The structure and regional setting of the Skei Group, Leka, north-central Norway

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The unconformity between the metasedimentary Skei Group and subjacent ophiolite on Leka has important implications for the tectonostratigraphy of the region. As a distinctive marker horizon, it permits correlations within and between nappes and provides a datum level on which to establish lithostratigraphies in the several units of the Helgeland Nappe Complex. The unconformity records a major change in the pattern of events and partitions the tectonothermal history into two polyphase orogenies, whose individual effects can be recognised in many nappes along the whole length of the belt. Deformations predating the unconformity relate to ocean-floor tectonics and a subsequent phase of regional tectonothermal development.

The Skei Group records two fold phases accompanied by low-grade regional metamorphism. The distinctive lithostratigraphy facilitates delineation of macroscopic folds, whose geometry indicates that the whole outcrop lies within the inverted limb of the major D1 Leknes Syncline. This, in turn, controlled the attitude of mesoscopic D2 folds which are themselves parasitic to the large-scale Austra Antiform, one of a regional system of near-symmetrical late folds which affect both the Helgeland Nappe Complex and its substrate.

The litho- and tectonostratigraphic relationships established on Leka and extended to the adjacent mainland reiterate a theme currently being espoused for the evolution of the whole Scandian belt, namely dissection and disruption by Scandian thrusts of a cratonic substrate, already structured into a Finnmarkian and in part Late Ordovician nappe pile.

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Introduction

The bedrock geology of the island of Leka comprises the Leka Ophiolite Complex (LOC) and the unconformably overlying, probably Lower to Middle Ordovician metasediments of the Skei Group (Sturt et al. 1985). These rocks were assigned to the Upper Allochthon by Roberts & Gee (1985), though they are most likely to be part of the Helgeland Nappe Complex (HNC) of the Uppermost Allochthon (Furnes et al. 1988). This latter interpretation is based on a correlation of the ophiolite fragments of the region (Sturt 1984, Sturt et al. 1984). Many details of the LOC are given in Furnes et al. (1988) and the reader is referred to this as an essential source reference.

The metasedimentary rocks of the Skei Group have been described in some detail by Sturt et al. (1985), who confirmed the general proposition of Birkeland (1958) that they were: "a younger sequence overlying an older complex of basic and ultramafic rocks", the latter now known as the LOC. The break between the two was, however, not noted by Prestvik (1974, 1980) or by Prestvik & Roaldseth (1978). The latter authors, however, identified the igneous suite as the LOC. The sedimentary rocks of the Skei Group were reassessed by Prestvik (1980) as the cap-rock to the LOC and hence essentially eugeoclinal in character. Sturt et al. (1985), on the other hand, clearly demonstrated that the sediments of the Skei Group had been deposited unconformably on a deeply eroded substrate of the LOC. The lithostratigraphy (Table 1) and palaeogeographic interpretation of the Skei Group were further refined including the recognition of the continental character of the unconformity, with a variably preserved regolith in the upper levels of the substrate. Quartz keratophyres intruding sheeted mafic dykes, immediately below the unconformity, have been dated (U-Pb zircon) at 497±2 Ma (Dunning & Pedersen 1988) and provide a maximum age constraint for the base of the Skei Group.

A number of smaller ophiolite fragments, with a similar tectonostratigraphic setting, have been identified in the HNC (Sturt 1984, Sturt et al. 1984, Bang 1985, Heldal 1987, Husmo & Nordgulen 1988, Thorsnes & Løseth 1991). Nordgulen & Schouenborg

