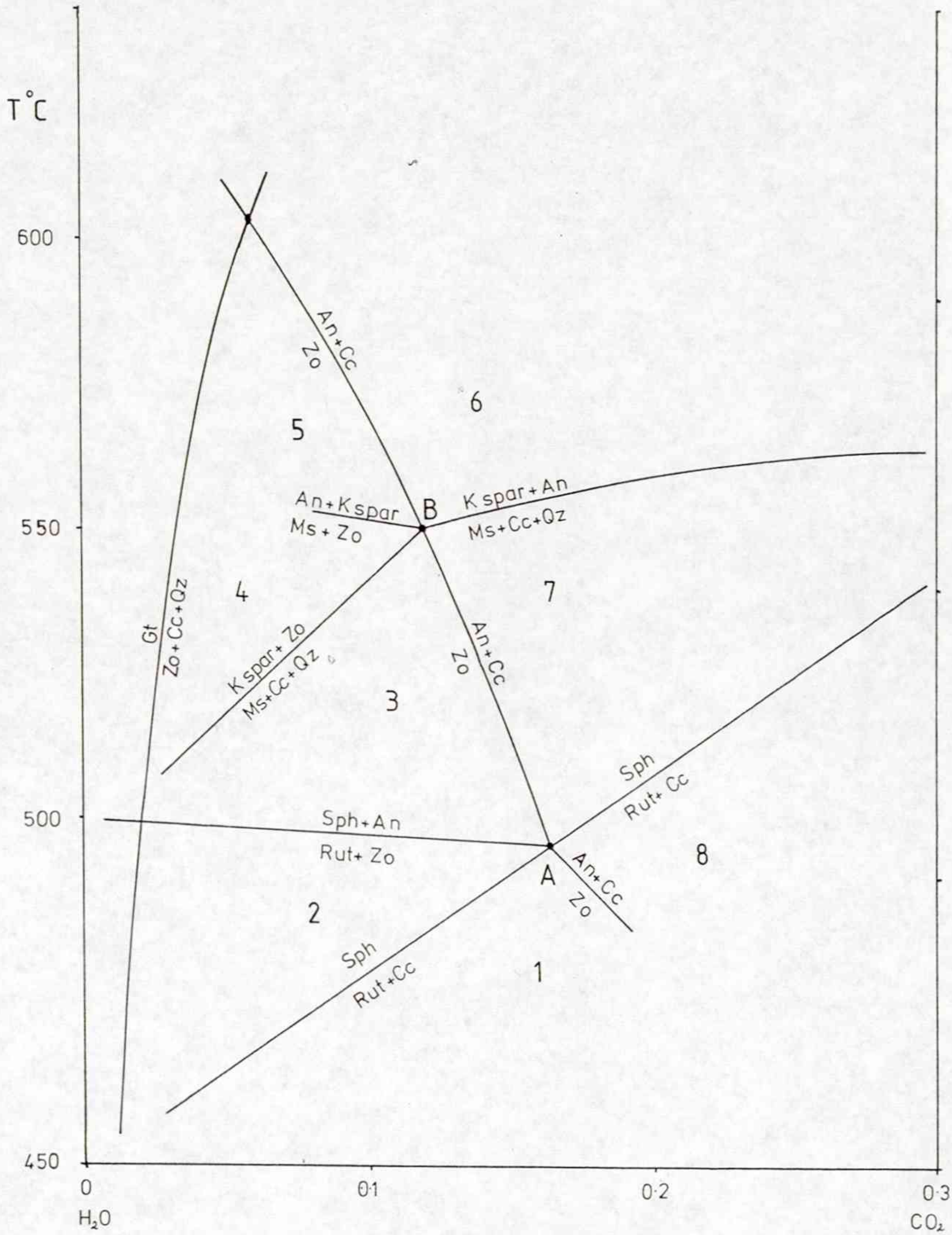


Fig. 3.9 T-X grid



curve was taken from the experimental data of J A Hunt and D M Kerrick (1976) and with reference to G T R Droop (1981). J M Allen and J J Fawcett's (1981) experimental data on the stability of zoisite - anorthite - calcite was used to plot the

zoisite $\rightleftharpoons$ anorthite + calcite

curve and the invariant point involving the zoisite + calcite + quartz $\rightleftharpoons$ garnet curve, not mentioned above. Experimental data from the work of David A Hewitt (1973) was used to plot the position of the invariant point B, and the curve muscovite + calcite + quartz.

The reader is reminded that the suggested pressure of metamorphism was approximately 5 Kbars. The T - X grid has been plotted at 5 Kbars fixed pressure. With reference to Fig. 3.9 the metamorphic grade can be estimated. The majority of assemblages belong to facies 3 with a temperature range of 500-550°C and XCO_2 = 0.02 - 0.16. Four of these assemblages can range between facies 2 and 3 and could have formed in conditions from 450 - 550°C at XCO_2 = 0.01 - 0.16. The assemblage in facies 1 could have formed in conditions from 450 - 500°C in XCO_2 = 0.01 - 0.2 . This assemblage can be considered to result from a variation in XCO_2 since it was located north of an south of sphene bearing rocks of facies 2 and 3. Hence the outer bracket of the metamorphic grade throughout the area can be estimated at 450-550°C at 5 Kbars with XCO_2 = 0.01 - 0.2 .

IV

STRUCTURE

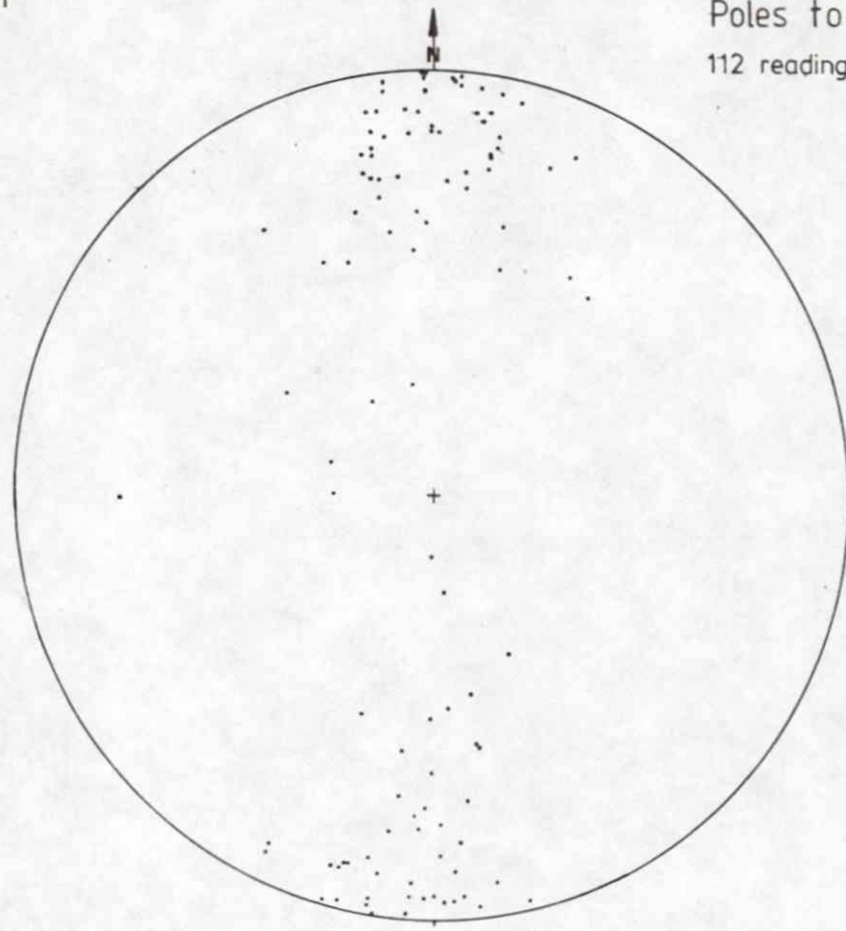
Most of the rocks are psamitic to semi-psmitic with a few igneous rocks and a few pelites. Most units dispslay bedding and cleavage and some sedimentary textures. Less competent units that do not show sedimentary texture show strong cleavage often crenulated. In the conglomerates the plane of pebble flattening is apparent and similarly a plane of phenocryst flattening is apparent in the andesite porphyrite. The data recorded is displayed on stereograms Figs. 4.1 to 4.10.

The poles to S_0 are contoured on Fig. 4.9. Their plot fits a π circle the pole to which lies close to the main plot of F_1 fold hinges and bedding cleavage intersections at 06°/093°. It must however be realised that subsequent D_2 deformation will have had some re-orientation effect on this geometry.

The poles to S_1, the poles to the plane of phenocryst flattening and the poles to the plane of pebble flattening are plotted on separate stereograms, Figs. 4.2, 4.3 and 4.4. Their geometry is very similar, suggesting that the planes of pebble flattening and the planes of phenocryst flattening were formed in response to D_1 parallel to S_1. They are all plotted together on a contoured stereogram, Fig. 4.10. The pole to the π circle of these plots is very close to the position of the F_2 hinges and the F_2 crenulations at 06/094°. This is almost exactly parallel to the π circle for the S_0 orientations. In the field S_0 and S_1 were also sub-parallel in most of the outcrops. The majority of the mapped area is therefore part of a major fold limb.

