The Geological History of the Grønsennknipa Nappe, Valdres

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Eocambrian conglomerates and arkoses were deposited on the Precambrian Jotun rocks. The subsequent polyphase structural evolution of this sequence to form the Grønsennknipa Nappe is described. The emplacement of this nappe over the phyllites of the Quartz Sandstone Nappe to its present position is shown to have occurred during the last movement phase recognised in the area.

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CONTENTS

Introduction

Grønsennknipa has always been important in discussions about the geology of the southeast part of the Norwegian Caledonian thrust zone because there, the three major rock groups which make up much of the thrust zone, can be seen in contact with one another. Briefly, the thrust zone in the Valdres area consists of three major nappes or nappe complexes piled one over the other. The lowest nappe, which has been thrust over the southeast Precambrian foreland of the Caledonian Mountain belt, is called the Quartz Sandstone Nappe (Fig. 1). Above this has been thrust a middle major nappe

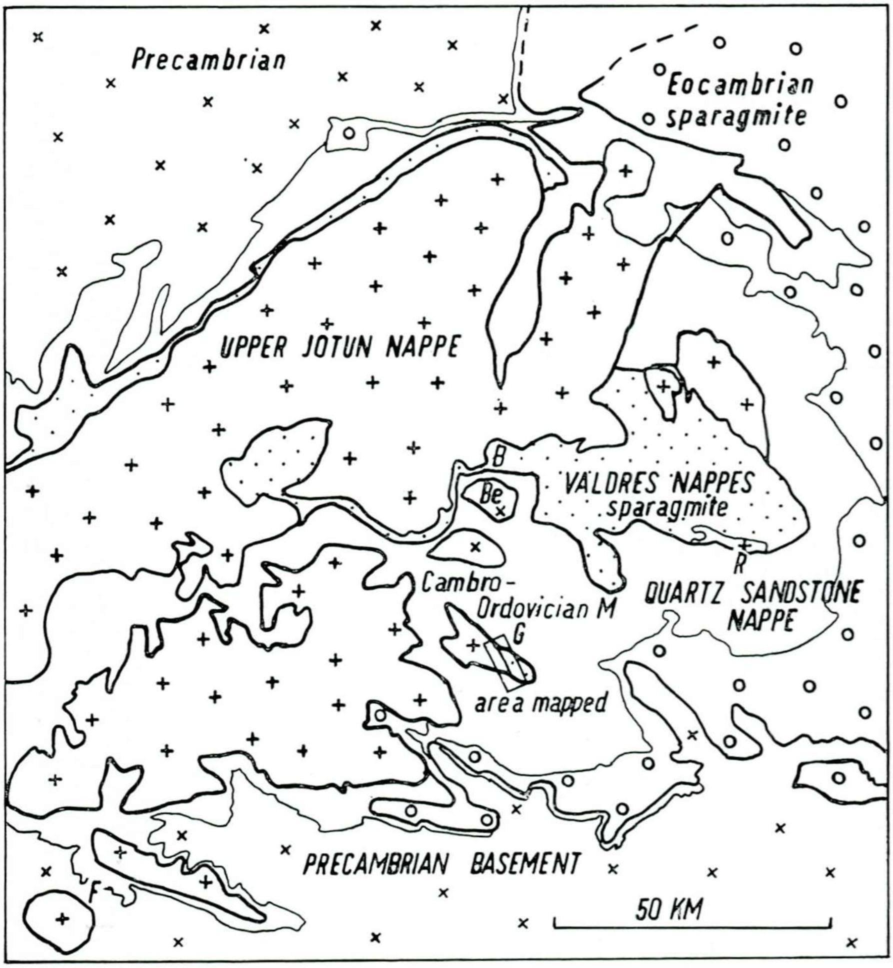


Fig. 1. Regional geology and location map. G—Grønsennknipa, B—Bygdin, Be—Beito, M—Mellane, R—Røsjøkollan, F—Finse.

complex called the Valdres Nappes, and finally the highest nappe is the Upper Jotun Nappe (Fig. 1).

The lowest part of the Quartz Sandstone Nappe consists of Eocambrian Sparagmite which passes up into fossiliferous Cambro-Ordovician sandstones, shales and phyllites (Strand 1938). The Valdres Nappes have recently been described by Loeschke & Nickelsen (1968) and consist largely of Valdres Sparagmite which at Røsjøkollan (Fig. 1) apparently overlies an older gabbro with a gabbro (basal?) conglomerate between. The Valdres Sparagmite consists mainly of arkoses, conglomerates and greywackes (Loeschke 1967 a and b) and is unfossiliferous. However, at Mellane (Fig. 1) the Sparagmite has a tillite band which suggests a correlation with the Eocambrian rocks of the Lake Mjøsa region (Loeschke 1967 a).

The Upper Jotun Nappe consists mainly of igneous rocks (granites, syenites, gabbros, anorthosites and ultrabasics) with some pyroxene-bearing granulites. These rocks were originally described by Goldschmidt (1916a) and more recently by Battey (1965). The Upper Jotun Nappe has been thrust over the Valdres Nappes, and at Bygdin (Fig. 1) the structural relations of the thrust between these nappes has been described in detail by various authors (Goldschmidt 1916b, Strand 1945, Flinn 1959, 1961, Hossack 1968a, b). Strand (1951) showed that at the northeast end of the Jotun Nappe at Sel, the Jotun rocks were overlain by Cambro–Ordovician sediments, thus suggesting a Precambrian age for the former.

At Grønsennknipa, phyllites of the Quartz Sandstone Nappe, Valdres Sparagmite and Jotun igneous rocks are all in contact with one another and the structural relations of these three major rock groups have always been of some considerable interest.

Goldschmidt (1916b) was the first to show that the Jotun rocks at Grønsennknipa formed a nappe which had been thrust over the underlying phyllites. The sparagmite here has a thick quartzite conglomerate at its base and Goldschmidt, in a series of east–west sections through the area (ibid., Fig. 2), showed that the conglomerate and the sparagmite mainly lie above, and dip eastwards off, the Jotun rocks. He thought he could recognise an unconformity between the Valdres Sparagmite and the underlying Jotun rocks. Goldschmidt further suggested that the sparagmite and conglomerate had been deposited during the actual thrust displacement, because at the southern end of the nappe the sparagmite lay apparently undisturbed over the Jotun rocks and the phyllite, but at the northern end the Jotun rocks had overthrust the sparagmite (ibid., Fig. 5).

Holtedahl (1959, 1961) showed that, in fact, the sparagmite and the Jotun rocks at Grønsennknipa form a complete nappe (the Grønsennknipa Nappe) and that the nappe is everywhere underlain by a thrust plane which separates it from the underlying phyllites of the Quartz Sandstone Nappe. He also was the first to describe an important structural relationship of this basal thrust plane, namely, that the thrust truncates the steeply dipping cleavage of the underlying phyllite.

Nickelsen (Loeschke & Nickelsen 1968) was the next to work at Grønsennknipa. He showed that in the sparagmite there were several large eastward-facing recumbent folds which were folded about the main slaty cleavage. He further corroborated Holtedahl's idea that the Jotun and sparagmite rocks formed a separate Grønsennknipa Nappe which had been thrust over the phyllite. He correlated this nappe structurally with the Valdres Nappes.

The present writer mapped part of the area in order to study the deformation of the Grønsennknipa conglomerate. The outcrops were mapped on aerial photographs on the scale of 1 : 13,000 and a map was later constructed from the photographs with the aid of a stereographic radial-line plotter. The results of the investigations of the conglomerate will be reported elsewhere, but some new structural observations were made which the author describes in the present paper.

Stratigraphy and descriptions of rock types

JOTUN ROCKS

The Jotun rocks occur in the western half of the area and make up the highest ground (Fig. 12). These rocks are of two types: gabbro and granite. The gabbro is older as it occurs as inclusions in the granite. The gabbro, when fresh and undeformed, has a coarse ophitic texture and in a few localities shows a layering defined by pyroxene-rich and feldspar-rich bands. The gabbro is distributed on the map as a series of isolated blocks which are apparently surrounded by granite. Because of the poor exposure, the complete outline shapes of these large blocks cannot be discerned, except for one block just to the south of Svenskekampen where the west margin of the block is sufficiently exposed to show that it is quite irregular. On average, the blocks of gabbro are some tens or even hundreds of metres in diameter. However, in a few localities midway between Grønsennknipa and Svenskekampen, the gabbro occurs as small, irregular xenoliths within the granite. These relationships indicate that the granite has been intruded into the gabbro.