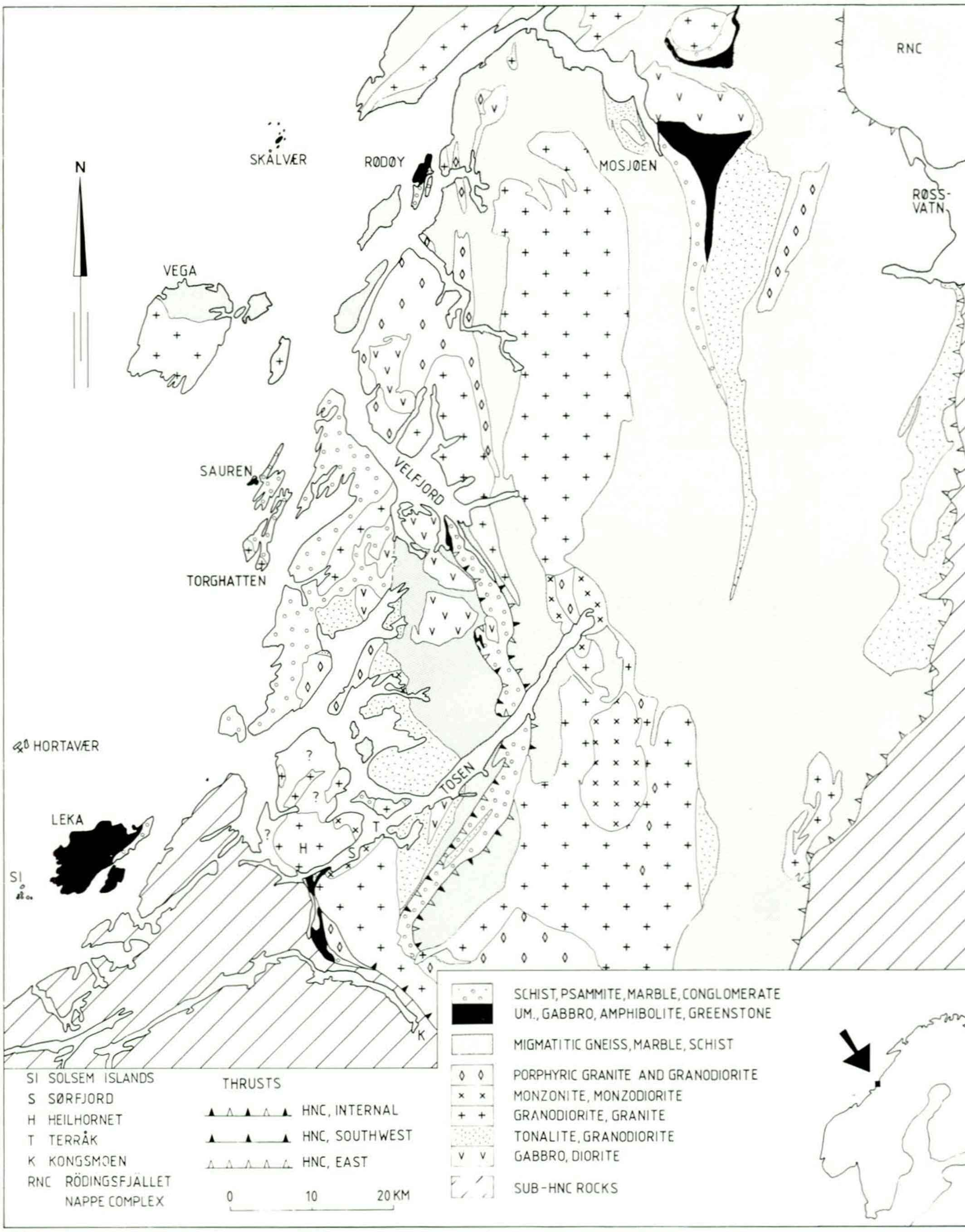


Fig. 1.Simplified tectonostratigraphic map of northern Vestranden. (Prepared by T Thorsnes,NGU).

(1990) demonstrated that the granitic Heilhornet Pluton cuts both such ophiolite fragments and their deformed/metamorphosed cover sequences (Fig. 1). They provided a U/Pb zircon age of 444±11 for the Heilhornet Pluton, thus giving an upper age con-

PRESTVIK (1974)		STURT et. al. (1985)		
SKEI FORMATION	black schist & siltstone			
	u. conglomerate			
	volcanic sequence	black slate (sandstone + conglomerate)	HAVNA FM.	SKEI GROUP
	greywacke & black schist	sandstone (+conglomerate)		
	marble	marble		
	conglomerate	conglomerate	STEGAFJELL FM.	
STORØYA FORMATION	ophiolite complex	ophiolite complex	LOC	

Table 1. Lithostratigraphy of the Skei Group (Sturt et al. 1985) and comparisom with the nomenclature of Prestvik (1974).

straint for both the deposition and the initial deformation of the Skei Group; assuming that the correlation of the cover sequences is viable.

On the wider scale, unconformable cover sequences, usually of continental derivation in their lower part, overlying ophiolite complexes are widespread in the Scandinavian Caledonides, and these occurrences are summarised in a recent review paper (Sturt & Roberts 1991). The present paper is concerned particularly with details of the structural geology of the Skei Group, the geometrical relationships between the Skei Group and the LOC and with evidence for pre-unconformity deformation and metamorphism of the LOC.

