Basement-cover relationships on northern Vanna, Troms, Norway

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Remapping of mylonitized Precambrian tonalitic basement gneisses on northern Vanna has shown them to be allochthonous (Skipsfjord Nappe) relative to the metatonalites further south. The allochthonous rocks are separated from the tonalites on northern Vanna by a major high-angle brittle normal fault, possibly of Mesozoic age. The Skipsfjord Nappe is composed of three major lithotectonic units; a lower and upper mylonite–gneiss sheet separated by a metasedimentary sequence (Kvalkjeften group). The latter probably has a tectonically disturbed depositional contact against the lower mylonite–gneiss sheet. The lower third of the Kvalkjeften group is composed of metapsammite and calcareous metapelite (Geitdalen fm.), whereas the upper part is dominated by metapelites with some minor quartzite towards the top (Brattfjell fm.). Both the allochthonous mylonite gneisses and the Kvalkjeften group are transected by mafic sheets, now transformed to biotite–chlorite schists. A correlation with the dike intruded portions of the Kalak Nappe Complex is suggested. The mylonitized upper portion of the basement, the allochthonous mylonite gneisses and the psammitic lithologies within the Kvalkjeften group all have a well-developed mylonitic foliation with a NW–SE trending stretching lineation. The basement rocks north of Vannareid are transected by an anastomosing network of steeply dipping shear zones. The shear zones strike NNE and dip steeply WNW. They are interpreted to be due to crustal shortening at a late stage in the Caledonian orogeny.

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The Scandinavian Caledonides are characterized by a series of flat-lying nappes and thrust sheets that were emplaced onto the Baltoscandian Craton in Early to Mid-Paleozoic time following closure of the Iapetus Ocean. The nappes are subdivided into four main nappe complexes or allochthons named in ascending order the Lower, Middle, Upper and Uppermost Allochthon (Gee 1975; Roberts & Gee 1985). Lower and Middle Allochthons are dominated by folded and faulted Late Precambrian (Riphean–Vendian) to Silurian sediments, locally with their depositional basement preserved. Both the sediments and the crystalline rocks are readily correlated with the underlying autochthonous to parautochthonous sequences, and are interpreted as the shortened miogeoclinal sequence deposited along the western passive margin formed during and after opening of the Iapetus Ocean. With the exception of its lower part (Seve nappes), the Upper Allochthon is composed of sequences or terranes that are suspect with respect to Baltica (Stephens & Gee 1985). Also the sequences making up the various tectonic units of the Uppermost Allochthon are exotic with respect to Baltica, and have been considered by some authors to be part of Laurentia, which bordered the Iapetus Ocean to the west.

Emplacement of the four allochthons in their present position was, at least in its final stage, the result of a continent–continent collision between Laurentia and Baltica. The presence of Caledonian eclogites in the Western Basement Region of South Norway, showing increasing equilibrium pressures from east to west (Krogh 1977), is interpreted by most authors in terms of westward underthrusting of Baltica. However, the structural development of the Western Basement Region is not well understood, partly because of difficulties in distinguishing the rocks and structures of Precambrian age from those of Caledonian age. Cuthbert et al. (1983), however, have interpreted the crustal thicknesses necessary to form eclogites as the result of large-scale imbrication within the underthrusted plate (Baltica). The presence of local mantle peridotites in the region suggests that some of these reverse faults root in the mantle. Similar tectonic processes are also envisaged for the little known basement gneisses making up the bedrock of western Troms and northern Nordland (Hodges et al. 1981), although the depth of subduction was considerably less as Caledonian high pressure rocks are apparently lacking in this area.

The purpose of this study is to present structural and petrographic data from an area of highly sheared rocks on northern Vanna (Figs. 1, 2) interpreted by us to represent highly deformed Precambrian orthogneisses of the Middle Allochthon.

Geological setting

Vanna is located in northern Troms (Fig. 1) and represents the northernmost exposure of the NW Basement Region which covers much of the coastal areas from Bodø via Lofoten to Troms. The basement rocks are overlain to the east by Caledonian nappe rocks. Basement rocks also occur as several small and large windows where a thin veneer of autochthonous Late Precambrian to Cambrian metasediments is sometimes preserved unconformably on top of the basement (Andresen et al. 1985). Autochthonous to parautochthonous cover sequences are also found

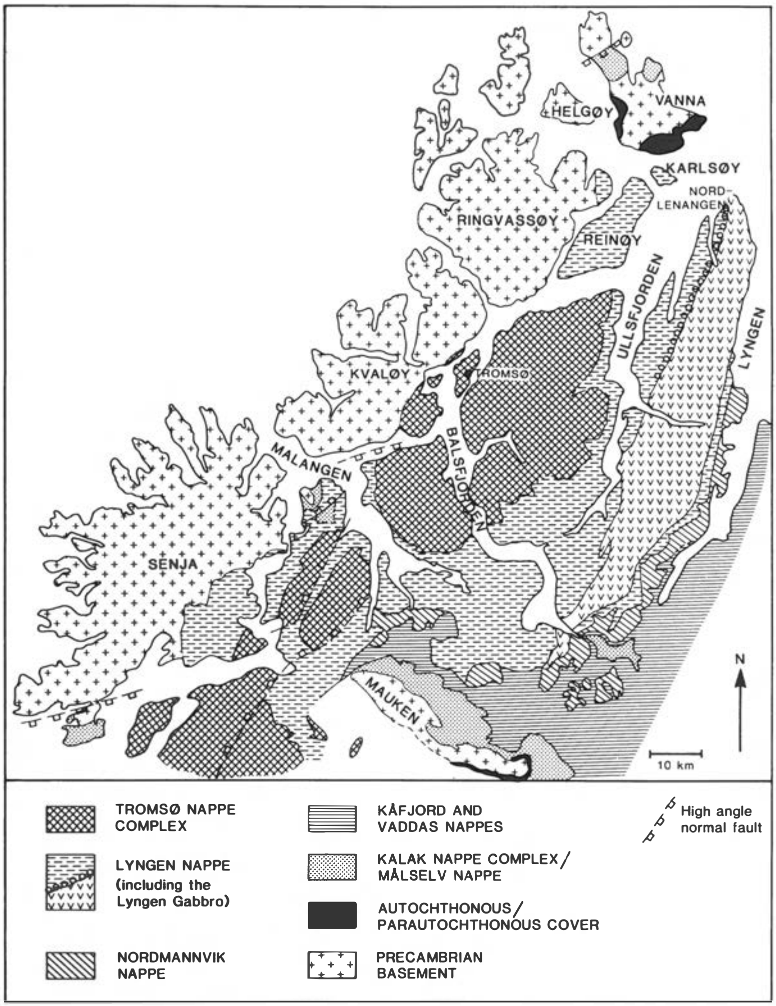

Fig. 1. Simplified geological map of West Troms showing the distribution of the main Caledonian allochthons in the region. The highly sheared rocks on Vanna discussed in the text correlate tectonostratigraphically with the Kalak Nappe Complex.

locally above the Early Proterozoic to Archean rocks making up the Western Basement Region (Bjørklund 1987; Binns et al. 1981). Vanna is one of the few places along the generally intensely deformed basement-cover contact where an unconformity is still recognizable.