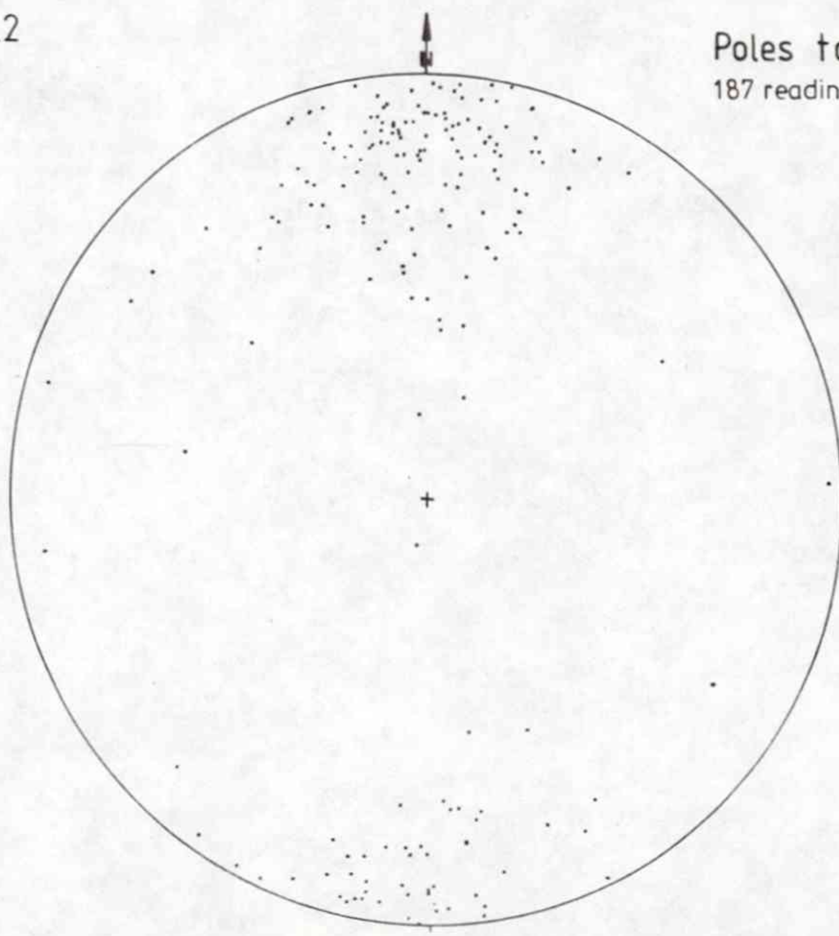
Unfortunately only limited S_2 and F_2 axial planes were located and these were random in orientation. In the field, several folded veins and crenulations were found which may represent a third minor deformation.

Fig. 4.1



Poles to S_0
112 readings

Fig. 4.2



Poles to S_1
187 readings

Fig. 4.3

Poles to the plane of pebble flattening in the conglomerate.

18 readings

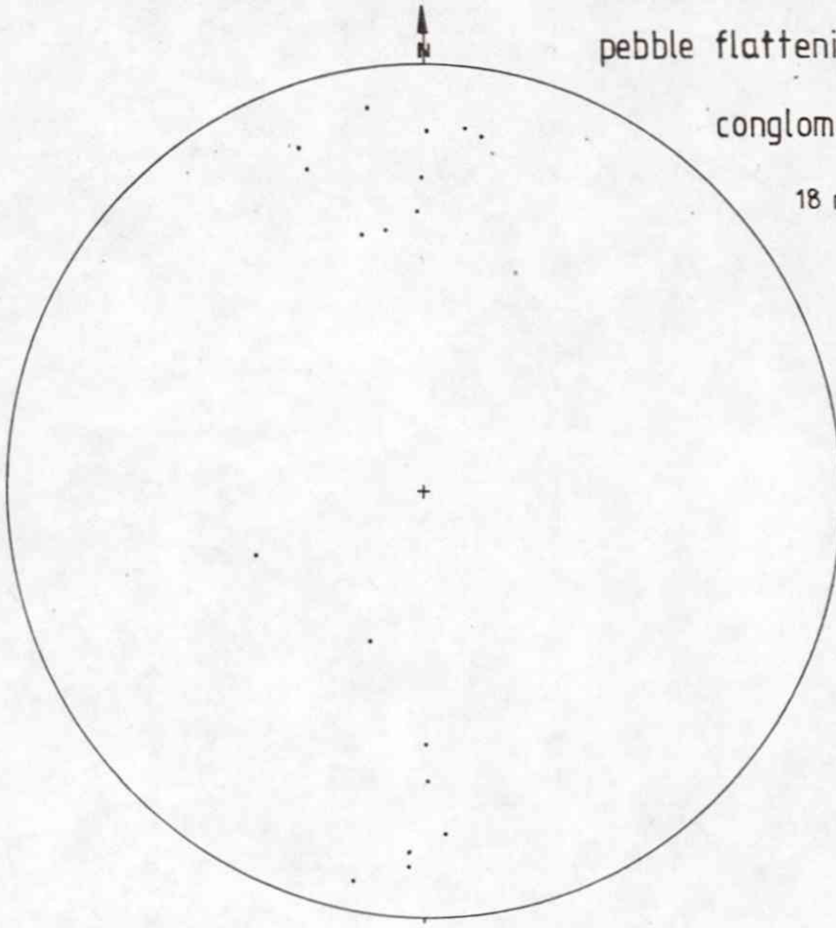


Fig.4.4

Poles to the plane of phenocryst flattening in the andesite porphyrite

7 readings

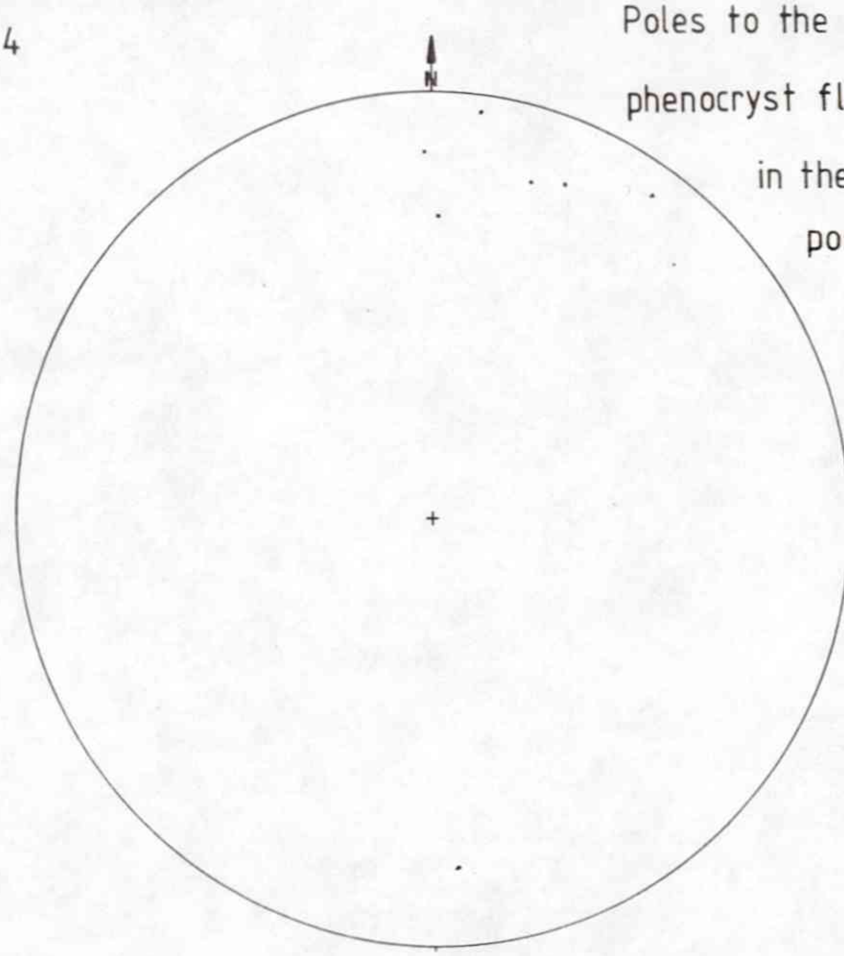


Fig. 4.5

Poles to F_1 axial planes.

7 readings

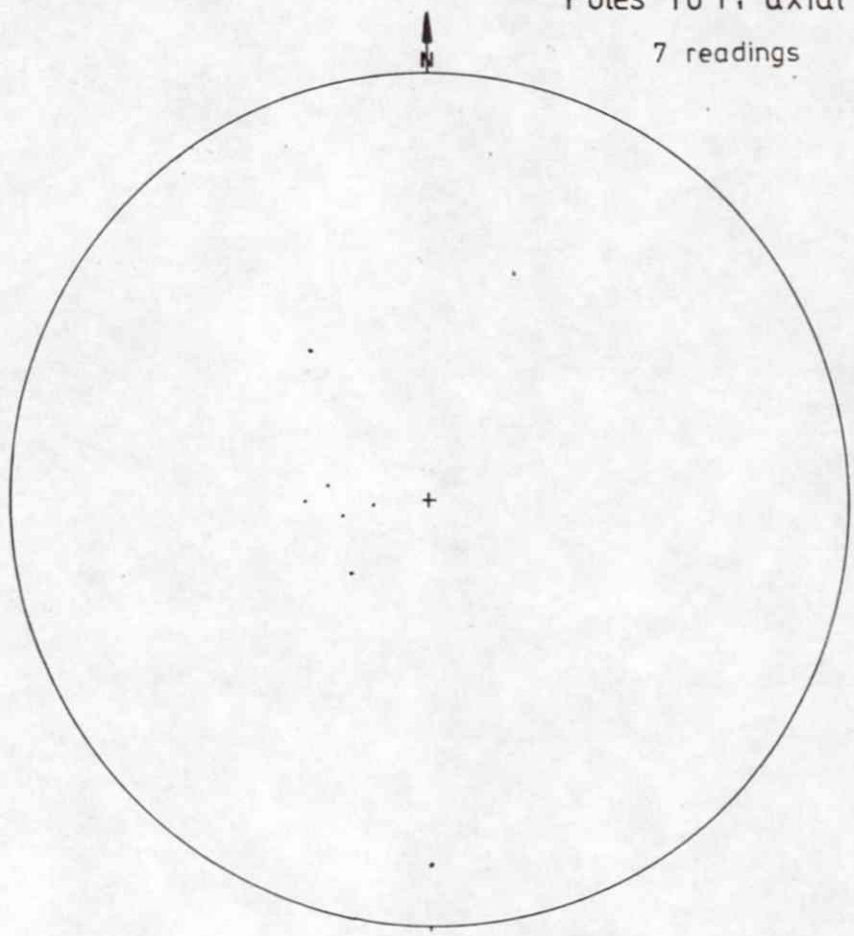
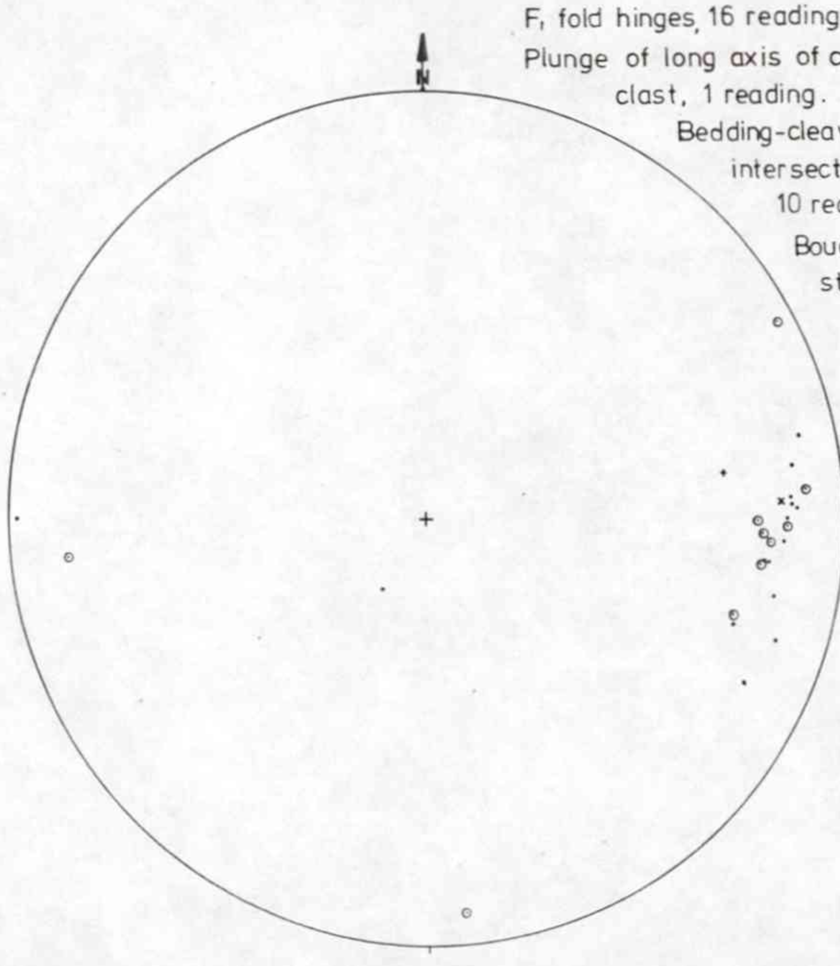