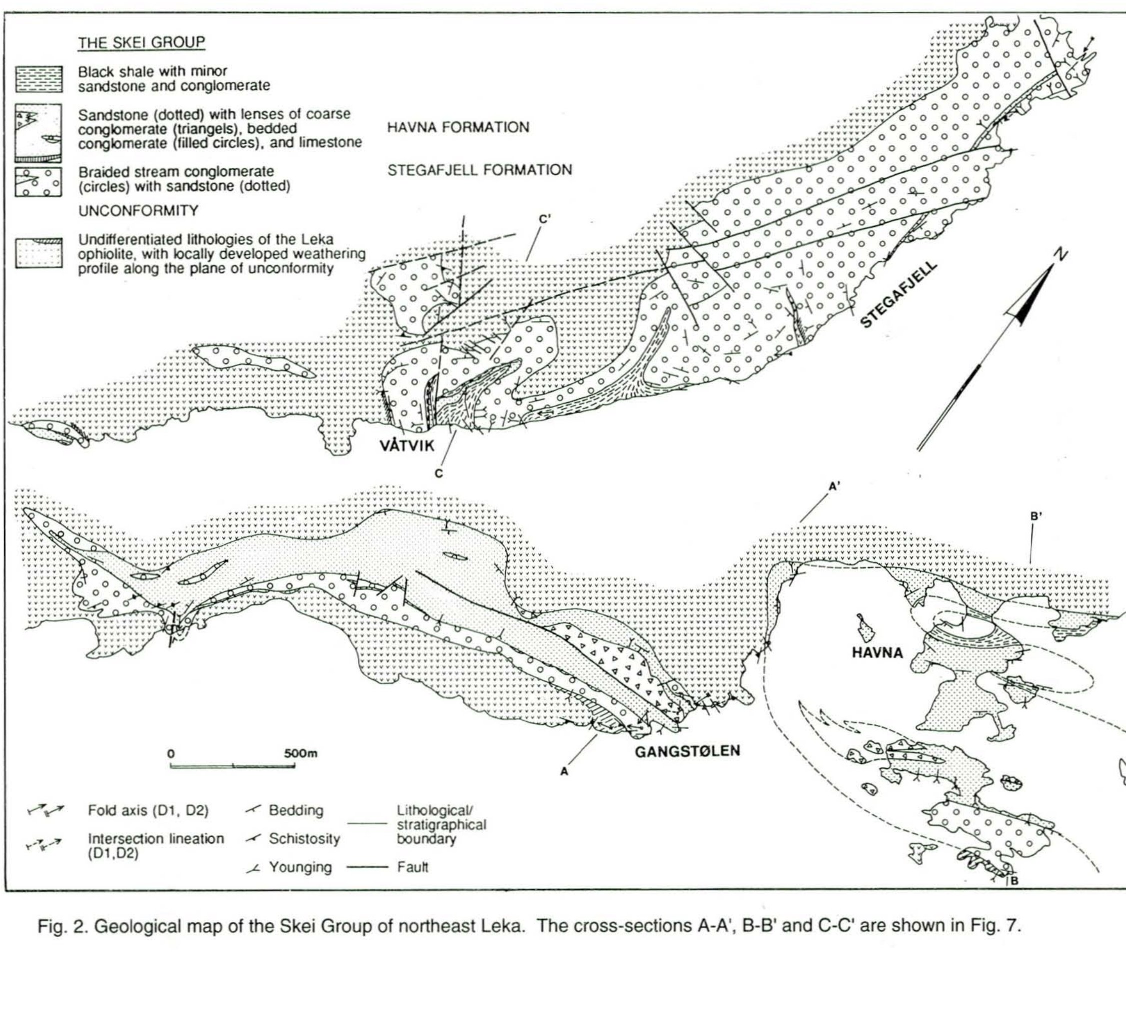


Fig. 2. Geological map of the Skei Group of northeast Leka. The cross-sections A-A', B-B' and C-C' are shown in Fig. 7.