The first mapping of the island was done by Pettersen (1887), who showed that most of the island consists of gneisses, presumably Precambrian in age, overlain by Caledonian metasediments along its southern shores. Pettersen also mapped a slice of micaschist in the vicinity of Skipsfjord (Figs. 2, 3). A remapping of the island was carried out about 100 years later by Binns et al. (1981). In their publication most attention was focused on the stratigraphy and depositional environment of the metasediments on the southern part of the island (Fig. 2). However, they did comment on the Caledonian 'schistose rocks' around Skipsfjord, which they interpreted as highly sheared basement orthogneisses.

The dominant basement lithology on Vanna is a variably deformed tonalite/tonalitic orthogneiss. Locally it contains smaller xenoliths of various supracrustal lithologies, including both quartzite

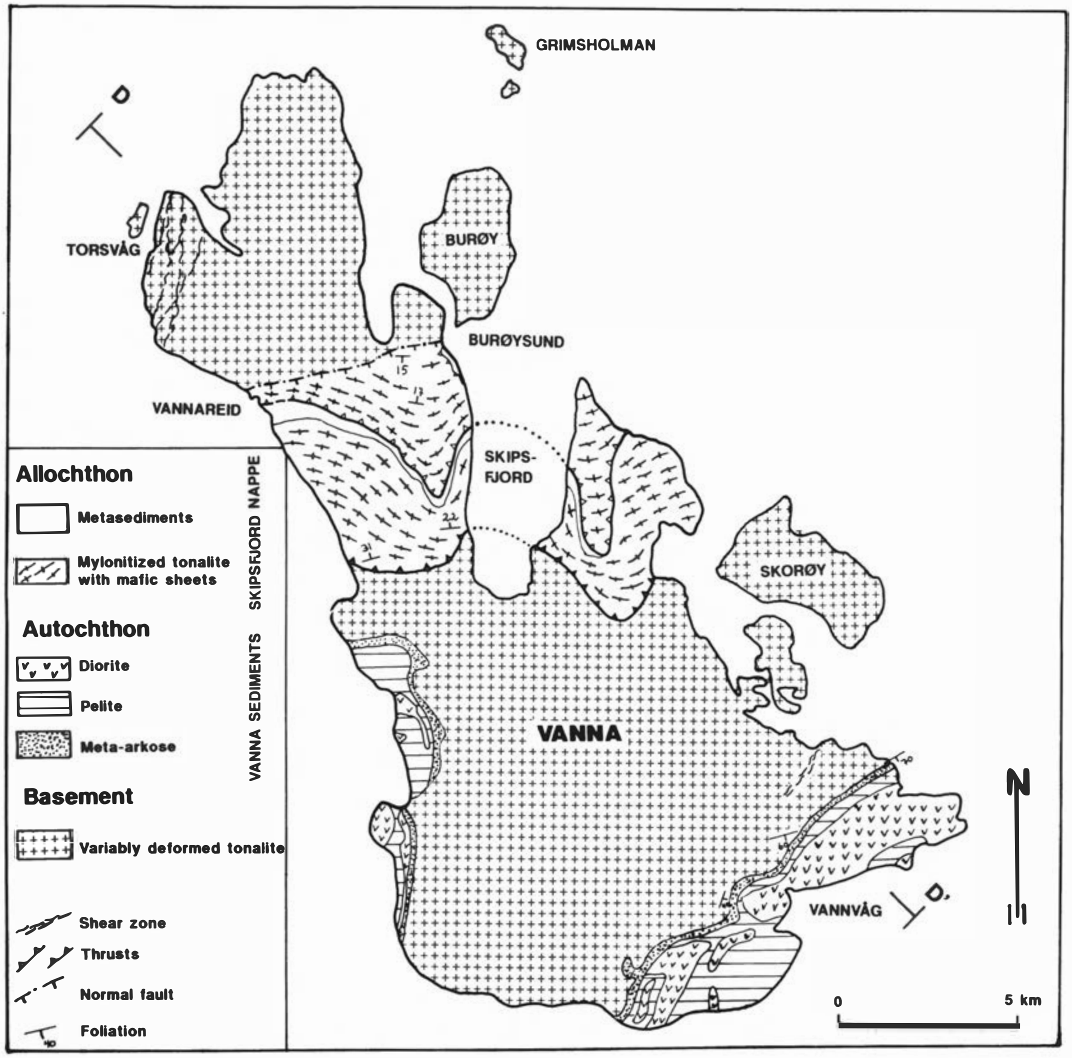

Fig. 2. Geological map of Vanna based on data from Binns et al. (1981), Johansen (1987) (southern half), and our own data.

and conglomerate (Johansen 1987). The tonalite is cross-cut by numerous mafic dikes (Binns et al. 1981; Johansen 1987). The dikes intruded the tonalite prior to formation of the mylonitic gneiss foliation (Johansen 1987). The tonalite is unconformably overlain by a metasedimentary sequence which Binns et al. (1981) subdivided into the Tinnvatn and Bukkheia formations. The former is dominated by arkosic sandstones and minor conglomerate, whereas the overlying Bukkheia formation is dominated by calcareous metapelites. Binns et al. (1981) interpreted the metasediments to have been deposited in a deltaic/shallow marine environment.

The metasedimentary cover is intruded by a gabbro–diorite complex (Fig. 2) which occurs as a sheet more or less concordant with the basement-cover contact. Nowhere are the intrusives seen cutting the basement-cover contact. The metamorphism never exceeded middle greenschist facies (biotite grade) (Johansen 1987). Folding has locally rotated the contact into an almost vertical and even inverted position at several places (Figs. 2, 10). The age of the metasediments is unknown, but by comparison with other described unconformities in the region a Late Precambrian age seems most reasonable (Johansen 1987). Deformation seen in the gneisses and the sediments is considered Caledonian.

The central part of the island is occupied by highly sheared and mylonitized rocks (Fig. 2) which Pettersen (1887) interpreted as Caledonian micaschists, and Binns et al. (1980) as highly sheared basement gneisses. Our initial observations reinforced the interpretation that these rocks are highly sheared basement rocks, probably representing a major shear zone, as apparently less deformed rocks were located northward and structurally above the mylonitic rocks. The aim of this paper is to describe the deformation and kinematics of these sheared rocks.

Lithologic description

The area mapped in this study covers approximately 50 km^2 and is located in an 8 km wide zone across the island southward from Vannareid (Fig. 3). The degree of exposure varies from almost none in the mountainous areas to excellent along the shoreline. Our mapping (Figs. 3, 4) showed the highly mylonitized rocks forming a separate allochthonous unit structurally on top of the less deformed tonalitic gneisses making up the southern part of the island. It also became evident that the tonalitic orthogneisses making up the area north of Vannareid were not part of an upper plate structurally on top of the NW dipping mylonites. Instead it was shown that the northern orthogneisses represent the autochthonous basement which had been uplifted relative to the rocks further south along a south-dipping ENE–WSW striking high-angle brittle normal fault along Vannareid. According to this, the description of lithologies on northern Vanna can be grouped into two major units (1) a Precambrian basement and (2) an allochthonous nappe or nappe complex termed the Skipsfjord Nappe.