Towards the margins of the gabbro blocks, the gabbro is often deformed and has a well-developed foliation defined by the preferred orientation of hornblende crystals. This foliation can also be bound within shear planes only a few metres thick inside the gabbro blocks. The foliation has a random orientation on a stereonet (Fig. 2c). However, where the contacts between the gabbro and the granite are exposed, the hornblende foliation is usually parallel to the block margin, even where it is irregular in shape. The significance of this foliation will be discussed later.

The granite is typically pink and medium-grained but in a few localities it is dark-coloured. It often has a faint schistosity defined by the dark minerals and this schistosity cuts across a granite/gabbro contact. Hence the schistosity must be later than the intrusion of the granite. Elsewhere a few schlieren occur and these were probably derived from completely digested xenoliths of gabbro. In addition to the schistosity, the granite also has two other types of structure which have been superposed on the granite subsequent to its crystallisation. In the south near Nøsekampen and to the north of Grønsennknipa, the granite contains bands of dark-coloured phyllonite with a mainly southeast plunging lineation (Fig. 2b). In the north, the phyllonites are intruded by lineated brick-red pegmatites with the same southeast plunging lineation. Outside these phyllonite bands, which seem to be only a few metres thick (although they are never completely exposed), the granite shows no sign of the southeast plunging lineation.

The other type of superposed structure was formed by a crushing, which produced black flinty layers. These are the result of ultra-mylonitisation and the layers occur as regular and irregular bands. One of the best examples of the ultramylonite occurs in an easterly trending planar band just south of Grønsennknipa in a fault plane already described by Holtedahl (1959). The

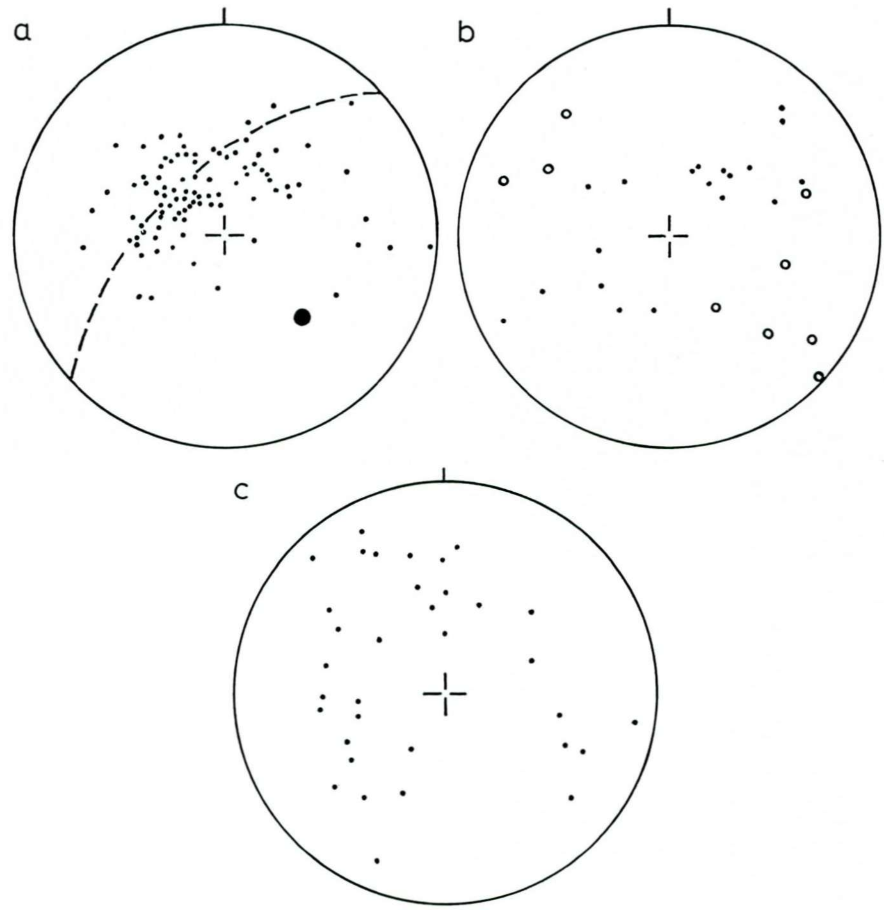


Fig. 2. Stereographic projections of tectonic structures in the granite. a. dots — poles to Precambrian schistosity: dashed line — F2 girdle: large dot — F2 girdle axis. b. dots — poles to phyllonite S1 cleavage: circles — L1 lineation in the phyllonite. c. poles to gabbro foliation.

fault dips at about 45° to the north and the footwall of the fault plane is beautifully exposed as a sloping wall running up the hill towards Grønsennknipa (cf. Fig. 7, Holtedahl, ibid.). Because of the presence of the mylonite, the fault is marked on the author's map as a thrust (Fig. 12).

To the north of Grønsennknipa, the granite shows examples of regular and irregular ultramylonites. As the boundary between the granite and conglomerate is approached, the granite contains more and more black flinty crushing and becomes darker in colour. Usually, the ultramylonite is formed along anastomosing cracks only a hairline in width. Often these hairline cracks define crude planar structures which do not seem to have a preferred orientation.

In the north there are two, thin, parallel, northwest trending basic dykes in the granite with chilled margins (Fig. 12, locality C). A dolerite dyke has already been mapped by the author, intruding the granite of the Upper

Fig. 3. Conglomerate unconformably overlying granite. The contact is just to the lower left of the hammer head. View looking east.

Jotun Nappe at Bygdin (Hossack 1968a) and the overall time sequence of igneous intrusion is the same at Grønsennknipa as already reported at Bygdin:

a) crystallisation of gabbro
b) intrusion of granite
c) dolerite dyke intrusion

CONGLOMERATE AND SPARAGMITE

These rocks occur to the east of the Jotun Granite. In the southern part of the area, the conglomerate and sparagmite dip towards the east, apparently dipping off the granite, but the contact between them and the granite is not exposed. However, at the point marked B on Fig. 12 a contact between the granite and the conglomerate is exposed and is interpreted as an unconformity. The conglomerate lies above and is separated from the granite by a few cm of brownish sparagmite (Fig. 3). The junction is not faulted and there is no evidence that the granite has been intruded into the conglomerate. It was near here that both Goldschmidt (1916b) and Nickelsen (Loeschke & Nickelsen 1968) also recognised an unconformity. An unconformity at the base of the conglomerate is also suggested by the fact that all the examples of cross-bedding in the southern half of the conglomerate and sparagmite indicate that these rocks are right-way-up above the granite (cf. facing indicators on Fig. 12 and Loeschke & Nickelsen 1968, p. 353).

To the north of locality B, the contact between the granite and conglomerate is quite well exposed and is largely a fault zone which truncates the bedding surfaces in the conglomerate and sparagmite. The fault also appar-

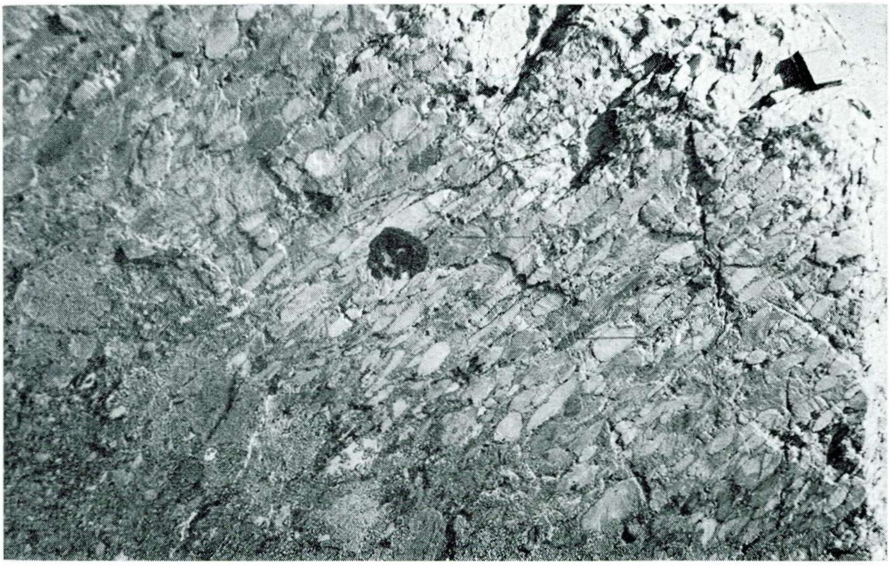


Fig. 4. Deformed Grønsennknipa conglomerate with the pebbles flattened in the S1 cleavage. From part of the northern inverted limbs of the Grønsennknipa Neutral Fold. View looking north.

ently truncates the cleavage in some conglomerate exposures and is usually defined by a black flinty ultramylonite band a few mm thick. The fault is normally seen as a well-marked steeply dipping wall with a smooth polished surface (cf. Holtedahl 1959, Fig. 6).