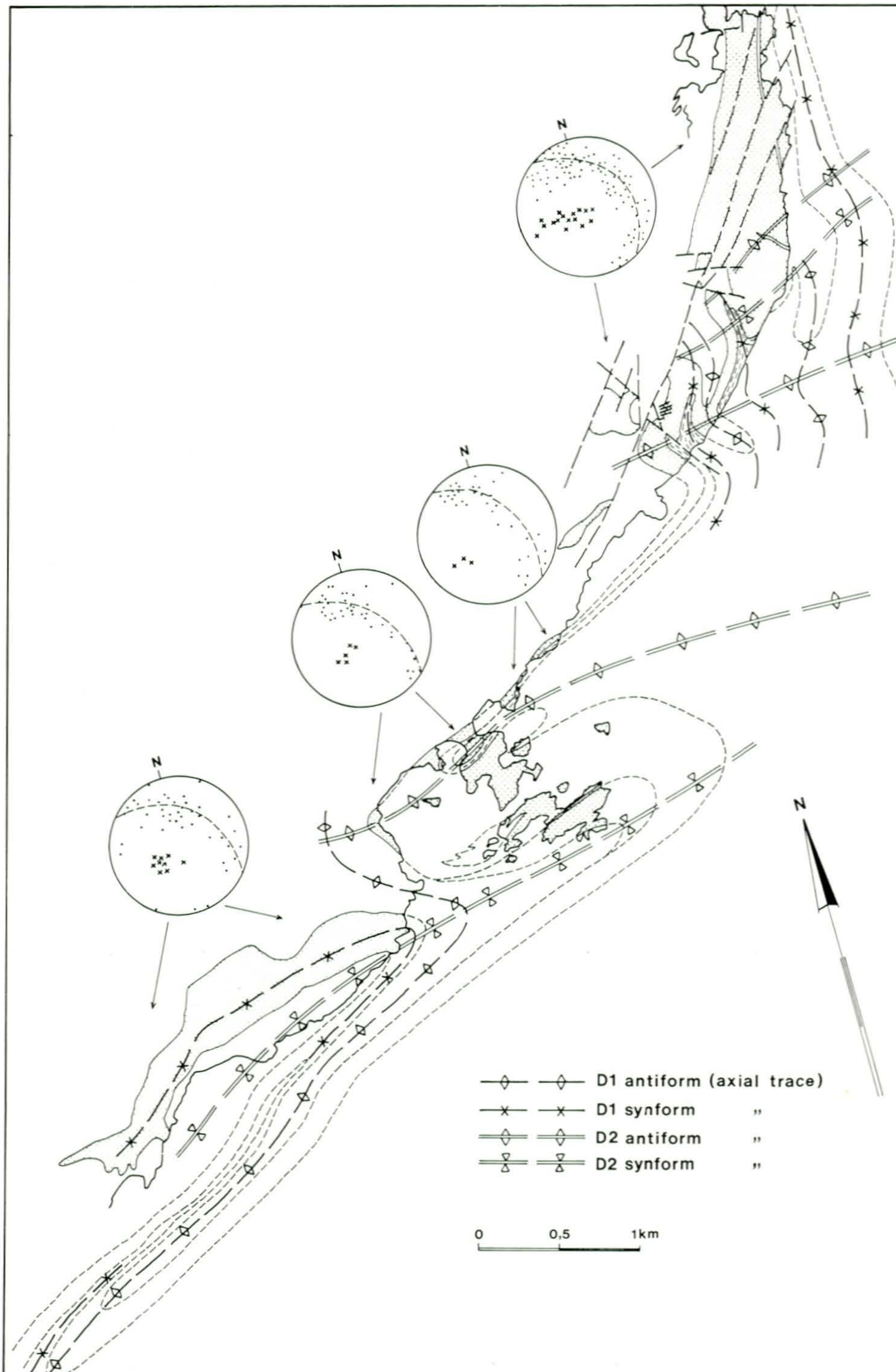


Fig. 3. Structural map of the Skei Group (dotted ornament). Small stereograms present attitudes of poles to bedding and S1 (dots), and of D2 fold axes (crosses), for four sub-areas.

Structure of the Skei Group

The structural history of Leka records a complex sequence of events spread over at least two orogenies and extending back, in the case of the ophiolite, to pre-orogenic deformation associated with the formation of the complex. The unconformity at the base of the Skei Group denotes a significant time interval between two orogenic sequences during which uplift and erosion unroofed the metamorphic Solsemøy Formation (Furnes et al. 1988) and the LOC. In so doing, it distinguished pre- and post-unconformity tectonism. The dominant Caledonian fabric of the island is post-Skei Group in age. Polyphasal deformation in greenschist facies created both large- and small-scale folding and associated phenomena in the Skei Group. This deformation is locally penetrative, although sizeable areas may be little affected by structures of any one tectonic phase.

