

SVERIGES GEOLOGISKA UNDERSÖKNING

SERIE C NR 778

AVHANDLINGAR OCH UPPSATSER

ÅRSBOK 74 NR 6

JOHAN SANDWALL

CALEDONIAN GEOLOGY
OF THE JOFJÄLLET AREA
VÄSTERBOTTEN COUNTY, SWEDEN

STRATIGRAPHY, METAMORPHISM,
DEFORMATION



UPPSALA 1981

SVERIGES GEOLOGISKA UNDERSÖKNING

SERIE C NR 778

AVHANDLINGAR OCH UPPSATSER

ÅRSBOK 74 NR 6

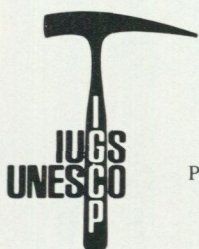
JOHAN SANDWALL

CALEDONIAN GEOLOGY
OF THE JOFJÄLLET AREA
VÄSTERBOTTEN COUNTY, SWEDEN

STRATIGRAPHY, METAMORPHISM,
DEFORMATION

UPPSALA 1981

ISBN 91-7158-221-5



Project No. 60: Correlation of Caledonian
Stratabound Sulphides

Kartorna godkända ur sekretessynpunkt för spridning.
Statens lantmäteriverk 1981-01-13.

Address:

Johan Sandwall
Avd. för ekonomisk geologi
Tekniska Högskolan
S-951 87 Luleå

C. DAVIDSONS BOKTRYCKERI AB, VÄXJÖ 1981

CONTENTS

Summary	6
1. General introduction	8
1.1. Opening remarks	8
1.2. Location	8
1.3. Previous work	8
1.4. Tectonic framework	10
1.4.1. Björkvattnet Nappe	10
1.4.2. Laxfjället Nappe and Storfjället Nappe Complex	10
1.4.3. Closing remarks on structures	11
2. Lithostratigraphy	12
2.1. Opening remarks	12
2.2. Björkvattnet Nappe	12
2.2.1. Skälvattnet Volcanite	12
2.2.1.1. Type section	12
2.2.1.2. Lateral continuation	12
2.2.1.3. Interpretative remarks on environment of deposition	14
2.2.2. Västansjö Phyllitic Quartzite	14
2.2.2.1. Type section	14
2.2.2.2. Lateral continuation	16
2.2.2.3. Interpretative remarks on environment of deposition	17
2.3. Laxfjället Nappe	17
2.3.1. Jovattnet Calcareous Phyllite	17
2.3.1.1. Type section	17
2.3.1.2. Lateral continuation	17
2.3.2. Joeström Quartz-Keratophyre	19
2.3.2.1. Description of the formation	19
2.3.2.2. Lateral continuation	19
2.4. Storfjället Nappe Complex	19
2.4.1. Metartjärnen Formation	19
2.4.1.1. Type section	19
2.4.1.2. Lateral continuation	21
2.4.2. Jofjället Calcareous Phyllite	22
2.4.2.1. Type section	22
2.4.2.2. Lateral continuation	24
2.4.2.3. Interpretative remarks on environment of deposition	24
2.4.3. Tjåter Phyllite	24
2.4.3.1. Type section	24
2.4.3.2. Lateral continuation	26
2.4.3.3. Interpretative remarks on environment of deposition	27
2.4.4. Seinesbäcken Volcanite	27
2.4.4.1. Type section	27
2.4.4.2. Lateral continuation	29
2.4.4.3. Interpretative remarks on environment of deposition	31
2.4.5. Rikarsjön Phyllite	32
2.4.5.1. Type section	32
2.4.5.2. Lateral continuation	34
2.4.5.3. Interpretative remarks on environment of deposition	34

2.4.6.	Ruffe Greenstone	34
2.4.6.1.	Type section	34
2.4.6.2.	Lateral continuation	36
2.4.7.	Rövattnet Formation	36
2.4.7.1.	Description of the formation	36
2.4.7.2.	Lateral continuation	38
2.4.8.	Brackfjället Greenstone	38
2.4.8.1.	Type section	38
2.4.8.2.	Lateral continuation	38
2.4.9.	Skinnfällträsket Mylonite	40
2.4.9.1.	Description of the formation	40
3.	Metamorphism	41
3.1.	Opening remarks	41
3.2.	Björkvattnet Nappe	41
3.3.	Laxfjället Nappe	41
3.4.	Storfjället Nappe Complex	42
3.4.1.	The higher grade part	42
3.4.2.	The lower grade part	42
3.4.3.	Skinnfällträsket Mylonite	46
3.5.	Conclusions	48
4.	Deformation and metamorphism-deformation relationships	48
4.1.	Opening remarks	48
4.2.	Megascopic structures within the Storfjället Nappe Complex	48
4.3.	Mesoscopic structures – Folds	50
4.3.1.	Preliminary remarks	50
4.3.2.	Björkvattnet Nappe	50
4.3.3.	Laxfjället Nappe	51
4.3.4.	The higher grade part of the Storfjället Nappe Complex (Metartjärnen Formation)	51
4.3.5.	The lower grade part of the Storfjället Nappe Complex	51
4.3.5.1.	Early structures	51
4.3.5.2.	Late structures	56
4.3.6.	Skinnfällträsket Mylonite (Storfjället Nappe Complex)	57
4.4.	Mesoscopic structures – Foliations	59
4.4.1.	Opening remarks	59
4.4.2.	Björkvattnet Nappe	60
4.4.2.1.	Early foliations	60
4.4.2.2.	Late foliations	66
4.4.3.	Laxfjället Nappe	66
4.4.4.	The higher grade part of the Storfjället Nappe Complex	66
4.4.5.	The lower grade part of the Storfjället Nappe Complex	67
4.4.5.1.	Early foliations	67
4.4.5.2.	Late foliations	67
4.4.6.	Skinnfällträsket Mylonite (Storfjället Nappe Complex)	68
4.5.	Mineral growth and relationship to foliation	68
4.5.1.	Opening remarks	68
4.5.2.	Björkvattnet Nappe	68
4.5.2.1.	Biotite	68
4.5.2.2.	Amphibole	68
4.5.3.	Laxfjället Nappe	68

4.5.3.1.	Garnet	68
4.5.3.2.	Biotite	68
4.5.3.3.	Amphibole	69
4.5.4.	The higher grade part of the Storfjället Nappe Complex	69
4.5.4.1.	Garnet	69
4.5.4.2.	Biotite	73
4.5.4.3.	Amphibole	73
4.5.5.	The lower grade part of the Storfjället Nappe Complex	73
4.5.5.1.	Garnet	73
4.5.5.2.	Biotite	73
4.5.5.3.	Amphibole	74
4.5.5.4.	Chloritoid	74
4.5.5.5.	Stilpnomelane	74
4.5.5.6.	Siderite	74
4.5.6.	Skinnfällträsket Mylonite (Storfjället Nappe Complex)	78
4.5.6.1.	Garnet	78
4.5.6.2.	Biotite	78
4.5.7.	Minerals present in all nappes	78
4.5.7.1.	White mica	78
4.5.7.2.	Chlorite	78
4.5.7.3.	Accessory minerals	78
4.6.	Variation in metamorphism and deformation throughout the Jofjället area	82
4.6.1.	Opening remarks	82
4.6.2.	Björkvattnet Nappe (1)	83
4.6.3.	Laxfjället Nappe (2)	84
4.6.4.	Metartjärnen Formation (in Storfjället Nappe Complex) (3)	85
4.6.5.	Jofjället Calcareous Phyllite (in Storfjället Nappe Complex) (4)	86
4.6.6.	Formations in the middle part of the lower grade Storfjället Nappe Complex (5)	87
4.6.7.	Skinnfällträsket Mylonite and the uppermost formations in the lower grade Storfjället Nappe Complex (6)	88
4.7.	Discussion	89
4.7.1.	Correlation of structural and metamorphic events between different tectonic units	89
4.7.2.	Correlation of structural history of the lower grade Storfjället Nappe Complex with other areas in the Caledonides	91
5.	Stratigraphic and tectonic correlation with other areas in the Caledonides	94
5.1.	Opening remarks	94
5.2.	Correlation with adjacent areas	94
5.2.1.	Björkvattnet Nappe	94
5.2.2.	Laxfjället Nappe	95
5.2.3.	Storfjället Nappe Complex	96
5.3.	Correlation with the Trondheim-Tännforsen region	97
5.3.1.	Opening remarks	97
5.3.2.	Björkvattnet Nappe	98
5.3.3.	Laxfjället Nappe	100
5.3.4.	Storfjället Nappe Complex	100
6.	Summary of conclusions	101
	Acknowledgements	103
	References	104

SUMMARY

The rocks of the Jofjället area in Västerbotten belong to the Seve-Köli Nappe Complex. The overlying Rödingsfjället Nappe Complex occurs on both sides of the Norway-Sweden border, a few hundred metres north-west of the mapped area.

The succession, about 4 km thick, can be divided into at least three major nappe units separated by important thrusts. These nappe units are named from bottom to top; the Björkvatten Nappe, the Laxfjället Nappe and the Storfjället Nappe Complex. Within the Storfjället Nappe Complex, which is the dominant unit, there are several minor thrusts and repetitions of the rock sequence. A conspicuous feature – especially for the lower nappes – is their lens-like character.

Whitin these tectonic units a formal lithostratigraphy has been established consisting of thirteen different formations. The formations are described mainly from type sections, but their lateral continuation and possible environment of deposition are also discussed. The succession consists dominantly of supracrustal rocks. The metasediments comprise mainly phyllites of different composition. However, the rocks in the lowermost formation in the Storfjället Nappe Complex – the Metartjärnen Formation – are higher grade and more schistose in character. A formation with a large extension in the area is the Jofjället Calcareous Phyllite while the formation structurally above – the Tjäter Phyllite – is the country rock for the stratiform massive sulphide deposits, a study of which motivated this investigation. Metavolcanic rocks are present at five major levels. They are interpreted as lavas, tuffs and tuffites, both mafic and felsic volcanites being present. The Seinesbäcken Volcanite, of mixed mafic and felsic composition and showing distal tuff character, occurs above the ore-bearing Tjäter Phyllite. In the upper part of the Storfjället Nappe Complex there is a thick sequence of mafic volcanic rocks (predominantly lavas) – the Ruffe and Brackfjället Greenstones.

The rocks in the Jofjället area belong mainly to the lower greenschist facies. The upper and the lowermost parts of the Storfjället Nappe Complex – the Skinnfällträsket Mylonite and the Metartjärnen Formation respectively – belong, however, to the upper greenschist facies. There is thus an inversion of the metamorphic grade in the area. The metamorphism is of the Barrovian type. A special investigation shows that the composition of the carbonate minerals is influenced by the metamorphic grade.

The distinctive lithological sequence of low grade rocks is repeated in a series of thrust slices between the higher grade rock sequences. The sulphide deposits Tjäter, Storbäcksdalen and Rikarbäcken are thus interpreted to occur at the same stratigraphic level but repeated at two different tectonic levels.

In each of the tectonic units in the Jofjället area there has been established a sequence of deformation events, referred to as D_1 , D_2 , D_3 and D_4 . The late deformation phases (D_3 and D_4) formed numerous open to gentle folds with steep axial surfaces and varying orientation of fold axes (F_3) and locally kink folds with flat-lying axial surfaces (F_4). The axial surface to the late folds is locally developed as a spaced crenulation cleavage. The large synformal structure in the Jofjället area is an F_3 fold with a westerly fold axis orientation. The late folds are tentatively related to gravity-controlled disturbance in the basement due to superimposition of a denser allochthonous cover. The early deformation phases (D_1 and D_2) formed tight to isoclinal folds (F_1 and F_2). They are reclined folds with flat-lying axial surfaces and varying fold axis orientation. The difference between the two phases is the nature of the axial surfaces of the folds, which in the F_1 folds are developed as a phyllitic cleavage and in the F_2 folds as a crenulation cleavage. The F_1 folds are rather uncommon, while the F_2 folds are numerous in the vicinity of shear zones related to the D_2 thrusting. The main foliation, which is subparallel to bedding (S_0), formed during the early deformation phases. S_1 is developed as a phyllitic

cleavage, while S_2 is mainly developed as a metamorphic layering occasionally with relics of S_1 (S_{1+2}). S_2 (and S_{1+2}) is the main foliation over a large part of the area and is thought to be genetically related to the thrusting during D_2 .

In order to investigate the relation between metamorphism and deformation, porphyroblast growth and its relation to various foliations have been studied. As a result the formations in the Jofjället area have been arranged in six groups showing a similar tectonic and metamorphic history, which is shown graphically for each group. To summarize the relationship between metamorphism and deformation one may characterize F_1 as syn-metamorphic, F_2 as late-metamorphic and F_3 and F_4 as post-metamorphic fold phases.

The late deformation phases (mainly D_3) are present in the whole sequence and are more or less of the same age in each tectonic unit. The time relations of the early deformation phases are more uncertain. Assuming that the thrusting was synchronous in the whole rock pile, then the D_2 structures are also simultaneous in each tectonic unit. D_2 - D_4 is, thus, Silurian in age. Correlation of the earliest deformation structures (D_1) in each tectonic unit is not possible. Correlation with adjacent areas implies that the earliest deformation is Silurian in age in the Björkvattnet Nappe, while an Ordovician age is likely for D_1 in the higher grade part of the Storfjället Nappe Complex (Metartjärnen Formation). The age of D_1 in the Laxfjället Nappe, lower grade part of the Storfjället Nappe Complex and the Skinnfällträsket Mylonite is uncertain.

A table has been compiled which correlates structural events in the lower grade Storfjället Nappe Complex with other areas in the Caledonides. The areas chosen include the Tärna area, the northern Jämtland-southern Västerbotten area, the Marsfjällen area and the Kvarnbergsvattnet area.

A tentative tectono-stratigraphic correlation of the Jofjället area with other areas in the Scandinavian Caledonides is also put forward. These include the adjacent Tärna area, Björkvattnet-Virisen area, Södra Storfjället and the more remote Trondheim-Tännforsen region. The more important results are the following. The Björkvattnet Nappe in the Jofjället area has been correlated with two formations (Gilliks "series" and Viris quartzite) in the classical Köli stratigraphy of central Västerbotten. In the Laxfjället Nappe the gabbro-intruded Jovattnet Calcareous Phyllite has been correlated with similar lithologies in the eastern Trondheim-Tännforsen region and the Joeström Quartz-Keratophyre with the Ropen "granite" (Södra Storfjället) and the Fundsjø Group (eastern Trondheim region). The thin Metartjärnen Formation in the lowermost part of the Storfjället Nappe Complex is thought to be equivalent to the thick, relatively high grade sequence of Södra Storfjället (also Norra Storfjället) and to the Gula Group in the central Trondheim region. The Ruffe and Brackfjället Greenstones in the upper part of the Storfjället Nappe Complex are correlated with the Støren Group in the western Trondheim region. The rocks in the middle part of the Storfjället Nappe Complex are broadly correlated with the sequence situated in between the Gula and the Støren Groups ("pseudo-Gula").

These correlations have clarified the stratigraphy of the Jofjället area and placed it in a broader geological context. Tentative conclusions are that the Jofjället sequence is partly inverted, is Early Paleozoic in age and was deposited on the margins of both the Greenlandian and Baltoscandian plates.

1. GENERAL INTRODUCTION

1.1. OPENING REMARKS

The present paper, concerned with the stratigraphy, metamorphism and deformation of the Jofjället area, is the first in a planned series of publications dealing with different aspects of the geology in the Jofjället area. The second paper (in prep.) will be devoted to the geochemistry of the different volcanic formations in an attempt to establish, in particular, the tectonic environment in which the rocks formed. A third paper will discuss the Zn-Pb-Cu sulphide mineral deposits in the area. The ultimate aim of the whole investigation is to clarify the genesis of these deposits. In relation to this the first two papers provide the necessary context in which the mineral deposits may be studied.

1.2. LOCATION

The Jofjället area is situated in the county of Västerbotten in northern Sweden, between 65°44'N and 65°51'N latitude and 14°36'E and 15°07'E longitude. The area investigated lies at the junction between four different map sheets: 24E Joesjö, 24F Tärnaby, 25E Gräsvattnet and 25F Umfors. A detailed geological map of the Jofjället area on the scale of 1:50 000 and covering approximately 250 km² is presented (Plate 1). Location of analyses to be discussed in following publications is indicated on the map and in the type profiles of the various stratigraphic units (see following section).

1.3. PREVIOUS WORK

The first geological map which includes the Jofjället area is the county map of Västerbotten on the scale of 1:200 000 (Backlund and Quensel 1929). A description of this map was published later by Quensel (1960). Kulling has also presented a description and a 1:400 000 map of the Caledonian geology of Västerbotten (Kulling *in* Gavelin and Kulling 1955).

Murrin (1957) published a geological map on the scale of 1:75 000 over the Jofjället area with a description. This work concerned particularly a detailed mineralogical description of the rocks.

Later works by Kulling including the Jofjället area are the 1:1 000 000 map of the pre-Quaternary rocks of Sweden (Sveriges Geologiska Undersökning 1958, described by Kulling *in* Magnusson et al. 1960) and his synthesis of the Swedish Caledonides (*in* Strand and Kulling 1972). In the latter work Kulling introduced the term "Storfjäll nappe complex". According to Kulling, this nappe complex is situated in the north-western part of the Västerbotten mountains lying between the typical Seve-Köli rocks in the east and the Rödingsfjället nappe to the west (Fig. 1). According to the figure, a large part of the Jofjället area lies within the "Storfjäll nappe complex", but its lower boundary was only partly established in this area.

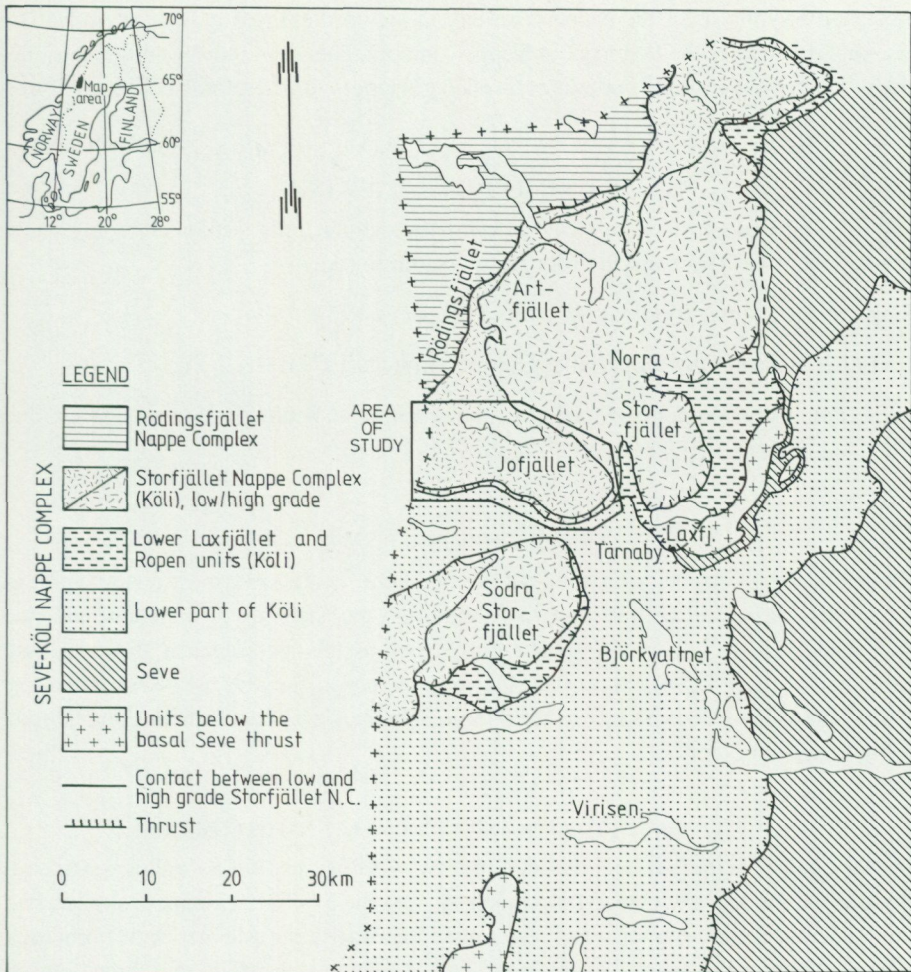


Fig. 1. Regional geological setting of the Jofjället area (modified after Zachrisson 1977).

Some of the mineral deposits in the Jofjället area were briefly described by Tegengren et al. (1924). Boliden AB has investigated the area and its mineral deposits in greater detail. The results consist of unpublished geological maps, one covering the whole area (1:100 000, by L. A. Barkey 1962) and another covering the central and eastern parts of the area (1:20 000, by L. A. Barkey and C. A. Nilsson 1962); there are also unpublished maps, profiles and records of drillcores from the mineral deposits. This Boliden AB material proved extremely useful during the mapping. A summary of the mineral deposits was presented by Grip and Frietsch (1973). A compilation of the Caledonian geology and mineral deposits of Västerbotten and northern Jämtland was made by Zachrisson (1977). Häggbom (1980) has recently

presented a synthesis of the nappe geometry in the northern part of Västerbotten. The essential division of the "Storfjället Nappe" into a higher grade lower unit (Kruttfjellet Nappe) and a lower grade upper unit (Jofjället Nappe) with a tectonic contact between them is discussed.

1.4. TECTONIC FRAMEWORK

The Jofjället area consists of at least three major tectonic units, separated by important thrusts (Plate 1). These are in order from bottom to top:

Björkvattnet Nappe (Björkvattnet Unit of Stephens 1977)

Laxfjället Nappe (Lower Laxfjället Unit of Stephens 1977)

Storfjället Nappe Complex (Storfjäll nappe complex of Kulling *in* Strand and Kulling 1972 and Upper Laxfjället Unit of Stephens 1977).

1.4.1. BJÖRKVATTNET NAPPE

The Björkvattnet Nappe, which is little studied here, is the lowermost tectonic unit in the Jofjället area and comprises two formations, the Skälvattnet Volcanite and the Västansjö Phyllitic Quartzite, which wedge out to the west against the overlying Laxfjället Nappe. The metamorphic grade is mainly in the chlorite subfacies of the greenschist facies but increases to the biotite subfacies when approaching the contact to the Laxfjället Nappe.

1.4.2. LAXFJÄLLET NAPPE AND STORFJÄLLET NAPPE COMPLEX

The Laxfjället Nappe has been divided into two formations, the Jovattnet Calcareous Phyllite and the Joeström Quartz-Keratophyre, and the Storfjället Nappe Complex into nine different formations of which the lowermost one is the Metartjärnen Formation (Plate 1). Within the Storfjället Nappe Complex, which is the dominant nappe unit in the area, there are several thrusts of secondary significance.

The whole packet, including the Västansjö Phyllitic Quartzite, the Jovattnet Calcareous Phyllite, the Joeström Quartz-Keratophyre, and the Metartjärnen Formation, is to a greater or lesser extent strongly deformed and is in part mylonitic. Furthermore, the Laxfjället Nappe is extremely attenuated in the Jofjället area. It is, therefore, quite difficult to assess the relative degree of deformation along the contacts of the Joeström Quartz-Keratophyre. This is of particular significance when trying to establish the nature of the lower contact of this formation.

Although it is difficult to ascertain real cutting out relationship in a sequence so deformed and attenuated like the one under consideration, it seems that both the Joeström Quartz-Keratophyre and the Jovattnet Calcareous Phyllite are locally cut out discordantly at the contact to the Metartjärnen Formation. The base of the Storfjället Nappe Complex has, therefore, been placed at the base of the Metartjärnen Formation.

The Västansjö Phyllitic Quartzite seems to wedge out against the overlying Jovattnet Calcareous Phyllite. The contact is phyllonitic and is often marked by attenuated isoclinal folds. The Laxfjället Nappe, therefore, comprises the rocks in between the Storfjället Nappe Complex and the base of the Jovattnet Calcareous Phyllite.

Within this part of the Caledonides the Laxfjället Nappe and the Storfjället Nappe Complex exhibit extreme lens-like geometries (Häggbom 1980). In the Jofjället area, the Laxfjället Nappe is 10–100 m thick, while over the Formliden Antiform (Stephens 1977) to the east around Tärnaby the same unit is about 1 000 m thick. The Laxfjället Nappe is mainly within the biotite subfacies of the greenschist facies. The Storfjället Nappe Complex consists of an upper greenschist facies (garnet grade) phyllonitic schist sequence at the base, only about 200 m thick in the southern part (Metartjärnen Formation), overlain abruptly by about 3 000 m of lower greenschist facies phyllites and metavolcanites (in the upper part biotite and garnet grade rocks are also present). The boundary between these two units in the Storfjället Nappe Complex, may represent an early tectonic break (see also Häggbom 1980). However, the problems associated with this boundary are well illustrated by the varying opinions expressed by Aleva (1950) and Mulder (1951) from areas to the north of Jofjället and the discussion by Kulling (*in* Strand and Kulling 1972, p. 248). To the north and north-east the higher grade base swells dramatically to several kilometres in thickness, containing amphibolite facies, partly migmatized schists and amphibolites (cf. for example Uyenbogaardt 1961), while the overlying very low grade sequence is less than 500 m in thickness. The detailed correlation of the lithologies within the Metartjärnen Formation with the higher grade rocks to the north is open to some question. As will be discussed in the following section, individual formations within the Laxfjället Nappe and Storfjället Nappe Complex also show marked lens-like character.

The Jofjället area provides the most complete low grade stratigraphy of the Storfjället Nappe Complex in Västerbotten. It is also within these phyllites and metavolcanites that the massive Zn-Pb-Cu sulphide deposits are situated. For this reason the low grade rocks of the Storfjället Nappe Complex are the main concern of this paper.

A zone of more or less mylonitic rocks near the international border to Norway defines the north-western limit of the mapped area. This Skinnfällträsket Mylonite which is the tectonically highest formation investigated in the Jofjället area belongs mainly to the garnet and biotite subfacies of the greenschist facies. Since the Skinnfällträsket Mylonite deviates in certain aspects from the rest of the Storfjället Nappe Complex it will often be discussed separately in this paper.

1.4.3. CLOSING REMARKS ON STRUCTURES

The regional foliation in the area is flat-lying and complex, often composed of two foliations showing intense transposition characteristics and was established, like the thrusts, during the "early" deformation stages.

The dominant major structure is a large open synform, with a fold axis plunging

gently westwards (Jofjället Synform). This synformal structure interferes with folds trending N-S, creating a distinctive dome and basin outcrop pattern especially in the eastern part of the area. These intersecting E-W- and N-S-trending structures formed "late" in the deformation history.

2. LITHOSTRATIGRAPHY

2.1. OPENING REMARKS

A formal lithostratigraphy consisting of 13 formations has been established within the three different nappe units. A short description of these formations now follows, the formations being described within each nappe unit in their tectonic order from bottom to top.

2.2. BJÖRKVATTNET NAPPE

2.2.1. SKÄLVATTNET VOLCANITE

2.2.1.1. Type section

The type section is situated in the brook 200 m north of Skälvattnet in the south-western part of the Jofjället area (24E 9-j; Fig. 2). Here the formation is 85 m in thickness.

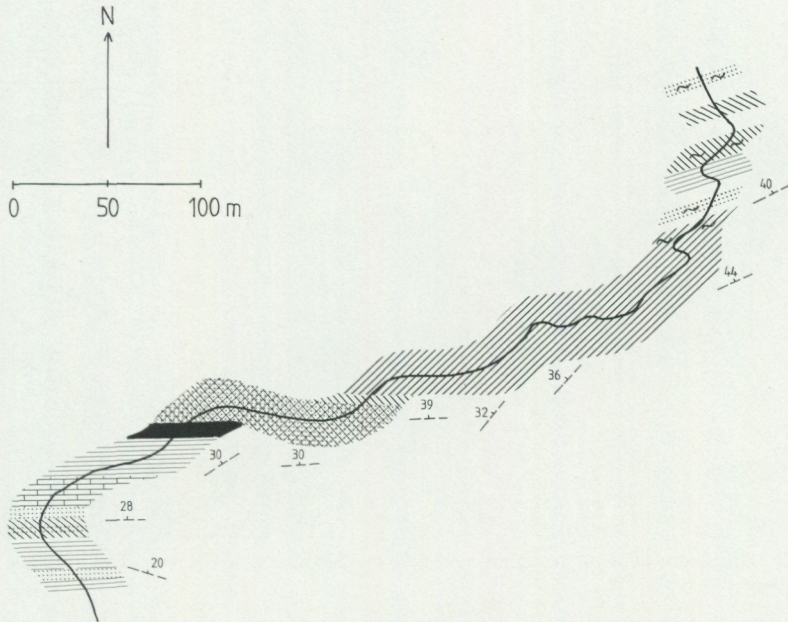
The lower part of the formation consists of rather felsic tuffs and tuffites (Zachrisson 1971) and non-volcanogenic sediments including terrigenous sandy phyllite (3 m), limestone (8 m), calcareous pelite (10 m), and graphitic phyllite (4 m). The upper purer volcanite part of the formation starts with a thin quartz-keratophyre, which is succeeded by a thick (40 m) pile of mafic volcanites. The essential minerals in the mafic volcanites include albite, bright green chlorite (15–30 %), epidote (6–55 % and increasing upwards in the formation), amphibole (5–20 % and occasionally poikiloblastic) and variable amounts of calcite. Quartz, white mica and biotite may be present in small quantities.

The lower boundary of the formation is adequately exposed and has been placed below the first appearance of volcanogenic rocks (felsic tuffs and tuffites). At the top there is a small gap in exposure to the following formation, which consists here of phyllites partly with a mylonitic appearance and containing abundant quartz veins. The same features are characteristic also of the uppermost part of the volcanites.










2.2.1.2. Lateral continuation

The formation can be followed westwards to the Norwegian border and eastwards it crosses the Joesjö-Tärnaby road at a point 3 km west of Nedre Jovattnet. North of this area another volcanic horizon – more felsic in composition and at a higher structural level – appears to wedge out against the overlying Jovattnet Calcareous Phyllite. In the south-east of the map area around Västansjö there occur volcanogenic rocks,

SKÄLVATTNET VOLCANITE



LEGEND

-  pelitic phyllite
-  quartz phyllite/schist
-  graphitic phyllite
-  limestone
-  greenstone/greenschist
-  quartz-keratophyre
-  tuffite (mixed)
-  tuffite (felsic)
-  mylonite
- A70 chemical sample

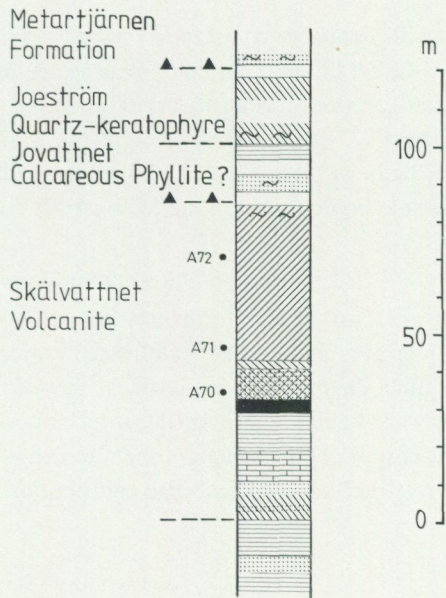


Fig. 2. Type section of the Skälvattnet Volcanite.



Fig. 3. Pillow structures in greenstone belonging to "Skälvattnet Volcanite" (E79 road side locality at Västansjö, 24F 8-d).

which with regard to composition and structural level, largely resemble the Skälvattnet Volcanite, but also contain pillow structures at one roadside locality (Fig. 3). The volcanites around Västansjö occur at the same level as the Ruffevare greenschist (Stephens 1977) to the south-east in the Tärna area, which, according to Stephens (1977), belongs to the lower part of the Gilliks Formation (Kulling 1933). A few serpentinite bodies occur in the Skälvattnet Volcanite.

2.2.1.3. Interpretative remarks on environment of deposition

The lower part of the formation, consisting of limestone and fine-grained pelite (including graphitic phyllite) with a contribution of fine sandy material, suggests a rather quiet environment into which occasional incursions of sand from a terrigenous source were being deposited (distal turbidites?). The dominantly mafic volcanites in the upper part of the formation seem to consist mostly of tuffs, but the local presence of pillow structure indicates some contribution from submarine lava flows.

2.2.2. VÄSTANSJÖ PHYLLITIC QUARTZITE

2.2.2.1. Type section

The type section is situated in Samuelssonbäcken near Västansjö in the eastern part of the Jofjället area (24F 8,9-d; Fig. 4). Here the formation is about 300 m in thickness.

The formation consists of phyllitic quartzite and feldspathic greywacke, sometimes a little calcareous. The essential minerals include quartz (65–85 %), albite (5–15 %),

VÄSTANSJÖ PHYLLITIC QUARTZITE

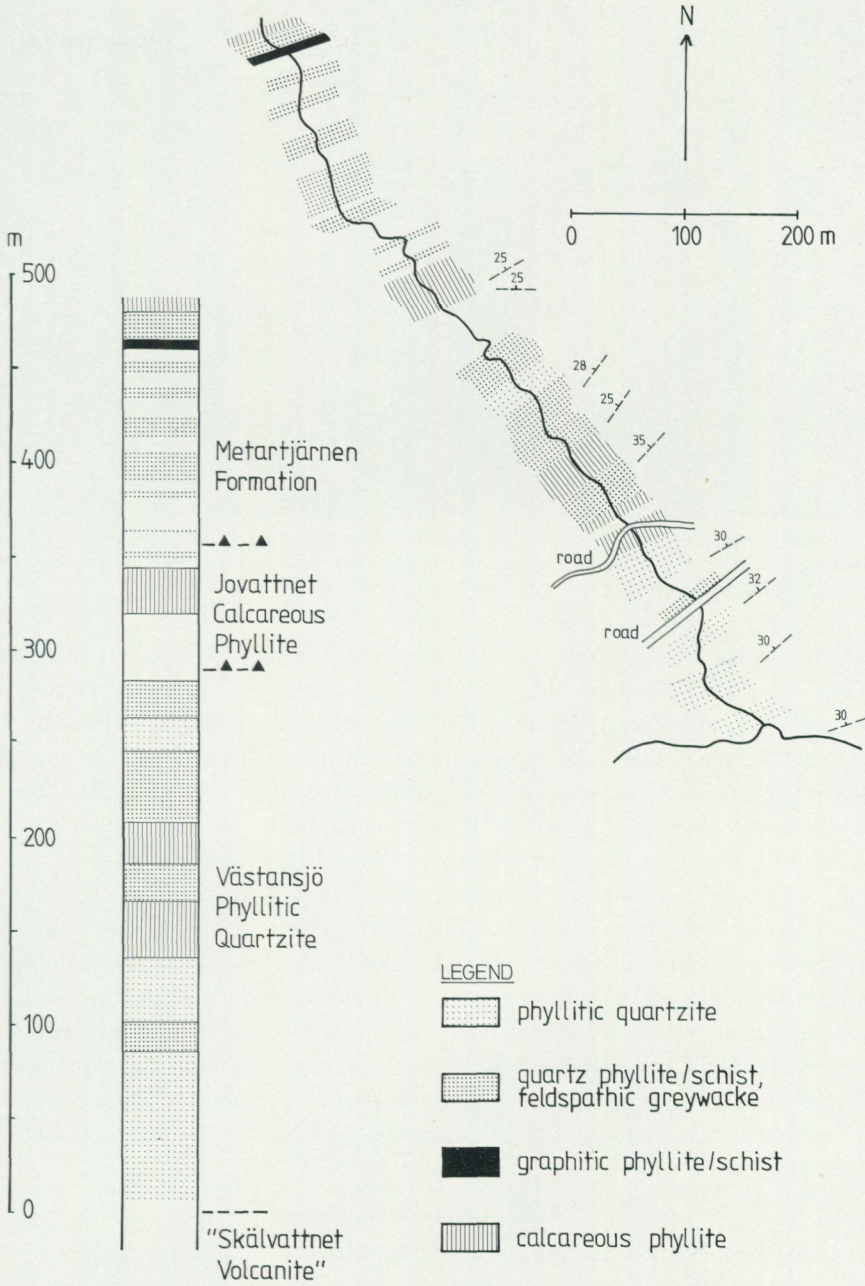


Fig. 4. Type section of the Västansjö Phyllitic Quartzite.



Fig. 5. Contact between Västansjö Phyllitic Quartzite and overlying Jovattnet Calcareous Phyllite. Note the abundant quartz veins and phyllonitic character of the calcareous phyllite. The contact is interpreted as the base of the Laxfjället Nappe (E79 road side locality north of Västansjö, 24F 9-d).

white mica (5–15 %), chlorite (1–5 % and ripodolitic in composition), and calcite (1–7 %). Biotite occurs in all samples but in small quantities. Tourmaline (schorl) is a common accessory mineral. There are also a few members of calcareous phyllite. The small contribution of pelitic and especially graphitic material is striking. The grain size is about 0.2 mm but larger clasts of quartz and feldspar are common. Graded bedding occurs in some zones. Bed thickness up to 10 cm has been noted.

Neither the lower nor the upper contact is adequately exposed in the type section. A supplementary type section has, therefore, been chosen in Gustavssonbäcken, 1.2 km to the south of Samuelssonbäcken (see Fig. 6). Here the thickness of the formation is only about 40 m, but both contacts are well exposed. The lower contact is mylonitic in character with strongly deformed greenschists ("Skälvattnet Volcanite") underlying quartz-rich rocks which are also strongly deformed (Västansjö Phyllitic Quartzite). Furthermore, in the border zone there are thick quartz segregations and a thin quartz-rich mylonite, which may represent a pure quartzite. The upper contact is sharp; a phyllitic quartzite is overlain by a pronounced phyllonitic rock (Jovattnet Calcareous Phyllite; Fig. 5).

2.2.2.2. Lateral continuation

To the east the formation thickens and can be correlated with similar rocks in the Tärna area, where according to Stephens (1977), they belong to the Lövfjäll Formation (Viris quartzite facies of Kulling 1933). To the west the formation thins out rapidly but can

be followed confidently as far as Nedre Jovattnet. West of this lake, in a structural position above the volcanites, there are occasionally thin layers that resemble the rock types in the Västansjö Phyllitic Quartzite; they may represent this formation in a strongly deformed and extremely attenuated condition.

2.2.2.3. Interpretative remarks on environment of deposition

It is tentatively suggested that the rocks of the Västansjö Phyllitic Quartzite represent a more proximal turbidite facies.

2.3. LAXFJÄLLET NAPPE

2.3.1. JOVATTNET CALCAREOUS PHYLLITE

2.3.1.1. Type section

The type section is situated in Gustavssonbäcken at Västansjö in the eastern part of the Jofjället area (24F 8-d; Fig. 6). Here the formation is only 12 m in thickness.

The formation consists of more or less calcareous phyllites, often with abundant quartz veins which give a phyllonitic appearance. The grain size is 0.1–0.2 mm, but there are also larger clasts of albite. The essential minerals include quartz (40–60 %), albite (5–20 %), white mica (5–25 %), chlorite (3–10 %), and carbonate (5–20 %, mainly calcite, but also ankerite has been identified). Biotite is often present in small quantities in the formation to the east of Nedre Jovattnet. In the calcareous phyllites there are elongate and concordant bodies of metagabbroic rocks. They are often strongly foliated, but the cores of the larger bodies have subophitic textures preserved. The essential minerals are albite, amphibole, chlorite and epidote (mostly in small quantities).

