

SVERIGES GEOLOGISKA UNDERSÖKNING

SERIE C NR 739 AVHANDLINGAR OCH UPPSATSER ÅRSBOK 72 NR 1

KENNERT RÖSHOFF

STRUCTURES OF THE
TÄNNÄS AUGEN GNEISS NAPPE
AND ITS RELATION TO
UNDER- AND OVERLYING UNITS IN THE
CENTRAL SCANDINAVIAN CALEDONIDES



STOCKHOLM 1978

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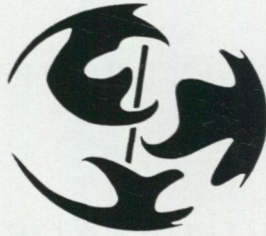
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ISBN 91-7158-136-7

INTERNATIONAL GEODYNAMICS PROJECT



SWEDISH GEODYNAMICS PROJECT —
CALEDONIAN RESEARCH PROJECT

Textkartorna godkända ur sekretessynpunkt för spridning.
Statens lantmäteriverk 1978-02-27

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Schmidts Boktryckeri AB
Helsingborg 1978

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ABSTRACT

Kennert Röshoff: Structures of the Tännäs augen gneiss Nappe and its relation to under- and overlying units in the central Scandinavian Caledonides. Manuscript received 1977-04-05.

The major and minor structures of the Tännäs augen gneiss Nappe and its relation to the overlying Särv Nappe and underlying Hede and Veman Nappes are discussed from the Central Scandinavian Caledonides. The Hede Nappe comprises late Precambrian feldspathic sandstones, the Långå Group, which is correlated with the Risbäck Group, and a Precambrian basement. The Veman Nappe, dominated by the gneissic granites of the "horst region" near the Caledonian front (Strömberg 1955, Asklund 1960), is regarded as a separate tectonic sheet, which overlies the Hede and Vemdal Nappes and is continuously traced into the base of the Fuda Nappe. The Veman Nappe can be followed westwards to east of Medskogen. The Särv Nappe is subdivided into three tectonic units. The name of the Tännäs complex (Strömberg 1961), which forms the lowest unit of the Särv Nappe, is suggested to be changed to the Svansjön basement unit. The Ulvberg complex (Strömberg 1961) is included in the Middle metasedimentary unit of the Särv Nappe.

The Tännäs augen gneiss Nappe is divided into three tectonic units namely the Lower and Upper augen gneiss units and a Middle metasedimentary unit. The nappe is traced as one continuous sheet from Hede in the east to lake Feragen in the west. Further southwestwards the augen gneisses occur as separate lenses between the Trondheim Nappe and the late Precambrian feldspathic sandstones. The geometry of the Tännäs augen gneiss Nappe shows that the nappe thins both east- and westwards.

A regional foliation (S_2) within the Tännäs augen gneiss Nappe and the different metasedimentary units developed during the main Caledonian thrusting. A strong stretching lineation (I_2) is associated with that event. A Precambrian tectonic foliation is found within the Svansjön basement unit. This foliation is intersected by the basic dykes of Ottfjäll type. A Precambrian mylonitic contact relationship is probable between the Svansjön basement unit and the overlying metasedimentary succession of the Särv Nappe. The regional Caledonian foliation (S_2) was folded during a third phase into re-

cumbent tight to close folds with axial orientations subparallel to the F_2 linear structures in WNW—ESE. A fourth phase with steep axial planes in N—S has been locally observed.

The major geometry of the different tectonic units demonstrates a passive autochthonous basement. The Hede Nappe may be allochthonous.

INTRODUCTION

This paper treats the major and minor structures and tectonic relationships within the late Precambrian feldspathic sandstones (Hede Nappe), the Tännäs augen gneiss Nappe and the lower part of the Särvi Nappe (Strömberg 1955) in the southern part of the Geotraverse area (Gee 1975) in the Central Scandinavian Caledonides. The geometry and the western extension of the Tännäs augen gneiss Nappe are also discussed.

The subdivision of the tectonic units is shown in Table 1.

Autochthonous Cambro-Ordovician sediments rest on the Precambrian basement at the eastern front (Fig. 1). These sediments are overthrust by the Vemdalen Nappe, which mainly consists of quartzites, the Vemdalen quartzite. The tectonic position of the nappe has been discussed by Asklund (1933), Strömberg (1955) and Stålhös (1956).

The Hede Nappe comprises late Precambrian feldspathic sandstones (sparagmites) and Precambrian basement rocks (Strömberg 1955). In the Hede area Stålhös (1956) also recorded shale, limestone and greywacke conglomerate. The sediments of the Hede Nappe are correlated with the Risbäck Group (Strand and Kulling 1972) further to the north. The nappe was thought to be parautochthonous (Stålhös 1958). Evidences are here presented for its allochthonous character.

Several Precambrian granitic bodies are included in the feldspathic sandstones in the Hede area. Primary sedimentary contacts of feldspathic sandstones on the granites are described (Stålhös 1956), indicating a primary sedimentary relationship.

The gneissic granites located between the Hede and Flåsjön areas (Fig. 1) were thought (Strömberg 1955, Stålhös 1956, Asklund 1960) to represent a parautochthonous "horst region", on which the feldspathic sandstones also had been deposited. The gneissic granites were interpreted to be separated from the Tännäs augen gneiss Nappe by a NNW—SSE striking fault northwest of Hede. This interpretation, however, leads to fundamental contradictions in the structural geometry and tectonic condition of the different tectonic units (Fig. 1). In this paper the gneissic granites are treated as a separate tectonic unit named the Veman Nappe.

The Tännäs augen gneiss Nappe is similar with the Mylonite Nappe as described by Strömberg (1961). Gee (1975) associated this nappe with the Offer-

TABLE 1. Summary of the tectonic relationships in the areas investigated. (Thicknesses are not to scale.)

Major units	Diagram	Minor units with dominating rock types
Trondheim Nappe		Various metamorphic rocks
Helags Nappe (Seve)		Various metamorphic rocks
Särv Nappe		Upper metasedimentary unit (Mainly feldspathic sandstone) Middle metasedimentary unit with local basement rocks Lower Svansjön basement unit
Tännäs augen gneiss Nappe		Upper augen gneiss unit Middle metasedimentary unit (Mainly fels pathic sandstone and dolomitic marble) Lower augen gneiss unit
Veman Nappe		Various Precambrian basement rocks
Hede Nappe		Långå Group (Mainly feld- spathic sandstone) Various Precambrian basement rocks
Vemdäl Nappe		Vemdäl quartzite
Autochthon		Cambro-Ordovician sediments Precambrian granites and porphyries

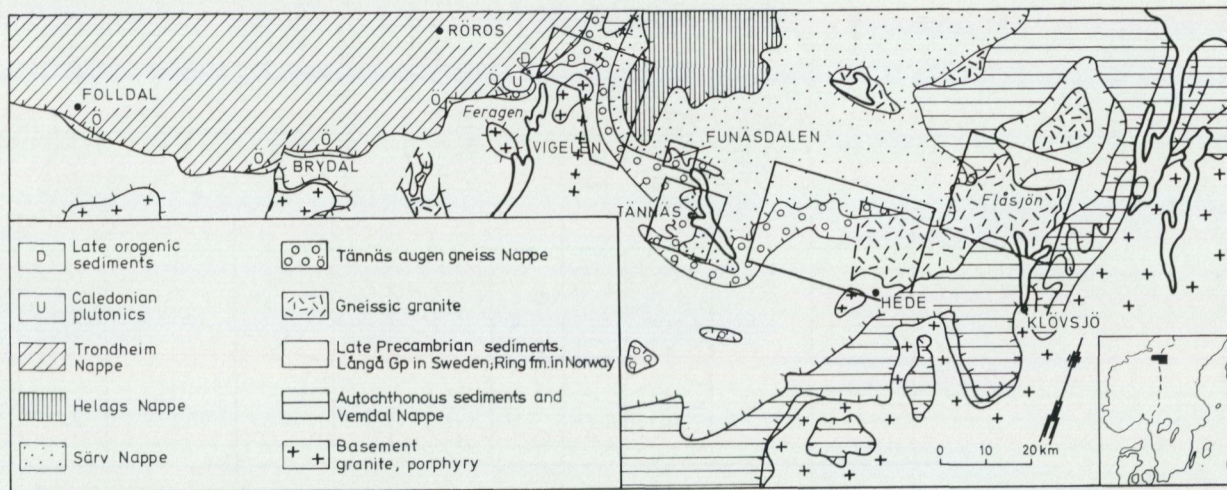


Fig. 1. Regional map of the southeastern part of the Geotravers area in the Central Scandinavian Caledonides. The areas investigated are specially marked. (The map is based on the geological maps of Sweden and Norway at a scale of 1:1 milj., with modifications by Gee 1975.)

dal Nappe. However, Törnebohm (1896), Högbom (1920) and Strömberg (1961) regarded the augen gneisses as a separate unit. It is evident that the Tännäs augen gneiss Nappe comprises three units namely two augen gneiss units, which locally are separated by a sedimentary succession. Minor portions of Precambrian foliated intermediate and acid plutonics and a few basic intrusives (Strömberg 1955, 1961) are also included. The nappe overlies the late Precambrian feldspathic sandstones from Hede and westwards. In Norway the augen gneisses occur at two tectonic levels namely as separating unit between the Trondheim Nappe and the late Precambrian sediments or as bodies within the latter unit (Holmsen and Holmsen 1950, Holmsen and Oftedahl 1956, Strand 1951, Rui 1972, Nystuen 1975, Point 1975).