First phase of deformation

Along its landward margin the Skei Group dips steeply westwards, beneath the rocks of the LOC, inverted in the limb of a large D1 fold (Leknes Syncline) with NNE-SSW axial trend (Figs 2, 3 & 9). Macroscopic z-folds with amplitudes up to 1 km in the Gangstølen-Hylla, Våtvik and Stegafjell areas are parasitic structures to the main fold (Figs. 3 & 7). Of these the Gangstølen-Hylla fold is a recumbent, westerly-closing syncline tightly folded by an upright D2 synform (Fig. 7). The form of the D1 syncline is delineated by the one-sided core of the Skei Group, sandwiched between upper and lower developments of ophiolite (Figs. 3 & 7), and confirmed by the unconformity and its attendent development of metasol. In addition to this, an abundance of sedimentary structures young away from the LOC towards the core of the syncline (Fig. 2). High D1 strains in the isoclinal core are reflected in a strong foliation within the metasol and a strong planar alignment of flattened pebbles in conglomerates of the Skei Group.

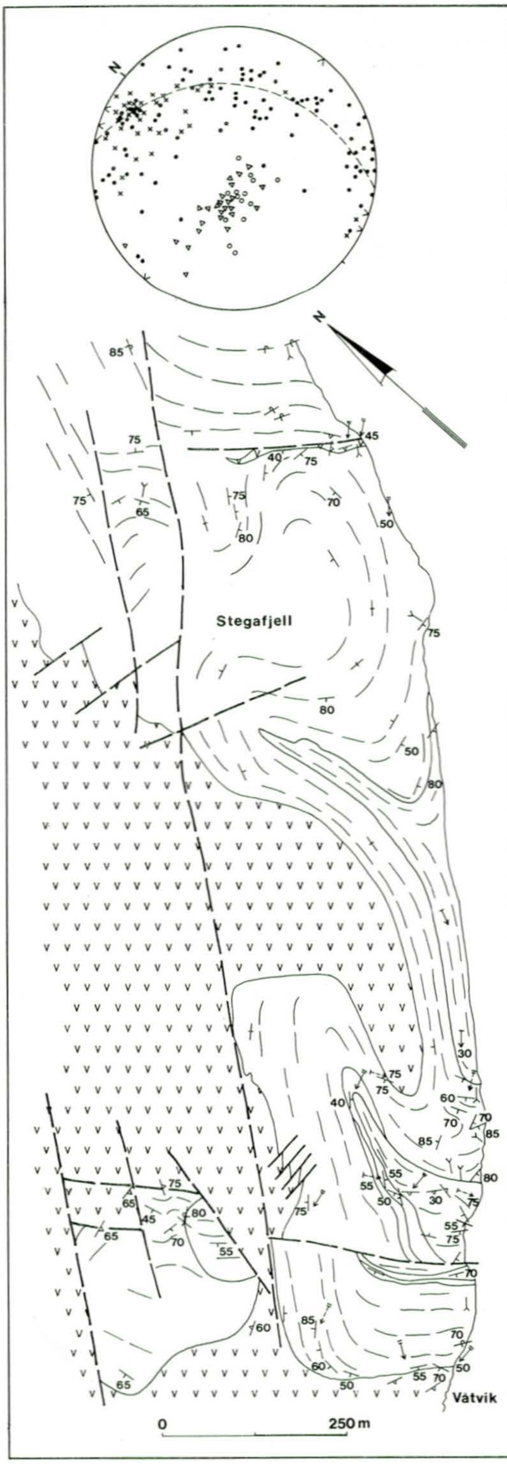


Fig. 4. Structural map of the Våtvik-Stegafjell sub-area Stereogram presents structural data: dots - poles to bedding and S1; crosses - poles to S2; open circles - D1 fold axes; triangles - D2 fold axes.

At Våtvik and south Stegafjell (Fig. 3) the form of the mesoscopic D1 folds is obvious, delineated by the outcrop pattern of a well-marked stratigraphy and confirmed by sedimentary structures and the presence of the metasol beneath the unconformity (Fig. 4).

On Leka, metamorphic reconstitution in the Skei Group is restricted and crystallinity is low. Greenschist facies is indicated by biotite and sporadic garnets in some pelitic horizons and by chloritoid in the metasol. This contrasts with the situation on the mainland to the northeast at levels farther removed from the base of the cover sequence where the Helgeland Nappes and the complex beneath generally display a metamorphic maximum in amphibolite facies.