The lower contact to the Västansjö Phyllitic Quartzite is well exposed (Fig. 5). Phyllonitic calcareous phyllite with abundant quartz veins is underlain, with a sharp contact, by a phyllitic quartzite. The upper contact – here to the Metartjärnen Formation – is also adequately exposed. The boundary, that is not so sharp, has been placed where the rocks are reduced in calcite and contain a higher content of quartz and especially graphite; the border zone is phyllonitic.

2.3.1.2. Lateral continuation

The formation can be followed in a north-easterly direction to the limit of the map. Outside the map area the formation occurs as far north as east of Hemavan (unpublished map by Uytengbaardt 1961). Correlation is also possible with similar but much thicker calcareous phyllites with only a few metagabbros in the Tärna area (Stephens 1977). Stephens has suggested that the gabbro-intruded calcareous phyllites in the Tärna area should be correlated with the Lasterfjäll Calcareous Phyllite of Zachrisson (1969) and lie in a separate tectonic unit to the Lövfjäll calcareous phyllite (Kulling 1933). The formation can be followed north-west of Nedre Jovattnet, where it

JOVATTNET CALCAREOUS PHYLLITE ETC.

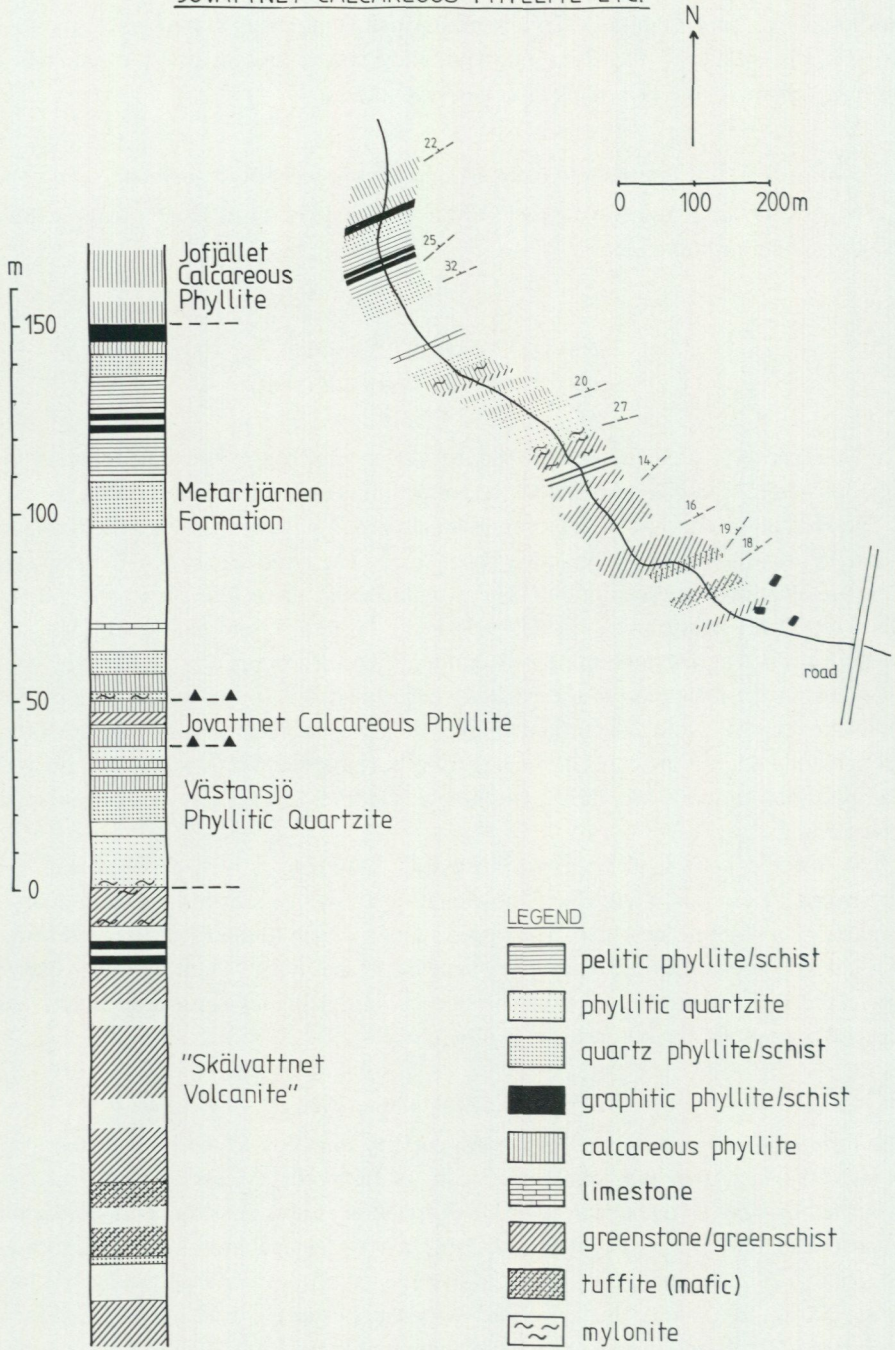


Fig. 6. Type section of the Jovattnet Calcareous Phyllite.

thickens and is heavily intruded by metagabbro. West of Metartjärnen the formation thins out rapidly and its continuation is dubious in the very attenuated sequence to the west.

2.3.2. JOESTRÖM QUARTZ-KERATOPHYRE

2.3.2.1. Description of the formation

The formation is found in a few places below the Metartjärnen Formation in the southern part of the Jofjället area. No type section has been established for this formation, but it is present in Fig. 2. The maximum thickness amounts to about 30 m but is generally much less.

The formation consists mainly of massive quartz-keratophyre. Some more mafic rocks have also been recognized. The matrix is fine-grained, in places with larger phenocrysts of quartz and albite. Quartz and albite dominate the mineralogy, but in the more mafic parts chlorite and epidote are also important. White mica is always present in small quantities and biotite, calcite and garnet (occasionally chloritized) may be present.

No contacts are exposed. The formation is overlain by the Metartjärnen Formation and is underlain by phyllites, that in the eastern part of the area belong to the Jovattnet Calcareous Phyllite and in the western part (Fig. 2) have been tentatively correlated with this formation.

2.3.2.2. Lateral continuation

The Joeström Quartz-Keratophyre can be traced over the Formliden Antiform around Hemavan (Uytenbogaardt 1961) and connects up with the Layered Metavolcanic Formation of Stephens (1977). This unit is more than 500 m thick (Stephens 1977) in the Tärnaby area. The so-called Ropen granite (Beskow 1927) on Södra Storfjället, about 20 km to the south, is probably also a stratigraphic equivalent occurring at the same structural level. This predominantly felsic sequence provides an excellent example of the extreme lens-like character of some of the formations within the Jofjället-Tärna region.

2.4. STORFJÄLLET NAPPE COMPLEX

2.4.1. METARTJÄRNEN FORMATION

2.4.1.1. Type section

The type section is situated in Storbäcken in the southern part of the Jofjället area (24F 9-a; Fig. 7). Here the formation is about 200 m in thickness.

The lower part of the formation consists of quartz-rich mica schists which become more pelitic upwards, the texture of the rocks often being transitional between typical schist and phyllite. This monotonous sequence is interrupted by thinner beds of graphitic schist. A characteristic mineral is garnet which increases in quantity and size upwards in the sequence towards the more pelitic rocks. The upper part of the

METARTJÄRNE N FORMATION

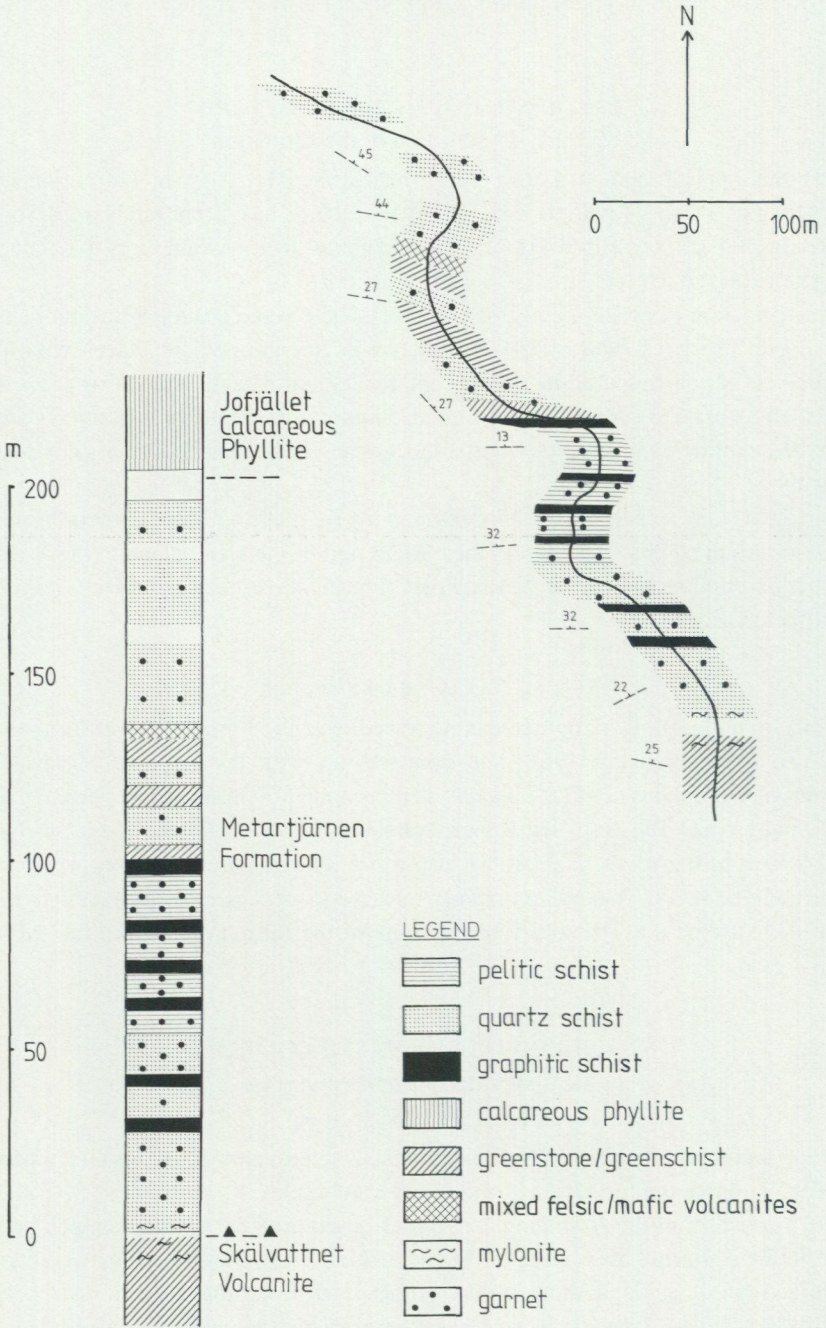


Fig. 7. Type section of the Metartjärnen Formation.

formation commences with a suite of volcanites – greenschists and greenstones with subordinate more felsic rocks. Then follow mica schists, often somewhat calcareous and a little graphitic. Garnet decreases in quantity and size upwards. The rocks of the Metartjärnen Formation are more or less phyllonitic, especially near the lower contact. The grain size is usually between 0.1–0.2 mm, but larger porphyroclasts are common. Important minerals in the mica schist include quartz, albite, white mica, chlorite, biotite, \pm garnet (occasionally more or less chloritized), \pm calcite, \pm tourmaline (schorl). Important minerals in the mafic volcanites include albite, amphibole chlorite, epidote, biotite, sphene, \pm calcite.

The Metartjärnen Formation lies on top of the Skälvattnet Volcanite. Although the actual contact is not exposed, both formations are strongly deformed in the vicinity of the contact. The upper contact is not exposed, so a supplementary type section has been chosen where both contacts can be studied; this is situated in Gustavssonbäcken at Västansjö (24F 8-d; Fig. 6). The Metartjärnen Formation here rests with marked tectonic contact (phyllonitic) on the Jovattnet Calcareous Phyllite; the garnets in the Metartjärnen Formation are partly chloritized near the contact. At the upper contact the Metartjärnen Formation underlies calcareous phyllites of the Jofjället Calcareous Phyllite. Immediately below the contact there is a graphitic phyllite (4 m thick) and then a calcareous phyllite (3 m thick) above the more common mica schists of the Metartjärnen Formation. The mica schist of the Metartjärnen Formation is biotite- and garnet-bearing, the calcareous phyllite in the upper part has biotite, but no garnet and the graphitic phyllite at the contact has minor biotite and garnet, partly chloritized. The calcareous phyllite of the Jofjället Calcareous Phyllite contains biotite, which rapidly decreases in abundance away from the contact. The rocks at the contact appear deformed (phyllonitic). It may be of importance to note that the lithologies in the uppermost part of the section in Gustavssonbäcken deviate from the typical schists below. In other places there are rocks in a similar tectonic position which are difficult to incorporate in either the Metartjärnen Formation or the Jofjället Calcareous Phyllite. They characteristically have a varied lithology; quartzitic and graphitic rocks and even a pure limestone lens have been found. This thin and lens-like unit (0–30 m) seems to have a somewhat lower metamorphic grade than the Metartjärnen Formation, but has for the case of convenience been included in this formation on the geological map (Plate 1).

2.4.1.2. Lateral continuation

The Metartjärnen Formation extends from the Norwegian border in the south-west along the southern side of Jofjället as a rather thin and lens-like unit. In the eastern part of Jofjället the formation thickens and can be followed around the large synformal structure to the north and west. Outside the map area on Artfjället to the north, Norra Storfjället to the north-east and Södra Storfjället to the south this unit attains a thickness of several thousand metres. It is also possible to correlate at least the lower

part of the Metartjärnen Formation with the Staurolite Schist Formation in the Tärna area to the south-east. According to Stephens (1977) the base of this unit forms the sole of the Storfjället Nappe Complex. The igneous rocks in the type section at Storbäcken seem to be traceable towards the Norwegian border, where also rocks with gabbroic texture occur. In the eastern part of the Jofjället area no igneous rocks have been found within this formation, but in the northern part igneous rocks are again present. In the eastern and northern part a calcareous member is also discernible.

The upper contact – that is the contact between the Metartjärnen Formation and the Jofjället Calcareous Phyllite – is generally poorly exposed in the Jofjället area. In the few places where the contact has been studied – as in Gustavssonbäcken – it appears tectonic. The mica schist of the Metartjärnen Formation is usually garnetiferous, often chloritized. The Jofjället Calcareous Phyllite is not garnetiferous, while biotite decreases in quantity away from the contact. Thus, the metamorphic grade apparently changes quite rapidly over the contact. However, the chemical composition of the rocks must also be taken into account. In this context, it is worth noting that the calcareous rocks in the Metartjärnen Formation are not garnetiferous, while biotite content is lower than in the mica schist.

2.4.2. JOFJÄLLET CALCAREOUS PHYLLITE

2.4.2.1. Type section

The type section is situated in the upper course of Samuelssonbäcken north of Västansjö in the eastern part of the Jofjället area (24F 9-d; Fig. 8). Here the formation is about 1 200 m in thickness.

The formation is composed of a thick pile of carbonate-rich phyllites consisting of an interlayering of thicker (0.5–10 cm) psammitic and thinner pelitic layers. In volume the psammitic beds dominate over the pelitic laminae especially in the upper part of the formation. Graded bedding-like structures occur, but deformation and metamorphism have largely obliterated the primary textures making the determination of younging directions hazardous. The grain size is 0.1–0.2 mm, but larger porphyroclasts are also present. In the more psammitic layers the quartz content is 45–57 % and the albite content is 14–20 % (Fig. 8), the quartz-albite ratio being quite constant at 3:1. The carbonate content is 15–30 % and increases in the upper part of the formation where the phyllosilicate content decreases. In the lowermost part of the formation there is more calcite than ankerite, but in the remainder of the formation ankerite dominates over calcite. The ankerite becomes more Fe-rich higher up in the formation. White mica (5–20 %) consists of muscovite which in the upper part occasionally occurs together with paragonite. Chlorite is mostly subordinate in quantity (<10 %). Biotite is only present in the lowermost part of the formation. Accessory minerals include tourmaline (schorl), apatite, zircon, sphene and opaque minerals.

The lower contact to the Metartjärnen Formation is not exposed, so a supplementary type section has been established in Gustavssonbäcken 1 200 m to the south (24F 8-d;

JOFJÄLLET CALCAREOUS PHYLLITE

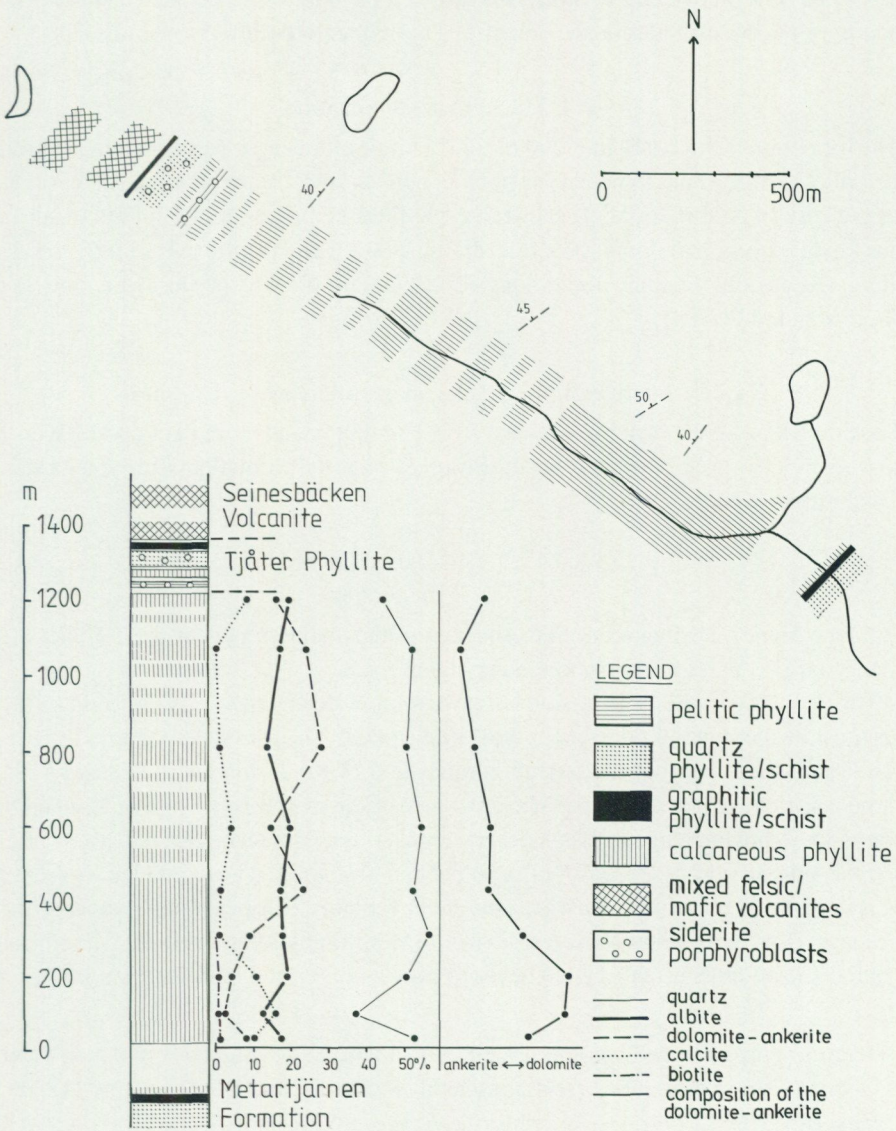


Fig. 8. Type section of the Jofjället Calcareous Phyllite.

Fig. 6). Here the Jofjället Calcareous Phyllite is underlain by a very graphitic phyllite, the contact having a phyllonitic appearance. The contact to the overlying formation is not exposed, the gap of non-exposure being about 10 m. The rock above the boundary is characterized by siderite porphyroblasts and belongs to the Tjäter Phyllite. In Seinesbäcken, in the southern part of the Jofjället area, the contact between the two

formations is exposed (24F 9-b; Fig. 9). Here also siderite porphyroblasts are present in the phyllite above the contact, while the rock below the contact contains both non-porphyroblastic siderite and ankerite. The contact is believed to be primary.

2.4.2.2. Lateral continuation

The formation is thick (about 1 200 m) in the hinge of the large west-plunging synform (Jofjället Synform) but thins out substantially on its limbs, especially the southern one. In the eastern part of Jofjället, calcareous phyllites belonging to the Jofjället Calcareous Phyllite occur in a domal structure. In the western and central part of the map area there are various tectonic repetitions of calcareous phyllite of this type (see later discussion and Plate 1).

2.4.2.3. Interpretative remarks on environment of deposition

The thin nature of the bedding between more psammitic and more pelitic interlayers as well as the presence of graded bedding suggest that the formation represents a more distal turbidite facies.

2.4.3. TJÅTER PHYLLITE

2.4.3.1. Type section

The type section is situated in Seinesbäcken in the southern part of the Jofjället area (24F 9-b; Fig. 9). Here the formation is 160 m thick.

This formation will be treated in somewhat more detail since it is the country rock for most of the mineral deposits in the Jofjället area. The rocks show a rapid vertical variation in lithology but the overall composition of the formation indicates a rather carbonate-rich, pelitic rock type. The grain size of the matrix is 0.1 mm or less and the grains are strongly elongate. Small quartz lenses, often with recrystallized grains, are – like the siderite porphyroblasts – prior to the main foliation. The quartz lenses seem to be relics of isoclinal folds, to which the main foliation is a penetrative axial surface cleavage. The rocks often show a tendency towards a phyllonitic texture. 12 informal members have been established. They will now be described in order from bottom to top.

1. Siderite porphyroblast-bearing phyllite (10–15 m). The blasts are numerous and about 1 mm in size. The essential minerals include quartz (37 %), albite (17 %), ankerite (9 %), siderite (6 %), chlorite (6 %), and muscovite (25 %).
2. Pelitic phyllite, in places with tiny (0.2–0.3 mm) siderite porphyroblasts (35–40 m). The essential minerals include quartz (28 %), albite (17 %), ankerite (6 %), siderite (<1 %), chlorite (18 %), and muscovite (30 %).
3. Pelitic phyllite, somewhat carbonatic (11 m). The essential minerals include quartz (43 %), albite (23 %), ankerite (7 %), chlorite (2 %), and muscovite (25 %).
4. Graphitic phyllite (9 m.) (The graphite content is rather low.)

TJÅTER PHYLLITE

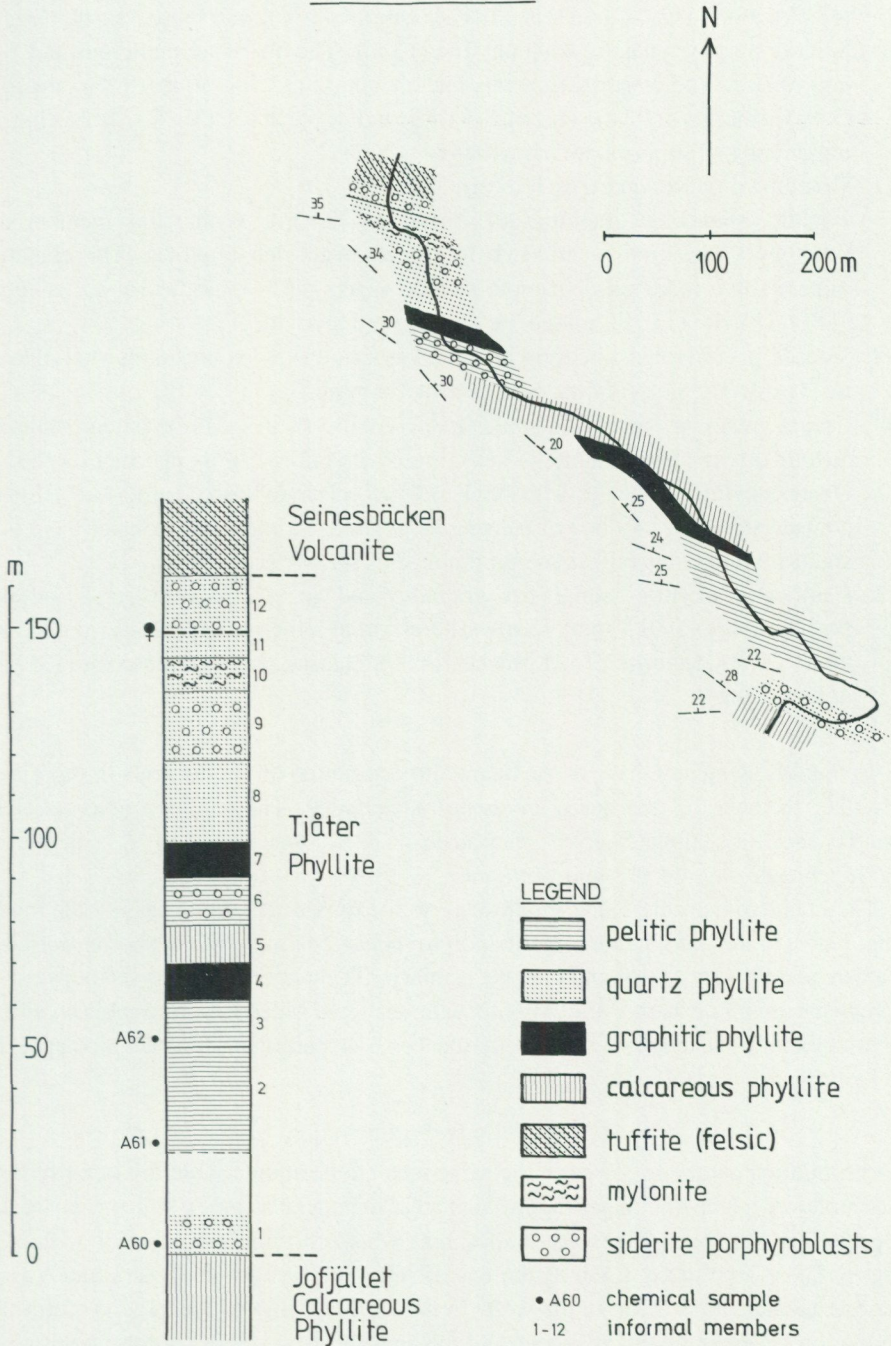


Fig. 9. Type section of the Tjäter Phyllite.

5. Calcareous (ankeritic) phyllite (10 m). The essential minerals include quartz (48 %), albite (12 %), ankerite (18 %), chlorite (7 %), and muscovite (15 %).
6. Siderite porphyroblast-bearing phyllite (12 m). The blasts are numerous and 1–2 mm in size. The essential minerals include quartz (35 %), albite (8 %), ankerite (5 %), siderite (12 %), chlorite (5 %), and white mica (35 %), consisting of muscovite and subordinate paragonite.
7. Graphitic phyllite, quartz-rich (8 m).
8. Phyllite, somewhat graphitic and carbonatic (20 m). Within this member the lithology varies from quartz-rich to phyllosilicate-rich phyllites. The essential minerals in a more pelitic sample include quartz (36 %), albite (14 %), ankerite (4 %), chlorite (15 %), muscovite (30 %), and graphite.
9. Siderite porphyroblast-bearing phyllite, rather quartz-rich and somewhat ankeritic (11 m). The porphyroblasts are about 1 mm in size.
10. Quartz mylonite, in places somewhat graphitic (8 m). The essential minerals include quartz (73 %), albite (15 %), muscovite (12 %), and ankerite (<1 %).
11. Quartz phyllite, in places with small siderite porphyroblasts (7 m). At the lower contact there is a thin bed of calcareous phyllite. At the upper contact there is a small sulphide mineralization in a thin bed of sericite schist.
12. Carbonatic phyllite, somewhat graphitic and in places with small siderite porphyroblasts (≤ 0.5 mm; 15 m). The essential minerals include quartz (45 %), albite (8 %), ankerite (7 %), siderite (4 %), chlorite (<1 %), muscovite (35 %), and graphite.

In the following summary of the quantitative variation of the minerals in the Tjäter Phyllite, member 10 (the quartz mylonite) is excluded. The variation is as follows: quartz 33–48 %, albite 8–23 %, carbonate 4–18 %, ankerite 4–18 %, siderite 0–12 %, chlorite < 1–15 %, and white mica 15–35 %.

The boundaries of the Tjäter Phyllite are well exposed. As stated earlier, the lower one, between the conspicuous siderite porphyroblast-bearing phyllite and the Jofjället Calcareous Phyllite, is thought to be primary. The upper boundary is between a somewhat graphitic carbonatic phyllite with scattered siderite porphyroblasts and a light-coloured volcanogenic rock (Seinesbäcken Volcanite); this contact also appears to be primary.

2.4.3.2. Lateral continuation

The formation can be followed in the same tectonic position around the large synformal structure which dominates the Jofjället area. In general a similar stratigraphy to the type locality has been observed in the areas where the mineral deposits occur. Of these, Tjäter is situated 1 km to the east of the type locality and Östra and Västra Storbäcksdalen about 2 km to the west. In the northern limb of the large synform the formation becomes more calcareous and the characteristic siderite porphyroblasts are missing; it, thus, becomes difficult to distinguish this formation from the Jofjället

Calcareous Phyllite. In the central and western parts of Jofjället there are large areas consisting of often calcareous pelitic phyllite; siderite porphyroblasts occur only in restricted areas (Plate 1). These pelitic phyllites are thought to be equivalents of the Tjåter Phyllite, tectonically repeated at higher structural levels.

As can be seen on the geological map (Plate 1) in many areas there is a considerable lateral variation in lithology of the Tjåter Phyllite. Pelitic phyllites conspicuously grade laterally into quartz-rich rocks with mylonitic appearance. There are two alternatives for the origin of these quartz-rich rocks. 1. They may represent quartz-rich sediments, where chert might be an important component. 2. They may have formed secondarily by metasomatic processes, being related to intense differential movements.

2.4.3.3. Interpretative remarks on environment of deposition

The pelitic character of the rocks indicates a quiet sedimentary environment, with a rather slow influx of erosional products derived from a terrestrial source. The presence of graphite indicates locally reducing conditions in the basin of deposition. The genesis of the siderite porphyroblasts is problematic; they are prior to the main foliation and may be interpreted as either diagenetic, metamorphic or a combination of these possibilities. The porphyroblasts are more or less restricted to the southern part of the Jofjället area, and in particular, to the mineral deposits.

2.4.4. SEINESBÄCKEN VOLCANITE

2.4.4.1. Type section

The type section is situated in the upper course of Seinesbäcken, in the southern part of the Jofjället area (24F 9-b; Fig. 10). Here the formation is 140 m in thickness.

The formation consists of a more or less well layered volcanogenic sequence. The rocks in the lower and upper parts of the type section are light-coloured, while the rocks in the middle part are light-green in colour. In places they are somewhat carbonatic and magnetite (also ilmenite) is a conspicuous mineral. Grain size is 0.1–0.2 mm, with some larger porphyroclasts of albite. The minerals tend to be segregated in mica- and quartz-rich domains. There are also small lenses and stringers of pure quartz (occasionally including carbonate or magnetite) which often seem to be isoclinally folded. This layering could be of a primary nature, but is probably largely metamorphic.

Fig. 10 shows that the proportion of the different minerals varies substantially within the formation. Albite varies between 0 and 49 %, being remarkably low in the upper third of the formation, where instead quartz (16–65 %) is abundant. White mica (25–48 %), including muscovite and often paragonite, is abundant at all levels. The light-coloured rocks are very poor in chlorite (Fe-ripodolitic), while the light-green rocks are richer (0–15 %). Epidote (0–4 %) is found only in some of the light-green

SEINESBÄCKEN VOLCANITE

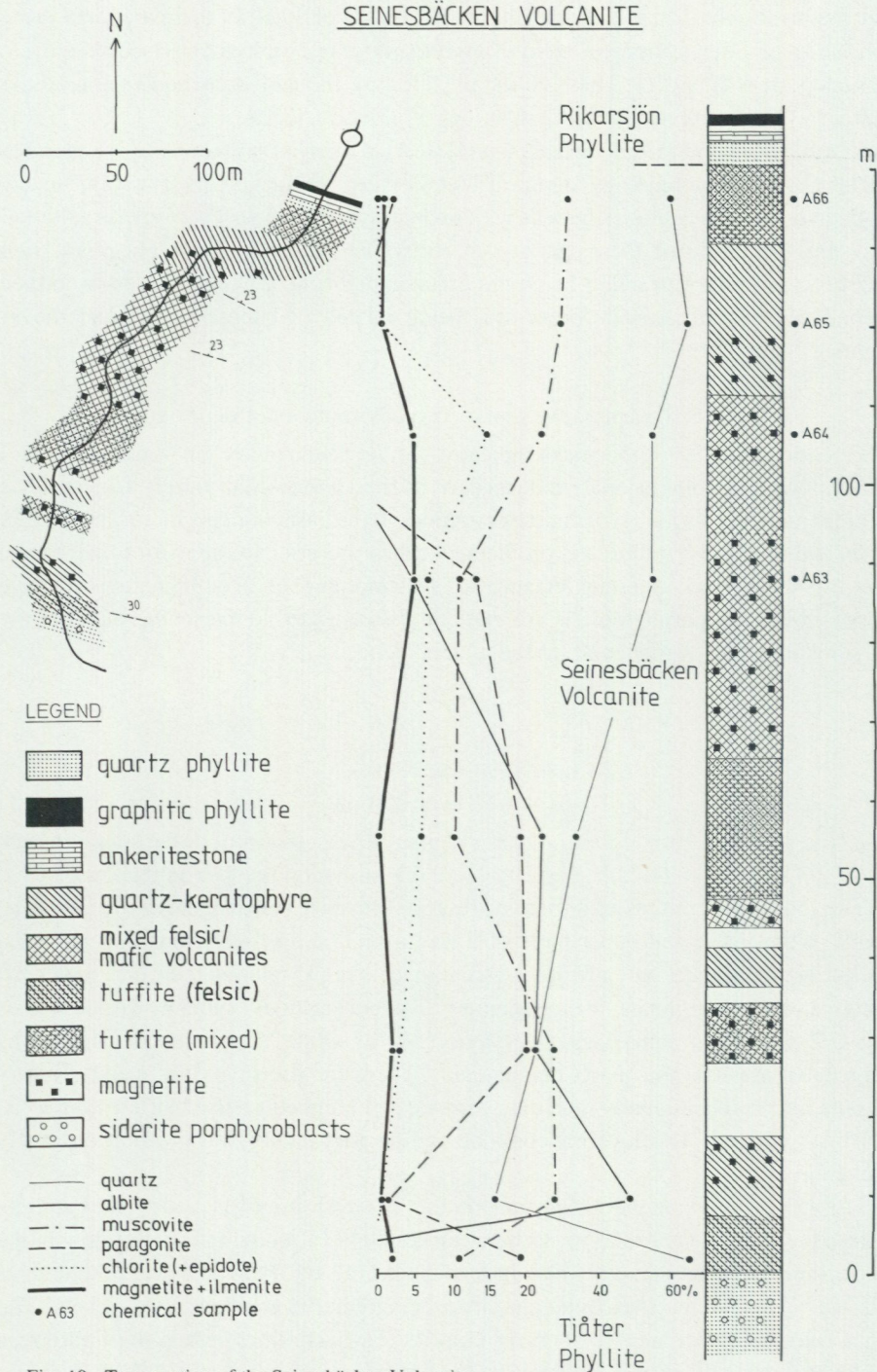


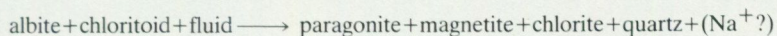
Fig. 10. Type section of the Seinesbäcken Volcanite.

rocks. Carbonate minerals (0–7 %) include ankerite and occasionally calcite and even siderite (in the lowermost part of the formation). Magnetite (0.5–5 %) is a common and characteristic mineral, especially in the light-green rocks, while ilmenite is common in the light-coloured rocks. Common accessory minerals include apatite, zircon, tourmaline, rutile, and sphene.

The boundaries of the formation are adequately exposed in the type section. The lower boundary is between a light-coloured volcanogenic rock (with grains of siderite) and a somewhat graphitic, carbonatic phyllite with scattered siderite porphyroblasts (Tjäter Phyllite). The contact seems to be gradual, with siderite on each side of the boundary. The upper boundary is between a light-coloured, rather carbonate-rich volcanogenic rock, and a graphitic quartz phyllite (Rikarsjön Phyllite). The rocks at the contact are somewhat phyllonitic.

2.4.4.2. Lateral continuation

The formation can be followed at the same tectonic level around the hinge, where it outcrops in a major depression, and limbs of the large synformal structure which dominates Jofjället. In the central part of the area the formation is tectonically repeated at higher tectonic levels (Plate 1). Although varying a lot along strike, both in lithology and thickness, the Seinesbäcken Volcanite is the most important marker horizon in the Jofjället area. In a few places there occur metagabbros. A conspicuous and rather common mineral in the Seinesbäcken Volcanite is chloritoid which, however, not has been found in the type section. It seems that chloritoid varies negatively with magnetite in the Seinesbäcken Volcanite. Considering also the remarkably low albite and high paragonite content in the type section the following reaction is proposed (cf. Halferdahl 1961):



Microscopic studies show that many of the minerals in the equation above have a largely post-tectonic recrystallization (see later section). Relatively high oxygen pressure for the formation of magnetite is required, while certain ions, especially Na, appear to have been highly mobile and have left the system. It is supposed that most of these reactions took place in response to the intense tectono-metamorphic processes generated by thrusting (see later section). A more thorough treatment of the problems involved in the Seinesbäcken Volcanite is forthcoming in a later paper.

