Bergvesenet

Postboks 3021, 7002 Trondheim

Rapportarkivet

Bergvesenet rapport nr	Intern Journal nr	Internt arkiv nr	Rapport lokalisering	Gradering
BV 1833			Trondheim	
Kommer fra ..arkiv	**Ekstern rapport nr**	**Oversendt fra**	**Fortrolig pga**	**Fortrolig fra dato:**

Tittel

The geology of the Løkken area, Central Norway

Forfatter	Dato	Bedrift
Rutter, Ernest H.	1967	The Imperial College, Univ. of London Orkla Industrier A/S

Kommune	Fylke	Bergdistrikt	1: 50 000 kartblad	1: 250 000 kartblad
Meldal	Sør-Trøndelag	Trondheimske		

Fagområde	Dokument type	Forekomster
Geologi		Løkken
Råstofftype	**Emneord**	
Malm/metall		

Sammendrag

THE GEOLOGY OF THE LØKKEN AREA

CENTRAL NORWAY

Report submitted for the B.Sc degree at
The Imperial College, University of
London.

by

Ernest H. Rutter

ACKNOWLEDGEMENTS

I should like to express my gratitude to the Orkla Grube Aktiebolag, and particularly to mining engineers Messrs. Sandvick, Bröndbo and Nordstein, for their help and encouragement during the period of the field investigations.

I should also like to thank Dr. W. Skiba, of the Imperial College Geology Department, for his supervision and unfailing interest during all stages of the project.

FOREWORD

This report is based on the results of 7 weeks field work in the Løkken Area of Central Norway. The area lying west of the Orkla River as far as Dragset Mine was investigated in some detail, and an attempt was made to gain a general appreciation of the structure east of the Orkla River as far as Höidal Mine. Mapping was done on 1:15,000 aerial photographs kindly loaned by Orkla Grube Aktiebolag. These photographs were later used to construct a base map covering the whole area. The area between Orkla River and Dragset Mine was enlarged to 1:10,000 to facilitate the presentation of data.

A certain amount of distortion is inevitable in the final maps, as a result of their compilation from aerial photographs.

CONTENTS

INTRODUCTION	1
STATEMENT OF THE PROBLEM	2
GLACIAL CONTROL OF PHYSIOGRAPHY	5
HISTORY OF PREVIOUS WORK	7
STRATIGRAPHIC SUCCESSION	9
SUMMARY OF THE GEOLOGY OF CENTRAL NORWAY	1~~0~~1
PETROLOGY	15
INTRODUCTION AND PROBLEMS OF NOMENCLATURE	16
PROBLEMS OF FIELD MAPPING	19
METAMORPHISM	21
THE BASIC METAVOLCANICS	27
BASIC INTRUSIVE ROCKS	3~~2~~3
THE ACID METAVOLCANICS	3~~6~~7
THE ROCKS OF THE RØROS GROUP	39 40

THE JASPER LENSES AND THE VASSKIS 41 42

STRUCTURAL GEOLOGY 43

THE MAIN GROUPS OF STRUCTURES 44

THE FIRST PHASE OF FOLDING (f_1) 46 47

THE SECOND PHASE OF FOLDING (f_2) 5~~5~~7

THE THRUSTING EPISODE 61 64

THE f_3 FLEXURE ~~69~~ 72

FAULTING AND JOINTING 7~~0~~3

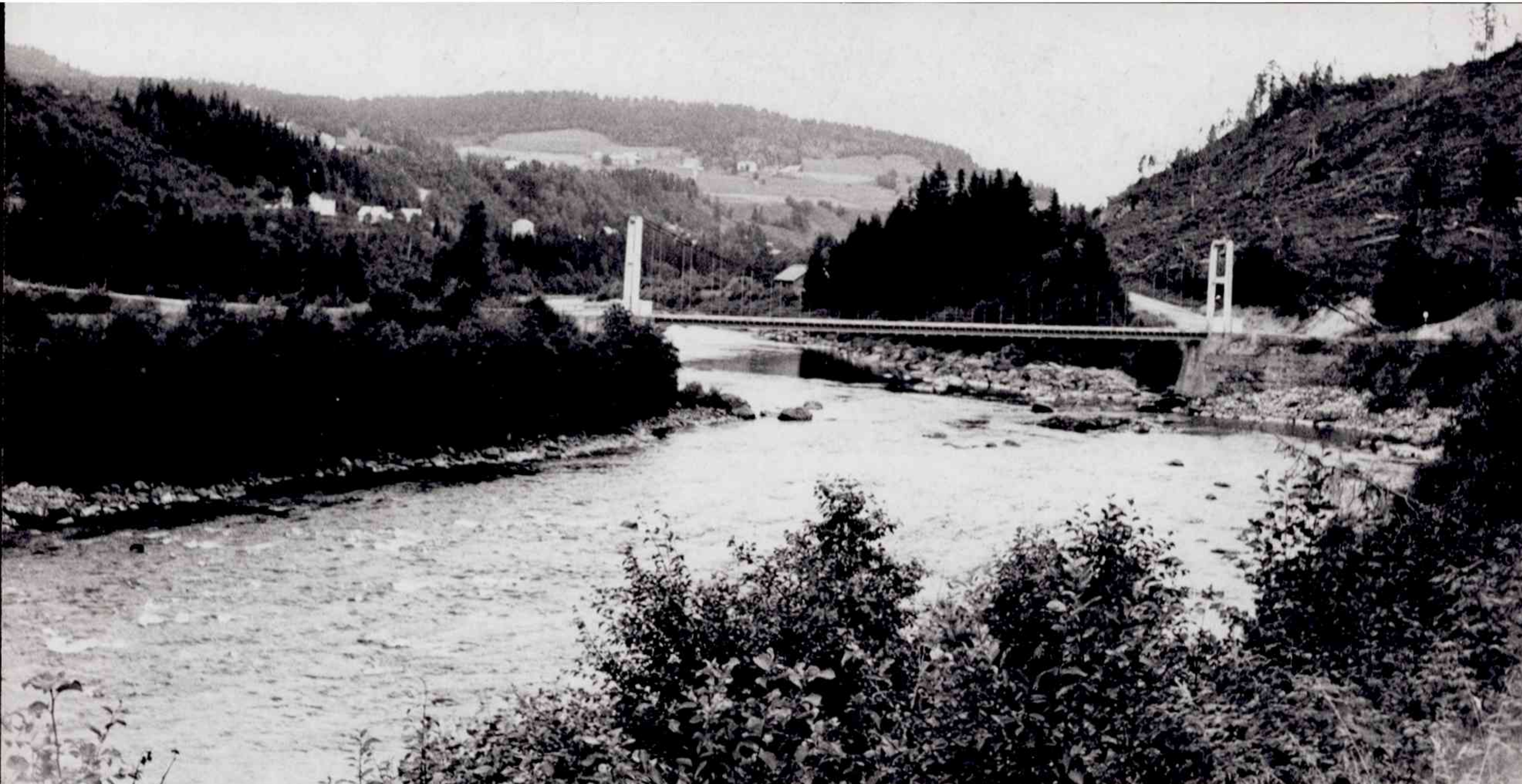
DEFORMATION AND STRAIN 7~~4~~8

SUMMARY OF THE STRUCTURAL HISTORY
OF THE LØKKEN AREA ~~76~~ 80a

PETROFABRICS ~~77~~ 81

RESULTS OF THE 1966 SUMMER MAPPING 82 86

SELECTED REFERENCES 85 89



INTRODUCTION

The Løkken Area lies in the County of Sør Trøndelag, Central Norway, about 70Km. south-west of Trondheim (see Map B.). The area is one of low to moderate relief, the average elevation being about 300 metres. The most significant physical features are three north-south valleys, cutting across the area and across the grain of the land. The central valley is occupied by the Orkla River, which drains the region and eventually empties into Trondheimsfjord. The two lateral valleys are glacial and the village of Løkken nestles in the easternmost one.

The whole of the area lies just below the tree line and most of the ground is covered by dense coniferous forest. There are a large number of lakes in the area and where the forest is thin there are extensive tracts of marshland. As a consequence of this, exposure over most of the ground is generally very poor. Odd Patches of glacially smoothed rock occasionally protrude above the boggy areas, which are often better exposed than the densely forested areas. In the forest it is usually necessary to deliberately search for exposure.

FRONTISPIECE : (facing page) View downstream of the Orkla River at Dragset Moen.

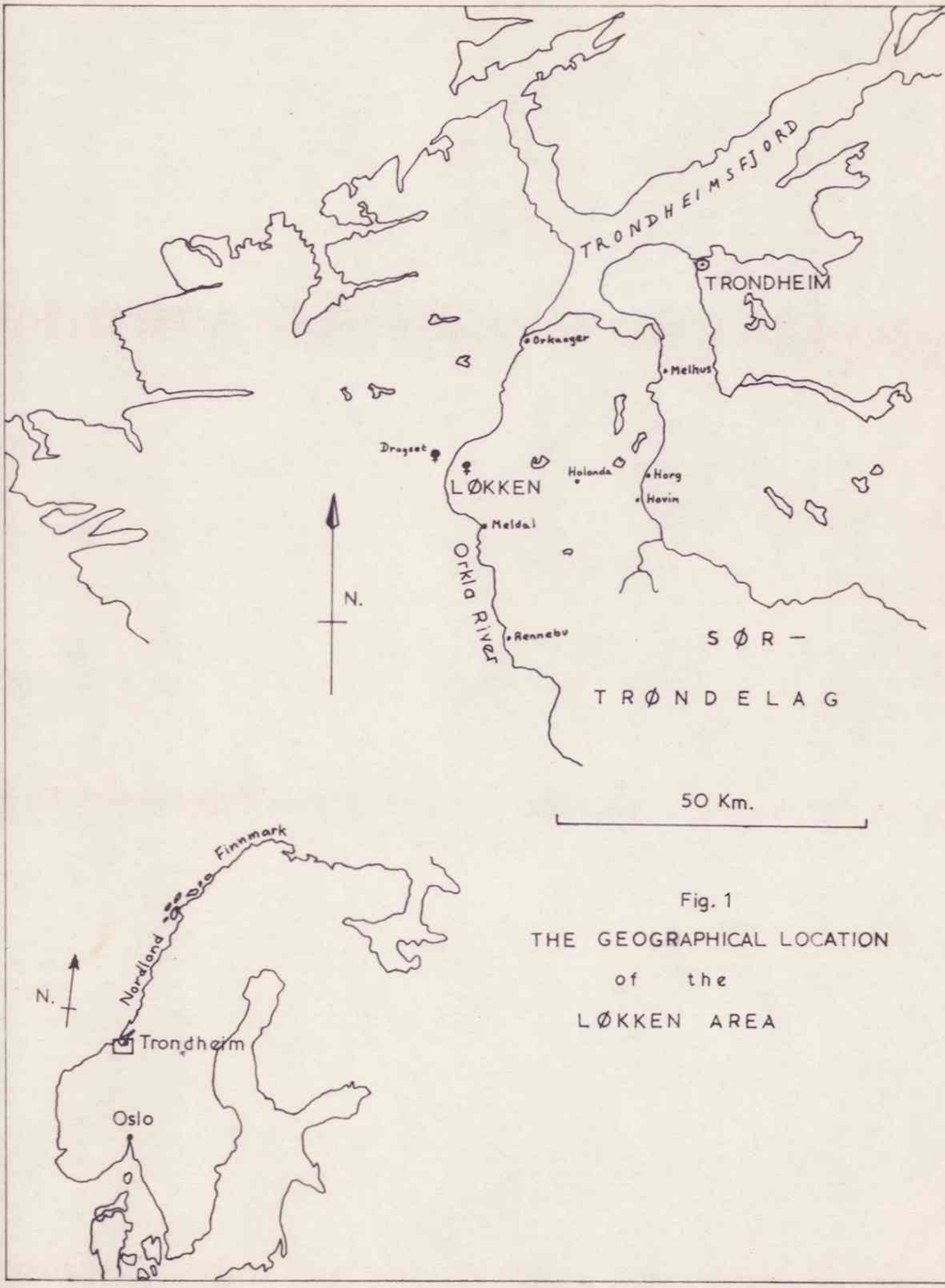


Fig. 1
THE GEOGRAPHICAL LOCATION
of the
LØKKEN AREA

NORWEGIAN NAMES USED IN THE TEXT

BERG	rock, hill
BJØRN	bear
DAL	valley
FJELL	mountain
FJORD	fiord
GRØN	green
GRÅ	grey
NY	new
SJØ	lake
SKIFER	slate, schist
SAETER	summer farm
TJERN	tarn, lake
TROLL	ogre, giant
VANN, VASS	lake
GRUVE, GRUBE	mine

NOTE ON SHADING OF POINT-DENSITY CONTOURED STEREOGRAMS

Unless otherwise stated the shading scheme for various point densities on contoured stereograms is as given for Fig.17. The single exceptional diagram is Fig.28.

All stereographic projections are projected from the LOWER hemisphere.

STATEMENT OF THE PROBLEM

The Løkken Area is particularly interesting for the following reasons :

1) Løkken is the site of a large, important deposit of cupriferous pyrite. Orkla Grube Aktiebolag, the company which operates the mine, has shown particular interest in learning about the geology of the surrounding area, the relationship of the orebody to the enclosing country rocks, and the origin of the ore. A detailed knowledge of the geologic history and structural control of the orebody is essential in the systematic exploration of the area to the end of locating further economic deposits.

2) A t first sight the rocks of the Løkken Area appear uninteresting and unattractive because of their massive, apparently featureless nature, structural complexity and poor exposure, As a result, rocks in this area and similar areas have received only cursory attention from geologists in the past. These rocks form one of the most important belts of greenschist facies metamorphics in the world. It was felt that it would be of considerable academic interest to pay more attention to such rocks, particularly in the Løkken Area in view of their association with economic mineral deposits. To this end it was

decided to approach the mapping of the Løkken Area from three viewpoints :

(a) Geochemical and Petrological. The aim was to establish valid geochemical and petrologic criteria for the mapping and subdivision of the basic metavolcanics, and to revise the nomenclature. This aspect of the approach was tackled by Mr.J.May.

(b) Economic Geology. Mr.G.M.Kershaw pursued investigations within and in the immediate vicinity of Løkken Mine, to the end of learning more about the mineralisation in the area.

(c) Structural Geology. The aim was to gain a general appreciation of the geometry and structural history of the area, in relation to metamorphism and the Caledonian Orogeny as a whole. It was hoped to learn more about the structural control of the orebody, and the relations between the various centres of mineralisation.

The main purpose of this report is to present the results of the structural investigations, but observations on the petrology of the rocks to the west of the Orkla River were also made, and these results are summarised in the text.

GLACIAL CONTROL OF PHYSIOGRAPHY

There are a number of physiographic features of the Lökken Area which are a consequence of glaciation.

A series of glacial valleys run north-south across the area, cutting across the grain of the land which is determined by the strike of the rocks. A possible exception is the Orkla Valley, but the Dragset and Lokken valleys parallel the most frequent direction of glacial striae as measured in the area and plotted on Fig.2.

The Lokken Valley is an excellent example of a U shaped glacial valley. Its floor is very flat and carries a small stream, and its sides are steep and high. A number of hanging valleys meet the main valley on the eastern side.

These valleys form significant physical features in an area which is otherwise of quite low relief. The whole area is probably a re-uplifted peneplanated surface.

Evidence for relatively recent uplift, which is probably still going on at the present time, is seen in the way that the Orkla River is being rejuvenated. The river is rapidly cutting its way down through a considerable thickness of earlier river gravels. (see plate 1.). This is resulting in the formation of a pronounced terrace. The boulders which are now being transported along the bed of this fast flowing river are very much larger than the largest pebbles of the river gravels which are now being eroded away.

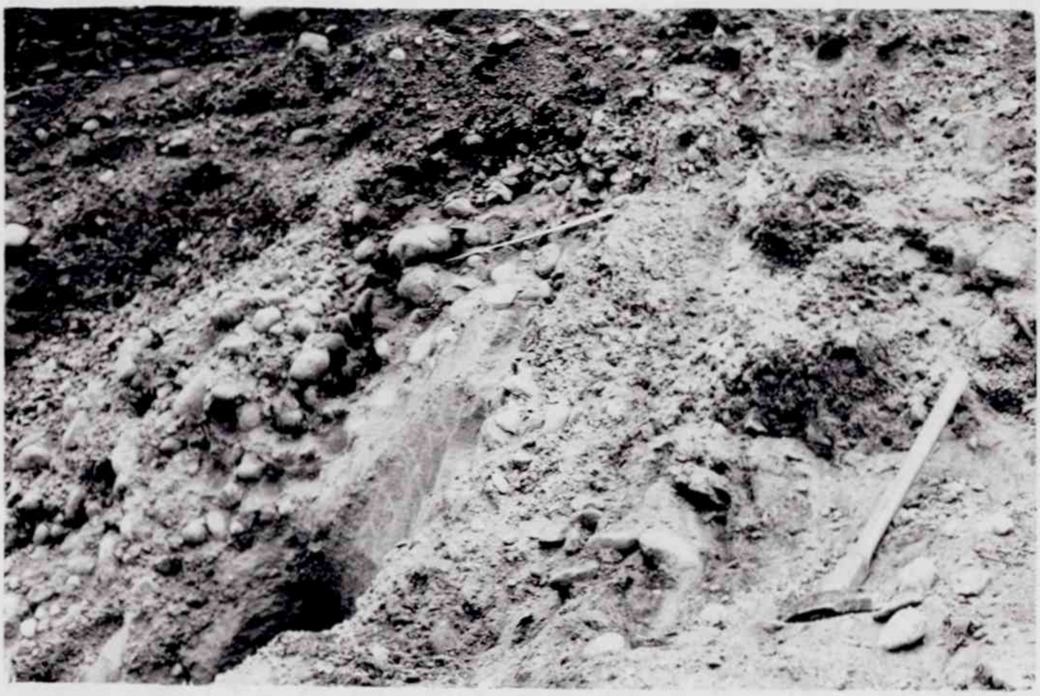
Considerable thicknesses of boulder clay are not commonly seen in the Lökken Area. However, a discrete deposit of boulder clay is seen on the west side of the Orkla River in the south of the area on map A. This is probably a morainic deposit. (Marine ?)

Mention will be made of the structural control of physiography in a later chapter.

PLATE 1.

(a) River gravels exposed on the banks of the Orkla.

(b) Rejuvenescence of the Orkla River. The rapid downcutting of the river through earlier gravels is leading to the formation of a terrace.



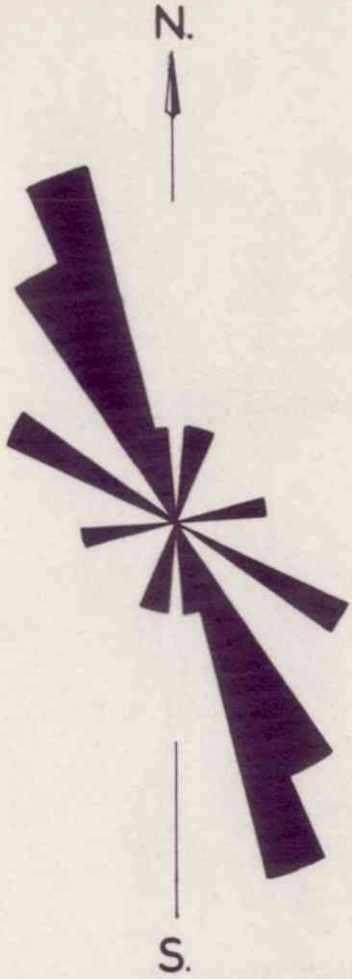


Fig. 2

CIRCULAR HISTOGRAM OF GLACIAL STRIAE ORIENTATIONS OVER THE WHOLE AREA. (13 readings)

HISTORY OF PREVIOUS WORK

The Løkken Area was covered as part of the map published by C.W.Carstens in 1952. The area covered by this map, originally on a scale of 1:50,000, is shown in Fig.3. Because of its scale this map could only show the geographical relations between the main rock groups in the Løkken Area.

For the purpose of the remainder of this report, "The Løkken Area" is considered to be that area covered by map B.

During the summers of 1959 and 1960 part of the area of Map A was investigated, chiefly from a petrological standpoint, by 2 Norwegian Student geologists under the direction of Prof. T.Strand. Further mention of their work will be made later.

A large part of the Løkken Area has been subjected to geophysical investigation in the last 25 years. Aeromagnetic and electromagnetic survey methods have been employed, and some of the anomalies have been interpreted in terms of known geologic features. However, the most useful geophysical methods have proved to be electrical and electromagnetic methods employed in, and in the immediate vicinity of, the mine.

A number of unpublished reports, most of which are somewhat dated, have been written on the petrography and bulk geochemistry of the rocks in the immediate vicinity of the mine. Unfortunately, all are in Norwegian. There has been virtually no attempt to make a detailed investigation of the structure of the Løkken Area. Most workers have been content to record only the obvious structure of the area, the great flexure of the Løkken Synform.

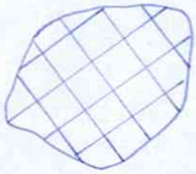
Immediately to the east of the area shown on Map B , lies a tract of country which wade the subject of investigations in the years 1960 & 1961 by Messrs. Blake, Chadwick, Rowling and Beswick, of Imperial College, who later published a joint paper which appeared in N.G.U. in 1964. The area covered by these investigators, in relation to the area covered by my colleagues and myself is shown in Fig.3.

These authors were interested mainly in the stratigraphy and petrology of the area, and little mention was made of the structure. However, it is clear from their paper that they were describing the primary stratigraphy of their area, and that the major structures were of f_1 age, with tight folding and axial plane schistosity. They were able in the metasediments of the Hovin Group to distinguish bedding from schistosity.

They do not describe any structures obviously related to the f_2 folds of the Løkken area since their whole area lies on the extensive southern flank of the Løkken Synform, but they do describe a sharp change in the f_1 trend, apparently with an associated cleavage. It is not clear whether this is related to f_2 or f_3 distinguished in the Løkken Area. It is probably part of the f_3 adjustments.

Fig. 3.

Geological Map of the Lökken Area after C. W. Carstens, 1952.



Area Mapped by Blake, Chadwick, Rowling and Beswick, 1960 & 1961.

Area Mapped by Kershaw, May and Rutter, 1966.

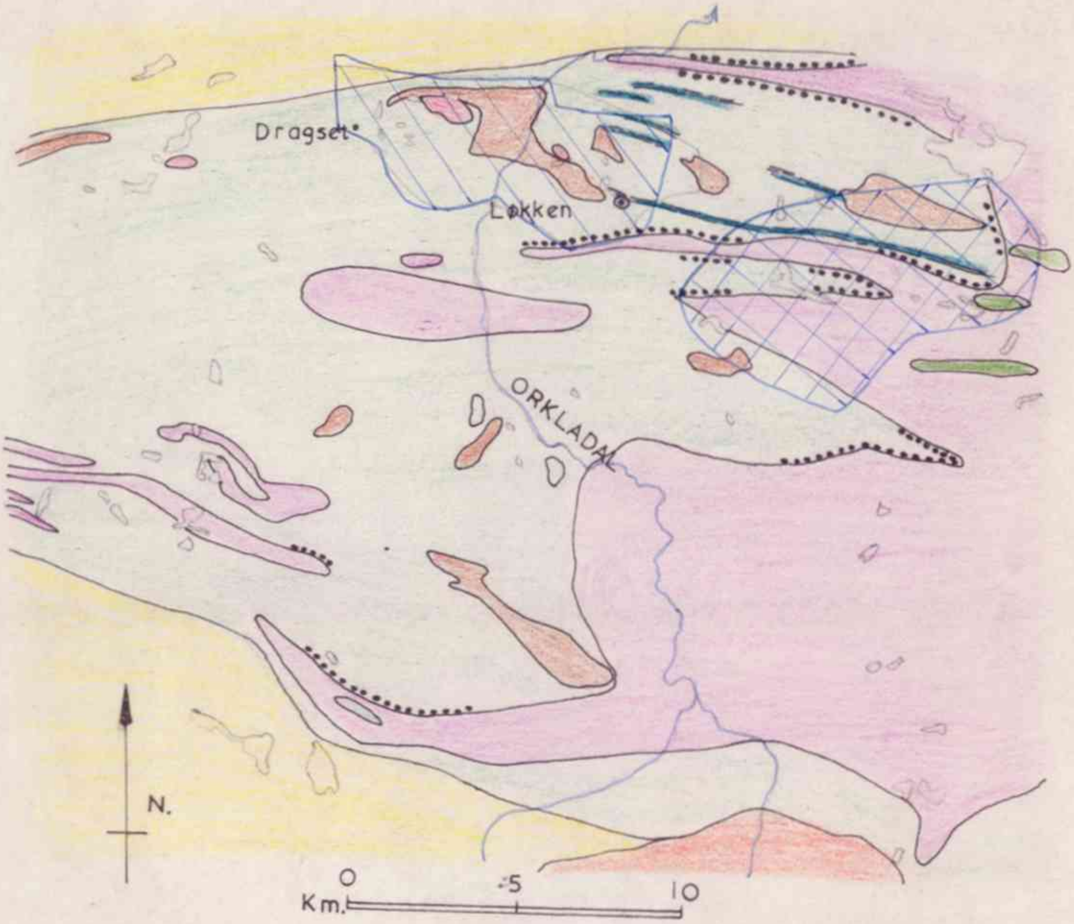
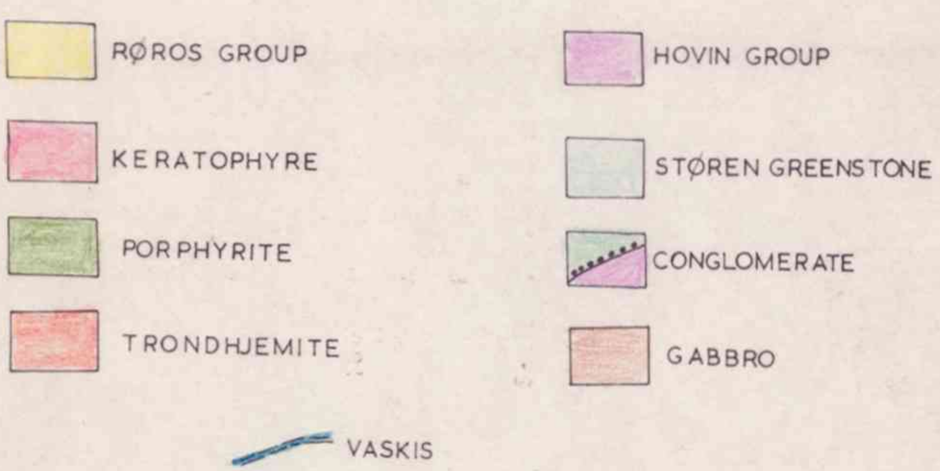


Fig. 3

GEOLOGICAL MAP OF THE LOKKEN AREA AFTER C.W. CARSTENS, 1952



THE STRATIGRAPHIC SUCCESSION IN THE LØKKEN AREA

On the basis of gross differences in lithology it is possible to divide the rocks of the Løkken A rea into three main groups :-

HOVIN GROUP	Metasediments & Intrusives
STØREN GROUP	Metavolcanics and Intrusives
RØROS GROUP	Mica Schists, Gneisses and Amphibolites.

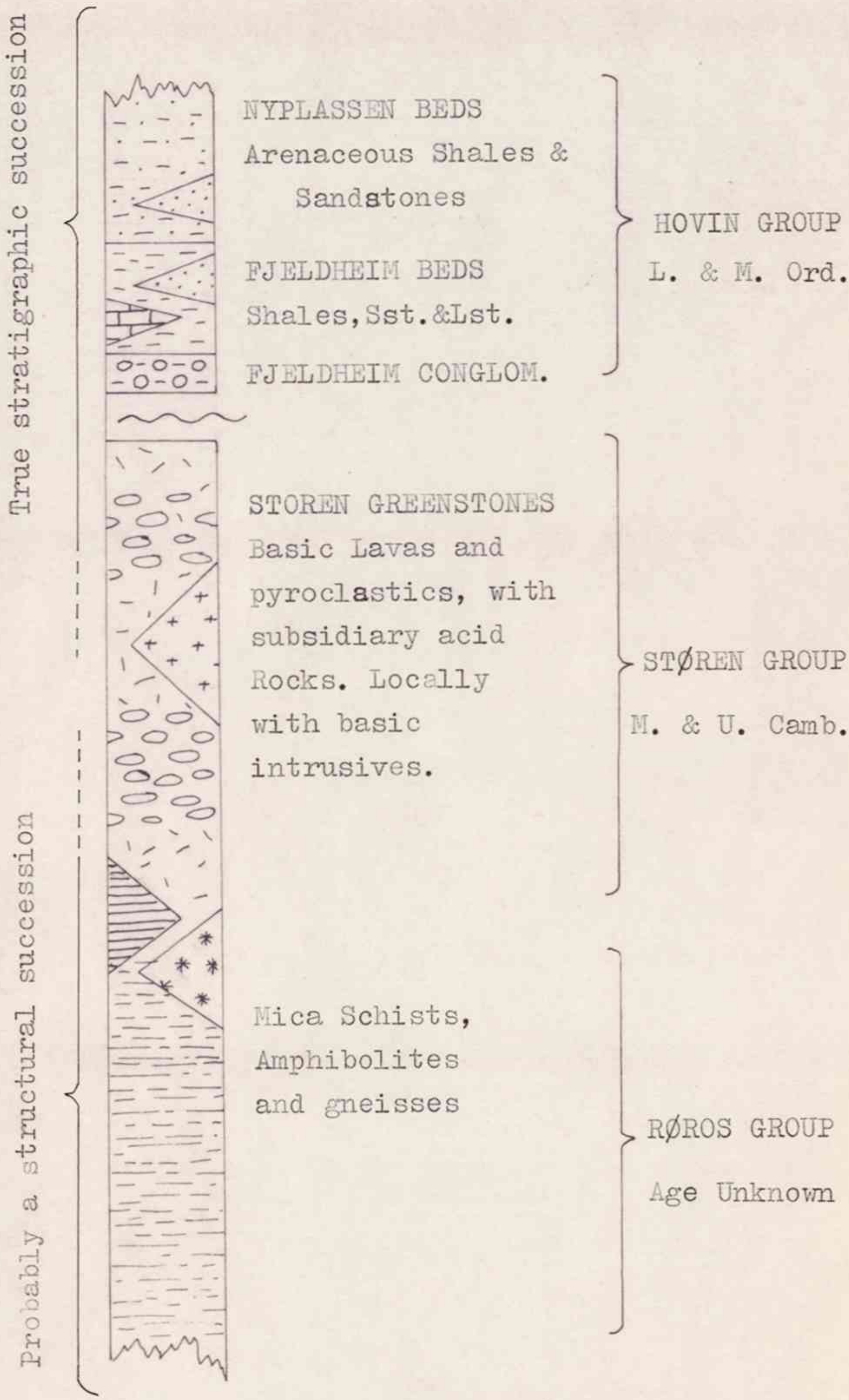
At the base of the Hovin group is exposed a conglomerate, locally called the Fjeldheim Conglomerate, which contains pebbles of greenstone and jasper typical of the rocks of the Støren group. The Hovin group is therefore stratigraphically younger than the Støren group. It has been assumed in the past that the Støren group is younger than the Røros group, by the principle of superposition. I feel that this should not be assumed so, since the succession could well be a structural one.

Blake, Chadwick & Co.(1964) describe the occurrence in the Fjeldheim beds of the Hovin group of Arenigian graptolites. The rocks of the Støren group are therefore tentatively assumed to be middle and upper Cambrian.

Despite the occurrence of a basal conglomerate in the Hovin group, thus indicating a time unconformity, there is no angular discordance recorded between the Hovin and Støren groups.

A more complete and generally descriptive stratigraphic column of the rocks of the Løkken Area is given overleaf.

Fig. 4.



True stratigraphic succession
Probably a structural succession
NYPLASSEN BEDS
Arenaceous Shales & Sandstones
FJELDHEIM BEDS
Shales, Sst. & Lst.
FJELDHEIM CONGLOM.
HOVIN GROUP
L. & M. Ord.
STOREN GREENSTONES
Basic Lavas and pyroclastics, with subsidiary acid Rocks. Locally with basic intrusives.
STØREN GROUP
M. & U. Camb.
Mica Schists, Amphibolites and gneisses
RØROS GROUP
Age Unknown

A SUMMARY OF THE GEOLOGY OF CENTRAL NORWAY (See Map C)

This part of Norway exhibits a succession of rocks and structures extending from the central part of the Caledonian Orogenic Belt in the North-West, to the foreland in the South-East. For the purpose of description the region may be divided into four.

A. The Area of Basal Gneiss.

B. Rocks of the Nappe Region.

C. The Sparagmite Region.

D. The Trondheim Region.

A. Rocks grouped together as the Basal Gneiss

These rocks are structurally and possibly also stratigraphically overlain by the Sparagmite series and the sedimentary and effusive igneous rocks of the Trondheim Region.

Petrographically, these rocks are very similar to the Archaean gneisses of South-Eastern Norway. They are believed to be Pre-Cambrian rocks strongly influenced by the Caledonian Orogeny and tectonically intercalated with Sparagmitean and Cambro-Siluriah rocks. The degree of metamorphic and tectonic transformation has been so great that only rarely can the Palaeozoic rocks be distinguished from the Pre-Caledonian rocks.

The Caledonization of the Archaean rocks has removed any trace of what might originally have been an angular unconformity between Pre-Caledonian rocks of the gneiss region and definitely recognisable

Sparagmitean and Cambro-Silurian rocks of the Trondheim Region. In contrast to this, there is a sharp angular unconformity where Archaean gneisses of South-Eastern Norway come into contact with rocks of the nappe area in the southern part of the covered by Map C.

B. ROCKS OF THE NAPPE REGION

This area may be delimited to the east by Gudbrandsdal and extends westwards toward Bergen. Structurally the highest unit of the Nappe Region is the Upper Jotun Nappe. In 1936 Holtedahl demonstrated that all around the margin of the Jotunheimen Massif the rocks are floating on a thrust plane without having any roots in the present substratum. It is only since that time that the idea that large scale nappe tectonics have played a large part in the geological evolution of Norway has become respectable.

The crystalline rocks of the Upper Jotun Nappe are predominantly those of the charnockitic suite. They range from basic to acid in composition. Peridotites occur as lenticular or rounded inclusions in the basic and intermediate rocks. Anorthosites outcrop over large areas of the nappe. Intermediate rocks are chiefly represented by the Jotun norites and syenites. Granites of different types form large massifs or occur as sills in the basic and intermediate Bergen-Jotun rocks. There are later intrusions of Caledonian igneous rocks,notably the Trondhjemites. The Upper Jotun Nappe is believed to have been transported a considerable distance from N.N.W. to S.S.E.

Beneath the Upper Jotun Nappe, and exposed in the northern part of Gudbrandsdal, lies the Lower Jotun Nappe. The rocks of this nappe are very similar to those of the Upper Jotun Nappe, and it is only the relationship with the Valdres Sparagmite which allows rocks of the two units to be distinguished. The Lower Jotun Nappe is overthrust above marine fossiliferous Cambro-Silurian phyllites.

Lying between the rocks of the Upper and Lower Jotun Nappes is a very important formation known as the Valdres Sparagmite. Many geologists believe this to be a synorogenic deposit formed after the mise - en - place of the Lower Jotun Nappe, and composed of detritus derived from erosion of the crystalline rocks of that unit. The Upper Jotun Nappe, therefore, tectonically overlies the Valdres Sparagmite. It has however, recently been suggested that the succession found in the Valdres Sparagmite is inverted, and that this formation is not a synorogenic deposit at all, but a third nappe sheet sandwiched between the Upper and Lower Jotun Nappes.