The Särvi Nappe (Strömberg 1955, 1961) rests on the gneissic granites near the eastern front and on the Tännäs augen gneiss Nappe from Hede to west of the political border between Norway and Sweden, where the Särvi Nappe thins out beneath the Trondheim Nappe. Strömberg (1961) subdivided the Särvi Nappe into a basal complex mainly consisting of white quartzite and dolomitic marble (the Ulvberg complex), basal fragmental rocks of the Grönstack complex and an upper part, the Särvi Nappe proper, dominated by feldspathic sandstones intruded by a basic dyke swarm, the Ottfjäll dolerites (Holmquist 1894). The sedimentary rocks are referred to as the Särvi Group (Strömberg 1969). Strömberg did not recognize any basic dykes in the Ulvberg complex, except one locality (Strömberg 1961, p. 35). The sedimentary rocks of the Särvi Nappe were thought to be deposited on the basic basement of the Tännäs complex, which he compared with the Jotun-Bergen suit (Gjeldsvik 1947). The Tännäs complex was described by Strömberg (1961) at Tännäsberget north of Tännäs. He commented that Törnebohm (1896) had here only recognized Ottfjäll dolerite dykes. In this paper it is proposed that the name Tännäs complex is changed to Svansjön basement unit as

- 1, the Tännäs complex risks confusion with the Tännäs augen gneiss Nappe,
- 2, the plutonic rocks show greater chemical and mineralogical variations in the Svansjön area than at Tännäs,
- 2, the relationships between the plutonic rocks and the Ottfjäll dolerite dykes are well exposed in the Svansjön area,
- 4, the area of the plutonic rocks in the Tännäs area is smaller than described by Strömberg (1961).

The Ulvberg complex is here included in the Middle metasedimentary unit of the Särvi Nappe (Table 1).

The western extension of the Tännäs augen gneiss Nappe into Norway is controversial depending on the divergence in the interpretations of the genesis

of the augen gneisses in Sweden and Norway. Since the work of Rosenqvist (1944), in the Oppdal area, a metasomatic development from late Precambrian sediments has been favoured (Holmsen and Holmsen 1950, Strand 1951, Rui 1972). However, Nystuen (1975) and Point (1975) have described the augen gneisses along the base of the Trondheim Nappe and, also the Sålekinna complex (Törnebohm 1896), as deformed basement rocks, which probably can be correlated with the Tännäs augen gneisses. Moreover, Törnebohm (1896) regarded the augen gneisses in Norway as deformed Precambrian porphyritic granites appearing along the base of his "nappe of the first order", which he rooted at Jettenfjell south of Dombås.

The regional foliation within the different tectonic units was thought by Strömberg (1961) to be Caledonian in age. However, older main foliations are observed in the basement rocks of the Svansjön suite. Strömberg (1961) also presented some petrofabric analyses, but no kinematic syntheses have been made on the different units.

The structural analyses carried out in this investigation are mainly based on work on the metasedimentary units at the base of the Särvi Nappe. Four phases are distinguished of which the second phase formed during the main Caledonian thrusting.

Several models have been suggested to represent the main structures and geometrical relationships at the eastern front of the Caledonides and further westwards (Törnebohm 1896, Strömberg 1974, Gee 1975, Stephansson 1976).

The two outermost different models are presented by Strömberg and Gee. Strömberg favours an active basement both at the front and towards the central part of the Caledonides. The Vemdalen Nappe is rooted below the easternmost basement slice. The allochthonous nappes, with the Offerdal Nappe as the lowermost unit, override the basement slices. The proposed model by Gee shows a classical décollement geometry of the eastern parautochthonous nappes and a passive basement.

The data presented in this paper have resulted in a model sketched in Fig. 2, which principally agrees with the model out-lined by Gee (1975).

TECTONIC STRUCTURES

THE VEMAN AND HEDE NAPPES

The gneissic granites located between Hede and Flåsjön (Fig. 1) consist of a variety of plutonic rocks. The main part comprises granodiorite with K-feldspar megacrysts, which has been correlated with the Rätan granites (Strömberg 1961), and a greyish medium-grained granite (Figs. 3 and 4). Even-grained granites cover the main part of the large areas north of Hede. Minor portions

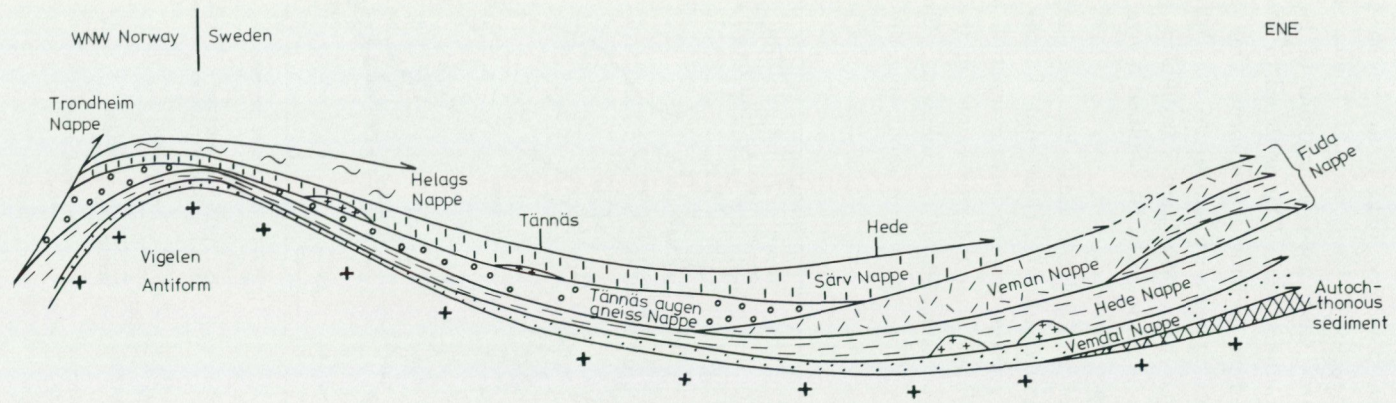


Fig. 2. Generalised presentation of the structural geometrical relationships between the different tectonic units. Not to scale.

are occupied by greyish porphyry, reddish to greyish granites, light gneisses, augen gneisses and a few small basic plutonic bodies. The amount of augen gneisses increases towards west. Two generations of basic dykes are younger than the intermediate plutonic rocks. One is found to be older as the dykes are brecciated by the K-feldspar bearing granodiorite. One of the younger generations has a petrographic appearance similar to the Åsby dolerite (Krokström 1936) and therefore has been correlated (Strömberg 1961) with that rock. Petrographically similar granitic rocks, as outlined above, also occur as isolated bodies in the Hede Nappe (Fig. 3).

Detailed investigations in the Hede area (Fig. 3) along the contact zone between the gneissic granites and the Hede and Tännäs augen gneiss Nappes have revealed that the gneissic granites form a separate tectonic unit. The unit is named the Veman Nappe after the type section in the river Sör-Veman east of Hede. This conclusion is based on the following. There are neither petrological nor structural evidence of a fault separating the gneissic granites from

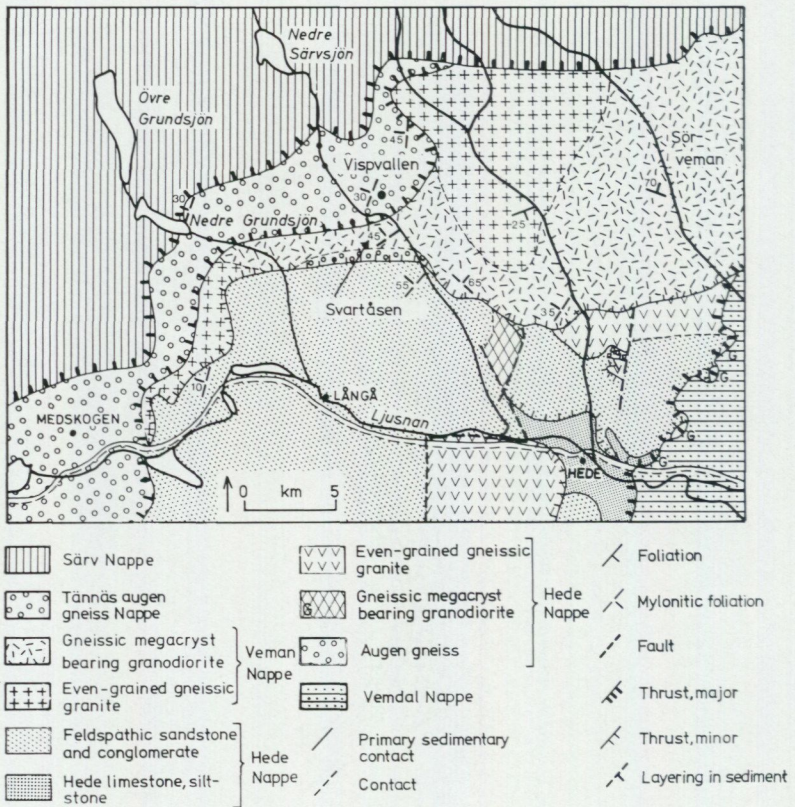


Fig. 3. Geological map of the Hede area.

the Tännäs augen gneisses as suggested by Strömberg (1955) and Stålhös (1956). The gneissic granites can be traced across the "fault zone" without any petrological changes. The penetrative deformation, however, increases both upwards and westwards. The Veman Nappe can therefore be followed westwards as far as east of Medskogen, where the unit thins out below the Tännäs augen gneisses.

A thrust separates the Veman Nappe from the overlying Tännäs augen gneiss Nappe. East of Lake Nedre Särvsjön the thrust comes closer to the upper thrust contact of the Tännäs augen gneiss Nappe, which further east probably thins out completely.