The conglomerate has been deformed, but in its least deformed state it consists of well-rounded, red, quartzite pebbles in an arkosic matrix. The quartzite pebbles are the most dominant although pebbles of acid and basic volcanic rocks, granite, sandstone and syenite were reported by Goldschmidt (1916b). The arkosic matrix of the conglomerate is petrographically equivalent to the sparagmite. In addition to the large area of sparagmite in the east mapped by Nickelsen (Loeschke & Nickelsen 1968), the sparagmite also occurs as bedding layers within the conglomerate. Some of these layers are only a few cm thick but larger layers, several tens of metres thick, can be mapped. The main occurrence of these thicker layers is to the southeast of locality B where they trend parallel to the granite-conglomerate boundary.

Towards the north, the amount of deformation in the conglomerate and sparagmite increases. The pebbles become flattened within a cleavage (Fig. 4) and the sparagmite matrix has a cleavage defined by muscovite. Even the matrix of the least deformed conglomerate contains this cleavage. The long axes of the pebbles define a southeast plunging lineation which can also be found in the sparagmite matrix. With increasing deformation, the conglomerate and sparagmite gradually lose their red colour and become grey.

The conglomerate has a maximum thickness of about 330 m and in the east passes up into sparagmite, which is stratigraphically higher. These sparagmites have already been described by Loeschke & Nickelsen (1968) as petrographic equivalents of arkoses and graywackes and are at least 1400 m thick. The age of the conglomerate and sparagmite has already been adequately discussed by Loeschke & Nickelsen (1968). They show that the conglomerate and sparagmite at Grønsennknipa are Eocambrian on the basis of stratigraphic correlation with the rocks of Mellane and Lake Mjøsa. Because the Jotun rocks underlie the Eocambrian sequence here, they are presumably of Precambrian age.

PHYLLITES

The Jotun rocks and the Eocambrian sparagmite described above form the Grønsennknipa Nappe, which has been thrust over phyllites (Holtedahl 1959, Loeschke & Nickelsen 1968). Wherever the boundary between the rocks of the Grønsennknipa Nappe and the phyllites is seen, the phyllites are always underneath.

The phyllites are usually black in colour with a well-developed slaty cleavage which typically is not perfectly planar, but curved. Thin sandy bedding layers from a few mm to a few cm in thickness can be found and often these surfaces are cut at an angle by the cleavage. The phyllite also contains numerous quartz veins, which are folded about the cleavage and lineated.

The phyllite is unfossiliferous but has been mapped by Bugge (1939) as Ordovician on the basis of correlation with fossiliferous rocks to the east in Etnedal (cf. Strand 1938) and seems to form the upper part of the Quartz Sandstone Nappe (Fig. 1). A tectonic discordance between the phyllites of this nappe and the overlying Grønsennknipa Nappe has already been noted by Holtedahl (1959). The main slaty cleavage in the phyllites trends east-west with an almost vertical dip, and is truncated by the almost flat-lying basal thrust plane of the Grønsennknipa Nappe. This truncation is obvious on the geological map (Fig. 12), especially in the north.

CAMBRIAN QUARTZITES

At the northern end of the Grønsennknipa Nappe (locality A, Fig. 12), there is an outcrop of quartzite beds up to a metre thick separated by thin slaty layers. The cleavage in the slates and quartzites is oblique to the bedding and some of the quartzite layers have been boudinaged. This locality has already been described by Holtedahl (1959, locality 2).

The quartzites lie above the phyllites and are separated from them by what appears to be a flat-lying thrust. Above the quartzites are schists, one metre thick, which appear to be strongly deformed sparagmite. Above these schists is the Jotun granite.

These rocks are thought by the author to be Cambrian in age. They can be correlated, on lithology, with either the supposed Cambrian quartzites which lie above the Precambrian rocks of the Beito window, which the author is presently mapping (Fig. 1), or with the Mellsenn Group of Mellane (Loeschke & Nickelsen 1968), which is also thought to be partly of Cambrian age. Stretched and broken slices of Mellsenn rocks have been described beneath the basal thrust of the Mellane Nappe by Nickelsen (1967).

An exotic origin is proposed for these quartzites by the present writer. They belong neither to the phyllite succession nor to the Eocambrian sparagmite sequence. They are thought to be a tectonic pip or lens which has been picked up during the movement of the Grønsennknipa Nappe and emplaced along the basal thrust of that nappe.

Tectonic structures

INTRODUCTION

The area has undergone a series of tectonic deformations, the earliest of which seems to be of Precambrian age and occurs in the Jotun granite. The most prominent deformations are Caledonian and are to be found in all the rock groups The various tectonic structures in the two main nappes, the Grønsennknipa Nappe and the Quartz Sandstone Nappe, will be described, and possible correlations will be discussed.

PRECAMBRIAN DEFORMATION IN THE JOTUN GRANITE

The earliest tectonic structure visible in the Jotun rocks is the schistosity defined by the alignment of dark minerals in the granite. This is tectonic in origin as in one exposure it is parallel to the axial surface of a small fold core picked out by coarse- and medium-grained layers in the granite. This is the schistosity which cuts across a gabbro/granite contact. The schistosity has a general east or northeast trend with moderately inclined southerly dips (Fig 2 a). Locally, however, this schistosity has been deformed by later Caledonian folds and this is responsible for some of the variations in trend of the schistosity (Fig. 12).

This schistosity cannot be found in the overlying Eocambrian conglomerate and sparagmite, and hence would seem to be of Precambrian age. This Precambrian deformation may also be responsible for the hornblende foliation in the gabbro which lies parallel to the granite/gabbro contacts. During the deformation, the granite and the gabbro probably had different competencies which produced a differential strain along the gabbro boundaries. This differential strain in turn may have produced the foliation. The internal parts of the gabbro blocks remained undeformed. However, it is also possible that the hornblende foliation was produced in a similar manner during the later Caledonian deformations.

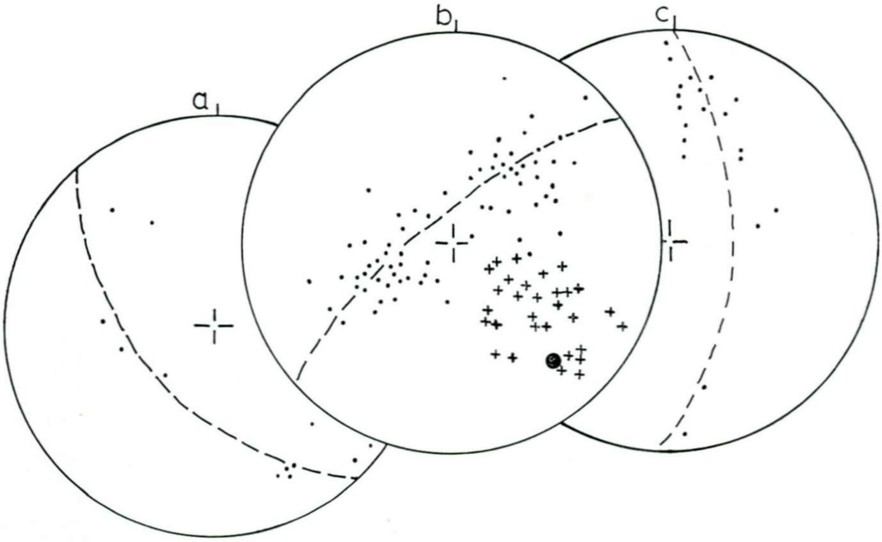


Fig. 5. Stereographic projections of tectonic structures in the conglomerate. a. dots — cleavage/bedding intersections and F1 fold axes on the lower limb of the Grønsennknipa Neutral Fold: dashed line — average dip of S1 on this limb of the neutral fold. b. dots — poles to S1: crosses — L1 stretching lineation: large dot — F2 girdle axis and axial direction of the Grønsenknipa Neutral Fold. c. dots — cleavage/bedding intersections and F1 fold axes on the upper limb of the Grønsennknipa Neutral Fold: dashed line — average dip of S1 on this limb of the fold.

CALEDONIAN DEFORMATION OF THE GRØNSENNKNIPA NAPPE

Three main Caledonian deformations can be recognised in the rocks which form the Grønsennknipa Nappe.

*F1 deformation**

The earliest deformation in the Eocambrian conglomerate and sparagmite is responsible for the formation of the main cleavage (S1) and lineation (L1). These F1 structures are simplest in the southern half of the conglomerate and will be described first.