Precambrian orthogneisses

Precambrian autochthonous/parautochthonous basement rocks outcrop in two distinct areas: (1) South of Olkeeidet–Skorøy and (2) north of Vannareidet. The dominant lithology is a leucocratic, homogeneous, light grey, medium- to coarse-grained tonalitic orthogneiss. A weak foliation defined by parallel oriented biotite aggregates occurs throughout. The orientation of the foliation is rather variable, except around Torsvåg (Fig. 2) where an anastomosing network of WNW-dipping shear zones is developed. No primary undeformed, unaltered magmatic minerals or textures are preserved, even in the least deformed samples. Quartz, plagioclase (An_{20} to An_{40}) and biotite are the dominant rock-forming minerals occurring in variable proportions. The texture shows irregular, sericitized and partly recrystallized plagioclase grains surrounded by a matrix of finer-grained recrystallized polygonal quartz aggregates. Fine-grained parallel-oriented biotites occur in small aggregates (1–5 mm) with sericite and epidote occurring as inclusions in the biotite. Tourmaline and sphene occur in accessory amounts.

The tonalitic orthogneisses throughout the island are cut by mafic sheets which may be up to 10 m across. Their frequency is about 1 dike per 200–300 m. The dikes are fine-grained, massive to weakly foliated with hornblende, plagioclase, biotite and epidote as the dominant rock-forming minerals.

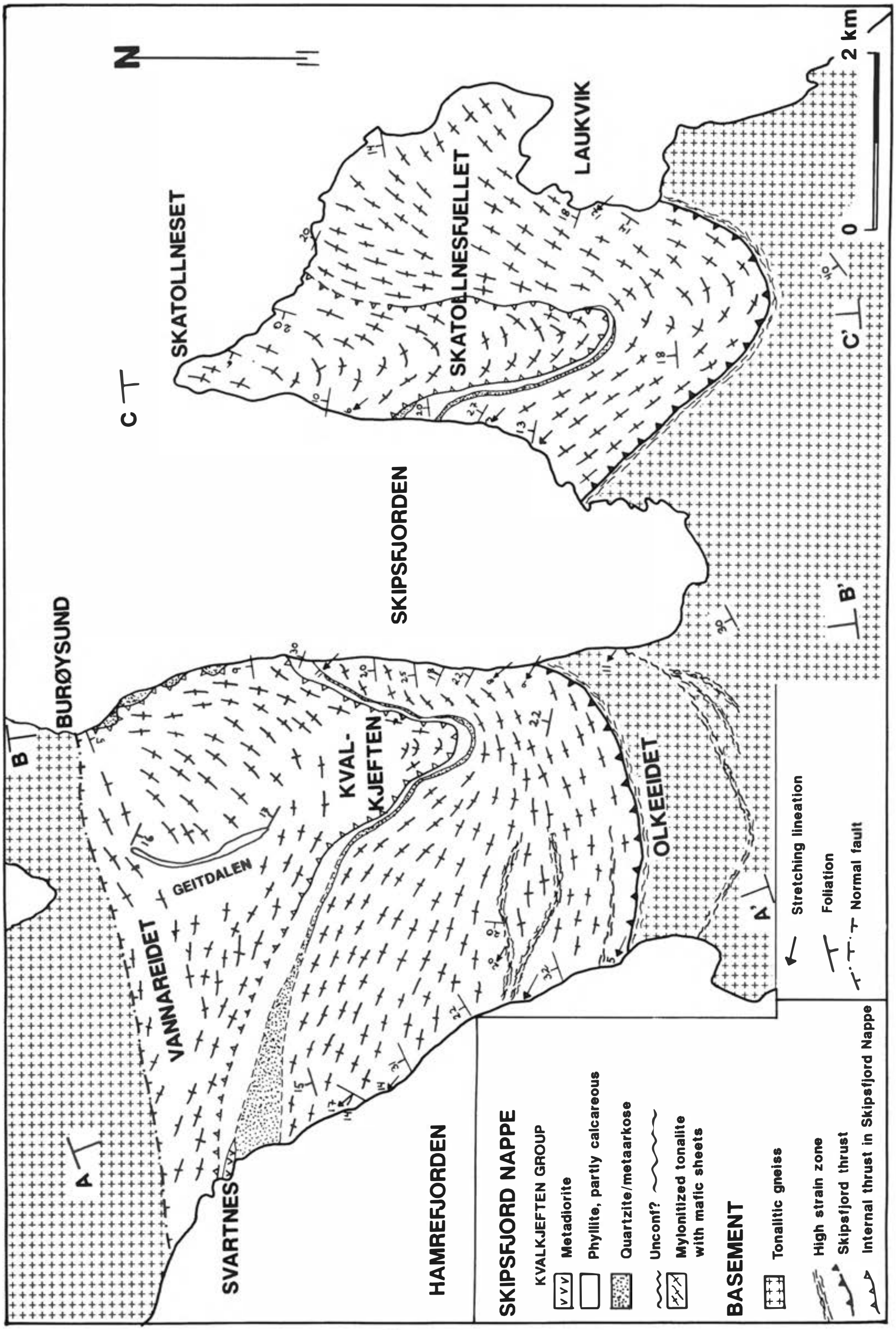

Fig. 3. Geological map of the Vannareid–Skipsfjord area, Vanna.

Skipsfjord nappe

A distinct change in topography and vegetation occurs across Olkeeidet (Fig. 5) and further east across Skipsfjord to Laukvik, which marks the boundary between the basement and the overlying Skipsfjord nappe. South of this contact typically massive tonalitic orthogneisses of the autochthonous basement are developed. A few *narrow* shear zones transecting the foliation in the orthogneisses occur close to and beneath the contact (Fig. 3). These shear zones are west-dipping and subparallel with the contact to the overlying Skipsfjord nappe. The base of the Skipsfjord nappe is marked by the appearance of a fine-grained mylonite. The contact is exposed