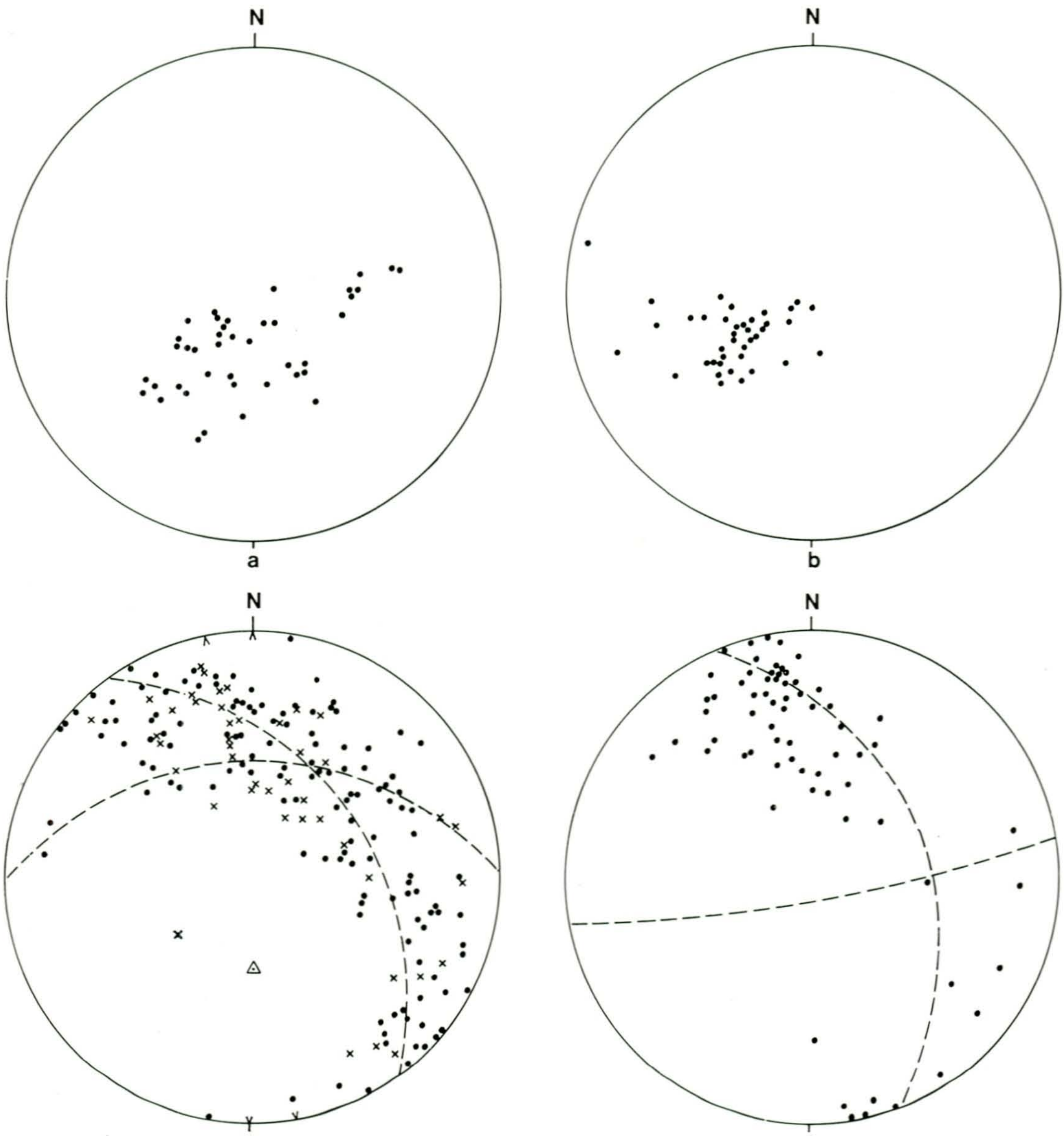
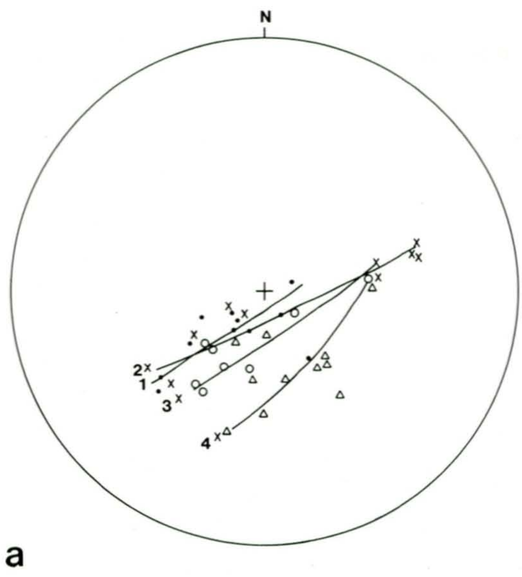


Fig. 5. Synoptic plot of structural data from the Skei Group. (a) D1 fold axes; (b) D2 fold axes; (c) poles to bedding (dots) and S1(crosses); (d) poles to S2.