C. The Sparagmite Region

The western limit of the Sparagmite Region is approximately defined by Gudbrandsdal. To the east it extends into Swedish territory. To the north the Sparagmite is tectonically overlain by Cambro-Silurian rocks of the Trondheim Region. The Sparagmite overlies, apparently in an allochthonous position, Archaean gneisses, with which the contact may be seen along the southern border of the outcrop. The observed displacement along the southern margin is up to 35 kilometres, (Strand 1954).

The term "Sparagmite" was coined 150 years ago, initially to describe the slightly metamorphic feldspar rich sandstones occurring in the Østerdal district. The word is derived from the Greek word meaning "fragment".

The Sparagmite sedimentary complex is stratigraphically older than the superjacent fossiliferous Cambro-Silurian strata. Its age is described by the term EoCambrian, which stresses the close association between the Sparagmite and the fossil bearing Cambrian. The formation undoubtedly crosses the base of the Cambrian and extends a considerable way into the Pre-Cambrian. The Upper part of the Sparagmitean appears to be broadly equivalent to the Scottish Dalradian.

The Sparagmite Formation includes a wide range of rock types, Sandstones, Shales, Conglomerates and Limestones. The formation is generally unfossiliferous but locally trace fossils and stromatolites have been found. Some of the Sparagmitean conglomerates have been interpreted as glacial tillites. The Sparagmite is generally devoid of igneous intrusions.

D. The Rocks of the Trondheim Region.

The Trondheim region is a broad axial depression in which metamorphosed Cambro-Silurian sedimentary and igneous rocks have been protected from erosion. The narrow south-western part of the region is connected to the Nappe Region, and the south and east apparently tectonically overlie the Sparagmite Region. To the west the Trondheim Region rocks are underlain by a strip of Sparagmite of variable thickness, which eventually grades into conformably underlying basal gneiss. A map of the subfacies zones of the greenschist facies in this region is shown in Fig.5. From the map it may be seen that the structurally higher parts of the succession exhibit the lowest grades of metamorphism. Fpr example, the rocks exposed in the core of the Trondheim Synclinorium are virtually unmetamorphosed, whereas garnet grade rocks outcrop at the base of the succession immediately overlying the basal gneiss.

The petrography of the rocks of the Trondheim Region is well known. The rocks are dominantly meta-argillites in various stages of metamorphism. There is, however, a considerable development of meta-volcanics, represented by the Støren Greenstones, closely associated with intrusions of gabbro and sulphide ore deposits. Locally there are large intrusive bodies of Trondhjemite.

In the north-western part of the region at least, schistosity, which is developed to a greater or lesser extent, seems to parallel the primary layering. The schistosity is then folded into the large wavelength, large amplitude folds which have a characteristic Caledonian trend, and are the most obvious indicators of deformation in the area. It may be generally stated that the pattern of deformation becomes more complex as one proceeds north-westwards from the core of the Trondheim Synclinorium. Lack of exposure makes it difficult to demonstrate precisely the changes in the style and extent of deformation across the region. As Strand has pointed out, we cannot yet be sure that the rocks of this region do not belong to more than one tectonic unit.

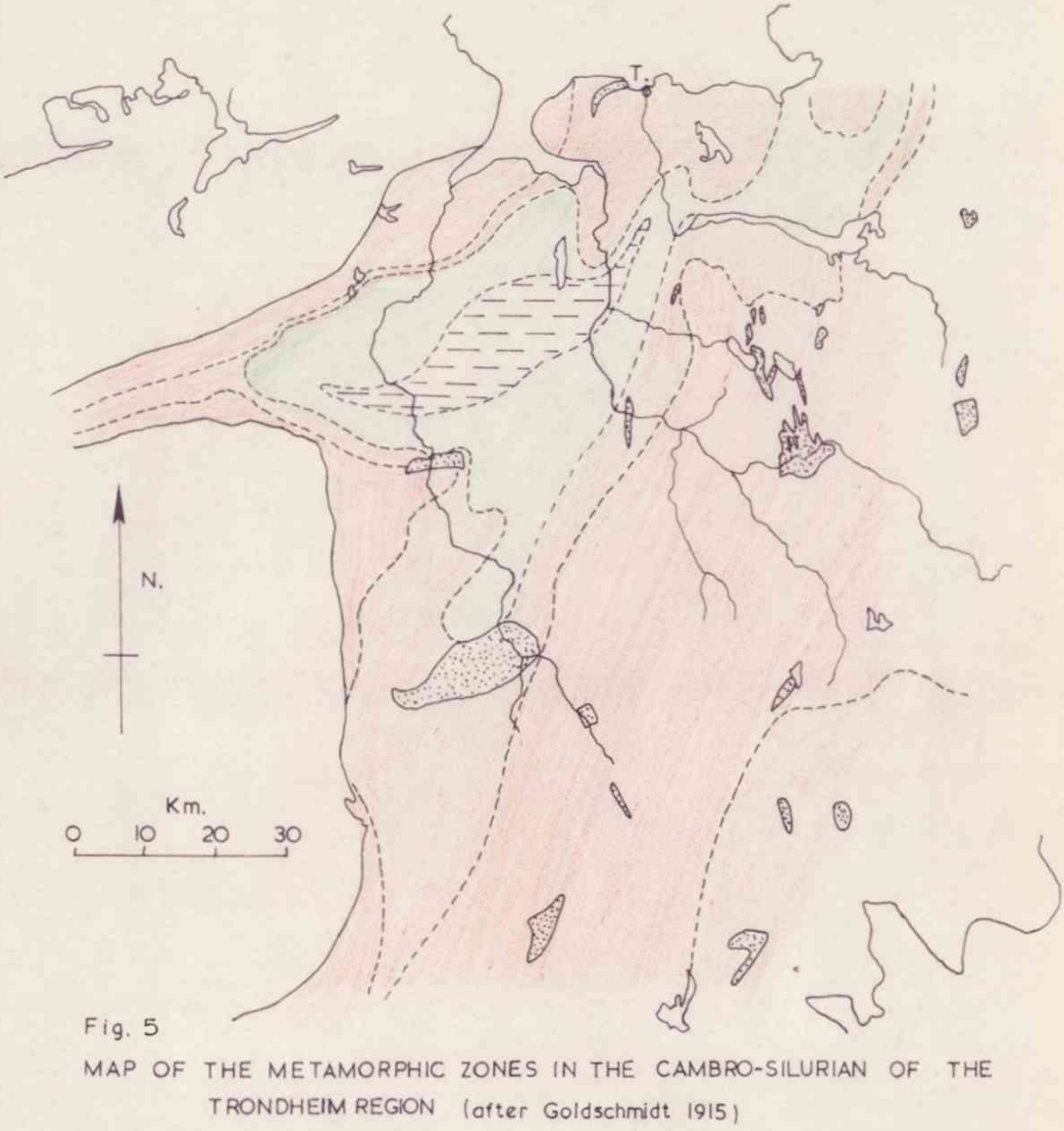


Fig. 5

MAP OF THE METAMORPHIC ZONES IN THE CAMBRO-SILURIAN OF THE TRONDHEIM REGION (after Goldschmidt 1915)

PETROLOGY

INTRODUCTION

A discussion of the petrology of the rocks of the Lökken Area involves description of the rocks which make up part of the Röros group, the Stören group and part of the Hovin group. The entire sequence has been regionally metamorphosed in the greenschist facies. In some parts of the sequence the primary structures and textures of the rocks may still be distinguished, and in these cases problems arise over the nomenclature of the rocks.

PROBLEMS OF NOMENCLATURE

Problems of nomenclature arise where the primary nature of the rock before metamorphism can be recognised to some extent. Where the rocks are metamorphosed to a higher grade and deformed so that primary structures are no longer recognisable, no difficulties arise and metamorphic terminology must be applied. In the former case, however, the difficulties are twofold:-

1) One can apply either a metamorphic terminology or names which describe the primary nature of the rock. However, where primary structures and textures can still be recognised it seems illogical to apply a terminology which does not attempt to describe them. Therefore, as a guiding principle, I propose to employ the terminology which takes account of the primary nature of the rock where this can be inferred.

2) At the grade of metamorphism to which these rocks were raised,

the stable mineral assemblage is albite + epidote + chlorite. The terminology adopted for these rocks depends on whether this is the same mineral assemblage as was present in the rock before metamorphism, or whether it is secondary, as a result of the metamorphism. In most rocks which have undergone soda metasomatism as part of the metamorphic event, textural details are usually preserved, providing tectonic stresses were not overwhelming. This is the case in the south and west of the Lökken Area, so it is not clear whether the present mineralogy is primary or secondary. If the mineralogy was unchanged as a result of the metamorphism, then the metavolcanics must be grouped within the spilite-keratophyre-quartz keratophyre suite. If the present mineralogy was imposed entirely as a result of the regional metamorphism, then the rocks should be named according to the composition of the initial feldspar, e.g. basalt-andesite-rhyolite, if the original feldspar was more calcic.

In respect of the influence of chemical composition on nomenclature a further problem arises. My colleague, Mr.May, has shown that the Na_2O content of the metavolcanics is by no means constant. Variations in soda content between approximately 2%, typical of "normal" basalts, and approximately 5%, typical of spilites, are reported. This conflicts to some extent with petrographic evidence, which suggests that all the feldspar is albite (Low extinction angle and refractive index less than canada balsam). It is obvious from thin section studies that the feldspar content is variable in these rocks, and could account for the soda variation even if all the feldspar were albite. It would be interesting to see a contour map of Na_2O percentage over the whole of the Løkken area, though the collection of such data required would be extremely laborious.

From what has been said above it is not easy to generalise about the nomenclature of the metavolcanics of the Løkken Area. This question is discussed more fully by Mr.May in his report. For my part I propose to make a generalisation and call all the metavolcanics with relict igneous textures and structures members of the Spilite-Keratophyre group, in view of the uncertainty as to their original composition. It is pointless, of course, to ehter into a discussion of whether unmetamorphosed spilites are products of late magmatic metasomatism of basaltic lavas or otherwise. I also propose to include in the spilite group all metavolcanics in which possible igneous textures have been destroyed, and no pillow structures or any other igneous structures are developed, but which from their field relations are obviously metavolcanic rocks. A few of the basic metavolcanics exhibit primary banding or fragmentary structures, and these will be regarded as of pyroclastic origin.

The scheme of nomenclature which has been evolved is outlined diagrammatically overleaf.

Fig. NOMENCLATURE OF THE ROCKS OF THE LØKKEN AREA

METAMORPHIC NOMENCLATURE

Applied to rocks in which the primary structures and textures are largely unrecognisable. e.g. Schists and Gneisses.

NON-METAMORPHIC NOMENCLATURE

Applied to rocks in which primary structures and textures can be recognised.

METASEDIMENTS

Rocks not obviously rich in primary volcanic detritus. e.g. Cherts & associated sediments, Vasskis, and rocks of the Hovin Group.

METAVOLCANICS

Pyroclastics

"Acid" and "Basic" types are recognised. Characteristically show bedding or fragmentary structures.

Igneous Rocks

Spilites and keratophyres suite. Showing relict igneous textures.

INTRUSIVE ROCKS : Include Metagabbros, Minor crosscutting intrusives, "Diabases", and Basic Porphyries (Holonda Porphyrites?)

PROBLEMS OF FIELD MAPPING

For the purposes of field mapping the following main groups of rocks were provisionally recognised :

1) METAGABBRO Recognised by presence of large amphibole crystals with white feldspar.
2) VASKISS Thin bands of banded pyritic sediment intercalated within the greenstones.
3) CHLORITE SCHIST Schistose rock rich in chlorite, epidote and calcite.
4) MICA SCHISTS Schistose rock rich in muscovite $\pm$ chlorite . Locally a gneissose texture is developed, particularly in the north.
5) THE STØREN GREENSTONES Of which 3 types were distinguished :
   i) Coarse grained greenstone - rich in epidote and amphibole, and sometimes exhibiting banding. This "Gabbroic Greenstone" of earlier authors provides one of the few mappable features of the Stören Greenstones.
   ii) Fine grained greenstone - exhibiting either pillow structure or a massive character. Interpreted in the field as representing submarine or subaerial lava flows respectively. These rocks are strongly green coloured, principally by epidote, and never exhibit visible quartz. They were interpreted as basic metavolcanics and form the bulk of the surface outcrop in the Lökken Area.

iii) The felsites - Distinguished by the presence of visible quartz and notable lack of epidote and chlorite in hand specimens. These are therefore interpreted as acid rocks, Rocks showing lack of epidote but no visible quartz and very fine grain were mapped as "felsitic greenstone", and provisionally regarded as intermediate types.

6) JASPER AND BLUE QUARTZ occur as localised lenses in the greenstone.

7) CROSSCUTTING DYKES

A black, fine grained rock, very few occurrences.

Upon examination of thin sections of these rocks the nomenclature has been modified and rendered more precise. In particular the term "greenstone" has been abandoned and the classification of the metavolcanics has been revised.

METAMORPHISM

1) REGIONAL METAMORPHISM

As was mentioned earlier the whole of the Løkken Area was metamorphosed in the Greenschist Facies during the Caledonian Orogeny, probably at a late stage in the f_1 deformation. Most of the area considered was metamorphosed to chlorite grade. The grade increases northwards.

Fig.5. shows the map produced by Goldschmidt in 1915 showing the distribution of grade in the metamorphosed Cambrosilurian rocks of the Trondheim Region. Earlier it was emphasised that the metamorphic isograds parallel the regional scale structure. The cores of present day synclinoria are of lower grade than the cores of present day anticlinoria. Metamorphic grade appears to increase with structural depth. In the Løkken Area also the grade increases as one proceeds down the structural succession, the rocks of the Røros group being of higher grade than the rocks of the Hovin group.

The criteria adopted for the description of metamorphic rocks are those suggested by Winkler (1965). The mineral assemblage noted in the rocks of the Løkken Area makes it clear that we are dealing predominantly with a suite of metamorphosed basic rocks. Winkler describes the following sequence of mineral parageneses as being typical of basic rocks metamorphosed in the greenschist facies :-

1) Quartz-Albite-Muscovite-Chlorite Subfacies.

Albite + epidote + chlorite + actinolite + sphene
± stipnomelane ± quartz.

2) Quartz-Albite-Epidote-Biotite Subfacies.

Chlorite + actinolite + epidote + albite + sphene
± quartz ± biotite

3) Quartz-Albite-Epidote-Almandine Subfacies.

Hornblende + epidote + albite ± almandine ± biotite
± quartz

(a) Through the whole of the greenschist facies chlorite is stable, and is thus not an index mineral of the chlorite subfacies. Stilpnomelane is the index mineral of the chlorite grade.

(b) Biotite is the index mineral of the biotite subfacies. However, this is rarely developed in metamorphosed basic rocks.

(c) The most reliable indicator of the transition from biotite to garnet grade in basic rocks is the change from tremolite/actinolite to the more aluminous amphibole hornblende. The chlorite of the garnet grade is enriched in magnesium.

These three points emphasise the main problems of the delimitation of subfacies zones in areas of metamorphosed basic rocks, and the Lökken Area is no exception. Stilpnomelane, biotite and garnet all occur within the area mapped, but always in very small quantities, and only in the few rocks whose original compositions were suitable. It is difficult to know whether this is sufficient justification for the erection of subfacies.

In the extreme north of the area of Map A, schists and gneisses containing small quantities of garnet outcrop along the road section. However, these rocks are invariably rich in large grains of a colourless, non-pleochroic clino-amphibole of the tremolite - actinolite series. There is no trace of hornblende. For this reason I believe that there is no justification for considering these rocks to be in the garnet zone. On the other hand, however, it would seem reasonable to infer that at this point we are well into the biotite zone, despite the fact that no biotite is developed.

Further south, near Laksöyen, specimens of mica schist were collected. These rocks are rich in quartz and albite, the schistosity planes being marked by a little chlorite and muscovite. Accessory quantities of biotite were observed. For this reason this area is believed to be in the lower grade part of the biotite zone.

South from Laksöyen, we pass into schists rich in chlorite , epidote, albite and calcite, with accessory quartz and no biotite.. These rocks are tentatively considered to be in the chlorite zone. This mineral assemblage is fairly typical of all the basic greenstones of the Lökken Area. In the acid volcanics of the Hoslynga-Segel Vatn area however, an abundance of stilpnomelane has been observed. The greater part of the Lökken Area is therefore considered to fall into the chlorite zone. It is impossible to precisely define the boundary between the chlorite and biotite zones. It probably follows the strike of the schistosity and is here believed to approximate to the lithological break between the chlorite-albite-quartz schists to the north and the calcite-epidote-chlorite schists to the south.

Fig.7. shows the distribution of metamorphic grades in the Løkken Area.

The stable amphibole series of the chlorite grade of the greenschist facies is the tremolite/actinolite series. In basic rocks hornblende is not normally stable until garnet grade. However, in a number of rocks in this area in the chlorite zone, hornblende, distinguished by its characteristic pleochroism, has been noted along with tremolite/actinolite. Occurrences of minerals crystallising metastably in metamorphism are described by Turner and Verhoogen (1963, p.457), who say:-

"Rather exceptionally minerals formed by metamorphism are metastable from the moment of their first appearance. According to Ostwald's law, such phases tend to crystallise in preference to truly stable phases, when their appearance involves minimal disturbance of the internal structure of the reacting system. So in the stable greenschist albite-actinolite-chlorite-epidote-sphene formed by regional metamorphism of basic rocks at low temperatures, it is by no means uncommon to find scattered grains of metastable green hornblende pseudomorphous after igneous augite or brown hornblende. Appearance

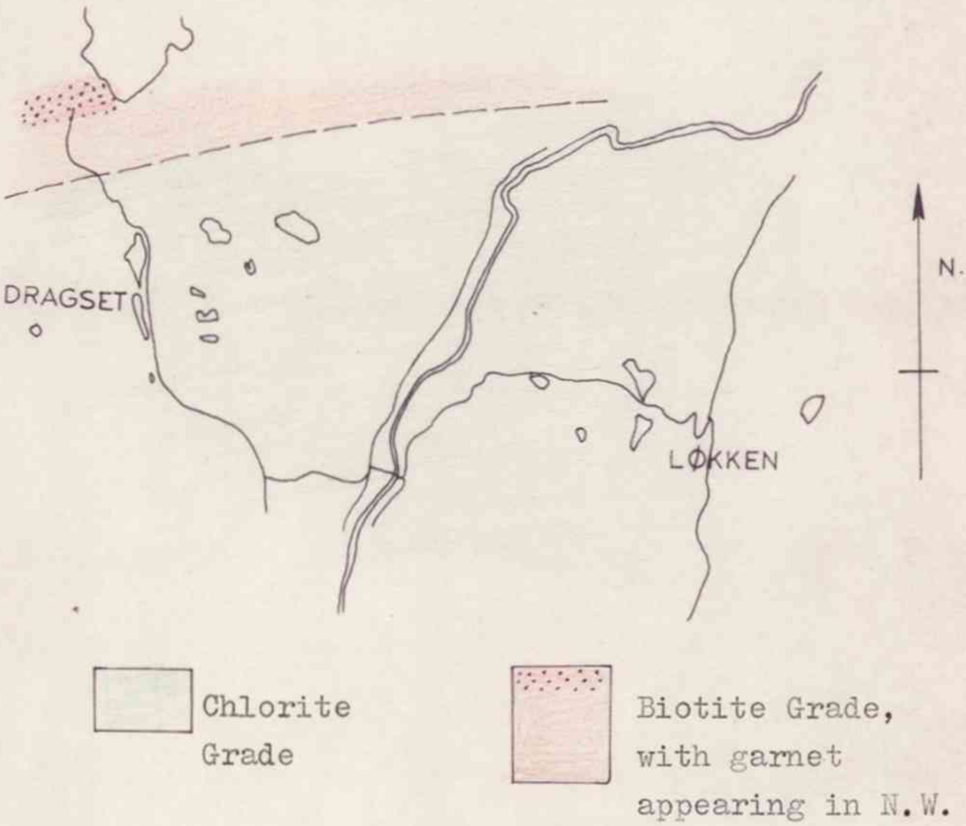
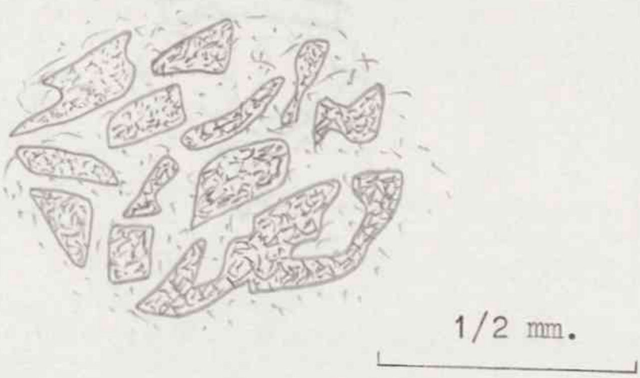


Fig.7. DISTRIBUTION OF METAMORPHIC GRADE IN THE LØKKEN AREA

of hornblende as a transitory phase involves relatively slight change in previously existing space-lattices of pyroxenes. In this example, hornblende, though unstable, is not a relic."

2) CONTACT METAMORPHISM

Possible effects of contact metamorphism on the country rocks by the gabbro intrusion were anticipated and a number of specimens of country rock from around the main body of the gabbro were collected. Xenolithic inclusions of country rock occur within the gabbro close to its margins. A specimen of one such xenolith was sectioned. The section exhibited an unusual mottled texture :-



The dark areas are almost opaque in crossed polars, but their anomalous interference colours suggest that they may be clinozoisite pseudomorphing an earlier mineral. The lighter areas are made up of actinolite and albite. The mineral paragenesis, therefore, appears to be that of greenschist facies regional metamorphism, obscuring any traces of an earlier contact metamorphism due to inclusion within the gabbro mass.

Despite its unusual nature, I do not feel that the texture of the rock is "typically" that resulting from contact metamorphism. Consequently, it appears that any traces of contact metamorphism at the edges of the gabbro will have been completely obscured by later regional metamorphism. It seems reasonable to regard this as evidence that the gabbro was intruded either before or during the period of the regional metamorphic event.

THE BASIC METAVOLCANICS

The work of Björlykke in part of the area of Map A, in the summers of 1959 and 1960, was concentrated on the petrology of the basic metavolcanics. Björlykke attempted to divide up the basic greenstones for mapping purposes according to the following principles:-

i) Grain Size.

It is true that two distinct types of greenstone may be recognised according to grain size, and that this forms a useful distinction for mapping purposes.

ii) Colour.

Light green and dark green greenstones were distinguished among the finer grained rocks. Within each colour group massive structureless varieties were distinguished from rocks exhibiting pillow structure.

I strongly doubt the validity or value of the distinction between light and dark greenstones, although the distinction on the basis of grain size is useful for mapping purposes, irrespective of its significance. In the field I found no consistency in rocks of a particular shade of green. In almost any given exposure the shade of colour of the rock was observed to be extremely variable. For descriptive and mapping purposes therefore, I have tried to recognise only the differences in the primary structures and textures of the rocks, with the possible exception of the grain size distinction.

The Basic Metavolcanics may be considered under three headings:-

(i) The Chlorite Schists.

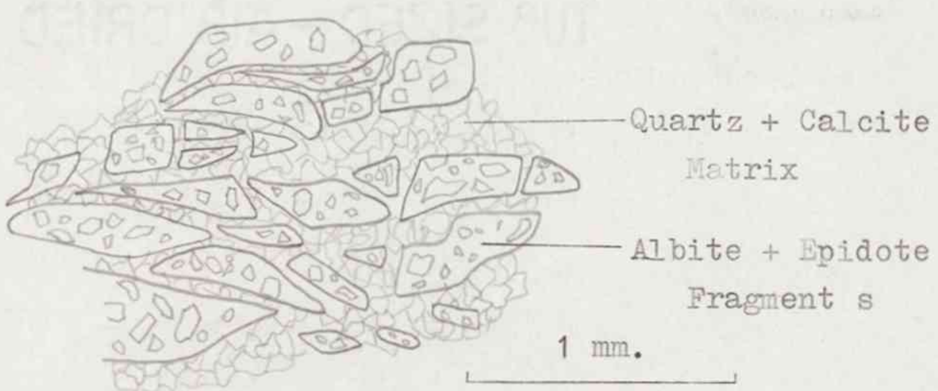
(ii) The Pillow Lavas.

(iii) The Massive Metavolcanics.

(i) The Chlorite Schist.

The Chlorite Schist forms a mappable band nearly 1 Km. wide in the north of the area. The schistosity dips steeply to the south. Mineralogically, the rock is composed of chlorite, calcite , colourless epidote and albite in varying proportions, with a little quartz and muscovite. The minerals tend to be concentrated into thin bands. The concentration of chlorite into discrete bands gives the rock its pronounced schistosity. (See fig.8(a)).

Originally the rock may have been a fine grained pyroclastic deposit. Massive inclusions, which deflect the schistosity, can be seen in field exposures (See fig.16(e)). These structures are tentatively interpreted as volcanic bombs. On the micro-scale, relict fragments of what may have been pyroclastic particles, now completely recrystallised and deformed, can be seen :-



The entire band of chlorite schist may form a distinct tectonic uhit.

(ii) <u>The Pillow Lavas.</u>

The greater part of the rocks of the Stören Group appears to comprise pillow lavas. This is especially true in the immediate vicinity of Lökken. To a large extent the pillows are deformed, and the styles of deformation will be discussed under the heading, "Deformation and Strain."

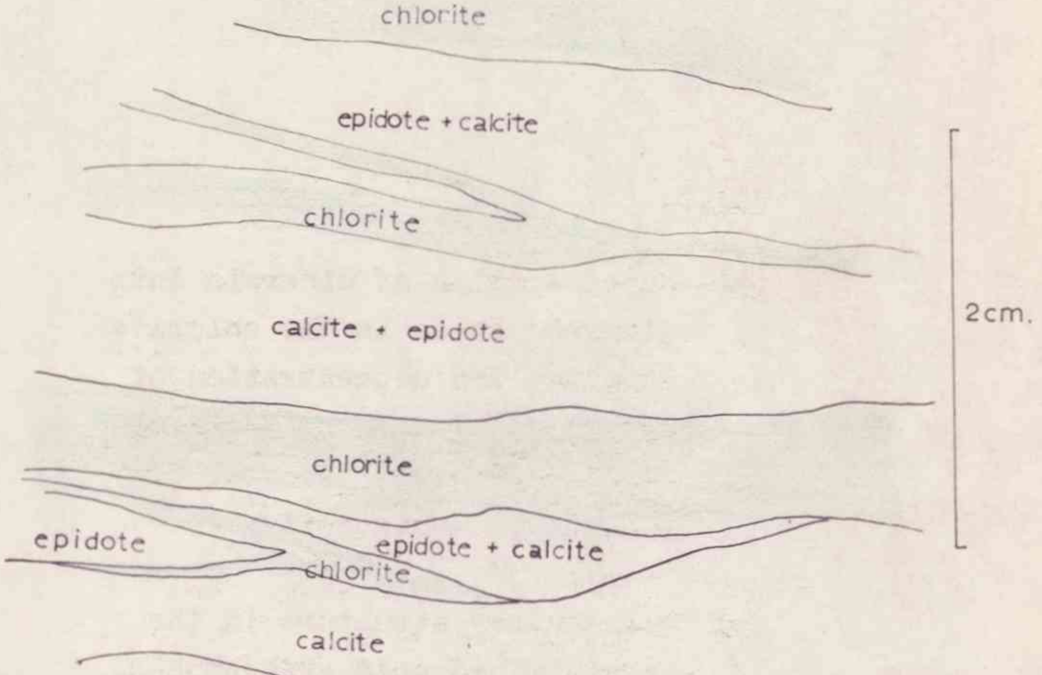
In the southern part of the area of Map B the amount of deformation is low, and the pillow structure of the rocks is readily appreciated. In many cases the "way-up" of the flows can be determined (See Plate 2(b)). The pillows vary in size from 20 cm. to 2 metres, and usually show a visible zonation. The outer part of the pillow is usually a thin zone of chlorite. This passes into a zone of yellowy-green epidote rich rock. This zone is usually a bout 1 cm. thick. There are vague indications that this represents a zone of infilled vesicles. The whole of the central part of the pillow is a fine grained mass of epidote, albite and chlorite with small acicular crystals of actinolite. (See Plate 5(b) and fig.9). No visible subzonation of the central zone can be detected.

An interesting feature of the pillow lavas is seen in the exposures around Björnlivann, where well shaped pillow outlines on a glaciated surface are seen to grade laterally into "fragmented" pillows (See Plate 3). This may represent true pillow brecciation or

Fig.8.

(a) Concentration of minerals into discrete bands in the chlorite schists. The concentration of orientated flakes of chlorite into bands gives the rock its pronounced schistosity.

(b) Fragmentary structure in the fine grained acid greenstones. A delicate schistosity cuts across the rock, which appears quite massive in hand specimen.


chlorite
epidote + calcite
chlorite
calcite + epidote
2cm.
chlorite
epidote
epidote + calcite
chlorite
calcite
epidote

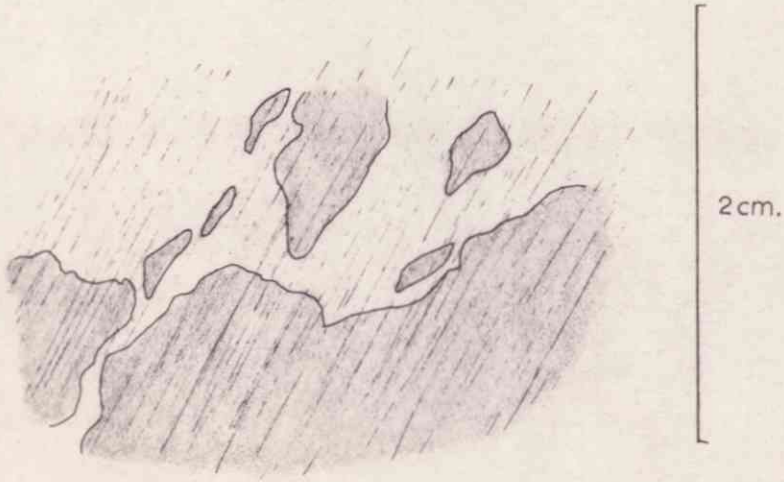

2cm.

PLATE 2.

(a) An outcrop of pillow lava in the southern part of the Lökken Area. Note the unstrained pillows.

(b) An inverted pillow in the same outcrop. The scale tape (passing through the root of the pillow)is half a metre long).

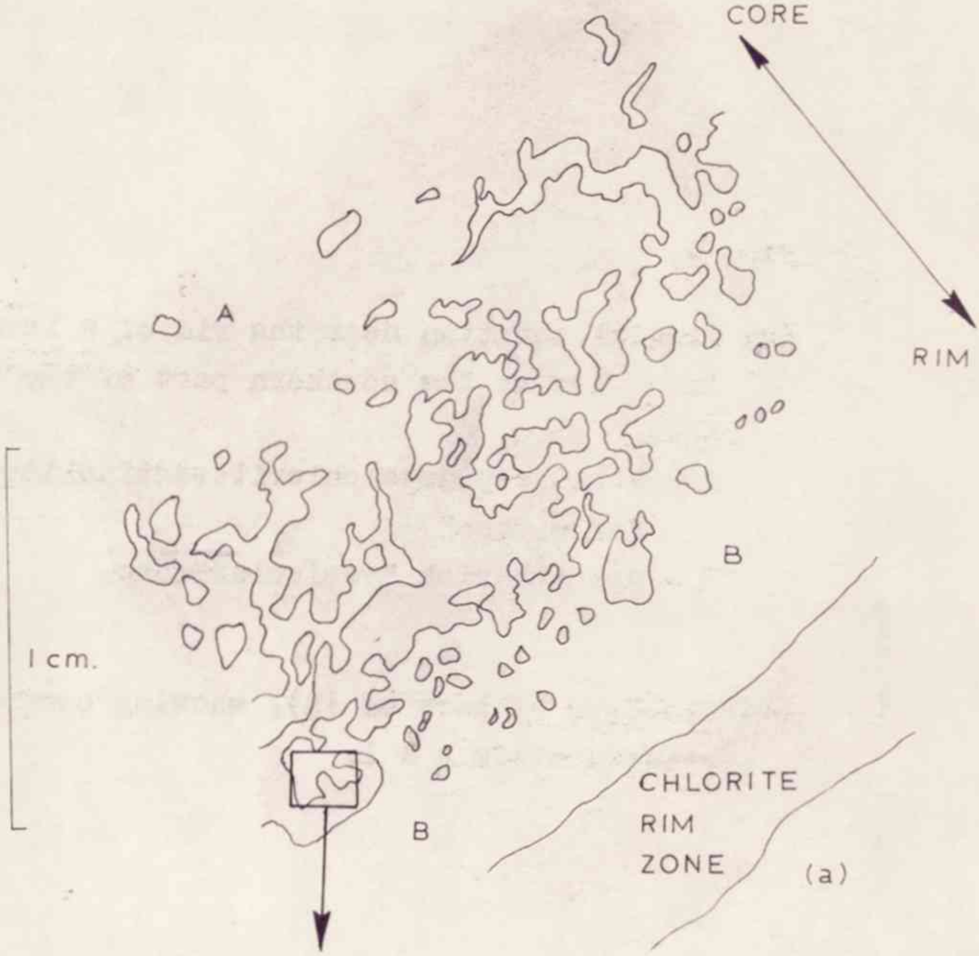
Fig. 9.

(a) Mineral zonation near the rim of a lava pillow in a flow in the southern part of the Lökken Area.

A = albite+epidote+chlorite+actinolite "core zone"

B = epidote rich "vesicular" zone.

(b) Close-up of part of (a), showing contrast between zones A & B.


CORE
RIM
A
B
1 cm.
CHLORITE
RIM
ZONE
B
(a)

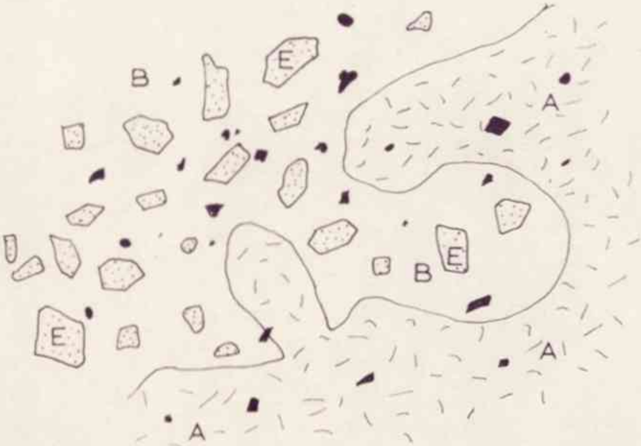

B
E
A
(b)
E
B
E
A
A

PLATE 3.

(a) "Fragmentation" of basic pillow lava as seen on the shore at Björnlivann.

(b) Well formed pillows at the same locality. There is complete lateral gradation between (a) & (b). It is suggested that this is a veining phenomenon. Note the "fracturing" and displacement of the edge of the pillow seen in (b).