An important key member, again absent in the type section, is the Seinesfjället Carbonatestone. The thickness of this unit is up to 30 m but is generally much less and the carbonatestone is apparently absent in many places. It is a very pure dolo-ankeritestone, always showing a sharp contact to the volcanites (Fig. 11a). It is often conglomeratic, usually with rather sharp-edged fragments (Fig. 11b). Fig. 12 shows the chemical composition of the Seinesfjället Carbonatestone in different parts of the

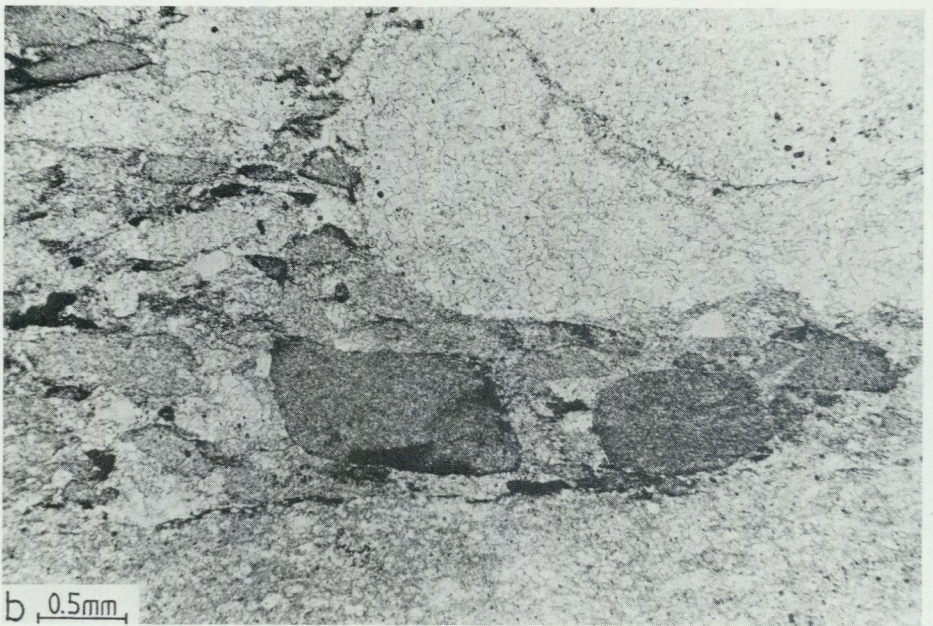
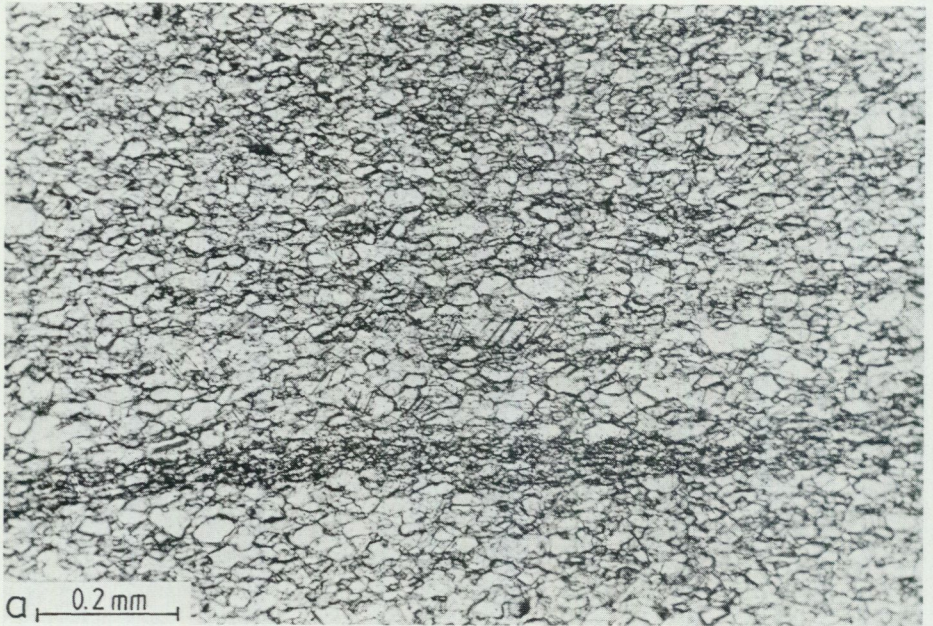


Fig. 11. Seinesfjället Carbonatstone.

a: Equigranular ("non-fragmentary") dolostone. Note the "anomalous" monomineralogic nature of the rock and the laminae of carbonaceous ("graphitic") matter (24E 9-j, uncrossed nicols).

b: Conglomeratic ("fragmentary") dolostone. The fragments and the matrix (and also veins not present in the picture) have the same dolomitic composition (25F 0-a, uncrossed nicols).

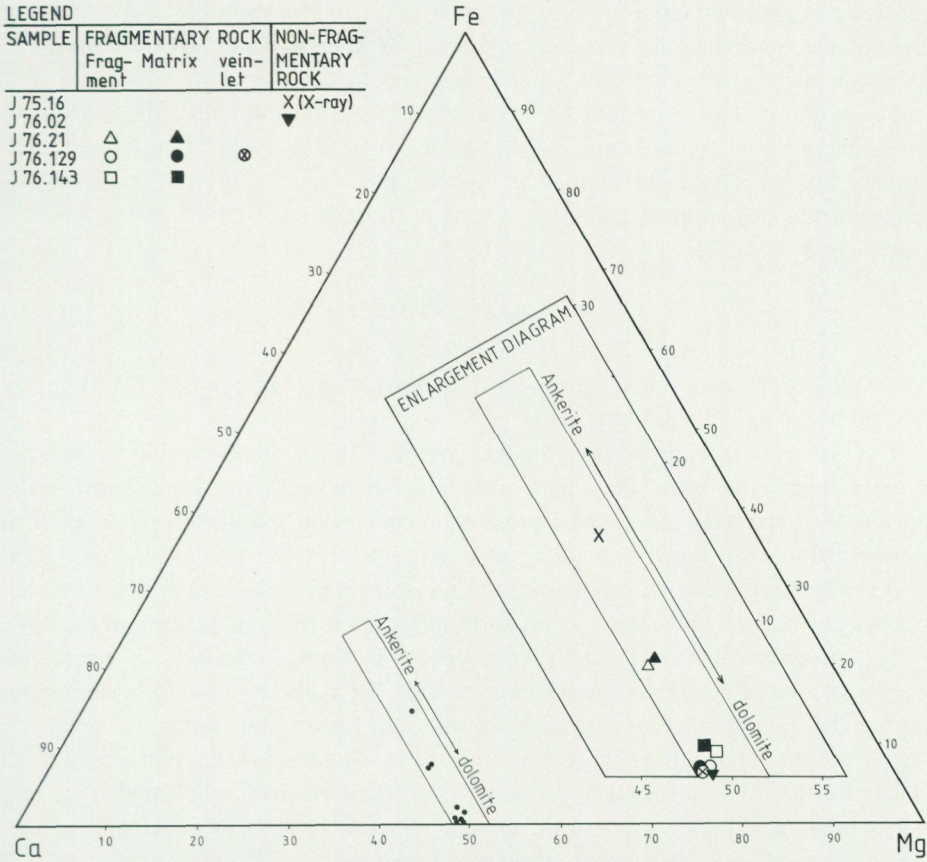


Fig. 12. Triangular diagram showing plots of analyses of ankerite and dolomite from the Seinesfjället Carbonatestone. An inset enlargement diagram differentiates the plots according to the legend above. The analyses were carried out at SGU (Stockholm) in 1977 on an ARL electron microprobe with voltage varying from 15 to 30 kV.

Jofjället area and the chemical composition of the fragments and other constituents of each rock sample. The conclusion drawn from the figure is that the composition of the carbonate varies from dolomitic to ankeritic in different parts of the map area (metamorphic effect?), but that the different constituents of the rock at one locality do not vary (also metamorphic effect?).

2.4.4.3. Interpretative remarks on environment of deposition

Although predominantly volcanic-influenced, there appears to be some contribution of terrestrial-derived material in the Seinesbäcken Volcanite. The often low feldspar and high white mica and quartz contents, however, might to a large degree, be the result of metasomatic alteration of the rocks during regional metamorphism. Reworking of mixed felsic (light-coloured) and mafic (light-green) tuffs is thought to have taken

place but a contribution from air-transported ashes is probably most important. In general the Seinesbäcken Volcanite appears to represent a rather distal volcanite facies, perhaps related to a relatively mature island arc complex.

The origin of the Seinesfjället Carbonatestone is somewhat uncertain. Chemical precipitation from hydrothermal solutions in connection with the distal volcanic activity may be speculated. The conglomeratic appearance of the carbonatestone is interpreted as being due to submarine sliding of more or less lithified carbonatestone (sedimentary breccia).

2.4.5. RIKARSJÖN PHYLLITE

2.4.5.1. Type section

The type section is situated in the upper part of Storbäcken (24F 9-a; Fig. 13). Here the formation is about 600 m in thickness.

The formation consists mainly of quartz phyllite, often somewhat pelitic, with little or no carbonate content. The graphite content is, in general, also low, apart from a zone in the lowermost part of the formation, in connection with the greenschist in the middle and in a few horizons in the upper part of the formation. In the uppermost part of the formation there occurs a pelitic phyllite, while in the middle part there are a 60 m thick layered greenschist and a thin horizon (less than 10 m) of tuffitic rocks.

The quartz phyllites are usually between 0.1–0.2 mm in grain size, but larger porphyroclasts of quartz and albite are common. The rocks are usually layered with mica- and quartz-rich domains and often with lenses and stringers of quartz (metamorphic layering). The essential minerals in the typical quartz phyllites include quartz (60–70 %), albite (5–15 %), chlorite (2–5 % and normally a Fe-ripodolite), and white mica (15–25 %). Common accessory minerals include zircon, apatite, tourmaline (schorl), and ore minerals. Biotite seldom occurs, but in the lowermost part of the formation a garnet-rich quartz phyllite (35 % garnet) is present.

The grain size of the pelitic phyllites is about 0.05 mm and the quartz grains are strongly elongate. The main foliation is here a slaty cleavage. The pelitic phyllites have the same minerals as the quartz phyllites, but in different proportions. Phyllosilicates, for example, often make up 50–75 % of the rock.

The grain size of the layered greenschist is 0.1–0.5 mm and the main foliation is a slaty cleavage. Thin calcite-rich layers are occasionally present. Essential minerals include quartz (5–10 %), albite (15–25 %), white mica (0–1 %), amphibole (1–45 %, light-green and poikiloblastic), chlorite (20–45 % and Mg-ripodolitic), epidote (6–20 %), and calcite (0–4 %).

The graphitic quartz phyllites at the lower boundary to the Seinesbäcken Volcanite appear somewhat phyllonitic. It is near this contact also that the garnet-rich rock occurs. The upper contact is not exposed in the main course of Storbäcken, but in a side stream 400 m to the west. Here the pelitic phyllite is overlain by a narrow zone (less than 5 m) of a mylonitic quartz phyllite, interpreted as belonging to the base of the Tjäter Phyllite, which here is at a higher tectonic level compared to its type section.

RIKARSJÖN PHYLLITE

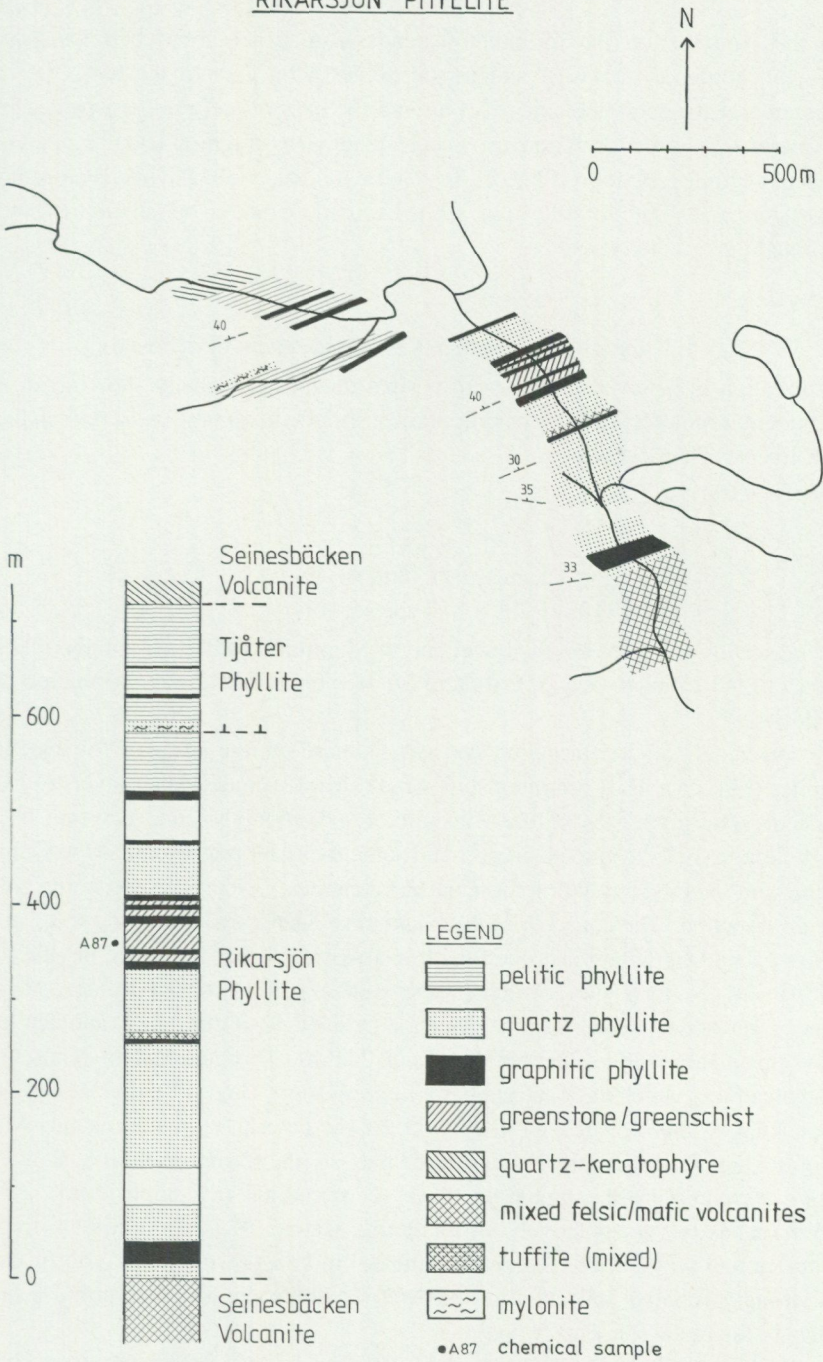


Fig. 13. Type section of the Rikarsjön Phyllite.

2.4.5.2. Lateral continuation

From the type section the formation extends in a rather broad belt towards the Norwegian border to the west and to the Seinesfjället area to the east. It is also encountered at the same tectonic level around the eastern and northern parts of lake Tängvattnet. The same formation also occurs at a higher structural level as a part of an important tectonic repetition (Plate 1). In general the Rikarsjön Phyllite is more pelitic in the eastern part of the Jofjället area, while being more quartz-rich in the western part and in the higher tectonic unit.

2.4.5.3. Interpretative remarks on environment of deposition

The formation is believed to represent basinal conditions, locally showing strongly reducing environments. Minor contemporaneous mafic magmatic activity is indicated by the greenschist occurrence.

2.4.6. RUFFE GREENSTONE

2.4.6.1. Type section

The type section is situated in the lower part of Skinnfällträskbäcken in the north-western part of the Jofjället area (25E 0-j and 24F 0-a; Fig. 14). Here the formation is 360 m in thickness.

The lower half of the formation consists of more or less strongly foliated mafic volcanites (Fig. 15). They are often somewhat calcareous and thinner layers of calcite also occur. The grain size of the volcanites is commonly around 0.1 mm but the amphibole-rich rocks tend to be coarser and some rocks are porphyritic. Metasedimentary units are interlayered within these mafic volcanites, five such layers being present in the type section. They are 3–6 m thick and have been classified as graphitic quartz phyllites except the uppermost one which is a pyrrhotite-rich graphitic phyllite. The upper part of the formation, which is less well exposed, consists of less strongly foliated greenstones. One member is coarse-grained (2–3 mm) and another has a porphyritic texture (albite phenocrysts about 2 mm). The essential minerals in the mafic volcanites, which vary substantially in proportions (Fig. 14), include quartz (in most rocks very subordinate), albite (10–65 %) and chlorite (1–40 %, usually Mg-Fe ripodolitic but Fe-ripodolitic in the upper part of the formation); both showing a negative correlation with amphibole (0–70 %, tremolitic in composition). Epidote (4–25 %) tends to vary positively with chlorite. Calcite (0–6 %) shows an irregular distribution and white mica is very subordinate. In general, the mafic volcanites are more strongly foliated and chlorite and epidote dominate over amphibole near the contacts to the metasedimentary beds.

The lower boundary is well exposed. A strongly foliated greenstone is in contact with a few metres thick graphitic quartz phyllite which is underlain by a somewhat

RUFFE GREENSTONE

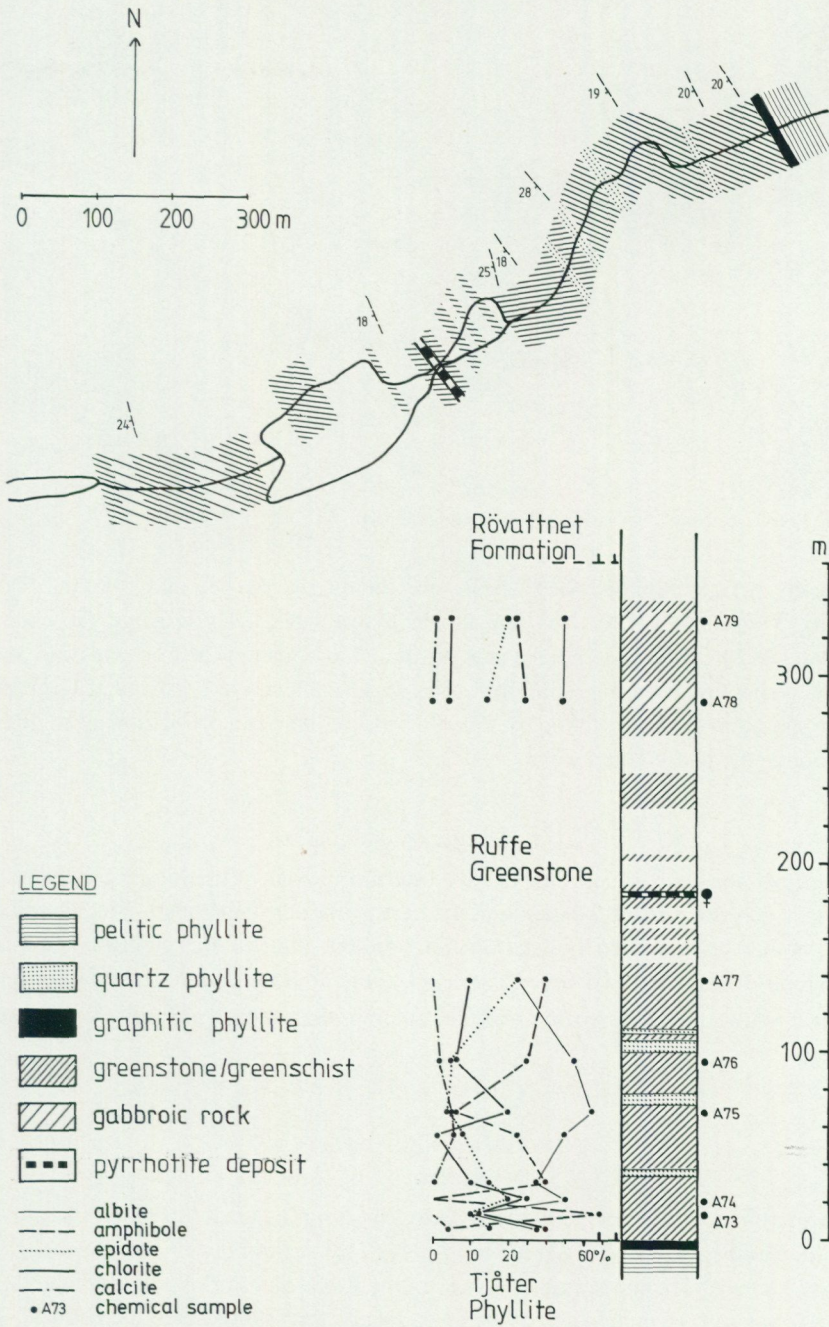


Fig. 14. Type section of the Ruffe Greenstone.



Fig. 15. Localized shear zones in Ruffe Greenstone (25F 0-a).

calcareous pelitic phyllite; these rocks are interpreted as belonging to the Tjäter Phyllite. The contact here does not appear to be particularly tectonic (absence of mylonites and phyllonites), but several stratigraphic units appear to be missing and a tectonic contact relationship is inferred. The upper contact to the Rövattnet Formation is not exposed in the type section, but in other places there is a broad zone of mylonitic rocks above the Ruffe Greenstone.

2.4.6.2. Lateral continuation

The Ruffe Greenstone is restricted to the western core zone of the Jofjället Synform. In a strongly deformed mafic volcanite in the eastern part of the formation an abundance of stilpnomelane has been found. On the southern limb of the synform the Ruffe Greenstone shows a marked tectonic contact to the underlying units (see later discussion in section 4.2.). The rocks, especially below the contact, are here mylonitic in character.

2.4.7. RÖVATTNET FORMATION

2.4.7.1. Description of the formation

The formation is located in the western part of the Jofjället area. A section through the upper part of the formation is shown in Fig. 16. This section is situated in Brackfjällsbäcken (25E 0-j). The maximum thickness of the Rövattnet Formation is about 500 m.

The formation is composed of metasediments and subordinate volcanites. The metasediments are variable, including pelitic, calcareous, graphitic, and most com-

RÖVATTNET FORMATION

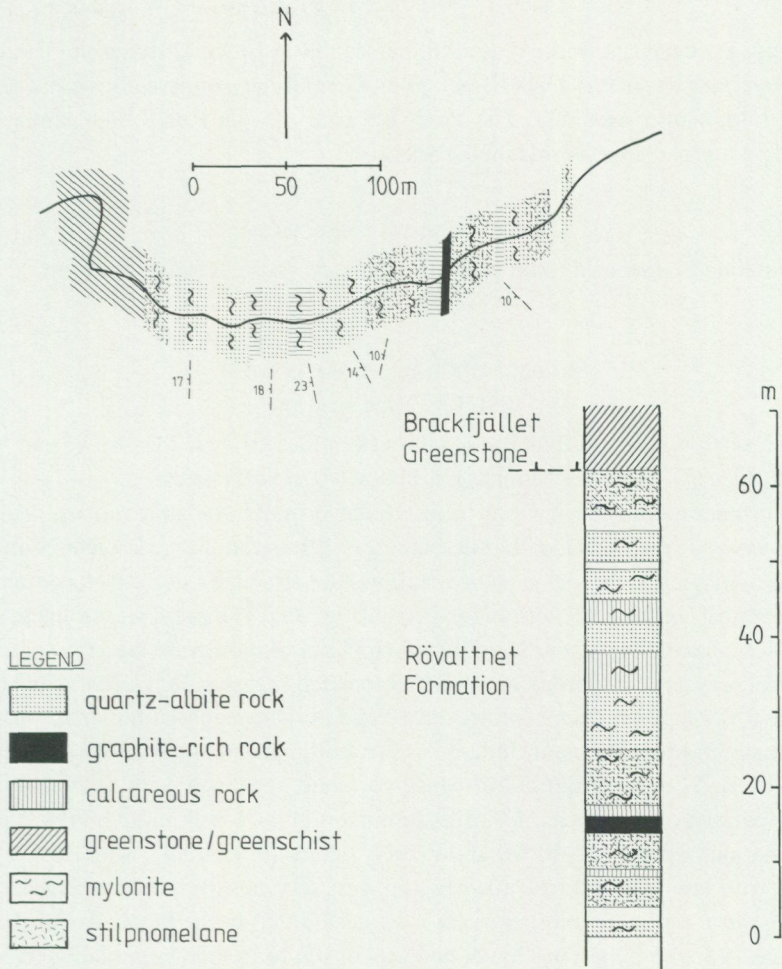


Fig. 16. Section through the upper part of the Rövattnet Formation.

monly quartz-rich rocks. In large areas these rocks are strongly deformed and are more or less mylonitic. The volcanites often have a mafic composition and are usually also severely deformed, but occasionally a relict igneous texture is preserved. In the section through the upper part of the Rövattnet Formation (Fig. 16), the whole rock sequence is more or less mylonitized. These mylonitic rocks consist of a very fine-grained matrix (about 0.03 mm) dominated by recrystallized albite and quartz which together often constitute around 90 % of the rock (metaquartz-keratophyre?); larger post-tectonic porphyroblasts of biotite and occasionally stilpnomelane also occur (see later

discussion). In the Rövattnet Formation the index mineral chlorite and – to a less extent – biotite is quite common, while garnet has been found only in a couple of thin sections.

The upper contact is well exposed in the section in Brackfjällsbäcken. The formation is overlain by greenschists (Brackfjället Greenstone), apparently with a tectonic contact (abundant mylonites). The lower boundary to the Ruffe Greenstone is also marked by a broad zone of mylonitic rocks.

2.4.7.2. Lateral continuation

The formation is restricted to the western core zone of the Jofjället Synform.

2.4.8. BRACKFJÄLLET GREENSTONE

2.4.8.1. Type section

The type section is situated in Brackfjällsbäcken located near the Norwegian border (25E 0-j; Fig. 17). Here the formation is about 170 m in thickness.

The formation consists of more or less foliated mafic volcanites, often somewhat calcareous and occasionally biotite-bearing. Terrestrial-derived metasedimentary rocks are not present in the sequence. Pillow-like structures are rather common but most, if not all, of them are tectonic in origin (Fig. 18). The grain size of the matrix is usually less than 0.1 mm, but larger porphyroblasts of biotite are rather common and albite phenocrysts occur infrequently. Small rounded segregations of quartz and calcite in some rocks may represent infilled lava vesicles. The essential minerals, that vary substantially in proportions, include quartz (subordinate), albite (35–70 %) and chlorite (1–45 %, Fe-ripodolitic); all of which correlate negatively with amphibole (0–45 %, tremolitic in composition). Chlorite dominates in the lower and uppermost part of the formation. Epidote (0–10 %) shows an irregular distribution, while biotite (0–17 %) and to a less extent calcite (0.8 %) tend to vary positively with chlorite. White mica is very subordinate in quantity. It is suggested that in the more strongly foliated rocks – as near the upper and lower contacts of the formation – amphibole has been converted into chlorite, biotite and calcite.

The lower contact is well exposed. Here the Brackfjället Greenstone is strongly foliated and the rocks of the underlying Rövattnet Formation are mylonitic, indicating a pronounced tectonic contact. The actual contact at the upper boundary is not exposed. But the gap of non-exposure to the Skinnfällträsket Mylonite is small and a tectonic boundary is inferred.

2.4.8.2. Lateral continuation

The Brackfjället Greenstone is restricted to the extreme western part of the map area. In the northern part of the formation there is a large body of pure limestone while to the south the formation is apparently thicker due to the progressive northwards attenuation

BRACKFJÄLLET GREENSTONE

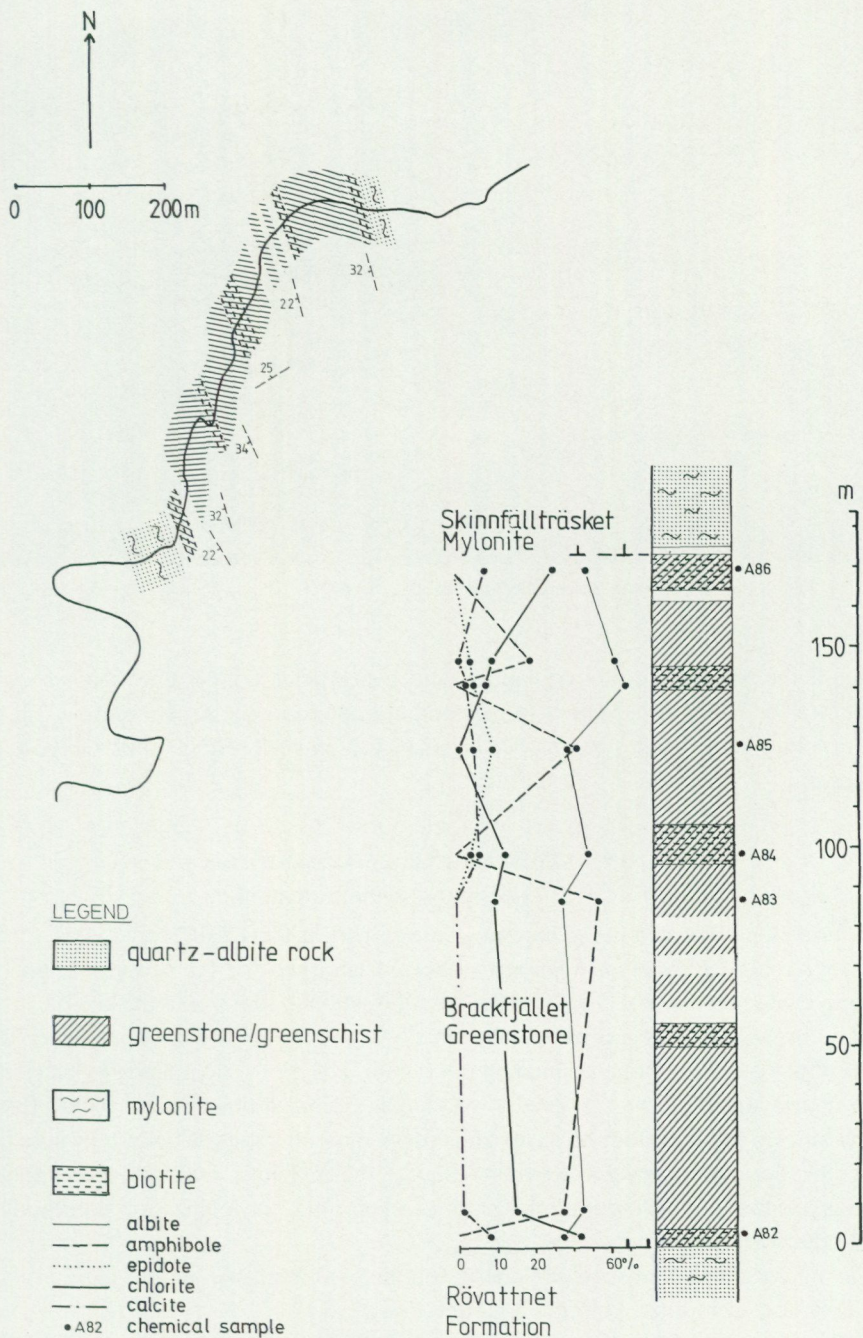


Fig. 17. Type section of the Brackfjället Greenstone.



Fig. 18. Pillow-like structures in Brackfjället Greenstone (25E 0-j).

beneath the Skinnfällträsket Mylonite. The Brackfjället Greenstone appears quite similar to the Ruffe Greenstone. In the southern outcrop area, similar metasediments as are found in the Ruffe Greenstone occur higher up in the Brackfjället Greenstone succession.

2.4.9. SKINNFÄLLTRÄSKET MYLONITE

2.4.9.1. Description of the formation

The formation is located in the extreme western part of the Jofjället area close to the Norwegian border. No type section has been established for the formation, but its lower part is shown in Fig. 17 (25E 0-j). The formation is 10–75 m in thickness.

The formation consists of more or less mylonitic rocks of varying appearance. The rocks often have a very fine-grained matrix (about 0.03 mm) – dominated by recrystallized quartz and albite – occasionally with larger grains of albite and/or biotite (blastomylonites). The petrology of the original rocks can sometimes be deduced where the mylonitization is less severe. At least some of the mylonitic rocks have apparently been greenstones, which seem to be more resistant to the mylonitization process than most other rock types.

The important minerals include quartz (often very abundant), albite, \pm microcline, \pm white mica, \pm chlorite, \pm biotite, \pm garnet.

As discussed earlier, the lower boundary to the Brackfjället Greenstone is inferred to be a tectonic contact.

3. METAMORPHISM

3.1. OPENING REMARKS

The rocks in the Jofjället area have been metamorphosed under greenschist facies conditions and metamorphic grade variations are summarized in Fig. 19. The metamorphism is now described for each tectonic unit in structural order from bottom to top.

3.2. BJÖRKVATTNET NAPPE

As shown in Fig. 19, the rocks within this unit belong, in the lower part, to the quartz-albite-muscovite-*chlorite* subfacies (Winkler 1967) and in the upper part mainly to the quartz-albite-epidote-*biotite* subfacies of the greenschist facies. In both parts, however, there are certain deviations from this metamorphic pattern. In the lower part biotite and even garnet have been noted in a few places, while in the upper part biotite is occasionally absent. Whole rock composition is evidently influencing particular mineral assemblages.

The same metamorphic grade conditions are indicated by the mafic and the more pelitic rocks in the Skälvattnet Volcanite, although biotite seems to be somewhat more frequent in the mafic rocks. The mafic rocks have a mineral association including albite, chlorite, \pm epidote, \pm actinolite (seldom present in the Västansjö area), \pm calcite, \pm quartz, \pm muscovite, \pm biotite. The more pelitic rocks contain quartz, albite, chlorite, muscovite, calcite, \pm biotite. In the Västansjö Phyllitic Quartzite biotite appears to be less common in the calcareous members than in the other rock types.

3.3. LAXFJÄLLET NAPPE

The calcareous rocks of the Jovattnet Calcareous Phyllite belong to the quartz-albite-muscovite-*chlorite* subfacies, apart from the upper part of the formation and in the area north of Västansjö where they belong to the quartz-albite-epidote-*biotite* subfacies. Chloritized garnets have been found at one locality in the upper part of the formation. The calcareous rocks have a mineral association including quartz, albite, chlorite, muscovite, carbonate, \pm biotite, \pm garnet (retrogressed).

The metamorphic grade of the metagabbros within the Jovattnet Calcareous Phyllite shows the same regional pattern as for the calcareous rocks. The mineral association is albite, chlorite, epidote, \pm actinolite, \pm muscovite, \pm quartz, \pm calcite, \pm biotite, \pm garnet (chloritized and found at one locality only).

The felsic volcanic rocks of the overlying Joeström Quartz-Keratophyre belong mainly to the quartz-albite-epidote-*almandine* subfacies. The mineral association is quartz, albite, chlorite, muscovite, \pm epidote, \pm calcite, \pm biotite, \pm garnet (usually present, occasionally partly chloritized).

3.4. STORFJÄLLET NAPPE COMPLEX

Metamorphically the Storfjället Nappe Complex is conveniently divided into three parts: a lower, higher metamorphic, basal part (the Metartjärnen Formation), a middle, lower metamorphic part which includes most of the formations and an upper, higher metamorphic part (the Skinnfällträsket Mylonite).

3.4.1 THE HIGHER GRADE PART

The rocks in the Metartjärnen Formation are mainly in the quartz-albite-epidote-*almandine* subfacies of the greenschist facies. The garnets are especially large (2–5 mm) and numerous in pelitic rocks, somewhat less well developed in more psammitic rocks and are mostly lacking in very graphitic, calcareous and mafic rocks. The garnets are usually more or less chloritized. Beds with fresh garnets and beds with retrogressed garnets are often characteristically interlayered. In the type section in Storbäcken (Fig. 7) the garnets are most conspicuous in the middle part of the formation, this being probably a whole rock compositional control, the rocks here being largely pelitic. In the eastern part of the area, Murris (1957) observed rectangular sericite aggregates that might represent pseudomorphs after staurolite and even higher grades than indicated here.

The mineral association for the pelitic and psammitic rock types is typically quartz, albite, muscovite, chlorite, biotite, garnet, \pm calcite. The mineral association for the calcareous phyllites is quartz, albite, muscovite, biotite, carbonate (about 10–35%), epidote, \pm chlorite, \pm actinolite. The mineral association of the mafic rocks (in the type section) is albite, biotite, chlorite, actinolite, epidote, \pm calcite, \pm quartz.

3.4.2. THE LOWER GRADE PART

The formations in the Storfjället Nappe Complex lying above the Metartjärnen Formation belong to the lower or middle greenschist facies. The lowermost part of the Jofjället Calcareous Phyllite, the Rövattnet Formation and the Brackfjället Greenstone, belong to the quartz-albite-epidote-*biotite* subfacies, while the other formations, which dominate the Jofjället area, belong to the quartz-albite-muscovite-*chlorite* subfacies.

The mineral association of the calcareous rocks is quartz, albite, muscovite (one sample also with paragonite), carbonate (ankerite and calcite), chlorite, \pm biotite, biotite being present only in the lowermost part of the Jofjället Calcareous Phyllite (Fig. 8). The more pelitic rocks contain quartz, albite, muscovite (occasionally also paragonite), chlorite, carbonate, \pm biotite, biotite being present in the pelitic rocks at higher tectonic levels; the carbonate is dominantly ankerite. The Tjäter Phyllite in the southern part of Jofjället contains siderite porphyroblasts whereas the carbonate in the same formation at higher tectonic levels is mainly calcite and ankerite. The mineral association of the felsic rocks of the Seinesbäcken Volcanite (Fig. 10) is quartz, albite, muscovite (paragonite is common), \pm chlorite, \pm epidote, \pm carbonate (ankerite and subordinate calcite), \pm chloritoid, \pm magnetite. The mafic volcanites of the Ruffe and

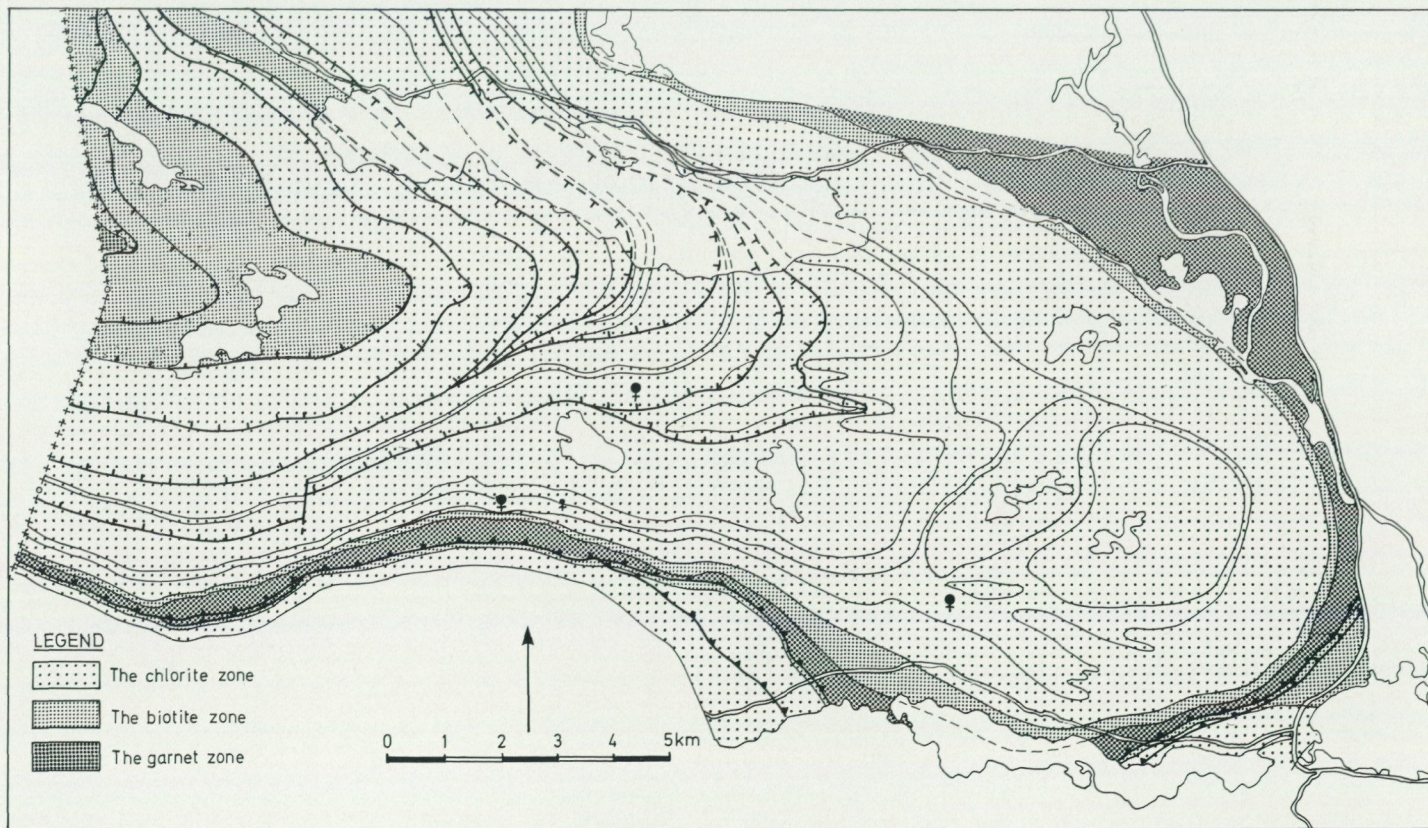


Fig. 19. Schematic distribution of metamorphic zones in the Jofjället area.