The gneissic granites of the Veman Nappe are strongly foliated with porphyroclastic textures along its lower contact. As similar plutonic rocks are found both in the Veman and Hede Nappes difficulties may arise to separate the two nappes, especially where they are in close contact with plutonic rocks on both sides. This is illustrated northwest of Hede (Fig. 3). The earlier described fault (Strömberg 1955, Stålhös 1956), shown on Fig. 1, is in this paper interpreted to form one side of a local fault. A piece of the basement, belonging to the Hede Nappe, is surrounded by down-faulted feldspathic sandstones. The basement piece is in close contact with the plutonic rocks of the Veman Nappe, but a thin slice of feldspathic sandstone is squeezed between the two blocks. The foliation in the Veman Nappe clearly indicates that the gneissic granites overthrust both the feldspathic sandstone and the basement piece. The foliation in the latter is found to be discordant to the foliation in the Veman Nappe, c. 200 m south of the thrust contact. Similar tectonic relationships are also observed elsewhere along the contact zone and north-east of Hede.

As a consequence, the primary contacts of feldspathic sandstone and conglomerate on basement granites, described by Stålhös (1956), only indicate a primary basement-cover relationship between the Långå Group and its basement, and not between the basement rocks of the Veman Nappe and the Långå Group.

The contact zone between the Veman Nappe and the overlying Särv Nappe is poorly exposed between lake Nedre Särvsjön and the Flåsjön area (Figs. 3 and 4). A very good section is exposed at Gavelåsen (Fig. 4). The total contact zone is here approximately 75 m thick. It consists, from below, of phyllonitic greyish granite, which locally has an augen gneiss structure, greenish wavy phyllonite with quartz lenses, banded mylonite with greenish porphyroclastic bands and an upper part of wellbanded mylonitic Särv sediments.

Within the lake Flåsjön area the gneissic granites are observed above the Vemdal Nappe in several sections. The contact west of lake Fotingen is a 20 m thick phyllonite-mylonite unit dipping towards northeast. Both the quartzite and the overlying granite are strongly cataclastically deformed. A similar tectonic relationship can be traced northeast of lake Fotingen.

However, in the eastern part of the Flåsjön area the earlier described primary sedimentary contact (Asklund in Magnusson et al 1960) between red feldspathic sandstone and a greyish granite is apparently of tectonic origin. The contact zone is approximately 20 m thick, consisting of a phyllonitic granite overlain by a red mylonitic sandstone, dipping c. 30° NE.

Two internal thrusts have been developed in the Veman Nappe. The larger of these begins at Börtnan and can be followed along the lake system towards southeast. The rocks within the tectonic zone have a well developed cataclastic foliation with moderate dips towards southwest or west. Ultramylonitic bands are locally observed.

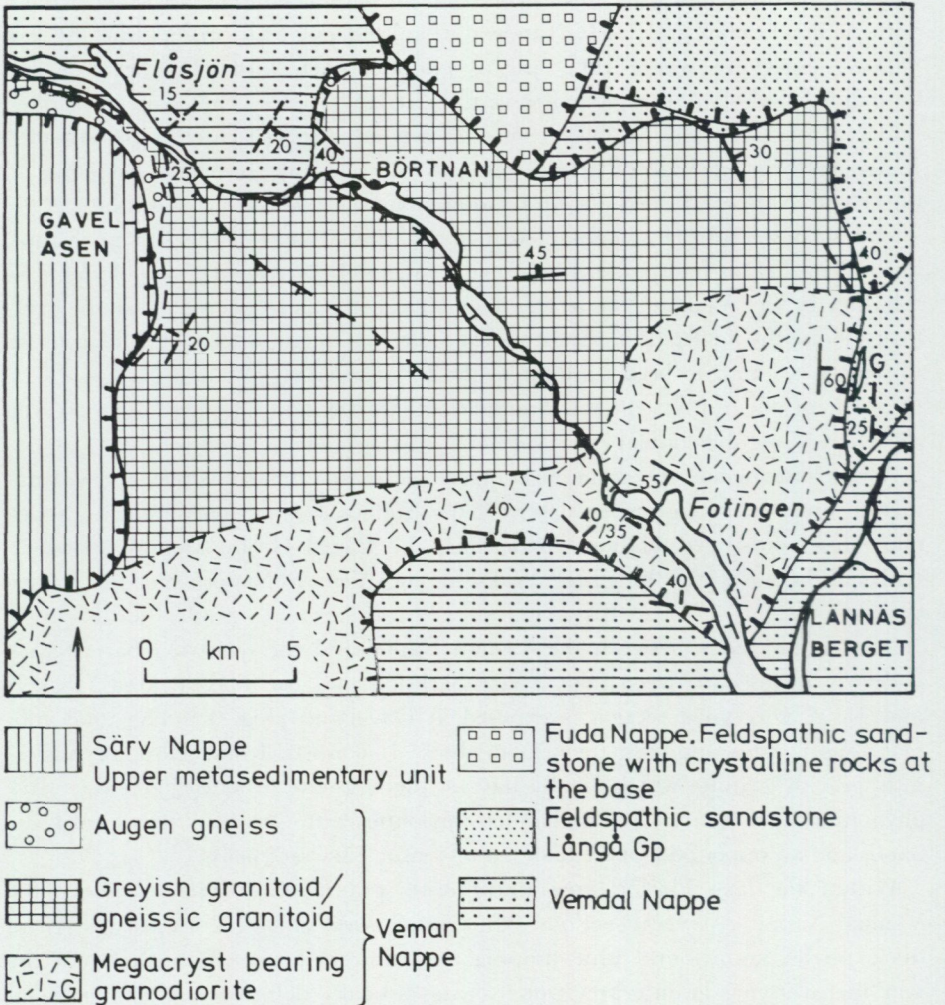


Fig. 4. Geological map of the Flåsjön area. For structural symbols see Fig. 3.

The strain within the Veman Nappe is very heterogeneous. The rocks vary from a random microbrecciation to intensely deformed gneissic granites, characterized by a penetrative often mylonitic foliation with occasional blasto-mylonitic bands and augen gneisses. The rocks become more intensely foliated towards the major tectonic contacts and internal minor thrusts. Narrow shear zones with strong cataclastic deformation occur locally within the whole nappe unit.

No mesoscopic foliation has been developed in the basic plutonic bodies.

The mylonitic foliation is subparallel to the general strike and dip of the S_2 foliation in the overlying Tännäs augen gneiss Nappe. It has been more intensely developed towards the major Caledonian tectonic contacts and in general towards west. Thus it should be regarded as a result of the main Caledonian thrusting.

THE TÄNNÄS AUGEN GNEISS NAPPE

The augen gneisses form a Lower and an Upper tectonic unit locally separated by a metasedimentary sequence. The lower unit outcrops from east of lake Nedre Särvsjön westwards to the Trondheim Nappe (Figs. 3 and 5). The upper unit covers the area northeast of a line Tännäs—5 km southwest of Funäsdalen (Figs. 6 and 7) and the main part of the Vigelen area (Fig. 5). The upper unit is discordant towards overlying units.

The nappe is dominated by augen gneisses (Fig. 8), which vary in petrology and structure (Point 1975, Röshoff in prep.). Minor parts of deformed granodiorites, granites, and basic plutonic rocks have been observed. Greenstone dykes, among them the Åsby dolerites, which sometimes have preserved chilled margins, are penetrated by the regional foliation. Dykes of the Ottfjäll type have not been observed. The contacts between the different plutonic rocks are mostly tectonic and subparallel to the regional foliation. The greenstones have usually been strongly deformed with boudinage structures.

The augen gneisses are believed to have been developed by progressive deformation of K-feldspar megacryst bearing Precambrian plutonic rocks mainly granodioritic in composition. This interpretation is mainly based on observations, that transitions occur between augen gneisses and low to moderately deformed plutonic rocks. This is in agreement with Törnebohm (1896), Nystuen (1975), and Point (1975).

The two augen gneiss units are separated by a sedimentary succession in the Tännäs and Vigelen areas (Figs. 5 and 6). The sediments at Tännäs comprise quartzite, feldspathic sandstone and dolomitic marble and have a thickness of c. 30 m. In the Vigelen area the sediments also include mica quartzite, phyllonite, and greenstone. The contact between these sediments and the Upper augen

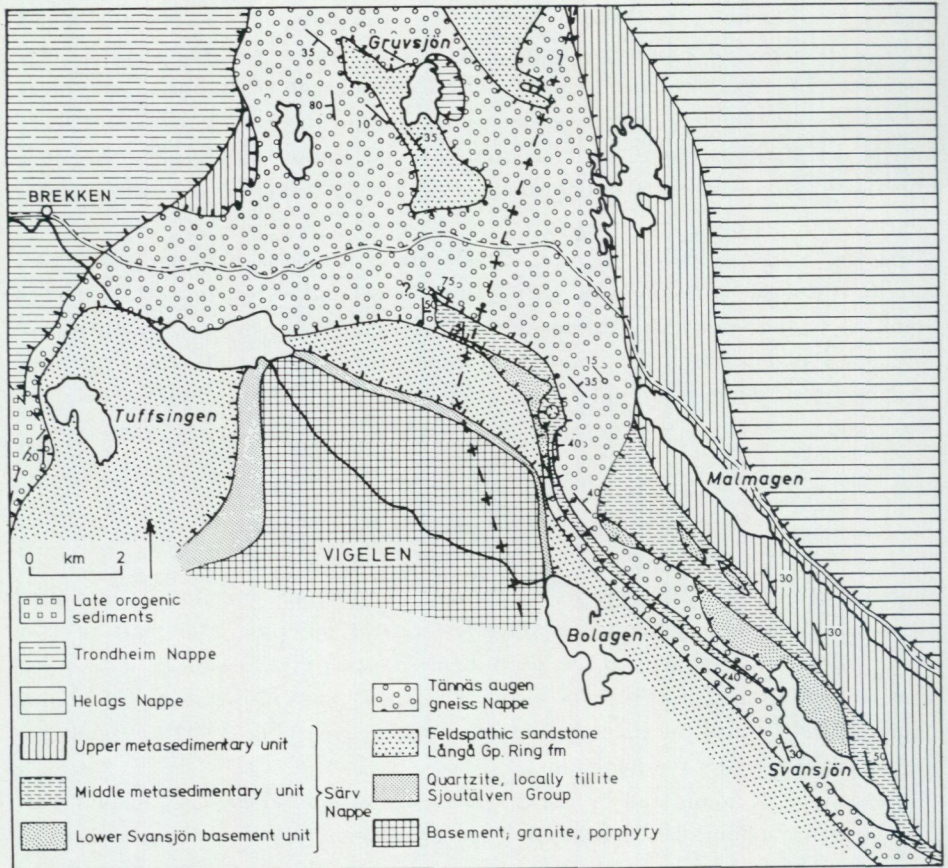


Fig. 5. Geological map of the Vigelen area. The Vigelen Window is based on Norén, (pers. comm). For structural symbols see Fig. 3.

gneiss unit is a phyllonite, which at Tännäs has a thickness of c. 15 m. The lower contact of the sediments is a well-banded mylonite, sometimes with refolded folds of the mylonitic banding.