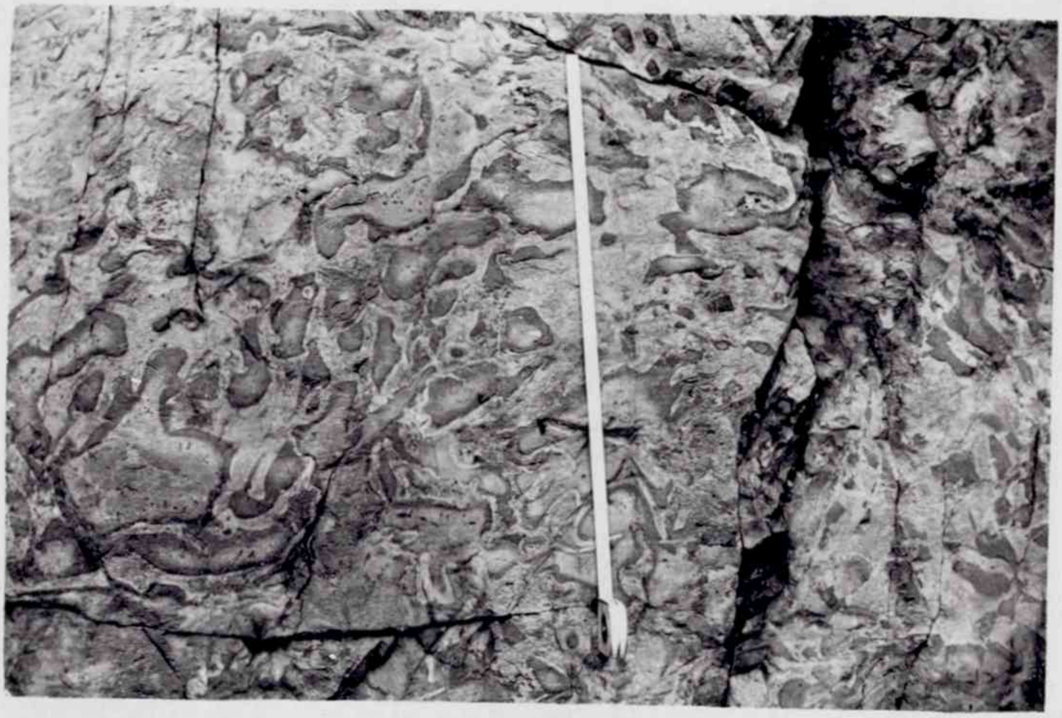
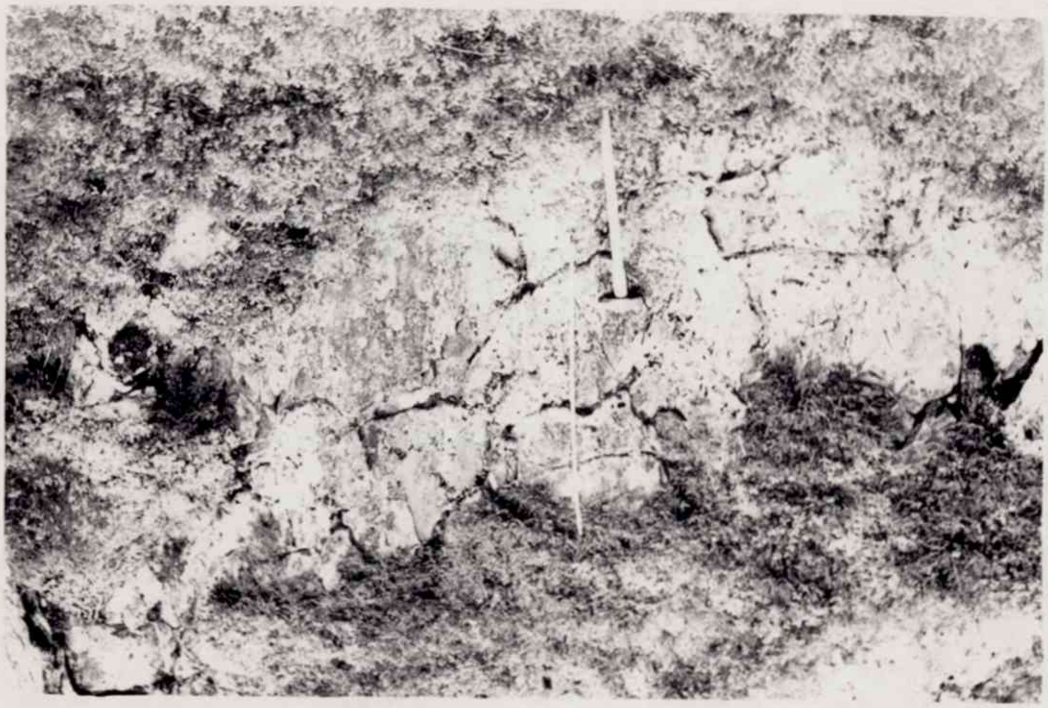
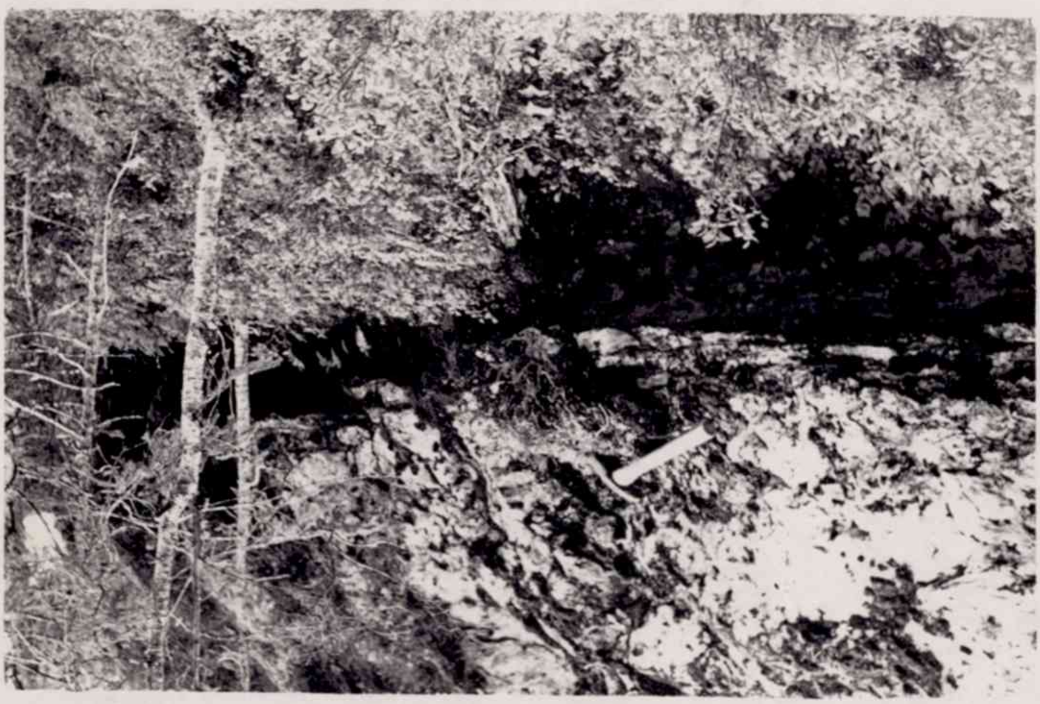


PLATE 4.

(a) Thrust plane exposed in the south-west corner of Hoslynga. Note contrast in dip of schistosity above and below the thrust plane.

(b) Crossjoint surface on well formed pillow lavas. South-east corner of Hoslynga.





a form of hydrothermal veining.

(iii) The Massive Metavolcanics.

These are basic rocks showing no sign of a pillow structure, but there seems to be considerable variety within the group. Schistosity is developed to a greater or lesser extent, but particularly so in the north. Mineralogically, these rocks are identical to the pillow lavas, though there are considerable textural variations.

For the purposes of field mapping, two quite distinctive types could be distinguished.

(a) A Coarse Grained Variety.

This rock occurs in the form of lenses intercalated within the Støren Metavolcanics, and because it is easily mapped it is shown on Map A without any allusions as to its primary nature. The maximum thickness of such lenses is rarely more than 20 metres, and their limited lateral extent is taken as a general indication that one should never expect to find useful, thin marker horizons of great lateral extent in rocks of this type, with the possible exception of the vasskis bands.

It is occasionally possible to distinguish a form of graded bedding in these rocks by a variation in epidote content across layers. Plate 5(a) shows such banding. It thus appears that the banded rocks probably represent pyroclastic deposits, though primary textures have been completely destroyed by metamorphic recrystallisation.

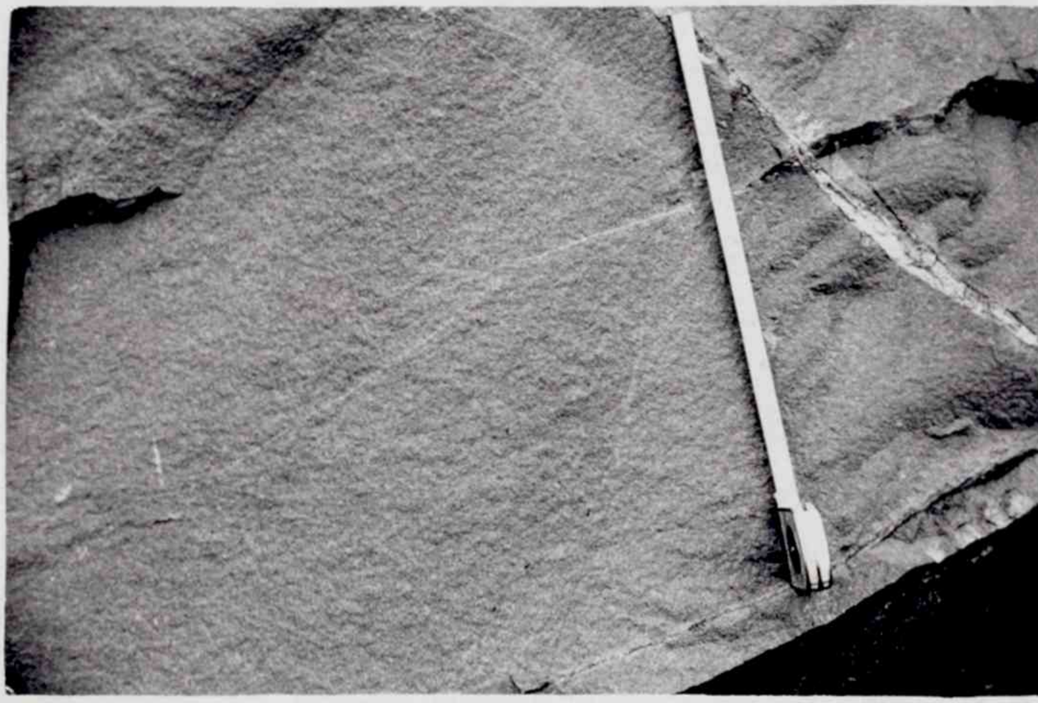
I find it is generally not possible to make any inferences about

PLATE 5.

(a) Primary banding in coarse grained basic metavolcanic rock. The banding is best seen in the photograph by holding it at arms length.

(b) Zonation of the outer part of a pillow.

In (a) and (b) the scale tape is 25 cm. long.



the original nature of the coarse grained rocks where no primary banding can be detected. They may represent lavas, pyroclastics or hypabyssal intrusives. The coarse grain may be entirely secondary. Lack of exposure and the recrystallised nature of these rocks makes it impossible to be any more precise than this.

(b) A Fine Grained Variety.

Mineralogically, these rocks also are typical of basic rocks metamorphosed to chlorite grade, and here too it is virtually impossible to make precise inferences as to the mode of origin of these rocks in view of the metamorphic recrystallisation. However, in a few cases traces of what may have originally been fragments can be distinguished by slight mineralogical and textural differences, though in some specimens the effect of epidote veining is to produce an "agglomeritic" structure. Lack of epidote in the acid metavolcanics makes it easier to distinguish primary fragmentary structures than in the basic rocks. The delicate banded structures of the coarser rocks has never been observed in the fine grained massive basic metavolcanics. However, it is worth bearing in mind that a considerable proportion of these rocks may be pyroclastic in origin, though some are probably subaerial lavas or perhaps small basic sills.

Distribution of the Massive and Pillow Varieties within the outcrop of the Basic Metavolcanics.

Fig.10. shows a map of the area to the west of the Orkla River

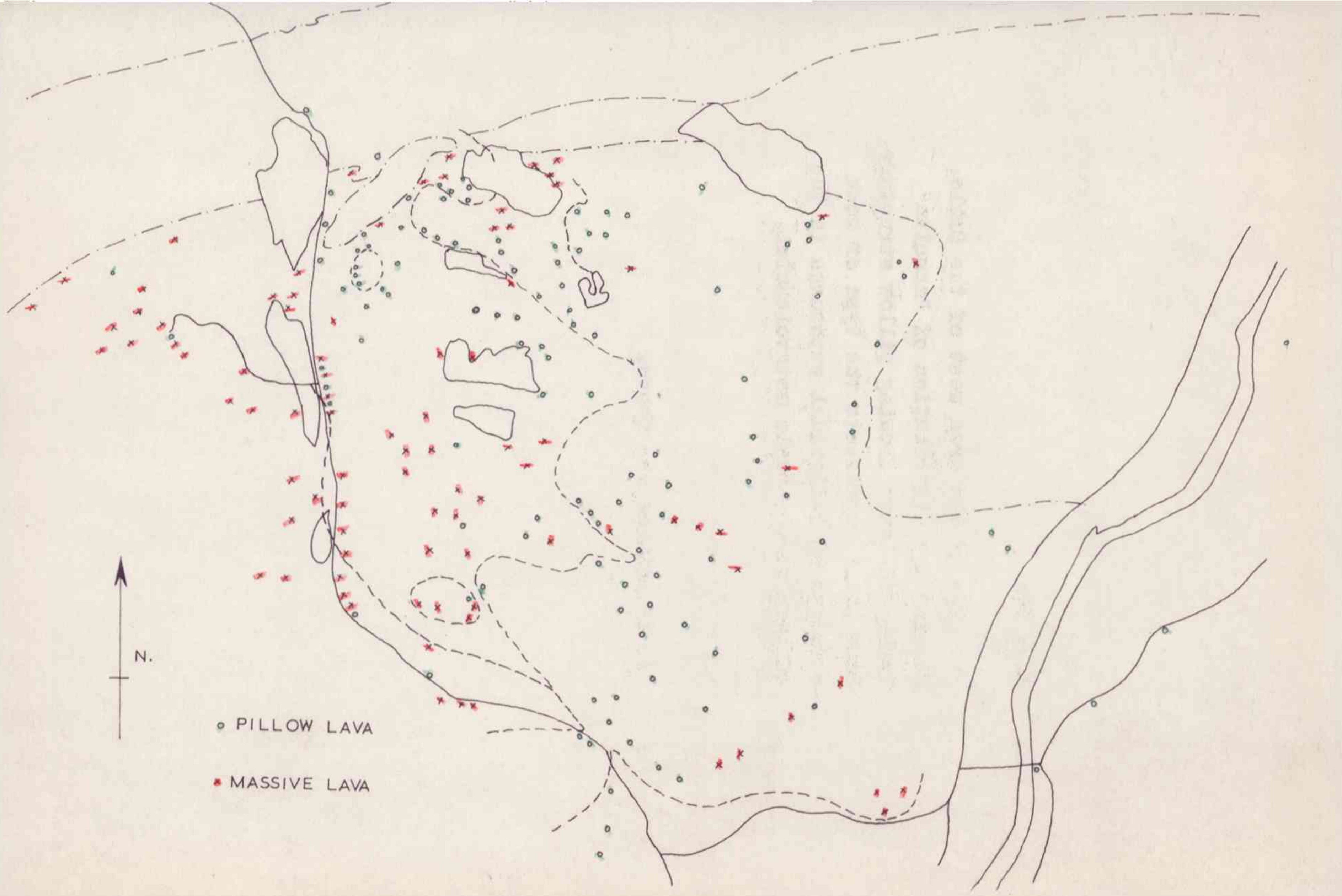
on which 213 observations of rock types observed in particular exposures are plotted. The map attempts to give a broad indication of the distribution of massive metavolcanics and pillow lavas within the Stören Group. Some indication of the distribution of exposures over the outcrop is implied.

There is a general indication that to the west of the area the rocks are predominantly of the massive type, and that the incidence of pillow lavas becomes greater as one proceeds eastwards. It is possible that this may be a reflection of the palaeogeography of the area at the time of the volcanic activity, but it should be borne in mind that lack of observations may mean that this east-west distinction is a random one.

Fig. 10.

Map of the area west of the Orkla, showing the distribution of "massive" lavas and lavas showing pillow structure. Each point represents the type of rock observed at individual exposures in the outcrop of the basic metavolcanics.

213 localities are shown.


N.
PILLOW LAVA
MASSIVE LAVA

BASIC INTRUSIVE ROCKS

1) Minor Intrusions

(a) Small Dykes.

In a few rare outcrops small dykes of a massive black rock can be seen cutting across the layering of the country rock (See fig.24). Because of their small size these intrusions are only rarely exposed. It was considered that these rocks might form useful time markers in the metamorphic event, and one such specimen was sectioned.

The mineral paragenesis is metamorphic. The rock is composed almost entirely of actinolite, albite, epidote and a little chlorite. The feldspar appears to be remarkably fresh, and occurs interstitially between the grains of amphibole and epidote.

It is possible that these dykes may be post f_1 folding (they are not seen to be contorted in the field, nor is there any tendency to the development of schistosity) but they have certainly been affected by one or more episodes of the regional metamorphic event.

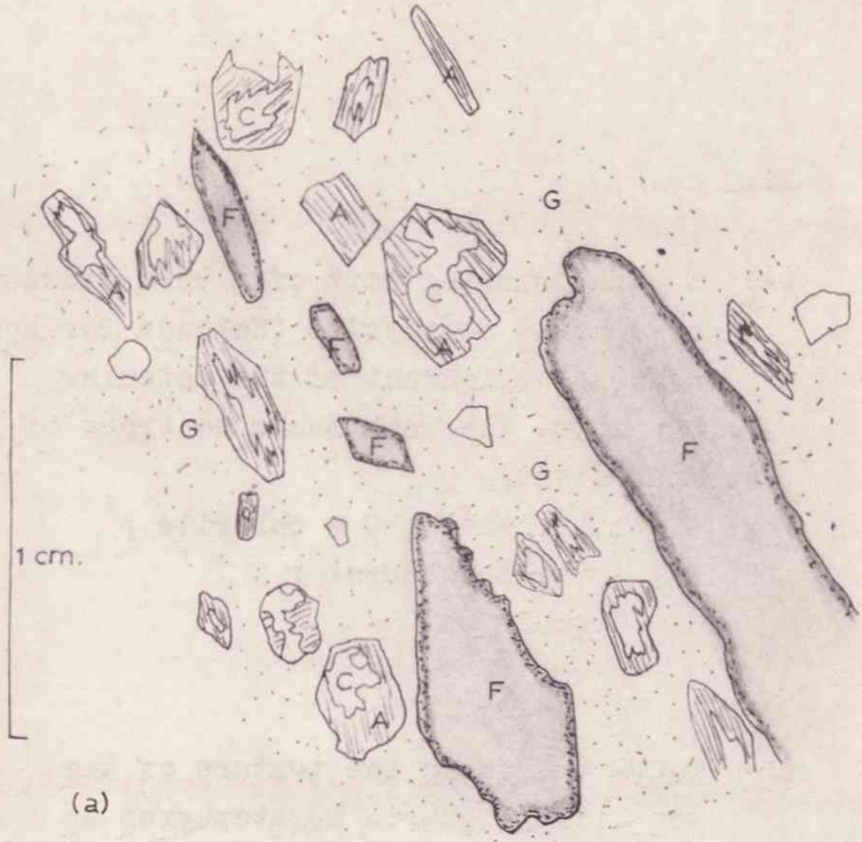
(b) Basic Porphyrite.

In 3 localities on Map B outcrops a most unusual porphyritic rock. The rock consists of large, completely saussuritised tablets of feldspar and smaller, euhedral phenocrysts of secondary chlorite being again replaced by hornblende . These phenocrysts are set in a fine grained matrix of albite, epidote, chlorite and leucoxene. The

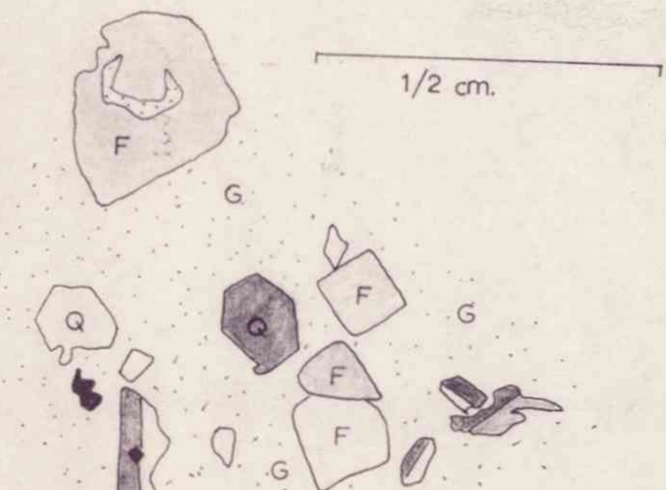
Fig. 11.

(a) Drawing showing part of a thin section of a basic porphyrite (Holonda Porphyrite?) Note the alignment of the acicular minerals. The rock shows no trace of schistosity.
A = hornblende ; C = chlorite ;
F = Altered feldspar ;
G = Groundmass.

(b) Drawing showing the texture of the porphyritic quartz keratophyres as seen in thin section.
Q = quartz ; F = feldspar (albite)
G = Groundmass.



(a)



(b)

phenocrysts are generally oriented into a flow structure. Fig.11(a). shows a sketch of a thin section of this rock.

The pseudomorphs after the original mafic mineral are particularly interesting. The original euhedral crystals were probably of a pyroxene, which was then completely pseudomorphed by chlorite, which is in turn being replaced by green hornblende.

The description of the basic porphyrite afforded here corresponds almost exactly with that given by Blake, Chadwick, Rowling and Beswick for the Holonda Porphyrites, which are extensively developed 10 Km. east of Løkken. It thus appears that the Løkken Porphyrites are probably equivalent to the Holonda Porphyrites, although I myself have not seen specimens of the latter.

2) Major Intrusives.

The Metagabbro Masses.

Metagabbro outcrops over some 6 sq.km. of the Løkken Area, the largest single mass being developed west of the Orkla River. The mass of the gabbro rising from the river can be seen in the top left of the frontispiece. The ground over which the metagabbro outcrops is characteristically flat, boggy, with few trees and low lying compared with the country rocks to the west.

The metagabbro is generally very poorly exposed, the best exposures being along the road section. It is in one of these exposures that banding of the metagabbro is particularly well seen

(See plate 6). In three or four exposures toward the centre of the mass banding is again seen. The banding generally strikes east-west and is approximately vertical. It consists of an alternation of layers rich in amphibole with layers rich in altered feldspar. In good exposures the banding is seen to undulate gently, but in the southern part of the metagabbro outcrop no banding was seen at all.

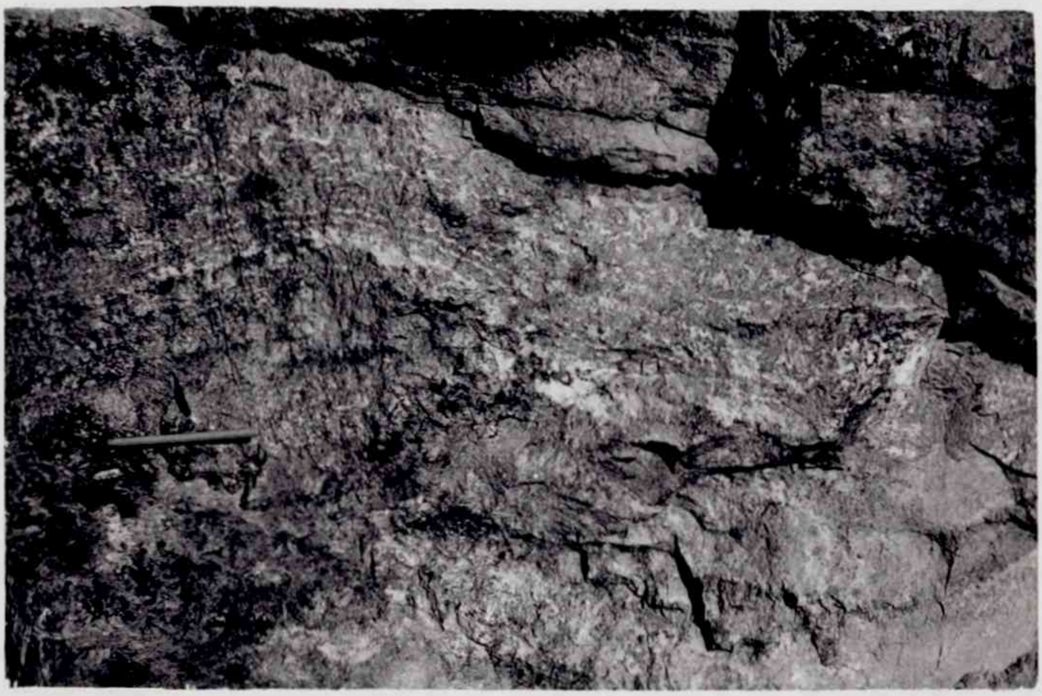
It is known from field evidence that the northern contact of the metagabbro dips steeply to the south, probably conforming to the schistosity. There is no evidence as to the shape of the contact to the south and east. To the north-west the extension of the metagabbro appears to be in the form of a sill. It may be seen from Map A that the layering and local plunge of the f_1 structures in the country rock in proximity to the western contact of the metagabbro are deflected. This may be due to a lobe of the metagabbro.

Mineralogically, the metagabbro consists of albite, colourless epidote, clinozoisite , hornblende, tremolite and chlorite. The original feldspar is pseudomorphed by an intergrowth of albite, epidote and clinozoisite. This I regard as convincing evidence to the effect that the feldspar was originally more calcic. The original mafic mineral, probably a pyroxene, is now replaced by hornblende, tremolite and chlorite. The whole rock remains coarsely holocrystalline, showing no tendency to develop a schistosity. It is suggested that the metagabbro was not affected by the f_1 deformation, i.e. was intruded post-f_1 , but was metamorphosed during a late stage of the

PLATE 6.

(a) Layering in the metagabbro, as seen in the north-eastern part of the outcrop west of the Orkla River. The banding is vertical at this locality.

(b) Close up of the banding seen in (a). The banding consists of alternations of amphibole layers with layers of altered feldspar.



Caledonian Metamorphic Event, before the commencement of the f_2 deformation.

Outcropping in the south-west part of the metagabbro mass, and apparently associated with it, is a rock which in the past has always been mapped as gabbro. Closer examination of this rock shows it to be not a gabbro at all, but a rock exhibiting a well developed granophyric texture. The rock contains about 15-20% of quartz, forming a graphic intergrowth with feldspar around large euhedral feldspar crystals, which are up to 2mm. long. The feldspar is entirely albite and appears to be quite fresh, unlike the feldspars in the metagabbro. The freshness of the albite, and the lack of clacium rich minerals e.g. epidote group, suggests that the feldspar was never very calcic to begin with, i.e. the feldspar of the granophyre was probably more sodic than that of the gabbro. Chlorite occurs interstitially between the large feldspars. Accessory quantities of epidote are seen, usually associated with the interstitial chlorite.

The granophyre appears to form a capping to the large gabbro mass, assuming the vertical banding in the gabbro to be an indication that it is turned on its side. It is possible that the metagabbro is a gravity differentiated intrusion, the granophyre representing the last stage of the differentiation, but further work is required to investigate this interesting possibility. The worst problem about investigating the metagabbro masses is that they are probably the worst exposed rocks in the Lökken A rea.

THE ACID METAVOLCANICS

The acid metavolcanics form fairly distinctive rocks in the field, and outcrop over restricted areas as Maps A and B show. The volumes of acid rock are extremely small compared with those of the basic rocks. On the western side of the river at least, the acid rocks form discrete layers, and, unlike the basic rocks, do not exhibit pillow structure. Individual bands of acid rock are usually quite thick (more than ten metres).

The acid rocks characteristically are rich in quartz and albite, and are impoverished in chlorite, muscovite and epidote. Phenocrysts of quartz and albite set in a fine grained groundmass of quartz and feldspar summarises the texture of these rocks in very general terms. Small quantities of stilphomelane occur in most of the acid rocks.

I have not studied sufficient samples of rock in thin section to be able to say whether there is a gradation from basic rocks to the acid rocks or not, but a cursory examination of hand specimens suggests that there are little or no rocks in the area of intermediate composition.

For the purposes of general description, three types of acid rock have been distinguished in the area west of the Orkla. Following the usage of the term "spilite" in connection with the basic rocks because of the albitic feldspar, the acid rocks will be called quartz-keratophyres.

(i) The porphyritic quartz-keratophyres.

These rocks comprise the greater part of the volume of acid rocks, and occur as thick, homegeneous layers.

As was mentioned above, these rocks consist of euhedral phenocrysts of quartz and albite set in a fine grained matrix of quartz, feldspar, chlorite and muscovite (See fig.11(b)). The rocks show no evidence of any structure, macroscopic or microscopic, which suggests a particular more of origin. The rock could be of pyroclastic origin, an acid lava, or a hypabyssal acid intrusive.

(ii) The fine grained quartz-keratophyres.

Despite the fact that no quartz is visible in hand specimen, these rocks are very rich in quartz of very fine grain. They consist of a very fine grained mass of quartz, albite, chlorite and muscovite. Schistosity is developed to a variable extent. The rocks are too massive to permit microfolding of the schistosity.

The interesting point about these fine grained acid rocks is that they exhibit a fragmentary structure. Discrete areas of coarser texture or of different colour can be distinguished in each hand specimen on a cut surface (See fig.8(b)). It thus appears that these rocks probably represent accumulations of acid pyroclastic debris.

(iii) The Banded quartz-keratophyres.

These rocks form a very small proportion of the total volume of acid rocks. A band 1½ to 2 metres thick underlies the thick porphyritic quartz-keratophyre lying to the east of Lillevatn. The rock is distinctive through the concentration of stilpnomelane into brown bands easily seen in hand specimen. In thin section the stilpnomelane banding is seen to go hand in hand with the congregation of phenocrysts into bands as shown in fig.12. The stilpnomelane flakes are seen to be oriented into a poor schistosity which lies at a slight angle to the coarser banding. This coarse banding is probably a primary structure, suggesting that the rocks is probably a pyroclastic accumulation.

The albite phenocrysts in this rock are generally seen to be mantled by a zone of fine grained quartz and feldspar, which is itself often mantled by flakes of stilpnomelane. These zones, figures in fig.12 b & c. and plate 7 c & d., are tentatively interpreted as devitrified glassy shrouds around crystal tuff fragments.

It is possible that the quartz in these acid rocks has an anisotropic fabric, but usually the rocks are too fine grained to make a quartz orientation analysis feasable.

From the features of the acid rocks pointed out above it appears that the bulk of acid rocks may be of pyroclastic origin. Some attempt is made on Map A to show the distribution of the various types of acid rocks. The banded acid rocks are too thin to be shown. Because of the poor exposure, this representation of the acid rocks is probably grossly oversimplified, but there is little that can be done to rectify this.

Fig. 12.

(a) Whole slide drawing of a thin section of a banded quartz keratophyre. Note the zones of oriented stilpnomelane, S.

(b) and (c) Enlarged portions of (a) showing finer textural details. Note the shrouds of matrix material and stilpnomelane around the phenocryst in (b).

F = Feldspar (albite)

S = Stilpnomelane

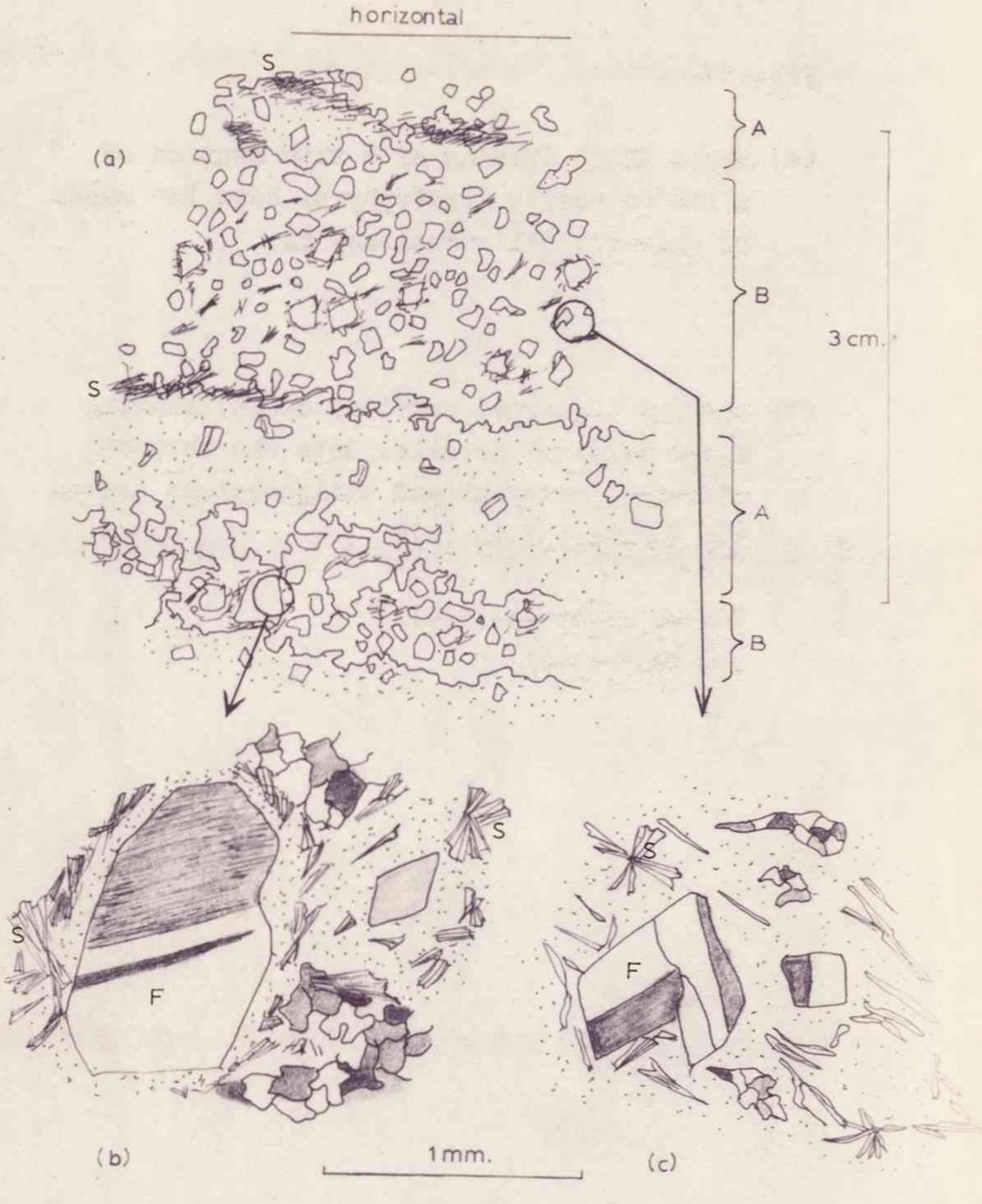

horizontal
S
(a)
A
B
3 cm.
S
A
B
S
S
F
S
F
(b)
1mm.
(c)

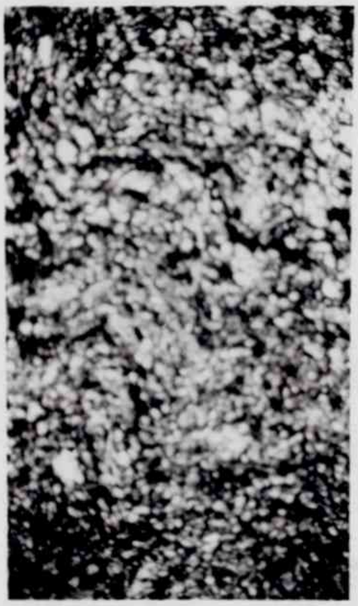
PLATE 7.

(a) Photomicrograph showing f_2 microfolds in Quartz-albite-chlorite-muscovite schist of the Röros Group.