S1 in the south is defined by an alignment of deformed pebbles in the conglomerate (Fig. 4) and by a muscovite schistosity in the sparagmite and conglomerate matrix. In the exposures of least-deformed conglomerate, the pebbles are still almost spherical, but usually the plane of greatest flattening of the pebbles lies near to the plane of muscovite schistosity With increasing deformation, the flattening of the pebbles becomes more extreme and they show better alignment in the plane of the schistosity. The longest axes of the deformed pebbles also have a tendency to be parallel to a southeast

* The terms F1, F2, F3 used in this paper only apply to the deformation sequence at Grønsennknipa and do not imply contemporaneity with any deformation phases already described elsewhere in the region.

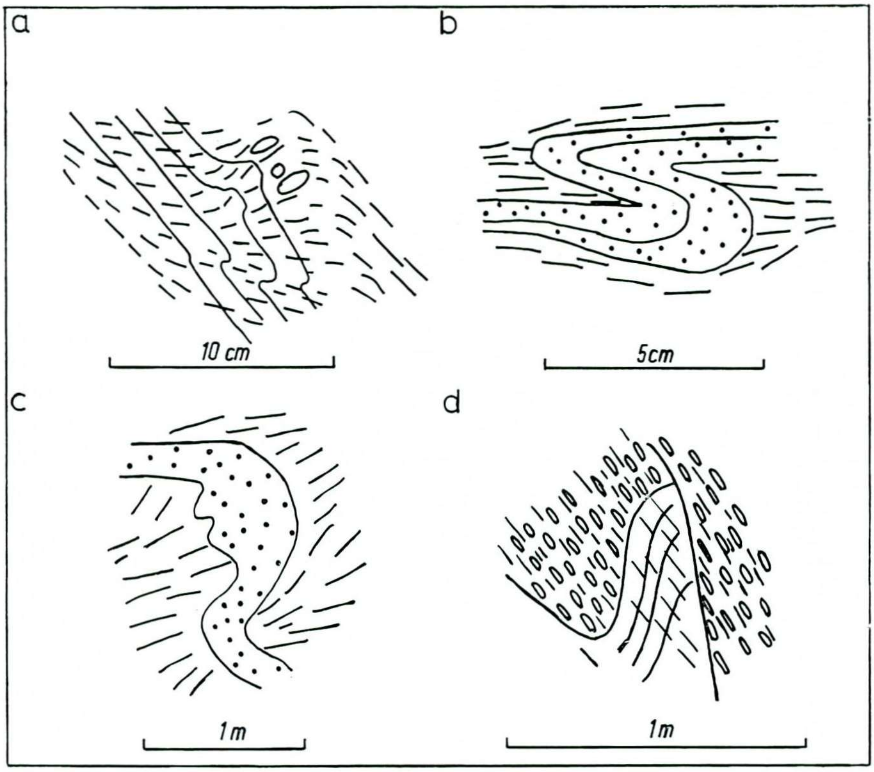


Fig. 6. F1 minor folds. a. fold in sparagmite layer. b. and c. folds in phyllite. d. fold in conglomerate. Dashed lines indicate S1 cleavage.

plunging lineation (L1) (Fig. 5 b), which lies in the plane of S1. L1 seems to be a so-called 'stretching lineation' and defines more or less the direction of greatest elongation in the rocks. In the sparagmite, L1 is usually seen as a striation along the bedding surfaces because S1 lies near the plane of the bedding. The S1 cleavage in the conglomerate is usually oblique to the bedding and shows a refraction as it passes from conglomerate layers into sparagmite layers.

In the southern part of the conglomerate, some F1 folds were found defined by sparagmite bedding layers (Fig 6 a). The S1 cleavage is parallel to the axial surfaces of these folds and has a moderate dip to the east (Fig. 12). Throughout the whole of the southern area, the cleavage always dips less steeply than the bedding. This relationship is usually taken to indicate that the beds are upside-down. However, cross-bedding structures in the sparagmite show that the beds here face upwards. Because the sense of intersection of the S1 cleavage and bedding is always the same in the south, this must mean that all the beds face the same way, i.e. to the east.

The intersections of bedding and cleavage define F1 fold axes. Stereonet solutions of the intersections are spread along an easterly dipping great circle, but the dominant trend of the F1 axes is towards the north (Fig. 5 c). This great circle corresponds to the average easterly dip of S1 in this area of conglomerate. Hence the F1 fold axes are apparently curved within their axial surfaces. These fold axes are of the same age as the major folds described by Nickelsen two km to the east at Grønlihovd (Loeschke & Nickelsen 1968). The L1 stretching lineation lies in the axial surfaces of these folds at an angle to the F1 fold axes; and the folds all face downwards to the east (Fig. 11 d).

As the S1 cleavage in the conglomerate is traced towards the north, it becomes more obvious and the pebble deformation becomes more extreme. Also, the dip of S1 steepens and eventually becomes overturned to the southwest. In this northern area, where the conglomerate is much thinner and is separated from the over- and under-lying rocks by fault planes, the F1 deformation is strongest. The deformed pebble shapes are the most extreme found, and the F1 minor folds are much more common than in the south. These F1 folds are defined by pebble-free sparagmite bands in the conglomerate; they have a 'similar' style, and have already been figured by Holtedahl (1959, Fig 5). However, the pebbles in Holtedahl's diagram are drawn schematically; they are, in fact, flattened parallel to the axial surfaces and not folded about the folds (Fig. 6d).

The conglomerate and the sparagmite in the north form bands which run more or less parallel to the S1 cleavage and seem to be large bedding units in the group. They are lensoid in shape but are not fold cores, because in at least one of these lenses the sense of the cleavage/bedding intersection is the same from one side of the lens to the other.

The L1 lineation in this northern area of the conglomerate still has the same gentle plunge towards the southeast, in spite of the apparent overturning of the S1 cleavage. The F1 fold axes, like those in the south, are curved. They are spread about a great circle which dips to the southwest and corresponds to the average dip of S1 in the northern area (Fig 5a).

Rare F1 structures can be found in the granite beneath the conglomerate. There, F1 is found as thin bands of dark phyllonite with a cleavage which dips parallel to S1 in the conglomerate. In the south, the phyllonites dip eastwards, whereas in the north they dip towards the southwest. The phyllonite cleavage also contains the southeast plunging L1 (Fig 2b). This can be correlated with the conglomerate L1 because in the north the phyllonites contain deformed and lineated brick-red pegmatites. These same deformed pegmatites have also been found in the conglomerate with the pegmatite lineation plunging parallel to the stretching lineation in the conglomerate.

Unfortunately, the phyllonites are not completely exposed, but seem to lie in bands which are only a few metres thick. The granite and gabbro outside these phyllonite bands appear to have largely escaped the F1 Caledonian deformation because the S1 cleavage and the L1 lineation are completely lacking.

The faulted contact between the granite and conglomerate north of locality B (Fig 12) is also thought to be of F1 age. As already noted, much of

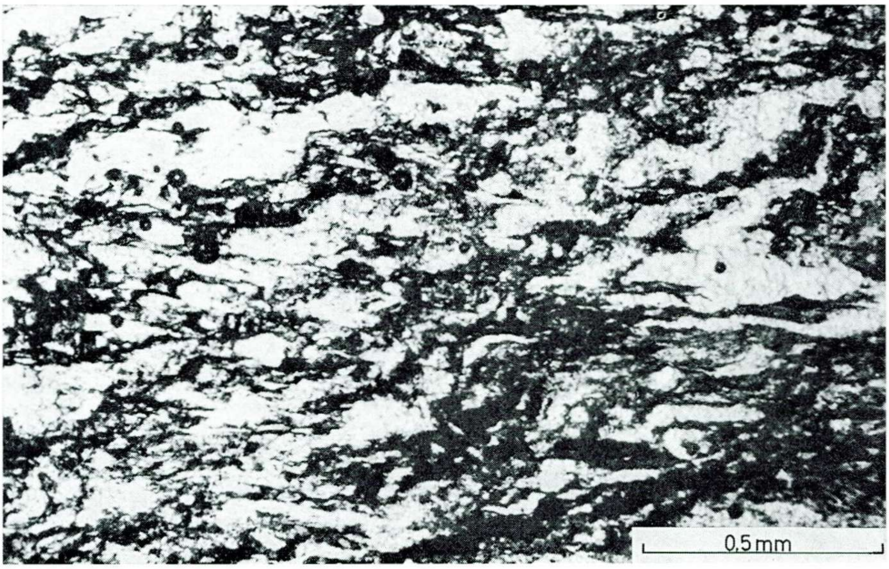


Fig. 7. Photomicrograph of black ultramylonite at the granite/conglomerate boundary. The ultramylonite banding is folded about F1 folds. The small circles are bubbles. Plane polarised light.

this fault is marked by a thin band of flinty ultramylonite. In some localities this mylonite lies at an angle to S1 in the sediments and may have small minor folds within it. One thin-section was cut across the contact fault with the granite on one side of the thin section and the semi-pelitic sediment on the other. The ultramylonite banding was found to be folded about the S1 cleavage of the semi-pelite. Hence the mylonite must be pre-S1 in age.