Fig. 4.6



F_1 fold hinges, 16 readings. - ·

Plunge of long axis of conglomerate clast, 1 reading. - +

Bedding-cleavage (S_0/S_1) intersection 10 readings. - ⊙

Boudines stretched - ×

Fig. 4.7

F_2 crenulations.
6 readings.

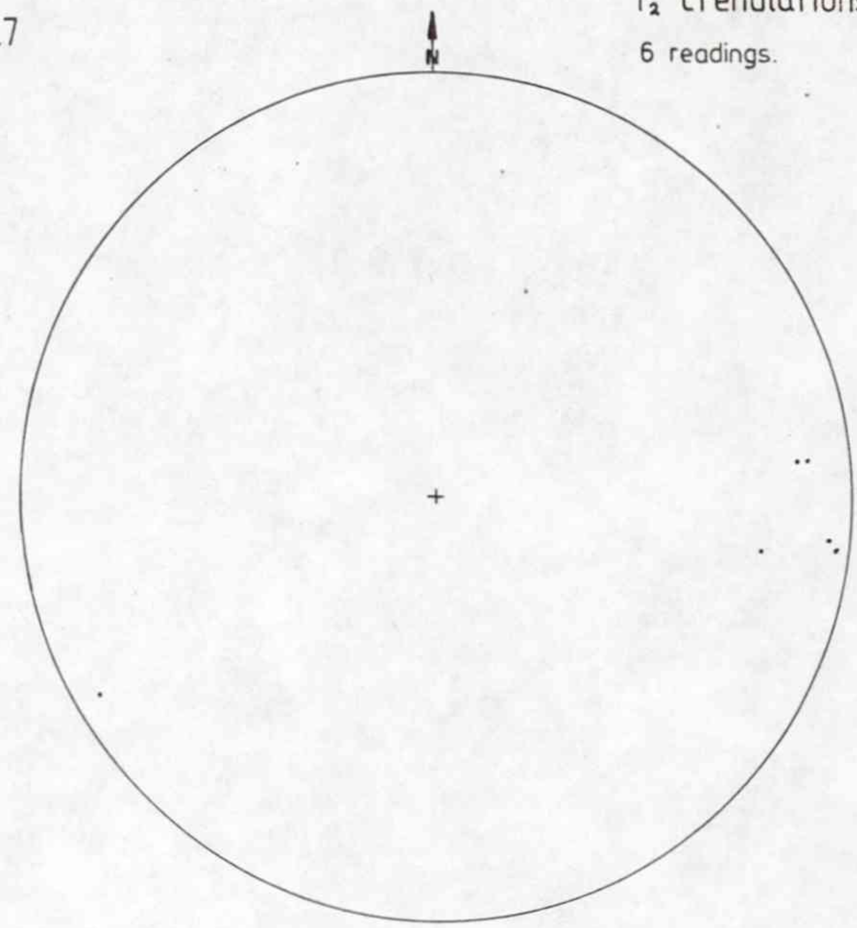


Fig. 4.8

Poles to S_2 – ·
Poles to F_2 axial planes – +

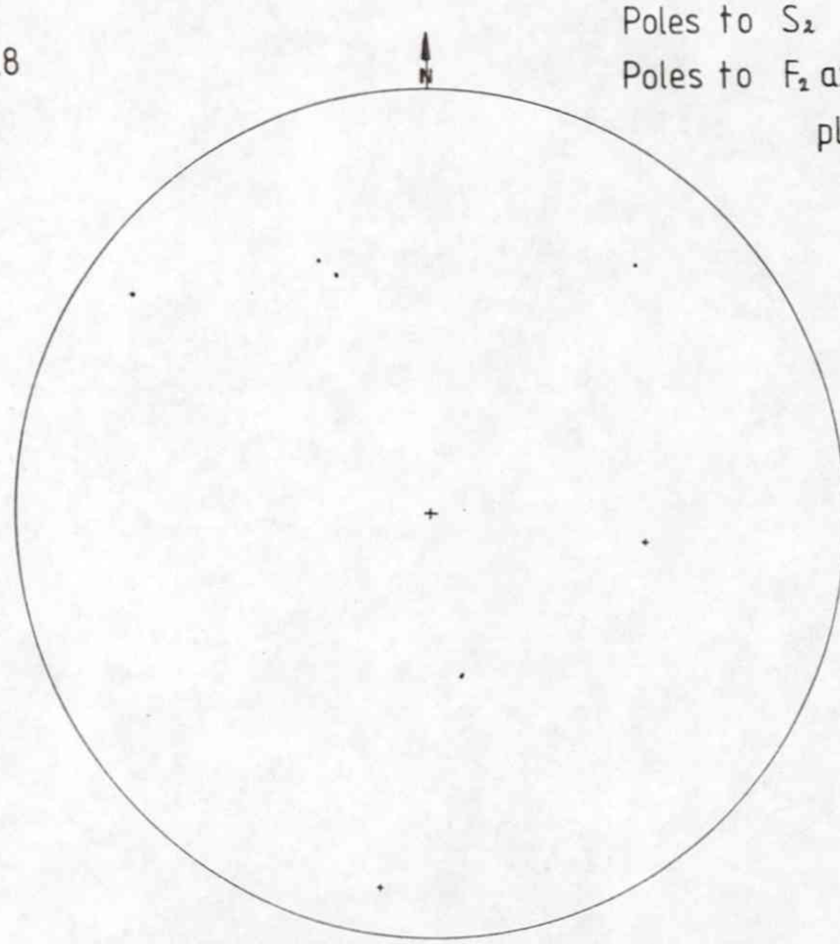


Fig.4.9

Poles to So

Contoured frequency

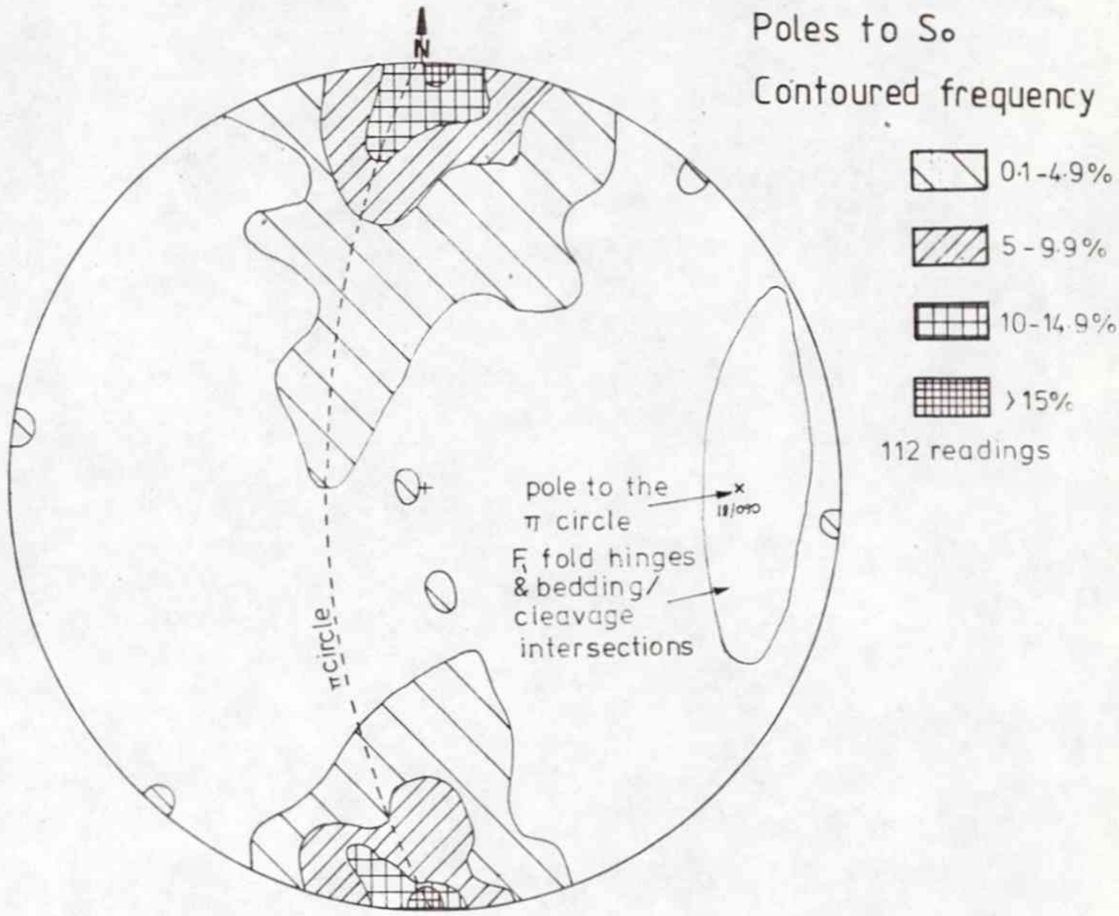
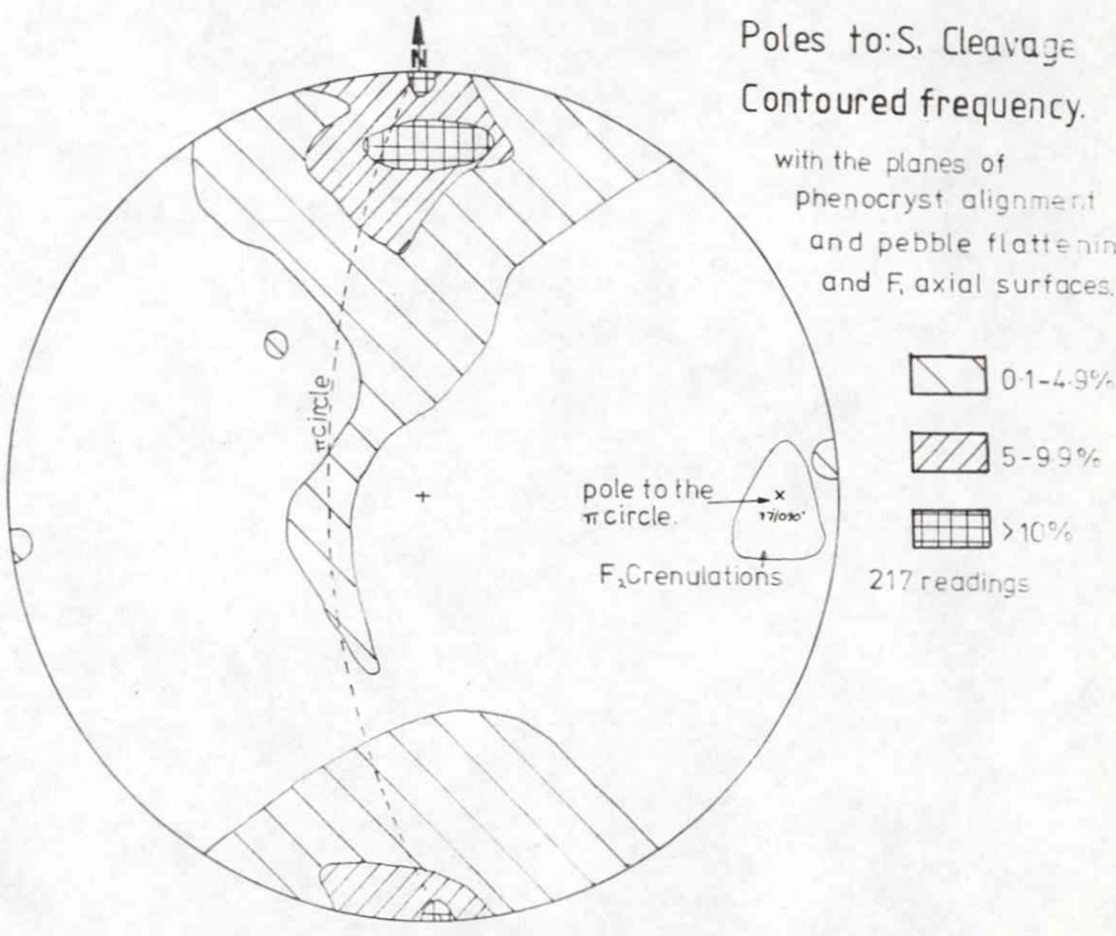


Fig.4.10

Poles to: S, Cleavage

Contoured frequency.

with the planes of phenocryst alignment and pebble flattening and F, axial surfaces.



In the field, younging evidence consistently shows an inverted sequence. Evidence consists of graded bedding in the silts, sands and grits and scoured bases and graded bedding in the grits and conglomerates. (See Plates 2.2 and 2.3). Great care was taken to only record evidence which unquestionably showed way-up. Some outcrops are confusing and show grading in both directions, apparently in the same unit. This could be a density flow or small scale isoclinal folding and was not used as a way-up. Care was taken to record bedding and cleavage orientation with way-up data wherever possible. Plates 4.1 and 4.2 show an F_1 fold hinge with possible inverted way-up. Unfortunately, the thin section of this rock, Plate 4.1, does not show particle size grading, but does show a concentration of heavy minerals into layers. Plate 2.3 shows more typically the grading found on good weathered surfaces in the sands and silts. Plate 2.2 shows very well the scoured bases typical of the contact between conglomerates and grits and sands and silts.