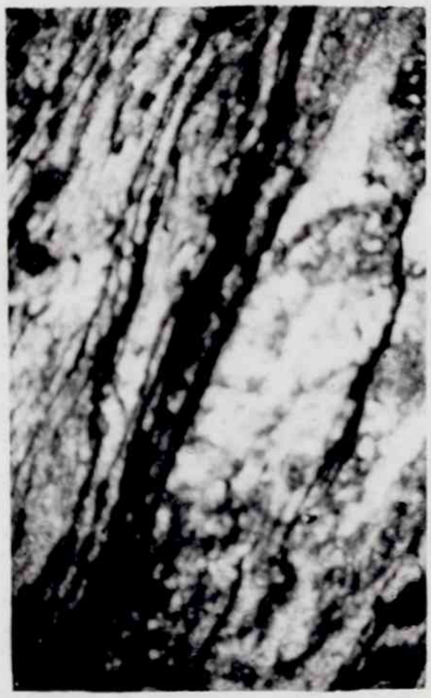
(b) Photomicrograph showing isoclinally folded polycrystalline quartz band in quartz-sericite rocksfrom the southern part of the area of Map A.

(c) and (d) Albite phenocrysts shrouded by fine grain quartz + albite in banded quartz keratophyre. (see fig.12.)

Magnification is X 40 in each case.

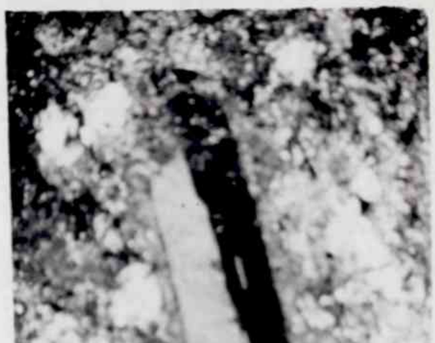


a



b

c



d

THE ROCKS OF THE RØROS GROUP

Rocks of the Röros group outcrop to the north of the Lökken Area, structurally underlying the rocks of the Stören Group. The rocks are metamorphosed to biotite and higher grades. A considerable variety of metamorphic rocks are recorded in the Röros Group, but because of poor exposure only the Laksöyen road section was open to close examination in the area mapped.

Immediately underlying the chlorite schists of the Stören Group lies a zone of Garben Schist. This is a very distinctive rock type and is recorded at many places in the Trondheim Region. Schistosity is well developed, and needles of actinolite arranged into characteristic rosettes are seen on the schistosity planes. There is no tendency toward alignment of the actinolite fibres. The contact between the chlorite schists and the garben schists is not exposed, but the transition takes place within a zone less than 4 metres wide.

Lying beneath the garben schists is a series of strongly schistose chlorite-albite-muscovite-quartz schists. These are very fine grained rocks, except on the schistosity planes where muscovite and chlorite are concentrated. Minor amounts of biotite are seen in thin section. Microfolding of the schistosity to produce a strong crinkle lineation is seen in most exposures. (See plates 7(a) & 8, and fig.16(b) & (d).

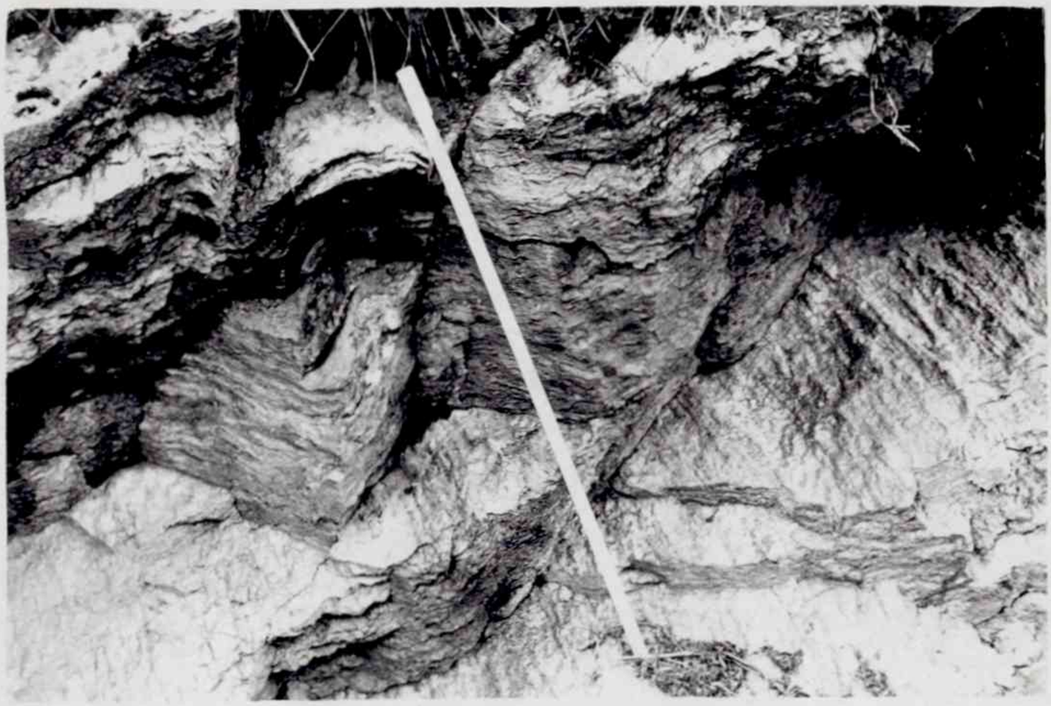
The mica schists described above grade downwards into coarser grained schists until the rock takes on a gneissose texture. The amount of quartz becomes reduced, muscovite increases in quantity and grain size and the schistosity becomes more irregular. Albite is low but of coarser grain. The chlorite becomes coarser and more magnesium rich. From being insignificant in quantity, tremolite, in the form of large, equant grains, becomes the predominant mineral. There is no hornblende and very little epidote. In the northernmost part of the area mapped small quantities of garnet begin to appear in the gneisses, but this is not accompanied by any appreciable development of hornblende.

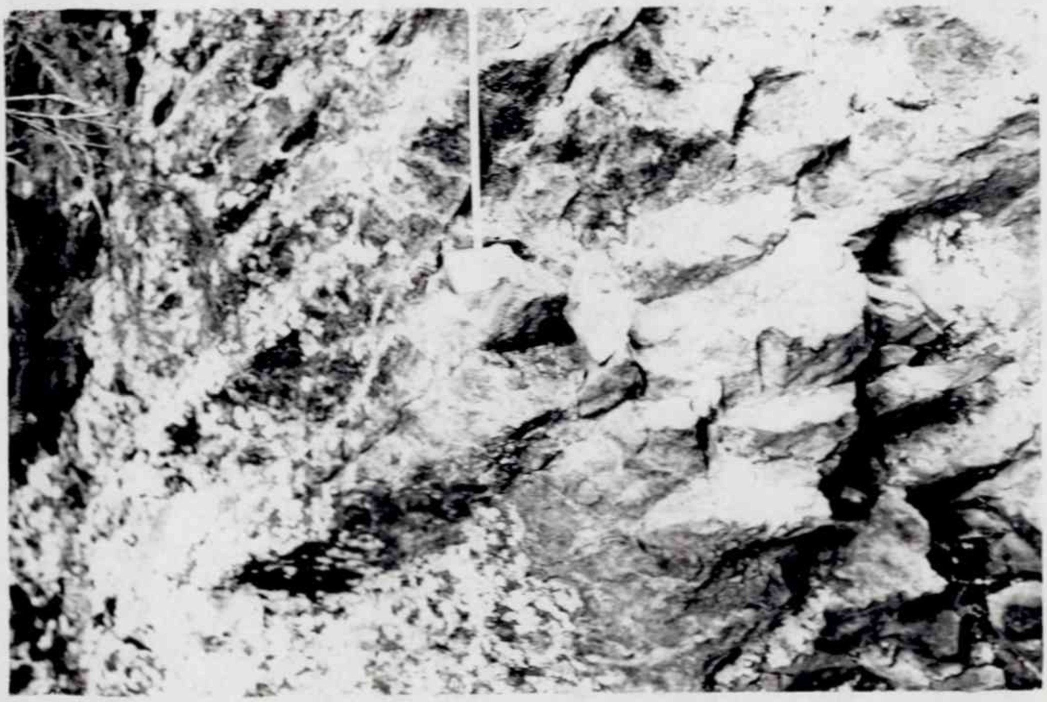
PLATE 8.

(a) Quartz-albite-muscovite-chlorite schist of the Röros Group showing well developed f_2 crinkle lineation.

(b) Small f_2 chevron folds in chlorite schist near Hoslynga.

The scale tape is one half metre long in each case.





THE JASPER LENSES

Lenticular masses of Jasper occur in the basic metavolcanics at a number of localities all over the Løkken Area. More rarely the rock does not have the intense red colour of Jasper, but may be blue or white. The lenses are elongated in the plane of the schistosity parallel to the f_1 stretch direction. They range in size from 3 metres to 50 or more metres in length. Texturally the rock consists of small, sutured quartz grains, about .1mm. in diameter. Scattered throughout the rock are small pyrite grains and patches of haematite. It is evident from the behaviour of the grains under crossed polars that the quartz has some sort of anisotropic fabric, but time precluded the detailed investigation of this feature at this stage. Many of the grains showed undulose extinction, associated with a late stage in the structural history of the area.

It is well known that cherts are commonly associated with submarine volcanic rocks. If the jasper lenses were originally bodies of radiolarian chert, then no trace of organic structures are left after the recrystallisation associated with the regional metamorphic event.

VASSKIS

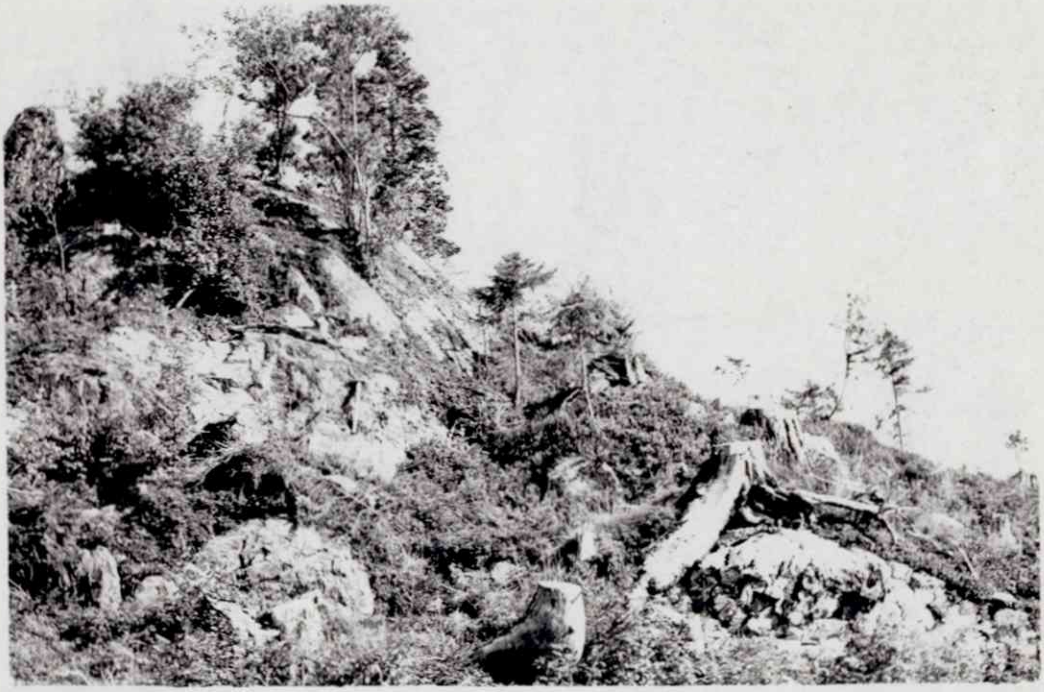
Vasskis is a banded pyritic shale which occurs intercalated within the acid and basic metavolcanics of the Løkken Area. Such bands rarely exceed 2 metres in thickness, but may extend over considerable areas. The Vasskis has been exhaustively studied by Norwegian geologists in the past, particularly in the immediate vicinity of the Lökken Mine, and will not be considered in detail here.

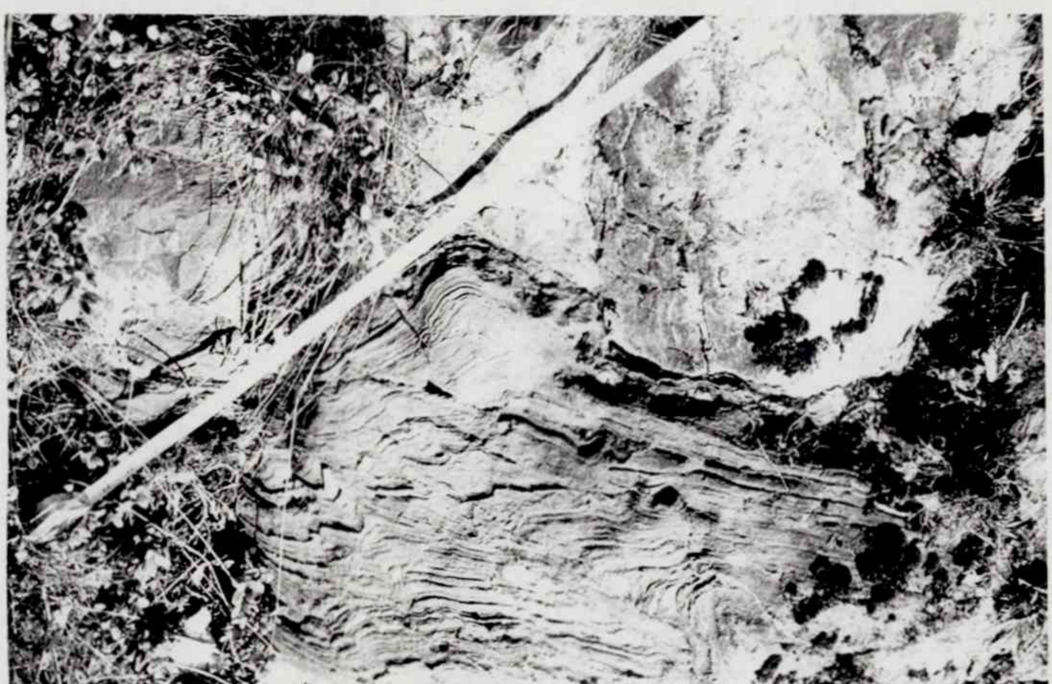
To the west of the Orkla River only one occurrence of vasskis is recorded. This is a strongly altered band lying beneath a thick layer of acid rock to the north of Lillevatn. This band shows considerable contortion in the southern part of its outcrop, where it is probably cut off by a fault. At this locality the band has been worked in the past, probably for its pyrite content.

PLATE 9.

(a) Outcrop of a jasper lens in basic pillow lavas.

(b) Small fold in a haematite-rich sediment trapped in a "pocket" within the above jasper lens.





STRUCTURAL GEOLOGY

THE MAIN GROUPS OF STRUCTURES

It is possible to discern in this area a number of phases of deformation, all of which are connected with the Caledonian Orogeny. In this context the term "Phases" is used to distinguish stages in the progressive deformation of an area. Each phase is represented by a particular association of structures, indicative of the particular dynamic conditions operative at the time.

The main structural episodes or phases which took place in the Løkken Area are summarised (in chronological order) as follows :

1) Isoclinal folding (f_1) associated with regional dynamothermal metamorphism in the Greenschist Facies.

Structures associated with this phase are :

a) Development of Schistosity.

b) Development of linear structures by stretching in the plane of schistosity.

e.g. Stretched pillow lavas, deformed spherulites, vesicle elongation, elongation of pyrite orebodies.

2) Folding of the Pre-F ormed schistosity (f_2) into areal scale parallel folds almost coaxial with the f_1 linear structures. No metamorphism is associated with this phase.

Structures associated with this phase are :

a) Development of "Minor" folds in the hinge of the major structure, The Løkken Synform. These are termed 2nd order structures.

b) Development of kink bands and kink folds, plunging parallel to the local axial direction of the Løkken Synform. These are termed 3rd. Order structures.

c) Development of a ripple lineation by microfolding of chlorite flakes. These are termed 4th. order structures.

3) Thrusting, occurring towards the end of f_2. The direction of transport appears to have been from north to south, corresponding generally with the direction of tectonic transport in the Norwegian Caledonides. The thrust planes appear to have suffered gentle warping associated with a late stage of f_2.

4) An episode of gentle flexuring about a north-south axis (f_3). This has produced local variations in the plunge of the f_1 and f_2 structures. The orientation of the thrust planes has been considerably affected by these movements.

5) Faulting. These faults have dissected all earlier structures, and their disposition, mainly north-south and east-west, has controlled present day drainage and geomorphology to a considerable extent. There appears to be a geometrical relationship between fault and joint orientation in the area.

The foregoing summary of the structural history of the Lökken Area will be used as a basis for the more detailed description of the structure which follows.

THE FIRST PHASE OF FOLDING (f_1)

This phase is simplified in the ensuing discussion to a single phase of tight or isoclinal folding, but may, and probably does, itself consist of a complex sequence of deformations, perhaps including several "sub-phases" of folding.

(a) The evidence for tight or isoclinal folding.

(i) The development of schistosity.

It is generally agreed that the development of schistosity in a rock indicates considerable shortening of the rock, usually involving folding. In addition, where primary layering can be distinguished in the rock, it is generally seen to parallel the schistosity. Schistosity is not, however, uniformly developed all over the area considered, especially in the metavolcanics in the south. In some banded acid rocks a slight angular discordance can be detected between primary layering and schistosity (as indicated by oriented stilpnomelane flakes). (See Fig.12.). (s. 39–40)

ii) Way-Up Criteria

In areas where schistosity is not so well developed it is often possible to distinguish the way-up of the rocks. Way-up criteria which have been observed are :

(a) Shapes of pillows in pillow lavas,

(b) Grading of bedding in pyroclastic deposits.

It is generally observed that in any given sub-area the rocks are never consistently one particular way-up, although they may dip consistently in one direction. This is to be expected if the rocks are isoclinally folded.

iii) Relation between the Chlorite Schists and the more massive metavolcanics.

The contact between the chlorite schists to the north and the more massive metavolcanics to the south is not straight. Lenticular masses of one occur in the other close to the contact without any deflection of the schistosity. Such lenticles must therefore represent pre-f_2 structures.

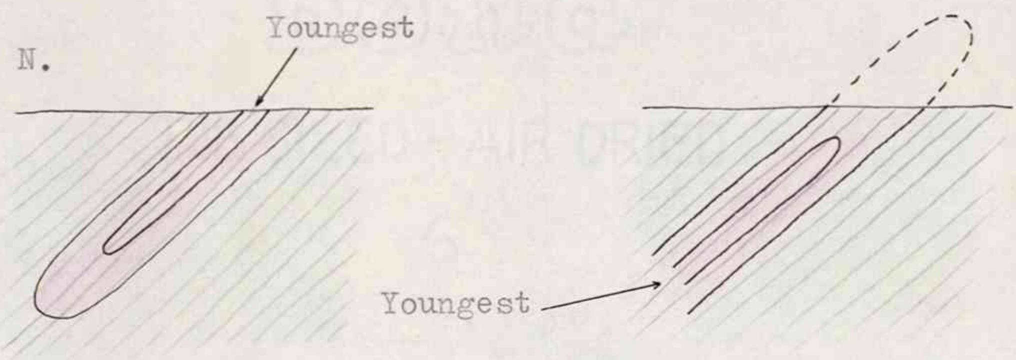
In the area of acid volcanics the character of the intercalated basic rocks is highly variable, from massive homogeneous lavas on the one hand to well foliated schists on the other. This is to be expected in an area of isoclinal folding.

iv) Relations between the Acid and Basic Rocks.

In the Hoslynga - Segel Vatn Area acid and basic rocks are seen to be intercalated. This intercalation may be primary or it may be a consequence of isoclinal folding. Unfortunately, from the field relations it is impossible to be sure which is the case.

v) The Disposition of the rocks of the Hovin Group south of Løkken.

A traverse of the road section south from Løkken village was made in order to determine the way in which the band of the Hovin Group rocks is disposed relative to the surrounding Stören Greenstones. (See Map B). Dip readings on schistosity were taken to see whether this is a synform fold core produced by folding of the schistosity, or whether the schistosity was constant in dip, thereby suggesting that this is the core of an f_1 isocline. As map B shows, no significant change in the dip of schistosity was detected. Since the style of f_2 folds observed elsewhere obviates the idea that this could be caused by isoclinally folded schistosity, it must be concluded that this is the core of an overturned f_1 syncline, as would be expected from the stratigraphic relations between the Hovin and Stören Groups. It is NOT clear whether this syncline is antiformal or synformal;



Synformal Syncline　　　　Antiformal Syncline

The Area of Blake, Chadwick & Co., adjoins the south-eastern edge of the area of Map B. The band of Hovin Group rocks mentioned above extends into their area. They have apparently been able to distinguish a slight angular divergence between bedding and schistosity.

They therefore interpret this Hovin Group band as the core of a synformal syncline, with axial plane schistosity, clearly a major f_1 fold. Unfortunately their paper does not suggest the axial direction of the syncline, nor do they describe any linear structures in the area.

I am not entirely satisfied that this is necessarily a synformal syncline: it could be neutral or antiformal. Which interpretation is adopted depends on whether evidence as to the axial direction can be found. It does not necessarily follow, of course, that the axial direction will parallel the stretch direction recorded in the Dragset area. The range of possibilities are summarised in Fig.13(a). In general the f_1 plunge direction must plunge to the north of the strike of the limbs of the fold.

Four kilometres north of Løkken, Carstens has mapped a similar band of Hovin Group rocks (see Fig.3.). IF this is part of the same fold structure as the band south of Løkken, then the fold could be described as a neutral fold, with its axis directed perpendicular to the f_1 stretch direction (see Fig.13(b).). It is not clear to me how this northerly band of Hovin Group rocks fits in with the chlorite schists to the west. These relations were not investigated during the period of the fieldwork.

It should be noted that for the Hovin Group band south of Løkken the interpretation of a synformal syncline plunging parallel to the stretch direction appears to be impossible, as Fig.13(a). shows. Only an antiformal syncline plunging parallel to the stretch direction can be envisaged.

Clearly, more work is required over a large area in order to determine the axial directions of the f_1 folds and their angular relations to the f_1 stretch direction.

vi) Observed f_1 minor structures.

It would be virtually impossible for small scale folds to develop in the massive metavolcanics, and none were ever seen. In the chlorite schists to the north, however, a careful search was made for small folds to which the schistosity was axial plane, but these rocks are so strongly schistose and recrystallised that no convincing trace of primary banding was ever seen. However, at a locality ½ km. north from Dragset mine, a trace was seen of what may have been a folded primary band. The behaviour of the schistosity in the hinge zone of this fold was observed to be typical of the competent-less competent relation in cleaved rocks :

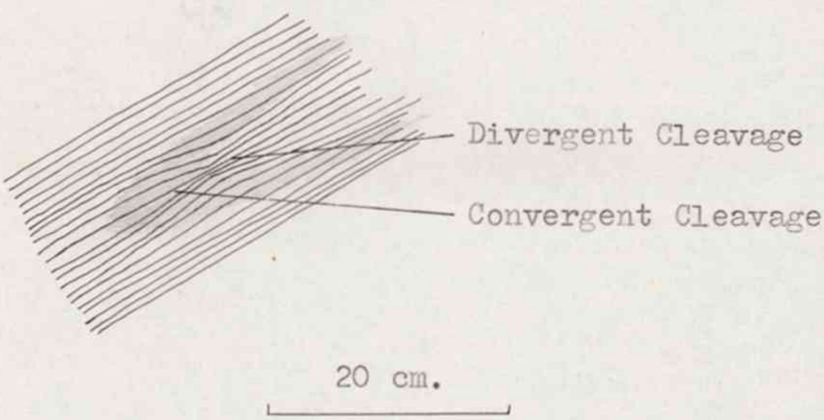
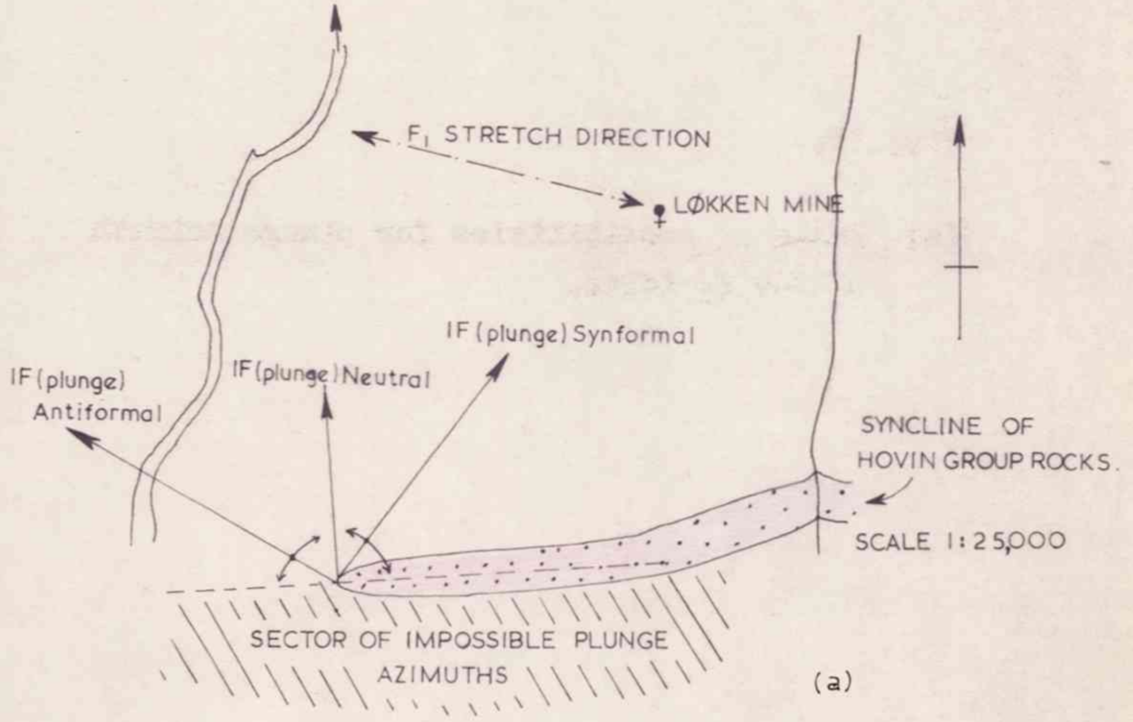


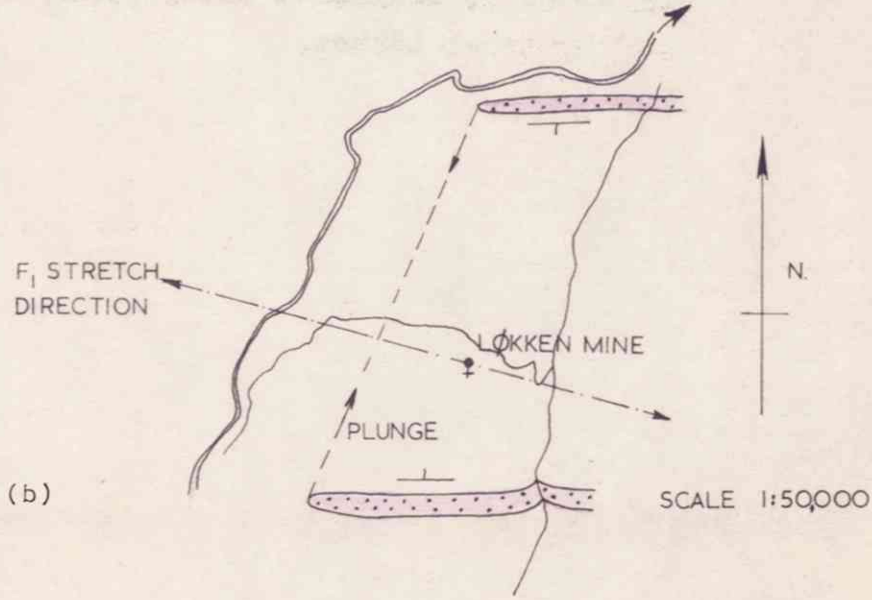
Fig. 13.

(a) Range of possibilities for plunge azimuth of the f_1 folds.

(b) Showing possible relation between bands of Hovin Group sediments outcropping north and south of Lökken.


F1 STRETCH DIRECTION
LØKKEN MINE
IF (plunge) Synformal
IF (plunge) Neutral
IF (plunge) Antiformal
SYNCLINE OF HOVIN GROUP ROCKS.
SCALE 1:25,000
SECTOR OF IMPOSSIBLE PLUNGE AZIMUTHS

(a)


F1 STRETCH DIRECTION
N.
LØKKEN MINE
PLUNGE
SCALE 1:50,000

(b)

In the south of the area of Map A, there outcrops a band of strongly deformed rock just above the thrust plane. This rock exhibits isoclinally folded bands with a well developed exial plane schistosity. It may well be that the banding seen in the rock is not of primary sedimentary origin but of tectonic origin, so that the later thrusting has become localised on earlier zones of weakness. Certain features of the rock, which will be discussed under the heading of petrofabrics, tend to suggest this. This rock also exhibits ptygmatic veins, which suggest that the f_1 phase of folding involves quite a complex sequence of events.

(b) Linear structures associated with the f_1 folding.

A number of significant linear structures are associated with f_1.

i) Elongation of pillows and bombs.

In the north-east corner of Malisetertjern in the chlorite schists are seen structures which are interpreted as volcanic bombs. These bombs are not closely packed as pillows would be, but are relatively widely spaced, and come in a variety of sizes up to perhaps half a metre across. They form structural inhomogeneities around which the schistosity is deflected. They are characteristically flattened perpendicular to the schistosity and are elongate in the plane of the schistosity and plunge gently to the east. (see Fig.16(e). The host sediment may have originally been a fine grained basic pyroclastic rock. Assuming these bombs to have originally been equant, there has clearly been a physical stretching in the plane of the schistosity and a shortening perpendicular to the schistosity.

A little further south pillow lavas begin to be well developed. In these rocks the pillows are closely packed and usually exhibit a pronounced elongation direction which plunges gently eastward. The section perpendicular to the schistosity is usually more equant than that seen in the bombs, although schistosity is commonly still developed. Pillows seen in the northern part of the area can be up to 8 times as long as their cross sectional diameter.

ii) Vesicle Elongation.

Over the whole area where pillow lavas are developed, the pillows generally possess a more or less vesicular interior. The vesicles are always elongate parallel to the elongation direction of their parent pillows. Commonly the strain is so high that the ends of the vesicles become ragged, sothat they degenerate into tubes. Measurement of the elongation direction of stretched vesicles is much more difficult than measuring the same for stretched pillows.

iii) Deformed Spherulites.

In one locality only, 300 metres north-east of Lillevatn, outcrops a spherulitic acid lava in which the spherulites have been deformed into ellipsoids. The ellipsoids are extremely consistent in axial ratio and orientation, and it seems reasonable to suppose that these spherulites were originally very close to being truly spherical. The ellipsoids are flattened in the plane of the primary layering and schistosity and their long axes plunge gently to the east.

iv) Preferred Orientation of Minerals.

This will be discussed under the heading of petrofabrics.

Although the amount of strain associated with the f_1 folding is not constant over the whole area, it seems fairly clear that the orientation of the strain ellipsoid with respect to the schistosity is fairly consistent, and that the long axis of the ellipsoid represents a direction of physical stretching and the shortest axis one of physical shortening.

Fig.14. is an equal area plot of the plunge directions of linear structures associated with f_1, i.e. linear structures like those described above. The vector mean plunges 10 / 95. On Map B the correspondence between the plunge of the f_1 linear structures, the elongation direction of the Løkken orebody and the line Dragset-Løkken-Høidal may be clearly seen. For this reason, and for others which will emerge in the discussion of the f_2 structures, I suggest that the structural control of the Løkken orebody is primarily associated with the f_1 folding.

(c) Possible pre-f_1 structures.

We have earlier seen that it is possible to erect in this area a succession of quite distinctive superposed metamorphic rocks. This stratigraphy ascends perpendicular to the schistosity in the area and

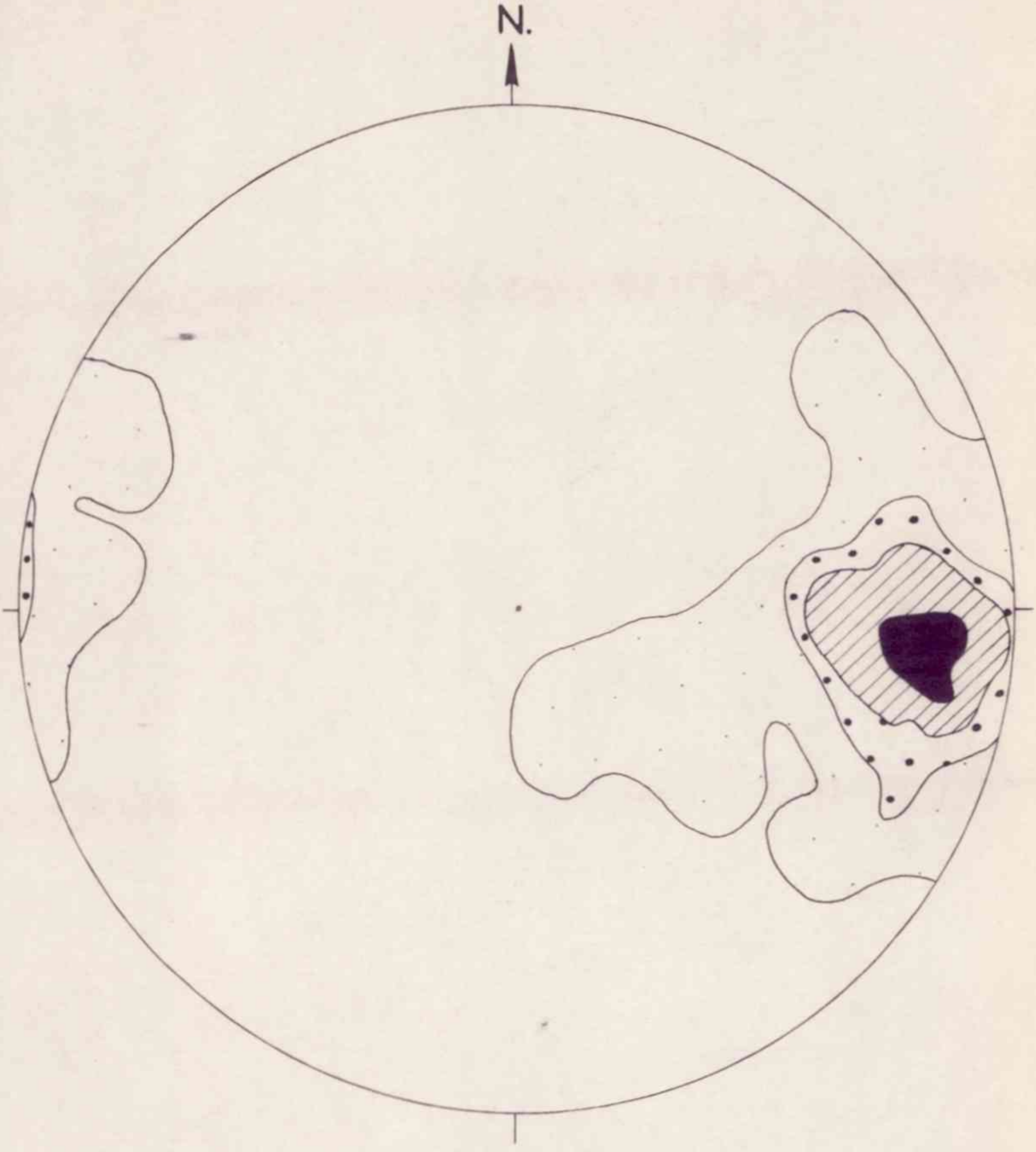


Fig.14. LINEATIONS

91 readings of stretch lineations over the whole of the area west of the Orkla River.
Stretch Lineation = Elongation of Pillows and bombs, vesicles & spherulites.

perpendicular to the metamorphic isograds. There is clearly no reason to suppose that this must be the primary stratigraphic succession in the area. It is probably a tectonically imposed stratigraphy.