This thin-section also suggests that the irregular flinty hair-line crushing in the granite is the same age as the ultramylonite. Away from the contact the granite in thin-section shows the crushing as an irregular anastomosing web structure of thin bands of very fine black dusty material. The areas between the web-structure consist of fine-grained quartz, which looks like the recrystallised relics of larger quartz grains. Towards the contact, the amount of dusty material increases and becomes more regular in orientation, finally forming a set of regular bands parallel to the contact. The contact with the semi-pelitic sediment (which is part of the conglomerate succession here) is sharp, and it is obvious that the rusty ultramylonite has formed from the granite alone.

Just before the contact, the mylonite bands are folded into a set of overturned folds whose axial surfaces are parallel to the S1 cleavage in the semi-pelite (Fig. 7). Elsewhere, folds of this age were seen in the mylonite as small 'similar', rootless, intra-folial folds.

The black flinty ultramylonite of the east-west fault just to the south of Grønsennknipa is similar in hand specimen to that just described. Hence the two are thought to be of the same age, although there are no structures in

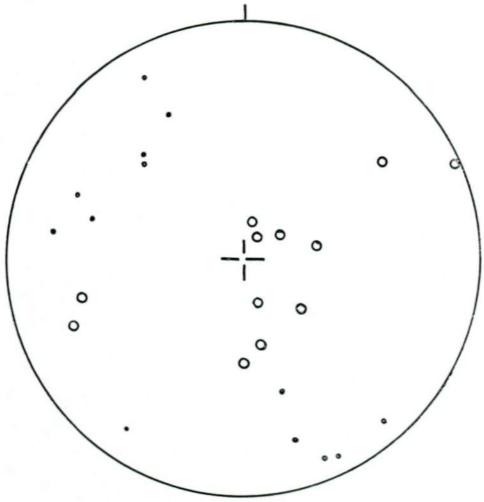


Fig. 8. Stereographic projection of F2 structures in the conglomerate. dots — fold axes: circles — poles to axial surfaces.

the granite on either side of the Grønsennknipa fault by which it may be accurately dated.

Although the mylonite appears to have formed prior to the S1 cleavage of the sediments, both structures are included in the F1 deformation because, the writer believes, they were closely associated in time. Otherwise an additional pre-F1 deformation (FO?) will have to be erected for the mylonite formation.

F2 deformation

F2 major and minor structures can be found in both the conglomerate and the granite. In the conglomerate, minor folds of this age occur only in the north. They are generally quite open folds with flat-lying axial surfaces and they refold the S1 cleavage (and the plane of pebble flattening). The axes have gentle plunges to the northwest or the southeast (Fig. 8). The folds have a concentric style without an axial surface cleavage or a lineation.

A major F2 fold (the Grønsennknipa Neutral Fold) is responsible for the gradual inversion of the S1 cleavage and bedding in the conglomerate as it is traced from south to north. This inversion was originally described by Goldschmidt, (1916b, Fig. 2), The axis of the fold plunges to the southeast (Fig. 5b) like all the minor folds in the granite and some in the conglomerate. The shape of this fold can be found by constructing a profile normal to the fold hinge-line (cf. Wegmann 1928, 1929, Wilson 1967). It has a gently dipping axial surface (Fig. 9) like the minor folds in the conglomerate, and closes sideways. Because it is neither an antiform nor a synform it is called a neutral fold (cf. Bailey & McCallien 1937 and Fleuty 1964, for terminology). The minor F2 folds in the conglomerate are parasitic folds of the Grønsennknipa Neutral Fold. Note that in the profile,

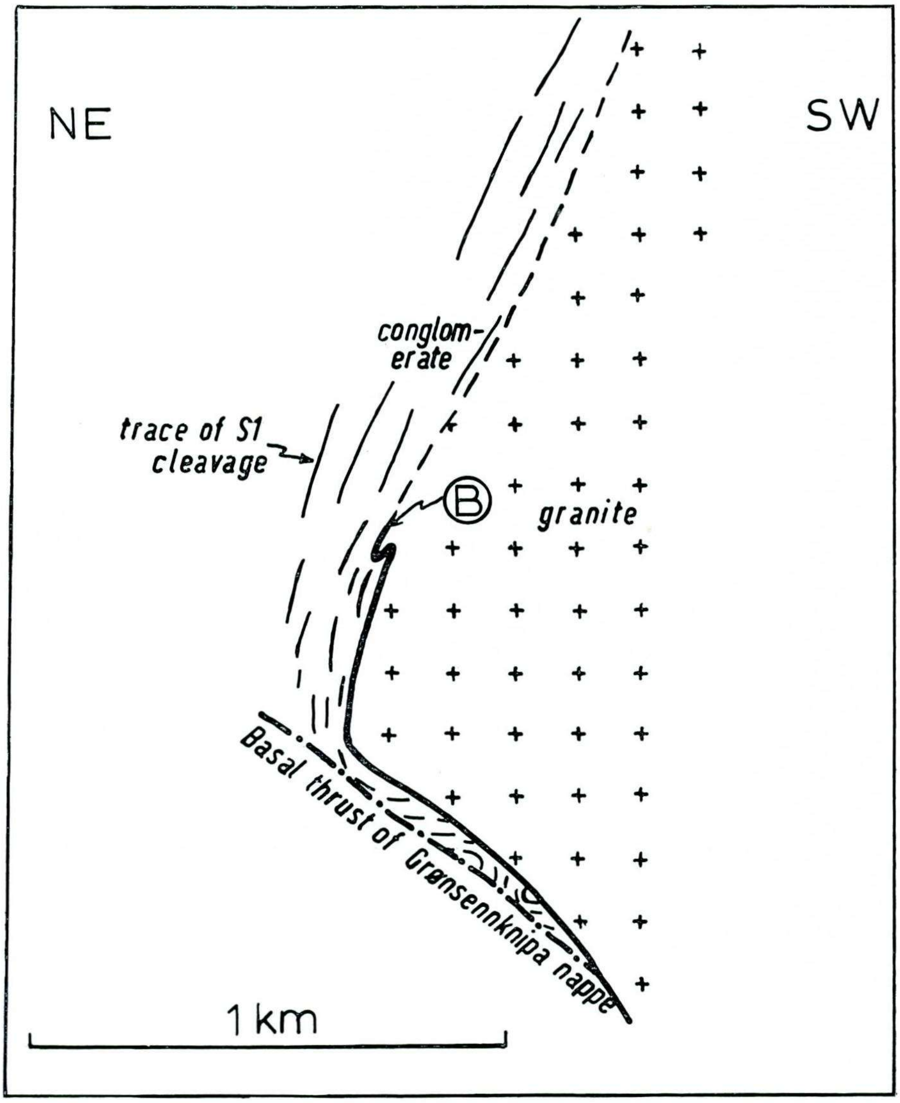


Fig. 9. Tectonic profile of the Grønsennknipa Neutral Fold. Ornamentation the same as in Fig. 12.

the traces of S1 on the lower limb of the fold define Z-parasitic folds with the correct sense of overturning for this limb. The major (F1) folds described by Nickelsen in the sparagmite to the east are earlier than this fold. These large F1 folds must be folded about the Grønsennknipa Neutral Fold, since S1, which corresponds to the axial surface cleavage of these folds, is folded about the neutral fold (Fig. 5b).

Minor folds of this age can also be found in the granite. These folds refold the Precambrian schistosity picked out by the dark minerals in the granite. A stereonet plot of the poles to this schistosity displays a great circle with a southeast plunging axis (Fig 2a). This axis is parallel to the axis of the Grønsennknipa Neutral Fold.

The trace of the axial surface of the large neutral fold has been drawn on the geological map (Fig. 12), separating the areas with easterly dips in the conglomerate from areas with southwesterly dips. The easterly dips represent the upper limb of the Grønsennknipa Fold, and the southwesterly dips the lower limb. The trace of the axial surface cannot be drawn very far into the granite because of the paucity of dip readings in the intrusion. However, it is evident that the Precambrian granite in the west lies in the core of the fold with Eocambrian conglomerate and sparagmite forming an envelope around this core (cf. the profile plane, Fig. 9). Hence, stratigraphically the Grønsennknipa Neutral Fold is an anticline. The ultramylonite fault contact between the granite and the conglomerate is obviously folded about the Grønsennknipa Fold and this confirms the F1 or pre-F1 age of the former.