The greenstones have only been observed in the Vigelen area. They are plagioclase megacryst bearing and may therefore represent deformed Ottfjäll dolerite dykes.

The contact of the augen gneisses towards the feldspathic sandstones of the Långå Group is a mylonite frequently with ultramylonitic bands. Very good sections are found southwest of Tännäs and northwest of lake Bolagen (Figs. 5 and 6). The contact between the augen gneisses and the plutonic rocks of the Svansjön basement unit is not exposed. A "close" contact exists between augen gneisses and the Middle metasedimentary unit of the Särvi Nappe, 2 km northwest of Tännäs. The augen gneisses are here strongly deformed (Fig. 9) with

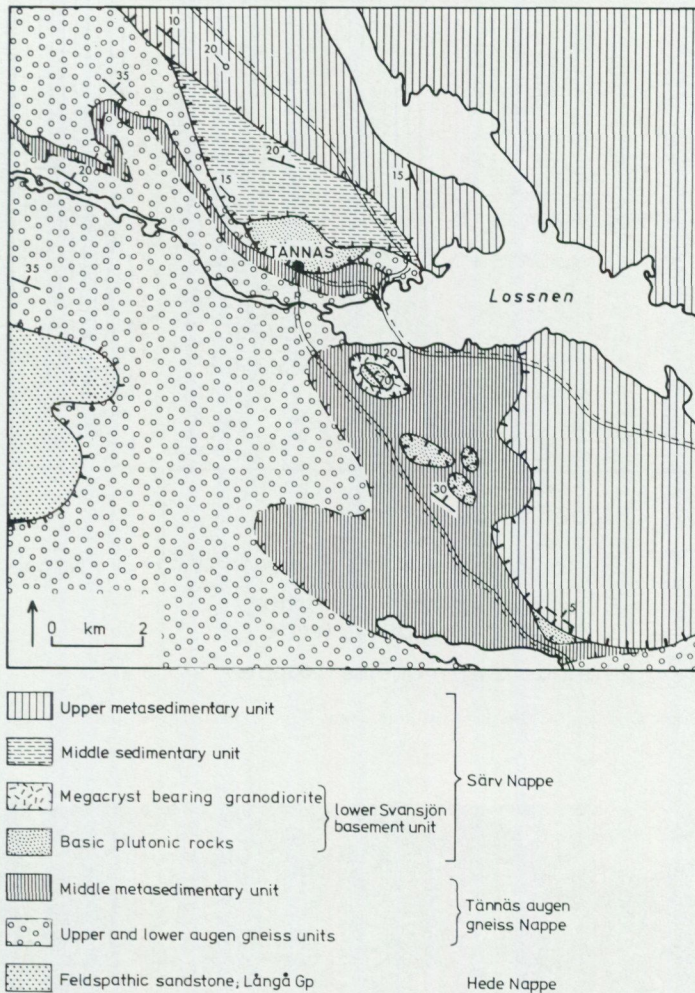


Fig. 6. Geological map of the Tännäs area. For structural symbols see Fig. 3.

lens-shaped K-feldspar megacrysts and overlain by banded mylonitic sediments. At Ljusnedal (Fig. 7) the contact between the augen gneisses and the Särvi Nappe is a thick phyllonite and at lake Nedre Grundsjön a banded mylonite.

The augen gneisses are characterized by a very heterogeneous strain, which is obvious from the great variations in the degree of deformation. This is observed within all investigated areas. Little to moderately deformed plutonic rocks occur in more strongly deformed augen gneisses. Areas of low deformation may either become progressively more intensely deformed outwards or have sharp usually mylonitic contacts towards the stronger deformed surrounding augen gneisses.

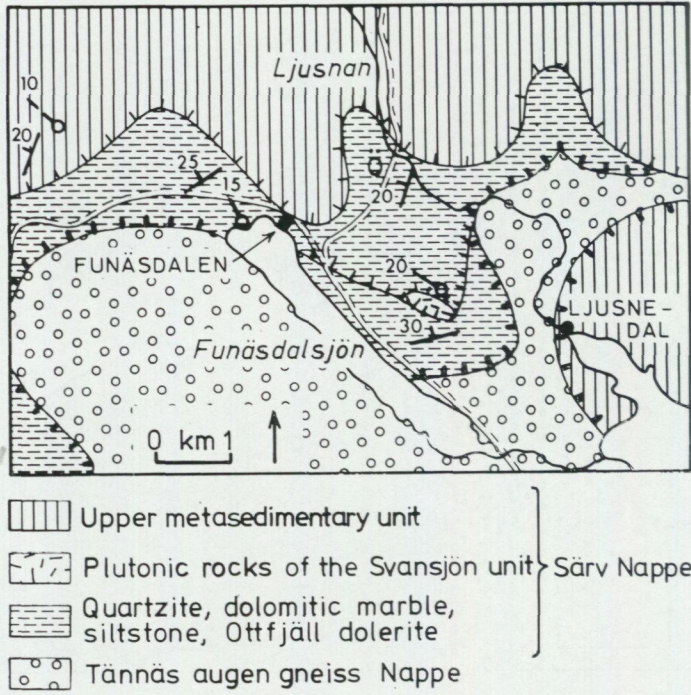


Fig. 7. Geological map of the Funäsdalen area. For structural symbols see Fig. 3.



Fig. 8. Tännäs augen gneiss, general type.



Fig. 9. Strongly deformed Tännäs augen gneiss located at the contact towards the base of the Särv Nappe, 1 km northwest of Tännäs.

The main foliation is a schistosity or sometimes a crude banding marked by the parallelism of mica, flattened K-feldspar megacrysts and quartz aggregates (Fig. 9). The foliation is subparallel to the mylonitic banding and the regional foliation of the overlying Särv Nappe metasediments and therefore considered as a mylonitic foliation (S_2) developed during the main Caledonian thrusting. The foliation (Figs. 10 and 11) is regionally rather constant in strike (WNW—ESE) in the different areas, with varying dips towards northeast. A stretching lineation (l_2) is caused by the preferred orientations of the K-feldspar megacrysts and quartz aggregates and has a general WNW—ESE strike with gentle plunges towards WNW and ESE. No F_2 folds have been observed.

During a third phase the regional foliation was generally raised into its present position. The F_3 folds are recumbent, open to tight structures with an S_3 axial plane cleavage occasionally developed in the hinges. These structures correspond to the F_3 structures in the overlying metasedimentary units.

The youngest phase (F_4) has so far only been identified north of Vigelen. The S_2 foliation is here folded into open structures with steep axial planes. The fold axes strike N—S to NNE—SSW, with varying low angle plunges.

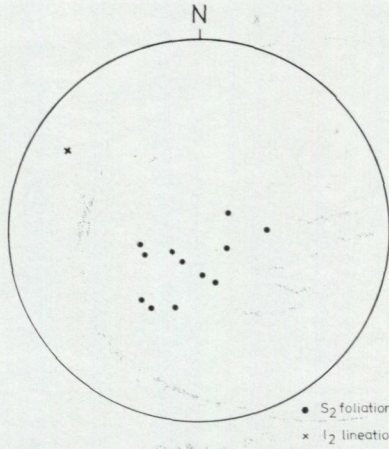


Fig. 10. Stereographic projection (Schmidt net, lower hemisphere) of the planar and linear structures of the augen gneisses in the Vigelen area.

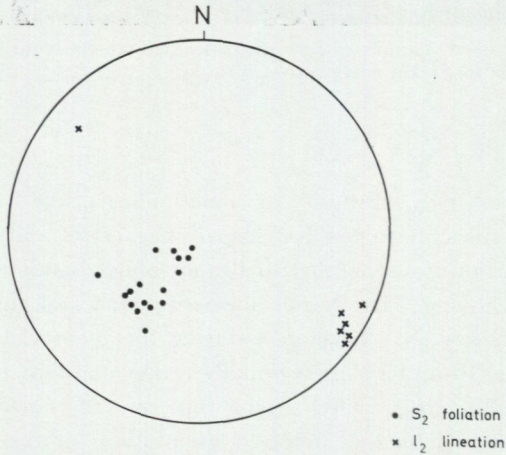


Fig. 11. Stereographic projection (Schmidt net, lower hemisphere) of the planar and linear structures of the augen gneisses in the Tännäs area.

THE SÄRV NAPPE

At least three tectonic units are recognized in the Särsv Nappe. Only the lowermost two will be discussed in this context, namely the Lower Svansjön basement unit and the Middle metasedimentary unit. These two units are here included in the Särsv Nappe because they have been intruded by the Ottfjäll dolerite dykes. The units occur as thin slices, often together, along the base of the nappe.