There is no gradual increase in the development of schistosity as one passes down from the massive metavolcanics into the chlorite schists. The development of schistosity is abrupt, although no actual contact is exposed. The chlorite schists apparently represent an original rock type which yielded easily to deforming forces, unlike the massive metavolcanics. This band of chlorite schist does not outcrop again on the southern flank of the Løkken Synform, it probably pinches out at depth. The continuation of investigations west from Dragset will probably answer this point.

I am inclined to suspect, that by analogy with the succession of structures demonstrated in the Scottish Highlands, the band of chlorite schist may be a tectonic unit emplaced before the period of isoclinal folding and metamorphism. A phase of free tectonic transport before the main f_1 deformation would lead to a tectonic stratigraphy which would, after the f_1 folding and metamorphism and f_2 refolding, have a form like that observed today. If this suspicion is true, then the Støren and Røros Groups represent tectonic units emplaced very early in the history of the Norwegian Caledonides.

The possible occurrence of an important phase of dislocation very early in the tectonic history of the Trondheim area does not appear to have been generally appreciated in the past. Overemphasis of the later, more obvious phases of thrusting in Norway appears to be the case. Critical re-examination of the "classical" Nappe region of Central Norway is revealing hitherto unexpected complexity. Occurrences of late thrusting being localised on earlier, isoclinally folded thrust planes have been described to me.

THE SECOND PHASE OF FOLDING (f_2)

The f_2 folding is very nearly coaxial with the linear structures associated with f_1, and is the most obvious phase of deformation to have affected the area. It is manifest in the folding of the f_1 schistosity into regional scale flexures on the one hand, to microscopic kinks on the other, In the Lökken area there is no trace of the development of a cleavage or schistosity associated with f_2, and there are strong indications that the folding is parallel in character, i.e. produced by buckling of the stratified mass.

(a) Evidence for the parallel nature of the f_2 folding

i) The absence of associated cleavage or schistosity.

There is no trace of a steeply inclined cleavage cutting the metavolcanics, neither is there any tendency in the chlorite schists to the north of the area to the development of a regular strain-slip cleavage.

ii) Minor Folds.

In the chlorite schists where small scale folds of the f_1 schistosity are developed they are seen to die out very rapidly away from the centre of maximum disturbance. Such folds are never observed to be very tight.

Structures similar to kink bands, but which are conjugate microfolds of the f_1 schistosity, are seen in the chlorite schists (see Fig.16(c).). The axial directions of these microfolds are consistently parallel to the local plunge of the major structure but their axial plane orientations are variable by rotation about the axial direction. These structures are interpreted as having formed at different stages in the history of the major f_2 structure. Perhaps, for example, they formed parallel to the axial plane of the major structure (an assumption for the sake of the argument). Depending on the particular stage in the history of the major structure at which each microfold was formed, the amount of rotation subsequently suffered was different, hence the different axial plane orientations but common plunge directions at the present day. For this interpretation to be correct, the major structure (The Lökken Synform) must be of a parallel nature. (See Fig.15.).

(b) Minor Structures Associated with the f_2 folding.

The major f_2 structure, to which the size of all other f_2 structures is relative, is the "Lökken Synform". This, however, is a relatively minor flexure on the flank of the regional structure, The Trondheim Synclinorium.

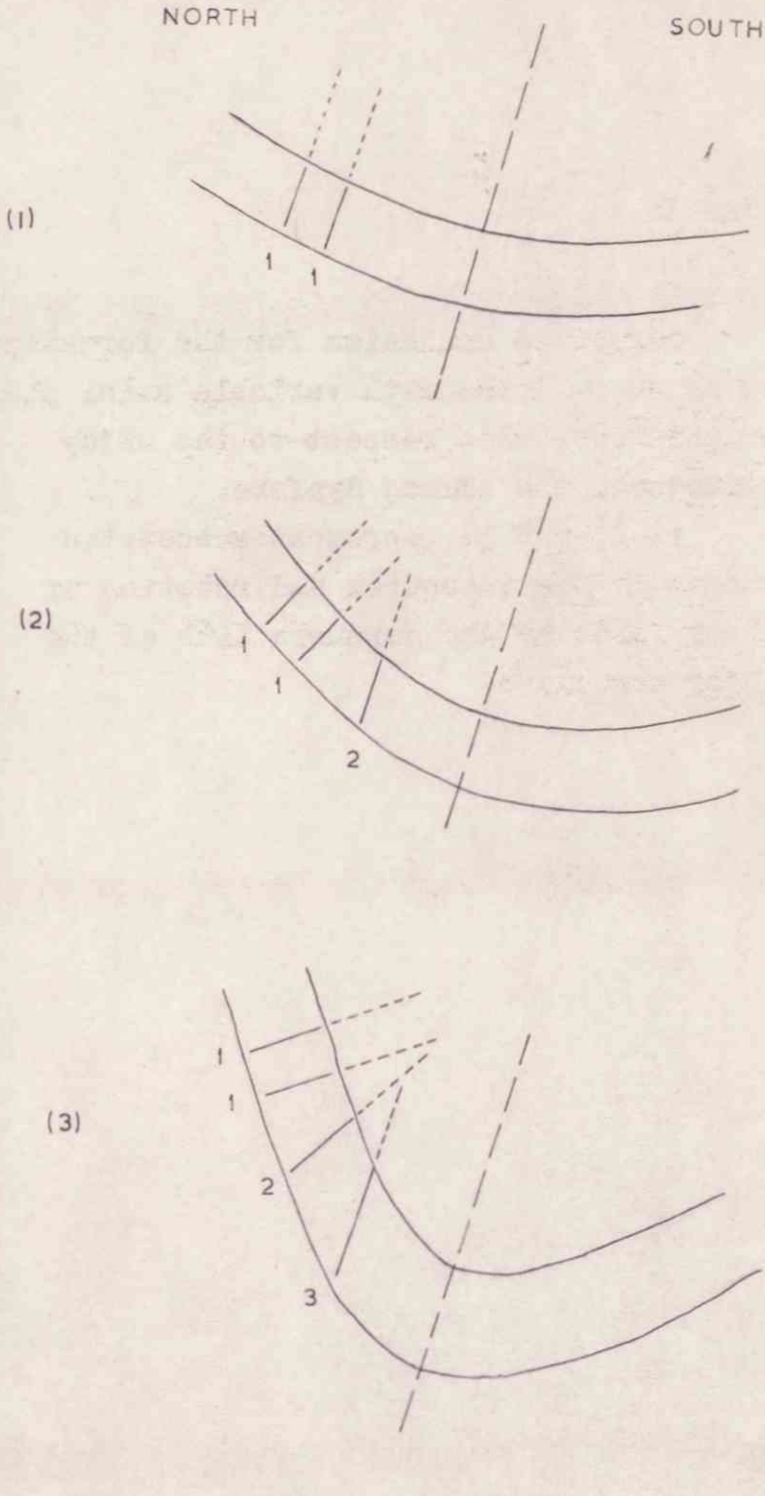
i) Second Order Minor Folds.

Second order minor folds on the flank of the Lökken Synform can only be appreciated by detailed mapping on well exposed ground. In the area of acid volcanics between Hoslynga and Segel Vatn it is possible to infer first order folds from readings of dip and strike

Fig. 15.

Suggested mechanism for the formation of minor f_2 folds with variable axial plane orientations with respect to the major structure, the Lökken Synform.

1),2) and 3) represent successive stages in the inception and rotation of minor folds on the northern limb of the major structure.


NORTH
SOUTH
(1)
1
1
(2)
1
1
2
(3)
1
1
2
3

of the f_1 schistosity. When this can be done it seems that there is no relation between the orientations of their axial planes and the orientation of the axial plane of the Lökken Syncline. The wavelength of these folds appears to be of the order of 20 to 100 metres and they appear to be closed but never tight. Readings of the dip of the schistosity suggest that the first order folds are best developed in those areas where the mean dip of the schistosity is very low, i.e. in the hinge of the Lökken Synform and in the extreme north-west of the area of Map A. No second order minor folds of the schistosity have been detected in the steep parts of the northern limb of the Lökken Synform. Only very gentle, very large wavelength and low amplitude flexures are apparent in the southern limb of the Lökken Synform.

ii) Third Order Minor Folds.

Such folds, having wavelengths visible on the scale of a single exposure cannot be developed in the massive metavolcanics in the south of the area. Such folds can only be developed where individual layers are thin, i.e. in the schistose rocks to the north. The parallel nature of these small flexures has already been emphasised, but truly concentric and chevron varieties can be distinguished. (See Plate 8). Very small (wavelength of the order of 1cm or less) Third order minor folds are commonly observed to be conjugate (See Fig.16(c).).

The inconsistency in the orientation of the axial planes of these folds with respect to the orientation of the axial plane of the major

Fig. 16.

Minor structures in the Schists.

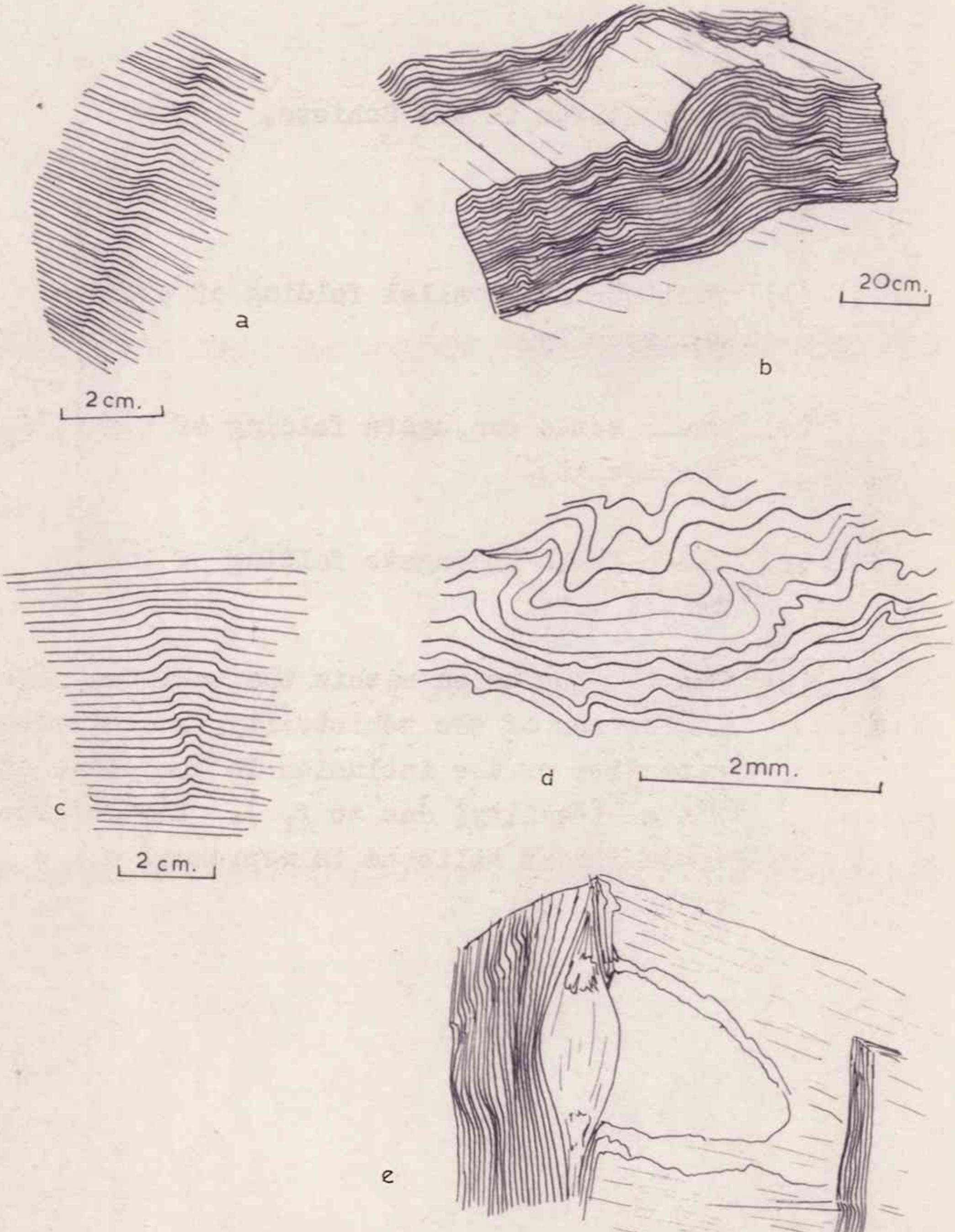
(a) Kink Band. ⎫

(b) Small Scale parallel folding of the schistosity. ⎪

(c) Small scale conjugate folding of the schistosity. ⎬ f_2

(d) Micro-scale conjugate folding of the schistosity. ⎭

(e) Massive inclusion within the schists, note deflection of the schistosity, and stretch direction of the inclusion in the plane of the schistosity(due to f_1). The deformed inclusion is believed to represent a volcanic bomb.


a
2 cm.
20cm.
b
c
2 cm.
d
2mm.
e
20 cm.

structure has already been mentioned and an explanation suggested.

iv) Fourth Order Minor Structures.

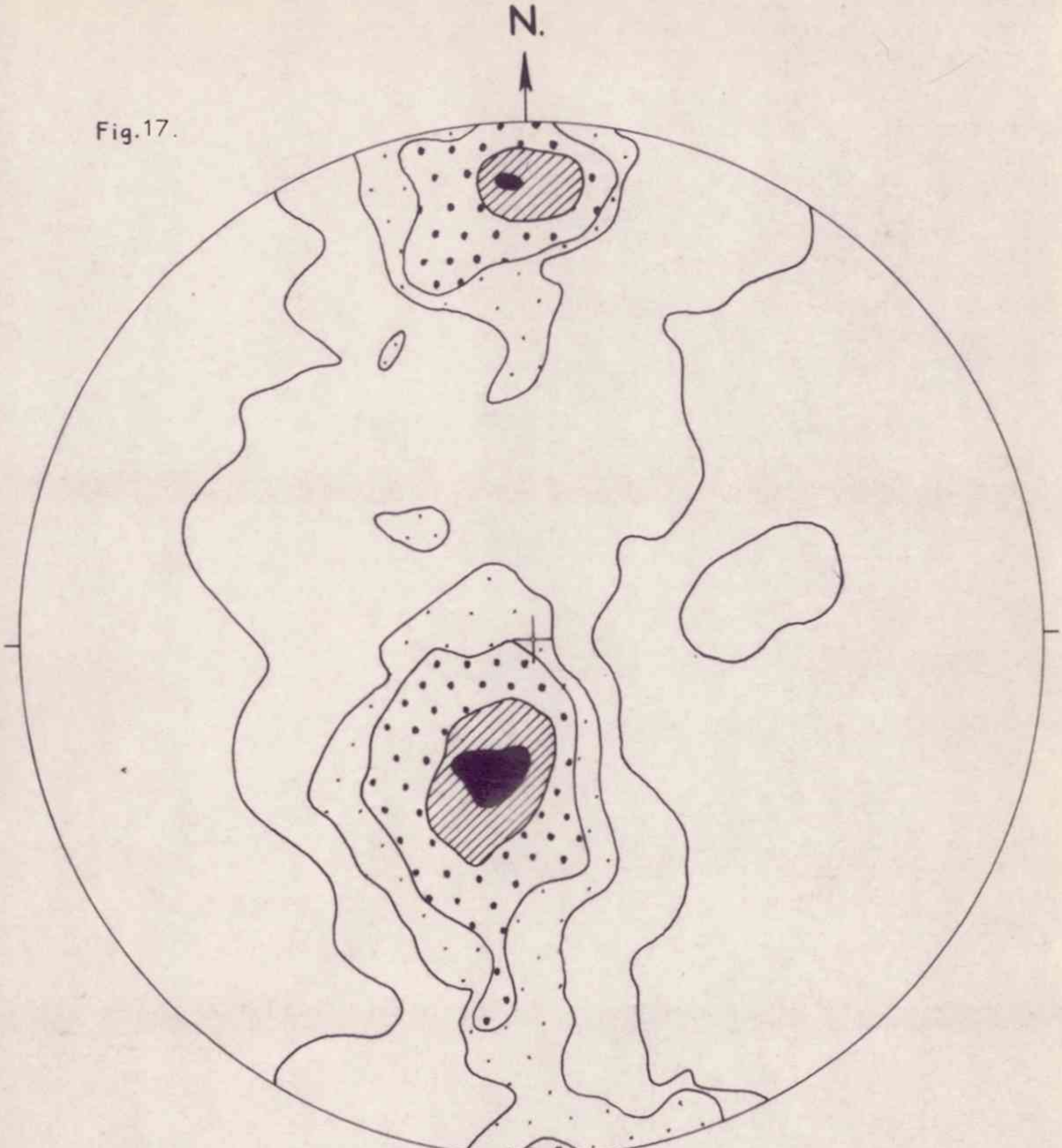
These are represented by the microscopic ripple lineation seen on the surface of the chlorite schists. This is simply a small scale crenulation of the platy minerals, chlorite and muscovite, in the rock. It is essentially a lineation produced by compression, in contrast to the linear structures produced by extension described in connection with the f_1 deformation.

This ripple lineation is parallel to the axial direction of the third order f_2 folds and to the local plunge direction of the Løkken Synform. On the stereogram in Fig.18. is plotted 22 readings of the plunge directions of the linear structures associated with f_2. The sparcity of readings is because these structures are only well developed in the well laminated chlorite schists to the north of the Løkken Area.

(c) The Geometry of the Løkken Synform west of the Orkla.

Fig.17. shows poles to 328 readings of the orientation of the f_1 schistosity over the whole of the area west of the Orkla River. There are two main concentrations of poles, indicating a well defined hinge zone between two essentially planar limbs. The apical angle of the hinge is approximately 85 degrees and the mean plunge of the fold is 10 degrees to the direction 80 degrees east of true north. This

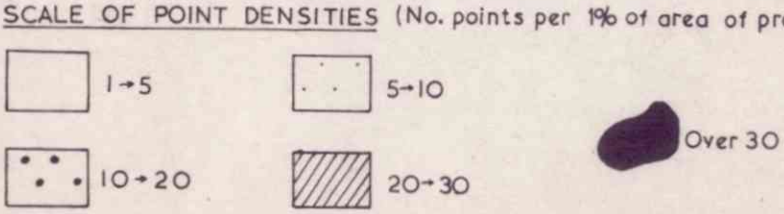
Fig. 17.



POLES TO SCHISTOSITY SURFACES (Projected from lower hemisphere)

328 readings over whole of the area W. of Orkla River

SCALE OF POINT DENSITIES (No. points per 1% of area of projection)



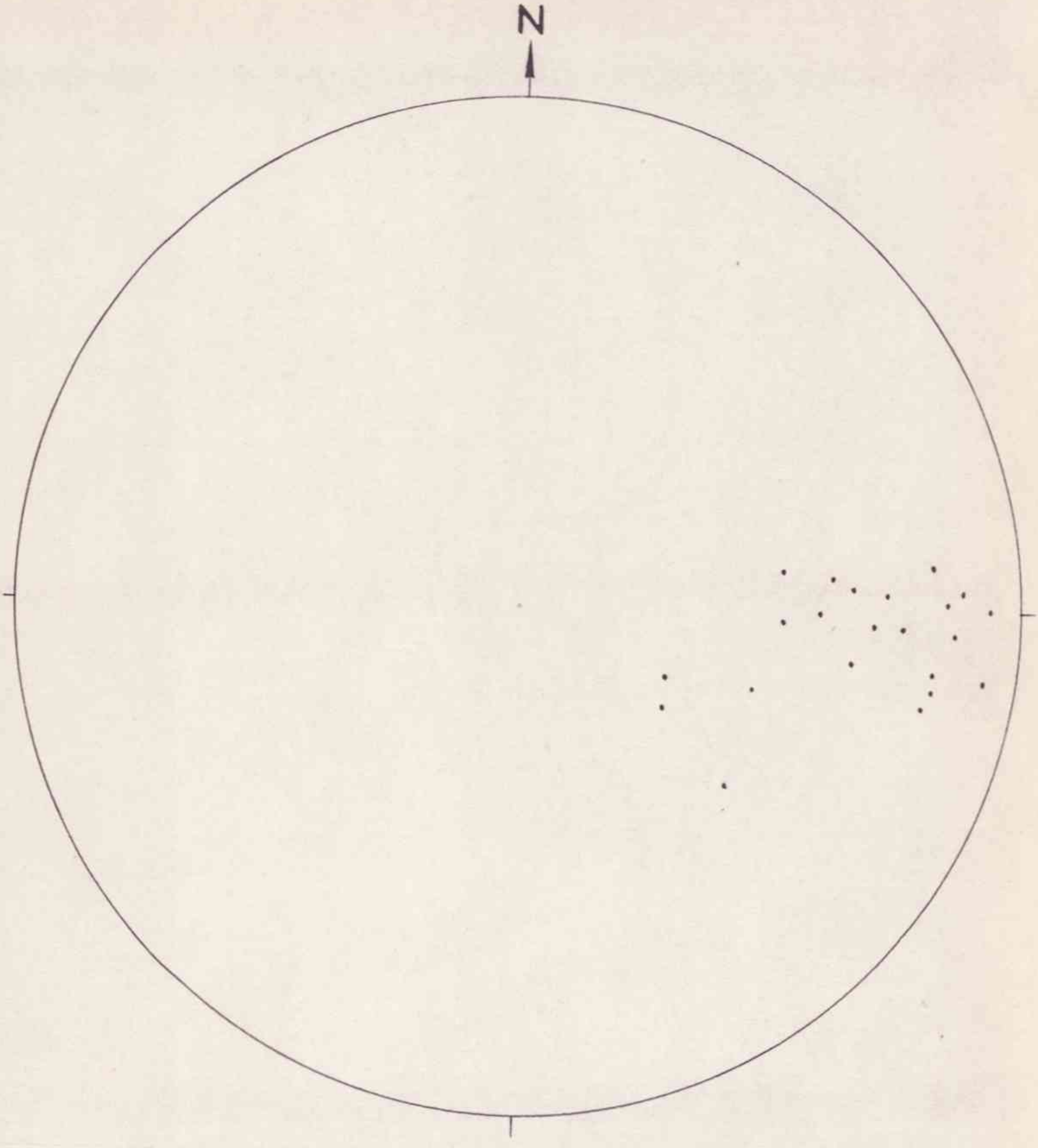


Fig.18. LINEATIONS

22 readings of ripple lineations in the schistose rocks west of the River Orkla. Ripple Lineation = Lineation produced by microfolding of platy minerals in the schistose rocks.

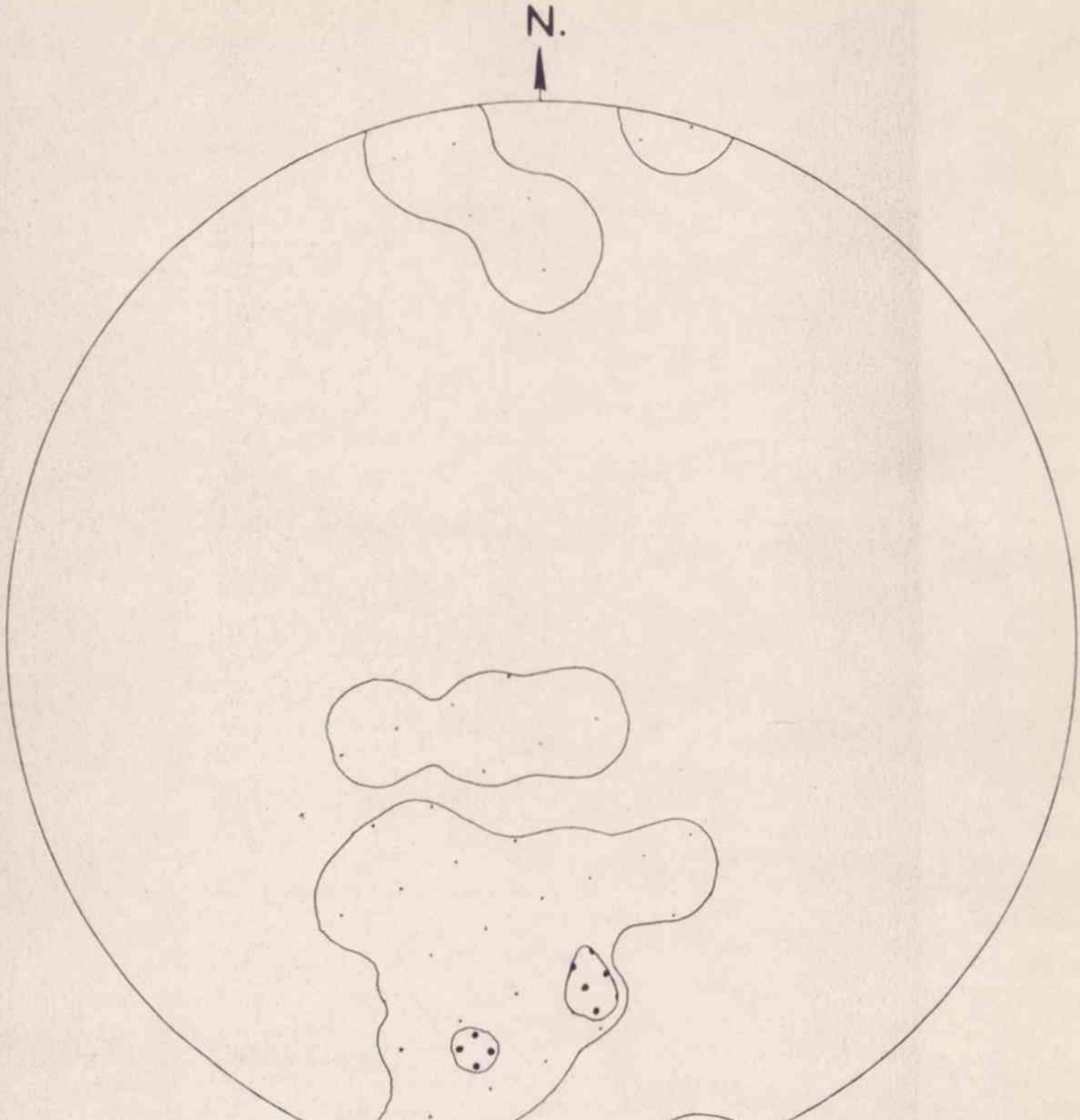


Fig. 19. POLES TO SCHISTOSITY SURFACES

28 readings taken east of the Orkla River.

compares very closely to the vector mean of the readings plotted in Fig.18. A deviation of ± 5 degrees from the mean plunge direction about an axis directed north-south is apparent on Fig.17. This is a consequence of the f_3 flexure.

Assuming no steep limb attenuation of the fold (a conservative assumption) the axial plane bisects the apical angle, in which case the theoretical orientation of the axial plane, from Fig.17. alone, will be strike 85 degrees, dip 63 degrees north.

The Lökken Synform does not appear to be a tight enough structure for the relatively resistant mass of the gabbro intrusion to have affected the trend of the rocks.

(d) Angular Relations between the f_1 & f_2 structures.

Fig.22. is a diagrammatic representation of the geometric features of the f_2 folds. Also shown is the stretch direction of the f_1 folds.

i) The Lökken pyrite deposit is markedly elongate in the east-west direction. It is a noteworthy fact that if the length of this deposit is produced westwards it intersects Dragset Mine, and if it is produced eastwards it intersects Höidal Mine. This direction, here called the Dragset-Höidal Line, corresponds very closely with the plunge direction of the f_1 linear structures, lying within the cone representing the maximum density of field readings (over 20 per 1%

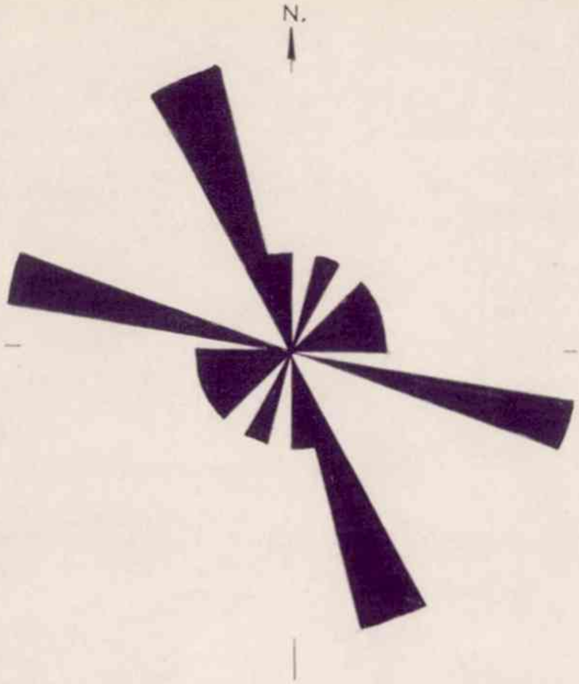


Fig. 21 (a)
Histogram of shearplane strike directions east of the Orkla River.

11 readings

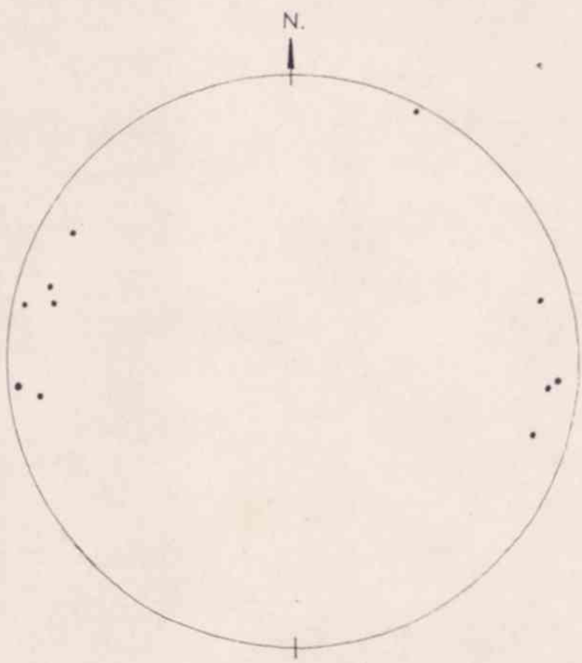


Fig. 21 (b)
Lineations east of the Orkla River.

11 readings

area of the sphere) as plotted on the stereogram in Fig.14. The plunge direction of the Lökken Synform lies outside this cone.

ii) Whereas the Dragset-Höidal Line crosses the hinge of the Lökken Synform at Dragset Mine, the Lökken orebody is well away from the hinge, apparently climbing the southern limb of the synform in an easterly direction.

iii) Although it is not easy to do so because of the more massive character of the rocks, it has been possible to take a small number of readings on linear structures which are believed to give an impression of the plunge of the Lökken Synform on the east side of the Orkla River. These readings suggest that the axis of the synform is almost horizontal or plunging gently (less than 10 degrees) to the west. However, carefully prepared sections parallel to the length of the Lökken orebody show that the average plunge is 20 degrees or more to the W.N.W. Clearly the orebody plunges along a line of greater slope than the plunge direction of the Lökken Synform. In other words, the orebody is ascending the flank of the f_2 structure, oblique to the axial direction of the f_2 structure.

iv) If the f_1 linear structures and the surface trend of the f_2 axial surface were used to construct a solution for the axial surface orientation of the Lökken Synform, it would dip to the south. This is clearly an erroneous conclusion. It attenuation of the steep limb of the synform were considered, the effect of the divergence of f_1 and f_2 structures would be even more pronounced. Hence the earlier statement that it is a conservative assumption to suppose that the axial surface of the Løkken Synform bisects the apical angle.

The lines of evidence suggested above suggest a small angular divergence of about 5 degrees between the f_1 and f_2 structures, and that the structural control of the Løkken orebody is by the f_1 structures.

Fig. 22.

Geometric Representations of the comparative features of the f_1 and f_2 structures.

(a) Shows the azimuths of the geometric features of the f_1 and f_2 folds. Note the divergence between the f_2 plunge azimuth and the f_1 stretch direction azimuth.

The axial trace of the Lökken Synform on the horizont is presumed to bisect the apical (hinge) angle of the fold. This is a conservative assumption.

(b) shows the same relations presented stereographic

A and B represent the vector means of the concentrations of poles to the (flat) limbs of the Lökken Synform.

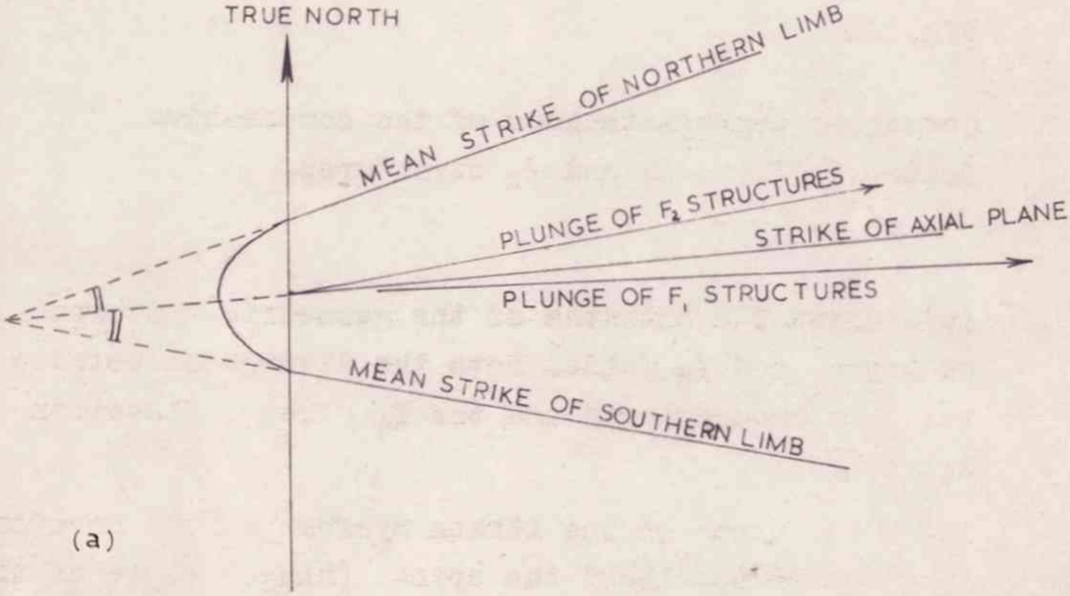
C - D represents the axial trace on the horizontal of the Lökken Synform.

ψ = half of the (hinge angle. minus 90°)

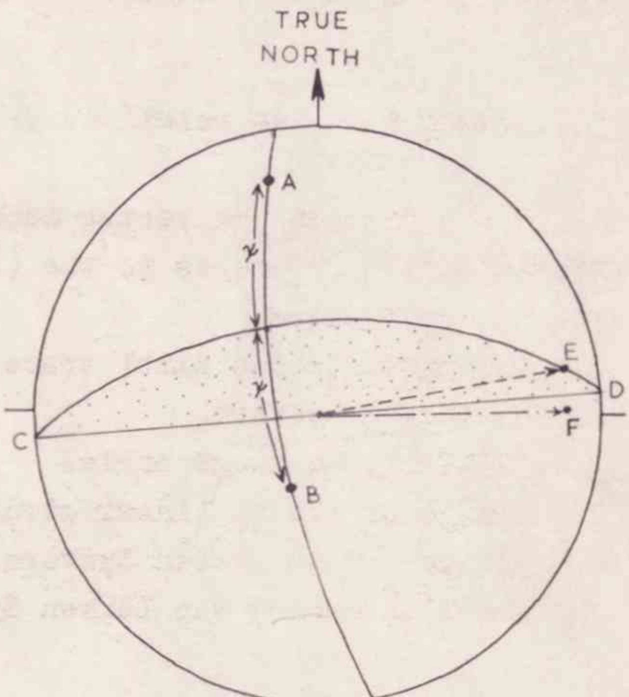
F = Plunge of the f_1 linear structures.