From the field evidence a cross-section has been drawn, Fig. 4.11. By closely following bedding cleavage relationships it is possible to draw the overall structure. One problem encountered was that many of the units often have poor latteral extent due to rapid facies changes. The section shows the lower inverted limb of a nappe structure closing just to the north of the mapped area. A sketch section is included, Fig. 4.12. Within this limb two parasitic folds are evident, one folding the bands of greenstone lava in the Lake Bakktj area and one in the far north of the mapped area. These folds are sub-horizontal, plunging 06°/093°. The whole structure is then folded a second time which is well displayed by the folding of the cleavage in the north and the outcrop of the conglomerates and grits in the south which form a pronounced antiform. In conjunction with the stereographic evidence the F_2 structure can be described as tight to isoclinal upright folds with sub-horizontal hinges plunging 06°/094°.

A sketch section including the sections drawn by J E Matthews to the south and C A R Robin to the north, shows the overall structure. The area mapped is dominated by the F_2 Svørkmo Antiform with the conglomerates in the core. This passes south into the F_2 Lökken

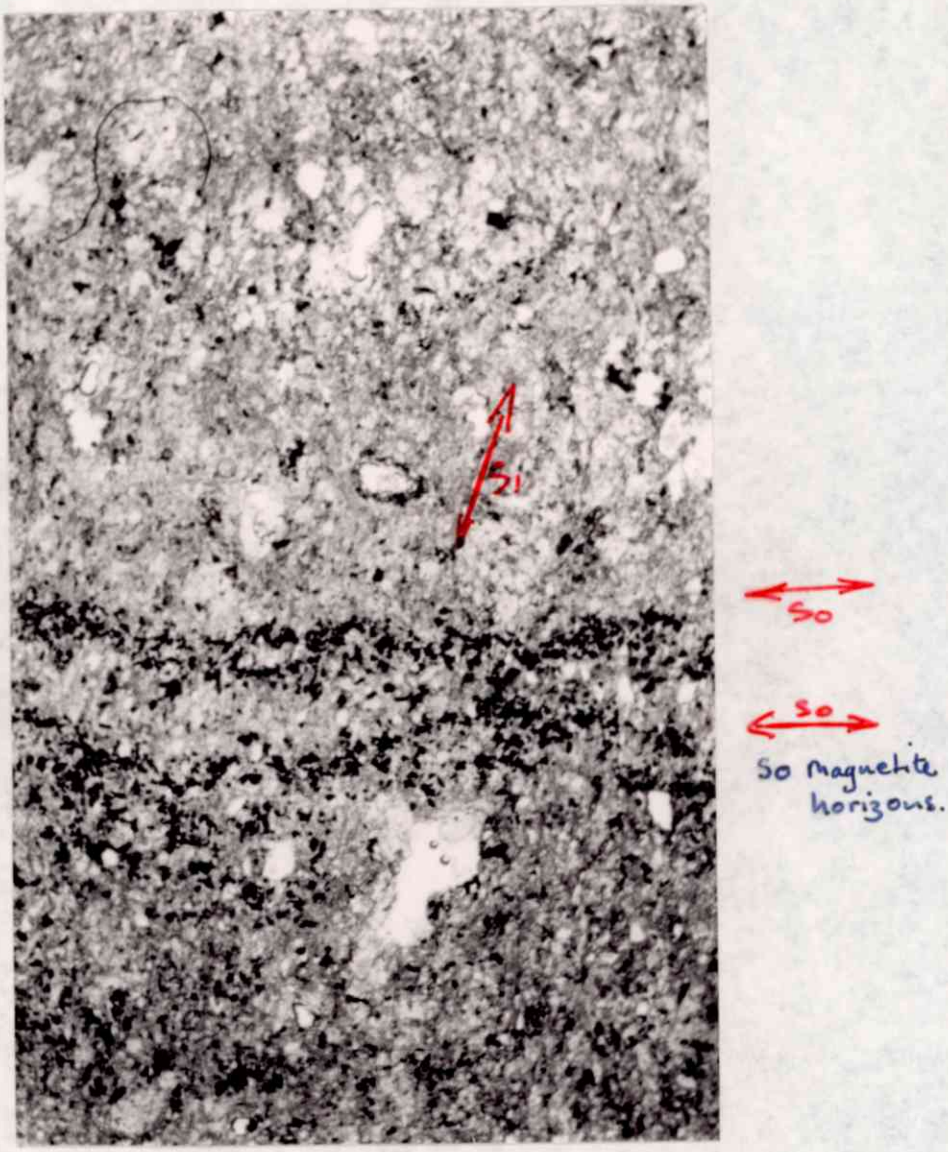


Plate No.4.I Bedding/cleavage intersection in sandstone No. 44, micro photograph. The high angle intersection S_0/S_1 represents an F_1 fold hinge.

Plate No.4.2 Sandstone No.44.Outcrop.