THE LOWER SVANSJÖN BASEMENT UNIT

The plutonic rocks of the Lower Svansjön basement unit comprise mafic gabbro, gabbro, diorite, granodiorite, and granite cut by a few Ottfjäll dolerite dykes. The unit is dominated by basic rocks. Units of the Lower Svansjön basement suite are lenticular bodies appearing partly along the base of the Särsv Nappe partly as isolated bodies thrust into the overlying metasediments (Figs. 5 and 7). The plutonic rocks have particular been investigated in the Tännäs and Vigelen areas (Figs. 5 and 6).

A clear age relationship between the plutonic rocks is found on Röstberget in the Funäsdalen area (Fig. 7), where megacryst-bearing granodiorite has inclusions of a gabbro. Strömberg (1961, p. 49) interpreted the Ottfjäll dolerite dykes on Röstberget to intersect the regional cataclastic foliation. However, it is evident that the basic dykes have been mistaken for a strongly deformed gabbro. Instead the dykes were deformed during the Caledonian thrusting and thus became subparallel in strike to the regional foliation.

The basement bodies in the Middle metasedimentary unit are interpreted to have been thrust into their positions along low-angle thrusts at an early stage of the evolution and later folded together with the sediments.

Three foliations are identified in the basic rocks of the Svansjön basement unit. Two of these are Precambrian, the other Caledonian in age. One Precambrian foliation is defined by the alignment of amphibole and plagioclase and probably represents an igneous flow texture. An old tectonic foliation, intersecting the flow texture, is Precambrian in age as it is cut by the Ottfjäll dolerite dykes (Fig. 13). This tectonic foliation is often mylonitic and the main structure of the massifs. At Krökterberget, 3 km southeast of Tännäs (Fig. 6), this foliation is steeply inclined and discordant to the Caledonian S_2 foliation (Fig. 12).

The flow texture, especially recognized in the inner parts of the basic bodies, is cut by millimetre thin shear zones, which are ultramylonitic and pseudotachy-

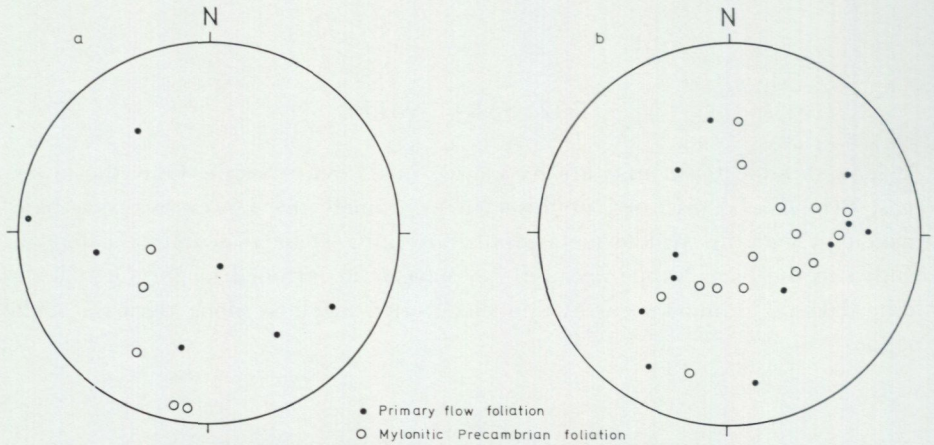


Fig. 12. Stereographic projections (Schmidt net, lower hemisphere) of the planar structures in the gabbros of the Svansjön basement unit in the Vigelen area (a = 2 km north of lake Svansjön) and the Tännäs area (b = 3 km southeast of Tännäs).

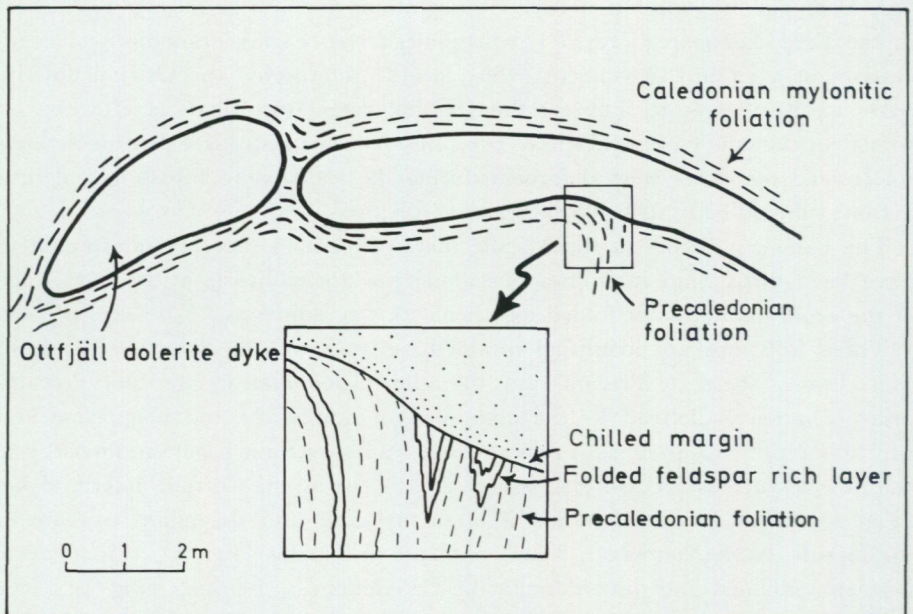


Fig. 13. An Ottfjäll dolerite dyke intersects a Precambrian foliation in the gabbro north of Tännäs and is later deformed by the Caledonian thrusting.

litic in appearance. The marginal parts of the massifs have been strongly affected by a tectonization, which has caused an intense penetrative, locally ultramylonitic, foliation. It is very difficult to identify the Caledonian foliation in areas where the Caledonian foliation is superimposed parallel to earlier schistosity. The Precambrian foliation is, however, cut by the Caledonian foliation where the former is steeply inclined. This is illustrated in Fig. 13. An Ottfjäll dolerite dyke intersects the Precambrian tectonic foliation and associated isoclinal folds. During the Caledonian thrusting the dyke and the older foliation were rotated into parallelism with the flat-lying Caledonian S_2 foliation. It seems therefore likely that the main foliation within the basic massifs are mainly Precambrian in age, but local intense shear zones of Caledonian age have been observed to cut through the bodies.

The intermediate and acid plutonic rocks are usually more or less strongly cataclastically deformed with the development of microbreccia. At Krökberget, southeast of Tännäs (Fig. 6), a megacryst-bearing granodiorite is separated from the overlying gabbro by a thick ultramylonite. The granodiorite has a strong flat-lying penetrative foliation locally giving the rock an augen gneiss character.

The plutonic rocks at Röstberget, 2 km southeast of Funäsdalen (Fig. 7), mainly consists of well-preserved intermediate and acid plutonics with a weakly developed foliation. The rocks are microbrecciated. They are in contact with a gabbro, which has been strongly deformed in its marginal parts, probably in Caledonian time.

THE MIDDLE METASEDIMENTARY UNIT

The Middle metasedimentary succession of the Särvi Nappe comprises several lithological members namely quartzite, feldspathic sandstone, mica quartzite, phyllite often calcareous, dolomitic marble, and occasionally siltstone and a diamictite (Röshoff 1975). These rocks are everywhere intruded by the Ottfjäll dolerites. It is also evident that this succession is much more variable in lithology than the Ulvberg complex as described by Strömberg (1961).

The succession composes a separate tectonic unit (Figs. 5, 6 and 7) at the base of the Särvi Nappe.

The contact towards the Upper metasedimentary unit is often a phyllonite, which north of Tännäs is approximately 20 m in thickness. This phyllonite was described by Strömberg (1961) as the Grönstack complex and interpreted as a primary sedimentary unit.

In the Vigelen area, 3 km north of Svansjön, the contact between the plutonic rocks of the Svansjön basement unit and the overlying sediments is a blastomylonite with scattered K-feldspar porphyroclasts in a fine-grained my-



Fig. 14. Basic dyke of Ottfjäll type (lower half of the photograph) cuts the mylonitic contact between the Svansjön basement unit and the overlying Middle metasedimentary succession of the Särvi Nappe. Location: the Vigelen area. The mylonitic foliation strikes almost E—W on the photograph.

lonitic matrix. A dolerite, very probably of Ottfjäll type, intrudes the blastomylonite and intersects the mylonitic foliation (Fig. 14). The dyke very likely continuous into the underlying gabbro. The dyke is in general only weakly deformed, but local intense shear zones occur, which are subparallel to the mylonitic foliation.

The rocks within the metasedimentary succession are usually strongly deformed with a regional often mylonitic foliation and banding as main structures. Sedimentary structures have not been observed, however, the mylonitic banding is sometimes seen to lay subparallel to a layering which may be primary. The regional foliation is in general flat-laying with gentle northeast dips in all investigated areas (Figs. 15 and 16).

The earliest folds recorded are related to the F_2 phase as seen in Biskopsån south of Sylsjön (Strömberg 1961, p. 25). The regional foliation here forms the axial plane foliation and crenulates an older foliation in the hinge. Thus, the regional foliation developed during a second phase of deformation, which is synchronous with the main thrusting of the different tectonic units.