E = Plunge of the Lökken Synform.

The Axial "Plane" of the Lökken Synform is stippled.


TRUE NORTH
MEAN STRIKE OF NORTHERN LIMB
PLUNGE OF F2 STRUCTURES
STRIKE OF AXIAL PLANE
PLUNGE OF F1 STRUCTURES
MEAN STRIKE OF SOUTHERN LIMB

(a)


TRUE NORTH
A
x
x
E
D
C
F
B

(b)

PLATE 10.

Looking west ward at the Höidal open cast workings. Note the gentle easterly plunge of the orebody as inferred from the shape of the workings.

THE THRUSTING EPISODE

Investigations carried out to the west of the Orkla River show that the f_2 structures are transected by a number of low angle, gently undulating thrust planes. The existance of thrusts in this area was not recognised by Bjørlykke during the 1959-60 investigations. Through detailed geological investigations in the Løkken mine east of the Orkla River it has long been known that there is at least one persistent thrust plane cutting the metavolcanics and passing through the mine just above the orebody.

(a) Evidence for Thrusting and Movement Direction.

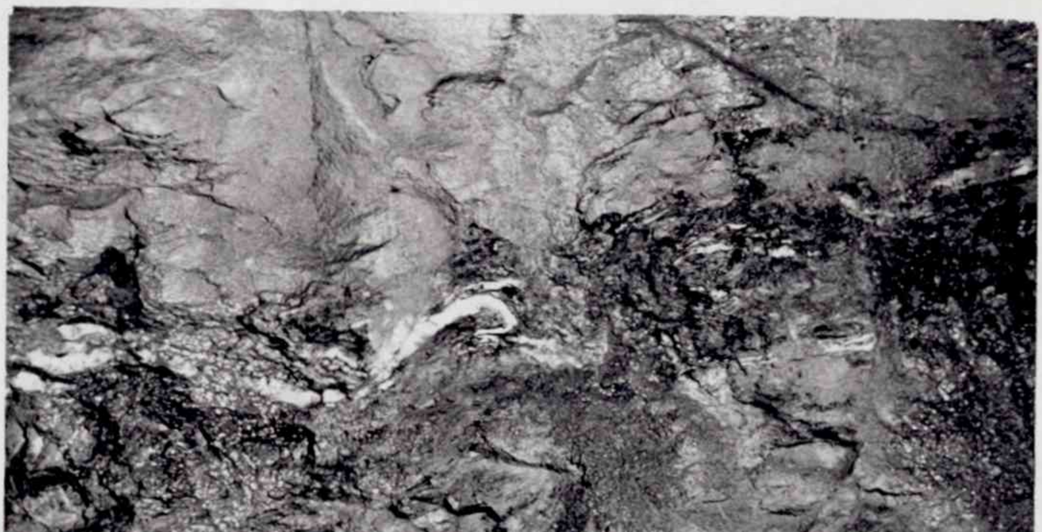
The existence of thrusts east of the Orkla River is undoubted, and projection onto the surface strongly suggests that the main thrust occupies a topographic depression marked by the line of lakes which includes Bjørnlivann and Fagerlivann. (See Map B).

It is not so easy to demonstrate the significant development of thrusts west of the Orkla, where there are no underground workings. This is especially so in the south of the area, but in the north, around Hoslynga and Mjovatn, the task is much easier. This is a consequence of the rapid change in dip of the f_1 schistosity as one goes south from the belt of chlorite schists across the hinge of the Løkken Synform. In this area a block of vertical or steeply dipping schistose pillow lavas is seen to be resting on near horizontal metavolcanics

PLATE 11.

Thrust plane exposed in Lökken Mine.

The lower photograph shows crushing of the rock and folding of quartz vein in the thrust plane.



(see Map A & Fig.23.). In a number of places the actual contact is exposed, and is seen to consist of a thin zone (10cm.) of clayey gouge passing relatively rapidly into more massive rocks above and below. The disposition of dips seems to suggest fairly conclusively that the block of steeply dipping rocks represents a part of the steep northern limb of the Løkken Synform which has been moved a few hundred metres southward onto the hinge of the fold.

The thrust plane seems to be locally associated with a thin, persistent, schistose band of coarse grained rock which exhibits no pillow structure. In addition it is observed that the thrust plane is progressively let down to the west by a series of normal faults.

West of the river the thrust plane dips gently to the east, but apparently less steeply than the local plunge value of the Løkken Synform. To the east of the Orkla, however, where the Løkken Synform appears to plunge gently westward, the thrust dips more steeply westward, at about 30 degrees. The relative orientation of thrust planes with respect to the plunge of the f_2 structures, therefore, appears to be fairly consistent over the whole of the Løkken area.

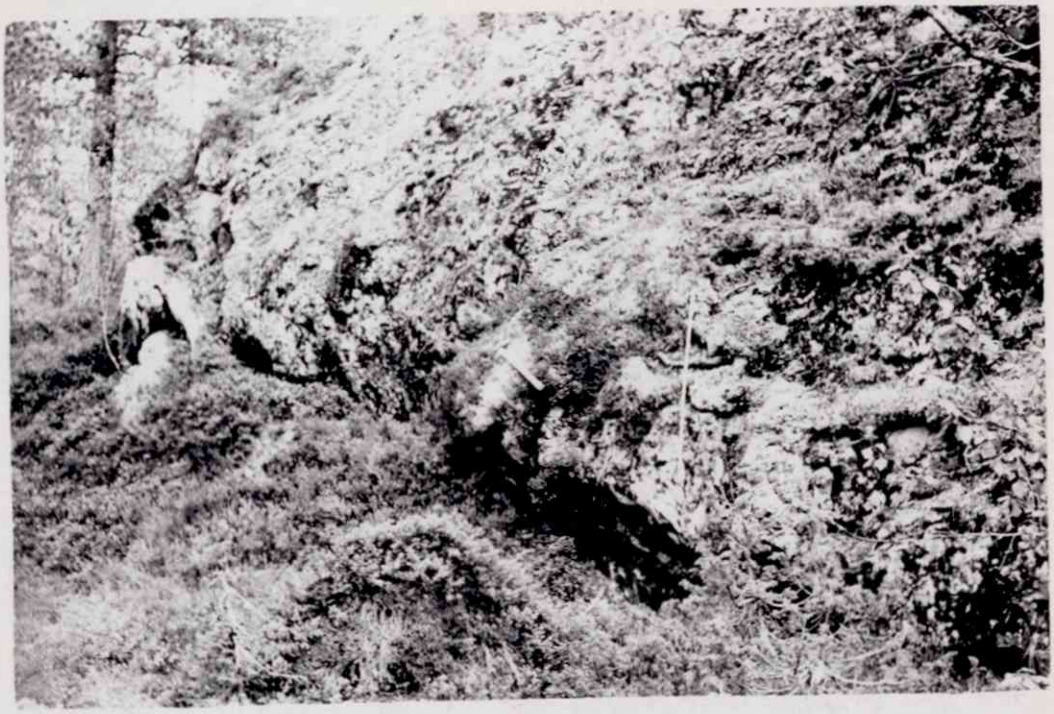
In the area west of the Orkla, as one proceeds south from the hinge zone of the Løkken Synform, changes in dip values of the f_1 schistosity become less pronounced, and it becomes more and more difficult to detect evidence of thrusting. Here the picture presented of the disposition of thrust slices is constructed from actual exposed thrust planes and topographical features. A particularly good

PLATE 12.

Thrust planes exposed on the surface west of the River Orkla.

(a) Thrust plane exposed in the south-east corner of Hoslynga

(b) Thrust plane, showing strong brecciation, exposed on the road section near Björtjern.



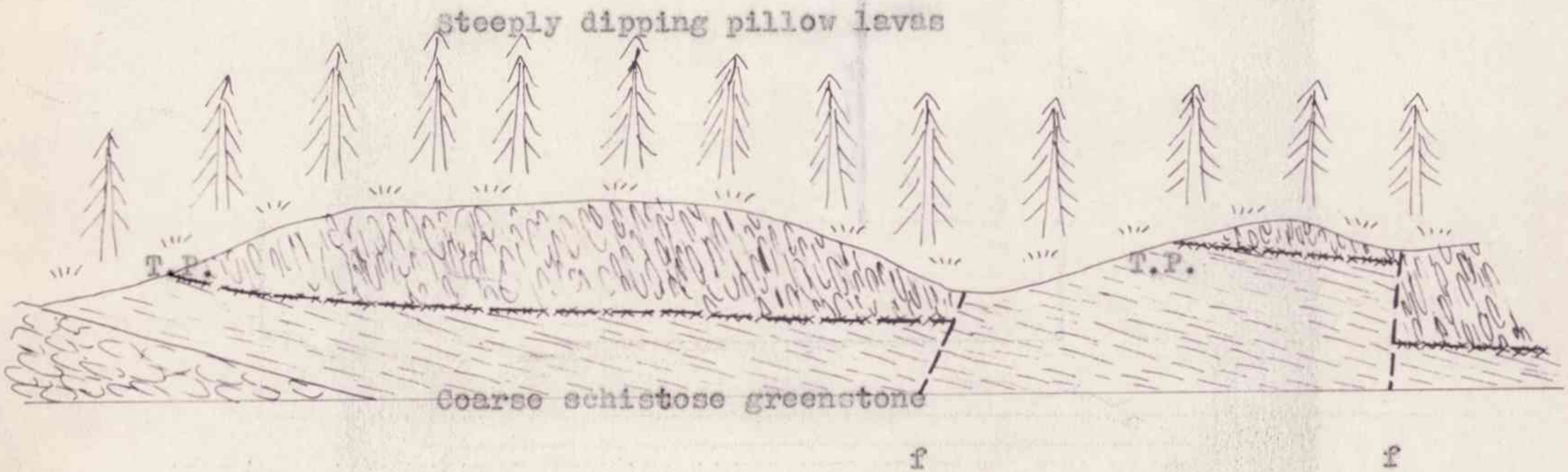


Fig.23. Diagrammatic section along the northern shore of Mjovatn.

100 metres

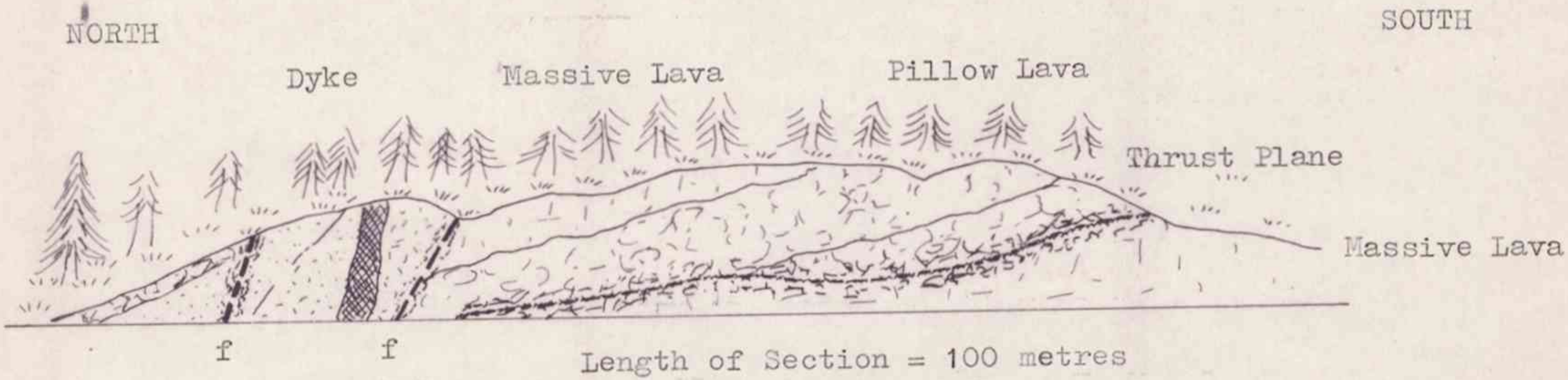


Fig.24. Sketch of part of the road section near the causeway leading to Dragset Mine.

section showing thrust imbrication is exposed in a valley 600 metres south-east of Langdalsvatn. On the road section east of Grubedammen a gently northward dipping thrust plane is seen cutting obliquely across the primary layering of the massive lava flows. (See Fig.24.). In the southern part of the area, where the Drugu stream meets the cross connecting road from Dragset Moen to the Dragset Road, the stream falls over a small cataract, the only natural waterfall in the area (See Plate 13.). Closer examination shows that the cause of the waterfall is a thrust plane cutting through its base. This plane, which dips gently to the north-west, can be traced for about 30 metres along the road section. The thrust plane consists of about 20cm. of clay gouge which passes above and below into a zone of 1 metre of crushed and cleaved rock. A specimen taken from about 1 metre above the thrust plane exhibits a well developed shear cleavage which crenulates the f_1 lamination (see section on petrofabrics). The pillow lavas lying above this thrust plane exhibit considerable f_1 strain, whereas beneath the thrust are pillows showing virtually no sign of strain by elongation. This is regarded as evidence of a north to south movement by the thrust slice.

There are many other examples of exposed low angle shear planes in the area west of the Orkla River.

It is not easy to conclusively demonstrate the direction of movement on thrust planes by correlation of displaced rock horizons above and below the thrust planes. In the Björtjern Lake area ~~a thick~~

PLATE 13.

Small cataract in the Drugu River formed by erosion along a thrust plane. The rock is crushed for a considerable distance above and below the actual plane of movement.

a thick band of coarse grained rock occurs just north of the lake and west of the thrust plane. This band dips gently northwards and exhibits a vague primary banding. Just south of the lake a similar rock of similar orientation and exhibiting a definite primary banding is exposed just above a thrust plane. It is possible that these bands are equivalent, and therefore suggest a north to south thrust displacement of about 500 metres. Similarly, east of the Orkla, a gabbro mass is exposed north of Björnlivann just beneath the thrust plane. This may be equivalent to the main gabbro mass which lies above the thrust plane to the south-west of Björnlivann. If this is so then the direction of movement on the thrust plane is north to south.

There do not appear to be any consistently developed minor structures associated with the thrusting which provide evidence of the direction of movement.

Over the whole of the Lökken Area, the thrust planes exposed in the south generally show evidence of greater crushing and greater displacements than those exposed to the north. No evidence of thrusting has ever been found further north than the belt of chlorite schists. The impression, therefore is that the strain by thrusting is greater in the south than in the north. This too, is regarded as evidence for north to south thrust displacements.

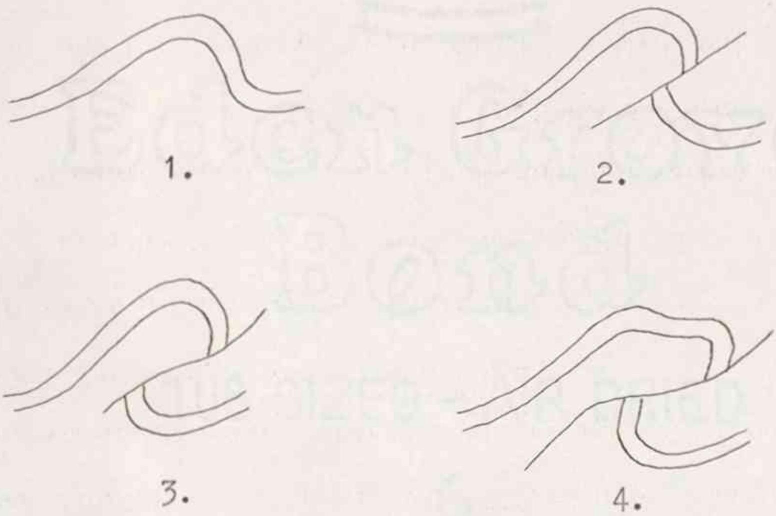
(b) Timing of the episode of thrusting.

The thrust planes appear to undulate :

i) gently about an east-west axis.

ii) gently about a north-south axis.

As was mentioned earlier, there seems to be a fairly consistent angular relation between the thrust planes and the plunge of the Lökken Synform, which also undulates about a north-south axis (axis of the f_3 flexure). This suggests that the thrusts are related to a late stage in the formation of the Lökken Synform, according to the sequence of events suggested by de Sitter :



(Reproduced from "Structural Geology" pp.203, by L.U.de Sitter)

This is the typical association of thrust faults and parallel folds. If this association is correct, then we would expect north to south movement on the thrust faults. I shall therefore refer to these thrust faults as "late stage f_2 thrusts" in future.

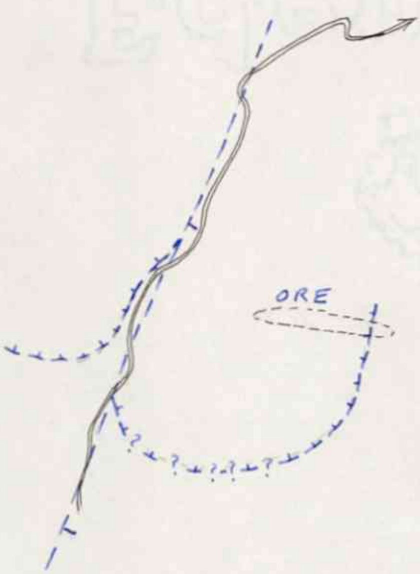
It has been suggested that these thrust faults are entirely post f_2. and are related to the f_3 flexure. This would imply an east to west movement for the thrusts west of the Orkla and a west to east movement for the thrusts east of the Orkla, i.e. a conjugate set of thrusts associated with the f_3 flexure. There does not appear to be any evidence to substantiate this theory.

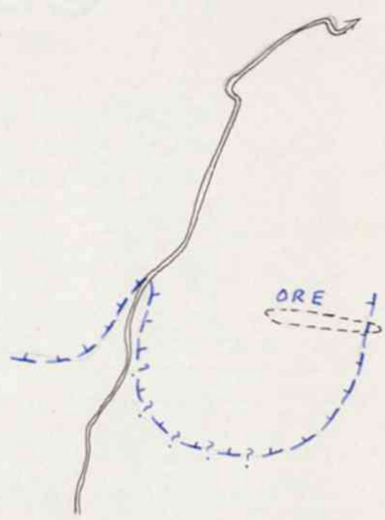
(c) Relation Between the Main Løkken Thrust and the thrusting west of the Orkla River.

There is no definite evidence to support a possible continuity of the thrust which occurs just above the Løkken Orebody and any particular one of the thrust slices which occur west of the Orkla. There exists a possibility that the thrust plane exposed in the south of the area of Map A either is or was continuous with the Løkken Thrust. Surface evidence south of the Løkken Mine suggests that the Løkken Thrust, which strikes north-south near the Wallenberg Shaft, swings around toward the west. This would be expected according to the idea of gently folded thrust planes outlined above. A detailed search is now required for evidence of whether this thrust plane, which appears to be continuous over a wide area, can be eventually shown to vee down the Orkla Valley.

There exists a possibility that the Orkla Valley may locally be structurally controlled, e.g. by a fault. This was suggested at first by the curious fact that the main gabbro mass ends abruptly against the western bank of the river. A day was spent investigating this possibility by searching for features which might have been expected in association with a large fault. No such evidence was found.

However, at that time the possibility of tracing a continuous thrust plane across the river in the south of the area was not considered. Extrapolation of the dips of thrusts on either side of the river is too imprecise an indication of possible faulting in the Orkla Valley, even though any steep fault controlling the Orkla Valley would produce a large displacement in the outcrop of a low angle thrust plane. Thus the two main hypotheses to be tested by future work are summarised below :





With Fault

Without Fault

The possibility of a fault of large displacement downthrown to the east must always be considered until the truth is established one way or another. This could be of considerable economic importance as present mining operations get deeper as they approach the river.

(d) Comparison with regional scale nappe tectonics.

It has been empasised above that the obvious thrusting which has occurred in the Løkken Area is associated with a late stage in the orogenic history of the area. Similarly, it appears from the literature that the great nappes south of the Trondheim region are rather late structures. They cut across metamorphic zones and late folds, though it is not clear from the present literature to what extent the late thrusts of the Nappe Region are rejuvenated movements along earlier, perhaps isoclinally folded thrust planes. In both cases the rocks appear to have moved from north to south, though of course there is a tremendous difference in scale. There is considerable dislocation metamorphism associated with the great nappes, whereas in the Løkken Area the rocks around the thrust planes are only crushed to a clay gouge and locally cleaved.

Apart from the difference in scale, there appear to be remarkable similarities between the Løkken thrusts and the late movements of the Great Nappes. Both appear to have moved in a direction roughly perpendicular to the length of the Norwegian Caledonides, relatively late in the orogenic cycle, though not necessarily simultaneously.

THE f_3 FLEXURE

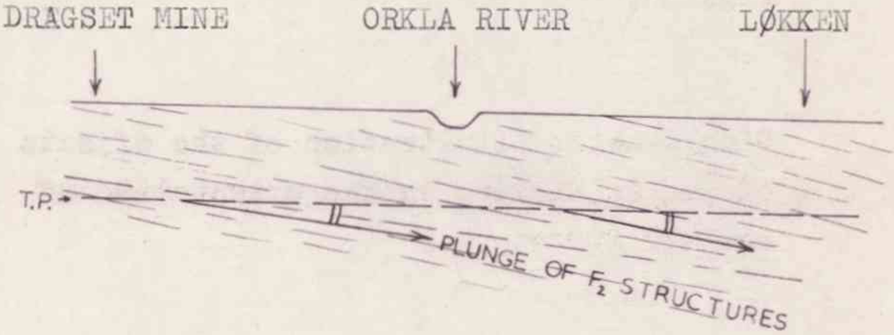
The use of the term f_3 to describe this flexure about a north-south axis may be misleading. It is not a distinct phase of folding if we regard folding as a relatively severe deformation. However the f_3 flexure appears to have a very definite time relationship with the other structures in the area in that it follows the late stage f_2 thrusting movements. The result of the f_3 flexure is merely to alter the plunge of the Løkken Synform and the dip of the late stage f_2 thrusts. The diagrams in Fig.25. sum up the effects of the f_3 flexure.

It is because the transition from westerly to easterly plunging structures takes place approximately beneath the Orkla River at the present day that structural data from the east and west of the Orkla are considered and plotted separately in this report.

From the stereogram in Fig.14. it is inferred that the average change in the plunge of the f_2 structures from Dragset to the Orkla River is 15 degrees.

Fig. 25.

Diagrammatic illustration of the effects of the f_3 flexure on the orientation of earlier structures.


DRAGSET MINE
ORKLA RIVER
LØKKEN
T.P.
PLUNGE OF F2 STRUCTURES


T.P.

FAULTING AND JOINTING

(a) Faulting

Fig.26a is a circular histogram showing the strike directions of 31 faults exposed to the west of the Orkla River. It was considered that this method of data presentation was better than plotting poles to shearplane surfaces, since the dip of such shearplanes, though always greater than 45 degrees, showed no c onsistency. The diagram shows pronounced directions of maxima running north-south and east-west.

The topography, as reflected in the drainage pattern (see Fig.27), of the area shows a series of valleys trending N-S, W.N.W.-E.S.E. and E.N.E.-W.N.W. The north-south features are probably fault controlled, and some can in fact be shown to be so. These valleys have probably also been emphasised by glaciation. The approximately east-west trending features are apparently controlled by the trend of the underlying rocks, particularly in the north in the belt of chlorite schists. Further south, in the Dragset open cast workings, a large normal fault is seen to trend parallel to the trend of the schistosity, although the fault dips more steeply than the schistosity. This fault can be traced eastwards via a topographic depression until it is exposed in the Grubedammen road section as a shear zone. It thus appears likely that the east-west trending faults are locally controlled by the strike of the rocks.

Fig. 26.

Dragset Mine

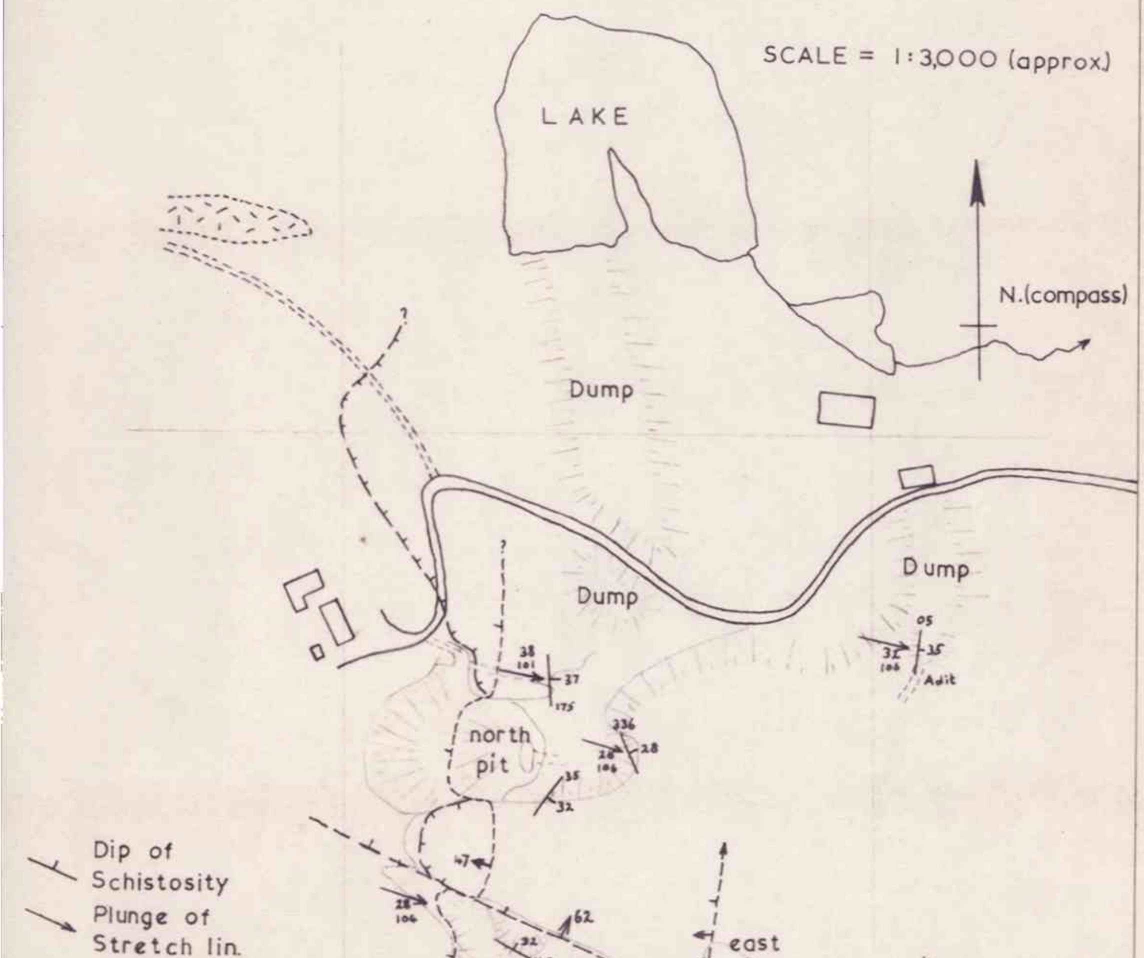


PLATE 14.

Normal fault in the east pit - Dragset.

Note drag of the layering in contact with the fault plane.

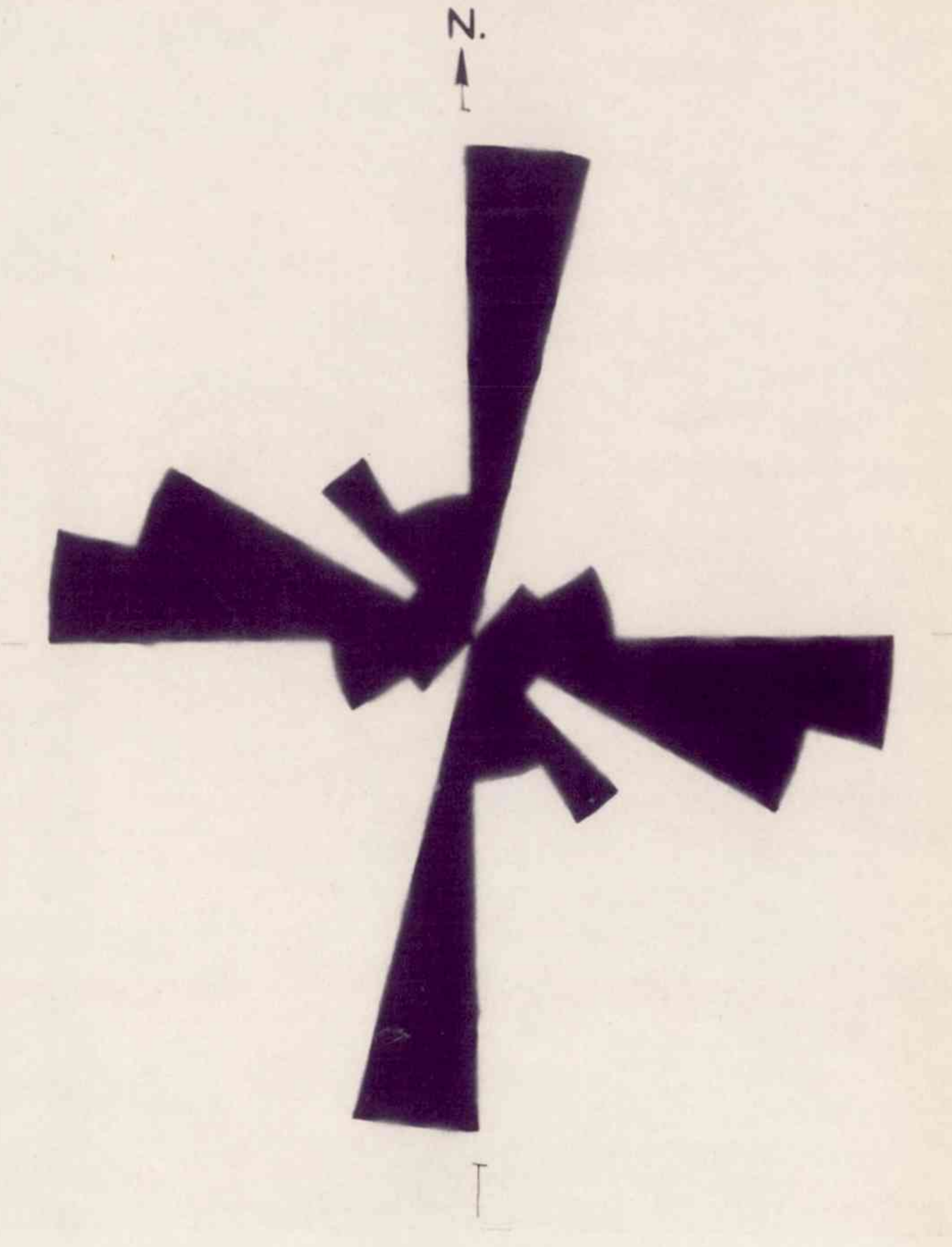


Fig. 26. a. SHEAR PLANES

31 readings of the strike directions of exposed faults west of the Orkla River.

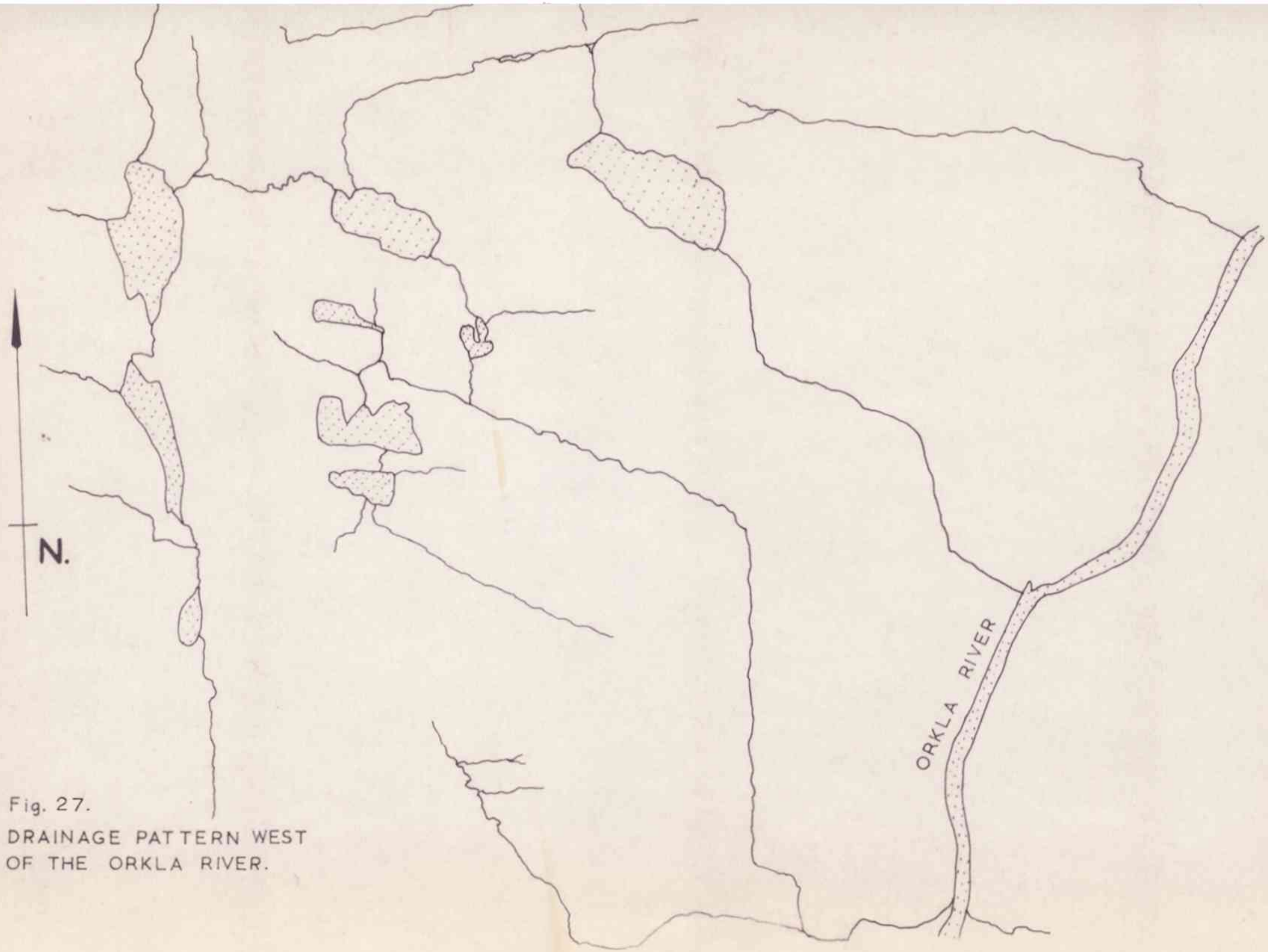


Fig. 27.
DRAINAGE PATTERN WEST OF THE ORKLA RIVER.

The east-west set of faults appears to involve larger throws than the north-south set. They also seem to be fewer in number, although they are probably more difficult to detect. Plate 14. shows a normal north-south fault exhibiting drag of bedding on either side.

On the eastern side of the Orkla River also the faults trend north-south and east-west, as the circular histogram in Fig.21(a). shows. Very few readings of exposed shear planes were made east of the Orkla.