F3 deformation

The basal thrust of the Grønsennknipa Nappe was produced during this third phase of deformation. The thrust plane underlies the granite and conglomerate and carries them over the phyllite. It is exposed, in the area mapped, to the south of Nøsekampen or to the north of Grønsennknipa. Locally, the thrust may have dips of up to 45° but over the whole area seems to be more or less flat-lying (cf. Goldschmidt 1916 b, Fig. 4, Loeschke & Nickelsen 1968, Fig 10).

The trace of the axial surface of the Grønsennknipa Neutral Folds is truncated at its southeast end by the thrust plane which also cuts across the north and south ends of the conglomerate outcrops (Fig. 12).

In the north the thrust is structurally transgressive on a minor scale. In two or three exposures it was found to truncate F2 minor folds in the conglomerate. The thrust also apparently cuts across F2 parasitic folds in the fold profile (Fig. 9). Hence the basal thrust must be later than the F2 movements.

The basal thrust also truncates the main cleavage in the phyllite beneath the nappe. This discontinuity was originally described by Reusch (1901) and later by Holtedahl (1959). The cleavage in the phyllite trends east-west and is almost vertical. In many exposures in the north the thrust can be seen to truncate the phyllite cleavage. Sometimes the cleavage in the phyllite bends over northward into parallelism with the thrust plane. This bending could have been brought about by either flattening under the weight of the overlying nappe, or by a drag effect during the movement of the nappe. If the bending has been produced by thrust-drag, the overturning suggests a general south to north movement.

In the north, just above the thrust plane, the sparagmite is often represented by a phyllitic semi-pelite in which the main cleavage is an S3 (3) crenulation cleavage lying parallel to the basal thrust contact. This cleavage has probably been formed from an earlier S1 cleavage by the basal thrust movements. A cleavage of this type was not seen elsewhere in the area and was probably only formed in the vicinity of the basal thrust.

The F1 fault between the granite and the conglomerate appears to have been rejuvenated during this phase. A relationship where the mylonite along the fault has been folded about the S1 cleavage has already been described. However, just to the north of locality B, there is a fault contact exposed between the granite and the conglomerate, which is later than the S1 cleavage in the conglomerate. This locality has already been described by Holtedahl (1959, Fig. 8). The granite cuts across and truncates some of the flattened pebbbles in the conglomerate. Along the contact in a few places there are a few mm of soft clayey gouge. Also, in the profile plane of the Grønsennknipa fold (Fig. 9), the F1 fault plane seems to truncate F2 parasitic folds on the lower limb. Hence the present fault would appear to be a composite structure which includes elements of F1 and F3 movements. This composite fault dips more steeply than the basal thrust plane of the Grønsennknipa Nappe and is probably truncated at depth by the basal thrust.

The thrust is structurally transgressive on the major scale as it also truncates parts of the Grønsennknipa fold. In the north of the area, the thrust lies in the lower limb of the fold (cf. Fig. 11d). In the south it lies in the upper limb of the fold. Passing from one end of the nappe to the other, the thrust gradually cuts across the fold from one limb to the other. This suggests that the thrusting of the nappe has been quite considerable. A large part of the major F2 fold has been cut out by this thrusting.

CALEDONIAN DEFORMATION OF THE PHYLLITES IN THE QUARTZ SANDSTONE NAPPE

Two periods of deformation are recognised in the small area of phyllite mapped by the writer. They will only be described briefly, and correlation of the phyllite phases of deformation with those of the Grønsennknipa Nappe will be discussed later.

F1 deformation

The earliest deformation in the phyllite formed the main cleavage (S1), which has an easterly trend with almost vertical dips. Locally, cleavage/bedding intersections and early 'similar'-type folds are visible. The folded beds are defined by more sandy layers and S1 is an axial surface cleavage to these folds (Fig. 6b and c). The fold axes and cleavage/bedding intersections have a widespread trend but generally have southerly plunges (Fig. 10b). L1 lineations are rare but plunge towards the southeast (Fig. 10b).

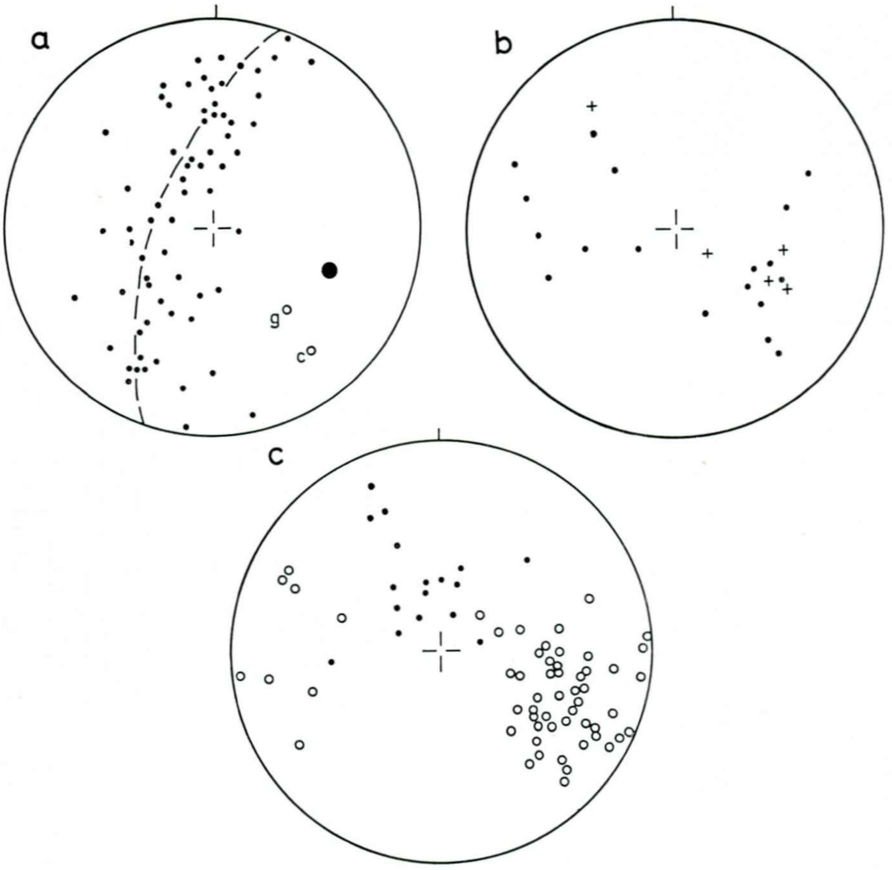


Fig. 10. Stereographic projections of tectonic structures in the phyllite. a. dots — poles to S1: dashed line — F2 girdle: large dot — F2 girdle axis: g — F2 girdle axis in the granite: c — F2 girdle axis in the conglomerate. b. dots — F1 fold axes and cleavage/bedding intersections: crosses — F1 lineations. c. circles — F2 fold axes and crinkle lineation: dots — poles to S2 axial surfaces and cleavages.

F2 deformation

The F2 deformation is defined by crenulation folds and lineations, and because they refold S1 they are obviously later. The fold axes and lineations have a gentle east-southeasterly plunge and the axial surfaces of the folds are gently dipping (Fig. 10c). The folds have largely Z-shapes, and are overturned towards the southwest. Poles to S1 define a girdle with an east-southeast plunging axis (Fig. 10a) and this is the F2 fold axial direction. In general the style of the F2 folds and crenulations suggests that they are related to kink bands and conjugate folds. Locally some incipient S2 crenulation cleavage is formed.