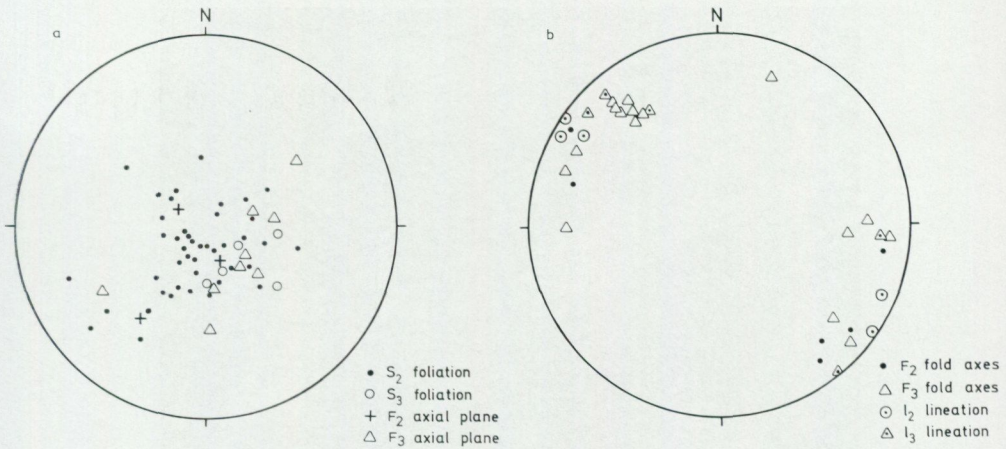


Fig. 15. Stereographic projection (Schmidt net, lower hemisphere) of planar (a) and linear (b) structures of the Middle metasedimentary unit of the Särvi Nappe in the Tännäs area.

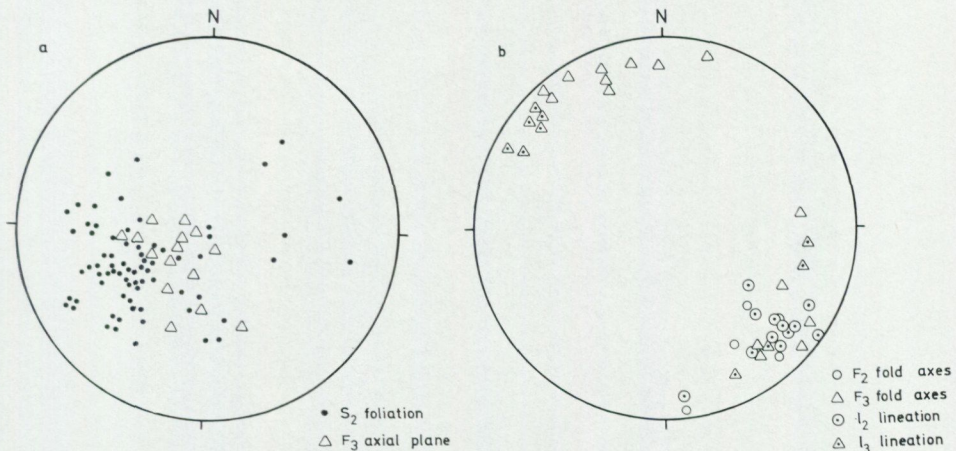


Fig. 16. Stereographic projection (Schmidt net, lower hemisphere) of planar (a) and linear (b) structures of the Middle metasedimentary unit of the Särvi Nappe in the Vigelen area.

Rootless, intrafolial, isoclinal folds deform the mylonitic banding. These folds, with axial plane foliation discordant to the mylonitic banding in the hinges, are interpreted as progressive syntectonic second phase structures developed during the thrusting (Fig. 17). A stretching lineation l_2 , marked by the preferred orientation of quartz and K-feldspar porphyroclasts, is subparallel to the F_2 folds. All the second phase linear structures strike NW—SE to NNW—SSE with gentle dips towards NW and SE (Figs. 15 and 16).

The Ottfjäll dolerite dykes were strongly deformed during the Caledonian



Fig. 17. F_2 isoclinal folds in the Middle metasedimentary unit of the Särvi Nappe, Vigelen area. The mylonitic foliation is subparallel to a layering.

thrusting. The dykes are often boudinaged with their contacts subparallel to the mylonitic foliation.

During a third phase, the regional foliation S_2 was folded into large open to tight recumbent, parallel to similar folds (Fig. 18). A crude semipenetrative crenulation cleavage (S_3) has locally been developed in the hinges of the F_3 folds. The lineation l_3 , only observed in the hinges, is either an intersection between S_2 and S_3 or a small scale crenulation of S_2 . The F_3 linear structures



Fig. 18. F_3 folds of the mylonitic foliation S_2 in the Middle metasedimentary unit of the Särvi Nappe, Tännäs area.

are subparallel to the F_2 structures. The F_3 axial planes strike NW—SE to almost E—W in the Tännäs area, while in the Bolagen area they strike similar to S_2 (Figs. 15 and 16).

A fourth phase has been observed in Biskopsån south of Sylsjön (Strömberg 1961, p. 35). This phase shows folds with varying interlimb angle and fold style.

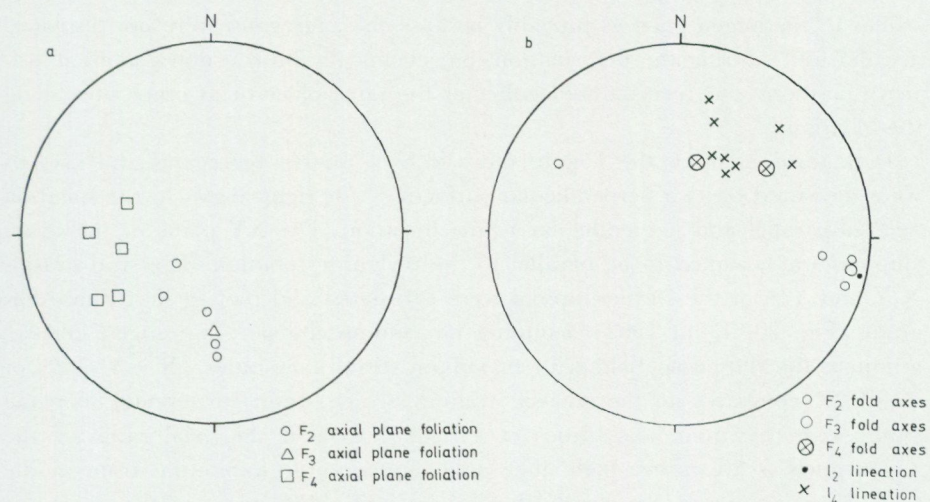


Fig. 19. Stereographic projections of the planar (a) and linear (b) structures from the river Biskopsån south of lake Sylsjön.

The axial planes are steep with easterly dips, and strike in NNW—SSE (Fig. 19). The fold axes F_4 and the lineation 1_4 are oriented in NE—SW. A S_4 crenulation cleavage has been developed in the chloritic and calcareous layers of the section.

STRAIN ANALYSES OF THE VEMAN AND TÄNNÄS AUGEN GNEISS NAPPE

In order to calculate the minimum strain differences between the Tännäs augen gneiss Nappe and the underlying Veman Nappe six samples, three of each unit, were taken for strain analyses. The rocks were sampled along a N—S profile northeast of Långå from Svartåsen (Fig. 3) in south to Vispvallen in north. The rocks from the Veman Nappe consist of megacryst-bearing granodiorite, with varying degrees of deformation, representing the general degrees of strain within this unit. The samples of the augen gneisses display K-feldspar megacrysts (3—5 cm in length) in a strongly foliated matrix.

Three different strain methods were tested. Only one of these turned out to give promising results. In the first method the length and the width of the megacrysts were measured. However, it proved impossible to define the shape of the megacrysts as they are disrupted due to deformation; broken crystal fragments are displaced within the foliation. It is also evident that the matrix is much more deformed than the megacrysts, which thus do not represent the actual state of strain in the rock.

A second method, the grain-centre method (Ramsay 1967, p. 195), was applied on the mafic crystal aggregates in the rocks. This method also gave low strain values in the augen gneisses probably because the aggregates were not displaced as solid units during the deformation, but chemically broken down at their primary positions and recrystallized either at the same place or at other sites along the foliation.

In a third method, the length and width of quartz aggregates and crystals were measured on two perpendicular surfaces cut at right angles to the foliation and subparallel and perpendicular to the lineation. The XY plane of the strain ellipsoid was assumed to be parallel to the mylonitic foliation. The strain ratios X/Y and Y/Z of the strain ellipsoid were calculated and plotted in a Flinn diagram (Fig. 20; Flinn 1962) assuming no volume change. The augen gneisses group in the flattening field with maximum strain axes ratios ($X > Y > Z$) of 18.3:9.2:1 compared to the gneissic granites, which strain corresponds to plane strain with maximum axes ratios of 4.5:2.3:1. Even if the axial ratios of the augen gneisses are rather high, they only represent the minimum strain in the rock, however, the values clearly show the relative differences in the degree of deformation between the two tectonic units.

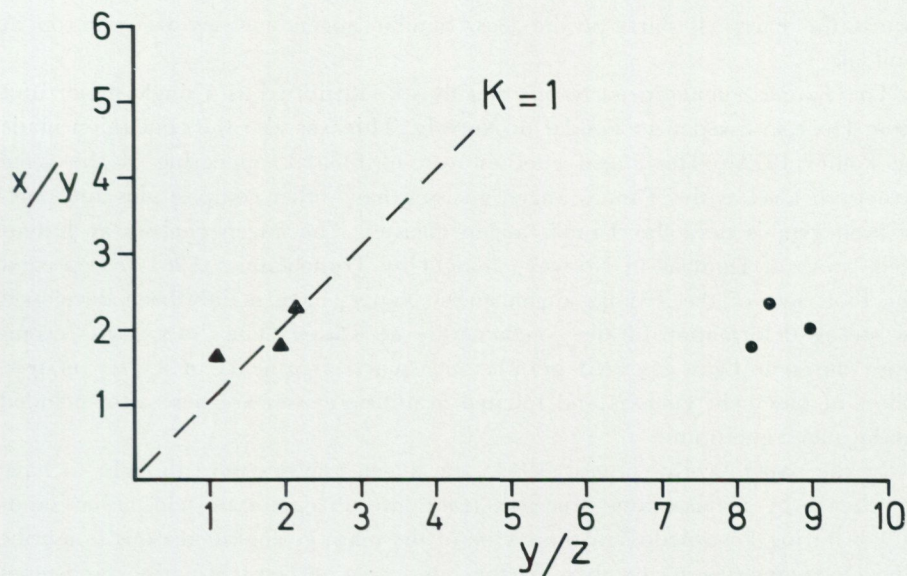


Fig. 20. Flinn diagram (1962) showing the strain within the Tännäs augen gneiss Nappe (filled circle) and the Veman Nappe (filled triangle).