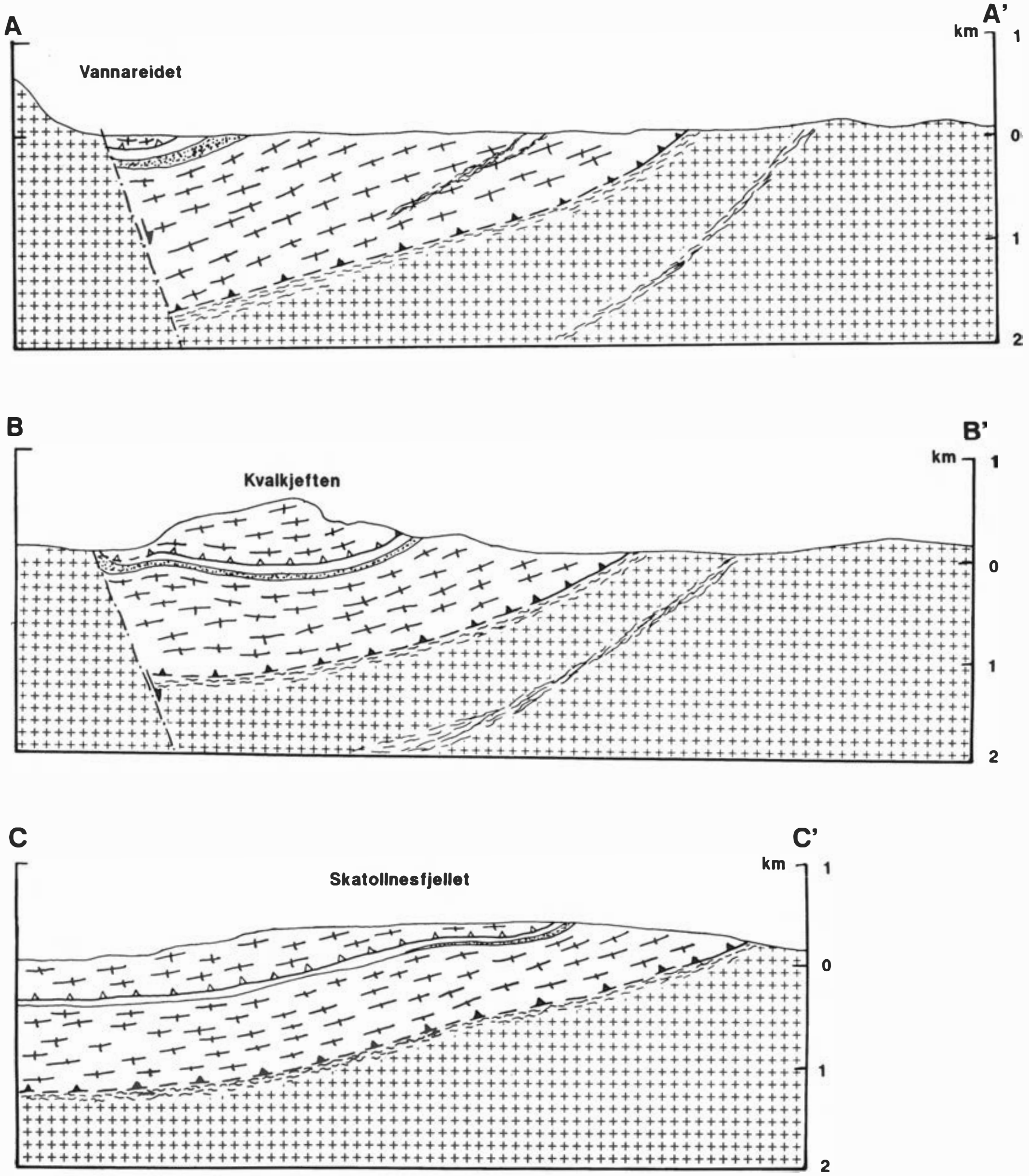

Fig. 4. Geological cross-sections from the Vannareid–Skipsfjord area. Location of profile lines are shown in Fig. 3.

along the shoreline southward from Vannareid (Olkeidet) (Fig. 3). We include all lithologies structurally above the orthogneisses as part of the Skipsfjord nappe.

The Skipsfjord nappe is composed of intensely mylonitized tonalitic orthogneisses, alternating with mylonitized metasedimentary sequences, both units locally containing lenses and layers of mafic rocks.

Based on the distribution of metaigneous and

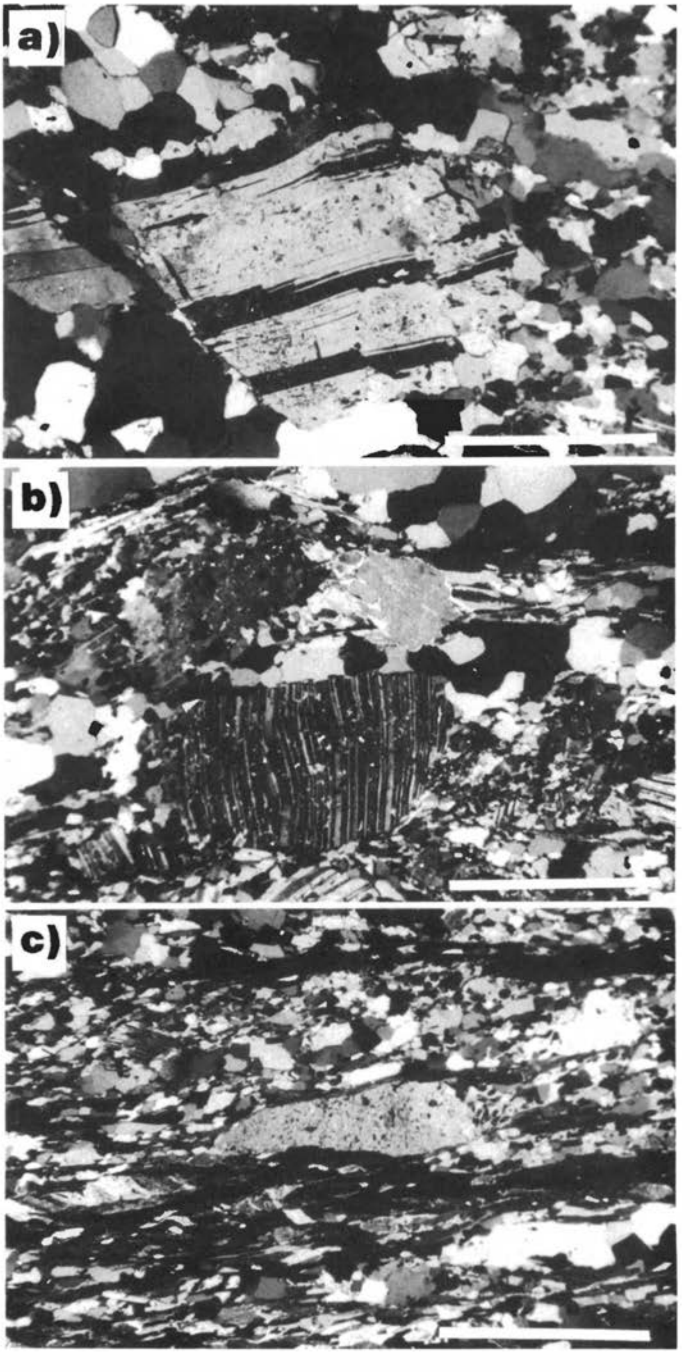

Fig. 5. Photomicrographs of progressively deformed tonalite from the lower mylonite-gneiss sheet. Length of bar is 1 mm.

metasedimentary lithologies the Skipsfjord nappe has been subdivided into three lithotectonic units. These are referred to as the lower mylonite–gneiss sheet, the Kvalkjeften group and the upper mylonite–gneiss sheet respectively.