(b) Jointing

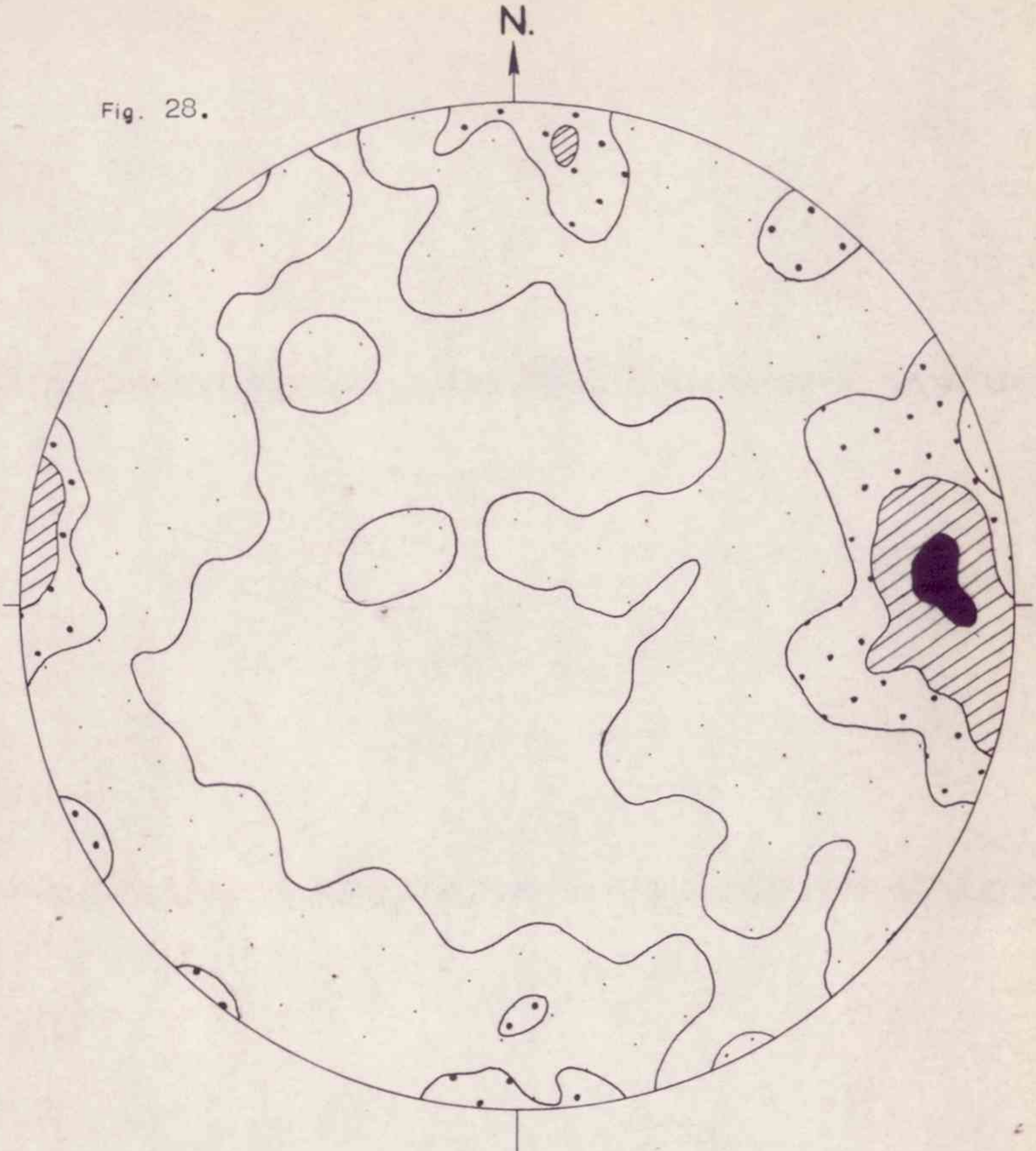
A total of 253 readings west of the Orkla River and 66 readings east of the Orkla River were made on the orientation of joint surfaces.

i) West of the Orkla River.

The large area covered on the stereogram (Fig.28.) by the point densities between 1 & 5 suggests that a lot of the joint data was taken on non-systematic joints. However it is quite clear that there are two main sets of systematic joints emerging. These two sets strike roughly north-south and east-west and are steeply dipping (compare faults). The north-south striking set is clearly the better developed.

These sets of joints are geometrically related to the structural elements of the Løkken Synform. The north-south striking set is generally very close to perpendicular to the plunge of the Løkken Synform, and the east-west striking set is close to parallel to the axial surface of the fold. These two joints sets will therefore be

Fig. 28.



POLES TO JOINT SURFACES (lower hemisphere projection)

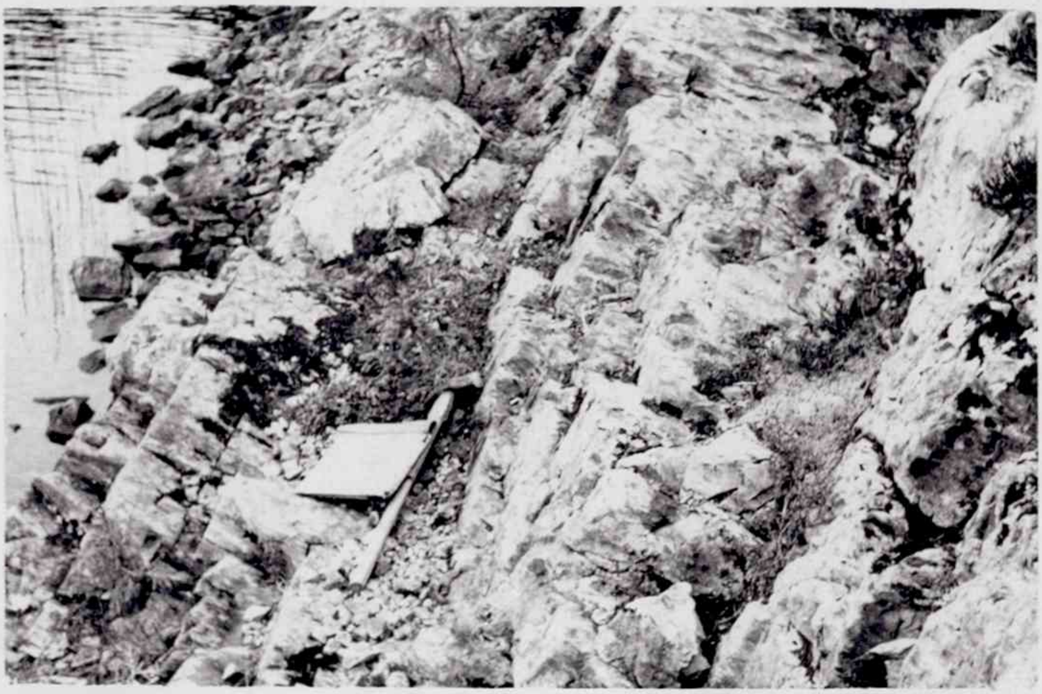
253 readings over the whole of the area W. of Orkla River

SCALE OF POINT DENSITIES

PLATE 15.

(a) Well developed cross joints in fine grained quartz keratophyre; North-east corner of Hoslynga.

(b) Unusually well developed cross joints in basic pillow lava, near Druguvatn. Note the f_1 stretch direction, shown by the elongation of the pillows, is normal to the plane of the crossjoints.



designated cross joints and longitudinal joints respectively.

1) The Crossjoints.

In the field joints of this set are usually very obvious. The degree of development of systematic crossjoints varies according to rock type. In general the acid rocks exhibit crossjointing extremely well (See Plate 15(a)). The joints are usually closely spaced (approx. 20cm.) and are very flat. An extreme example of regularity of cross and longitudinal jointing is seen in an exposure of acid rock near Björnli, where the rock surface is like a sheet of corrugated iron.

Crossjoints are not so well developed in the basic rocks, and they are more widely spaced. Sometimes however, pillow lavas exhibit cross jointing unusually well, for example in Plate 15(b), which shows well developed cross joints in pillow lavas near Mjovatn. The long axes of the deformed pillows can be seen to be approximately perpendicular to the joint surfaces.

In the gabbro, jointing is much less systematic, as might be expected, and crossjoints are not particularly well developed at all. Occasionally, however, where a xenolith of country rock is embedded in the gabbro, particularly near its margin, the gabbro is seen to develop a systematic set of joints inherited from the country rock. The joints in the gabbro are more closely spaced than the joints in the country rock.

Xenolith in south end of the gabbro on the west side of the Orkla River.

2) The Longitudinal Joints

These are no more frequently developed on the scale of the individual exposure than non-systematic joints, and are not as easily recognisable as a set as are crossjoints. They are apparently no better developed in acid rocks than in basic rocks.

A characteristic feature of all joints is the development of "plumose" structure, characteristic of brittle fracture, on the joint surfaces.

ii) East of the Orkla River.

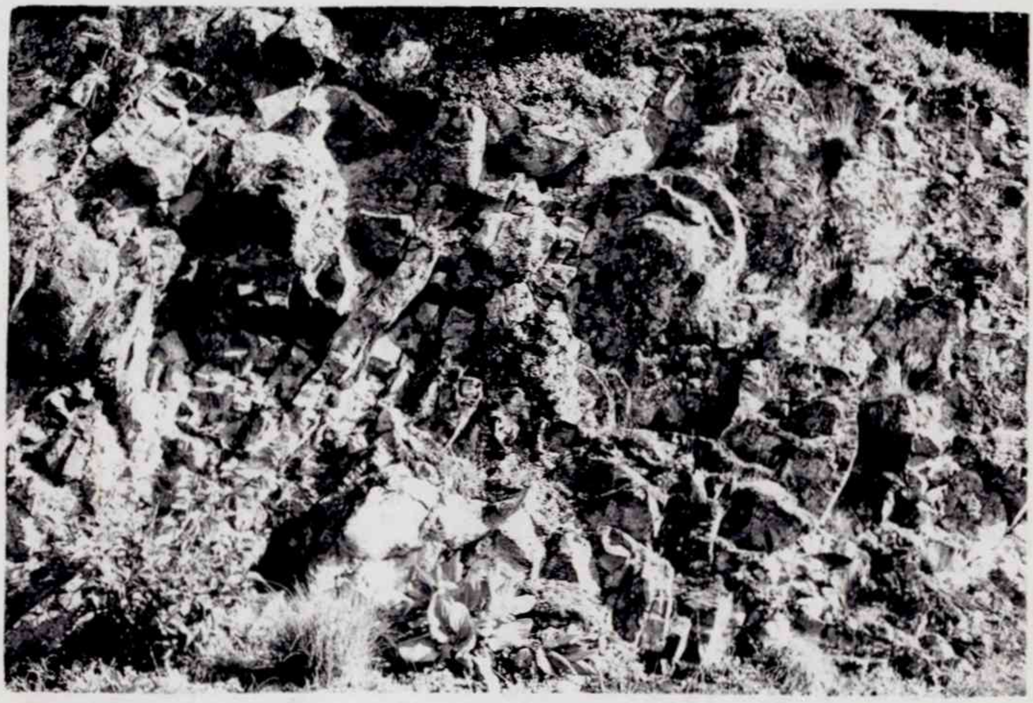
Orientations of joint planes measured east of the Orkla are plotted on the stereogram in Fig.29. It is clear that either there is a lack of data from this area, or that non-systematic joints are more common than systematic sets. In general the rocks are more massive here and do not show evidence of the f_1 deformation to the extent as do the rocks in the north-west part of the area west of the Orkla. For example one rarely sees a well developed elongation of the pillows in basic lavas. This means that the eye does not readily distinguish systematic joints from non-systematic joints. When such is the case systematic sets of joints only become apparent when a large amount of data is collected.

In a particular outcrop of pillow lavas in the village of Løkken itself, a particularly interesting mode of jointing was observed. (See Plate 16.). Here the pillows are unusually large (up to 1 metre), almost spherical and quite undeformed. As the plate shows, concentric and radial jointing of the pillows is extraordinarily well developed, so that the rock tends to split into cubes of side approximately 10cm.

PLATE 16.

Steeply dipping pillow lavas in Lökken Village. The pillows exhibit very well developed radial and concentric jointing.

The lower photograph is a close-up of one of the pillows in the same exposure.



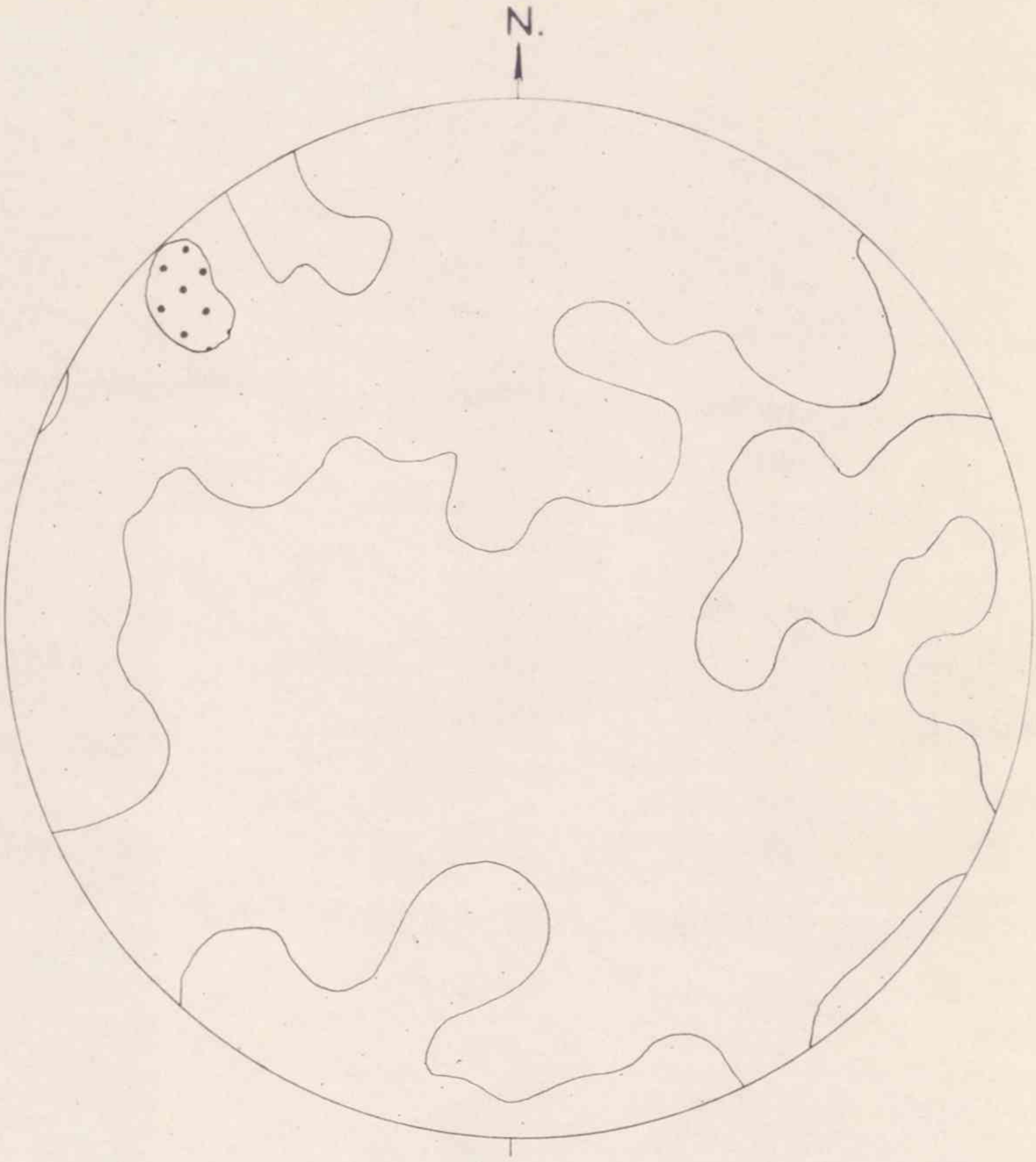


Fig. 29. <u>POLES TO JOINT SURFACES</u>

66 readings east of the Orkla River.

DEFORMATION AND STRAIN

The amount of deformation suffered by rocks in the Lökken Area is far from uniform throughout the area. The bulk of the deformation suffered by the rocks since they were first formed is associated with the f_1 phase of deformation. Indicators of the state of strain in the area are :-

i) Deformed Pillows. These are useful especially where the strain is high.

ii) Deformed Vesicles. Small and difficult to measure in the field. The ends are generally ragged.

iii) Deformed Spherulites. Such rocks are very rare, and only 3 localities were found. Very well shaped ellipsoids are preserved however.

Unfortunately, systematic measurements of a large number of these strain indicators were not made in the field. However, a number of comparative observations were made throughout the area. From these a number of general principles have emerged.

(a) Deformation is stronger in the area around Dragset Mine than anywhere else in the area investigated. The amount of strain decreases as one goes south and east.

(b) Marked changes are often observed in the state of strain across thrust planes, in particular across the thrust in the south of the area of Map A. Beneath this thrust pillows are perfectly formed and show no signs of distortion (see Plate 2(a).), but rocks above the thrust show a definite schistosity and the Pillows are deformed.

(c) On the south of the Løkken Area, where the pillows are not distorted, there is evidence that strain was accommodated by slip between the pillows. The rims of the pillows are generally heavily chloritised and exhibit irregular slickensides over their surfaces. It is thus envisaged that an early stage in the deformation of a pile of pillow lavas, before distortion of the individual pillows has begun, is a stage of slip between pillows, analogous to the close packing of sand grains under pressure.

(d) Over the whole of the area east of the Orkla River, there is no great tendency toward distortion of the pillows or elongation of vesicles. The rock has a very massive character and schistosity is not developed. It has been suggested that the pile of metavolcanics thickens eastward from Dragset and is at its thickest at Løkken, where it is therefore more resistant to deformation.

Fig.30. is a map of the Løkken Area which attempts to illustrate the relative amounts of distortional deformation over the area. Structures indicating the shape of the strain ellipsoid (axial ratio

of greatest to least axes) vary from 1:1 in the south 10:1 in the north-west.

The rapid change in f_1 strain from north to south is possibly accompanied by a corresponding change in the style of the f_1 folds. Unfortunately, lack of data prevents me from amplifying this suggestion.

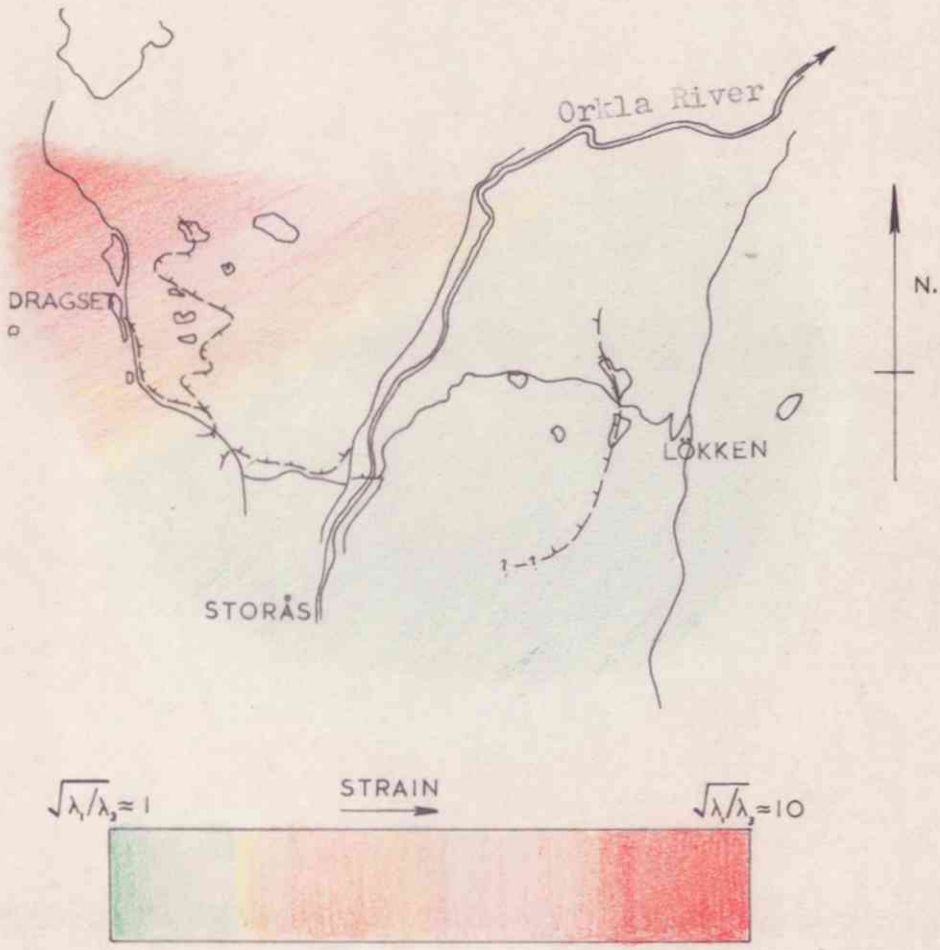


Fig. 30. Diagrammatic Representation of the variation in distortional strain in the Lökken Area.

SUMMARY OF THE STRUCTURAL HISTORY OF THE LØKKEN AREA

The diagram overleaf gives an "at a glance" summary of the structural history of the Lökken Area, which has been described in the foregoing sections.

Phase	Style of Deformation	Associated Structures	
f_1	Earliest Tectonic Movements-Thrusting? Initiation of f_1 isoclinal folds Recrystallisation of minerals in response to metamorphic environment. Establishment of Schistosity.	Elongation of pillows, spherulites, bombs and vesicles in the plane of the schistosity. Preferred orientation of mineral grains.	Caledonian Metamorphic Event
	Intrusion of Gabbro & basic dykes & sills.		
f_2	Folding of f_1 schistosity into areal scale parallel folds about E.-W. axis.	Crinkle lineation, minor conjugate kink folds and kink bands.	
	Thrusting, cutting across the f_2 folds.		
f_3	Flexuring of f_2 folds about N.-S. axis.		
UPLIFT, FAULTING AND JOINTING.			

PETROFABRICS

In many orogenic areas, the sequence of deformations suffered is reflected in the microscopic fabric of the rocks. This is true, to some extent, of the Løkken Area. It is found that the response of particular rocks to the various environments imposed through time depends upon the lithological characters of the rock.

The structural history of the area, as recorded in the fabric of the rocks, is summarised as follows :

(a) The f_1 deformation and metamorphism.

The most significant effect of the f_1 deformation and subsequent metamorphism was the imposition of a schistosity on the less massive rocks. The schistosity is a consequence of the preferred orientation of mica and chlorite flakes, and appears to be axial plane to the f_1 folds. There is no evidence to suggest that the schistosity is a shear phenomenon; it probably formed normal to the direction of maximum compression.

Examination of a large number of specimens has failed to reveal any tendency for dimensional alignment of acicular or fibrous crystals either within or oblique to the plane of the schistosity. The complete absence of mineral elongation lineation is noteworthy in view of the fact that linear structures produced by physical stretching in the plane of the schistosity have been observed. It may therefore be the case that acicular crystals (e.g. amphiboles) formed at a late stage in the metamorphic event, after the peak of the f_1 deformation.

In many of the rocks of the Lökken Area quartz grains occur. The smaller grains commonly show a vague form orientation with triple point grain intersections. The grains are usually slightly flattened normal to the plane of the schistosity. Usually the quartz is too fine grained in these rocks to permit a stereographic analysis of the c-axis orientations.

Sometimes the outlines of healed cracks formed before or during f_1 can be distinguished. Open cracks in rocks cannot, of course, survive metamorphic recrystallisation, but very commonly the outlines of such dislocations are preserved by an infilling of coarsely crystalline quartz or calcite. Possible ancient joints or the outlines of fragments have been preserved in this fashion. (See the section on the chlorite schists).

Microscopic traces of the f_1 stretching can sometimes be seen in the form of boudinaged grains of pyrite and rutile. The cracks are filled either with fibrous chlorite or quartz. Such cracks appear normal to the schistosity and the stretch direction. One such rutile grain is seen in Fig.30(b). Note that this particular grain has poor crystal outlines. This is unusual, for rutile is characteristically high in Becker's crystalloblastic series, though exceptions are recorded.

From observations such as these, the following rather speculative scheme is suggested for the f_1 deformation and metamorphism :

1) f_1 folding and deformation (including stretching)

2) Formation of axial plane schistosity by crystallisation of oriented flakes of chlorite and muscovite. Crystallisation of albite and epidote.	Caledonian Metamorphic Event
3) Crystallisation of tremolite and actinolite.	

(b) The f_2 Deformation.

This phase probably followed very soon after the metamorphism, and is represented microscopically by crinkling of the f_1 schistosity to produce a lineation on the schistosity surfaces. Flakes of mica and chlorite are observed to be physically flexed, but in some rocks laths of feldspar and actinolite are also observed to be bent.

The amplitude of such crinkle folds is controlled to a large extent by the lithology and thickness of schistosity laminae. f_2 is therefore not represented as crinkle folds in the massive metavolcanics.

Microfolds are only seen in the schists to the north.

Throughout the whole area quartz grains are generally seen to be strained, as evidenced by undulose extinction, in the hard, massive rocks. In the calcite, sericite and chlorite rich schists the strain appears to have been relieved by flow of the matrix. It is possible that strain stored in quartz grains in rocks with rigid matrices may be inherited from f_2. The quartz grains are never observed to be extensively ruptured.

(c) The Late Stage f_2 Thrusting.

Over most of the area massive metavolcanics are observed to be cut by the thrust planes, but no microscopic effects, other than irregular crushing of the rock close to the thrust planes, are observed. However, in the south of the area of Map A, the thrust plane cuts through a relatively soft, banded rock which shows a number of interesting features. This rock is shown in Fig.30(a) & (b). By virtue of its nature the rock appears to have taken on a very regular and delicate cleavage, obviously associated with the thrusting, which crenulates the f_1 schistosity.

This particular specimen also shows a number of interesting features connected with f_1, which suggest that f_1 was a lot more complicated than simply isoclinal folding followed by metamorphism. However, due to lack of rocks like this one in the Løkken Area, a detailed analysis of the f_1 deformation may never be possible. The

The rock consists mainly of sericite, mica and chlorite, and is banded. It is shot through with tightly folded bands of polycrystalline quartz with chlorite. The tracing of the hand specimen shows a gently folded ptygmatic quartz-chlorite vein, presumably intruded half-way through the isoclinal folding, and a similar vein which is not folded at all. The unusual texture and strongly deformed state suggest that this rock may have been deformed before the commencement of the f_1 folding. The rock may have been a mylonite, so that the late stage f_2 thrusting has located itself on an earlier, isoclinally folded thrust plane. As was emphasised earlier, it is worth bearing in mind that an important phase of dislocation may have occurred before the main f_1 folding.

(d) Shearing

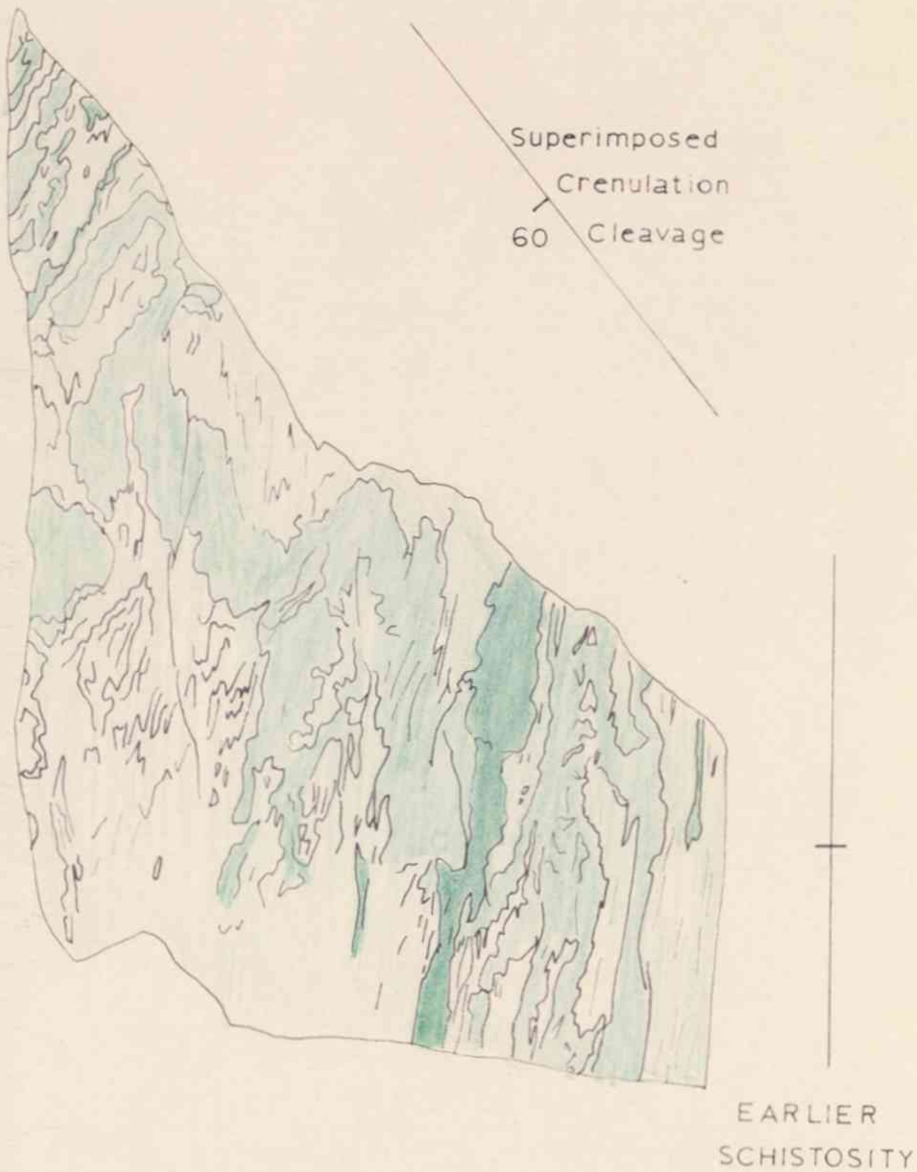
Where recent small shears, geometrically related to the latest faulting, transect the rocks, local crushing and truncation of mineral grains may be observed. Some such shears have been healed by the growth of quartz or calcite, sometimes showing slickensides.

Fig. 30. a.

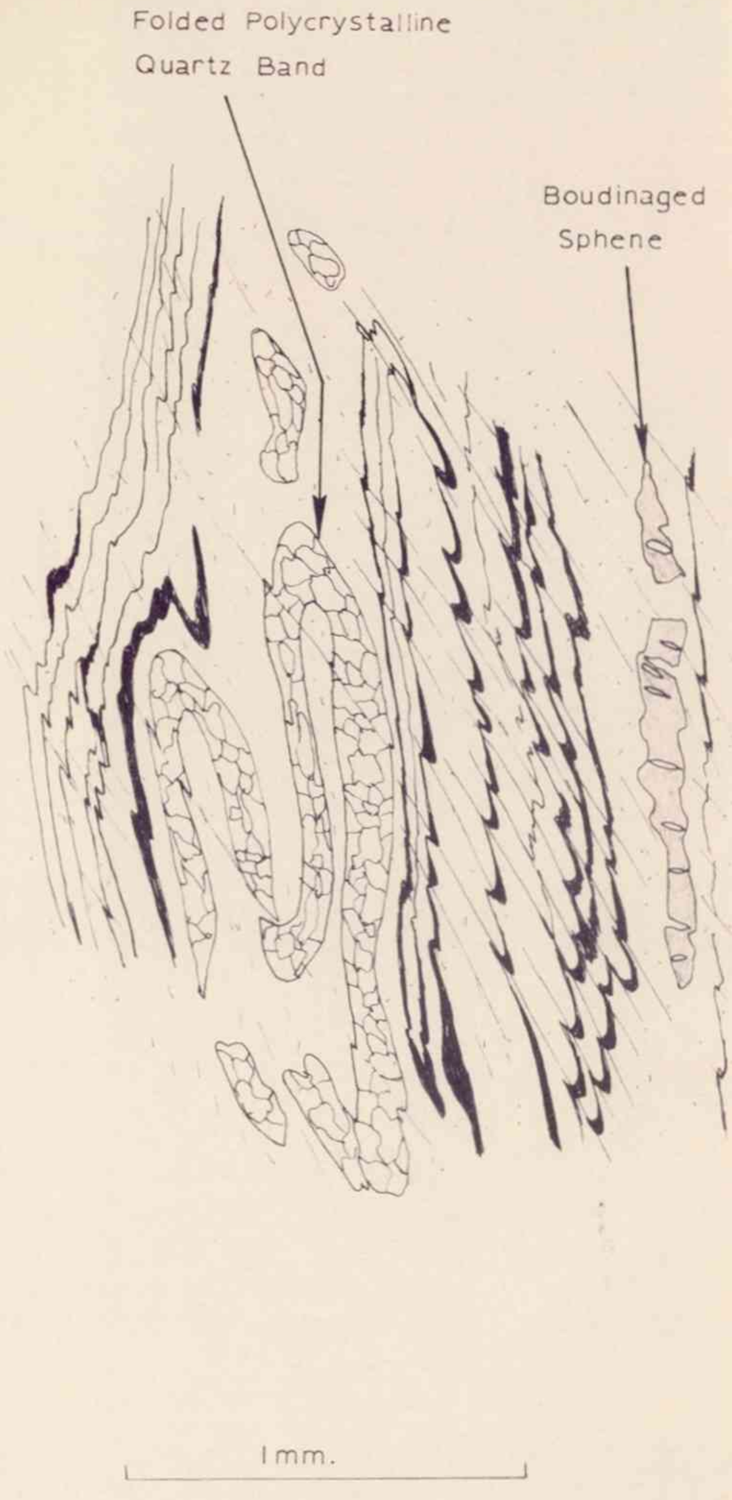
(a) Drawing of a cut surface of a hand specimen of chlorite-sericite schist exposed near Dragset Moen.

(b) Drawing of part of a thin section of the same rock.

See text for description. (page 84)



(a) NATURAL SIZE



(b)

RESULTS OF THE 1966 SUMMER MAPPING

1) Structural Geology

A scheme of structural history of the Lökken Area is presented, and an account of the geometry of the structures seen in the area is given, as far as is known at present. It is important to extend the work over a much larger area than the immediate vicinity of Lökken, since the structures themselves are large. It will be interesting to discover the manner in which the geometry of the deformation changes laterally, and to tie in the sequence of events with those established in adjacent areas, for example, the area lying to the north of Lökken which was mapped by J.S. Peacey in 1961.

A number of remarks have been made in the text with regard to a number of specific problems which need to be tackled within the Lökken Area, for example, the establishment of the axial directions of the f_1 folds.

With particular reference to the economic aspects of the structural geology, it seems probable that the structural control of the pyrite orebodies is by the f_1 deformation, such that the orebodies are elongated parallel to the f_1 stretch direction. This implies that the orebodies were probably in position before the commencement of the orogenic movements, i.e. they are syngenetic, associated with the geosynclinal volcanism. This is corroborated by petrofabric evidence of disseminated pyrite grains being deformed by f_1 movements.

One of the problems of the area which soon became apparent was the question of whether the Dragset, Løkken and Høidal orebodies are genetically connected or represent separate centres of mineralisation. The correspondence between the direction of elongation of the orebodies, the f_1 stretch direction and the line Dragset-Løkken-Høidal, seems to suggest a genetic relationship. For this reason it seems to me that the line Dragset-Løkken is the most obvious place to investigate for possible new pyrite deposits.

2) Petrology.

(a) Nomenclature.

A number of primary structures and textures have been found in the metavolcanics. These are useful for the revision of nomenclature. The field associations, mineralogy, structures and textures of the metavolcanics suggest that they should be named according to the spilite-keratophyre nomenclature. However, the geochemical work of Mr.May has shown that chemically not all the rocks are typically spilitic, but since the application of the spilite nomenclature to a suite of rocks should not be based on one set of criteria only, but on the combination of mineralogy, mode of occurrence (geologic environment), modal composition and chemistry, it has been decided to recommend the adoption of the spilite-keratophyre nomenclature for these rocks.

(b) The Metagabbros.

Cursory examination of the metagabbro west of the Orkla has shown that it is not a homogeneous intrusion. In the lower part it exhibits layering, and it is capped by a sheet of granophyre. The whole mass appears to be lying on its side.

There is clearly room for further investigation of the petrology and structure of the gabbro masses.