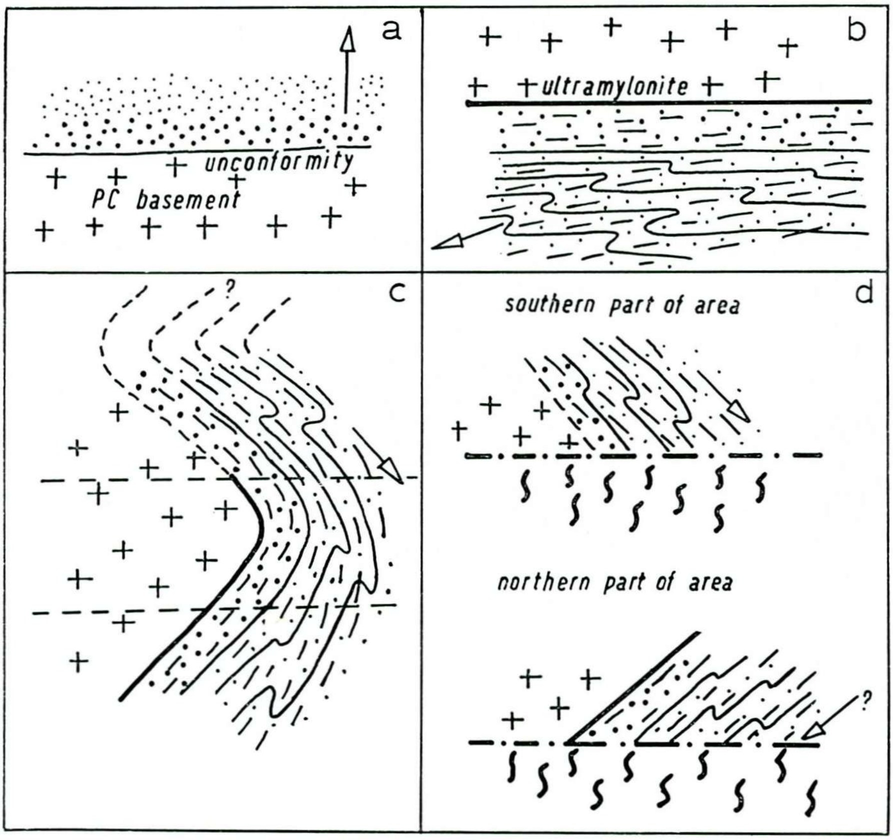


Fig. 11. Geological history of the Grønsennknipa Nappe. Ornamentation the same as in Fig 12. The arrows indicate the facing directions of the beds and the folds. a. pre-F1. b. F1 deformation. c. F2 folding. d. F3 thrusting over the phyllites. The folds drawn in the sparagmite represent the folds described by Loeschke & Nickelsen (1968). All sections are east-west and are viewed from the south.

Geological history

The geological history is illustrated by a sequence of east-west sections through the area at different times (Fig. 11). This sequence was constructed by going backwards in time gradually unravelling the effects of later deformations, although the farther back in geological time, the more uncertain are the deductions. The history, however, will be described in the reverse sequence of oldest to youngest.

Several phases of deformation have been described in the granite, conglomerate, sparagmite, and phyllite and a correlation of these phases is suggested in Table I. F1 in the conglomerate and granite has already been shown to be of the same age on the basis of a lineated pegmatite which is common to both rock-types. However, only a tentative correlation can be made between the F1 of the Grønsennknipa Nappe and the F1 in the phyllites of the Quartz Sandstone Nappe. The writer is presently engaged

Table I. Suggested correlation of deformation phases

	Granite of the Grønsennknipa Nappe	Conglomerate and sparagmite of the Grønsennknipa Nappe	Phyllite of the Quartz Sandstone Nappe
Precambrian	Early hornblende schistosity		
Caledonian	F1 phyllonite ultramylonite formation along unconformity	F1 folding and main cleavage Pebble deformation	F1 folding and main cleavage
	F2 minor folding	F2 Grønsennknipa Neutral Fold and minor folding	F2 crenulation folds
	F3 rejuvenation of the F1 fault between the granite and the sediments	F3 late thrusting Local S3 crenulation cleavage formed at thrust plane	Bending of early cleavage into parallelism with late thrust

in mapping the phyllites and sparagmites in the Beito window (cf. Fig. 1); here the two rock groups are in more intimate association and with further work it may be possible to date the relationship between the sparagmite F1 and the phyllite F1 more accurately. The F2 structures in the granite, conglomerate, and phyllite are correlated because they all have the same southeast trend.

The geological history of the rocks of the Grønsennknipa Nappe began with the disposition of the conglomerate and sparagmite on the Jotun granite (Fig. 11a), which had already undergone a phase of Precambrian deformation. The unconformity at the base of the conglomerate has been largely effaced by later deformation but can still be seen at locality B, Fig. 12. The conglomerate and sparagmite would obviously 'face' or 'young' upwards (Fig. 11a). As the conglomerate pebbles are largely quartzite, they could not have been derived from the local granite basement. Loeschke & Nickelsen (1968) have suggested that a probable source for the quartzite pebbles of the Valdres conglomerates (including the Grønsennknipa conglomerate) was from the Precambrian Telemark formation to the south.

F1 is the earliest Caledonian deformation and was responsible for the formation of the large recumbent folds two km to the east described by Loeschke & Nickelsen (1968). It is not certain whether the granite was above or beneath the conglomerate during and after F1. If the Grønsennknipa Nappe is an erosional outlier of the Upper Jotun Nappe (cf. Fig. 1), then the granite was probably above the sparagmite as elsewhere in the Upper Jotun Nappe (e.g. Bygdin). However, if the Grønsennknipa Nappe is an erosional outlier of the Valdres Nappes (as suggested by Loeschke &

Nickelsen 1968, p. 345), the granite was probably underneath the sparagmite at as Røsjøkollan (cf. Fig 1).

In addition to the folding, F1 produced a penetrative deformation in the conglomerate and the sparagmite. The resultant S1 cleavage is more or less parallel to the granite/conglomerate contact and the axial surfaces of the large F1 folds. If the granite overlaid the conglomerate, these large folds would have to face towards the west (cf. Fig. 11b). However, if the rocks were the other way up, the folds would have to face east.

The F1 deformation was not penetrative in the granite. The deformation was confined to local phyllonite bands only a few metres thick. Outside these bands the granite remained largely undeformed. This suggests that the forces which caused F1 were not transmitted through the granite basement and that the deformation was largely the result of gravity tectonics. The boundary fault between the granite and the Eocambrian sediments probably arose because the folding and flattening which were taking place in the sediments did not extend into the granite: the fault formed along the strain discontinuity or décollement plane which must have appeared between the two rock groups.

The conglomerate pebbles were deformed in S1 at this time and a correlation is suggested between the pebble deformation here and that at Bygdin (Hossack 1968a). The conglomerate at Bygdin (which is also part of the Valdres Sparagmite) was deformed by the emplacement of the Upper Jotun Nappe over the conglomerate. This emplacement produced phyllonites in the nappe, which were shown to have formed prior to the Bygdin S1 cleavage, as in places they were folded about this cleavage (Hossack 1968a). The mylonites at Grønsennknipa have the same relationship. The writer has already suggested that the phyllonites at Bygdin were formed by the emplacement of the Upper Jotun Nappe and that the S1 cleavage was produced in a static phase of flattening under the weight of the nappe after the emplacement (an idea originally suggested by Flinn 1961, for the deformation in the Upper Jotun Nappe) (Hossack 1968b). The writer now suggests that the same relations may be true for Grønsennknipa (even though it may be part of a different nappe) and that the F1 Caledonian structures at Grønsennknipa are the result of an early nappe emplacement.

F2 caused large-scale folding of the Grønsennknipa rocks to form the Grønsennknipa Neutral Fold (or Anticline). The complete shape of this fold cannot be constructed as the fold is cut off down-plunge by the basal thrust and is eroded away up-plunge. The fold has been drown in the reconstruction (Fig. 11) looking up-plunge.

If the granite basement originally lay over the conglomerate at the end of the F1 movements, the Grønsennknipa Fold would have to have an S-shape looking up-plunge (as drawn in Fig. 11c). If, however, the rocks lay the other way up, the fold would have to have a Z-shape. The choice depends on whether the Grønsennknipa Nappe is correlated with the Upper Jotun Nappe or with one of the Valdres Nappes (cf. Fig. 1). A correlation with the Upper Jotun Nappe would suggest that the granite originally lay above the conglomerate (as at Bygdin) and a correlation with the Valdres Nappe would imply that the granite probably lay beneath the conglomerate (as at Røsjøkollan). On the large-scale geological map of Norway (Holtedahl & Dons 1960) the Grønsennknipa Nappe looks as if it could be an erosional klippe of either. Hence the problem is as yet unsolved.

The F2 fold must have refolded the F1 folds, as discussed earlier in the paper. The F1 folds on the upper limb of the F2 neutral fold face downwards towards the east, whereas the F1 folds on the lower limb probably face downwards towards the west.

During F3 the Grønsennknipa Nappe was emplaced over the phyllites of the Quartz Sandstone Nappe to its present position. The basal thrust of the nappe is structurally transgressive in relation to the Grønsennknipa Neutral Fold. In the north it lies within the lower limb and in the south in the upper limb of the fold. These two positions are indicated in the cross-section through the fold by dashed lines (Fig. 11c). Going from north to south the thrust must gradually transgress from the lower limb to the upper limb.