THE WESTERN EXTENSION OF THE TÄNNÄS AUGEN GNEISS NAPPE

The main part of the augen gneiss unit in the Gruvsjön—Tuffingen area (Fig. 5) comprises typical coarse heterogeneous augen gneisses with structures and compositions similar to those observed east of the political border. Foliated granitic and dioritic bodies are subordinate. The augen gneisses west of lake Tuffingen consist of coarse augens in a strongly flattened matrix, which have a wavy porphyroclastic appearance. The deformation increases in general from the political border westwards towards the Trondheim Nappe. Within the Gruvsjön area the deformation is even more heterogeneous than observed in Sweden. Units characterized by moderate deformation rapidly alternate with strongly mylonitic zones.

From lake Tuffingen southwestwards the augen gneiss unit occurs as disrupted lenses below the Trondheim Nappe (Fig. 1). At Brydal the augen gneisses form up to a 30 m thick lens between the Trondheim Nappe and the underlying late Precambrian feldspathic sandstones (sparagmites; Holmsen and Holmsen 1950). The main part of this lens comprises typical coarse augen gneiss of Tännäs type. However, a well-preserved rock outcrops 2—2,5 km south and southwest of Brydal Chapel and consists of K-feldspar megacrysts (6—8 cm in diameter) bearing granodiorite with a primary igneous texture.

This rock is progressively transformed into coarse mylonitic augen gneisses to-

wards the marginal parts of the lens. Similar augen gneisses also outcrop at Folldal.

The Tännäs augen gneiss Nappe can thus be identified as a single major unit from Hede in Sweden to Folldal in Norway. This was also the conclusion made by Point (1975). The augen gneisses west of Folldal, appearing at the same structural level as the Tännäs augen gneisses, have other compositions and partly even genesis than the Tännäs augen gneisses. The augen gneisses at Jettenfjell, south of Dombås in Norway, thought by Törnebohm (1896) to represent the root zone of the Tännäs augen gneiss Nappe, have mainly been developed by strong deformation of the conglomerate at Rosten. The "megacrysts" comprise different light coloured granite and quartz fragments in a grey matrix. Slices of basement gneisses and foliated granitic gneisses are here also included in the augen gneiss unit.

In the paper by Rosenqvist (1944) the augen gneisses were thought to have developed by metasomatic processes from late Precambrian feldspathic sandstones during Postcaledonian time. One of the main geological reasons to ascribe the augen gneisses as members of the late Precambrian feldspathic sandstones was the often observed transitional contacts between the sediments and the overlying augen gneisses (Rosenqvist 1944, Holmsen and Holmsen 1950, Strand 1951). In general, the upper 50 to 100 m of the feldspathic sandstones below the augen gneisses, in the western part of the Vigelen area to Folldal, have a strong phyllonitic texture with porphyroclasts of plagioclase, K-feldspar, and quartz set in a greyish or greenish grey wavy matrix. A very good section showing this transformation of light grey sandstones to dark greenish grey, wavy phyllonite with feldspar and quartz porphyroclasts, is exposed along the road section 5 km south of Folldal. The phyllonitic texture gives the feldspathic sandstones an augen gneiss appearance with small augens. The contact between the phyllonitic feldspathic sandstones and the augen gneisses can usually be defined as the augens in the augen gneiss become strongly reduced in size and abundance 1 to 2 m from the contact. The augens usually have normal sizes (3—5 cm) above that zone.

THE GEOMETRY OF THE TÄNNÄS AUGEN GNEISS NAPPE

The calculation of the variations in thickness of the Tännäs augen gneiss Nappe is based on data from field observations, drill cores, and tunnel sections. The calculation has been made along a WSW—ENE profile from lake Flåsjön to Tännäs and along a WNW—ESE profile from Tännäs to the Trondheim Nappe (Fig. 21). The error of calculation is estimated to ± 50 m except from the Hede—Långå area and the area north of Vigelen, where the error is less.

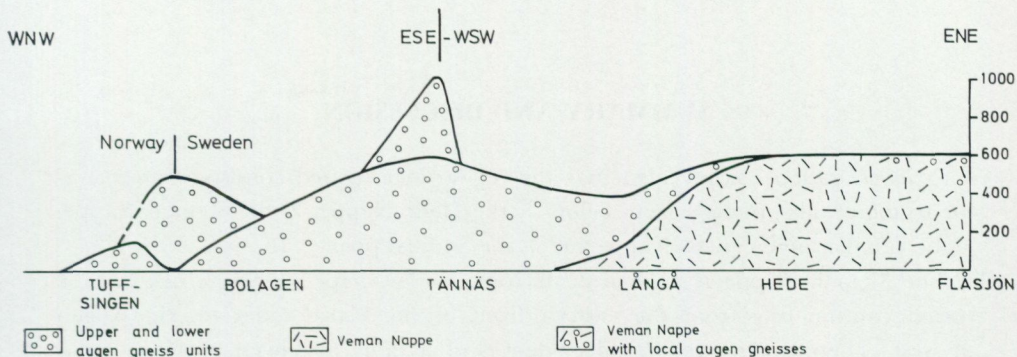


Fig. 21. The thickness variation of the Tännäs augen gneiss Nappe and the Veman Nappe.

It is evident that the Tännäs augen gneiss Nappe thins both east- and westwards (Fig. 21). From the area east of lake Nedre Särvsjön the augen gneisses gradually increase in thickness. Several drill holes and tunnel section in the Hede—Långå area give an almost complete section through the whole unit. The augen gneisses here have a thickness of 250 m underlain by 150 m thick, strongly foliated and lineated granitic rocks of the Veman Nappe.

The thickest part of the augen gneisses occurs in the Tännäs area, where the two augen gneiss units have a total thickness of 1050 m, of which the Lower augen gneiss unit occupies 600 m. West of the Tännäs area the augen gneisses are gradually reduced in thickness and are 180 m northeast of lake Bolagen and thin out northeast of Vigelen. The unit reappears further west at the same structural level (Fig. 5) and has a thickness of 20 m below the western part of the Middle metasedimentary rocks. The unit gradually increases in thickness westwards into the Gruvsjön—Tuffsjö area. West of lake Tuffsjö the augen gneisses range in thickness from 50 to 200 m.

The augen gneiss lenses along the thrust plane between the Trondheim Nappe and the late Precambrian sediments in the Röros area have thicknesses, which probably not exceed 100 m. At Brydal, Holmsen (Holmsen and Holmsen 1950) has estimated the thickness of the augen gneiss unit to be up to 30 m.

The Tännäs augen gneiss Nappe also seems to increase in thickness in a N—S profile from 20 m at the Vigelen Antiform to at least 50 m west of lake Gruvsjön. The exact figures are, however, difficult to assess as the area is complexly folded.

SUMMARY AND DISCUSSION

This investigation has revealed that the region investigated consists of four major tectonic units, namely from below 1, the Hede Nappe, 2, the Veman Nappe, 3, the Tännäs augen gneiss Nappe and 4, the Särsv Nappe.

The Veman Nappe is a separate tectonic wedge-shaped sheet, which can be traced continuously from the eastern front of the Caledonides to Medskogen in west. There are no geological evidences of a fault northwest of Hede separating the Veman Nappe from the Tännäs augen gneiss Nappe as suggested by Strömberg (1955, 1961) and Stålhös (1956). Instead the Veman Nappe has been separated from the augen gneisses by a low angle major thrust, which begins east of Medskogen and terminates east of lake Nedre Särsvsjön (Fig. 2).

There is a tectonic contact between the Veman Nappe and the underlying late Precambrian feldspathic sandstones and associated crystalline basement rocks of the Hede Nappe. The petrology of the granitic rocks of the former nappe is similar to that of the basement rocks of the Hede Nappe. Consequently the Veman Nappe can be interpreted as a slice of the crystalline basement, which has overridden its own cover with associated basement. That thrust is probably of minor dimension. A primary basement cover relationship has been observed between the Långå Group and its basement as described by Stålhös (1956).

The Veman Nappe tectonically overlies the Vemdal quartzites near the eastern front (Fig. 3). The description of a blue-black quartzite on a granite northwest of lake Flåsjön (Fig. 4) by Strömberg (1961, p. 11) indicates that there are two different basement units of which the one presented by Strömberg forms the basement of the Vemdal quartzite.

The tectonic relationship between the Veman and the Fuda Nappes (Fig. 4) is not definitely assessed in the northeastern part of the lake Flåsjön area. The gneissic granites of the Veman Nappe are traced into the base of the Fuda Nappe. Therefore the mylonitic granites and augen gneisses at the base of the Fuda Nappe represent the continuation of the Veman Nappe and not a slice of the Tännäs augen gneiss Nappe.

The Tännäs augen gneiss Nappe consists of three tectonic units comprising a Lower and an Upper augen gneiss unit and locally a Middle metasedimentary sequence. The two last units have limited extension and thin out both easterly and westerly towards the overlying Särsv Nappe. The sedimentary sequence and the Upper augen gneiss unit are interpreted to have been thrust on top of the Lower augen gneiss unit. Plutonic rocks have been recognized in minor portions within the augen gneisses. The augen gneisses are thought to have developed during the main Caledonian thrusting by progressive deformation of Precam-

brian crystalline basement rocks, which mainly were granodioritic in composition (Röshoff in prep.).