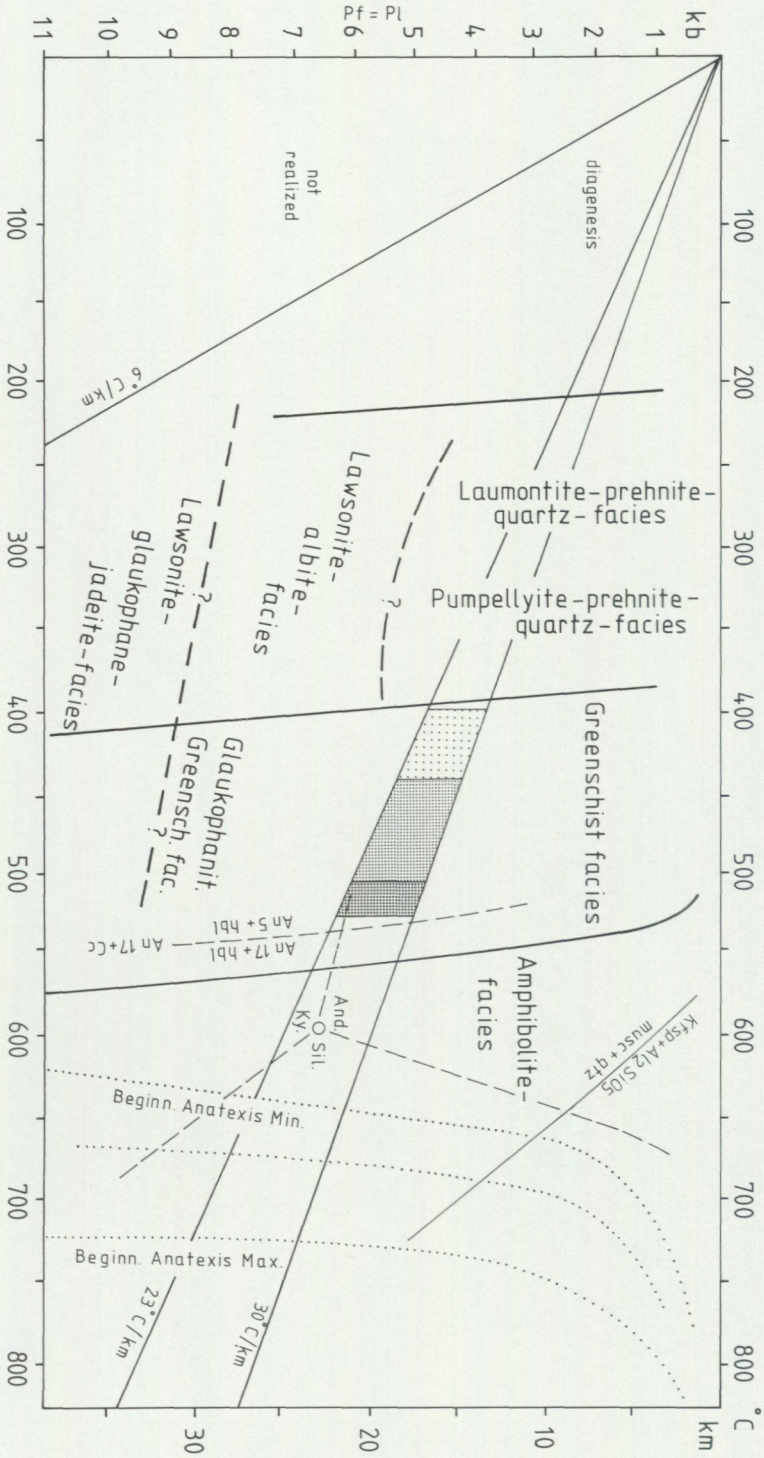


Fig. 20. P-T diagram showing metamorphic facies (Winkler 1967) and some important isograds. The shaded area indicates the inferred metamorphic conditions in the Jofällar area during the peak of metamorphism (for further explanation see Fig. 19 and text).

Brackfjället Greenstones consist of albite, chlorite, \pm epidote, \pm tremolitic amphibole, \pm muscovite, \pm quartz, \pm calcite, \pm biotite; biotite being present only in the Brackfjället Greenstone (Figs. 14 and 17).

According to Fig. 19 the Rövattnet Formation belongs entirely to the quartz-albite-epidote-biotite subfacies. This picture is somewhat oversimplified; in reality all three subfacies of the greenschist facies – often close to each other – are represented. Stilpnomelane, which is rather abundant in some areas is, according to Winkler (1967), restricted to the *low* greenschist facies. In the Rövattnet Formation, however, it occurs together with biotite¹ which, like stilpnomelane, is post-tectonic (see later discussion). Chloritoid and paragonite, which are quite common in the Seinesbäcken Volcanite, are characteristic minerals for the greenschist facies but cannot be used to pigeon the formation into a special subfacies (Winkler 1967).

Hutchison and Scott (1980) have determined pressure values using sphalerites encapsulated in pyrite from the massive sulphide deposit at Tjåter, which is hosted by the Tjåter Phyllite. The inferred pressure is 4.8 kbar and probably coincides with the temperature peak during the regional metamorphism. The value of 4.8 kbar corresponds to a crustal depth of 18 km (Fig. 20) assuming P_f (pressure of any fluid phase) = P_l (load pressure). This depth, which is a maximum value, corresponds to a geothermal gradient of 23°C/km if the temperature of metamorphism is around 410°C (lower greenschist facies according to Winkler 1967). This indicates that the metamorphism is of the medium-pressure or Barrovian type (Miyashiro 1973). The load pressure, which relates to the real depth of burial, may be considerably less than the total pressure corresponding to a depth of 18 km, fluid overpressure and directed pressure possibly contributing to the total pressure. Consequently the thickness of the rock pile above the Tjåter Phyllite during the peak of metamorphism may have been less than 18 km and, thus, the value of the geothermal gradient correspondingly higher than 23°C/km. Considering this problem a gradient of 30°C/km has been arbitrarily drawn in Fig. 20, which corresponds to a depth of 15 km for the Tjåter Phyllite during the peak of metamorphism.

A special investigation of the carbonate-bearing rocks in the lower grade Storfjället Nappe Complex has been carried out, samples having been taken from the bottom of the Jofjället Calcareous Phyllite through the Tjåter Phyllite into the Seinesbäcken Volcanite. The chemical composition of the different rocks with respect to Ca, Fe and Mg has been plotted on Fig. 21. On the same diagram the chemical composition of the constituent minerals with respect to Ca, Fe and Mg corresponding to each of these rock samples has been plotted. In the table below there is a semiquantitative estimation of these minerals in volume percent. The order of the rock samples in the table corresponds roughly to their stratigraphic position. It is of importance to bear in mind

¹ Winkler – referring to Chatterjee (1966) – notes that phyllosilicates appearing like brown biotite in association with stilpnomelane have been demonstrated to be oxidized iron-rich chlorite. In this case, however, x-ray studies have shown that the mineral is indeed biotite.

that metamorphic grade decreases upwards from the base of the Jofjället Calcareous Phyllite.

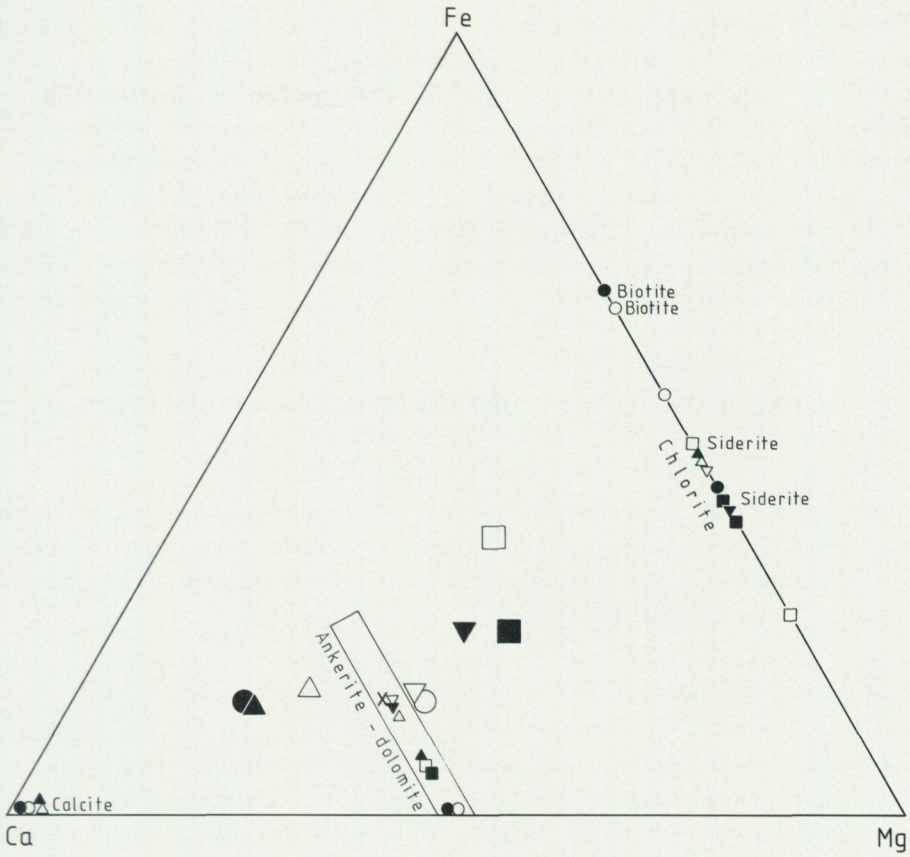
According to Fig. 21 the carbonate minerals are totally dominated by calcite at higher metamorphic facies (1.2=quartz-albite-epidote-*biotite* subfacies). However, a minor amount of pure dolomite is also present. At lower metamorphic grade (1.1=quartz-albite-epidote-*chlorite* subfacies), dolomite-ankerite becomes stable and calcite decreases accordingly. According to Fig. 21, the Mg component of the calcite tends to increase slightly towards lower metamorphic grade. The diagram also seems to indicate that the Fe content of the ankerite increases with decreasing metamorphic grade. However, whole rock composition is also important here. For example, when the bulk composition of the rock is Fe-Mg-rich (large squares in Fig. 21), Mg-rich siderite (small squares, labelled siderite) is present as porphyroblasts (mestisite). In this case the Fe content of the coexisting ankerite is lower, although the metamorphic grade is probably still decreasing. This investigation shows therefore that the composition of the carbonate minerals is influenced by the metamorphic grade.

In general the chlorites have high Al and Fe contents, making them ripodolitic. The accuracy of the chlorite x-ray analyses has been checked by a limited number of electron microprobe analyses. According to the triangular diagram in Fig. 21, the Fe/Mg ratio in the chlorites appears to depend on the composition of the coexisting carbonates. When siderite is present the coexisting chlorite is relatively poor in Fe. When enough CO₂ is present at lower metamorphic facies, Fe and Mg are preferentially incorporated into carbonate minerals and the composition of the chlorite then depends on which of the two ions is in excess after the formation of the carbonate minerals. As Fe content in ankerite increases with decreasing metamorphic grade, so the Fe content in coexisting chlorite appears possibly to decrease.

3.4.3. SKINNFÄLLTRÄSKET MYLONITE

The rocks of the Skinnfällträsket Mylonite belong to the greenschist facies. All three subfacies are represented but in general the metamorphism is in the quartz-albite-epidote-*biotite* subfacies or in the quartz-albite-epidote-*almandine* subfacies. The mineral association includes quartz, albite, muscovite, ± microcline, ± calcite, ± chlorite, ± biotite, ± garnet.

Fig. 21. Triangular diagram showing the distribution of Ca, Fe and Mg in carbonate-bearing rocks from the Jofjället area (large symbols). The whole rock chemical analyses were performed at SGU by optical emission spectrography on crude powder (Danielsson 1967). It also shows the distribution of Ca, Fe and Mg in the minerals in these rocks (small symbols). The analyses were carried out by x-ray diffraction (Luleå) and checked by electron probe (for performance data see text to Fig. 12). The symbols not named on the Fe-Mg line represent chlorite. The position of the biotite on that line is not accurately determined. The table shows a semiquantitative estimation of the minerals in volume per cent for each rock sample (microscopic estimation checked with point counting). For the interpretation of the data see text.



Formation	Subfacies	Rock type	Symbol	Calcite	Dolomite-ankerite	Siderite	Biotite	Chlorite
Seinesb. Volc.	↑	1.1	Ankeritestone	X	100			
		1.1	Carbonate phyllite	▽	93			7
Tjätter Phyllite	↑	1.1	- " -	▼	85			15
		1.1	Siderite porphyroblastb. ph.	□	55	26		19
		1.1	- " -	■	50	38		12
		1.1	Calcareous phyllite	△	19	77		4
Jofjället Calcareous Phyllite	↑	1.1	- " -	▲	32	64		4
		1.2(1)	- " -	○	60	3	3	34
		1.2	- " -	●	64	3	7	26

3.5. CONCLUSIONS

The metamorphic grade variation shows a consistent pattern throughout the different nappe units in the Jofjället area. The metamorphic grade increases from the Björkvattnet Nappe through the Laxfjället Nappe and culminates in the lower part of the Storfjället Nappe Complex (Metartjärnen Formation). This involves an increase in grade from the low to the high greenschist facies. Upwards from the Metartjärnen Formation there is a continuous decrease in metamorphic grade to low greenschist facies in the middle part of the Storfjället Nappe Complex. In the upper part of this nappe unit the metamorphic grade increases again and culminates in high greenschist facies (Skinnfällträsket Mylonite).

4. DEFORMATION AND METAMORPHISM-DEFORMATION RELATIONSHIPS

4.1. OPENING REMARKS

As discussed earlier, the rock sequence in the Jofjället area can be divided into three nappe units. This chapter is concerned with the large scale internal structures in the Storfjället Nappe Complex and the mesostructures, microstructures and metamorphism-deformation relationships in the whole area.

4.2. MEGASCOPIC STRUCTURES WITHIN THE STORFJÄLLET NAPPE COMPLEX

The distinctive lithological sequence consisting in order from bottom to top of calcareous phyllite, graphitic and carbonatic pelitic phyllite, mixed volcanites and graphitic quartz phyllite, characterizes the southern part of the Jofjället area. These lithological units have earlier been referred to as Jofjället Calcareous Phyllite, Tjåter Phyllite, Seinesbäcken Volcanite and Rikarsjön Phyllite respectively.

Careful study of other calcareous phyllite and mixed volcanite rocks occurring at structurally higher levels in the lower grade part of the Storfjället Nappe Complex suggests that they are the same stratigraphic level. Thus, the existence of several fold and thrust repetitions of lithological units within the Storfjället Nappe Complex is inferred. The interpretation of these internal megascopic structures is shown on the formation map and in the sections (Plate 1). According to this interpretation the investigated sulphide deposits in the Jofjället area – Tjåter, Storbäcksdalen and Rikarbäcken – occur at two different tectonic levels, but probably at the same stratigraphic level.

The complex outcrop pattern in the central and western part of the area may now be clarified. The outcrop pattern is largely controlled by early, large, isoclinal folds, overturned to the south and east respectively, with important thrusts along their limbs. This picture is complicated by imbrication of some of the units and modified by the late E-W synformal fold phase. The localization of thrust planes shown on the map is



Fig. 22. A deep valley marks the tectonic contact between Tjäter Phyllite (to the left) and overlying Ruffe Greenstone (24E 9-j, looking north-westwards into Norway).

to some extent inferred from theoretical considerations i.e. the repetition of the same stratigraphic sequence at higher structural levels. However, direct field evidence for such tectonic contacts is also present and are now described.

The thrust immediately north of lake Rikarsjön can be followed westwards towards Gierdetjakke as a rather narrow zone of mylonitic rocks. West of Gierdetjakke towards the international border with Norway this zone of highly deformed rocks becomes broader and more diffuse. The continuation of the thrust east of Rikarsjön is less certain but is thought to lie along the topographic lineament marked by the lakes situated to the north-east of Rikarsjön. No mylonites have been found here but the rocks are often rather phyllonitic and show much quartz veining. Many of the rocks on the islands in northern Tängvattnet show signs of intense deformation; movement along the same thrust level is inferred.

Thrusts are also inferred in association with the broad zone of highly deformed, often mylonitic rocks, that can be followed from the Norwegian border via lake Stuoressjåure to Tängvattnet. A branch of this tectonic zone can be traced from lake Filpojaure via Uttje Filpo towards the north-west. This thrust plane forms the sole of the imbricated calcareous phyllites in this area.

From Stuore Tjakke to the Norwegian border a deep valley marks the contact between the Ruffe Greenstone and the underlying Tjäter Phyllite (Fig.22). Brecciation, abundant quartz veins and occurrence of mylonitic rocks indicate strong differential movements along this contact. The northern continuation of the contact between the Ruffe Greenstone and the Tjäter Phyllite is, however, not so apparently tectonic in

all places. The Rövattnet Formation is intensely deformed especially in its lower and upper parts. There are abundant mylonitic rocks with which stilpnomelane is often associated.

As stated earlier, these early folds and thrusts as well as the basal thrust of the Storfjället Nappe Complex are folded by the late, open Jofjället Synform. This structure plunges approximately N75W/10 and has an axial surface approximately N75W/85S. All these structures are modified by late N-S trending flexures.

4.3. MESOSCOPIC STRUCTURES – FOLDS

4.3.1. PRELIMINARY REMARKS

Polyphase deformation has been recognized in each of the tectonic units, including the Metartjärnen Formation, within the Jofjället area.

The most important structures which formed during the different deformation phases – folds and foliations – are listed for each tectonic unit below.

Skinnfällträsket Mylonite (Storfjället Nappe Complex)	– composite foliation,	$F_3^W + F_3^N$ ¹
Lower grade Storfjället Nappe Complex	– S_1F_1, S_2F_2 ,	$F_3^W + F_3^N, F_{4kink}$
Higher grade Storfjället Nappe Complex	– composite foliation, F_2 ,	$F_3^W + F_3^N$
Laxfjället Nappe	– composite foliation, F_2 ,	$F_3^W + F_3^N, F_{4kink}$
Björkvattnet Nappe	– S_1F_1, S_2F_2 ,	$F_3^W + F_3^N, F_{4kink}$

This section is concerned with the fold structures, while the foliation development is discussed in the following section.

Since the lower grade part of the Storfjället Nappe Complex is by far the largest unit and hosts the base metal mineral deposits, emphasis is placed on this unit. However, the mesoscopic structures are described for each unit in the tectonic order from bottom to top.

4.3.2. BJÖRKVATTNET NAPPE

In the Björkvattnet Nappe four deformation phases have been recognized. Isoclinal folds with a penetrative phyllitic cleavage (F_1) as axial surface structure and tight to isoclinal folds with a crenulation cleavage as axial surface foliation (F_2) make up the early deformation phases; the F_2 folds have only been found near to the contact with the Laxfjället Nappe. Open to rather tight folds with steep axial surfaces and with variable (NE–W) fold axis orientation are numerous (F_3). Minor late kink folds with subhorizontal axial surfaces have also been noted (F_4). Both F_3 and F_4 occasionally have a weak crenulation cleavage as axial surface foliation.

¹ F_3 is characteristically composed of two sets of almost perpendicular fold axes trending approximately E–W and N–S respectively.

4.3.3. LAXFJÄLLET NAPPE

An intense, complex and composite foliation dominates the early mesoscopic structures (S_{1+2}).

Three different types of folds have been noted:

1. Minor tight to isoclinal folds with a crenulation cleavage (S_2) as axial surface foliation (F_2).
2. Common, open to tight folds with steep axial surfaces and with variable fold axis orientation (F_3).
3. Late kink folds (F_4).

4.3.4. THE HIGHER GRADE PART OF THE STORFJÄLLET NAPPE COMPLEX
(METARTJÄRNE FORMATION)

An intense, complex and composite foliation characterizes the early structures in the Metartjärnen Formation (S_{1+2}).

Only two different fold types have been identified in the Metartjärnen Formation. The older type characteristically consists of quartz segregations which have been deformed into tight to isoclinal folds with a reclined attitude. These folds are often ruptured along their limbs so only the hinges of the folds are intact. The axial surface foliation of these folds is the main schistosity of the Metartjärnen Formation (S_{1+2}). For this reason these folds are referred to as F_2 . The younger fold type has an open to gentle fold style with upright axial surfaces and variable (often NE-W) fold axis orientation (F_3). A crenulation cleavage (S_3) often forms an axial surface foliation.

4.3.5. THE LOWER GRADE PART OF THE STORFJÄLLET NAPPE COMPLEX

4.3.5.1. Early structures

The early folds, belonging to deformation phases D_1 and D_2 , are difficult to discriminate from each other in the field. The style and orientation of these early folds are quite similar. The principal difference is the character of their axial surface foliation. F_1 structures have a penetrative phyllitic cleavage as axial surface foliation, whereas F_2 structures show a variably differentiated crenulation cleavage. No clear refolding relationship between F_1 and F_2 has been observed on the mesoscopic scale, but in the hinges of the F_2 folds the relict axial surface foliation (S_1) of F_1 can often be identified microscopically.

F_1 folds are rare, having only been recognized with confidence in the Jofjället Calcareous Phyllite (Fig. 23). The fold style is isoclinal, often with well developed parasitic folds. They belong to class 2 and 3 according to the fold classification of Ramsay (1967, p. 368) and have a phyllitic cleavage (S_1) as axial surface structure. Fig. 24b shows that the F_1 folds have rather flat-lying axial surfaces and variable fold axes, possibly with a concentration towards north-west. F_1 folds have a tendency to be reclined.

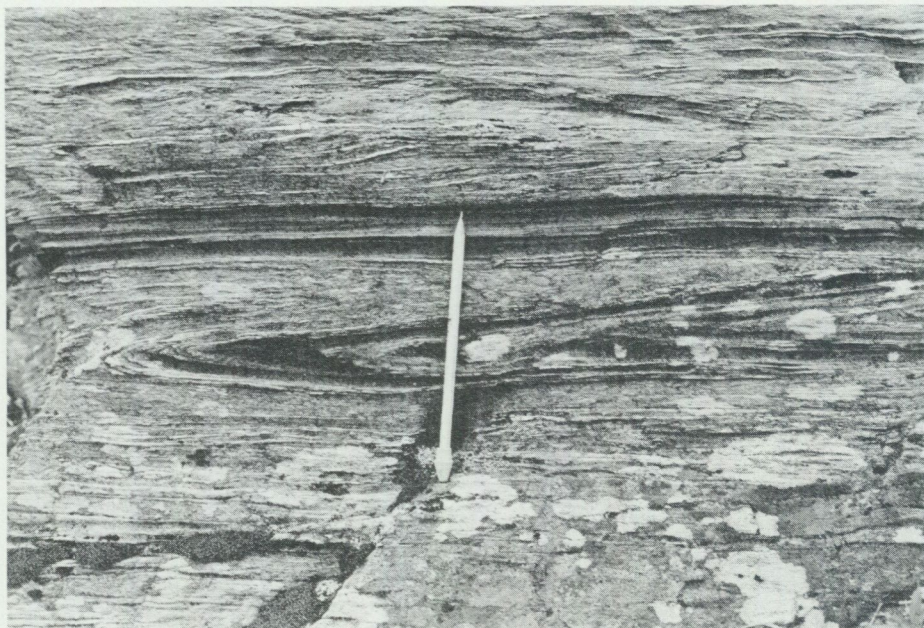


Fig. 23. Tight fold, inferred to belong to F_1 fold phase, in Jofjället Calcareous Phyllite (24F 9-d).

F_2 folds occur most frequently in quartz-rich rocks in the vicinity of shear zones; F_2 have not been recognized in the eastern part of the Jofjället Calcareous Phyllite. The fold style is, in general, tight to isoclinal but more open folds may occur in very competent rocks (Fig. 25a). Both symmetrical and asymmetrical folds are present. The hinges of the folds are thicker than the limbs, the folds belonging to classes 1C, 2 and 3 in Ramsay's (1967) classification. The axial surface foliation is developed as a penetrative crenulation cleavage in mica-rich layers and as a differentiated layering in quartz-rich layers. The F_2 folds also appear as intrafolial folds (Fig. 25b) and locally the S_2 foliation is deformed in late D_2 shear zones as shown in Fig. 25c.

Fig. 26a shows that the F_2 folds have rather flat-lying axial surfaces (around 30° to the north). Many of the poles to the axial surfaces appear to fall along a great circle on the stereographic net. The constructed fold axis to this great circle coincides approximately with the F_3^N axis (Fig. 24a). The orientation of the F_2 fold axes shows a considerable spread, but with some concentration to the north (Fig. 26b) i.e. the axes are often reclined. It should be noted that the majority of the measured F_2 elements come from the southern limb of the late Jofjället Synform and especially from the Tjåter Phyllite, i.e. the ore-bearing formation. A quartz mineral lineation (L_2) shows a distinctly more E-W trend (Figs. 25d, 26c) when compared with the F_1 and F_2 fold axis.

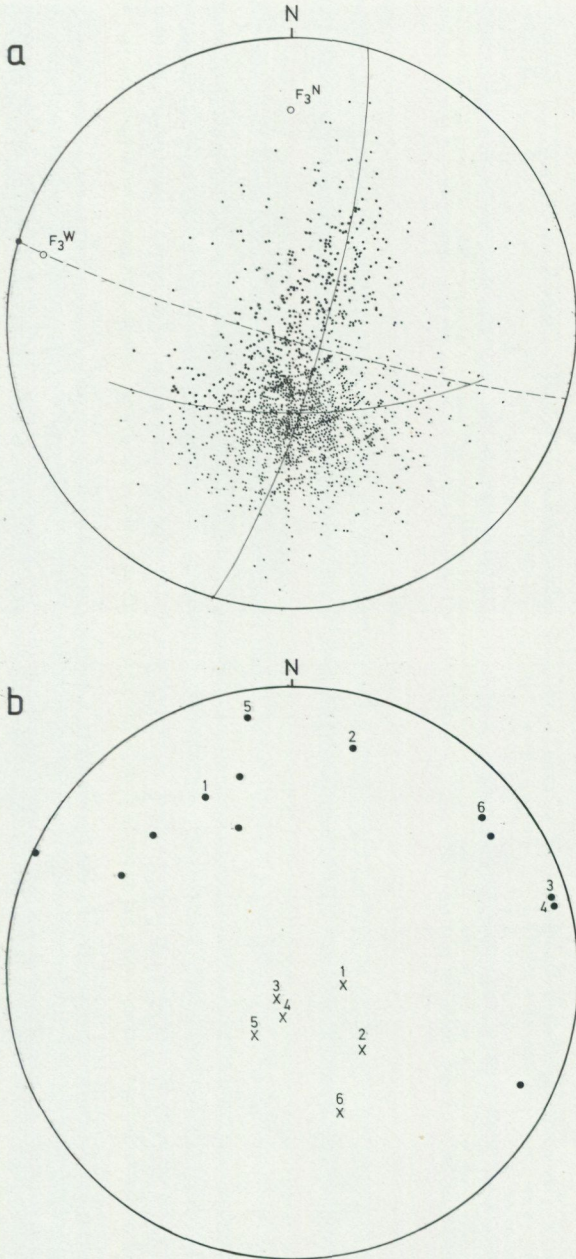


Fig. 24. Stereogram showing tectonic elements from D₁ and D₂ deformation (most of the elements are coming from the lower grade Storfjället Nappe Complex).

a: Poles to the main foliation (S₁ or S₂) in the Jofjället area. Deduced foldaxes (F₃^W and F₃^N) are plotted and the inferred axial surface of the Jofjället Synform (---) is also drawn.

b: Poles to axial surfaces of F₁ folds (x) and F₁ fold axes (●).

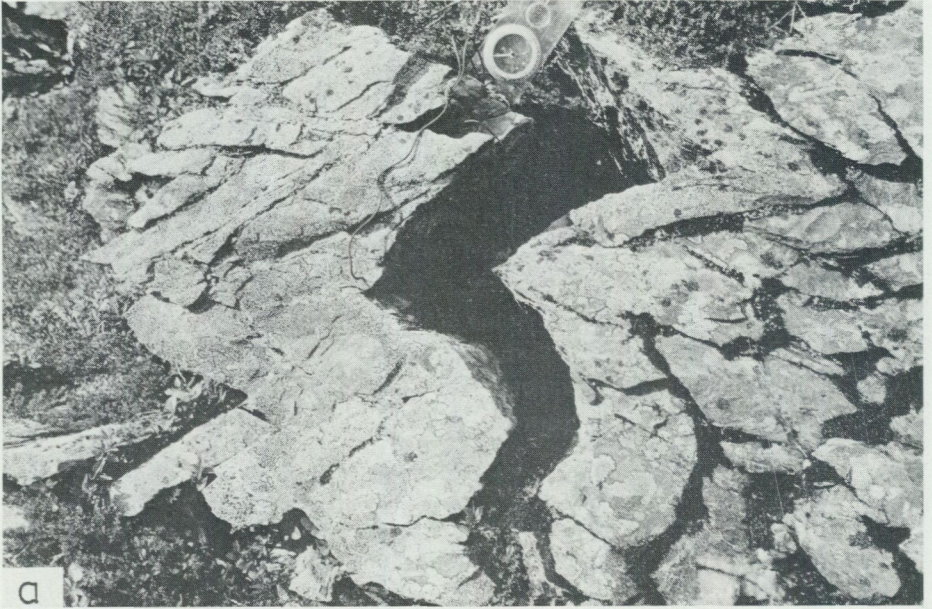
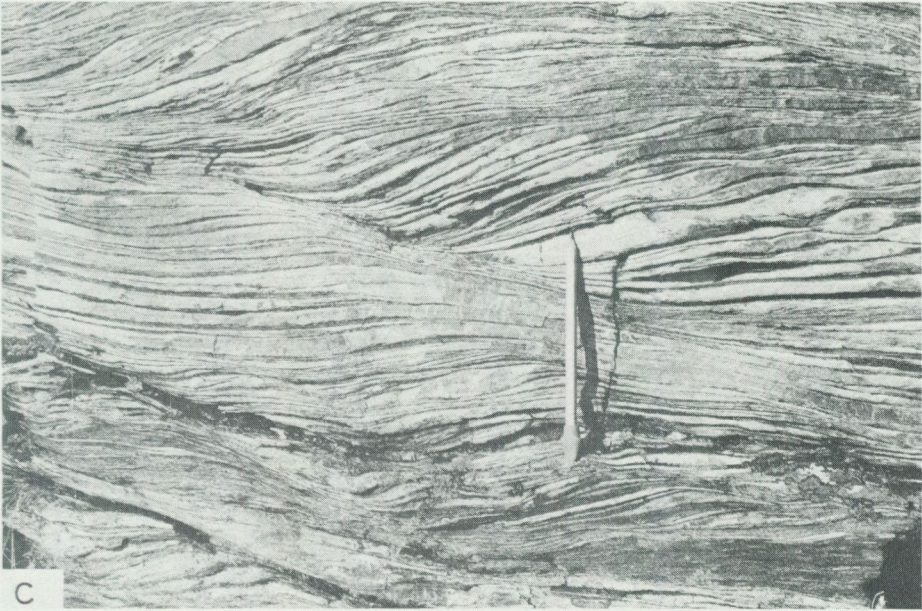


Fig. 25. D_2 structures.

a: Close F_2 fold in a very competent quartz-rich rock in Tjäter Phyllite (24F 9-a).

b: Isoclinal intrafolial F_2 folds in Västansjö Phyllitic Quartzite in the vicinity of the thrust contact to the overlying Laxfjället Nappe. The folds are extremely transposed and attenuated (24F 9-d).



c



d

c: Pronounced metamorphic layering (S_2), defined by thick quartz- and thin mica-rich layers. Locally, e.g. left of the pencil, an earlier foliation can be seen. Late D_2 shear zones are also an impressive element in the picture (Tjäter Phyllite, 24F 9-a).

d: L_2 lineation and J_3 joints in mylonitic rocks in Rövattnet Formation. The lineation is mainly a quartz mineral lineation, which is inferred to indicate the direction of the nappe translation during D_2 (25E 0-j, the pencil is pointing to the north).

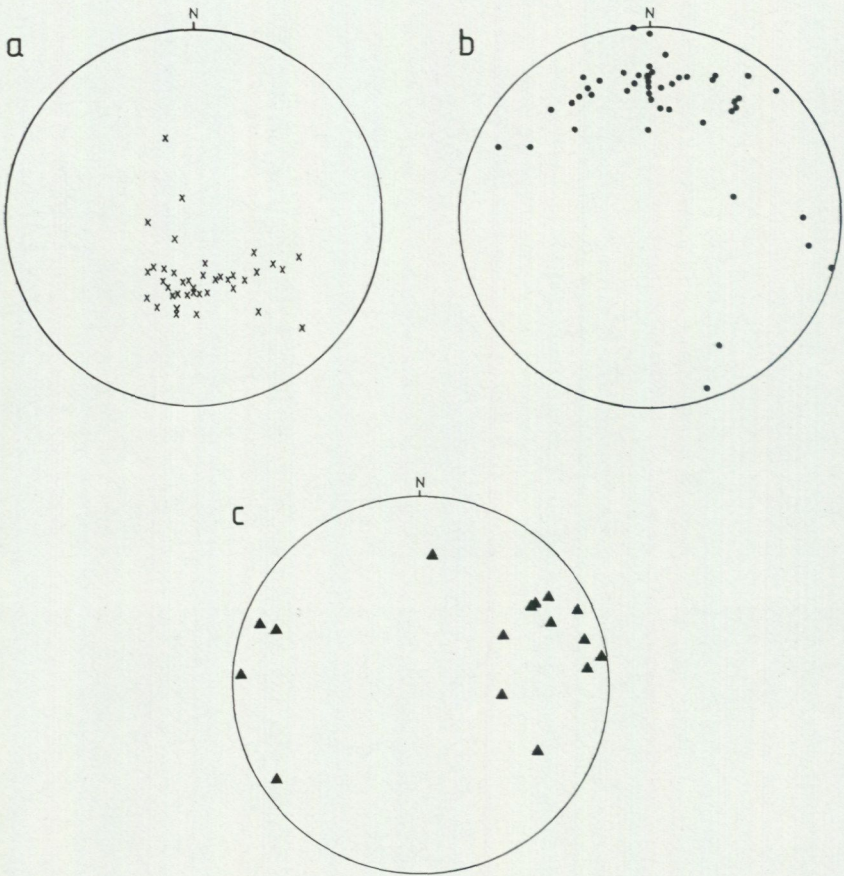


Fig. 26. Stereogram showing tectonic elements from D₂ deformation (most of the elements are coming from the lower grade Storfjället Nappe Complex).

a: Poles to axial surfaces of F₂ folds.

b: F₂ fold axes.

c: L₂ lineation.

4.3.5.2. Late structures

The late folds belong to deformation phase D₃. They may be divided into two groups with E–W and N–S fold axis. There are locally late kink folds with variable fold axis orientation belonging to deformation phase D₄.

In particular cases it can be demonstrated that these structures deform the early folds and their axial surface foliations. However, the age relationship between the late folds themselves is often difficult to establish. It is inferred that the two fold sets were more or less simultaneous in large parts of the Jofjället area. The east-west orientated folds are here designated as F_3^W and the north-south folds as F_3^N . The kink folds are labelled F_{4kink} . Although they probably formed close in time to the other folds, they are apparently very late in the total structural development (Fig. 27b).

The F_3^W folds are very common and are present in all the formations of the lower grade part of the Storffjället Nappe Complex. Fig. 28a shows that the F_3^W folds have rather steep axial surfaces with E-W strike. The subhorizontal fold axes also show an E-W trend (Fig. 28b). This direction deviates, however, somewhat from the direction of the axial surface trace to the Jofjället Synform and from the constructed fold axis deduced from the poles to the main foliation (Fig. 24a); they give an approximate value $N75^\circ W$ and $N75^\circ W/10^\circ$ respectively. This deviation depends partly on data bias since a large part of the measurements come from restricted areas around the mineral deposits.

The F_3^N folds are also very common and the fold style is the same as for the F_3^W folds (Figs. 27a, b). A dome and basin pattern developed on different scales occurs when the F_3^N folds interfere with the F_3^W folds. Fig. 28c shows that the F_3^N folds often have steep axial surfaces with a N-S strike. Fold axis orientations lie in a sector to the north or the south dependent on their localization within the E-W Jofjället Synform (Fig. 28d). The constructed F_3^N fold axis, which is deduced from the poles to the main foliation in the Jofjället area, has an approximate value N-S/26N (Fig. 24a).

Steep joint surfaces with N-S strike are common in some areas (Figs. 25d, 28c); they are typically localized in F_3^N antiforms (Fig. 27a). In some cases minor faults have occurred along these surfaces. A more important fault is indicated on the geological map 1 km south-west of Stuoressjaure (24E 9-j). Whether the joints are syn- or post- F_3 is not clear from field evidence, but it is possible they have formed in connection with the F_3^N folding as AB-joints.

F_4 kink folds occur only locally and are then present in steeper parts of the large E-W Jofjället Synform. The kink folds have subhorizontal axial surfaces and varying fold axis orientation (Fig. 27c). Occasionally a spaced crenulation cleavage is present as an axial surface foliation (Fig. 27b).

4.3.6. SKINNFÄLLTRÄSKET MYLONITE (STORFJÄLLET NAPPE COMPLEX)

The structures in this unit have not been studied in any detail; however both early reclined isoclinal folds and late upright more open folds have been noted.