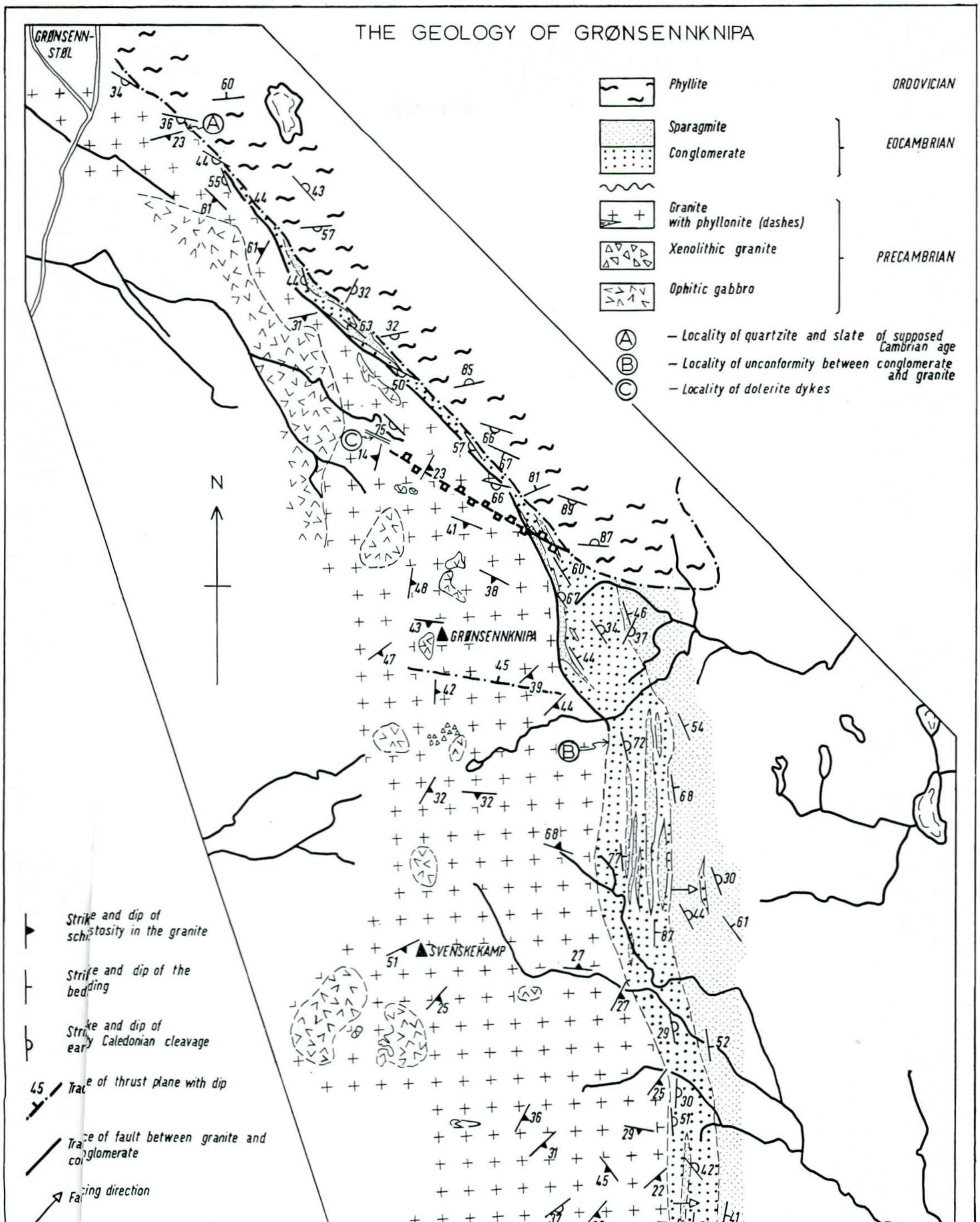
The late thrusting must have been quite considerable to have cut out so much of the earlier F2 major fold. In the southern part of the Grønsennknipa Nappe, the core and the lower limb of the F2 fold have been cut out by the F3 thrusting (Fig. 11d; upper diagram). Here the F1 folds face downwards towards the east and the structure is the same as that already reported by Loeschke & Nickelsen (1968, Fig. 10). In the north the F1 folds are inferred to face downwards towards the west although this could not be proved in the field (Fig 11d; lower diagram).

The writer believes that this late thrusting is quite widespread and is important. Late thrusting was reported at Bygdin (Hossack 1968a) but there it is only of minor importance. However, the degree of late thrusting seems to increase towards the south. Cross-sections constructed by Nickelsen (1967, Fig. 11) through Mellane show that the basal thrust plane of the Mellane Nappe cuts across about a dozen F1 folds going from one limb to the next and certainly looks as if it is later than the folding. Hence the thrusting described by Nickelsen (1967) may be of F3 age and not of F1.

A truncation of a phyllite cleavage by the Upper Jotun Nappe is figured by Holtedahl (1960, Fig. 56) at Finse, (cf. Fig 1) and this is just like the truncation of the phyllite cleavage at Grønsennknipa. This suggests that the same structural relations may stretch for at least 100 km to the southwest.

The structural relations between the Grønsennknipa Nappe and the phyllites of the Quartz Sandstone Nappe during the earlier phases of the Caledonian deformation are largely unknown yet, but they seem to share the same phases of deformation. One interesting feature is that the F2 fold axes in both the conglomerate and the granite lie to the southeast of the F2

Fig. 12. Geological map of part of Grønsennknipa.


THE GEOLOGY OF GRØNSENNKNIPA
Phyllite
ORDOVICIAN
Sparagmite
Conglomerate
EOCAMBRIAN
Granite with phyllonite (dashes)
Xenolithic granite
Ophitic gabbro
PRECAMBRIAN
A – Locality of quartzite and slate of supposed Cambrian age
B – Locality of unconformity between conglomerate and granite
C – Locality of dolerite dykes
GRØNSENN-STØL
GRØNSENNKNIPA
SVENSKEKAMP
NØSEKAMP
REINSENVANN
Thrust boundary after Nickelsen
N
Strike and dip of schistosity in the granite
Strike and dip of the bedding
Strike and dip of early Caledonian cleavage
Trace of thrust plane with dip
Trace of fault between granite and conglomerate
Facing direction
Geological boundary - dashed where inferred
Axial trace of Grønsennknipa neutral fold
0 km 1
J.R. HOSSACK

fold axes in the phyllite. There are two possible explanations for this. Either the difference in trend is original and caused, say, by the difference in competence of the rock groups, or the axes were originally parallel and the difference has been brought about by a body rotation during the post-F2 thrusting. If the Grønsennknipa Nappe has rotated during its late emplacement, it would appear to have rotated 25°–30° in a clockwise direction. Also, this late movement may possibly have taken place in a south to north direction (i.e., from the margin towards the centre of the mountain belt!) because the cleavage in the phyllite just beneath the nappe bends over towards the north.

Conclusions

The Grønsennknipa area consists of a thrust klippe, the rocks of which have undergone a complicated structural history. The emplacement of this klippe over the phyllites of the Quartz Sandstone Nappe was the result of late thrusting produced during the last tectonic phase recognised in the area. This contrasts with the age of the thrusting reported for the Upper Jotun Nappe at Bygdin (Hossack 1968a) where the main thrusting occurred during the earliest Caledonian tectonic movements.

During the Eocambrian, the conglomerate and sparagmite of the nappe were deposited on top of Precambrian granite and gabbro which had already undergone at least one Precambrian deformation. With the first Caledonian deformation, the conglomerate and sparagmite were folded into large folds and deformed internally to produce the pebble deformation and the main cleavage of the sediments. The deformation of the Precambrian basement during this F1 phase appears to have been slight and restricted to the formation of a few phyllonite bands and to the formation of a fault with ultramylonite along the plane of the unconformity. This deformation may be the same age as the F1 deformation at Bygdin (Hossack 1968a), and the result of early nappe emplacement, as at Bygdin.

During the later F2 phase, the Precambrian and Eocambrian were then refolded into the major Grønsennknipa Neutral Fold or Anticline, but the complete shape of this fold is unknown and depends on whether the Grønsennknipa rocks are correlated with the Upper Jotun Nappe or the Valdres Nappes.

With the F3 movements, the Grønsennknipa Nappe was emplaced into its present position. This thrusting cut out quite a large part of the earlier Grønsennknipa fold and implies a reasonable amount of displacement to allow this to happen. The tectonic position prior to this is not known, but it may have lain farther towards the south. However, the phyllites of the nappe beneath the Grønsennknipa Nappe have apparently undergone the same sequence of deformation, and hence it seems likely that both nappes were in contact with one another prior to the late thrusting. The thrusting may have caused the Grønsennknipa Nappe to have undergone a clockwise rotation of 25°—30°.

Later erosion separated the Grønsennknipa Nappe from its roots to form a klippe and caused the uncertainty of its position in the tectonic pile of Caledonian Nappes.

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