Fig. 4.11 Cross section

Scale 1:5000

No vertical exageration

0 — 0·5Km

(Legend as for the map)

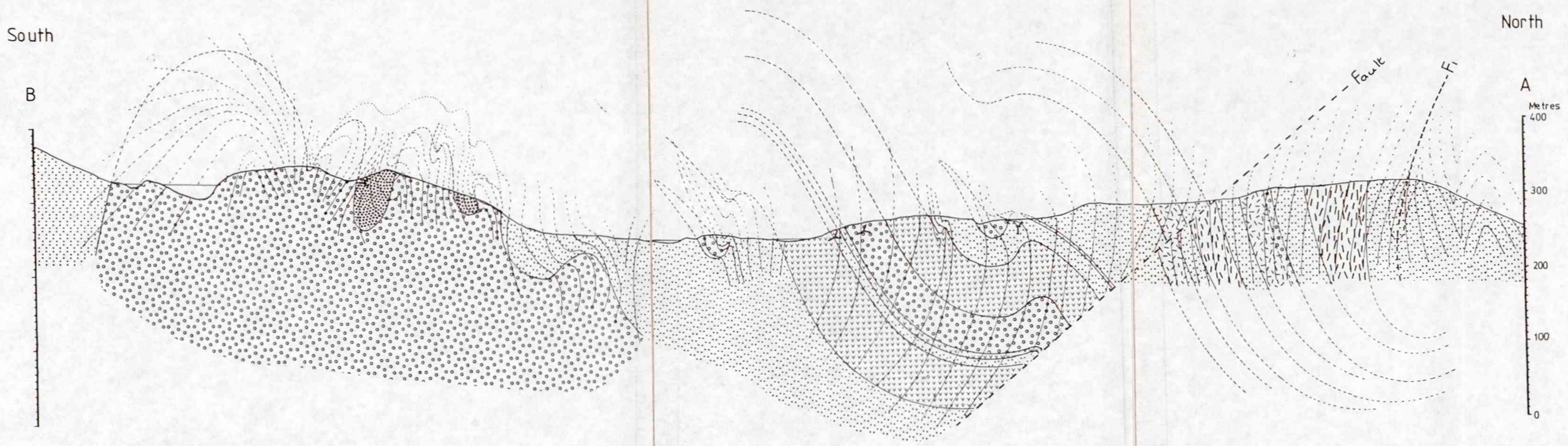
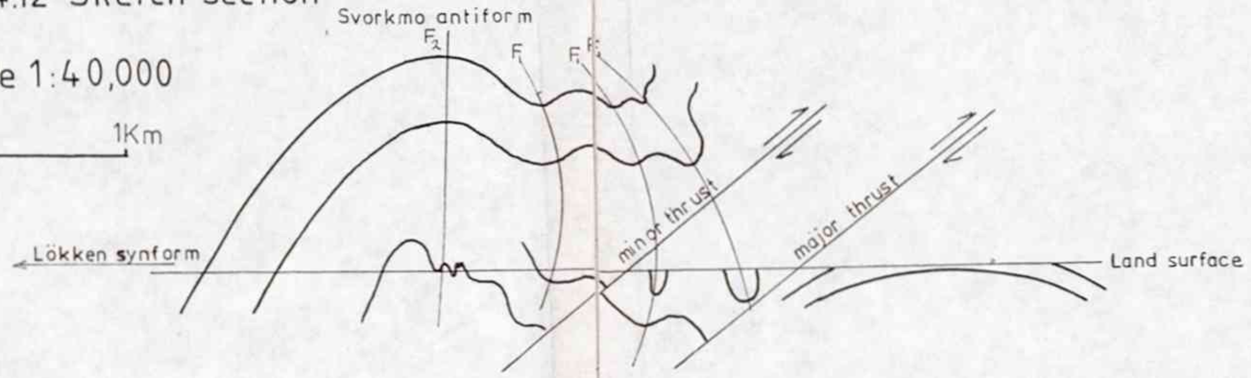


Fig. 4.12 Sketch section

Scale 1:40,000

0 — 1Km



synform. The rocks to the north of the Svorkmo Anticline are folded by F_1 parasitic folds and secondly by minor F_2 folds. This structure passes north into the F_1 fold hinge suggested by C A R Robin which is then thrust out.

Faulting is not as well displayed as the folding. Small scale faulting is evident thoughout the area. These faults usually occur in the greenstones and conglomerates. Plate 4.3 shows a good example of this faulting with en echelon tension gashes formed by progressive simple shear showing displacement of only a few centimetres. The fault strikes 354° and dips 70° to the east with a down throw to the east.

A major fault running NE-SW cross cuts the whole area and lies beneath Lakes Svartj and the unnamed lake in the south west. It is well displayed on the aerial photographs (ref. Norway collection C13-5191) and can be inferred from the outcrop of the Hölonda porphyrites. This is a low angled fault dipping to the south east and thrust approximately 25m north west. Outcrops of the fault plane were not found and its relationship to the deformation are uncertain, suffice it to say that thrusting may have occurred with the development of the F_1 nappe structures.

Faulting also occurs at the westerly limit of the limestone outcrop in the east of the map. These two faults also show on the aerial photographs and explain the outcrop of the limestone. The eastern most fault is down thrown to the west but the throw of the western most fault is uncertain.

The only faults located cross cut the strike. It is possible that many more faults occur parallel to the strike in response to the development of the F_1 nappe structures but remain inconspicuous. The outcrop of the Hölonda porphyrites could be influenced by a thrust fault running parallel to their strike. The outcrop pattern of basic porphyrite then andesite from south to north is repeated. There may, in fact, be only one band of each thrust to produce a repeated outcrop.

Plate No.4.3 En echelon tension gashes around a minor fault.

It is not possible to say much about the relative dating of the faults as most of them are inferred and therefore their relationships to the folding cannot be assessed.

V

TEXTURES

The key to the relationship between the metamorphism and deformation of these rocks is illustrated by the textures. Most of the rocks show a good planar fabric most of which have been effected to a greater or lesser extent by a second deformation. Each type of fabric is described with reference to photomicrographs and sketches. All the rocks are recrystallized under the metamorphic conditions described in Chapter III and deformed by at least two phases of deformation described in Chapter IV.

Planar fabrics

Four thin sections examined, Nos. 28, 83, 96 and 144, contain planar fabrics unaffected by a second deformation. Planar fabrics are evident in both the basic porphyrite No. 96, Plate 5.1 and the andesite porphyrite No. 28. In the andesite this is better observed in hand specimen. Sterographic analysis was used to show this to be S_1 (ref. Plate 4.10). The poikiloblastic phenocysts of plagioclase only show in the chaotic jumble of mineral growth as flattened brick shapes made up of a haze of sericite, zoisite, quartz and albite. The basic porphyrite, however, shows a strong planar fabric wrapped around large grains of actinolite adjacent to conspicuous pressure shadows. These grains are strongly twinned and in some cases fractured, Fig. 5.1. Lath like bodies of polymorphic quartz segregations overprinted with a shadowy extinction lie within a streaked out groundmass.

Specimen No. 144 was located adjacent to the Hölonda porphyrite and may have suffered thermal metamorphism as well as regional metamorphism. In the slide sericite, quartz and some epidote has grown parallel to the fabric. Much of the epidote is detrital and the fabric is wrapped around it. The biotite in this rock is both concordant with the fabric and discordant with the fabric wrapped around it. Some of this is likely to be thermal metamorphic, the rest of the mineral growth is contemporaneous with the D_1 deformation.

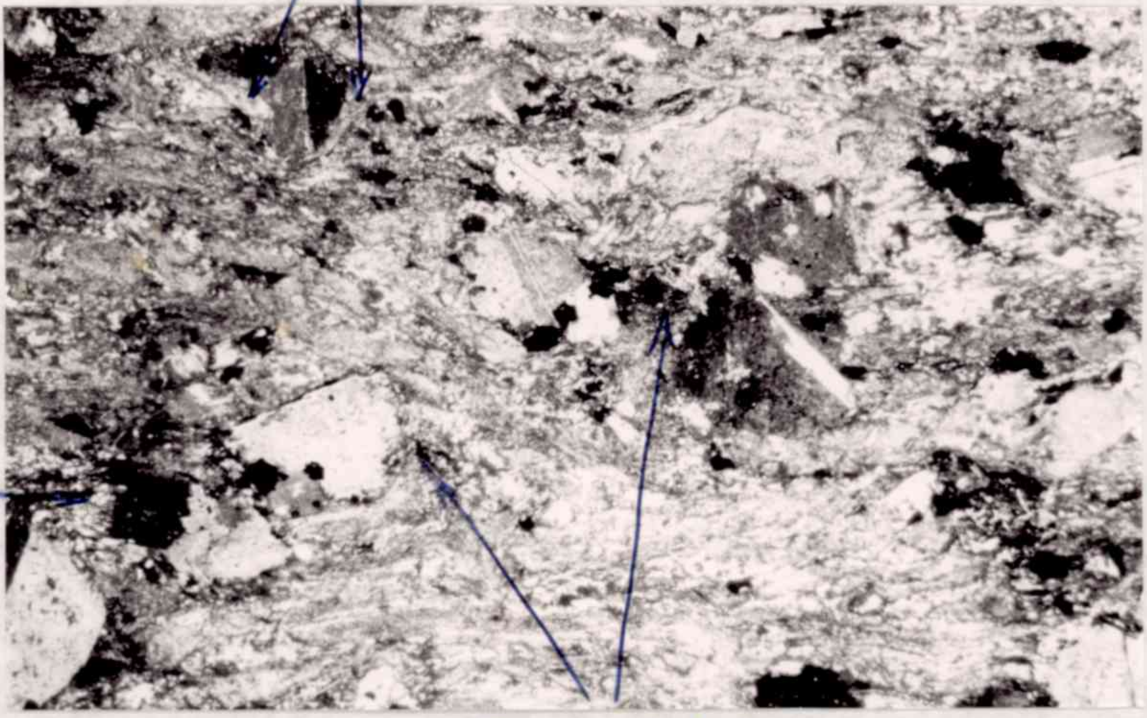


Plate No. 5.I Basic porphyrite No. 86

crossed polarized light

Specimen No. 83 is a porphyritic greenstone lava which, in part, is crenulated slightly but generally shows a good planar cleavage. This is developed by the alignment of quartz and plagioclase grains and the growth of chlorite.