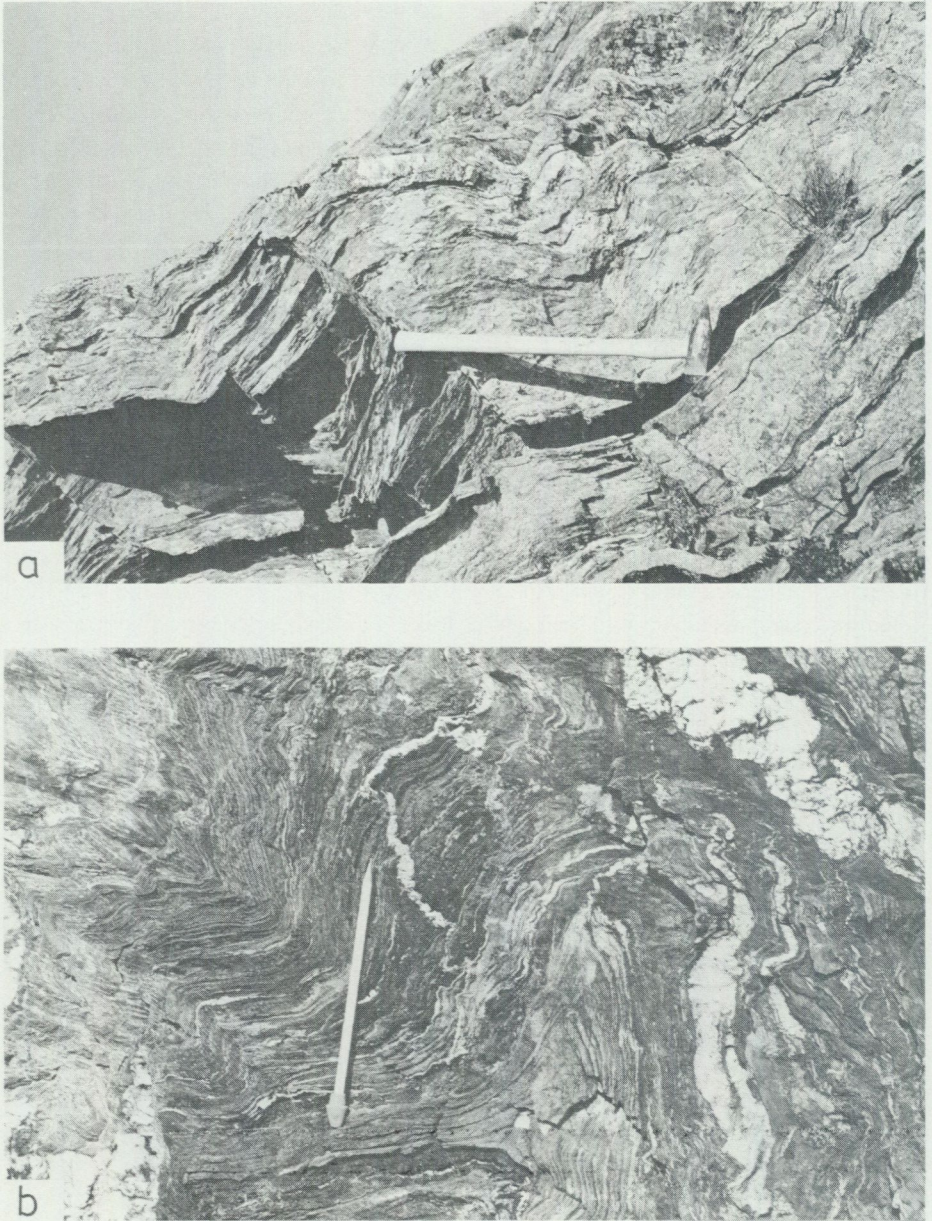


Fig. 27. Late tectonic (D_3 and D_4) structures.

a: Open to gentle F_3^N folds in rather quartz-rich rocks in Tjäter Phyllite. Note the N-S joint surfaces which are typically localized in the F_3^N antiforms (24F 9-a).

b: Rather tight F_3^N fold refolded by F_4 kink fold. The F_3^N fold has an upright crenulation cleavage as axial surface foliation, while the F_4 fold has a subhorizontal crenulation cleavage (Jofjället Calcareous Phyllite, 24F 9-d).



c: F₄ kink fold with subhorizontal axial surface in Jofjället Calcareous Phyllite (24F 9-d).

4.4. MESOSCOPIC STRUCTURES – FOLIATIONS

4.4.1. OPENING REMARKS

The main foliation in the Jofjället area is composed of one or two foliations whose relative development varies throughout the area (Fig. 29). The following foliations have been noted in each of the tectonic units and are discussed in more detail below. Foliation terminology used in the discussion is according to Hobbs et al. (1976).

Skinnfällträsket Mylonite (Storfjället Nappe Complex)	-	(S ₁₊₂) ¹ , S ₂ , (S ₃)
Lower grade Storfjället Nappe Complex;		
Remaining formations	-	S ₁₊₂ , S ₂ , (S ₃), (S ₄)
Jofjället Calcareous Phyllite	-	S ₁ , (S ₃), (S ₄)
Higher grade Storfjället Nappe Complex	-	S ₁₊₂ , S ₂ , (S ₃)
Laxfjället Nappe	-	S ₁₊₂ , S ₂ , (S ₃), (S ₄)
Björkvattnet Nappe	-	S ₁ , (S ₁₊₂), (S ₂), (S ₃), (S ₄)

¹ Bracket means that the foliation is present only locally.

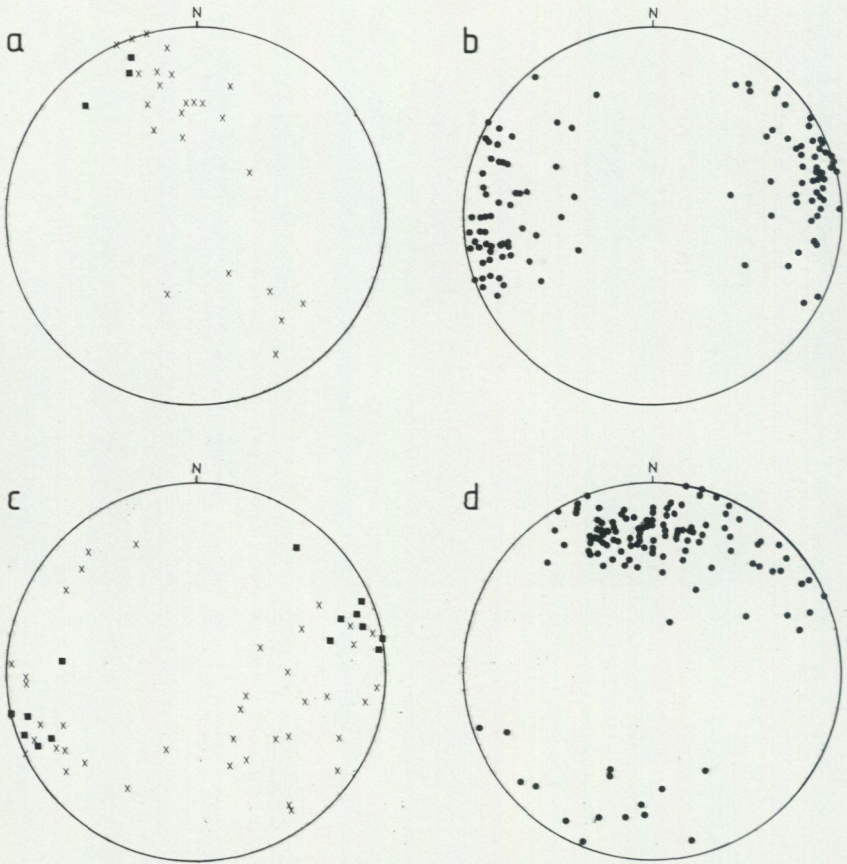


Fig. 28. Stereogram showing tectonic elements from D_3 deformation (most of the elements are coming from the lower grade Storfjället Nappe Complex).

- a: Poles to axial surfaces of F_3^W folds (x) and J_3^W joints (■).
 b: F_3^W fold axes.
 c: Poles to axial surfaces of F_3^N folds (x) and J_3^N joints (■).
 d: F_3^N fold axes.

4.4.2. BJÖRKVATTNET NAPPE

4.4.2.1. Early foliations

S_1 is the dominant foliation in the Björkvattnet Nappe, especially in its eastern part. The morphology of the S_1 foliation depends mainly on lithology. In pelitic phyllites, which are, however, quite rare, S_1 is developed as a slaty cleavage, while in more quartz-rich phyllites and volcanites a phyllitic cleavage to metamorphic layering is present (Fig. 30c). In quartz-dominated phyllites (mica < 10 %) the micas are largely oriented along the boundaries of the quartz grains, thus defining a diffuse, anastomosing foliation (Fig. 30a).

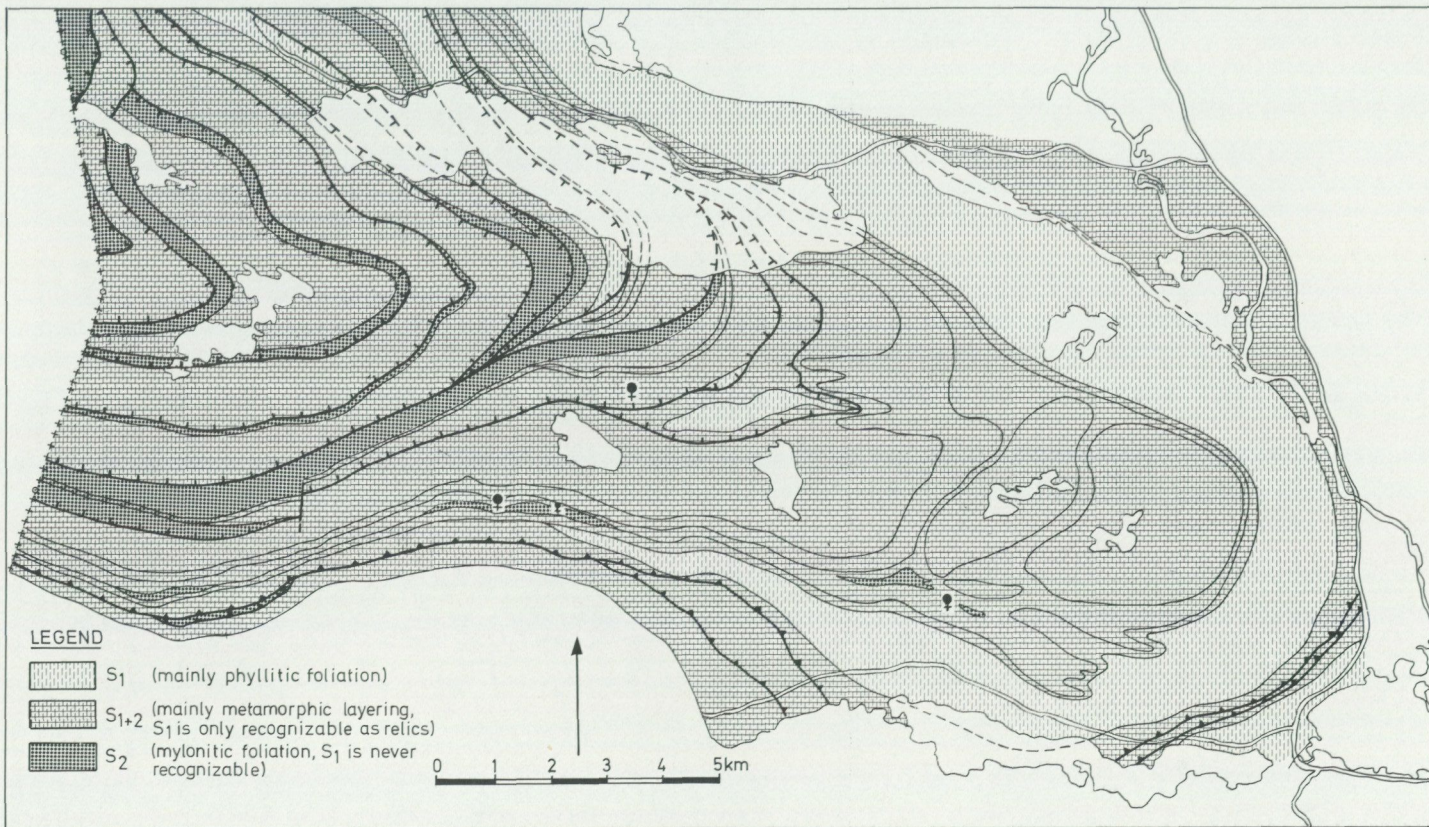


Fig. 29. Schematic distribution of the main foliation in the Jofjället area.

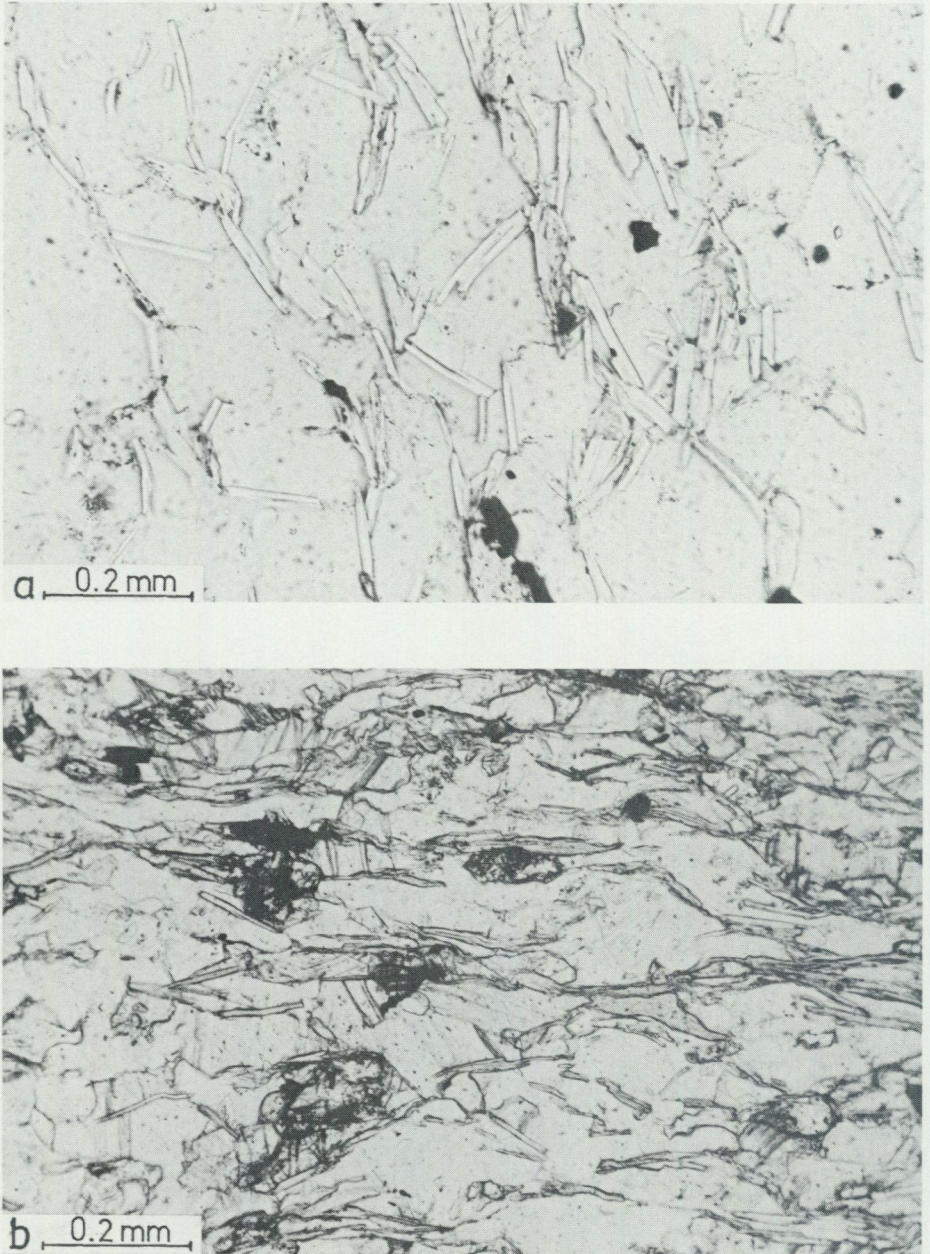
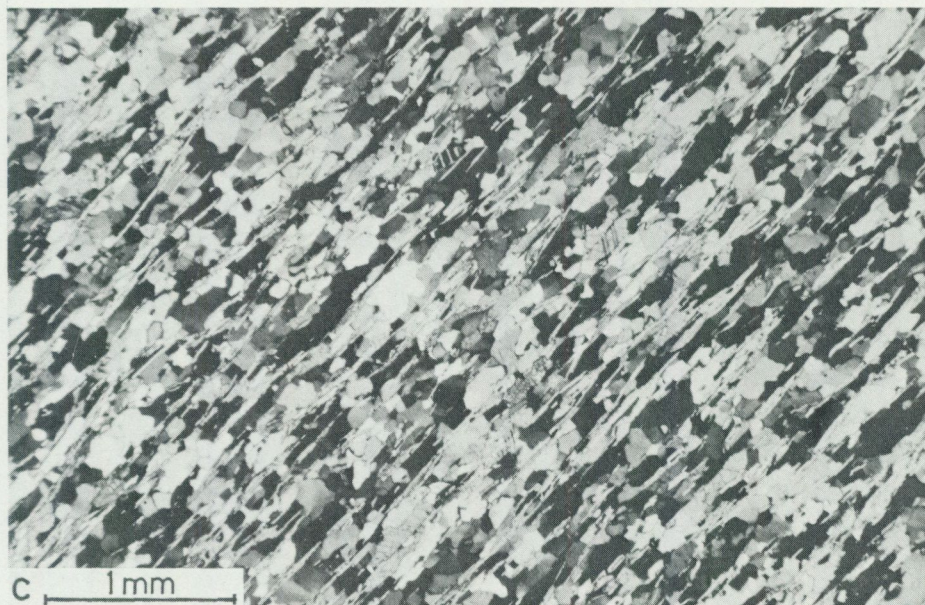


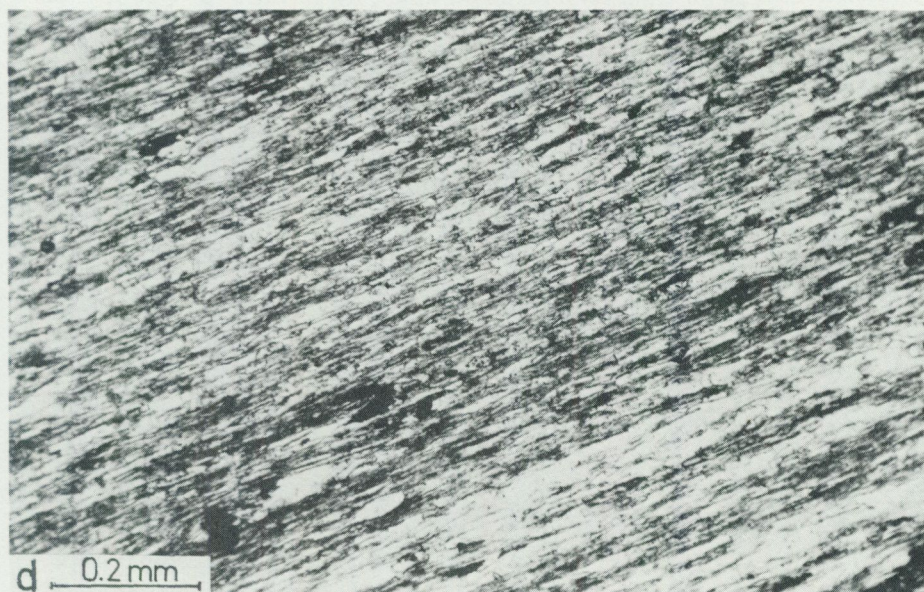
Fig. 30. Various foliation types in relation to S_1 , S_2 , S_3 and lithology in the Jofjället area.

a: Phyllosilicate-poor rock in Västansjö Phyllitic Quartzite with the micas orientated along the boundaries of the quartz grains, thus defining a diffuse, anastomosing foliation, probably S_1 . (Björkvattnet Nappe, 24F 9-d, uncrossed nicols.)

b: Phyllitic cleavage (S_1) in calcareous phyllite. (Jofjället Calcareous Phyllite in lower grade Storjället Nappe Complex. 24F 9-d, uncrossed nicols.)



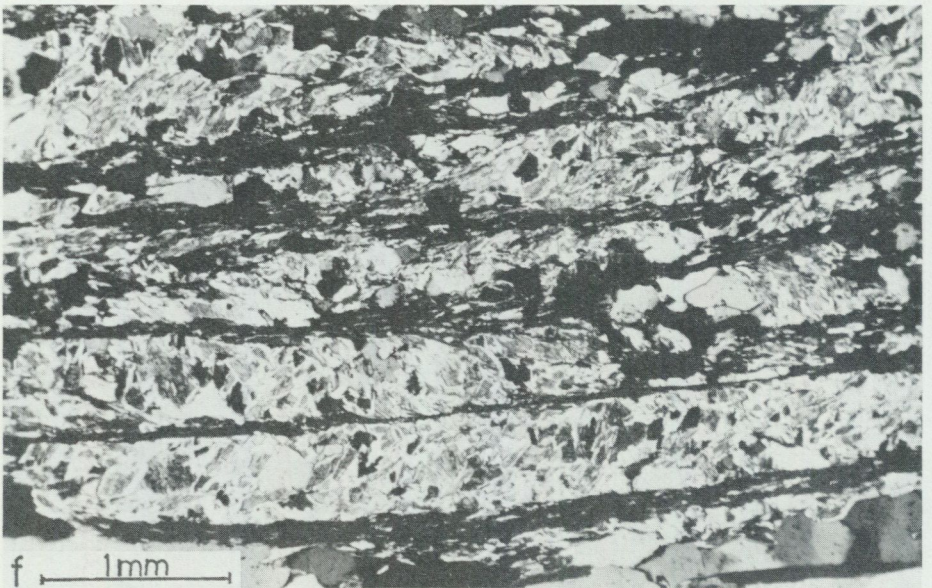
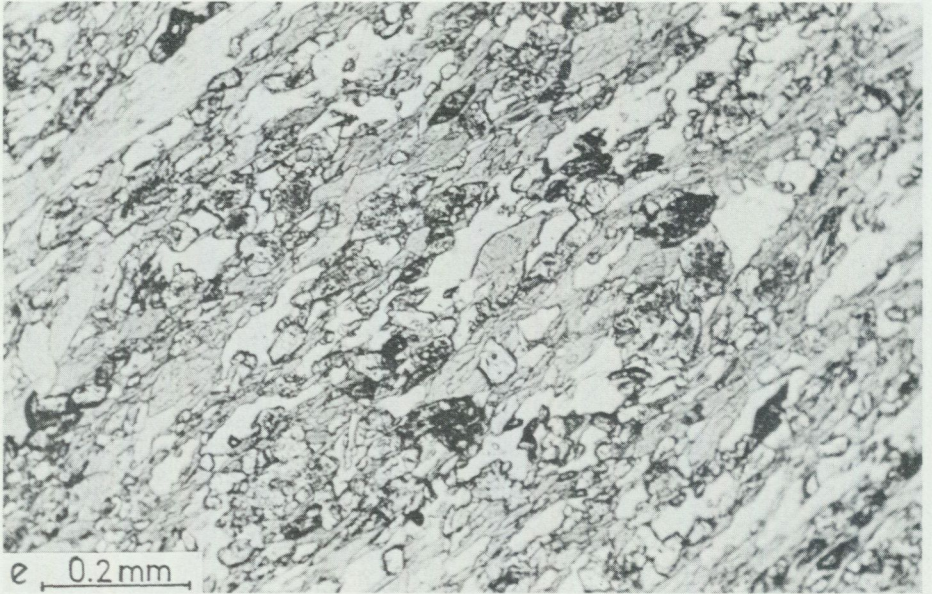
c 1 mm



d 0.2 mm

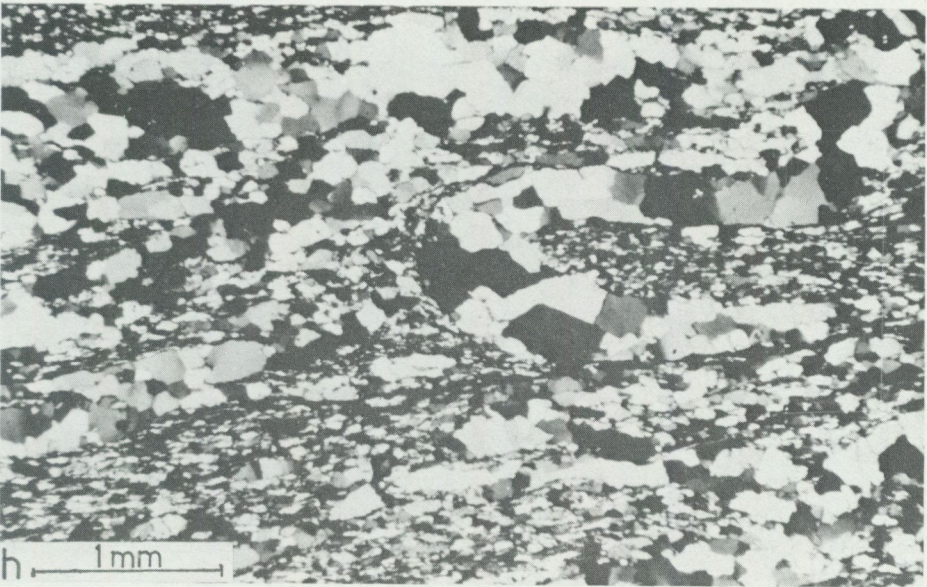
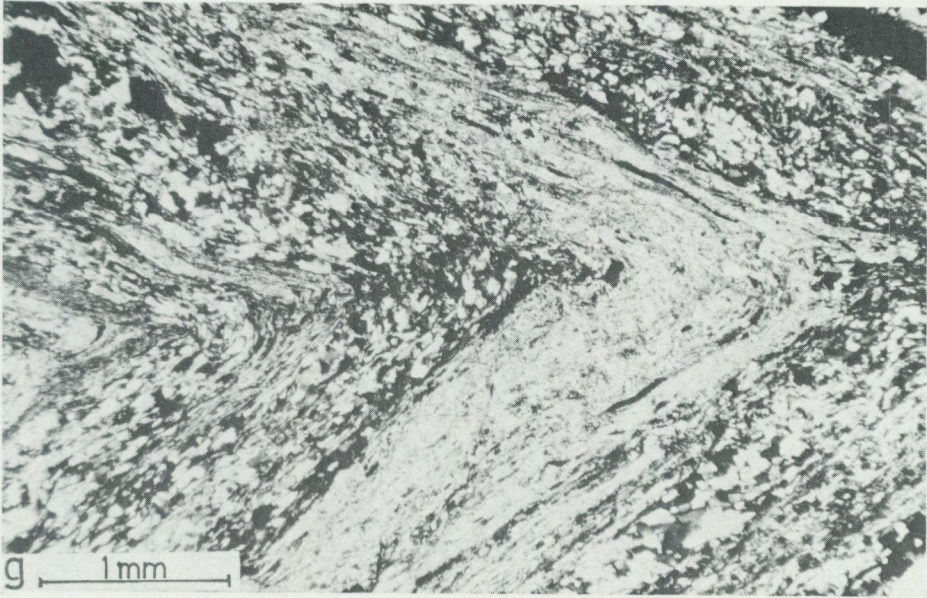
c: Phyllitic cleavage (S_1 ?) in a quartz-rich phyllite. (Västansjö Phyllitic Quartzite in Björkvattnet Nappe, 24F 9-d, crossed nicols.)

d: Slaty cleavage (S_2) in pelitic phyllite. (Rikarsjön Phyllite in lower grade Storfjället Nappe Complex, 24F 9-a, crossed nicols.)



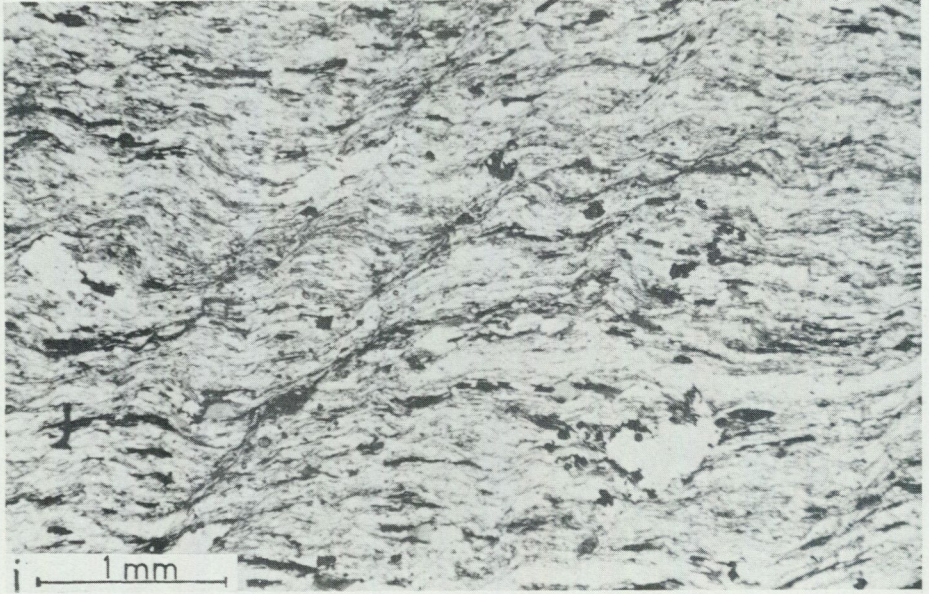
e: Slaty cleavage (S_2) in greenschist. Amphibole and chlorite are the foliation-forming minerals. (Skälvattnet Volcanite in Björkvattnet Nappe, 24E 9-j, uncrossed nicols.)

f: Crumpled cleavage (S_2) in a pelitic quartz phyllite. (Tjåter Phyllite in lower grade Storöfjället Nappe Complex, 24F 9-c, crossed nicols.)



g: Metamorphic layering (S_2) and a F_3^N fold in a schistose quartz phyllite. (Metartjärnen Formation in higher grade Storfjället Nappe Complex, 24F 8-d, crossed nicols.)

h: "Mylonitic" foliation (S_2) with isoclinally folded quartz veins in a graphite-bearing rock, demarcated by recrystallized quartz. (Tjåter Phyllite in lower grade Storfjället Nappe Complex, 24F 9-a, crossed nicols.)



i: Crenulation fold and cleavage (F_3 and S_3) deform the main foliation (S_2) in a quartz phyllite. (Tjäter Phyllite in lower grade Storfjället Nappe Complex, 25E 1-j, crossed nicols.)

The S_2 foliation is mainly localized in the western and upper part of the Björkvattnet Nappe. In more quartz-rich phyllites and quartz-dominated phyllites S_2 is generally present as a strong metamorphic layering; however relics of S_1 may be recognized (S_1+2). In mafic volcanites a slaty cleavage may be present (Fig. 30e).

4.4.2.2. Late foliations

An S_3 foliation, which is weak and only locally present, is developed as a spaced crenulation cleavage parallel to the axial surfaces of more close folds. S_4 occurs very locally; it is a spaced crenulation cleavage along the axial surface of certain kink folds.

4.4.3. LAXFJÄLLET NAPPE

The Laxfjället Nappe is characterized by a strong metamorphic layering, interpreted as S_2 . In the calcareous phyllite unit occasional relics of an earlier foliation (S_1) can be identified, which makes the main foliation complex and composite. S_3 and S_4 are present locally as a spaced crenulation cleavage.

4.4.4. THE HIGHER GRADE PART OF THE STORFJÄLLET NAPPE COMPLEX

The main foliation in the schists of the Metartjärnen Formation is generally developed as a strong metamorphic layering (Fig. 30g), often more or less phyllonitic in

appearance. The main foliation, which is tentatively interpreted as S_2 , wraps around garnet porphyroblasts with oblique inclusion trails (see later discussion), while occasionally there occur micas oblique to the metamorphic layering. These pre- S_2 textures may represent different foliation generations and are, thus, referred to as S_{1a} and S_{1b} respectively.

An S_3 foliation, which is locally present, is developed as a crenulation cleavage.

4.4.5. THE LOWER GRADE PART OF THE STORFJÄLLET NAPPE COMPLEX

4.4.5.1. Early foliations

In the Jofjället Calcareous Phyllite, particularly in the eastern part of the area, the main foliation is a phyllitic cleavage and is interpreted as S_1 (Fig. 30b). Elsewhere S_1 occurs as relics in the form of transposed layers, oblique micas or as inclusions in porphyroblasts and has been thoroughly transposed together with bedding (S_0) into S_2 , the main foliation being a complex transposition foliation (S_2 to S_{1+2}). The formation of S_2 is believed to be related to strong differential movements at different levels within the rock pile.

The character of the S_2 foliation varies greatly with lithology. In pelitic phyllites it is developed as a slaty cleavage (Fig. 30d), and is thus difficult to discriminate from S_1 . In more quartz-rich phyllites and in tuffs and tuffites, S_2 is often developed as a pronounced metamorphic layering and the earlier phyllitic cleavage is completely transposed. Relics of S_1 may, however, be present at micas obliquely orientated to the S_2 layering. In fold hinges and in pressure shadows of porphyroblasts, an S_2 crenulation cleavage is often present (Figs. 30f, 33f). Quartz-dominated phyllites (mica < 10%) have a strong metamorphic layering or mylonitic foliation interpreted as S_2 , relics of S_1 being difficult to identify.

The more massive igneous rocks are locally foliated, the main foliation being probably S_2 ; however, apart from peripheral zones and local shear zones, S_2 is weak and developed as a rudimentary crenulation cleavage. A relict subophitic texture is common in the more central parts of the bodies where S_1 may also be recognized. Transposition of D_1 quartz veins also occurred during D_2 , while phyllonites and mylonites were formed from phyllites in D_2 shear zones (Fig. 30h).

4.4.5.2 Late foliations

S_3 is present in restricted areas in the lower grade Storfjället Nappe Complex, especially its eastern part. The foliation is developed as a spaced crenulation cleavage parallel to the axial surfaces of more close F_3 folds (Fig. 30i). Only seldom it is sufficiently well developed to become the main foliation. S_3 is best developed in pelitic phyllites.

S_4 occurs very locally. It is present as a spaced crenulation cleavage along the axial surfaces of certain kink folds (Fig. 27b).

4.4.6. SKINNFÄLLTRÄSKET MYLONITE (STORFJÄLLET NAPPE COMPLEX)

The mylonitic rocks of this formation show an intense, penetrative foliation, interpreted as S_2 . Relics of an earlier foliation (S_1) are locally present.

4.5. MINERAL GROWTH AND RELATIONSHIP TO FOLIATION

4.5.1. OPENING REMARKS

In order to investigate the relationship between metamorphism and deformation, porphyroblasts of different species have been studied. Minerals specific to a particular tectonic unit are discussed first and described in the order of tectono-stratigraphy, from bottom to top. Minerals present in all nappe units are briefly discussed in a later section.

4.5.2. BJÖRKVATTNET NAPPE

4.5.2.1. Biotite

Fine-grained biotite is locally present in the Björkvattnet Nappe. The biotite is pre- and syn- D_1 , with perhaps some post- D_1 recrystallization.

4.5.2.2. Amphibole

Amphibole (mainly actinolite) is restricted to the western extension of the Skälvattnet Volcanite. It is normally fine-grained but sometimes large (2–3 mm) poikiloblasts occur. The fine-grained type is euhedral to subhedral, poor in inclusions and more or less deformed (Fig. 30e), being pre- D_2 . The coarse-grained type is euhedral and rich in inclusions which are often up to 0.1–0.2 mm (Fig. 32b). Inclusion species involve quartz, epidote and calcite, but white mica and chlorite are also present. Occasionally the amphibole porphyroblasts are zoned. They are seldom enveloped by the S_2 foliation, the amphibole porphyroblasts appearing mostly to be post- D_2 but pre- D_3 .

4.5.3. LAXFJÄLLET NAPPE

4.5.3.1. Garnet

Garnet is restricted to the Joeström Quartz-Keratophyre. The garnet is subhedral to anhedral with randomly orientated inclusions. It is often more or less chloritized. The garnet is older than the main foliation.

4.5.3.2. Biotite

Fine-grained biotite is rather common in the different lithologies of the Laxfjället Nappe. The biotite seems to have been formed prior to and possibly also during the main foliation.

4.5.3.3. Amphibole

Amphibole (actinolite) is restricted to the metagabbros of the Jovattnet Calcareous Phyllite and is mostly subhedral. In the cores of the metagabbros it has a rather random orientation but seems to be recrystallized to actinolite and weakly deformed. In the outer parts of the metagabbros the amphibole is more fine-grained and makes a considerable contribution to the main foliation. During this deformation (D_2) the amphibole was probably rotated and recrystallized. The amphibole has crystallized prior to and during the main foliation.

4.5.4. THE HIGHER GRADE PART OF THE STORFJÄLLET NAPPE COMPLEX

4.5.4.1. Garnet

Garnet is a common and characteristic mineral in the Metartjärnen Formation, where the main foliation has tentatively been interpreted as S_2 or S_{1+2} . As stated earlier the pre- D_2 history of the Metartjärnen Formation is unclear, there possibly being more than one foliation represented. Following earlier nomenclature, the inclusion trails within the garnet porphyroblasts are referred to as S_{1a} . Four types of garnet have been recognized and their relation to the foliations interpreted as follows:

Type 1 – anhedral to subhedral garnets containing inclusions without any preferred orientation. The size of the inclusions is smaller than the minerals outside the garnet. The main foliation sweeps around the garnet, which often show fracturing; type 1 is very common (Fig. 31a).

Type 2 – anhedral garnets with numerous "inclusions" without any preferred orientation and often larger than the minerals outside the garnet (fish-net garnet). The main foliation envelops this type which is uncommon (Fig. 31b). The shape of the "inclusions" may indicate that they were less deformed than the grains outside the garnet during the D_2 deformation; i.e. the "inclusions" were "protected" by the garnet, which hence existed prior to the D_2 deformation.

Types 1 and 2 are interpreted as being pre- S_2 , but with uncertain time relation to S_{1a} .

Type 3 – anhedral to subhedral garnets containing inclusions that show a distinct preferred orientation. The external foliation which deflects around these garnets is discordant to the trace of the foliation within the garnets. Furthermore, the size of the inclusions (0.05–0.1 mm) is smaller than the minerals outside the garnet, but in general they seem to be somewhat larger than the inclusions in the garnets of type 1. Type 3 is quite common (Fig. 31c). This type is interpreted as being pre- S_2 and probably post-" S_1 ".

Type 4 – small euhedral garnets without inclusions that transect the main foliation; this type has only been found in quartz-keratophyres in the western extension of the Metartjärnen Formation and is quite rare. They are believed to be later than the main foliation (S_2).