Lower mylonite–gneiss sheet

The lower mylonite–gneiss sheet occurs at the base of the Skipsfjord nappe. It is well exposed from the base of the nappe at Olkeelv northwards along the shore to Vannareid, and around the southern part of Skipsfjord (Fig. 3). Its structural thickness varies from 800 to 1600 m (see profiles Fig. 4). The lowermost 300–400 m of the gneiss sheet is composed of protomylonitic to mylonitic tonalite orthogneiss interlayered with a very fine-grained, equigranular quartz-rich schistose rock of presumably metasedimentary origin. The upper part of the gneiss sheet is more intensely strained and has the character of a relatively homogeneous mylonite gneiss. Amphibolite and quartzite occur locally. It is not clear whether these belong to the Precambrian gneiss complex or not. The upper boundary against the Kvalkjeften group is sharp and marked by the appearance of a mylonitic medium-grained quartzite. The Kvalkjeften group is interpreted as the depositional cover to the tonalitic gneisses making up the bulk of the lower mylonite–gneiss sheet. However, no basal conglomerate has so far been observed.

The dominant lithology within the lower gneiss sheet is a variably mylonitized tonalitic gneiss with quartz (20–50%) and plagioclase (50–80%) as rock-forming minerals. Other minerals are biotite, chlorite and white mica. Mylonitization generally increases upwards. In its least deformed state at the base of the sheet, both texture and composition appear to be identical to similarly deformed tonalitic orthogneisses of the autochthonous basement. The lower part of the lower mylonite–gneiss sheet is only weakly foliated with some large relict plagioclase porphyroclasts (0.5–3 mm) set in a fine-grained (<0.2 mm) matrix of recrystallized quartz and plagioclase. Other minerals in the matrix are biotite and epidote/clinozoisite. Plagioclase porphyroclasts generally show internal deformation features (deformation twins and micro-faults) and are often sericitized (Fig. 5). Some porphyroclasts display recrystallization textures along the edges.

The more deformed varieties of the gneiss are characterized by a reduction in grain-size, and an increase in white mica and chlorite content relative to the less deformed varieties. The schistosity is also more pronounced (Fig. 5b, c). In its most deformed state (ultramylonite), the rock shows a banded texture with thin laminae of lepidoblastic white mica and chlorite alternating with laminae or layers of granoblastic quartz and feldspar. The quartz–plagioclase layers occasionally contain larger (<1.5 mm) plagioclase porphyroclasts. A characteristic feature of both the mylonites and the ultramylonites is a pronounced stretching lineation oriented NW–SE (Fig. 8).

A characteristic feature of the lower mylonite–gneiss sheet is the occurrence of numerous sheets of mafic rocks. These mafic sheets share the same mylonitic deformation as the surrounding tonalite gneisses and are oriented subparallel to the gneiss foliation. These mafic layers are interpreted as pretectonic sills or dikes. The sheets vary from 0.5 to 5 mm in thickness. The primary igneous mineralogy and texture is now transformed into a fine- to medium-grained hornblende–epidote–biotite schist with minor plagioclase and locally occurring idioblastic garnet. The thinner dikes characteristically have well developed schistosity and a higher proportion of biotite and chlorite relative to hornblende than the more massive thicker ones.

Kvalkjeften group

The metasediments of the Kvalkjeften group have a sharp contact against the tonalitic mylonite gneisses of the lower sheet. The contact against the upper thrust sheet is also sharp, and a highly schistose quartzite characterizes the uppermost decimeters or so of the Kvalkjeften group. The structural thickness of the group varies from 20 to 100 m, with a general thinning eastwards most probably due to increasing strain in this direction. The best profiles through the group are found along the eastern shorelines of Skipsfjord between UTM coordinates 556870 and 556876 on map sheet 1535 II, and in the steep slopes of Skotallnesfjellet (Fig. 3), just north of the shore section. We have subdivided the group informally into two formations (Fig. 6) based on distinct lithological variations between the lower and upper portions of the group. The lower formation is named the Geitdalen formation and the upper the Brattfjell formation. A simplified composite

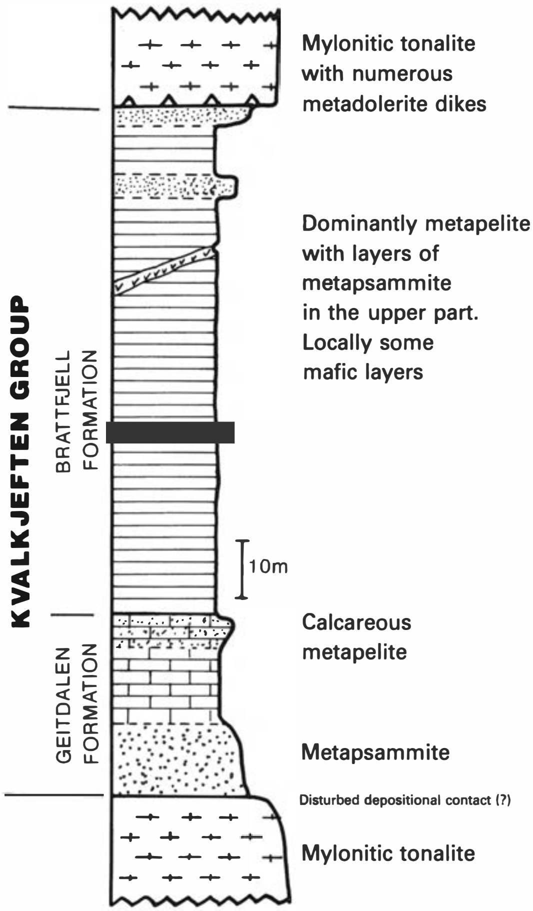

Fig. 6. Simplified columnar section through the Kvalkjeften group. Indicated thickness is only approximate.

vertical section through the Skipsfjord group is given in Fig. 6.

Geitdalen formation

The Geitdalen formation is dominated by psammites. A weakly foliated meta-arkose is found everywhere immediately above the lower tonalitic gneisses. Although no basal-conglomerate has been found we tentatively interpret this contact as a tectonized depositional contact. The basal meta-arkose is overlain by white to yellowish-white meta-arkoses and quartzites. These rocks display a weak compositional layering. These are in turn overlain by 20 m of alternating dark grey metasiltstone and lighter coloured mica-rich layers, the latter approximately 1–2 cm in thickness. Two 0.2–0.4 m thick layers of yellowish, medium-grained meta-arkose are typical of the uppermost 5 m of the Geitdalen formation.

Brattfjell formation

A characteristic brownish weathering calcareous 'button schist' marks the beginning of the Brattfjell formation. Its structural thickness is uncertain because of poor exposure, but is somewhere between 15 and 30 m. On fresh surfaces lensoid aggregates of carbonate are observed surrounded by thin anastomosing layers of mica. The texture is clearly of tectonic origin, most probably formed by folding and associated cleavage development in a sequence of alternating carbonate and shale lamina (Lister & Snoke 1984).