In general the planar fabrics are restricted to the most competent rocks. The less competent rocks show a greater influence from a second deformation.

Crenulated cleavages

The majority of rocks show a planar fabric crenulated by a second deformation. The biotite siltstones, Specimen Nos. 34 and 141, show planar cleavages outlined by quartz and biotite alignment. These have been crenulated by F_2. The biotite in these rocks is parallel to the S_1 cleavage, having developed contemporaneous with the D_1. The limestone shows large scale crenulation of earlier fabric, Specimen No. 128, Plate 5.2. This rock is divided up into clasts and fine cataclastic material. The tectonic clasts are boudins, the intersticies between show a growth fabric. S_0 is still evident with fe rich horizons, probably representing stylolitic boundaries. Subsequent F_2 folding has produced large scale folds with 2 - 2.5cm amplitude with small scale parasitic crenulations within the cataclastic material.

Crenulation cleavages

Crenulation cleavages showing an S_2 rather than a crenulated S_1 are evident in some rocks. In the chloritoid schist, Plate 5.3 shows a strong S_2 cleavage with sericite and chlorite in the plane of S_1, strongly folded into a nearly dominant S_2 fabric. The chloritoids possibly having grown as rosettes shortly after D_1 cross cut S_1 and are in many cases flattened into bow-tie structures parallel to S_2. The sandstone Specimen No. 44, Plate 5.4, shows S_0 outlined by bands of magnetite and S_1 perpendicular, outlined by sericite and chlorite, showing parallel growth. This is crenulated by F_2 and in places by S_2 as a crenulation sub-parallel to S_0. The

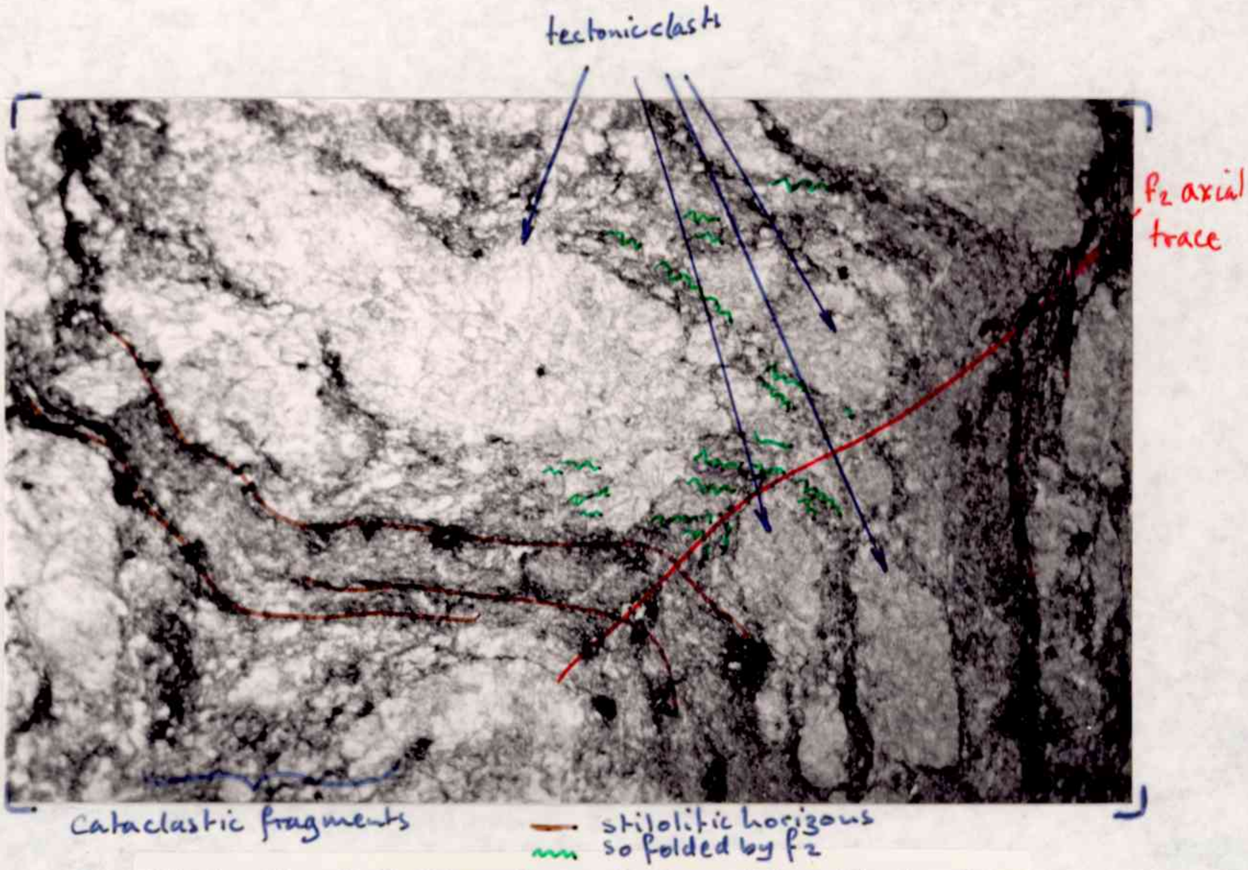


Plate No. 5.2 Limestone deformation. Tectonic clasts bounded by a folded growth fabric have an S_0 fabric still highlighted by Fe rich horizons or stilolites.

PlateNo.5.3 Chloritoid schist.
Cross polarized light.

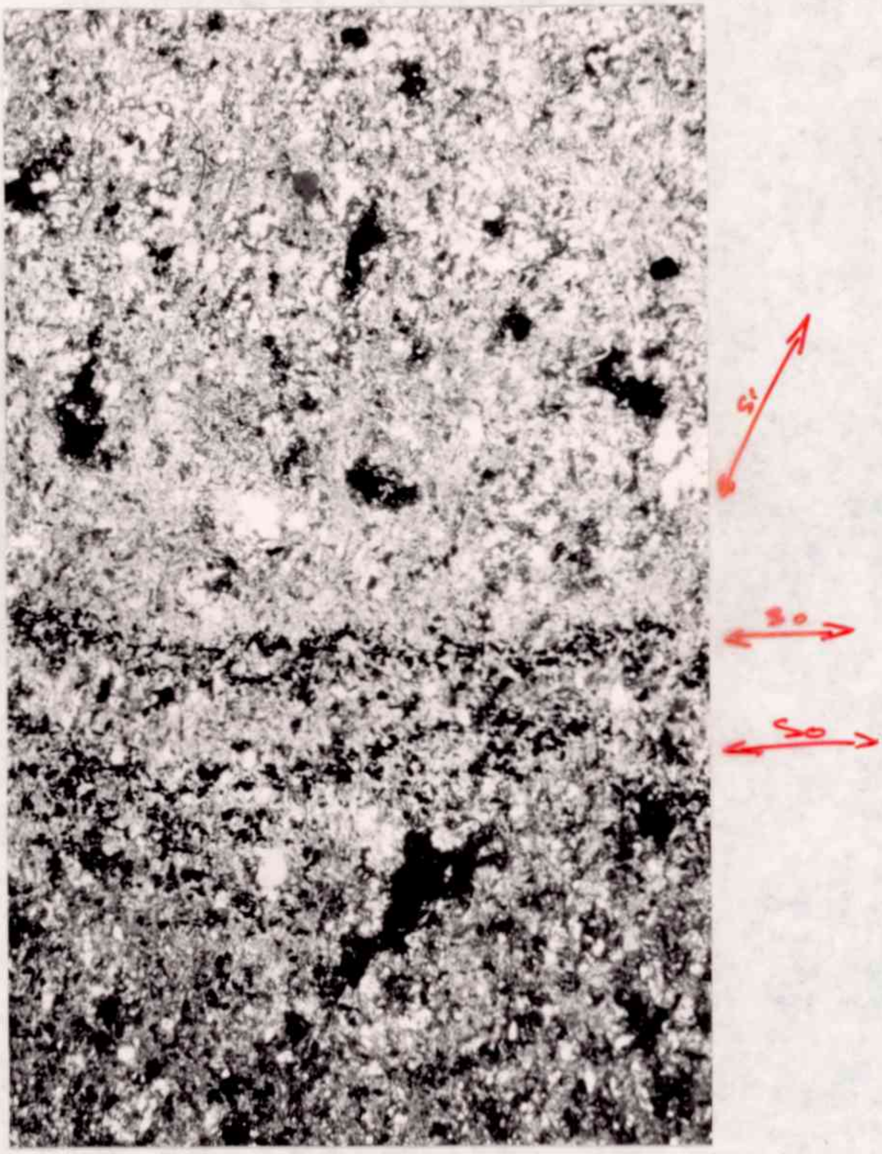


Plate No. 5.4 Sandstone No.44.

Cross polarized conds

siltstone Specimen No. 39, Plate 5.5, has a quite pronounced S_2 cleavage in places, picked out by the Fe staining. This however is not a strong S_2 cleavage. The mineral growth in this specimen is parallel to S_1.

In the grits and conglomerates the cleavages are only displayed in the matrix between the clasts by the growth of chlorite and muscovite and the alignment of grains of quartz and epidote. Specimen No. 82, Plate 5.6, shows a strong S_2 crenulation cleavage well dispslayed around the clast of quartz dislocated by brittle failure. The S_2 cleavage in places completely overprints the S_1 cleavage. Sericite growth has not taken place parallel to S_2 but shows undulose extinction, and therefore the last event was a deformation event, not a recrystallization event. The Specimen No. 92, of a grit, Plate 5.7, shows similar textures with a strong S_2 cleavage. A large pelitic clast in plate 5.7 has been folded and sheared by the D_1. In the conglomerate Specimen No. 86, the S_1 texture is displayed by the alignment of clasts, Fig. 5.2. In one large chloritic clast, the S_1 and S_2 is evident. The calcareous, chloritic, muscovite, quartz schist Specimen No. 91, is considerably deformed showing a strong S_2 cleavage and possible F_3 crenulation of a calcite vein. This is illustrated in Fig. 5.3 drawn from a polished surface. A strong S_2 fabric is apparent in the greenstone lava, Specimen No. 36, Plate 5.8. The S_2 fabric is axial, planar to the folds in the epidote calcite quartz vein which runs parallel to the S_1 cleavage.