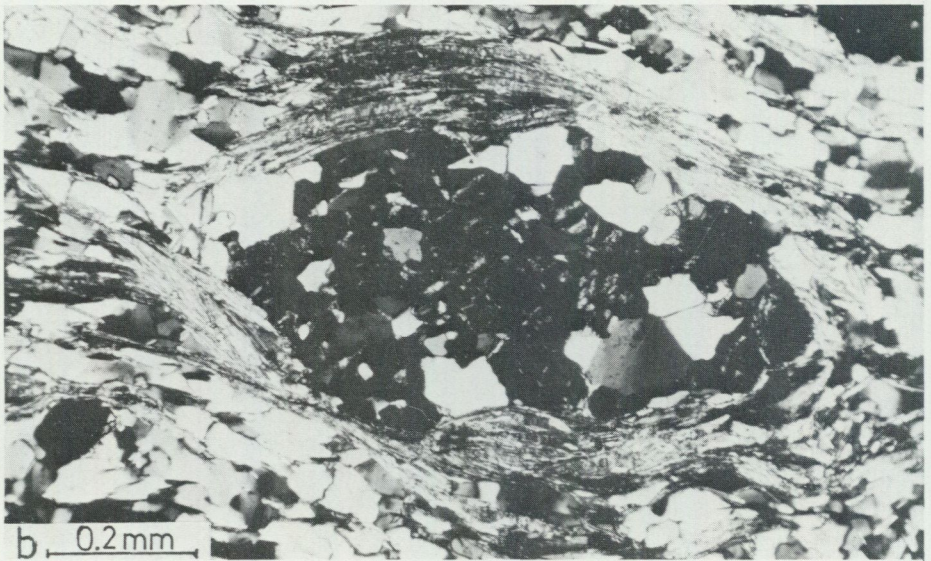
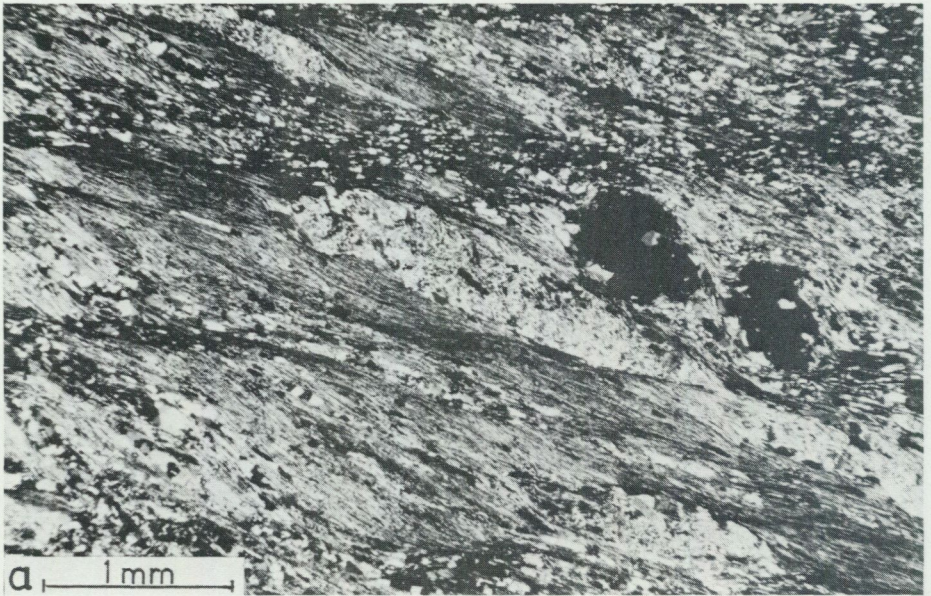
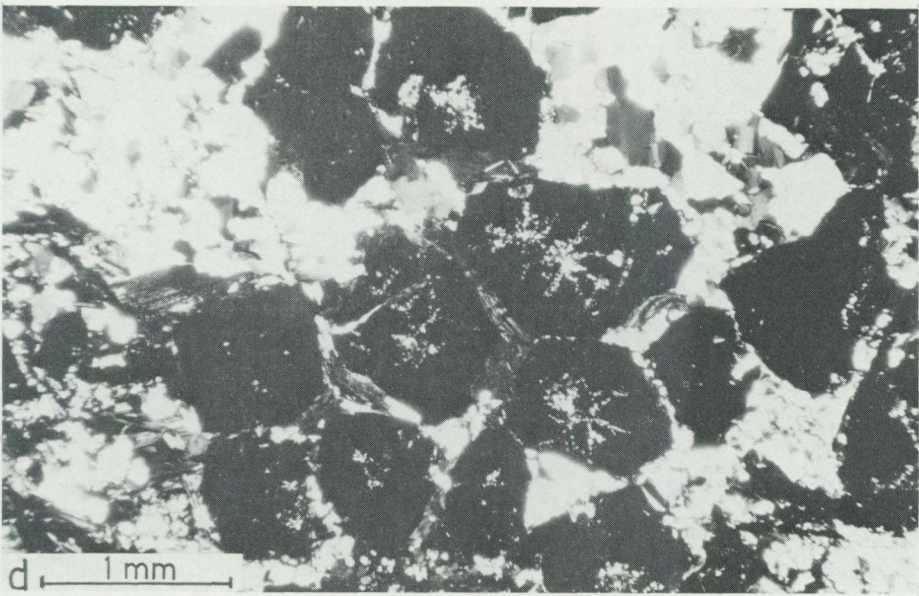
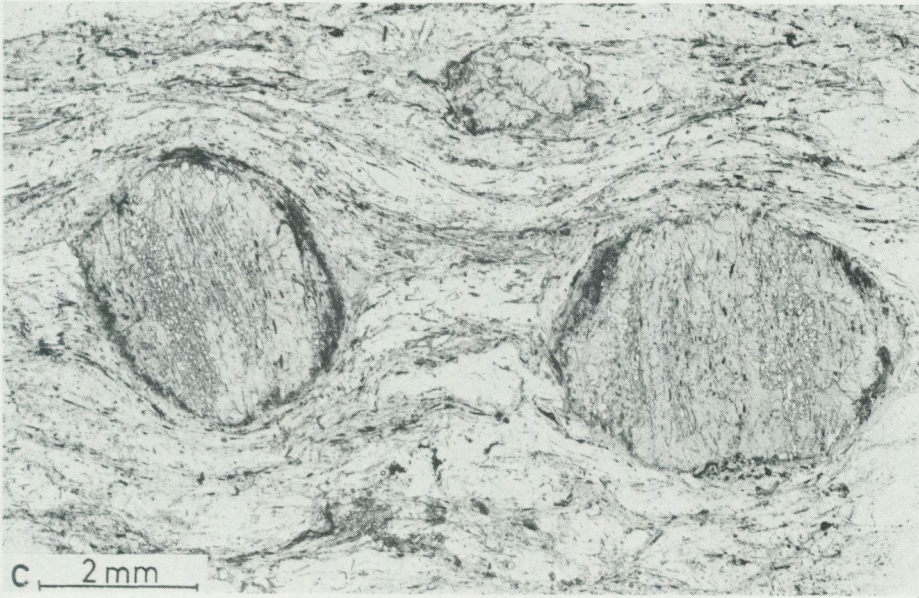


Fig. 31. Garnet porphyroblasts and their relationship to foliation.

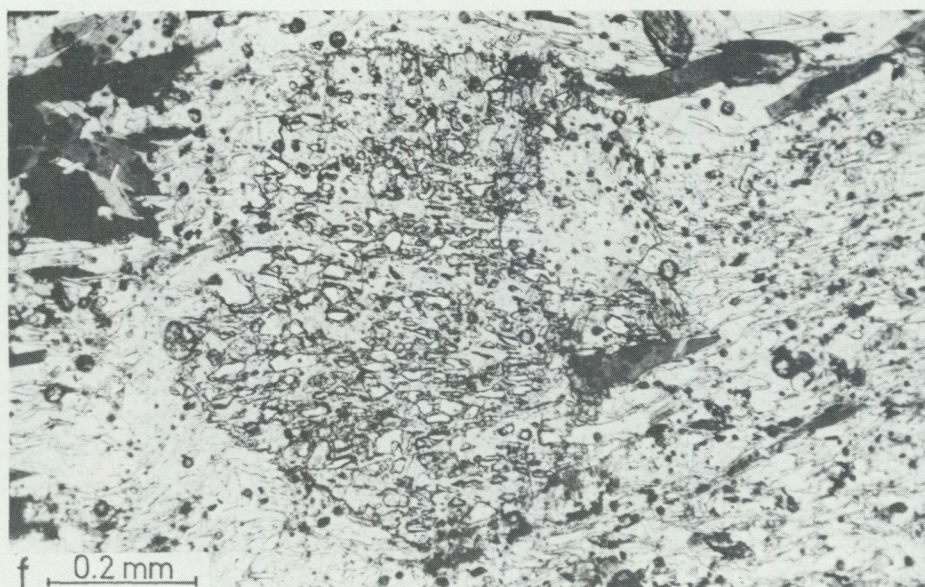
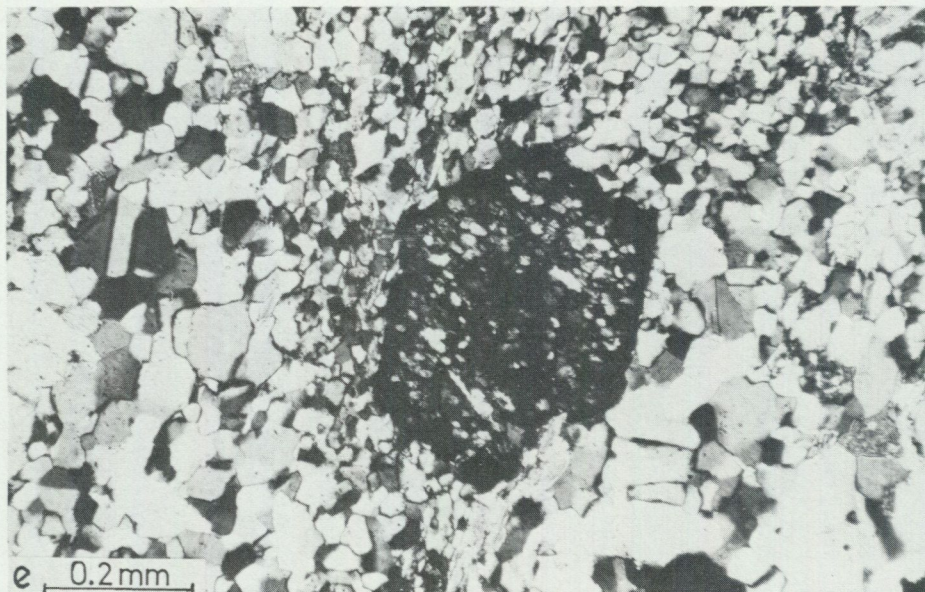
a: Anhedral garnets with small inclusions without any preferred orientation (type 1). They are enveloped by the main foliation (S_2), which here is phyllonitic in character. The garnets are pre- S_2 , but with uncertain relation to " S_1 ". (Metartjärnen Formation in higher grade Storfjället Nappe Complex, 24F 9-b, crossed nicols.)

b: Anhedral garnet with numerous large "inclusions" without any preferred orientation (fish-net garnet, type 2) and enveloped by the main foliation (S_2). The garnet is pre- S_2 , but with uncertain relation to " S_1 ". (Metartjärnen formation in higher grade Storfjället Nappe Complex, 24F 9-d, crossed nicols.)



c: Anhedra-subhedra garnets with inclusion trails that are discordant to the enveloping external foliation, which is S_2 (type 3). The garnets are pre- S_2 and probably post- S_1 . (Metartjärnen formation in higher grade Storjället Nappe Complex, 24E 9-j, uncrossed nicols.)

d: Subhedra garnets with a radial and locally also concentric pattern of inclusions. The garnets are thought to be pre- D_2 . (Rikarsjön Phyllite in lower grade Storjället Nappe Complex, 24F 9-a, crossed nicols.)



e: Euhedral garnet with inclusions showing a faint preferred orientation and a rim without inclusions. The garnet seems to have formed pre-D₂ but recrystallized post-D₂. (Rövattnet Formation in lower grade Storfjället Nappe Complex, 25E 0-j, crossed nicols.)

f: Retrogressed euhedral garnet with a helicitic S₂ texture. The garnet is post-D₂. (Skninfällträsket Mylonite in Storfjället Nappe Complex, 25E 0-j, uncrossed nicols.)

4.5.4.2. Biotite

Fine-grained biotite is common in the Metartjärnen Formation. Most of the biotite lies in the main foliation (S_2) but some occurs oblique to this structure and appears to represent relics of an earlier surface (S_{1B}). It is concluded likely that the biotite has largely rotated from this early orientation into the new main foliation, the process being accompanied by variable amounts of recrystallization. Accordingly the biotite is interpreted to have been developed prior to and simultaneously with the main foliation.

4.5.4.3. Amphibole

Amphibole is present in mafic volcanites but also in some calcareous phyllites. In the mafic volcanites it is fine-grained (0.2 mm) and subhedral or anhedral-poikiloblastic, while in the calcareous phyllites it is always anhedral-poikiloblastic. The amphibole has been formed prior to the main foliation.

4.5.5. THE LOWER GRADE PART OF THE STORFJÄLLET NAPPE COMPLEX

4.5.5.1. Garnet

Garnet is rare in the lower grade part of the Storfjället Nappe Complex. Abundant garnet is present at only one locality in the Rikarsjön Phyllite. At this locality the garnets are anhedral to subhedral and many are characterized by a radial and occasionally also a concentric pattern of carbonate inclusions (Fig. 31d); the garnets are pre- D_2 .

Some mylonitic rocks in the Rövattnet Formation contain euhedral garnets with inclusions showing a rather weak preferred orientation (Fig. 31e). The garnets seem to have formed before D_2 , but recrystallized afterwards.

4.5.5.2. Biotite

Biotite seldom occurs as larger porphyroblasts. It is present in smaller quantities in the lower part of the Jofjället Calcareous Phyllite, where the main foliation is S_1 , and is here pre- and syn- D_1 . In the Rikarsjön Phyllite a sample from a tuffite with biotite porphyroblasts has been examined (Fig. 32a). Here the biotite has evidently been formed prior to the main foliation (S_2); however, the clearly irregular margins parallel to the S_2 foliation suggest that the D_2 deformation effected dissolution of the biotite porphyroblasts. In the Rövattnet Formation and the Brackfjället Greenstone biotite is rather common. In the mylonitic rocks of the Rövattnet Formation the biotite is post- D_2 (Fig. 32d), while it seems to be pre- D_2 in the Brackfjället Greenstone.

4.5.5.3. Amphibole

Amphibole (tremolitic) is present in the greenschists and greenstones in the lower grade part of the Storfjället Nappe Complex. The amphibole is usually fine-grained (0.1–0.3 mm) but occasionally large (3 mm) poikiloblasts occur. Both types are pre-S₂.

4.5.5.4. Chloritoid

Chloritoid porphyroblasts¹ are a characteristic feature of the Seinesbäcken Volcanite and are restricted to this formation. The porphyroblasts are often present as spherical rosettes, apparently without any preferred orientation. The main foliation (S₂) partly envelops the chloritoid porphyroblasts which, however, have helicitic relics of the same foliation (Fig. 32c). It is concluded that the chloritoid porphyroblasts started to grow during D₂ but most of their growth was accomplished after this deformation phase, i.e. they are syn- to post-D₂.

4.5.5.5. Stilpnomelane

Stilpnomelane porphyroblasts are quite common in certain parts of the Rövattnet Formation, where they are associated with mylonitic rocks. The stilpnomelane needles show a random planar orientation in the rock matrix and are clearly post-S₂, which is the main foliation in this area (Fig. 32d).

4.5.5.6. Siderite

A characteristic feature of the Tjåter Phyllite is the presence of abundant siderite porphyroblasts. The main foliation in the Tjåter Phyllite – often developed as a pronounced metamorphic layering interpreted as S₁₊₂ or S₂ – sweeps around the siderite porphyroblasts, thus clearly defining them as pre-D₂. The siderite porphyroblasts are occasionally subhedral but mostly anhedral. They have few and small inclusions (mainly quartz) which are rather evenly scattered throughout the grains; occasionally, however, there is a core of quartz grains (Fig. 33a). In the pressure shadows the porphyroblasts often have a rim of undeformed siderite totally free from inclusions (e.g. Fig. 33b).

An often rather diffuse internal foliation in the porphyroblasts, mainly defined by tiny graphite grains, is common (Fig. 33c). This internal foliation is crenulated by D₂ (Fig. 33d) and in such cases a crenulation cleavage is developed in the porphyroblast and often continues into the matrix outside the porphyroblast where it forms the main foliation (S₂) (Figs. 33d, 33e). The porphyroblast shown in Fig. 33f exhibits particularly interesting features. In the pressure shadow of the porphyroblast the main

¹ Electron probe analyses (for performance data see text to Fig. 12) give the following formulae (the sum of Fe- and Mg-values is taken as 1):

sample J75.74 (Fe_{0.91} Mg_{0.09}) Al_{1.94} Si_{1.08} O_{6.06} (H₂O is missing)
 sample J75.77 (Fe_{0.88} Mg_{0.12}) Al_{1.88} Si_{1.09} O₆ (H₂O is missing)

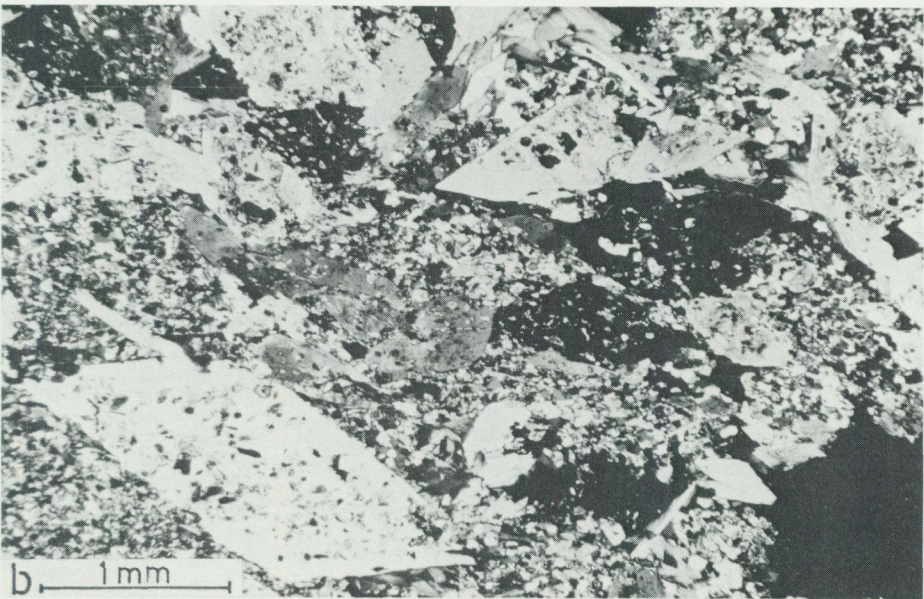
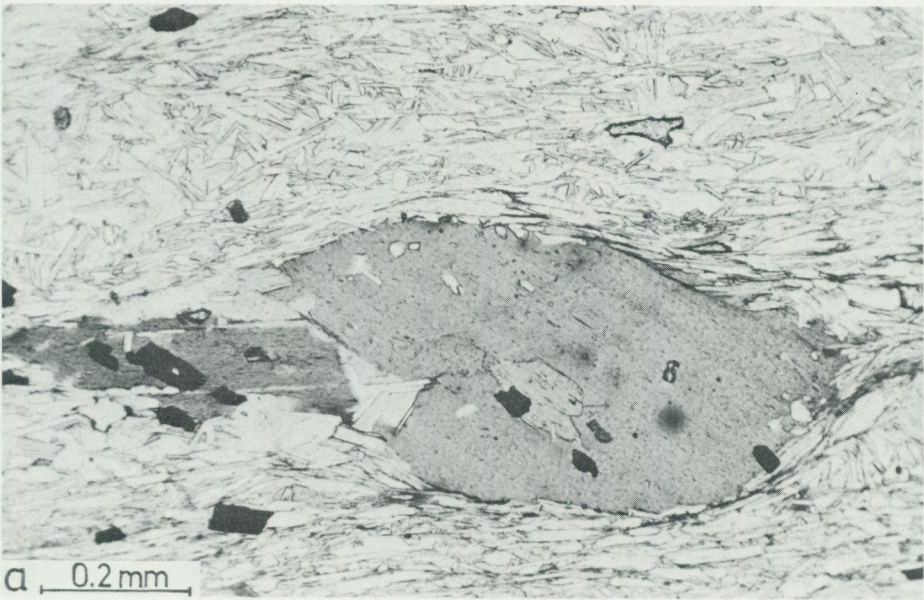
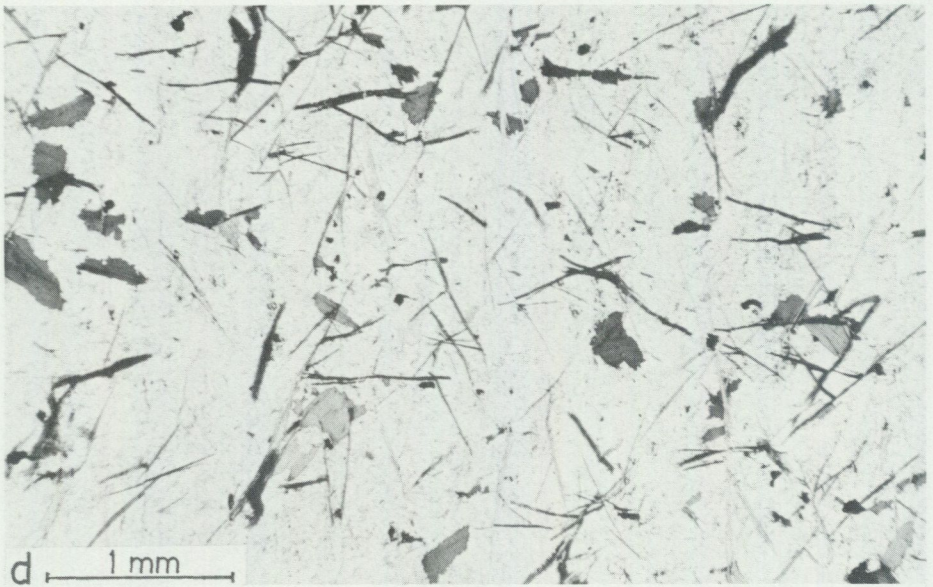
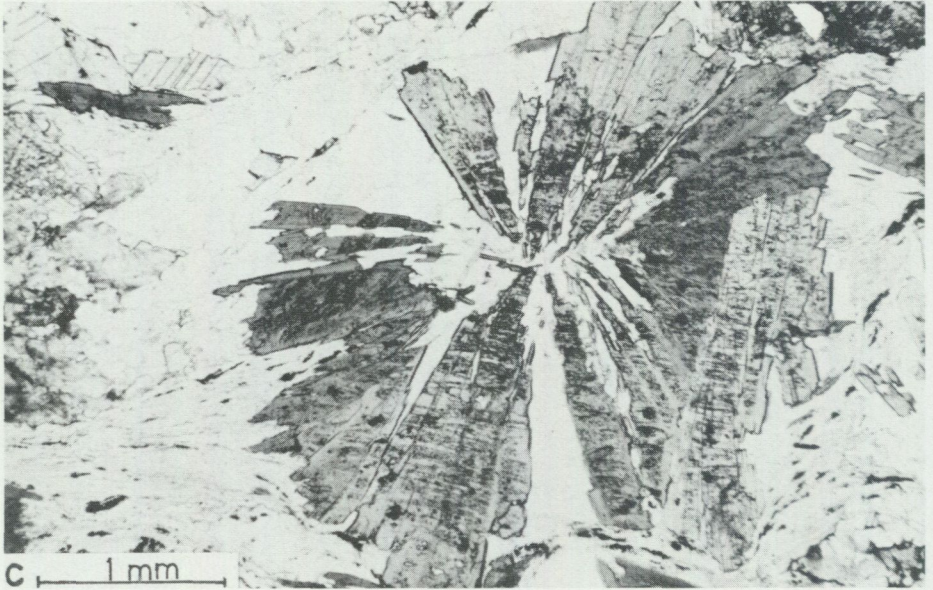
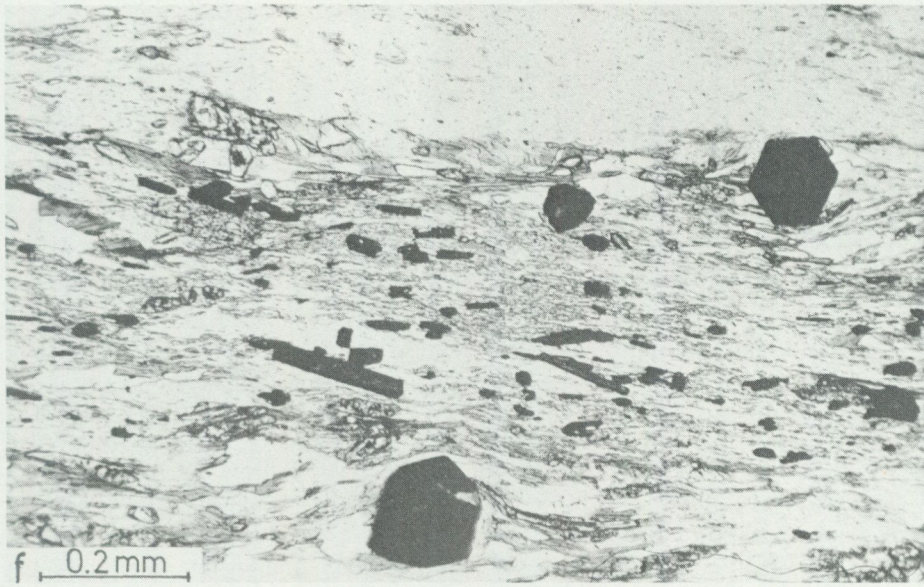
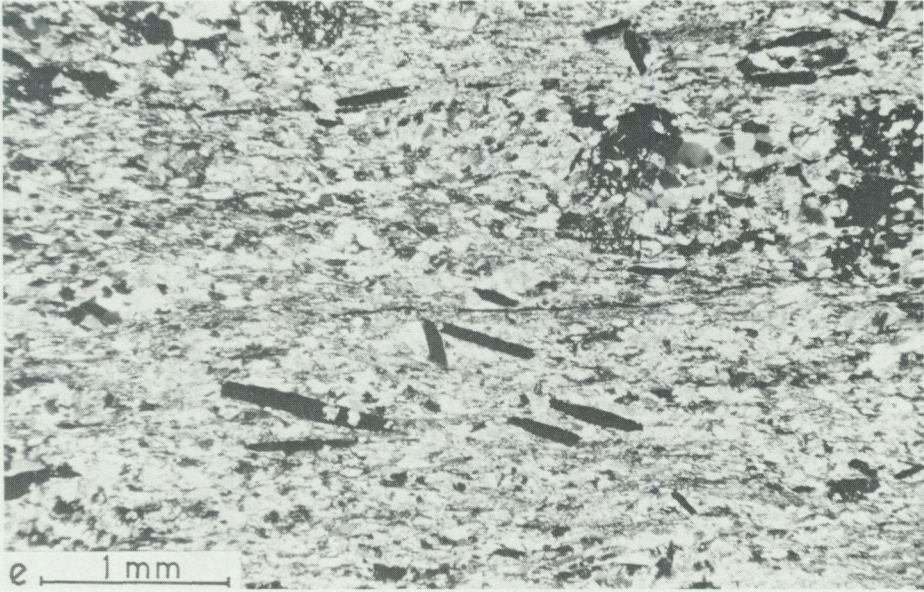


Fig. 32. Various porphyroblast minerals and their relationship to foliation in the Jofjället area.
 a: Biotite porphyroblast which is earlier than the main foliation (S_2), but also with some D_2 dissolution effects. Note relict S_1 in the foliation in the form of oblique micas. (Rikarsjön Phyllite in lower grade Storjället Nappe Complex, 24F 9-a, uncrossed nicols.)
 b: Euhedral amphibole porphyroblasts, rich in inclusions apart from the rims. At least the rims have been developed after the main foliation (S_2). (Skälvattnet Volcanite in Björkvattnet Nappe, 24E 9-j, crossed nicols.)



c: Chloritoid porphyroblast with helicitic relics of the main foliation (S_2). The porphyroblast is syn- to post- D_2 . (Seinesbäcken Volcanite in lower grade Storfjället Nappe Complex, 24E 9-j, uncrossed nicols.)
 d: Stilpnomelane (the needles) and biotite porphyroblasts in a mylonitic rock. They are later than the main foliation (S_2). (Rövattnet Formation in lower grade Storfjället Nappe Complex, 25E 0-j, uncrossed nicols.)



e: Ilmenite laths which to a large part appear to be orientated along an older foliation (S_1) but to some extent also parallel to a younger foliation (S_2). During the inferred rotation of the laths some of them appear to have been ruptured by the D_2 deformation. The growth of ilmenite is thus pre- D_2 . (Seinesbäcken Volcanite in lower grade Storffjället Nappe Complex, 24F 9-b, crossed nicols.)

f: Tourmaline (schorl) and rutile (needles). The tourmaline porphyroblasts transect the S_2 foliation and are thus post- D_2 here. (Seinesbäcken Volcanite in lower grade Storffjället Nappe Complex, 24F 9-b, uncrossed nicols.)

foliation is developed as a crenulation cleavage which continues into the porphyroblast, where it is less penetratively developed (S_2). The porphyroblast includes a rather tight fold defined by a compositional layering and with the internal foliation as an axial surface structure. Although the fold might be due to syn-sedimentary deformation this fold is tentatively interpreted here as an F_1 structure due to the well developed axial surface foliation and to have been helicically included within the siderite porphyroblast. Thus it follows that the internal foliation is S_1 and the siderite porphyroblast consequently grew post- D_1 and pre- D_2 .

4.5.6. SKINNFÄLLTRÄSKET MYLONITE (STORFJÄLLET NAPPE COMPLEX)

4.5.6.1. Garnet

Garnet is present locally in the Skinnfällträsket Mylonite. The garnet is euhedral, retrogressed to chlorite and contains a helicitic S_2 texture. It is apparently post- S_2 (Fig. 31f).

4.5.6.2. Biotite

Biotite is present as smaller subhedral porphyroblasts. It is syn- and post- S_2 .

4.5.7. MINERALS PRESENT IN ALL NAPPES

4.5.7.1. White mica

White mica occurs to a variable extent in all formations. It is the most important foliation-forming mineral and very seldom forms porphyroblasts. Muscovite is the predominant type of white mica but paragonite also occurs in the uppermost part of the Jofjället Calcareous Phyllite, the Tjäter Phyllite and especially the Seinesbäcken Volcanite. White mica apparently grew during D_1 . The D_2 deformation mainly deformed and rotated S_1 white mica with only minor new growth and/or recrystallization.

4.5.7.2. Chlorite

Chlorite is present in all formations. It is often an important constituent in the different foliations and often substitutes other minerals for example garnet and biotite. Chlorite formed during the deformation phases D_1 , D_2 , and to some extent also D_3 has been recognized in each of the tectonic units.

4.5.7.3. Accessory minerals

Ilmenite and tourmaline are present in most of the formations (Figs. 32e, 32f). Ilmenite is always pre- D_2 , while tourmaline occasionally is post- D_2 .

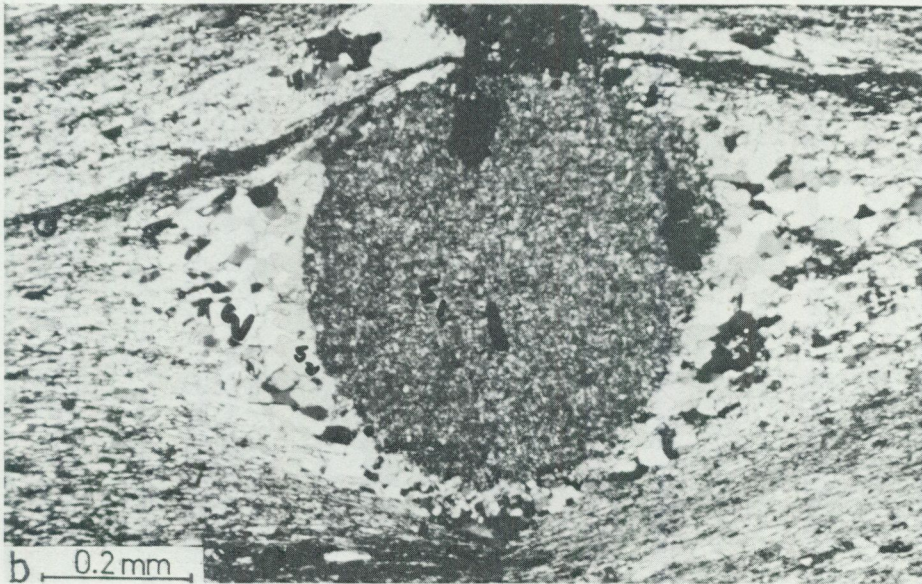
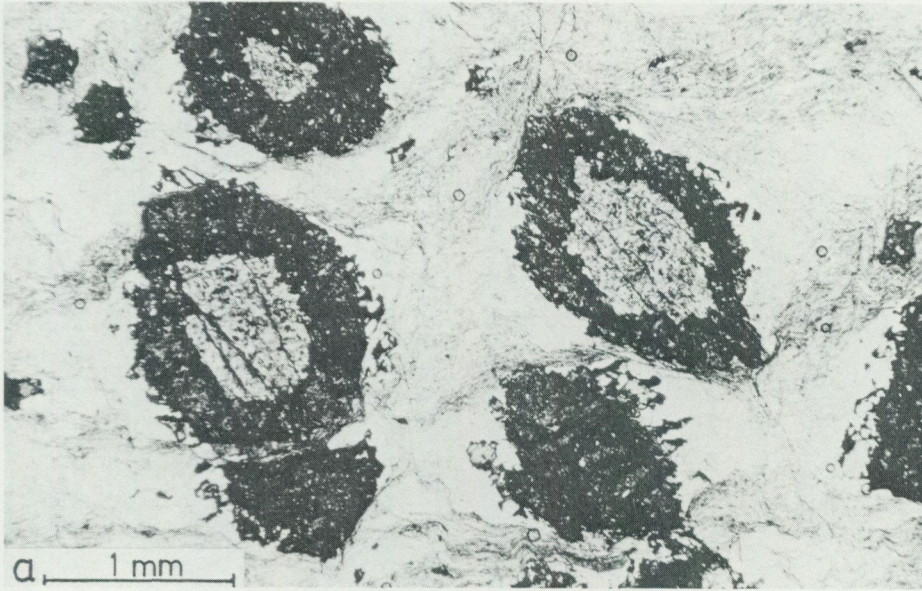
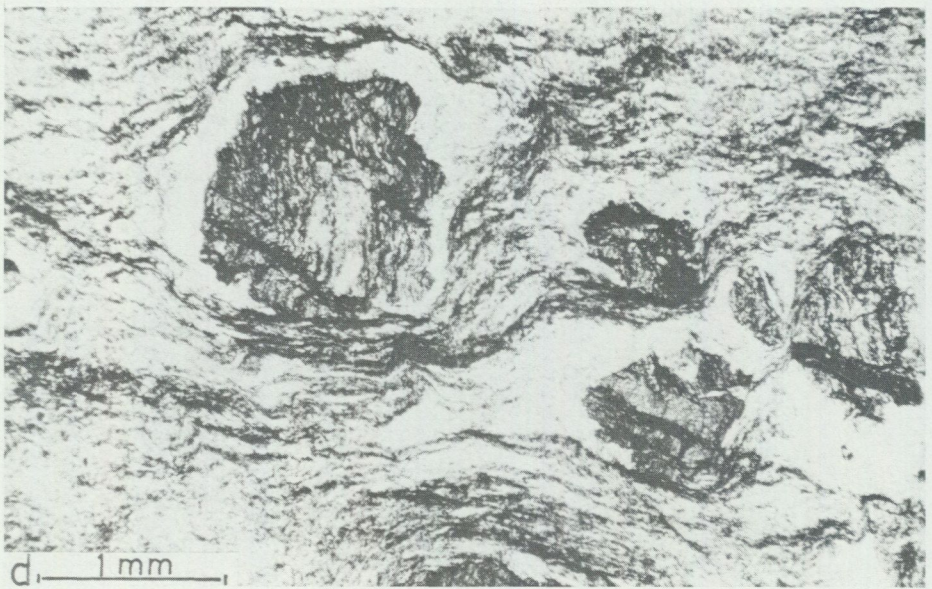
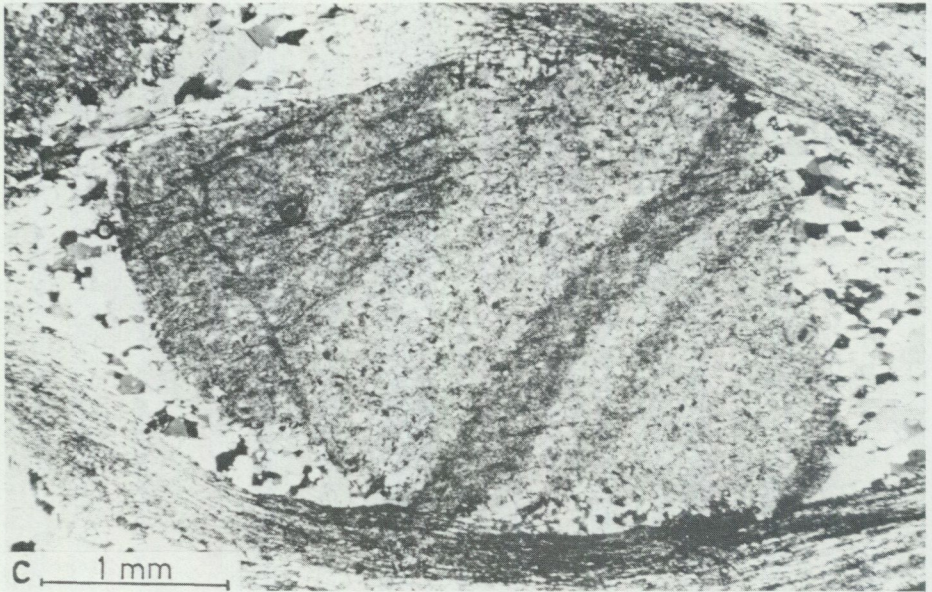


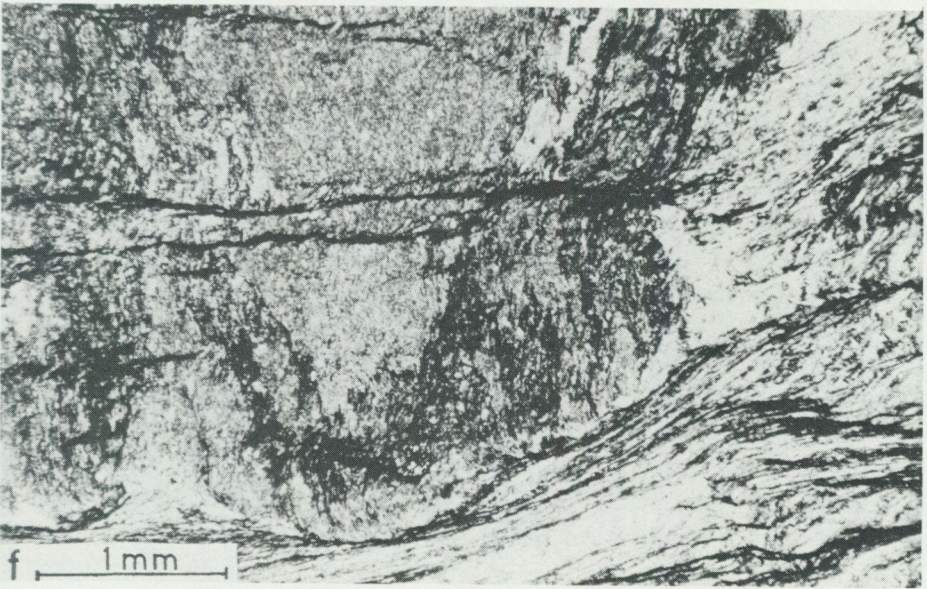
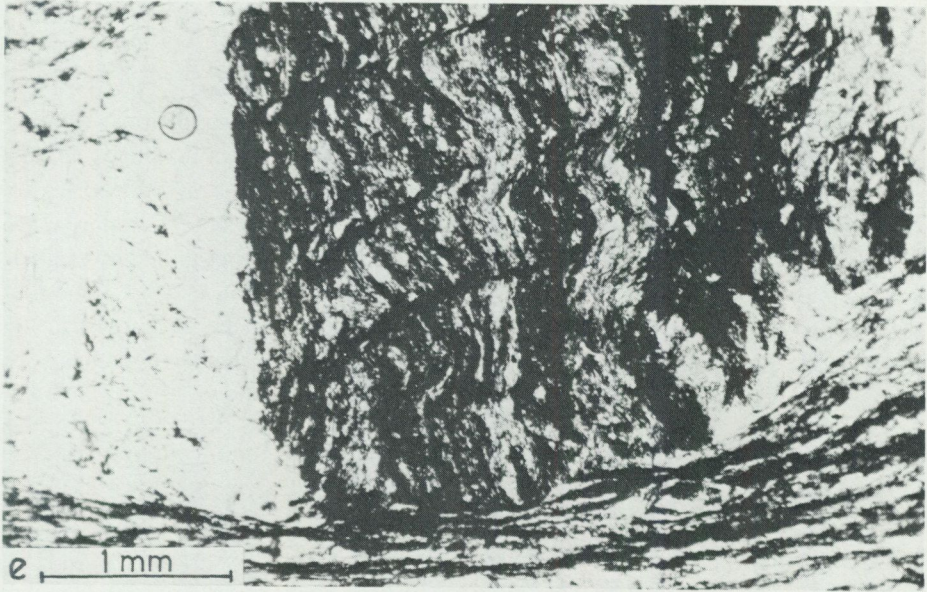
Fig. 33. Siderite porphyroblasts and their relationship to foliation (all samples from Tjäter Phyllite in lower grade Storffjället Nappe Complex, 24F 9-c).

a: Anhedral siderite porphyroblasts with large cores of quartz grains (light-grey). The main foliation (S_2) envelopes the porphyroblasts (crossed nicols).

b: Rounded siderite porphyroblast with a faint compositional layering (S_{0-1}) and internal foliation (S_{1-2}) at a high angle to each other and with siderite free from inclusions in the D_2 pressure shadow (crossed nicols).



c: Siderite porphyroblast with a compositional layering mainly defined by carbonaceous matter ($S_{0.1}$) and a weak crenulation cleavage (S_2), subhorizontal in the picture. The external foliation is S_2 (crossed nicols).
 d: Siderite porphyroblasts, where the internal foliation ($S_1?$) is crenulated by D_2 . The external foliation is S_2 (uncrossed nicols).



e: Detail of crenulation cleavage (S_2) in siderite porphyroblast (uncrossed nicols).
 f: Detail of a siderite porphyroblast (uncrossed nicols), showing a spaced D_2 crenulation cleavage and an internal fold structure defined by carbonaceous matter (F_1) and with an internal foliation as an axial surface structure (S_1).