(c) Mapping.

The geochemical work of Mr.May has led to the formulation of criteria which may lead in the future to the useful subdivision of the metavolcanics.

SELECTED REFERENCES

Backlund, H.G. 1930 Die Magmatesteine der Geosynklinale von Nowaja Semlja. Report of the scientific results of the Nòrwegian expedition to Novaya Zemlya, 1921.

Battey, M.H. 1956 The petrogenesis of a spilite rock series from New Zealand. Geol. Mag. Vol. 93.

Bailey, E. 1960 The Steinmann Trinity. Q.J.G.S. Vol.116, pp.365.

Björlykke, U. 1960 Geologisk Detaljkartlegging av omradet mellom Dragset Gruve og Orkladalen. Unpublished report.

Carstens, C.W. 1951. Løkkensfeltet Geologi. Norsk Geol. Tidsskr. 29, 9-25.

" " 1952 Geologisk Kart over Løkkensfeltet. Norges Geografiske Oppmaling.

Carstens, H. 1960 Stratigraphy and Volcanism of the Trondheimsfjord Area. Norges Geol. Unders. No.212b.

Carstens, H. 1954 Samt Løkken Verks Jubileumsbok: "En Norsk Grube Gjennom 300 Ar." ~~1965~~ 1654-1954. Publication celebrating 300 years of mining at Løkken.

Chadwick, Blake, Rowling & Beswick. 1964 The Geology of the Fjeldheim-Gasbakken Area, Sør-Trøndelag. Norges Geol. Unders. 223, 43-60.

Coates, R.R. 1936 Primary Banding in Basic Plutonic Rocks. J. Geol. Vol. 44, pp. 407.

Dewey, H. & Flett,J.S. 1912 On some British Pillow Lavas and the rocks associated with them. Geol. Mag. Vol.8.

de Sitter, L.U. 1964. Structural Geology. 2nd Edition. McGraw Hill, London.

Vokes, F.M. 1960 Mines in South and Central Norway. Guide book prepared for 21st, Int. Geol. Congress. Norges Geol. Unders. 212m.

Holtedahl, O. 1951 The Structural History of Norway and its relation to Great Britain. 7th William Smith Lecture. Q.J.G.S. Vol. 108 pp.65.

Johnson & Stewart	1963	The British Caledonides, Oliver & Boyd, London.
Kioer, J.	1932	The Hovin Group in the Trondheim Area. Norsk Vid. Akad. No. 4.
Kva le, A.	1953	Linear Structures and their Relation to Movements in the Caledonides of Scandinavia. Q.J.G.S. Vol. 109, p. 51.
Odegaard, M.	1959	Vasskis-Gangkis i Løkkenfeltet. Unpublished report on the Vasskis and ore at Løkken.
Overwein, E.	1960	Struktur-Geologiske Undersøkelser: Løkken Grube. Unpublished report on the structures in the Løkken Mine.
Peacey, J.S.	1961	The Geology of the area around Gangaasvann, Sør- Trøndelag, Norway. Unpublished Ph.D thesis, University of London.
" "	1964	Deformation in the Gangaasvann Area. Norges Geol. Unders. 223, pp.275-293.

Pitcher & Flinn 1965 Controls of Metamorphism. Oliver and Boyd, London.

Solomon, M. 1966 The Origin of the Pillow Lavas and Hyaloclastic Breccias of King Island, Tasmania. Geological Society of London Circular 133.

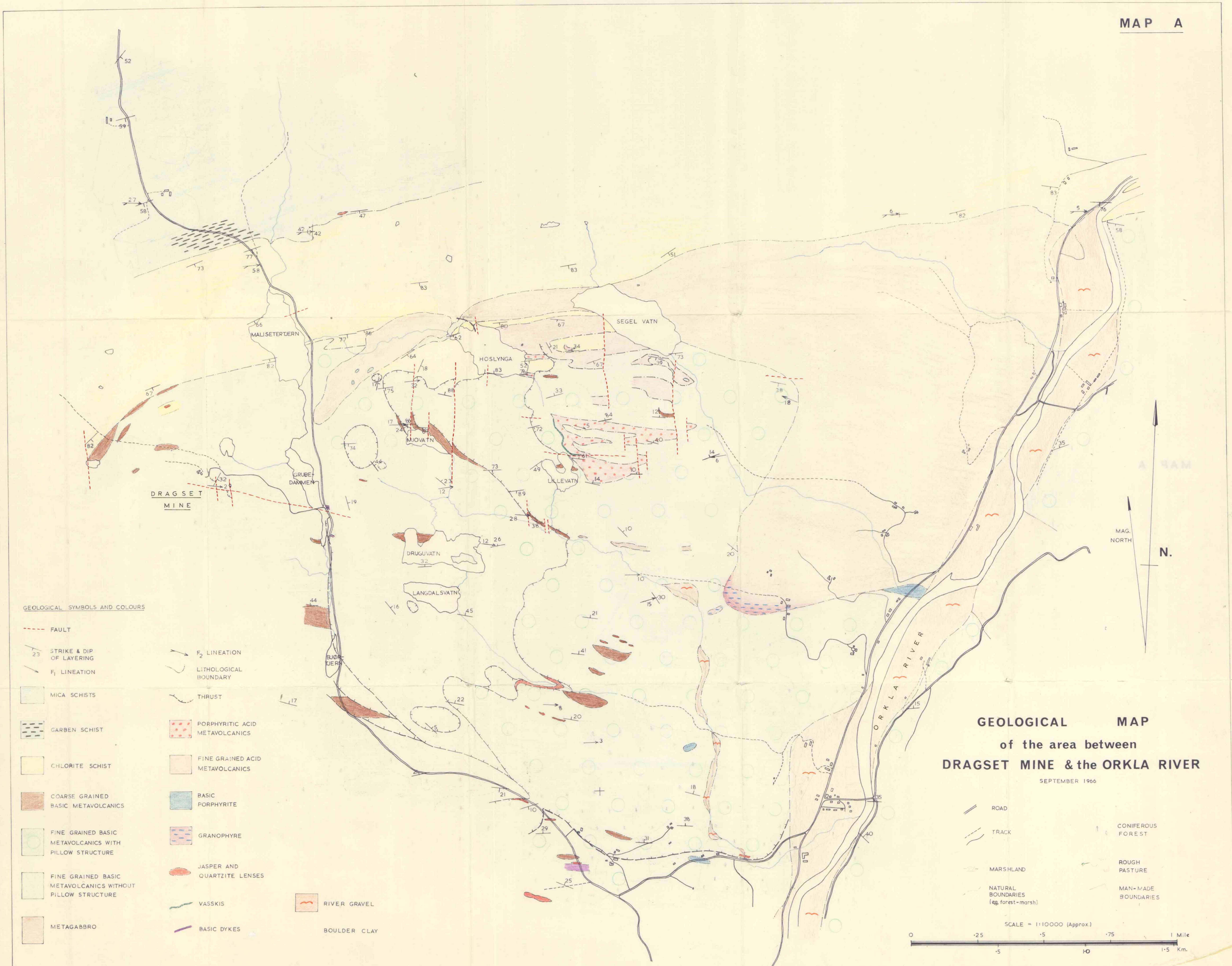
Störmer, L. 1966 Aspects of the Caledonian Geosyncline and the Foreland west of the Baltic Shield. 20th. William Smith Lecture. Geological Society of London Circular 134.

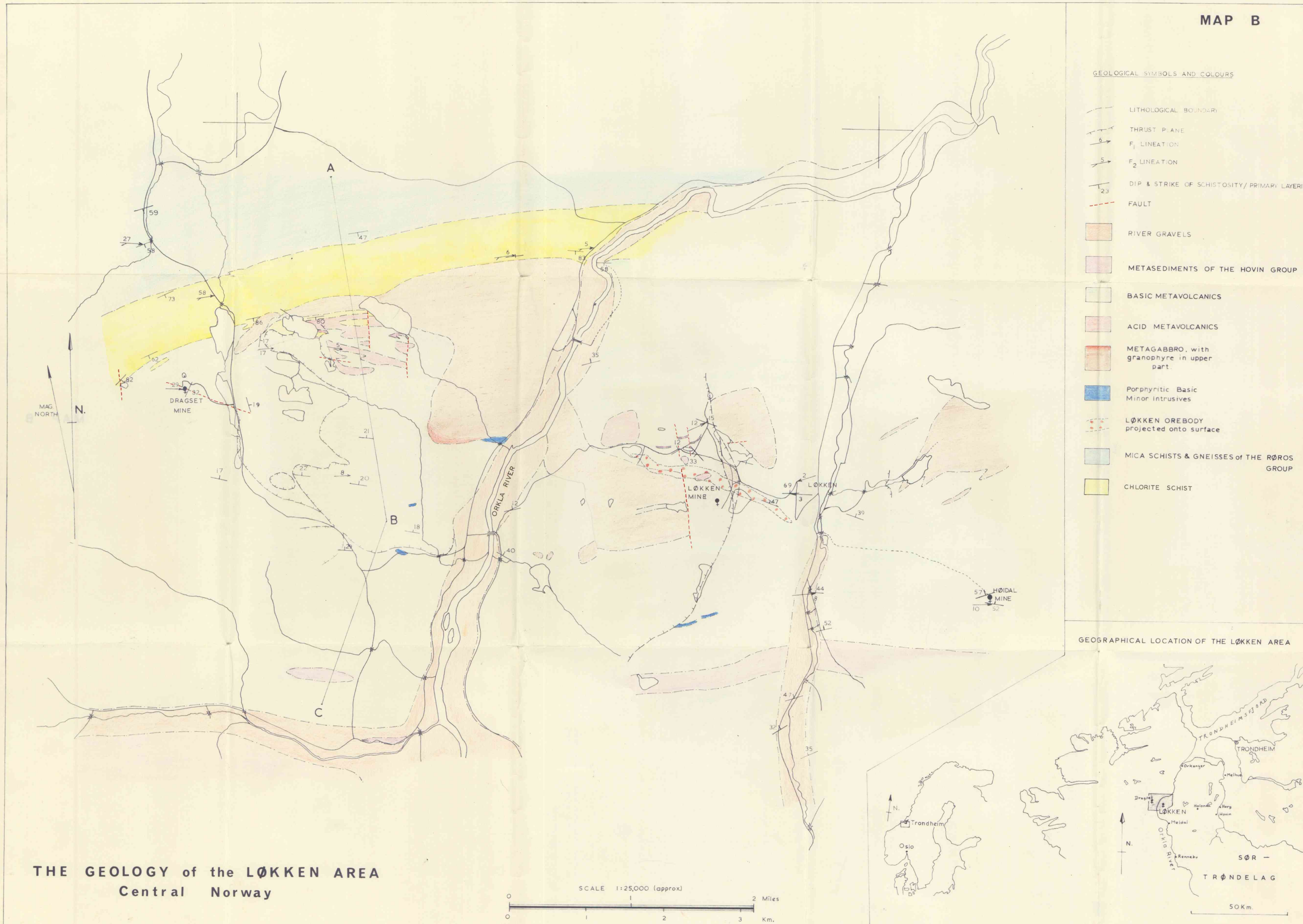
Strand, T. 1949 New Trilobites from the Holonda Limestone. Norsk. Geol. Tidsskr. Vol. 25. pp. 429-527.

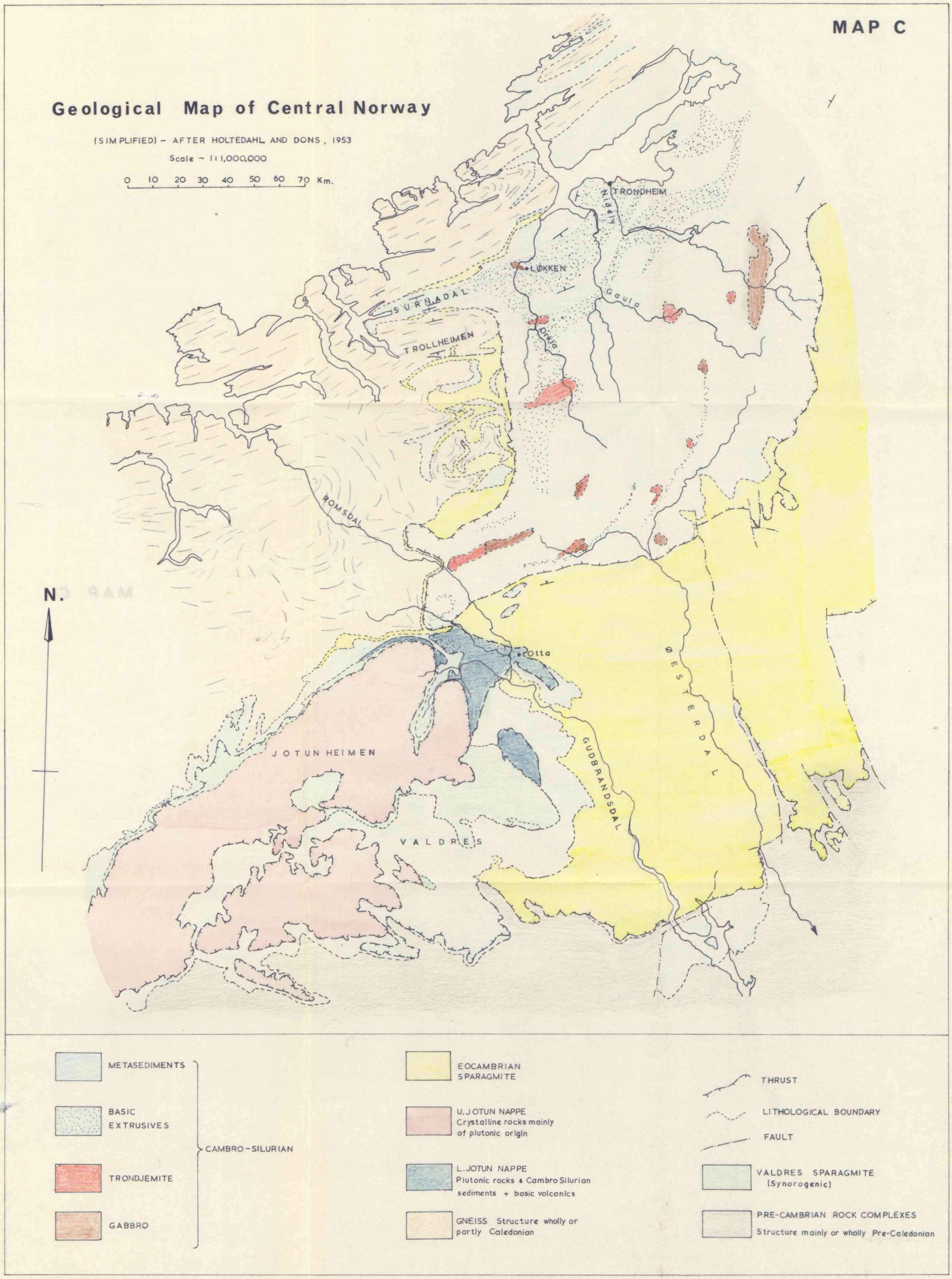
" " " Råpport til Orkla Grube Aktiebolag om Løkkenfeltets Geologi. Unpublished report on the Geology of the Løkken Area.

" " & Holmsen 1960 Stratigraphy, Petrology and Caledonian Nappe Tectonics of Central Southern Norway. Guide Book prepared for 21st Int. Geol. Congress. Norges Geol. Unders No.212I.

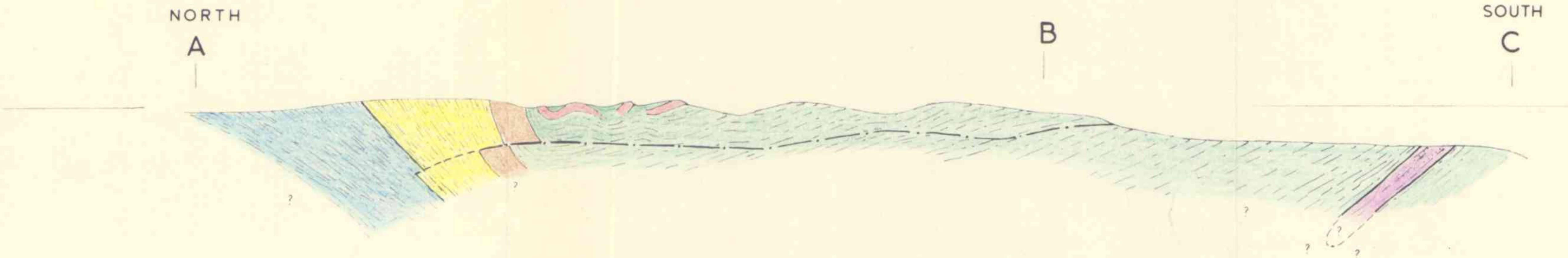
Turner & Verhoogen	1963	Igneous and Metamorphic Petrology. McGraw Hill, London.
Turner & Weiss	1963	Structural Analysis of Metamorphic Tectonites. McGraw Hill, London.
Vogt, T.	1949	The Geology of the Holonda- Horg District. Norsk.Geol. Tidsskr. Vol. 25 pp.449-527.
Winkler, H.G.F.	1965	Petrogenesis of Metamorphic Rocks. Springer-Verlag, Berlin.


MAP A
GEOLOGICAL MAP
of the area between
DRAGSET MINE & the ORKLA RIVER
SEPTEMBER 1966
DRAGSET MINE
MALISETERTJERN
GRUBE-DAMMEN
HOSLYNGA
SEGEL VATN
MIOVATN
LILLEVATN
DRUGUVATN
LANGDALSVATN
BJØR-TJERN
ORKLA RIVER
MAG. NORTH
N.
GEOLOGICAL SYMBOLS AND COLOURS
FAULT
STRIKE & DIP OF LAYERING
F1 LINEATION
F2 LINEATION
LITHOLOGICAL BOUNDARY
THRUST
MICA SCHISTS
GARBEN SCHIST
CHLORITE SCHIST
COARSE GRAINED BASIC METAVOLCANICS
FINE GRAINED BASIC METAVOLCANICS WITH PILLOW STRUCTURE
FINE GRAINED BASIC METAVOLCANICS WITHOUT PILLOW STRUCTURE
METAGABBRO
PORPHYRITIC ACID METAVOLCANICS
FINE GRAINED ACID METAVOLCANICS
BASIC PORPHYRITE
GRANOPHYRE
JASPER AND QUARTZITE LENSES
VASSKIS
BASIC DYKES
RIVER GRAVEL
BOULDER CLAY
ROAD
TRACK
CONIFEROUS FOREST
MARSHLAND
ROUGH PASTURE
NATURAL BOUNDARIES (eg. forest-marsh)
MAN-MADE BOUNDARIES
SCALE = 1:10000 (Approx.)
0 ·25 ·5 ·75 1 Mile
·5 1·0 1·5 Km.


MAP B
GEOLOGICAL SYMBOLS AND COLOURS
LITHOLOGICAL BOUNDARY
THRUST PLANE
F1 LINEATION
F2 LINEATION
DIP & STRIKE OF SCHISTOSITY/ PRIMARY LAYERING
FAULT
RIVER GRAVELS
METASEDIMENTS OF THE HOVIN GROUP
BASIC METAVOLCANICS
ACID METAVOLCANICS
METAGABBRO, with granophyre in upper part
Porphyritic Basic Minor Intrusives
LØKKEN OREBODY projected onto surface
MICA SCHISTS & GNEISSES of THE RØROS GROUP
CHLORITE SCHIST
A
B
C
MAG NORTH
N.
DRAGSET MINE
ORKLA RIVER
LØKKEN MINE
LØKKEN
HØIDAL MINE
GEOGRAPHICAL LOCATION OF THE LØKKEN AREA
TRONDHEIMSFJORD
TRONDHEIM
Orkanger
Melhus
Dragset
LØKKEN
Meldal
Hølonda
Horg
Hovin
Orkla River
Rennebu
SØR – TRØNDELAG
50 Km.
Trondheim
Oslo
N.
THE GEOLOGY of the LØKKEN AREA
Central Norway
SCALE 1:25,000 (approx)
0 1 2 Miles
0 1 2 3 Km.


MAP C
Geological Map of Central Norway
(SIMPLIFIED) ~ AFTER HOLTEDAHL AND DONS, 1953
Scale ~ 1:1,000,000
0 10 20 30 40 50 60 70 Km.
N.
TRONDHEIM
Nidelv
LØKKEN
Gaula
Orkla
SURNADAL
TROLLHEIMEN
ROMSDAL
Otta
JOTUNHEIMEN
VALDRES
GUDBRANDSDAL
ØESTERDAL
METASEDIMENTS
BASIC EXTRUSIVES
TRONDJEMITE
GABBRO
CAMBRO-SILURIAN
EOCAMBRIAN SPARAGMITE
U. JOTUN NAPPE Crystalline rocks mainly of plutonic origin
L. JOTUN NAPPE Plutonic rocks & Cambro Silurian sediments + basic volcanics
GNEISS Structure wholly or partly Caledonian
THRUST
LITHOLOGICAL BOUNDARY
FAULT
VALDRES SPARAGMITE (Synorogenic)
PRE-CAMBRIAN ROCK COMPLEXES Structure mainly or wholly Pre-Caledonian

Section 1



DIAGRAMMATIC SKETCH SECTION THROUGH A, B AND C ON MAP B.

SCALE ~ 1:25,000

0 1 2 3 Km.

HORIZONTAL SCALE = VERTICAL SCALE

RØROS GROUP

CHLORITE SCHIST

GABBRO

ACID METAVOLCANIC ROCKS

BASIC METAVOLCANICS

HOVIN GROUP

THRUST

The geology of the Lökken area by Ernest H. Rutter

Utdrag ved T. Strand

s. 1 - 15 Innledning, topografi, isbevegelse, oversikt over Sör-Norges geologi efter norske kilder.

s. 16 Nomenklatur, noen av bergartene har primære strukturer. Et problem om nuværende mineraler i grönstenene (albitt, epidot, klorit, hbl.) er primære eller sekundære (oppstått ved metamorfose). I förste tilfelle må bergartene

17 regnes som spilliter. Efter Mays undersökelser varierer Na_2O-innholdet mellem 2% ("normal basalt") og 5% (typisk spillit). (Henvisn. til Mays rapport).

18 I rapporten regnes alle meta-vulkaniter med primære strukturer til spillit/keratofyr-gruppen, videre også alle sikre meta-vulkaniter som har fått ödelagt de primære strukturer. Noen har primær bånding og må regnes som tuffer. (skjems efter s. 18)

19-20 Oversikt over de bergartstyper som ble utskilt under kartlegningen.

21-24 Metamorfosegrad, skjema efter Winkler. Bestemmelse av subfacies vanskelig, men metamorfosegraden öker nedover i lagrekken. Metamorfosekart fig. 7

25-26 Kontaktmetamorfose. Undersökelse av xenolither i gabbro viste ingen sikre tegn på kontaktmetamorfose, intrusjon av gabbroen för eller samtidig med regionalmetamorfosen.

27. Basiske meta-vulkaniter. Kommentar til Unni Björlykkes kart. Kornstörrelse, finkornet grovkornet regnes som et nyttig kriterium, derimot tvilsomt om fargen (lys eller mörk) er av betydning som skillemerke.

28. Meta-vulkanitene deles i tre grupper:

1. Kloritskifer. sammenhengende sone i nordlige del av området, ansees som en finkornet tuff, muligens med enkelte store vulkanske bomber.

29 2. Pillow-lavaer. Putestörrelse 20 cm til 2 m, sonert (anm: variolitstruktur beskrevet av H. Carstens) (fig. 9). I sydlige del av området med svak deformasjon kan opp-ned bestemmes i mange tilfelle.

Ved Björnlivann blotninger som viser fragmentering av puter (pl. 3)

30 3. Massive meta-vulkaniter. Basiske bergarter uten putestruktur. Skifrighet utviklet mest i nordlige del av området. Deles i

a. grovkornet varietet, kan lett skilles ut fra de finkornete, linseformete

31 inneslutninger (brune farge kart A). De er i noen tilfelle lagdelt (tuffer), men i alm. er opprinnelse (lava? tuff?) umulig å bestemme.

b. Finkornet varietet. Ansees som overveiende pyroklastiske (tuffer).

Fig. 10 viser utbredelsen av massive grönstener og pillow-grönstener

32 vest for Orkla (213 obs.). De massive og pillow-grönstener synes fremherskende vestover.

33 Basiske gangbergarter. 1. Små ganger. 2. Hölonda-porfyriter (med store feltspatinnsprengninger (fig. 11) beskrevet av Chadwick & Co. i Fjellheim-området)

34 Gabbro (pl. 6) er båndet, båndingen stryker öst-vest og er vertikal. Ved

35-36 diferentiasjon er det dannet granofyr (15-20% kvarts) i den övre del av gabbroen.

37 Sure meta-vulkaniter (kvarts-keratofyrer) rike på kvarts og albit. Tre typer: porfyrisk, finkornet og båndet, annen type med inneslutninger og

38-39 den tredje er sikkert pyroklastiske (tuffer) (fig. 12, pl. 7c-d)

40 Röros-gruppens bergarter, veiprofil Laksöien, garbenskifer og klorit-

41 albit-muskovit-kvarts-skifer. Går nordover i mer grovkornete bergarter ("gneiser") rike på klorit og tremolit

42-43 Jaspis-linser og vasskis (Pl. 9).

Strukturgeologi.

s. 44 Hovedgrupper av strukturer

1. isoklinalfoldning (f_1) samtidig med grönskifermetamorfosen. Strukturer: a. skifrighet, b. linjestrukturer ved strekning i skifrighetsplanet, strukne puter, sferolither og blærestrukturer, lengderetning av kislegemene.

2. Annen foldning (f_2) er foldning av f_1-skifrigheten efter akser nær sammenfallende i retning med f_1-linjestrukturene. Strukturer: "minor folds"

45 omböiningen av hovestrukturen. Lökken-synformen, disse kaldes annen ordens strukturer. b. Knekkfolder (V-folder) med akser parallelle med akseretningen for Lökken-synformen, tredje ordens strukturer. c. rynkelineasjon ved mikrofoldning av kloritflak, fjerde ordens strukturer.

3. Overskyvning (thrusting) ved slutten av f_2-foldningen, i retning tilsynelatende fra nord til syd.

4. svak böining om nord-syd akser.

5. Forkastninger i retning hovedsakelig nord-syd og öst-vest.

47 Förste foldefase (f_1) dannet tette isoklinalfolder. Evidens for dette

skifrighet 1. Dannelse av ~~skirfihet~~ i alm. parallel lagningen.

48 2. Opp-ned kriterier i putelavaer (se foran) og ved gradert lagning i tuffer (grovkornet nederst, gradvis mer finkornet oppvoer). I et bestemt ~~områd~~ område er bergartene aldri gjennemgående enten invertert eller i normal ~~lagstil~~ lagstilling, men vekslende begge deler med konstant fall (overbevisende argument)

3. Forhold ved linser av massive meta-vulkaniter i kloritskifer.

4. Stadig veksel av basiske og sure lag av vulkaniter ved Hoslynga, kan skyldes opprinnelig veksling, men kan også være gjentagelse av lagene ved isoklinalfoldning.

49 5. Folden av Hovin-bergarter med grönsten på begge sider syd for Lökken er utvilsomt en synklinal (med de yngste lag i midten), men det er uvisst om den er en synform (som lukker seg nedover) eller en antiform (som lukker seg oppover), det avhenger av retninger for foldningsaksen fall (pitch) Fig. 13. (Anm. Dette er lett å demonstrere når folden representeres av et

50 sammenbrettet papirstykke, hvor bretten må svare til foldningsaksen) Hvis foldningsaksen er parallel med strekningsretningen, må synklinalen være en antiform.

51 Direkte måling av foldningsaksen på små f_1-folder er det liten mulighet for, man kan ikke vente å finne dem i massive bergarter og de finkornete kloritskifrer i nord viser ikke lagning. En divergent retning av skifrighet (cleavage) ved Dragset er blitt tydet som et foldet ~~mørXKKX~~ lag mer kompetent enn de omgivende.

52 Det finnes isoklinalfolder i båndete bergarter ved skyveplanet, men båndingen her (kvarts) er muligens av sekundær opprinnelse (svarer ikke til lagningen)

53-54 f_1 linjestrukturer. Elongasjon av puter, bomber, blærerom og sfærulither har östlig retning med svakt fall i samme retning (diagram fig. 14, s.54-55)

55-56 Antydning at grensen Stören-gr. til Röros-gruppen i den nordlige del av området er en skyvegrense (hypotetisk formodning)

57 Annen foldefase, f_2. Foldenes akser har (omtrent) samme retning som som strekningsretningen for f_1. f_1-skifrigheten foldes, på den ene side til ~~Kelä~~ fleksurer av regional utstrekning, på den annen side til mikroskopiske små knekk. Ingen ny skifrighet ble dannet ved f_2-foldningen. Småfoldning av f_1- skifrigheten, knekkfolder og konjugerte folder er illustrert fig. 16 (s. 59-60). De har samme akseretning men foldenes akseplan har varierende stilling efter hvor meget eller litet de ble böiet ved dannelse av den store struktur, Lökken-synformen, som igjen er en underordnet fleksur ved kanten av Trondheims-feltets store synklinorium. (det mangler her og sene en klar definisjon av hva det menes med Lökken-synformen, bl. a. av hvor langt den strekker seg).

De forholdsvis små folder av annen orden er ikke blitt direkte iakttatt men kan utledes av skifrighetens vekslende fallstörrelse, de må være av störrelsesorden

störrelsesorden 20 til 100 m. De synes å være alminnelige.
Tredje ordens småfolder omtalt ovenfor.
s. 60 Fjerde ordens strukturer er mikroskopiske rynker.

Lökkensynformens geometri vest for Orkla. Diagram fig. 17 (poler til f_1 skifrighetsflater) viser to konsentrasjoner av lagstilling, èn med bratt fall mot syd og en annen med meget slakere fall mot nord. Vinkelen mellem de to ben i foldene (indikert ved de fremherskende fall av skifrigheten) er 95° akseplanet, som antas å halvere de to retninger faller 65° mot nord, foldningsaksen i retning E10°N eller 10° östlig.

61 Vinkelrelasjon mellem f_1 og f_2 strukturer. Fig. 22 (s. 63-64) viser geometriske data både for f_1 og f_2 foldene og linjestrukturer. Lökken-malmens lengderetning faller sammen med f_1 linjestrukturen (som er parallel med Dragset - Lökken - Höidal-linjen) men faller ikke sammen med akseretningen for Lökken-synformen.

62. Fig. 21 viser et litet antall av iakttatte linjestrukturer i de massive bergarter öst for Orkla, som sannsynligvis faller sammen med Lökken-synformens akse, som her (hvis så er tilfelle) er nesten horisontal eller faller svakt vestlig. Lökken-malmen hvis akse heller minst 20° WNW må være blitt löftet opp ved foldningen på sydflanken av Lökken-synformen.

63 Det er en divergens av 5° mellem f_1 og f_2-strukturene. Lökken-malmens retning må ha sin "structure control" ved f_1-deformasjonen.

64 Overskyvninger.

Disse er för kjent i gruveområdet öst for Orkla, men er vanskeligere å påvise i området vest for Orkla, men her dog mulig i den nordlige del omkring hoslynga og Mjovatn, hvor en blokk av vertikale eller steilt fallende skifrige pillow-lavaer ligger over meta-vulkaniter med nesten horisontal

65 skifrighet (kart A og fig. 23). På en rekke steder med blottet kontakt er det funnet leirmasse. Skyveplanet faller lokalt sammen med et tynt bånd av skifrig grovkornet bergart uten pillow-struktur.

Vest for Orkla faller skyveplanet svakt mot öst fallet svakere enn fallet for Lökken-synformens akseretning. (Fallet sterkere öst for elven). I den sydlige del av området vest for Orkla er det vanskelig å finne skyvninger, her antagelig skjellstruktur (en rekke sammenskjövne flak).

66 Nærmere beskrivelse av en del lokaliteter med skyvegrenser.

67 Skyvningens retning vanskelig å bestemme, muligens er samme lag på ett st sted påvist både over og under skyveplanet og viser en forskyvning fra nord mot syd av 500 m.

68 Skyveplanene svakt böiet om både en nord-sydlig og en öst-vestlig retning. det er en konstant vinkelrelasjon mellem skyveplanet og akseretningen for Lökken-synformen, dette tyder på at skyvningen har sammenheng med en sen fase i dannelsen av Lökken-synformen.

69 Ingen evidens for sammenheng av skyveplan öst og vest for Orkla, dog en mulighet for at skyveplanet fra gruben kommer igjen sydligst i området vest for Orkla.

70 Mulighet forforkastning langs Orkla (ingen evidens for dette funnet ved en nærmere undersökelse i marken). Virkningen av en eventuel forkastn forkastning på skyveplanets utgående (teoretisk) illustrert s. 70.

71 Sammenligning med annen kaledonsk dekketektonik.

s. 72 f_3- fleksur böier skyveplanet og likeledes Lökken-synformens akse (fig. 23)

73 Forkastninger og sprekker.

Fig. 26a er histogram av retninger for 31 forkastninger vest for Orkla og viser overveiende retninger av disse öst-vest og nord-syd, hva som gjenspeiles i topografien. De öst-vestlige synes å ha större spranghöide og

74 forskyvninger enn de nord-sydlige.

Sprekker (joints) har samme hovedretninger som forkastningene, nord-syd og öst-vest, de nord-sydlige sterkest utviklet. De står i relasjon til Lökken-synform, de nord-sydlige står nesten loddrett på dens akse, de öst-vestlige er parallele med dens akseplan, de er således

75 henholdsvis tversprekker (cross-joints) og lengdesprekker.

Tversprekkene er best utviklet, særlig i felsitene, mindre godt i de basiske bergarter. I gabbroen er sprekkemönstret mindre systematisk.

Sprekkene er mindre systematisk utviklet vest for Orkla (sammenlign diagrammer fig. 28 og 29)

76 Lengdesprekkene (öst-vest) er mindre systematisk utviklet enn tversprekkene.

78-80 .Deformasjonen er meget sterkere utviklet i den vestlige del enn i den östlige, fremstillet på fig. 30 ved akseforholdet i strain-ellipsoidet.

ved s. 80 Tabellarisk oversikt over deformasjonsfasene

81-85 Petrofabrics er en beskrivelse av bergartenes finstruktur m. h. t. orientering av mineralkorn som er blitt til i de forskjellige faser, f. eks. parallelinnordning av glimmer og klorit i f_1-skifrighetens plan, fyllte småsprekker o. l.

Til slutt foraftterens sammenfatning.

På en ekskursjon 10. august sammen med Rutter og de to andre engelske studenter og Sagvold gikk vi over området på østsiden av veien ved Dragset og la særlig vekt på de skyvesoner som Rutter her har beskrevet i sin rapport efter undersøkelsene sommeren 1966.

I bekkeprofilet ved veien (benveien) som tar opp ved Dragsetmoen er det tydelig en gnuggsone, som meget vel kan markere et skyveplan, som kan være fortsettelsen av skyveplanet fra Løkken grube.

Derimot er de andre skyvesoner som er kartlagt og beskrevet i rapporten mindre overbevisende fordi det på de fleste av dem i det minste ikke kan påvises noen gnuggsone (forskifring) av bergartene ved planet. Dette gjelder således XX det skyveplan som efter rapporten s. 65 skal være blottet ved Hoslynga og Mjovatn, xh hvor det ikke ble påvist noen forskifring ved det påståtte skyveplan. Noen leirmasse ved planene så jeg heller ikke, men noen steder finkornete skiferlag mellem benker av massiv vulkansk bergart, men dette vil jeg oppfatte som et primært trekk.

Efter hva jeg selv har sett, er jeg således skeptisk over for de fleste av de kartlagte skyvestrukturer.

Blindern 21. august 1967

Trygve Strand

(Dette kan betraktes som et vedlegg til mit reymé av Rutters rapport).