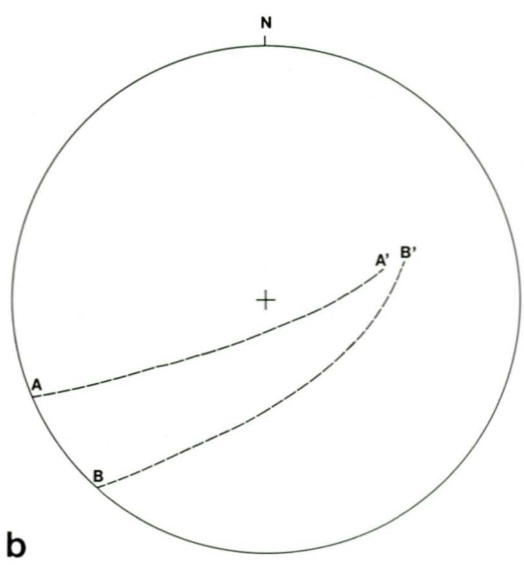


Fig. 6. (a) D1 fold axes from 4 sub-areas, Våtvik-Stegafjell - dots; central sector - crosses; Havna - open circles; Gangstølen - triangles. Lines 1-4 are the traces of axial spread resulting from D2 refolding, (b) Theoretical pattern of reorientated fold axes resulting from refolding initially Class 1b type but modified by later homogeneous strain to Class 1a (K=0.7). The initial axes trended N-S (fold A) and 030-210°(fold B) and both were horizontal. The axis of refolding was 236/60°, the same as the modal D2 attitude in NE Leka.

Minor structures

The small-scale structures of the D1 deformation phase, e.g. minor folds, mineral and pebble lineation, foliation and boudinage, are not developed uniformly throughout the Skei Group. For example, in the thick conglomerates, breccias and some sandstones there is locally no trace of D1 deformation, so that D2 features are the first record of strain. D1 structures are most prominently developed in the fine-grained members of the Havna Formation and in the weathered facies of the LOC. The only conglomerates to be significantly affected during this phase were those already mentioned, in the core of the Gangstølen-Hylla syncline.

Minor folds have a flattened concentric style (Class 1c, Ramsay 1967) with axial plunges varying between SW and SE (Figs. 4 & 5a). While some of this variation is possibly a function of primary noncylindrism it is also compatible with reorientation consequent upon D2 refolding (Fig. 6). Fig. 6a differentiates these fold axes from the four sub-areas as featured in Fig. 3. In each, the axes are distributed in flat great circle spreads which are compatible with the reorientation to be anticipated from refolding by D2 buckling (Class 1b), subsequently modified to Class 1c folds. Fig. 6b is a theoretical reorientation pattern for originally horizontal D1 fold axes, trending north-south (Fold a) and 030-210°(Fold B), respectively. The plunge of the later D2 fold axis is 255/60°, comparable to the mean attitude for the D2 population throughout the Skei outcrop, while the flattening strain has a k value of 0.7. The two fold axis loci A-A' and B-B' define a field within which most of the actual D1 fold axes fall (compare Figs. 6a & 6b).

Slaty cleavage and schistosity (S1) are strongly developed in the metasol and the pelitic horizons of the Skei Group. The strong preferred orientation of distorted pebbles within the axial plane schistosity of the Hylla fold, contrasts with the more common pattern of randomly orientated, angular and undeformed clasts in the massive upsequence developments, such as the lenses on Havnaholmen, at Våtvik and northeast of Stegafjell (Fig.2). On the mainland, a system of tight folds morphologically comparable with this phase refolds an older foliation, locally mylonitic in some very competent lithologies, and is D2 in the local tectonochronology.

Second phase of deformation (D2)

As mentioned earlier, on cessation of D1 deformation the Skei Group of eastern Leka lay in the overturned limb of the Leknes Syncline, dipping up to 60° westwards beneath the ophiolite. This inverted attitude subsequently controlled the axial orientation of D2 folds, which plunge towards WSW at 60° (Figs. 3, 4 & 5b, c). The several macroscopic folds which developed, together with their associated parasitic suites, have an homoaxial attitude and congruous relationships (Fig. 3).