4.6. VARIATION IN METAMORPHISM AND DEFORMATION THROUGHOUT THE JOFJÄLLET AREA

4.6.1. OPENING REMARKS

The formations in the Jofjället area can be divided conveniently into 6 groups showing similar metamorphic grades and tectono-metamorphic histories. It is noteworthy that five of these groups correspond to the different tectonic units as defined earlier (including the lower and higher grade parts of the Storfjället Nappe Complex). The sixth group is composed of the Jofjället Calcareous Phyllite lying in the lower grade part of the Storfjället Nappe Complex. This stratigraphic unit shows a somewhat different tectono-metamorphic history than the remainder of the formations in the lower grade Storfjället Nappe Complex. The groups and a tentative summary of possible deformation and metamorphic phases are presented below.

1. The chlorite (biotite) grade Björkvattnet Nappe (Skälvattnet Volcanite and Väs-tansjö Phyllitic Quartzite).
Deformation phases: $D_1 (D_2)^1 D_3 (D_4)$
Metamorphic phase: M_1
2. The garnet grade Laxfjället Nappe (Jovattnet Calcareous Phyllite and Joeström Quartz-Keratophyre).
Deformation phases: $D_1 D_2 D_3 (D_4)$
Metamorphic phase: M_1
3. The garnet grade Metartjärnen Formation in the higher grade Storfjället Nappe Complex.
Deformation phases: " D_1 "² $D_2 D_3$
Metamorphic phases: " M_1 " (M_2)
4. The chlorite (biotite) grade Jofjället Calcareous Phyllite in the lower grade Storfjället Nappe Complex.
Deformation phases: $D_1 (D_2) D_3 (D_4)$
Metamorphic phase: M_1
5. The chlorite grade Tjäter Phyllite, Seinesbäcken Volcanite, Rikarsjön Phyllite and Ruffe Greenstone in the lower grade Storfjället Nappe Complex.
Deformation phases: $D_1 D_2 D_3 (D_4)$
Metamorphic phase: M_1
6. The relatively high grade Skinnfällträsket Mylonite and the uppermost formations in the lower grade Storfjället Nappe Complex (Rövattnet Formation and Brack-fjället Greenstone).
Deformation phases: $D_1 D_2 D_3$
Metamorphic phases: (M_1) M_2

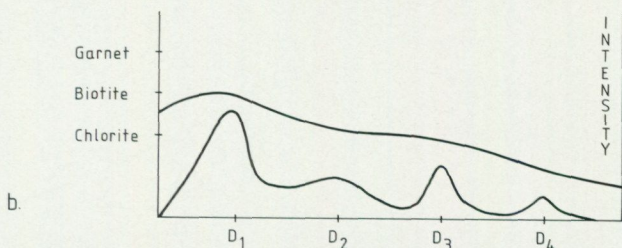
The data for each group are summarized in Figs. 34–39 and discussed briefly below.

¹ Symbol within brackets means that the phase is very weak or highly localized.

² Symbol within quotation marks means that it could be more than one phase.

	D ₁			D ₂		D ₃		D ₄	
Quartz	—								
Chlorite	—			—		—			
Muscovite	—								
Biotite	—								
Garnet									
Epidote									
Amphibole									
Albite	—								
Calcite/ankerite	—			—		—			
Ilmenite	—								
Tourmaline	—								
Chloritoid									
Deformation stage	pre	syn	post	syn	post	syn	post	syn	post
S - formed		S ₁		(S ₂)		(S ₃)		(S ₄)	

a.



b.

Fig. 34. This and following (35–39) figures show the variation in metamorphism and deformation for 6 different groups in the Jofjället sequence. For each group the figure consists of:

a: Table indicating the growth and recrystallization of minerals during different deformation phases.

b: Graph showing the relation between metamorphism (upper curve) and deformation (lower curve). The metamorphic grade is inferred from index minerals and is indicated by the left-hand axis. The intensity of the deformation is mainly inferred from the character of the various folds and foliations and is indicated by the right-hand axis. Fig. 34, representing group 1, shows data for the Skälvattnet Volcanite.

4.6.2. BJÖRKVATTNET NAPPE (1)

Group 1 is represented here by the eastern part of the Skälvattnet Volcanite (Fig. 34).

As shown by the deformation curve, D₁ dominates while D₂ is weak or absent. However, in the **western** part of the formation D₂ is more strongly developed. D₃ in the eastern part of the Skälvattnet Volcanite is of some importance, while D₄ is weak and only locally present.

The metamorphism curve indicates that the acme of metamorphism was during or shortly before D₁, when biotite grade was reached in some parts of the formation. During D₂ there was practically no growth or recrystallization of minerals in the eastern part of the Skälvattnet Volcanite. However, in the western part of the formation there was some growth of amphibole during and after D₂.

	D ₁			D ₂		D ₃		D ₄	
Quartz	—			—					
Chlorite	—			—		—			
Muscovite	—			—					
Biotite	—			—					
Garnet	—			—					
Epidote	—			—					
Amphibole	—			—					
Albite	—			—					
Calcite/ankerite	—			—		—			
Ilmenite	—			—					
Tourmaline	—			—					
Chloritoid	—			—					
Deformation stage	pre	syn	post	syn	post	syn	post	syn	post
S - formed		S ₁		S ₂		(S ₃)		(S ₄)	

a.

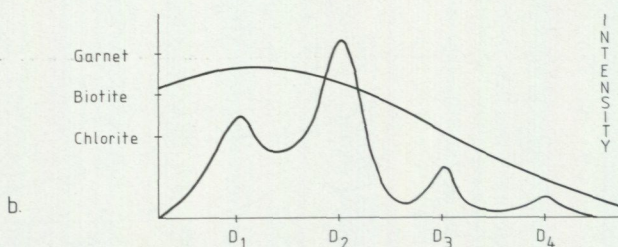


Fig. 35. Jovattnet Calcareous Phyllite, representing group 2.

4.6.3. LAXFJÄLLET NAPPE (2)

Group 2 is represented here by the Jovattnet Calcareous Phyllite (Fig. 35).

The deformation curve shows that the most intense deformation was during D₂. During D₂ a strong foliation was developed and the earlier foliation was more or less transposed into this surface. The intensity of the first deformation phase (D₁) is difficult to assess, while the later deformation phases (D₃ and D₄) were rather weak.

The metamorphism curve indicates that biotite grade was attained during both D₁ and D₂. However, there is some uncertainty in deciding if biotite actually grew during D₂, rotation of older biotite being perhaps the dominant D₂ mechanism.

	"D ₁ "			D ₂		D ₃		D ₄	
Quartz	—————								
Chlorite	—————								
Muscovite	—————								
Biotite	—————								
Garnet	—	—	—	— ^a					
Epidote	—————								
Amphibole	- - - - -								
Albite	—————								
Calcite/ankerite	—————								
Ilmenite	—————								
Tourmaline	—————								
Chloritoid	—————								
Deformation stage	pre	syn	post	syn	post	syn	post	syn	post
S - formed		"S ₁ "		S ₂		(S ₃)			

a. a = only locally present

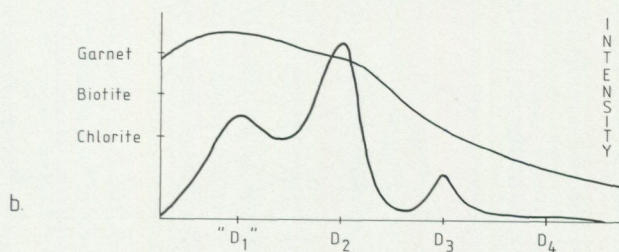


Fig. 36. Metartjärnen Formation, representing group 3.

4.6.4. METARTJÄRNEN FORMATION (IN STORFJÄLLET NAPPE COMPLEX) (3)

The higher grade part of the Storfjället Nappe Complex is represented by the Metartjärnen Formation (Fig. 36).

The deformation curve is similar to the corresponding curve for group 2 (Laxfjället Nappe). However, it must be kept in mind that the deformation phase labelled "D₁" may be polyphase and that the D₁ picture may be oversimplified. The most intense deformation occurred during D₂, while D₃ was rather weak.

The metamorphism curve shows that the peak of metamorphism was pre- and syn-"D₁", when garnet grade was reached. However, in the table some post-D₂ garnet is also indicated. Since this is very rare it has not influenced the shape of the metamorphic curve.

	D ₁			D ₂		D ₃		D ₄	
Quartz	—								
Chlorite	—					—			
Muscovite	—								
Biotite	—								
Garnet	—								
Epidote	—								
Amphibole	—								
Albite	—								
Calcite /ankerite	—					—			
Ilmenite	—								
Tourmaline	—								
Chloritoid	—								
Deformation stage	pre	syn	post	syn	post	syn	post	syn	post
S - formed		S ₁				(S ₃)		(S ₄)	

a.

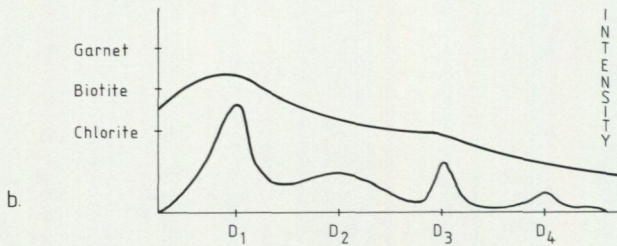


Fig. 37. Jofjället Calcareous Phyllite, representing group 4.

4.6.5. JOFJÄLLET CALCAREOUS PHYLLITE (IN STORFJÄLLET NAPPE COMPLEX) (4)

Group 4 is composed of the Jofjället Calcareous Phyllite where it outcrops in the eastern part of the Jofjället area (Fig. 37).

The deformation curve shows that there is only one strong deformation phase in this formation (D₁), the main foliation (S₁) being formed during this deformation phase. It is interesting that – apart from the westerly continuation of this formation – the D₂ deformation appears to be very weak in this unit.

The metamorphism curve shows a peak pre- and syn-D₁, when biotite grade was reached in the lowermost part of the formation. During D₂ there was only limited recrystallization of certain minerals.

	D ₁			D ₂			D ₃		D ₄	
Quartz	—									
Chlorite	—									
Muscovite	—									
Biotite	—									
Garnet	—									
Epidote	—									
Amphibole	—									
Albite	—									
Calcite/ankerite	—									
Ilmenite	—									
Tourmaline	—									
Chloritoid				—						
Deformation stage	pre	syn	post	syn	post	syn	post	syn	post	
S - formed		S ₁		S ₂		(S ₃)		(S ₄)		

a.

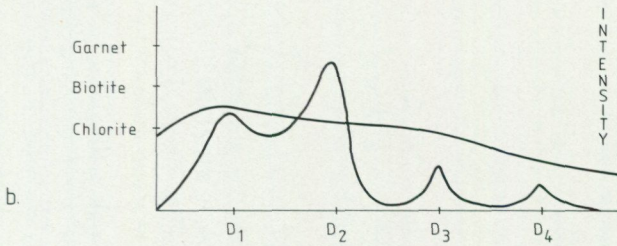


Fig. 38. Seinesbäcken Volcanite, representing group 5.

4.6.6. FORMATIONS IN THE MIDDLE PART OF THE LOWER GRADE STORFJÄLLET NAPPE COMPLEX (5)

Group 5 is represented here by the Seinesbäcken Volcanite (Fig. 38).

The deformation curve indicates that the most intense deformation phase occurred during D₂ when the main foliation was formed.

The metamorphism curve shows that chlorite grade was maintained during D₁ and also D₂.

	D ₁			D ₂		D ₃		D ₄	
Quartz	—			—					
Chlorite	—			—		-			
Muscovite	—			—					
Biotite				—					
Garnet				—					
Epidote									
Amphibole									
Albite	—			—					
Calcite/ankerite	—			—		-			
Ilmenite									
Tourmaline	— ?								
Chloritoid									
Deformation stage	pre	syn	post	syn	post	syn	post	syn	post
S - formed		S ₁		S ₂		(S ₃)			

a.

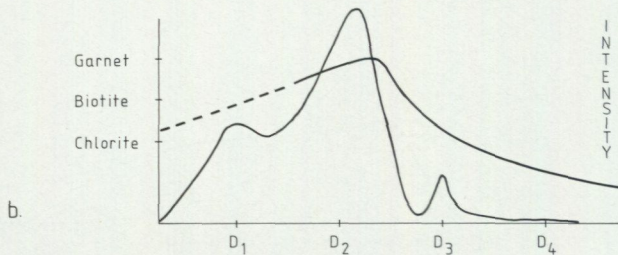


Fig. 39. Skinnfällträsket Mylonite, representing group 6.

4.6.7 SKINNFÄLLTRÄSKET MYLONITE AND THE UPPERMOST FORMATIONS IN THE LOWER GRADE STORFJÄLLET NAPPE COMPLEX (6)

Group 6 is represented here by the Skinnfällträsket Mylonite in the Storfjället Nappe Complex (Fig. 39).

The deformation curve shows that the deformation was very intense during D₂. Significant differential movements occurred at this stage and mylonitic rocks were formed.

The metamorphism curve shows a peak during or shortly after D₂, when garnet was formed locally. It may be speculated that this peak of metamorphism depends on the high friction heat generated by the thrusting.

4.7. DISCUSSION

4.7.1. CORRELATION OF STRUCTURAL AND METAMORPHIC EVENTS BETWEEN DIFFERENT TECTONIC UNITS

Post-metamorphic folding and foliation development (D_3 and D_4) affects all tectonic units and major F_3 folds deform the thrust contacts between these units. D_3 and the demonstrably later D_4 deformation are, thus, correlatable in time throughout the whole Jofjället area. It is possible that they are related to gravity-controlled disturbance of the Baltoscandian basement due to superimposition of a denser allochthonous cover.

The development of the late-metamorphic S_2 (S_{1+2}) foliation (syn-metamorphic in the case of the uppermost units in the Storfjället Nappe Complex) and the strong transposition of earlier surfaces into this foliation varies over the area. This planar structure appears to be associated with reclined folding (F_2) and local development of intrafolial folds, shear zones, phyllonites and mylonites. Based on this association the D_2 deformation in each of the units is suggested to have formed during thrust emplacement of the different units, and involved a high component of simple shear strain. Assuming that these movements occurred more or less at the same time throughout the pile, it may be inferred that the D_2 deformation is broadly time correlatable across the tectonic boundaries. A small diachroneity, involving earlier initiation of D_2 structures as the rock pile is traversed upwards, may be involved. Since D_2 in the Björkvattnet Nappe is known to be Silurian in age (see Stephens 1977), all D_2 structures should, thus, be of Silurian age.

On the basis of the development of the D_2 structures it would appear that significant differential movements occurred 1, from the upper, western part of the Björkvattnet Nappe through the highly deformed, attenuated Laxfjället Nappe and up into the lower higher grade part of the Storfjället Nappe Complex and 2, from the Tjåter Phyllite in the lower grade part of the Storfjället Nappe Complex upwards, towards and over the contact into the Skinnfällträsket Mylonite. This evidence sheds some light on the nature of the contact between the Metartjärnen Formation and the Jofjället Calcareous Phyllite which is marked by an apparently small jump in metamorphic grade and the apparent absence of D_2 structures above the contact. It is questionable whether this contact is a major D_2 thrust. An earlier pre- D_2 discontinuity is a possible alternative.

The D_1 structures appear to be homogeneously developed throughout each respective tectonic unit. It is suggested (see also Stephens 1977) that the various D_1 strains in each tectonic unit were related to flattening of the different rock sequences i.e. a large pure shear component was involved. The time relations of the earliest pre-syn-metamorphic structures between the different tectonic units are much more uncertain.

As stated above the D_1 folds and foliation in the Björkvattnet Nappe of the Jofjället area should be Silurian in age (see Stephens 1977). Dating of D_1 is lacking in the Laxfjället Nappe and the lower grade part of the Storfjället Nappe Complex. The higher grade Storfjället Nappe Complex, when followed to the north into the large

TABLE 1. Tentative correlation of structural events and porphyroblast growth between the different tectonic units in the Jofjället and Tärna areas. Italics mean less certain correlation and apply to D₁ in the

	BJÖRKVATTNET UNIT TARNA AREA (Stephens 1977)	BJÖRKVATTNET NAPPE Skälvattnet Volcanite	LAXFJÄLLET NAPPE Jovattnet Calcareous Phyllite	Metartjärnen Formation
	D ₄ Late kink folds Major, open to gentle synforms and antiforms, crenulation cleavage and minor folding	D ₄ Local kink folds (flat-lying axial surfaces) D ₃ Major and minor folding (steep axial surfaces) Local crenulation cleavage (S ₃)	D ₄ Local kink folds (flat-lying axial surfaces) D ₃ Major and minor folding (steep axial surfaces) Local crenulation cleavage (S ₃)	D ₃ Major and minor folding (steep axial surfaces) Local crenulation cleavage (S ₃)
	GARNET MUSCOVITE	CHLORITE	CHLORITE	GARNET BIOTITE CHLORITE
SILURIAN DEFORMATION	D ₃ Major and minor folding, crenulation cleavage Mylonitization and thrusting	(D ₂) Weak, stronger in the western part, where S ₂ = main foliation (mainly metamorphic layering) Tight folds	D ₂ Intense thrusting S ₁ transposed into the main foliation (S ₁₊₂ , S ₂) (crenu- lation cleavage and metamorphic layering) Tight folds	D ₂ Intense thrusting and phyllonitization S ₂ = main foliation (often metamorphic layering) Local tight folds
	AMPHIBOLE BIOTITE ALBITE	BIOTITE	BIOTITE	BIOTITE
	D ₂ Early regional foliation Tight to isoclinal minor folds	D ₁ Early regional folia- tion (phyllitic cleavage) S ₁ = main foliation Tight to isoclinal minor folds	D ₁ <i>Early regional folia- tion (S₁)</i>	
D ₁ Early synclinal repetition				
ORDOVICIAN DEFORMATION				"D ₁ " Early regional foliation (S _{1a} S _{1b})

Norra Storfjället lens, contains granitic intrusions. One such granitic body at Vilasund, known to have intruded after early foliation and garnet-staurolite porphyroblast development but prior to thrusting, has provided a Rb-Sr whole rock isochron age of 438 ± 6 Ma (Gee and Wilson 1974)¹. A similar structural-intrusion history has been described for the Artfjället gabbro (Senior 1978). Based on present Lower Paleozoic time scales (van Eysinga 1975) this dating would imply pre-Silurian deformation and metamorphism. Local occurrence of *Pelmatozoa* remains (Kulling *in* Gavelin and Kulling 1955) in the higher grade part of the Storfjället Nappe Complex in the Södra Storfjället lens indicates that this early deformation/metamorphism was probably Ordovician in age² (see also Stephens, 1980).

It is evident that the pre-D₂ structures in at least the Björkvatnet Nappe and higher grade Storfjället Nappe Complex cannot be correlated in time. Whereas the evidence

¹ The originally determined age 447 ± 6 Ma has been recalculated according to the 1976 recommended decay constant for Rb; $\lambda = 0.142 \times 10^{-10}/a$ (Wilson and Sundin 1979).

² Although the subphylum *Pelmatozoa* originated during Cambrian it did not become abundant before Ordovician time (Davies and Stubblefield 1961).

Laxfjället Nappe and lower grade Storfjället Nappe Complex (Skinnfällträsket Mylonite included).

STORFJÄLLET NAPPE COMPLEX		
Jofjället Calcareous Phyllite	Seinesbäcken Volcanite	Skinnfällträsket Mylonite
D ₄ Local kink folds (flat-lying axial surfaces)	D ₄ Local kink folds (flat-lying axial surfaces)	
D ₃ Major and minor folding (steep axial surfaces) Local intense crenulation cleavage (S ₃)	D ₃ Major and minor folding (steep axial surfaces) Local crenulation cleavage (S ₃)	D ₃ Major and minor folding (steep axial surfaces) Local crenulation cleavage (S ₃)
(D ₂) Weak, stronger in the western part, where often S ₂ = main foliation (often crenulation cleavage) Tight folds	D ₂ Intense thrusting S ₁ transposed into the main foliation (S ₁₊₂ , S ₂) (crenulation cleavage and metamorphic layering) Major and minor tight folds	D ₂ Very intense thrusting and mylonitization Often mylonitic foliation (S ₂) = main foliation Tight folds
D ₁ Early regional foliation (phyllitic cleavage) S ₁ = main foliation Tight to isoclinal minor folds	D ₁ Early regional foliation (S ₁) Tight to isoclinal minor folds	D ₁ Early regional foliation

suggests that the Björkvattnet Nappe has suffered polyphase deformation/metamorphism at one stage (Silurian), it is clear that the higher grade Storfjället Nappe Complex has suffered both Ordovician deformation + metamorphism (at least part of "D₁", "M₁" of the present study?) and Silurian deformation + low grade metamorphism [D₂₋₄, (M₂) of the present study].

A summary of these relationships is presented in Table 1, where uncertain correlations are indicated by italics.

4.7.2. CORRELATION OF STRUCTURAL HISTORY OF THE LOWER GRADE STORFJÄLLET NAPPE COMPLEX WITH OTHER AREAS IN THE CALEDONIDES

Table 2 summarizes the metamorphic and deformational history of the lower grade part of the Storfjället Nappe Complex. A tentative correlation of structural events with other areas in the Caledonides of Sweden is also presented in this table.

The first deformation phase of Zachrisson (1969), Stephens (1977) and Sjöstrand (1978) has not been recognized on field evidence in the Jofjället area. In this context it is necessary to point out that the structural correlation between the Marsfjällen area

TABLE 2. Summary of the metamorphism and deformation in the lower grade part of the Storffjället Nappe Complex in the Jofjället area and tentative correlation with other areas. The solid vertical line delimiting the

Event	Phase	Lower grade part of the Storffjället N.C. in the Jofjället area (present paper)	Björkvattnet Unit in the Tärnaby area (Stephens 1977)
Gravity-contr. disturbance of basement/cover post-metamorphic folding	D ₄	Local kinkfolds with subhorizontal axial planes (F ₄ kink), along which a crenulation cleavage sometimes is formed	D ₄ - Development of late kink folds
	D ₃	Development of open to gentle folds in all scales. Two sets of folds which give a dome and basin pattern when they interfere: One westerly with subhorizontal fold axes and rather steep axial planes, to which the large Jofjället Synform belong (F ₃ ^W) One northerly with moderately plunging fold axes and steep axial planes (F ₃ ^N) Joints with the same attitude as the axial planes of F ₃ ^N Locally a crenulation cleavage is formed (S ₃)	Development of major open to gentle folds Intense conc. of minor structures in certain restricted zones inc. S ₂ ^{CC} (locally transposes S _{C1}) Kink folds follow S ₂ trend on gently dipping axial surfaces Minor folds plunge gently N-S on steep axial surfaces (F _{4a}) Rare, steep WNW-plunging crenulation (F _{4b})
Thrusting late-metamorphic folding	D ₂	Strong deformation of S ₁ in shear-zones. S ₂ is developed as the main foliation over large parts of the area. It is formed mainly as a metamorphic layering, often with relics of S ₁ . S ₂ is parallel - subparallel to S ₁ and S ₀	D ₃ - Intense deformation of S _{C1} etc. in certain zones - continuous development of both major and minor folds and important thrusts Development of S _{CC} ¹ (locally transposes S _{C1})
		Important thrusts. Mylonites and phyllonites are formed in several zones. A continuous development of tight to isoclinal folds in all scales (reclined folds with flat-lying axial planes and varying orientation of fold axes) A mineral lineation in W-NW is formed	Minor folds plunge gently and trend approximately parallel to S ₂ strike (original orientation = NE-SW?) Major folds are overturned to the SW-S (original orientation = SE?)
Collapse of tectonic pile syn-metamorphic folding	D ₁	Development of a regional phyllitic cleavage (S ₁) parallel or subparallel to S ₀ (in places metamorphic layering) Isoclinal F ₁ folds of modest dimensions (reclined folds with flat-lying axial planes and varying orientation of fold axes)	D ₂ - Development of regional phyllitic cleavage (S _{C1}) and penetrative lineations inc. pebble elongation Associated with occasional minor folds Lineations plunge NW-WNW
			D ₁ - Early synclinal repetition of stratigraphy Uncertain orientation

D₁ field of this nappe unit indicates that the correlation with the other areas is not established.

N. Jämtland - S. Västerbotten (Zachrisson 1969)	The Marsfjällen area (Trouw 1973)	The Kvarnbergsvattnet area (Sjöstrand 1978)
F ₃ - Kink folds on flat-lying axial surfaces	F ₄ - Local gentle folding and crenulation (S ₄): subhorizontal	D ₅ - Development of open major and minor often kink-like reclinated to recumbent folds or flexures during gravity setting of steep earlier structures
F ₂ - Development of major antiforms and synforms NNE-SSW or NE-SW orientation and steep axial surfaces	F ₃ - Folding on several scales, local development of mainly steep cren. cleavage with variable strike (S ₃)	D ₄ - Development of major and minor antiforms, synforms, domes and basins and congruent minor folds
Associated with F ₁ or younger = local and possibly more regional low angle thrusts	F ₂ - Open to close folding of S ₀ and S ₁ on several scales; formation of a cren. cleavage, a transposition schistosity (S ₂) or a rotated schistosity (S ₁₊₂) and a NW-orientated mineral lineation F ₂ trends towards NNE or NW; rotation of syn-F ₂ garnets; thrusting	D ₃ - Formation of major and minor, often sideways-closing folds with a generally pronounced ax. pl. cren. cl.; continued SE shear and translation
F ₁ - Development of main schistosity (S ₁) General NW-SE or E-W orientation for rotated folds	F ₁ - Tight folding and formation of a slaty cleavage (S ₁); intense deformation indicated by deformed conglomerates	D ₂ - Strong penetrative deformation; development of the regional foliation, which locally is ax. pl. cl. to tight or isoclinal folds Development during D ₂ and D ₃ , in connection with NW-SE directed extension, shear and nappe translation parallel to the elongation of many congl. pebbles and to the axes of many D ₁₊₂ , D ₂ and D ₃ folds
Pre-F ₁ - Formation of large recumbent folds, which are cut across by the S ₁ schistosity		D ₁ - Folding and development of a bedding cleavage

(Trouw 1973) and northern Jämtland–southern Västerbotten (Zachrisson 1969) differs here from the one proposed by Trouw but follows Sjöstrand (1978). For reasons outlined in the previous section, it is uncertain whether the D₁ phase in the lower grade Storfjället Nappe Complex can be correlated with the early deformation phases of Zachrisson (1969), Trouw (1973), Stephens (1977), and Sjöstrand (1978).

The D₂ phase in the Jofjället area differs from the corresponding phases in the other areas in its degree of intensity and extent. During D₂ a strong foliation was formed as the main foliation over a large part of the Jofjället area. Simple shear deformation and thrusting processes were apparently more prominent in the Jofjället area than in the other areas.

The D₃ phase in the Jofjället area differs from the corresponding phases in the other areas since an east–west orientation of fold axes dominates, while D₄ is rather weak in the Jofjället area compared to the other areas.

5. STRATIGRAPHIC AND TECTONIC CORRELATION WITH OTHER AREAS IN THE CALEDONIDES

5.1. OPENING REMARKS

An attempt has been made to correlate, on a tectono-stratigraphic basis, the Jofjället sequence with other, more or less remote areas in the Scandinavian Caledonides. Lithologically similar units with equivalent tectonic or structural position have been placed on the same level in the correlation table, which thus differs from a stratigraphic correlation table, where lithology and/or age determine the relative position of different units (Sjöstrand 1978). Although the correlations are tentative, they are necessary to elucidate the stratigraphy of the Jofjället area and to try to place this problematic sequence in a broader geological context.

The main features of interest in the areas with which the Jofjället sequence is correlated are, apart from lithology and tectonic position, the following: 1. Occurrence of fossils, which serve not only to define age but also possible paleogeographic affinity. 2. Way-up criteria. 3. Isotope age determinations. 4. Volcanite petrochemistry as a mean of assessing tectonic environment.

5.2. CORRELATION WITH ADJACENT AREAS

Table 3 shows a tentative correlation of the tectono-stratigraphy of the Jofjället area with the Tärna area 1–20 kilometres to the east, the Björkvattnet–Virisen area 10–40 kilometres to the south-east (central Västerbotten) and the Södra Storfjället area 2–25 kilometres to the south (see also Fig. 1).

5.2.1. BJÖRKVATTNET NAPPE

The rocks of the Björkvattnet Nappe within the Jofjället area have been correlated tectono-stratigraphically with the Köli stratigraphy of Kulling (1933, 1958). Only two

formations have, however, been recognized; the Skälvattnet Volcanite has been correlated with the Gilliks "series" mainly on petrological grounds and the Västansjö Phyllitic Quartzite has been correlated with the Viris quartzite, which is probably a facies variation of the Lövfjäll phyllite (Zachrisson 1969). Kulling's key Vojtja and Slätdal formations which – following his stratigraphy – should occur between the above-mentioned formations have not been recognized with certainty in the Jofjället area. However, at one locality there do occur lenses of a strongly deformed pure quartzite, which might represent Vojtja quartzite, between the Skälvattnet Volcanite and the Västansjö Phyllitic Quartzite.

In the type area (Björkvattnet–Virisen) the Slätdal limestone and the Broken "series" have provided fossils of Ashgillian and Llandoveryan age respectively (Kulling 1933). In a thin limestone interbedded within the serpentinite conglomerate of the Ro "series", there has been found (Holmqvist 1980) a Lower Ordovician¹ fauna resembling the paleofauna of the Otta serpentinite conglomerate in Norway, which, according to Jaanusson (1973), has a dominantly Baltoscandian affinity. Thus, the rocks of the Björkvattnet Nappe in the Jofjället area should be both Ordovician and Silurian in age and were probably deposited on the Baltoscandian margin of the Iapetus Ocean.

5.2.2. LAXFJÄLLET NAPPE

The Laxfjället Nappe, which is very thin in the Jofjället area, is correlated with a much thicker unit in the Tärna area. On formation level the Jovattnet Calcareous Phyllite and the Joeström Quartz-Keratophyre in the Jofjället area are correlated with the Calcareous Phyllite and the Layered Metavolcanic Formations respectively (Stephens 1977). The Joeström Quartz-Keratophyre is also correlated with the Ropen "granite" of Beskow (1927) on Södra Storfjället, which shows more than 1 km maximum thickness. On the map of Beskow (1927) there are low grade phyllites, some with calcareous symbols, and greenschists to the east of the Ropen "granite", which can probably be correlated with similar rock types in the lower nappes of the Jofjället area.

In the Tärna area, Stephens (1977) placed a thrust below his Calcareous Phyllite Formation, while Kieft (1952) proposed tectonic contacts both beneath the Calcareous Phyllite Formation and the Layered Metavolcanic Formation. Kieft's interpretation is consistent with Beskow (1927) who likewise placed a thrust at the base of the Ropen "granite". These discrepancies illustrate the problem of assessing the nature of contacts in such low grade rocks. Differential movements have been focused along most important lithological contacts and it is a question of assessing the degree of relative movements. As stated earlier the contact between the Jovattnet Calcareous Phyllite

¹ According to the geological time scale of van Eysinga (1975) Ordovician is divided into Lower and Upper Ordovician, with the limit placed between Llandeilian and Caradocian. In this paper this time scale will be used.

TABLE 3. Tectono-stratigraphic correlation of the Jofjället area with adjacent areas.

CENTRAL VÄSTERBOTTEN (Kulling 1933, 1958)	S. STORFJÄLLET (Kulling 1972)	TARNA AREA (Stephens 1977)	JOFJÄLLET AREA (this paper)	TECTONIC UNITS
			Skinnfällträsket Mylonite	STORFJÄLLET NAPPE COMPLEX
			Brackfjället Greenstone	
			Rövattnet Formation	
			Ruffe Greenstone	
			Rikarsjön Phyllite	
			Seinesbäcken Volcanite	
			Tjäter Phyllite	STORFJÄLLET NAPPE COMPLEX
			Jofjället Calcareous Phyllite	
	13. Sandy calcareous phyllites and quartzites		graph. and quartz phy., lst.	SEVE-KOLI NAPPE COMPLEX
	12. Phyllitic slates		Metartjärnen Formation	
	11. Limestone			
	10. Quartzite cgl., quartzite		Staurolite Schist Formation	
	9. Mesket greenstone lava fm.			
	8. Mörto quartzite cgl.			
	7. Phyllitic slates			
	6. Polymict cgl.			
	5. Ropen quartzite cgl.			
	4. Greenstone lava			
	3. Ropen limestone		Layered Metavolcanic Formation	
	2. Phyllitic sandy schists			
	1. Ropen granite		Joeström Quartz-Keratophyre	LAVFJÄLLET NAPPE
			Calcareous Phyllite Formation	LAVFJÄLLET NAPPE
			Jovattnet Calcareous Phyllite	
Viris quartzite			Lövfjäll Formation	BJÖRKVATTNET NAPPE
Lövfjäll phyllite			Broken Formation	
Broken series			Slättdal Formation	
Slättdal limestone			Vojtja Formation	
Vojtja conglomerate			Gilliks Formation	BJÖRKVATTNET NAPPE
Gilliks series			Forsbäck/Seima Formations	
Seima series			Brakko schists/ Tärna schists	
Ro Series				SEVE
Seve				
			Västansjö Ph. Quartzite	BJÖRKVATTNET NAPPE
			Skälvattnet Volcanite	

and the Joeström Quartz-Keratophyre is a particularly difficult contact to interpret as it occurs in a highly attenuated sequence. For the present, the Ropen "granite", the Joeström Quartz-Keratophyre and the Layered Metavolcanic Formation are correlated and shown to lie in the same tectonic unit as the Jovattnet Calcareous Phyllite.

5.2.3. STORFJÄLLET NAPPE COMPLEX

The Staurolite Schist Formation in the Tärna area (Stephens 1977) is thought to correspond to the lower part of the higher grade Metartjärnen Formation in the Jofjället area.

The thin Metartjärnen Formation is correlated with a huge (several kilometres) upper greenschist-amphibolite facies packet of rocks on Södra Storfjället consisting of at least eight different formations (Kulling *in* Strand and Kulling 1972). As in the Metartjärnen Formation various phyllitic schists – often garnetiferous – dominate the

succession. The Ropen limestone of Södra Storfjället may correspond to the thin limestone bed in the lowermost part of the Metartjärnen Formation (cf. Fig. 6). Another conspicuous formation is the Mesket greenstone lava formation (Kulling *in* Strand and Kulling 1972) which may be an equivalent to the mainly mafic volcanites in the Metartjärnen Formation.

On top of this higher grade complex on Södra Storfjället there is a thin, more low grade sequence of rocks which Kulling tried to correlate with the Vojtja-Slättdal-Broken sequence in the Björkvattnet-Virisen type area. Occasionally in the borderzone between the Metartjärnen Formation and the Jofjället Calcareous Phyllite in the Jofjället area, there occur similar metasediments which are difficult to incorporate in either of these formations. They are low grade and vary in lithology, often being graphitic and even containing limestone. In this context it might be of interest that a similar sequence is also present at the same tectonic level at Essmitjåkko in northern Västerbotten i.e. the succession corresponding to formation 10-12 on Södra Storfjället (reconnaissance mapping by M.B. Stephens and the author).

According to Kulling the stratigraphically highest unit on Södra Storfjället consists of sandy calcareous phyllites and quartzites, which are thought to be equivalents to the rocks in the Jofjället Calcareous Phyllite.

No age-determinable fossils have been located on Södra Storfjället. However, at two different levels in the middle of the higher grade part of the succession, there occur pelmatozoan stems (Kulling *in* Gavelin and Kulling 1955). This strongly indicates that at least a part of the strata in the higher grade Storfjället Nappe Complex is post-Cambrian in age.

The remainder of the Storfjället Nappe Complex stratigraphy in the Jofjället area is not correlatable with the areas discussed above. There are probably regions in northern Västerbotten which contain rocks that might be equivalents to the higher strata in the Jofjället area, but since the stratigraphy is poorly understood in such regions, detailed correlation is not possible at this stage.

5.3. CORRELATION WITH THE TRONDHEIM-TÄNNFORSEN REGION

5.3.1 OPENING REMARKS

Besides the correlations with neighbouring areas already discussed, an attempt has been made to correlate the Jofjället rock sequence with the tectono-stratigraphy in a more remote area, the Trondheim-Tännforsen region (Table 4). The correlations are based mainly on maps and papers by Carstens (1960), Wolff (1960, 1967, 1973, 1976), Springer Peacey (1964), Torske (1965), Chaloupsky and Fediuk (1967), Zachrisson (1969, 1973), Rui (1972), Strand and Kulling (1972), Olesen et al. (1973), Gee and Zachrisson (1974), Gee (1975a, b), Sjöstrand (1978), Hardenby (1980) and also on the author's own short visits to these areas. The tectono-stratigraphic column for the Trondheim region (Table 4) is modified after the paper of Sjöstrand (1978). In

this region the occurrence of fossils allow the establishment of a crude chronostratigraphy for the sequence. The fossil occurrences are now briefly described.