Textures in the quartz

The textures in the quartz are similar throughout the specimens. The quartz commonly displays annealing overprinted with a shadowy extinction. Much of the annealing may belong to an earlier provenance, for instance many quartzite clasts. This is caused by an earlier metamorphic event overprinted by a deformation. Deformation lamelli, or Böhn lamelli occur in the conglomerate, Plate 5.9 and in the grit, Specimen No. 82. Many of the quartz and jaspar clasts also show brittle failure. This is well displayed in Plate 5.6.

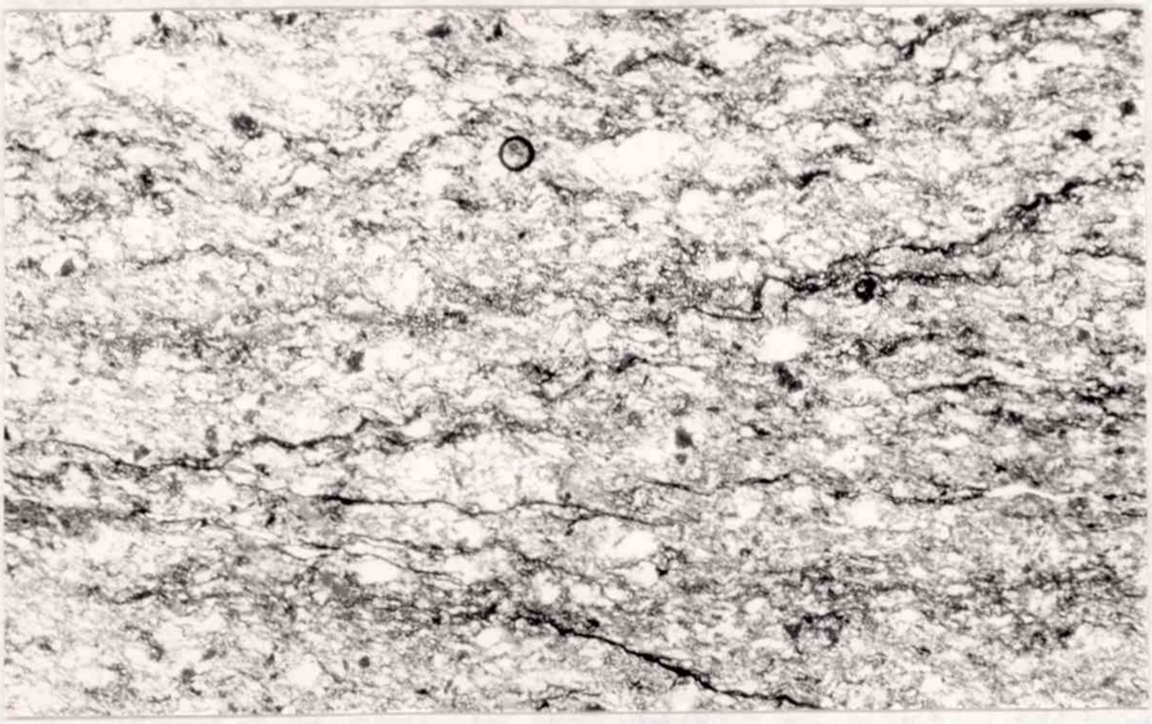


Plate No. 5.5 Sandstone No.39.

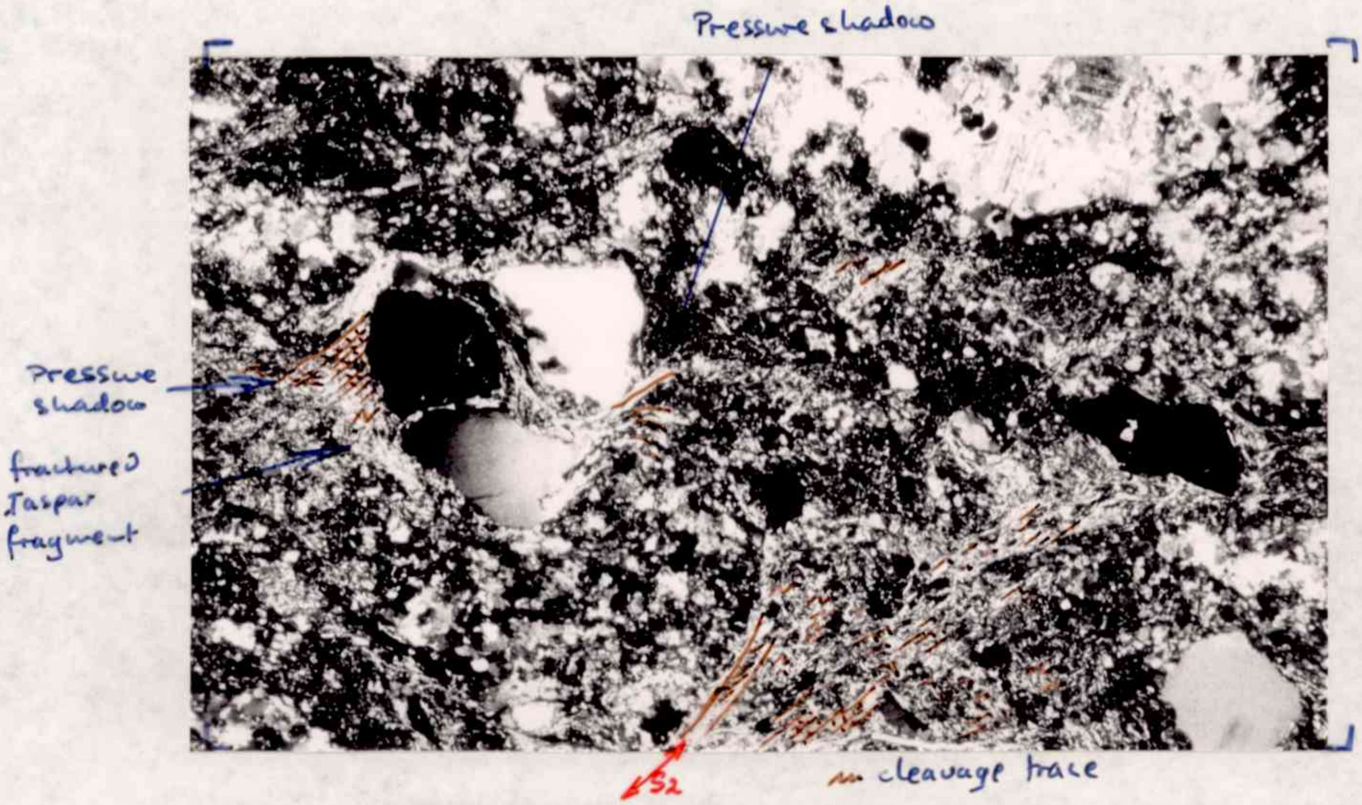


Plate No. 5.6 Grit No.82.Sericite grains show two prefered orientations highlighting chevron like F_2 crenulations and S_2 cleavages.The jaspar clast shows brittle failure and apressure shadow. The quartzite clastsare annealed and overprinted by a shadowy extinction.

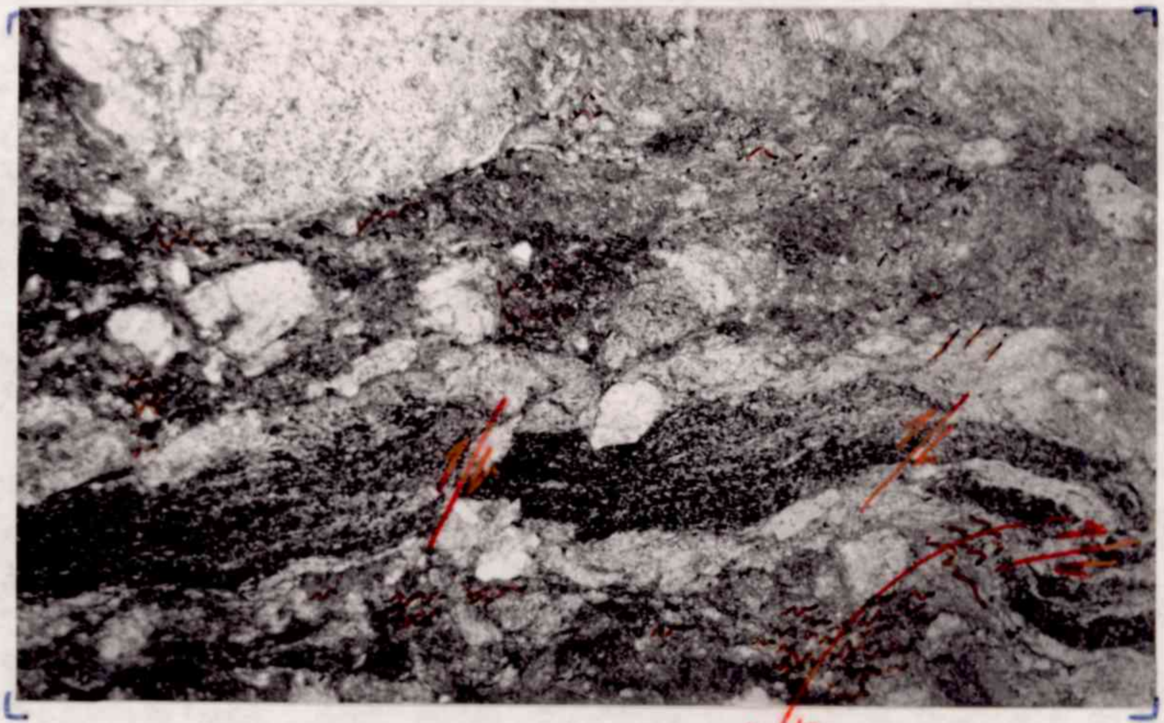


Plate No.5.7 Grit No.92 An S_1 fabric lies parallel to the large pelitic clast which itself is cleaved by S_1. This clast and the surrounding S_1 fabric has been folded by F_2. The clast shows failure planes sub-parallel to the S_2 cleavage in the matrix.