The carbonate content decreases upwards and the bulk of the Brattfjell formation is dominated by a grey metasiltstone with thin more pelitic layers. The latter are often characterized by a secondary transposition cleavage that has destroyed the primary lamination. Several thin psammitic layers (meta-arkoses), up to 0.5 m in thickness, are found in the uppermost 20 m of the formation.

Intrusives

Two types of intrusives, metadolerites and metadiorites, are recognized in the Skipsfjord nappe. The metadolerites are restricted to the upper part of the Brattfjell formation, where they occur as up to 1.5 m thick sheets subparallel to the dominant foliation in the rock. Their mineralogy and texture is almost identical to the mafic dikes described from the lower mylonite sheet.

Diorites intruding the metasediments of the Kvalkjeften group are observed at Vannareid and along the western shore of Skipsfjord. The diorites are variably deformed. The diorites at Skipsfjord are light grey, medium-grained and resemble those intruding the metasediments on southern Vanna (Binns et al. 1981; Johansen 1987). The diorite at Vannareid is however more strongly altered, and now occurs as an amphibolite/greenschist with a distinct secondary foliation.

Upper mylonite–gneiss sheet

The upper mylonite–gneiss sheet is compositionally identical to the lower mylonite–gneiss sheet. Texturally the mylonite gneisses of the upper sheet are in general finer grained and schistose than those in the lower mylonite–gneiss sheet. However, locally there are lenses or boudins of more coarse-grained massive tonalitic rocks. Where measurements have been possible the longest and intermediate axes in the boudins define a plane that is subparallel to the regional foliation. The longest axis is up to 2 m long and is oriented NW–SE. We prefer to interpret these lenses as tectonic lenses of less deformed protolith ('mega-porphyroclasts') that have escaped the intense strain seen in the surrounding mylonite gneisses. In Geitdalen (Fig. 3) a 2–6 m thick sequence of quartzite was found interlayered with the tonalitic mylonite gneisses. Its extent and significance is not clear, but it may indicate that the upper mylonite gneiss sheet is composed of two or more basement slices, locally with their cover sequence preserved.

Mafic dikes also occur in the upper mylonite–gneiss sheet (Fig. 7). Their appearance, texture and mineralogy are almost identical to those of the mafic sheets found in the lower mylonite–gneiss sheet.

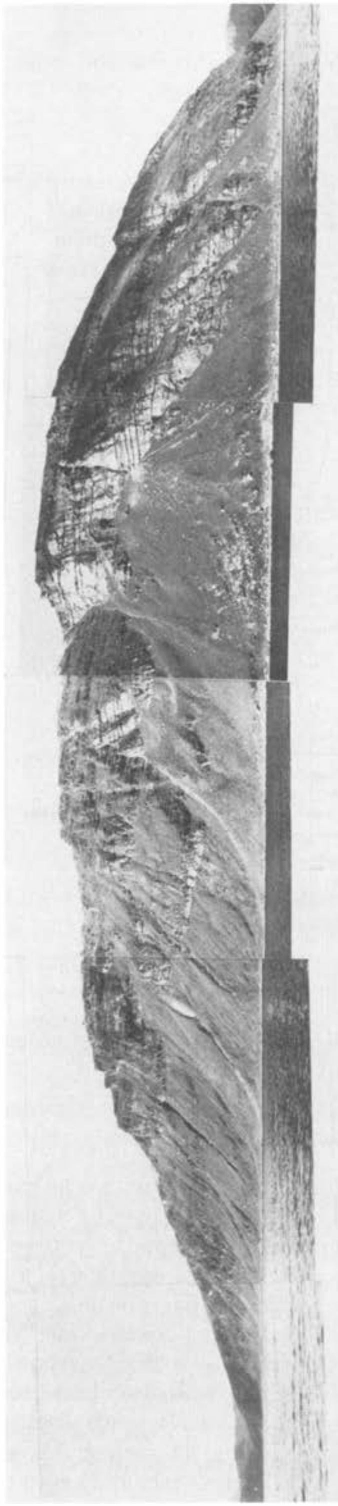

Fig. 7. The eastern cliff-face of Kvalkjeften mountain seen from Skipsfjorden, displaying interlayered mafic sheets (dark horizontal lines) and tonalite (light lithology) of the upper mylonite–gneiss sheet. The thrust at the base of the upper mylonite–gneiss sheet follows the shoreline on the right-hand side of the photo, and is located above the scree on the left-hand side of the photo. Height of cliff is approx. 600 m.

Metamorphism

The metamorphic grade has not exceeded greenschist facies as indicated by the mineral assemblage quartz + plagioclase + white mica + biotite ± chlorite in the tonalitic mylonite gneisses. White mica + biotite are also common minerals in the pelitic and semipelitic lithologies of the Skipsfjord group. Biotite growing across the dominant mylonitic foliation (S_1) is commonly observed, indicating that middle greenschist facies conditions outlasted the mylonite forming event.

The common mineral assemblage in the mafic sheets is hornblende + biotite + epidote + plagioclase ± garnet, indicating P–T conditions typical of upper greenschist facies/lower amphibolite facies. The idioblastic garnets have grown across the dominant foliation (S_1), suggesting that the metamorphic peak was reached at a relatively late stage or possibly post-dates the mylonite forming event. The alteration of biotite and amphibole to chlorite in the mafic sheets is considered a late breakdown reaction following the metamorphic peak.

Structural geology

The dominant structural elements in the area are: (1) a NNW-dipping mylonitic foliation, in both the basement tonalite and the allochthonous sheets (lower and upper mylonite–gneiss sheets, and the Skipsfjord group), which is later deformed by (2) superimposed kink folds; (3) a system of steeply-dipping anastomosing shear zones in the basement north of Vannareid (Fig. 2); and (4) a major, brittle post-Caledonian normal fault across Vannareid (Vannareid fault zone). A brief description is given below of the geometry of these structural elements, followed by a kinematic analysis.

Mylonitic foliation

A mylonitic foliation is recognized in the autochthonous basement, the lower mylonite–gneiss sheet, the Skipsfjord group and the upper mylonite–gneiss sheet. All stages from protomylonite to ultramylonite are recognized in the basement tonalite. The degree of mylonitization increases towards the contact with the overlying lower mylonite–gneiss sheet, although isolated shear zones also exist away from the contact. A distinct L–S fabric appears to be restricted to the uppermost part of the basement. Both the mylonitic foliation (S_1) and the stretching lineation (L_1) in the basement orthogneisses are co-planar and colinear with the respective structural elements in the overlying nappe rocks. Thin section studies have so far not revealed reliable shear sense indicators (rotated porphyroblasts, S–C mylonites, etc.), most probably due to the high strain these rocks have undergone.