By correlation of serpentinite conglomerates in the Tännforsen area in western Jämtland with the fossil-bearing Otta serpentinite conglomerate in the southern Trondheim region, a Lower Ordovician age and a Baltoscandian affinity are assumed for the lowermost part of the Köli rocks in the column (Jaanusson 1973). In the overlying tectonic unit (Trondheim Nappe), in the Slågån Group, there occur graptolites of Llandoveryan age, while in a graphitic phyllite, probably located in the structurally upper part of the Fundsjø Group (D.G. Gee, personal communication), there has been found *Dictyonema flabelliforme* (Vogt 1889). This pelagic Tremadocian fossil has, nevertheless, no pronounced geographical affinity (L. Karis, personal communication). In the Lower Hovin Group further west, structurally on top, there occur fossils of Lower Ordovician age with an American affinity, while in the uppermost part of this group there are rocks of Upper Ordovician age with a probably mixed faunal assemblage (Whittington and Hughes 1972, Gee 1975b).

Besides these fossil evidences for younging directions various structural criteria have also been used. The incorporation of pebbles from the structurally overlying Fundsjø Group into the Lille Fundsjø conglomerate indicates inversion of this part of the rock sequence. In a similar way a volcanogenic conglomerate above the Støren Group indicates the younging direction. The volcanites of the Fundsjø Group have dominantly an ensimatic immature island arc affinity (Furnes et al. 1979), while the volcanites of the Støren Group have an ocean floor character (Grenne et al. 1979).

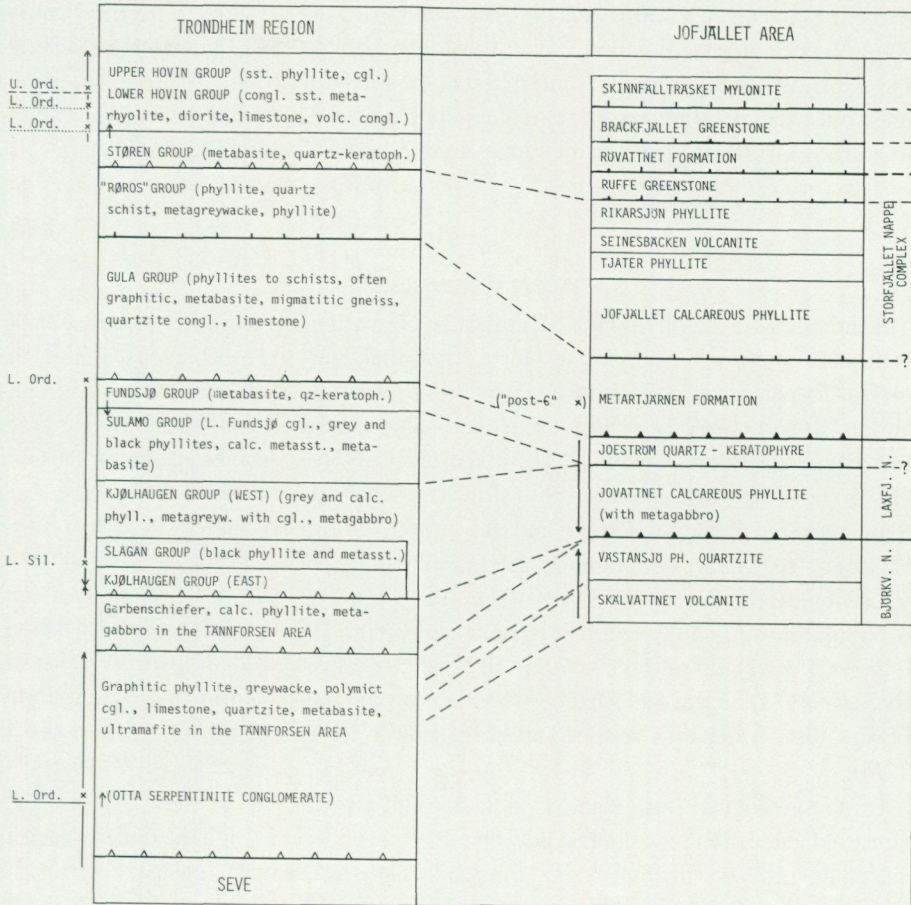
The Kjølhaugen group in the lower part of the geological column is somewhat problematic. The calcareous phyllite in the western part is typically associated with metagabbro, while in the eastern part no metagabbros are present (Wolff 1976). Structural younging evidence (graded bedding) indicates that the western sequence of the Kjølhaugen Group is inverted (Wolff 1973) and that the eastern sequence forms a synclinal structure dipping to the west (overturned to the east) and is cut by the thrust of the Trondheim Nappe (Hardenby 1980). The western and eastern parts of the Kjølhaugen Group are, thus, not simply correlatable. Considering the relationship to the Llandoveryan Slågån Group, which separates the eastern and western developments of the Kjølhaugen Group, the eastern part is probably Silurian in age while the western part is probably to a large extent pre-Silurian (Ordovician) in age.

The younging directions deduced for the succession in the Trondheim-Tännforsen region are indicated in Table 4.

5.3.2. BJÖRKVATTNET NAPPE

The tentative correlation of the formations in the Björkvattnet Nappe with the eastern Trondheim-Tännforsen region is difficult to convey adequately in Table 4. It is possible that the Västansjö Phyllitic Quartzite can be broadly correlated in time with the gabbro-free calcareous phyllites of both the Tännforsen area and the eastern Kjølhaugen Group.

TABLE 4. Tentative tectono-stratigraphic correlation of the Jofjället area with the Trondheim-Tännforsen region.



LEGEND

- | | | | |
|--|---|---------|--|
| | Major thrust in the Trondheim-Tännforsen region | | Correlation line |
| | Major thrust in the Jofjället area | L.Ord.x | Dated paleofauna, |
| | Minor thrust | — | with dominantly Baltoscandian affinity |
| | "Way-up" evidence | | with dominantly American affinity |
| | Younging direction deduced | --- | with mixed affinity |

5.3.3. LAXFJÄLLET NAPPE

The Jovattnet Calcareous Phyllite is correlated tectonically with the gabbro-intruded western Kjølhaugen Group, and the Joeström Quartz-Keratophyre with the Fundsjø Group. Assuming there is no tectonic break between the Lille Fundsjø conglomerate and the Kjølhaugen Group, it is inferred that the Laxfjället Nappe is also inverted; the Joeström Quartz-Keratophyre very tentatively having a Lower Ordovician age and the Jovattnet Calcareous Phyllite an Ordovician or possibly very early Silurian age.

5.3.4. STORFJÄLLET NAPPE COMPLEX

The retrogressed and phyllonitic Metartjärnen Formation is – as earlier mentioned – an extremely attenuated part of the Norra Storfjället lens. A conspicuous unit in the central Trondheim region with which this lens shows significant similarities is the Gula Group. In particular, they show similar association of lithologies, metamorphic grade and tectonic position. Roberts (1978) suggested a largely Precambrian age for the Gula Group for which he proposed a close similarity with the Seve unit in Sweden.

In between the Gula Group and the Støren Group volcanites there is a zone, varying in thickness, of dominantly metasedimentary rocks, which has been referred to as the Røros Group (Torske 1965), the "pseudo-Gula" (F.C. Wolff, personal communication) and the Selbusjøen mélange (Horne 1979). According to Torske this unit is right way up and older than the Støren and Lower Hovin Groups. Gale and Roberts (1974) on the other hand, proposed that the Støren Group had been upthrust on this unit, which was assumed to be of Lower Hovin age i.e. Ordovician (Wolff 1976).

On the geological map of the Trondheim region (Wolff 1976) there is a "minor" thrust indicated along the contact between the "pseudo-Gula" and the Gula Group. In this context it is worth emphasizing the problematic nature of the contact between the higher grade Metartjärnen Formation and the Jofjället Calcareous Phyllite in the Jofjället area, a possible pre-D₂ discontinuity being earlier inferred.

Torske (1965) described the following sequence (named in descending order) immediately below the Støren greenstone: upper phyllite (max. 30 m), quartz schist (100 m), metagreywacke (100–150 m), and lower phyllite (uncertain, large thickness); the rocks belonging to lower greenschist facies. The following points are of interest for the correlation with the lower grade part of the Storfjället Nappe Complex in the Jofjället area:

1. The upper phyllite is often light-green in colour and estimated to have as much as 40% chlorite, which may indicate a volcanogenic affinity.
2. The quartz schist, which is often in contact with the Støren greenstone, consists of alternating layers of quartz-rich rock and thin laminae of dark phyllite often strongly deformed.

3. The metagreywacke has a variety with porphyroblasts of siderite, averaging about 1 mm in size.
4. The content of carbonate minerals in the lower phyllite has been estimated to 13 %.

A most interesting feature of this rock sequence is the occurrence of siderite porphyroblasts, such porphyroblasts being also a characteristic feature of the Tjåter Phyllite in the Jofjället area. Furthermore, rock types reminiscent of the quartz schist are present in the Tjåter Phyllite. The lower phyllite with its rather high carbonate mineral content may then be equivalent to the Jofjället Calcareous Phyllite, while the upper phyllite could possibly represent the Seinesbäcken Volcanite. Thus it is possible to correlate the sequence between the Metartjärnen Formation and the Ruffe Greenstone in the Jofjället area with the "Røros Group" as described by Torske (1965) and lying between the Gula and Støren Groups in the central Trondheim region.

The Støren Group predominantly consists of mafic volcanites, being composed of pillow lavas and pyroclastics. The age of the Støren greenstone is unknown in detail. Since it is overlain by an Ordovician sequence, it is Lower Ordovician or older in age. The Støren greenstone is thought to be equivalent to the Ruffe and Brackfjället Greenstones, which tectonically overlie the remainder of the lower grade Storfjället Nappe Complex sequence in the Jofjället area.

The age of the Storfjället Nappe Complex is, thus, not accurately known. Via correlation with Södra Storfjället (Table 3 and earlier discussion) and Norra Storfjället (radiometric dating, see earlier discussion) part, at least, of the Metartjärnen Formation is inferred to be Ordovician in age. Via correlation with the Støren Group a minimum age of Lower Ordovician is inferred for the Ruffe and Brackfjället Greenstones. The age of the sequence in between the Metartjärnen Formation and the Ruffe and Brackfjället Greenstones is uncertain, but if the assumption by Wolff (1976) regarding correlation of the "pseudo-Gula" with the Lower Hovin Group is valid, then an Ordovician age and deposition on the Greenlandian side of the Iapetus Ocean is probable.

6. SUMMARY OF CONCLUSIONS

The Jofjället succession, which is about 4 km in thickness, consists of at least three nappe units of great regional importance (the Björkvattnet and Laxfjället Nappes, and the Storfjället Nappe Complex). In the Storfjället Nappe Complex, which predominates in the Jofjället area, there occur several tectonic repetitions of sequences. A conspicuous feature – especially for the lower nappes – is their lens-like character.

The succession in the Storfjället Nappe Complex consists predominantly of supra-crustal rocks. The metasediments comprise mainly phyllites of different composition.

However, the rocks in the lowermost part of the Storfjället Nappe Complex – the Metartjärnen Formation – are higher grade and more schistose in character. The phyllites represent mainly basinal deposition of distal sediments. A turbidite facies is, however, represented by the thick Jofjället Calcareous Phyllite. The Seinesbäcken Volcanite, which is situated structurally above the stratiform sulphide deposits, is interpreted to represent distal tuff. The greenstones in the upper part of the sequence are thought to be flows and high-level intrusions. The investigated sulphide deposits – Tjåter, Storbäcksdalen and Rikarbäcken – occur at two different tectonic levels, but probably at the same stratigraphic level.

The rocks in the Jofjället area have been metamorphosed under greenschist facies conditions. The metamorphic grade increases from the Björkvattnet Nappe through the Laxfjället Nappe and culminates in the lower part of the Storfjället Nappe Complex (Metartjärnen Formation). Upwards from this formation there is a continuous decrease in metamorphic grade to lower greenschist facies, which dominates in the Jofjället area. In the upper part of the Storfjället Nappe Complex the metamorphic grade increases again into upper greenschist facies.

Post-metamorphic folding and foliation development (D₃ and D₄) affect all tectonic units and are correlatable in time throughout the Jofjället area. Late-metamorphic deformation (D₂) is suggested to have formed during thrust emplacement of the different units. Assuming that these movements occurred more or less at the same time throughout the rock pile, it may be inferred that the D₂ deformation is broadly time correlatable across the tectonic boundaries. The D₂–D₄ deformation is Silurian in age. The time relations of the earliest pre-syn-metamorphic structures between the different tectonic units are much more uncertain. D₁ folds and foliation in the Björkvattnet Nappe are Silurian in age. Dating of D₁ is lacking in the Laxfjället Nappe and the lower grade part of the Storfjället Nappe Complex. The pre-D₂ structures and metamorphism in the higher grade part of the Storfjället Nappe Complex (Metartjärnen Formation) are suggested to be Ordovician in age.

Using tectono-stratigraphic correlations with other areas in the Scandinavian Caledonides an attempt has been made to clarify the stratigraphy of the Jofjället area and place it in a broader geological context. From these correlations it is inferred that the Björkvattnet Nappe is right way up, is Ordovician and Lower Silurian in age and the rocks were deposited on the Baltoscandian margin of the Iapetus Ocean. The rocks within the Laxfjället Nappe may well be inverted, with an Ordovician and possibly just into Silurian age. The age and younging directions of the Storfjället Nappe Complex are unknown in detail. A part of the Metartjärnen Formation is inferred to be Ordovician and the Ruffe and Brackfjället Greenstones are thought to be at least Lower Ordovician in age. The age of the sequence in between these units is not known, but an Ordovician age and deposition on the Greenlandian side of the Iapetus Ocean cannot be ruled out. In summary, the rocks in the Jofjället area are suggested to be Early Paleozoic in age and to have formed on the margins of both the Greenlandian and the Baltoscandian plates.

ACKNOWLEDGEMENTS

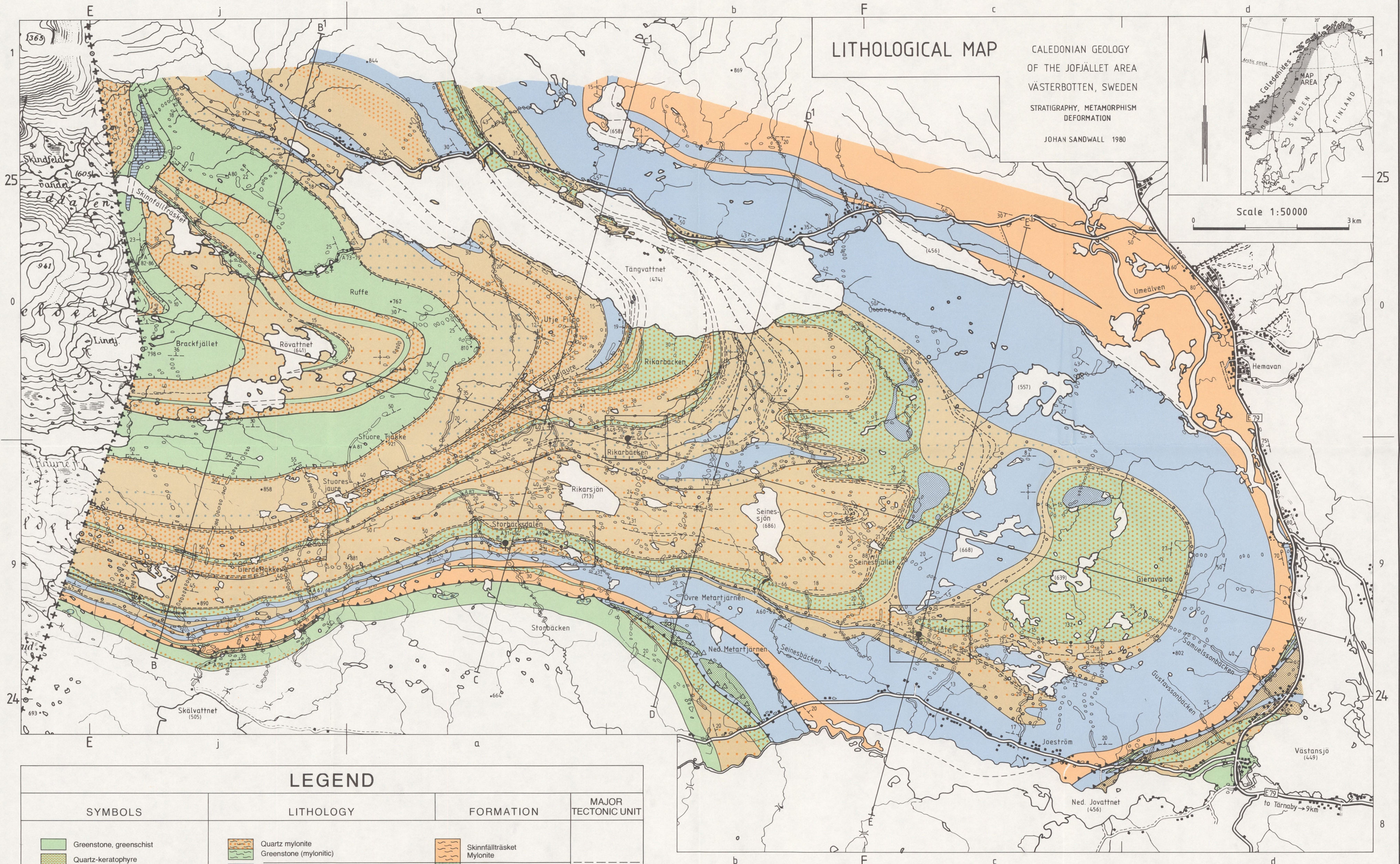
The Jofjället area with its sulphide deposits was suggested for study by Prof. K. Boström in Luleå and Dr E. Zachrisson of SGU to whom I am most grateful. Boliden AB kindly submitted unpublished material of great value and supported me generously in various ways. Most of the work was carried out at the Dept. of Economic Geology, Technical Univ., Luleå. Especially I want to thank Dr M. B. Stephens of SGU for his help towards the progress of the work. Besides valuable suggestions for the field work, he has read the manuscript at various stages of development and his criticism and comments have improved the final script considerably. Thanks are also due to O. Häggbom and P. Sandwall for assistance in the field. Sincere thanks go to A.-B. Malkan who redrew most of the figures and I. Lundmark who typed the manuscript. I am also much indebted to SGU in Luleå for kind assistance, especially Dr T. Sjöstrand for advice with preparation of the script and S. Erixon who redrew the maps. This study is a contribution to the IGCP Project No. 60: "Correlation of Caledonian Stratabound Sulphides" (CCSS) and has been partly financed by the Natural Science Research Council (NFR).

REFERENCES

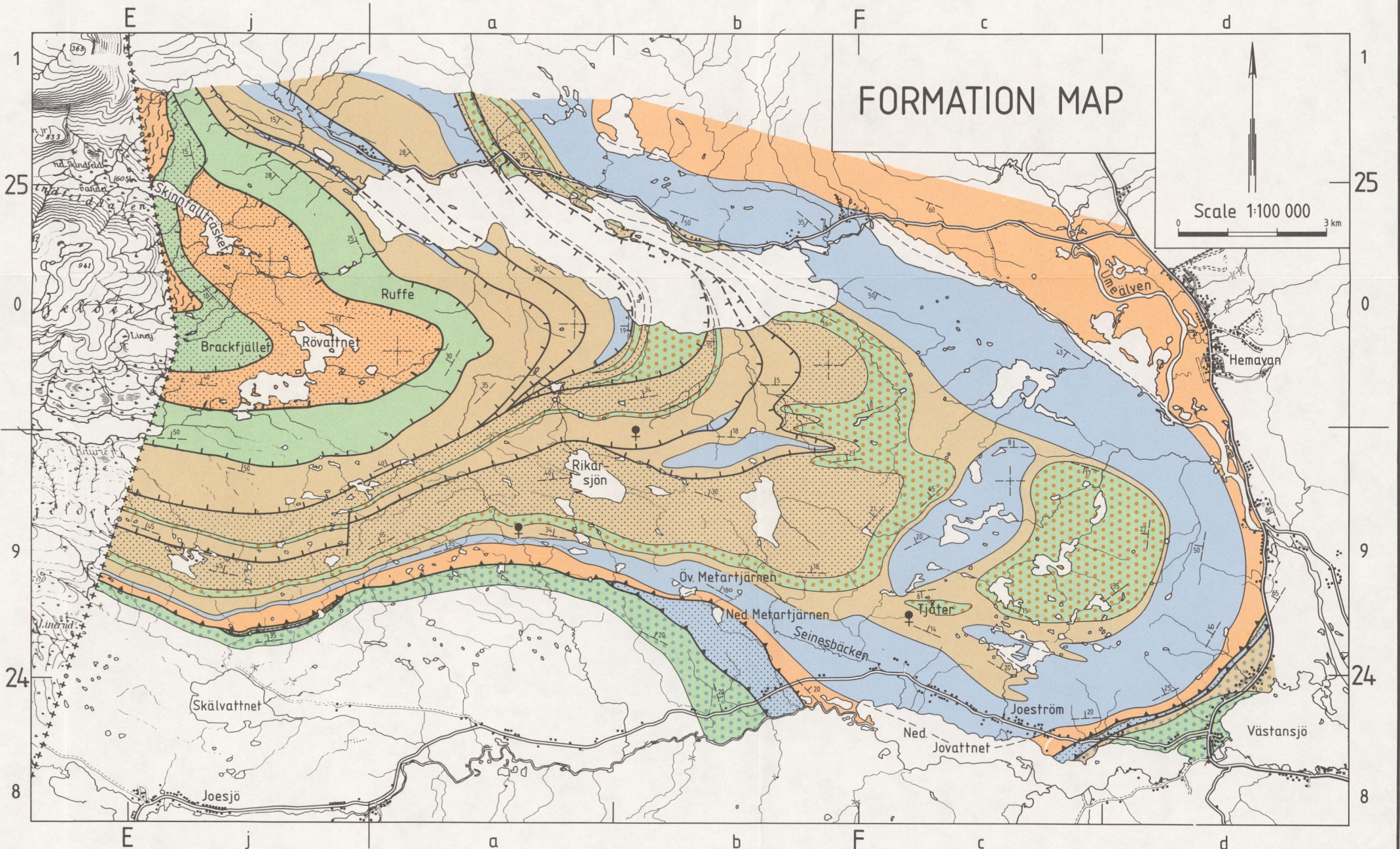
- GFF=Geologiska Föreningens i Stockholm Förhandlingar
 NGT=Norsk Geologisk Tidsskrift
 NGU=Norges geologiske undersøkelse
 SGU=Sveriges geologiska undersökning
- ALEVA, G. J. J., 1950: Geology and petrology of the Gabbi-Mesket region (Swedish Lapland). – Diss., Univ. Amsterdam.
- BACKLUND, H., and QUENSEL, P., 1929: Karta över berggrunden inom Västerbottens fjällområde (the map was printed but not published; see also Quensel 1960).
- BESKOW, G., 1927: Södra Storfjället im südlichen Lapland. – SGU C 350.
- CARSTENS, H., 1960: Stratigraphy and Volcanism in the Trondheimsfjord Area. – Guide to excursions No. A 1 and C 1. Inter. Geol. Cong. 21, Session Norden.
- CHALOUPSKY, J., and FEDIUK, F., 1967: Geology of the western and northeastern part of the Meråker area. – NGU 245, 9–21.
- CHATTERJEE, N. D., 1966: On the widespread occurrence of oxidized chlorites in the Pennine zone of the Western Italian Alps. – Contr. Mineral. Petrol. 12, 325–339.
- DANIELSSON, A., 1967: Spectrochemical analysis for geochemical purposes. – Colloq. Spec. Int. XIII, Ottawa, 311–326.
- DAVIES, A. M., and STUBBLEFIELD, C. J., 1961: An introduction to paleontology. – George Allen & Unwin Ltd.
- van EYSINGA, F. W. B., 1975: Geological time table. – Elsevier Scientific Publishing Company, Amsterdam.
- FURNES, H., ROBERTS, D., STURT, B. A., THON, A., and GALE, G. H., 1979: Ophiolite fragments in the Scandinavian Caledonides. – Abstract, International Ophiolite Symposium 1979, Nicosia, Cyprus.
- GALE, G. H., and ROBERTS, D., 1974: Trace element geochemistry of Norwegian Lower Paleozoic basic volcanics and its tectonic implications. – Earth planetary Sci. Letters 22, 380–390.
- GAVELIN, S., and KULLING, O., 1955: Beskrivning till Berggrundskarta över Västerbottens län. – SGU Ca 37.
- GEE, D. G., 1975a: A Tectonic Model for the Central Part of the Scandinavian Caledonides. – Am. Jour. Sci. 275A, 468–515.
- 1975b: A Geotraverse through the Scandinavian Caledonides – Östersund to Trondheim. – SGU C 717.
- GEE, D. G., and WILSON, M. R., 1974: The Age of Orogenic Deformation in the Swedish Caledonides. – Am. Jour. Sci. 274, 1–9.
- GEE, D. G., and ZACHRISSON, E., 1974: Comments on stratigraphy, faunal provinces and structure of the metamorphic allochthon, central Scandinavian Caledonides. – GFF 96, 61–66.
- GRENE, T., GRAMMELTVEDT, G., and VOKES, F. M., 1979: Cyprus-type massive sulphides in the western Trondheim region, central Norwegian Caledonides. – Abstract, International Ophiolite Symposium 1979, Nicosia, Cyprus.
- GRIP, E., and FRIETSCH, R., 1973: Malm i Sverige, Del 2. – Almqvist & Wiksell, Stockholm.
- HALFERDAHL, L. B., 1961: Chloritoid: Its composition, X-ray and Optical Properties, Stability, and Occurrence – Journal of Petrology, Vol. 2, Part 1, 49–135.
- HARDENBY, C., 1980: Liafjället – ett relativt odeformerat parti i Trondheimsfältets östrand. – Abstract, 14th Nordiske Geologiske Vintermøte 1980, Norsk geol. Forening, Geolognytt 13, 27.
- HOBBS, B. E., MEANS, W. D., and WILLIAMS, P. E., 1976: An outline of structural geology. – John Wiley & Sons, Inc., USA.
- HOLMQVIST, A., 1980: Ordovician gastropods from Vardofjället, Swedish Lapland, and the dating of Caledonian serpentinite conglomerates. – GFF 102, 493–497.
- HORNE, G. S., 1979: Selbusjøen mélange and forearc accretion of the Trondheim Nappe, Central Norwegian Caledonides. – Nature 281, 267–270.
- HUTCHISON, M. N., and SCOTT, S. D., 1980: Sphalerite geobarometry applied to metamorphosed sulphide ores of the Swedish Caledonides and U.S. Appalachians. – NGU, Bull. 360, 59–71.
- HÄGGBOM, O., 1980: Polyphase deformation of a discontinuous nappe in the central Scandinavian Caledonides. – GFF 100 (1978), 349–354.
- JAANUSSON, V., 1973: Aspects of carbonate sedimentation in the Ordovician of Baltoscandia. – Lethaia 6, 11–34.
- KIEFT, C., 1952: Geology and petrology of the Tärna region, southern Swedish Lapland. – Diss., Univ. Amsterdam.

- KULLING, O., 1933: Bergbyggnaden inom Björkvattnet-Virisen-området i Västerbottensfjällens centrala del. – GFF 55, 167–422.
- 1958: Om begreppen Vojtkonglomerat och Mesketlava i Västerbottensfjällen. – GFF 80, 226–234.
- MAGNUSSON, N. H., THORSLUND, P., BROTZEN, F., ASKLUND, B., and KULLING, O., 1960: Description to accompany the map of the pre-Quaternary rocks of Sweden. – SGU Ba 16.
- MIYASHIRO, A., 1973: Metamorphism and metamorphic belts. – George Allen & Unwin Ltd.
- MULDER, H., 1951: Geology and petrology of the region between Lake Överuman and Tärnasjön (southern Swedish Lapland). – Diss., Univ. Amsterdam.
- MURRIS, R. J., 1957: Geology and petrology of the Gieravardo – Jofjället region, Västerbotten, Sweden. – Diss., Univ. Amsterdam.
- OLESEN, N. Ø., HANSEN, E. S., KRISTENSEN, L. H., and THYRSTED, T., 1973: A preliminary account of the geology of the Selbu-Tydal Area, the Trondheim Region, Central Norwegian Caledonides. – Leidse. geol. Meded. 49, 259–276.
- QUENSEL, P., 1960: Beskrivning till karta över berggrunden inom Västerbottens fjällområde. – SGU Ba 21.
- RAMSAY, J. G., 1967: Folding and Fracturing of Rocks. – McGraw-Hill, New York, N. Y.
- ROBERTS, D., 1978: Caledonides of south central Norway. – In IGCP Project 27, Caledonian-Appalachian Orogen of the North Atlantic Region. – Geological Survey of Canada, paper 78–13, 31–37.
- RUI, I. J., 1972: Geology of the Røros district, south-eastern Trondheim region with a special study of the Kjøliskarvene-Holtsjøen Area. – NGT 52, 1–21.
- SENIOR, A., 1978: The Artfjället Gabbro, Västerbottens län. – Abstract, 13th Nordiske Geologiske Vintermøde 1978, København, 64.
- SJÖSTRAND, T., 1978: Caledonian geology of the Kvarnbergsvattnet area, northern Jämtland, central Sweden. – SGU C 735.
- SPRINGER PEACEY, J., 1964: Reconnaissance of the Tømmerås Anticline. – NGU 227, 13–84.
- STEPHENS, M. B., 1977: Stratigraphy and relationship between folding, metamorphism and thrusting in the Tärna-Björkvattnet area, northern Swedish Caledonides. – SGU C 726.
- 1980: Occurrence, nature and tectonic significance of volcanic and high-level intrusive rocks within the Swedish Caledonides. – In WONES et al: The Caledonides in the U.S.A., I.G.C.P. 1979; Blacksburg Virginia, 289–298.
- STRAND, T., and KULLING, O., 1972: Scandinavian Caledonides. – Wiley-Interscience, London and New York.
- SVERIGES GEOLOGISKA UNDERSÖKNING, 1958: Karta över Sveriges berggrund i tre blad, skala 1:1 000 000. – SGU Ba 16.
- TEGENGREN, F. R., 1924: Sveriges ädlare malmer och bergverk. – SGU Ca 17.
- TORSKE, T., 1965: Geology of the Mostadmarka and Selbustrand area, Trøndelag. – NGU 232.
- TROUW, R. A. J., 1973: Structural geology of the Marsfjällen area, Caledonides of Västerbotten, Sweden. – SGU C 689.
- UYTENBOGAARDT, W., 1961: The geology of the southern part of Norra Storfjället, province of Västerbotten, Sweden. – (Part of unpublished thesis; SGU archive.)
- VOGT, J. H. L., 1889: Funn av Dictyonema ved Holsjøen, Holtålen – Vid. selsk. Christiania Forh. Oversikt over Videnskaps-Selskabets Møder i 1888.
- WITTINGTON, H. B., and HUGHES, C. P., 1972: Ordovician geography and faunal provinces deduced from Trilobite distribution. – Phil. Trans. R. Soc., London B 263, 235–278.
- WILSON, M. R., and SUNDIN, N. O., 1979: Isotopic age determinations on rocks and minerals from Sweden 1960–1978. – SGU Rapp. & medd. 16.
- WINKLER, H. G. F., 1967: Petrogenesis of Metamorphic Rocks (2th ed.). – Springer-Verlag, New York Inc.
- WOLFF, F. C., 1960: Foreløpige meddelser fra kartbladet Verdal. – NGU 211, 212–230.
- 1967: Geology of the Meråker area as a key to the eastern part of the Trondheim region. – NGU 245, 123–142.
- 1973: Meråker og Faeren. Beskrivelse til de berggrunnsgeologiske kart (AMS-M 711) 1721 I og 1722 II – 1:50 000. – NGU 295.
- 1976: Geologisk kart over Norge, berggrunnskart TRONDHEIM 1:250 000. – NGU.
- ZACHRISSON, E., 1969: Caledonian geology of northern Jämtland – southern Västerbotten. – SGU C 644.
- 1971: The Structural setting of the Stekenjokk Ore Bodies, Central Swedish Caledonides. – Econ. Geol. 66, 641–652.
- 1973: The westerly extension of the Seve rocks within the Seve-Köli Nappe Complex in the Scandinavian Caledonides. – GFF 95, 243–251.
- 1977: Stratigraphic position and base metal proportions of stratabound Köli sulphide deposits, Central Swedish Caledonides. – In Kaledonske malmforekomster, BVLI's Tekniske Virksomhet, Trondheim, 8–16.

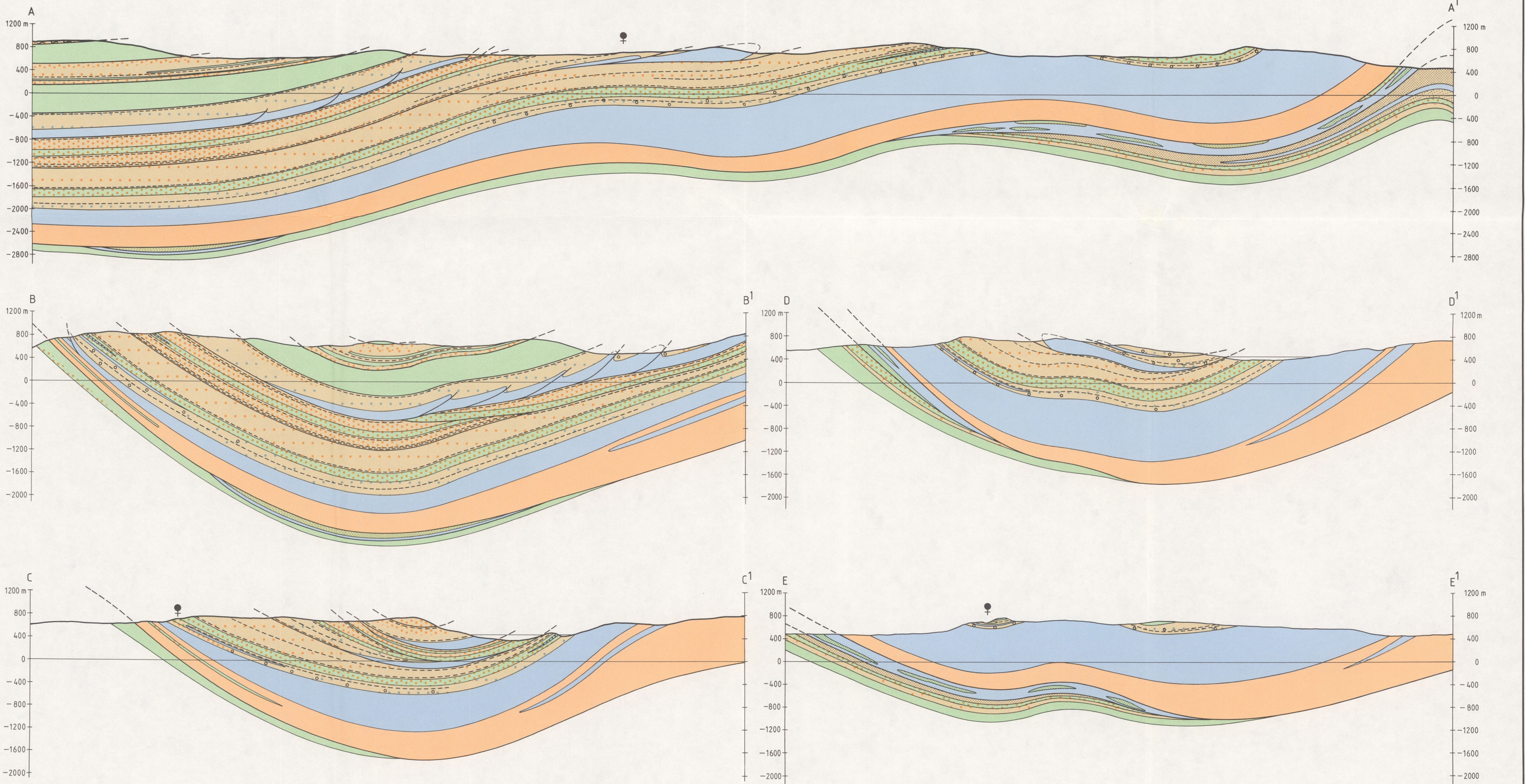
GEOLOGICAL MAP OF THE JOFJÄLLET AREA, VÄSTERBOTTEN, SWEDEN



SYMBOLS	LITHOLOGY	FORMATION	MAJOR TECTONIC UNIT
Greenstone, greenschist	Quartz mylonite	Skinnfällträsket Mylonite	
Quartz-keratophyre	Greenstone (mylonitic)		
Mixed felsic/mafic volcanites	Limestone	Brackfjället Greenstone	
Gabbro	Greenstone, greenschist		
Serpentine	Graphitic phyllite		
Calcareous phyllite (partly ankeritic)	Greenschist	Rövattnet Formation	
Ankerite-dolostone	Pelitic and quartz phyllite		
Limestone	Quartz phyllite (mylonitic)		
Pelitic phyllite	Greenstone, greenschist with some thinner beds of graphitic quartz phyllite	Ruffe Greenstone	
Phyllitic quartzite, feldspathic greywacke	Quartz phyllite (mylonitic)		
Calcareous pelitic phyllite (partly ankeritic)	Calcareous pelitic phyllite (partly ankeritic)		
Siderite porphyroblast-bearing phyllite	Pelitic phyllite	Rikarsjön Phyllite	
Graphitic phyllite	Greenschist		
Pelitic and quartz phyllite	Graphitic phyllite		
Quartz phyllite (mylonitic)	Pelitic and quartz phyllite		
Mica schist	Ankerite-dolostone		STORFJÄLLET NAPPE COMPLEX
Quartz mylonite	Mixed felsic/mafic volcanites (tuffite included)		
Greenstone (mylonitic)	Pelitic phyllite		
Sericite schist-quartzite in ass. with sulphide deposit	Graphitic phyllite		
Calcareous pelitic phyllite (partly ankeritic)	Sericite schist-quartzite in ass. with sulphide deposit	Tjärer Phyllite	
Pelitic and quartz phyllite	Siderite porphyroblast-bearing phyllite		
Quartz phyllite (mylonitic)	Calcareous phyllite (mainly ankeritic)		
Calcareous phyllite (ankeritic in upper part)	Calcareous pelitic phyllite (partly ankeritic)		
Mixed felsic/mafic volcanites	Pelitic and quartz phyllite	Jofjället Calcareous Phyllite	
Greenschist	Quartz phyllite (mylonitic)		
Mica schist, often garnetiferous	Calcareous phyllite		
Mixed felsic/mafic volcanites	Mixed felsic/mafic volcanites	Metartjärnen Formation	
Quartz-keratophyre	Greenschist		
Gabbro	Mica schist, often garnetiferous	Joeström Quartz-Keratophyre	LAXFJÄLLET?
Calcareous phyllite	Mixed felsic/mafic volcanites	Jovattnet Calcareous Phyllite	NAPPE
Phyllitic quartzite, feldspathic greywacke	Calcareous phyllite		
Serpentine	Phyllitic quartzite, feldspathic greywacke	Västansjö Phyllitic Quartzite	
Mixed felsic/mafic volcanites	Serpentine		
Pelitic and quartz phyllite	Mixed felsic/mafic volcanites		
Greenschist (tuffite included)	Pelitic and quartz phyllite	Skövattnet Volcanite	BJÖRKVATTNET NAPPE
	Greenschist (tuffite included)		



SCHEMATIC SECTIONS



PRISKLASS H

Distribution

Liber Kartor

162 89 STOCKHOLM

Växjö 1981, C. Davidsons Boktryckeri AB
Printed in Sweden

ISBN 91-7158-221-5
ISSN 0082-0024