The Tännäs augen gneiss Nappe can be traced continuously from lake Nedre Särvsjön (Fig. 3) to Folldal in Norway (Figs. 1 and 5). The augen gneisses west of the political border between Sweden and Norway have the same petrology, chemistry and texture as noticed east of the border (cf Point 1975). Nystuen (1975) also suggested that the augen gneisses along the Trondheim Nappe and within the Stålekinna complex possibly could be correlated with the Tännäs augen gneisses.

The augen gneisses along the thrust between the Trondheim Nappe and underlying late Precambrian sediments appear as separate thin lenses at lake Feragen, lake Rambergsjön, Brydal and Folldal (Fig. 1). These lenses represent boudins of the Lower augen gneiss unit, as suggested by Törnebohm (1896). All these lenses are located above the Röa Nappe and the Vangås Formation (Holmsen and Holmsen 1950, Rui 1972, Nystuen 1975).

The geometry of the Lower augen gneiss unit clearly demonstrates that the unit is thinning both east and west (cf. Törnebohm 1896). The easterly thinning may have been caused by the overthrusting of the augen gneisses on the Veman Nappe (Fig. 2) and a later cut out by the overriding Särv Nappe. The westerly thinning is a general sheet thinning comparable to that described by Zachrisson (1973) of the Seve Nappe. The extreme thinning north of the Vigelen Antiform may be the result of a late uplift of the Vigelen basement after the thrusting. These basement rocks and the overlying Sjoutälven Group sediments have only been little affected by the Caledonian deformation, while the sedimentary rocks of the Hede Nappe and the Tännäs augen gneisses are extremely strained.

The Upper augen gneiss unit and the metasedimentary sequences above and below that unit are cut out towards the Särv Nappe in the Tännäs and Vigelen areas. The discordance is very low angle and the units are almost subparallel to the base of the Särv Nappe.

The plutonic rocks of the Svansjön basement unit and the Lower metasedimentary succession of the Särv Nappe have related petrographic provenance as the Upper metasedimentary unit of the Särv Nappe, as all three have been intruded by the Ottfjäll dolerite dykes. Tectonically, however, the units mentioned appear as separate sheets along the base of the Särv Nappe. The plutonic rocks consist of an eruptive suit ranging from mafic gabbro to granite and represent detached parts of the Precambrian crystalline basement. Basic rocks predominate.

The Ulvberg complex was described by Strömberg (1961) to comprise white quartzite, feldspathic quartzite and dolomitic marble. This investigation demonstrates that these sediments are more variable in lithology including quartzite, feldspathic quartzite, mica quartzite, phyllitic rocks often calcareous, dolomitic

marble, Ottfjäll dolerite and occasionally siltstone and a diamictite (Röshoff 1975). These sediments are here gathered in the Middle metasedimentary unit of the Särsv Nappe. The Ottfjäll dykes often have the same frequency in both the Middle and Upper metasedimentary units. Based on this, the Middle metasedimentary unit definitely belong to the Särsv sediments, but its exact stratigraphic position is at present uncertain.

The intrusion of the Ottfjäll dolerite dykes into the plutonic suit of the Svansjön basement unit was taken as a proof by Srömberg (1961) to class the plutonics as the basement on which the Särsv sediments were deposited. However, only a few scattered dykes have been observed within the basement rocks and not a dyke swarm as in the Särsv sediments. The plutonic rocks are therefore thought to have had a marginal position in relation to the sedimentary basin, where the Särsv sediments were deposited. Another proof by Strömberg (1961) was the Grönstack complex, which was described as a fragmental basal unit of the Särsv sediments. The Grönstack complex is here regarded to be tectonic in origin, locally developed along the thrust plane between the Särsv Nappe and underlying tectonic units.

A Precambrian tectonic relationship is thought to exist between the metasedimentary succession of the Middle metasedimentary unit of the Särsv Nappe and the Svansjön basement unit. The blastomylonitic contact north of lake Svansjön is cut by a dyke probably of Ottfjäll type. The age of these dykes is very likely late Precambrian. Rb/Sr age determinations (Claesson 1977) have given an age of 735 ± 200 Ma. These dykes also intrude sediments of probable glaciogenic origin, which are thought to be Varangian in age (Röshoff 1975). However, Point et al. (1976) have presented a much older age (> 2200 Ma) for the dykes based on K/Ar determinations.

Several generations of foliation have been observed. The basic plutonic rocks of the Svansjön basement unit have a main tectonic foliation developed during a Precambrian deformation. This foliation is often mylonitic in character and probably developed synchronously with the Precambrian mylonite, which separates the Svansjön basement unit from the overlying sedimentary succession at the base of the Särsv Nappe. Later a Caledonian mylonitisation was superimposed on the Precambrian foliation; seen in the intense flat-lying shearzones. The mylonitic foliation in the augen gneisses is thought to be Caledonian in age. However, there may have existed a weak Precambrian foliation in the augen gneisses, as in areas of no visible Caledonian deformation (Medskogen and Brydalen), the megacrysts in the granodiorites sometimes intersect a weak planar structure. The gneissic granites within the Veman Nappe were strongly brecciated (locally?) in Precambrian time as the Långå Group sediments fill joints in the basement rocks. The mylonitic foliation within the Veman Nappe is thought to be Caledonian in age.

The regional mylonitic foliation of the Middle metasedimentary succession at

the base of the Särvi Nappe is subparallel to the mylonitic foliation in the Tännäs augen gneiss Nappe and therefore considered contemporaneous in time. This foliation is a second phase structure developed during the main Caledonian thrusting. The nature of the first Caledonian structures is not known from the areas investigated, but the second phase of deformation caused an isoclinal folding of an earlier planar fabric and a strong stretching lineation (l_2). The large scale structures developed during a third phase. This phase is characterized both in the sedimentary succession and the augen gneisses by recumbent tight to isoclinal folds with the axes orientated subparallel to the F_2 linear structure in WNW—ESE. A fourth phase of deformation, with steep axial planes, is locally recognized. The associated linear structures are orientated in NNE—SSW to NE—SW.

Strömberg (1974) proposed that the Vigelen and Hede areas are intersected by northwest oriented "transform fault" zones. These zones, named the Tännadalen zone, strike through the Vigelen area in NW—SE along the augen gneisses. According to Strömberg the steep positions of the regional foliation in the area were caused by that fault. It has been clearly demonstrated in this investigation that firstly there is no geological evidence of a major fault in the Vigelen area; and secondly the regional foliation within the augen gneisses was folded into its present steep positions during a third phase of Caledonian folding. The strong lineation in the augen gneisses is a l_2 structure. A similar geological situation is also valid in the Tännäs area. The "transform fault" named the Sylarna—Hede zone is a northwest-southeasterly extension of the earlier described fault northwest of Hede (Strömberg 1955, 1961, Stålhös 1956). As outlined above there does not exist any fault of that dimension northwest of Hede.

There is a fundamental change in the major tectonic geometry of the different units in the Hede area. East of Hede the thrusting is characterized by small and large imbrications which are concentrated to distinct shear zones leaving rather undeformed rocks in between. Stålhös (1956) described several imbricated granite lenses between the feldspathic sandstones of the Långå Group and the Vemdalen quartzite. The contact between the Veman Nappe unit and the underlying Vemdalen quartzite is often imbricated (A. Strömberg 1955). Thin lenses of quartzite alternate with gneissic sheets.

West of Hede the deformation of the rock units is more homogeneously spread through the different tectonic units. A strong penetrative foliation has been developed. The thrusts are flatlying, conformable to the regional mylonitic foliation. This is especially notable within the Tännäs augen gneiss Nappe and the base of the Särvi Nappe. The only imbrications observed here are those of the Svansjön basement unit, which occur as thin lenses in the overlying Middle metasedimentary succession of the Särvi Nappe. These imbrications may, however, be Precambrian in age.

The model suggested by Strömberg (1974) for the deep structure geometry of the crystalline basement shows that the gneissic granite slices of the Veman Nappe represent imbrications of the autochthonous basement. According to Gee (1975) and Gee et al. (1976) it can be demonstrated from the Tåsjön area that the eastern front of the Caledonides has a decollement geometry, with a passive basement. It is clear from this investigation that the crystalline rocks of the Veman Nappe do not represent slices of imbricated autochthonous basement as the nappe has been thrust both over the Vemdal and Hede Nappes and thins out westwards between the Tännäs augen gneiss Nappe and the Hede Nappe. Thus it is root-less. The original position of the Veman Nappe probably was just west of the location of deposition of the Långa Group. During the thrusting, the Veman Nappe was "picked up" by the Tännäs augen gneiss Nappe and displaced southeastwards above the Hede and the Vemdal Nappes.

The fact that the basement of the Vigelen Antiform is overlain by Sjouälven Group sediments (Gee and Norén, pers. comm. 1976) and overthrust by the Hede Nappe introduces the possibility that the entire tectonic complex of both Hede and Veman Nappes all have moved from somewhere west of the political border between Sweden and Norway.

ACKNOWLEDGEMENTS

This investigation has been supported by the Swedish Geodynamics Projekt (Annersten 1973, Bylund et al 1976). I am indebted to my colleagues involved in the project.

Mr S. Claesson and O. Zellman have partly assisted me in the field. Director G. Sundin and Civil eng. G. Wallmar, Bergvik & Ala Company, are thanked for supporting me with information concerning the geological situation around the Långå Water Power Plant.

An early draft of the manuscript was reviewed by Dr P. G. Andreasson. Dr D. G. Gee is thanked for encouraging discussions and helpful criticism of the manuscript. I am also grateful to Prof. H. Ramberg, Drs A. Strömberg, P. Nystuen and R. Point for discussions concerning the augen gneisses.

Miss Ch. Brun and Mrs M. Lövgren drew the figures. Miss G. Törnqvist typed the final manuscript. All are thanked for their contributions.

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PRISKLASS C

Distribueras genom

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162 89 VÄLLINGBY

Schmidts Boktryckeri AB
Helsingborg 1978

ISBN 91-7158-136-7