Both the lower and upper mylonite–gneiss sheets, as well as the Skipsfjord group, are characterized by L–S tectonites. The mylonitic foliation in the allochthonous tonalite varies from mylonite–gneiss to ultramylonite. The foliation (S_1) in the mylonitic gneisses is defined by 0.1–0.5 mm thick laminae of lepidoblastic white mica and chlorite surrounding porphyroclasts of plagioclase. Mica content appears to increase with increasing mylonitization. A prominent stretching lineation (L_1) occurs throughout the mylonite gneisses, generally defined by elongate plagioclase porphyroclasts with tails of quartz. Small-scale quartz rodding (0.2–1.0 cm in width) and elongate mineral aggregates of quartz and plagioclase define L_1 in the more fine-grained, schistose mylonites.

The metasediments are characterized by a different kind of foliation. It is a penetrative cleavage defined by parallel-oriented mica in the pelitic layers. In some samples this cleavage is clearly a transposition cleavage. Only the psammitic layers display an L_1 lineation.

The S_1 foliation is oriented with a strike approximately 30°–40° with a shallow dip towards NW in the basement as well as in the allochthonous units (Fig. 10a). Also the stretching lineation is coaxial in basement and allochthonous units, trending 330° and with plunge between 20 and 30° towards NW (Fig. 8b). Shear-sense indicators such as mica-fishes and asymmetric feldspar porphyroclasts (Lister & Snoke 1984) suggest movement of the upper plate towards the SE.

Post-mylonitic folds (F_2)

The S_1 foliation and L_1 lineation in the Skipsfjord nappe are folded by two sets of folds: (1) small-scale kink folds (up to a few centimeters in amplitude, but commonly mm size): (2) late N–S trending large-scale open flexures which refold both the mylonitic foliation and the kink folds. The small-scale kink folds are best developed in the schistose units (mylonite gneisses and ultramylonites), and the fold axes trend approximately 60°. The kink folds are consistently overturned towards SE.

Torsvåg shear zone

A system of anastomosing ductile shear zones trending approximately 10° and dipping steeply westwards cut through the tonalite in the area south of Torsvåg. The individual shear zones are easily recognized on aerial photographs as narrow valleys and clefts. Fig. 9 is a simplified structural map showing the distribution and surface geometry of the main shear zones as they have been recognized on aerial photographs. The correctness of the map has been verified by several traverses across Torsvåg shear zone.

The preliminary field observations have revealed several interesting features regarding this anastomosing network of shear zones: (1) the shear zones cut across a pre-existing foliation defined by parallel-oriented biotite porphyroblasts. Good examples of this are seen in a quarry approximately 500 m south of the pier at Koja; (2) hydrothermal quartz veins appear to be loca-

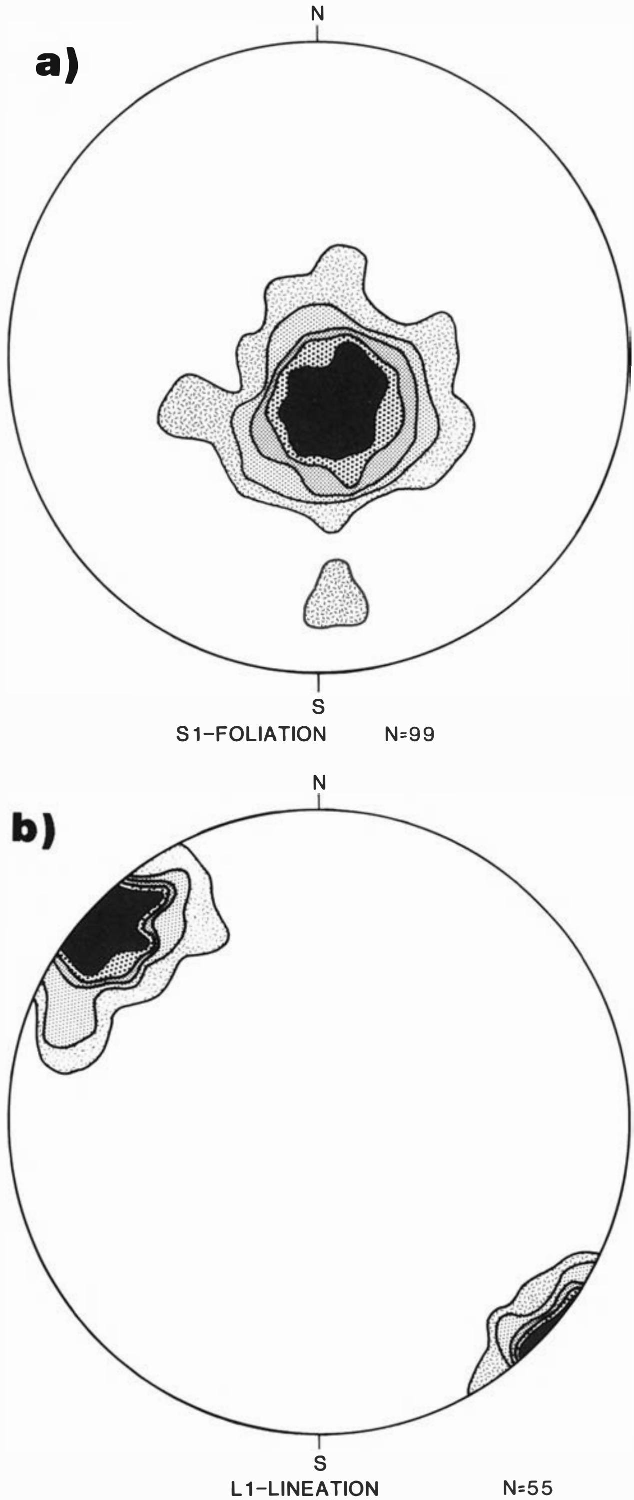

Fig. 8. Stereographic projection of structural observations: (a) poles to mylonitic foliation (S_1); (b) stretching lineations. The data are plotted in an equal area, lower hemisphere projection.

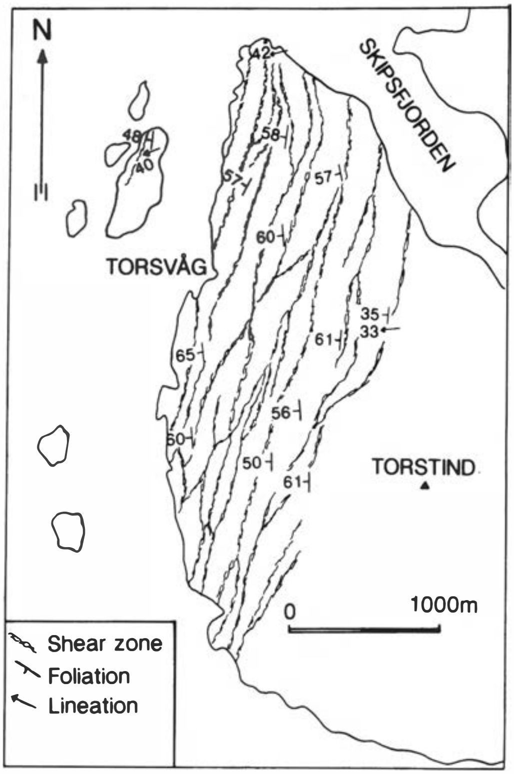

Fig. 9. Simplified structural map showing the geometry of the Torsvåg shear zones.

lized to the shear zones; (3) some of the shear zones are associated with mafic dikes and (4) the tonalite making up the country rock is transformed into a grey schistose rock with scattered plagioclase porphyroclasts (2–10 mm across) in the shear zones. These mylonites resemble the mylonitic orthogneisses of the Skipsfjord nappe, but differ somewhat in that they have a lower content of white mica and chlorite and larger plagioclase porphyroclasts. Another observation is the occurrence of small biotite and garnet porphyroblasts in the former.