Plate No. 5.8 Greenstone lava No. 36. An S_2 crenulation cleavage has developed in the groundmass axial planar to the folding in the folding in the calcite-quartz-epidote vein.

Plate No. 5.9 Conglomerate No. 86. Böhn lamelli have developed in the large quartz clast. This quartz also shows a very strong shadowy extinction.

In summary, the following evidence can be drawn on:

- recrystallization of the rocks;
- growth of sericite, chlorite and biotite parallel to the S_1 cleavage;
- alignment of clasts with the S_1 cleavage;
- brittle failure of quartz and jaspar clasts;
- moderate to strong S_2 cleavage in the micaceous minerals;
- shadowy extinction of minerals deformed by S_2;
- shadowy extinction of annealed quartz;
- possible development of F_3 crenulations.

From this, an outline of events leading to these textures can be compiled:

- deep burial and metamorphism of the terrain recrystallizing all the rocks;
- D_1 intense deformation developing an S_1 cleavage throughout, during metamophism, resulting in the growth of minerals parallel to S_1, the alignment and possibly the brittle failure of clasts and the annealing of much of the quartz;
- D_2 less intense deformation developing an S_2 cleavage in the micaceous minerals and leaving a shadowy extinction overprint in the quartz and many other minerals, in particular, those aligned with S_2;
- D_3 deformation forming an occasional crenulation not evident in most rocks.

CONCLUSION

A structural and petrological analysis of the Lower Ordovician sediments and greenstone igneous rocks 10km east of Lökken, Sör Tröngelag, Norway, revealed a complex geolgical history. These rocks are part of the Lower Hovin Group belonging to the Trondheim Supergroup. The sediments are dervied from a bipolar provenance in a high energy environment. The detritus comes from the Storen greenstone lavas and a continental terrain. The igneous rocks are greenstone lavas and intrusive igneous rocks known locally as the Holonda porphyrites.

The terrain mapped displays a Barrovian metamorphic sequence belonging to the chlorite zone. The pressure of metamorphism is estimated to be approximately 5 Kbars. Using this estimate, the temperature and vapour pressure range between 450° - 550°C at XCO_2 0.01 to approximately 0.2. Most assemblages can be bracketed within temperatures 500° - 550°C at XCO_2 0.02 - 0.16 at 5 Kbars.

The sequence has undergone two major deformations and a possible third minor deformation. The D_1 occured contemporaneous with the metamorphism and resulted in large nappe structures. The rocks mapped represent the inverted sequence of the lower limb of such a nappe structure. The D_2 was not as intense as D_1 and folded the rocks into tight upright folds folding the S_1 cleavage. The D_3 is only evident occasionally as a minor crenulation.

It would be very interesting to conduct further research to the north to establish the metamorphic sequence which certainly progresses into the epidote amphibolite facies. The structural geology to the south at Lökken is well established as a synformal anticline which is the lower limb of a nappe (Rutter, Chaplow and Matthews, 1967). The location of the hinge of the nappe has been suggested by the evidence of this report and the field work of C A R Robin. Further, more detailed work of is necessary to establish this and the effect of thrusting.

REFERENCES

ALLEN J M and FAWCETT J J 1982. Zoisite - Anorthite - Calcite stability relations in H_2O-CO_2 fluids at 5000 bars: An experimental and SEM study. J. Petrology, 23, Part 2, 215-239.

BHADKAR RAO B and JOHANNES W 1979. Further data on the stability for staurolite and quartz. N. Jb. Miner. Mn. H10, 437-447.

CARTER P 1967. The geology of an area north of Gasbakken, Sor Trongelag. Norges Geol. Undersök 347, 150-161.

CHALOUPSKY J 1970. Geology of the Hölonda-Hulsjöen area, Trondheim region. Norges Geol. Undersök. 266, 277-304.

DROOP G T R 1982. A clinopyroxene paragenisis of albite - epidote - amphibolite facies in meta-syenites from the South-East Tauern Window, Austria. J. Petrology. 23, Part 2, 163-185.

GREENE T and ROBERTS D 1980. Geochemistry and volcanic setting of the Ordovician Forbordfjell and Jonsvatn Greenstones, Trondheim Region, Central Norwegian Caledonides. Contrib. Mineral. Petrol. 375-386.

GREIVE R A F and FAWCETT J J 1974. The stability of chloritoid below 10 Kb PH_2O. J. Petrology. 15, Part 1, 113-139.

HEWITT D A 1973. Stability of the assemblage muscovite - calcite - quartz. Amer. Mineral. 58, 785-791.

HUNT J A and KERRICK D M 1977. The stability of sphene; experimental redetermination and geologic implications. Geochemica et Cosmochemica Acta. 41, 279-288.

RYAN P D, WILLIAMS D M and SKEVINGTON D 1980. A revised interpretation of the Ordovician Stratigraphy of Sör Tröndelag and its implications for the evolution of the Scandinavian Caledonides. Virgina Poly. Inst. and State Univ. memoir. 2, 99-103.

RUTLER E H, CHAPLOW R and MATTHEWS J E 1967. The geology of the Lökken area Sör Tröndelag. Norges Geol. Undersök. 255, 21-36.

SCHNEYER W 1965. Zur stabilitat des ferrocordierits. Beitr. Miner. Petrogr. 11, 297-322.

MIYASHIRO A 1973. Metamorphism and Metamorphic Belts. George Allen and Unwin Ltd.

Orkla Grube
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52 Princess Rd.
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England.

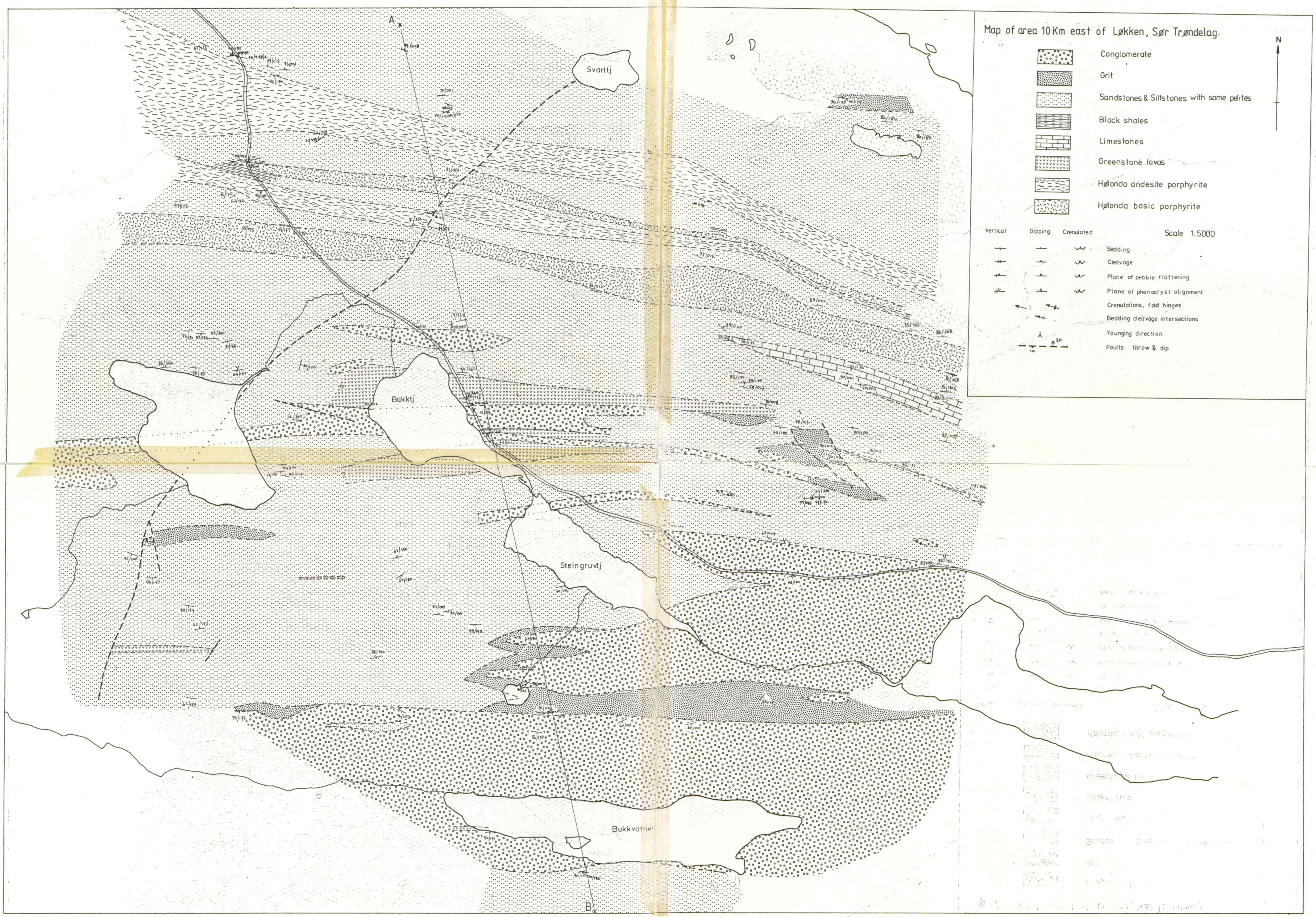
Dear Sir

I have enlosed a copy of my dissertation entitled "A petrological & structural analysis of an area east of Løkken, Sør Trøndelag Norway." You should have received this about two years ago. Unfortunately it was damaged in the post and eventually returned to my address. I have had another copy made but unfortunately the photographs are not as good as the origionals.

I hope this is of some interest. I apologise for the delay.

Yours sincerely
Mr S J Jenkins

Ps. Previously of Derby Lonsdale College of Higher Education (1983.)


Map of area 10 Km east of Løkken, Sør Trøndelag.
N
Conglomerate
Grit
Sandstones & Siltstones with some pelites
Black shales
Limestones
Greenstone lavas
Hølonda andesite porphyrite
Hølonda basic porphyrite
Vertical
Dipping
Crenulated
Scale 1:5000
Bedding
Cleavage
Plane of pebble flattening
Plane of phenocryst alignment
Crenulations, fold hinges
Bedding cleavage intersections
Younging direction
Faults throw & dip
A
B
Svarttj
Bakktj
Steingruvtj
Bukkvatnet