Post-Caledonian (Mesozoic?) brittle faults

Termination of the Skipsfjord nappe northward is controlled by a major ?post-Caledonian brittle fault following the valley between Vannereid and Burøysund (Figs. 3, 4). Several minor brittle faults striking approximately ENE and dipping steeply towards SW occur along the shore section south of Burøysund. The change in orientation of the mylonitic foliation into a steep southeasterly dip against the faults suggests normal movement across the fault. Minimum throw across this fault has to be of the order of 2–3 km based on offset of the contact between the autochthonous basement and the Skipsfjord nappe (Figs. 3, 10). The ENE trend and clearly brittle nature of this fault suggest a correlation with a NE-trending fault system recognized further south, which Andresen & Forslund (1987) linked to the Mesozoic half-grabens between Lofoten and the mainland to the south (Vestfjorden Basin).

Discussion and conclusion

The rock types and structural relationships presented above demonstrate that Caledonian cover rocks are present on northern Vanna, as suggested by Pettersen (1887). However, the tectonic setting of the inferred Caledonian rocks on northern Vanna is distinctly different from the basement-cover relationship described by Binns et al. (1981) and Johansen (1987) from southern Vanna. On southern Vanna a relatively well-preserved sedimentary sequence makes up the Caledonian cover rocks, whereas highly mylonitized basement rocks of allochthonous origin, interleaved with minor metasedimentary sequences, make up the Caledonian cover sequence, the Skipsfjord nappe, around Vannareid. The Skipsfjord nappe is composed of a lower and an upper mylonite–gneiss sheet separated by the metasedimentary Kvalkjeften group. Based on the dramatic increase in strain between the tonalitic gneisses dominating the southern half of the island and the tonalitic mylonite–gneiss sheet underlying the Kvalkjeften group, we prefer to interpret the mylonite gneisses as allochthonous rather than mylonitized autochthonous/parautochthonous basement. The definite proof of this interpretation would be to find a basal conglomerate/quartzite along the transition from strongly tectonized to less tectonized tonalite gneiss. Such a lithology has yet to be found. Our interpretation of the basement/cover relationships is given in Fig. 10.

The occurrence of a very persistent quartzitic unit along the contact between the lower mylonite gneiss and the Kvalkjeften group suggests that this assemblage represents an intensely deformed allochthonous 'basement-cover' association.

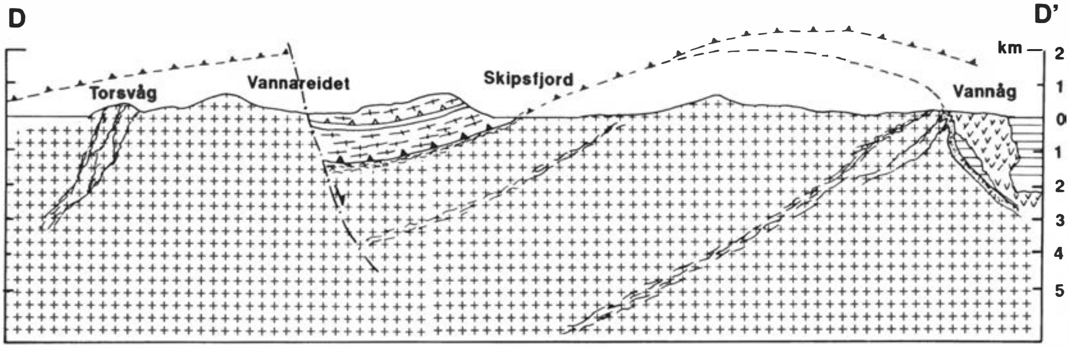

Fig. 10. Simplified NW–SE profile across Vanna showing the possible relationship between the basement tonalite, allochthonous mylonite gneisses and the autochthonous cover sequence. Position of profile line is shown in Fig. 2.

Intensely deformed basement-cover associations are typical of the Kalak Nappe Complex (Middle Allochthon) in Finnmark (Ramsay & Sturt 1977; Ramsay et al. 1979, 1985). The age of the allochthonous cover sequences (the Sørøy stratigraphy (Ramsay 1971)) in Finnmark is not well known, although a Late Precambrian to Early Cambrian age is suggested by most workers (Ramsay et al. 1985). A similar age is suggested for the metasediments of the Kvalkjeften group. The proposed correlation between the Caledonian rocks on Vanna and the Middle Allochthon is further strengthened by the occurrence of mafic sheets, most probably representing sills or transposed dikes, in the former; particularly the mylonite–gneiss sheet. Mafic dikes are a characteristic feature of the higher tectonic units within the Middle Allochthon (Solyom et al. 1979; Roberts & Gee 1985; Gayer et al. 1985), and are in most cases interpreted as rift-related dikes intruding the stretched western margin of Baltica and its overlying Late Precambrian metasediments at an early stage in the opening of the Iapetus Ocean. A similar age and scenario is envisioned for the emplacement of the mafic sheets in the mylonite gneisses on Vanna. It is hoped that a geochemical investigation of these dikes, now in progress, will confirm this interpretation.

From the map and cross-sections it seems well documented that the tonalitic mylonite gneiss occurring south of Vannareid is allochthonous, and not just sheared autochthonous basement rocks as suggested by Binns et al. (1981). The emplacement direction of the Skipsfjord nappe was most probably from NW, as indicated by the relatively consistent orientation of the stretching lineation and shear-sense data observed throughout the nappe. It is not possible to estimate the displacement distance of the Skipsfjord nappe. The presence of tonalite in the nappe, as well as in the basement, may indicate that the root zone was not too far to the NW.

An unanswered question is the structural status of the 'basement tonalite' making up most of the bedrock on Vanna. The basement tonalite is clearly affected by Caledonian deformation, particularly on the NW corner of the island, where the tonalite is transected by an anastomosing system of steeply dipping shear zones. Two possibilities exist: (1) the basement tonalite is allochthonous and forms part of a major basement sheet within the Middle Allochthon but at a lower structural level, or (2) the basement tonalite is truly autochthonous/parautochthonous. Based on the differences in strain between the Skipsfjord nappe and the underlying units, we prefer the second alternative. However, it is obvious that the solution to this problem depends on regional correlations. Such correlations are complicated by the presence of many large post-Caledonian (Mesozoic?) brittle faults in western Troms and northern Nordland offsetting the basement-cover contact by up to 2–3 km (Andresen & Forslund 1987). One such fault cuts across Vanna at Vannareid and is responsible for the northward termination of the Skipsfjord nappe.

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