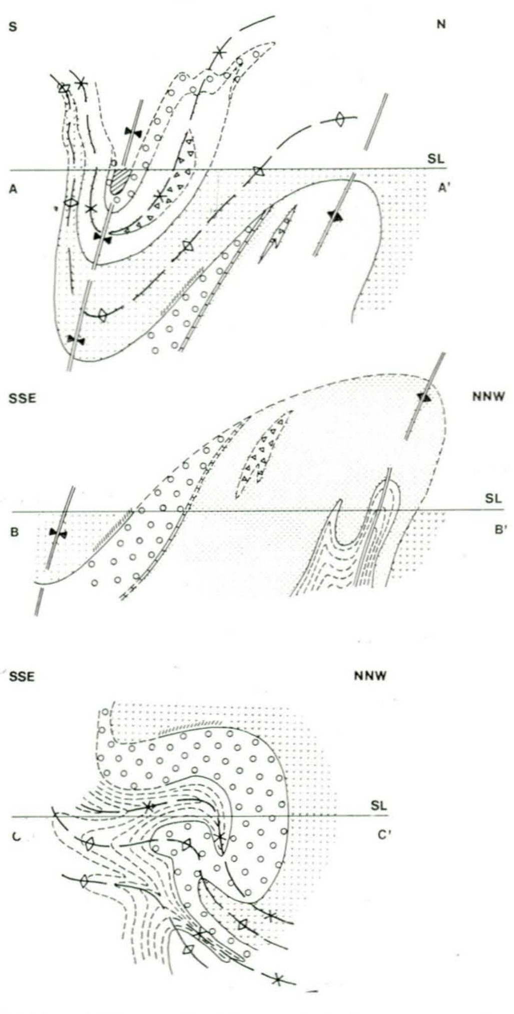


Fig. 7. Diagrammatic cross-sections through the Skei Group. For locations, see Fig. 2. Ornament as in Fig. 2.

On a regional scale this phase is expressed in a system of upright, high-amplitude, periclinal folds with wavelengths between 3 and 10 km and a broadly NE-SW axial trend, deflected locally by later open folds. On Leka, conspicuous geniculate deflections of the strike, between Havne and Stegafjell, delineate macroscopic folds with a step-fold, z-profile (Figs. 3, 4 & 7). These WSW-plunging structures have a constant sense of facing, consistent with the whole Skei Group outcrop being situated on the western limb of a large antiform, the Austra Antiform, whose axial trace runs through the Austra peninsula on the adjacent mainland, affecting both nappe rocks and the complex beneath (Figs. 1 & 9). On the mainland, however, this fold is a D3 structure in the regional tectonochronology.

Minor structures

In profile, the D2 minor folds vary from near-concentric (Class 1B) to strongly modified similar style (Class 1C). These folds are congruous with respect to their macroscopic host folds and together with the co-axial mineral and pebble lineation are homoaxial over the whole area of outcrop (Fig. 3).

In conglomeratic horizons at the base of the Stegafjell formation on Havnaholmen and at Våtvik, D2 strains were the first to imprint an obvious tectonic fabric. Pebbles are strongly distorted, chiefly into prolate ellipsoids with k-values in the range 1 - 4.4, depending on lithology. The long axes of these pebbles are parallel to the associated fold axes and intersection lineations. In pelitic and carbonate layers within the conglomerates the S2 foliation is a prominent spaced cleavage.

In the coarse-grained, up-sequence breccias of Havnaholmen and Hylla the effects of D2 deformation are confined to thin and discontinuous, fine-grained sand lenses. Angular and irregular clasts, up to 0.5 m in diameter, preserve their original clastic shapes, random orientation and pre-unconformity internal fabrics. As was the case with the D1 phase, the D2 strains are not completely penetrative and some bodies of rock show little or no evidence of it.

Deformation in the LOC

The rocks of the LOC have experienced a complex sequence of deformation events under conditions varying from high-temperature 'syn-magmatic' to amphibolite/greenschist facies probably related to ocean-floor metamorphism. They have also been affected by clearly superimposed deformations related to regional orogenic activity both prior to and subsequent to the deposition of the rocks of the Skei Group.

Furnes et al. (1988) emphasize the strongly developed tectonite fabric of the hartzburgite and suggest that "this was due to high-temperature ductile shearing in the mantle beneath an active spreading ridge". The present authors have also observed how cross-cutting sheets of dunite and pyroxenite in this fabric are also strongly folded with axial surfaces parallel to the sheet layering. Related to such structures, axis-parallel mineral lineations are part of the linear tectonite fabric. The essentially syn-magmatic nature of this deformation is clearly seen where folded pyroxenite veins are cut abruptly by non-folded pyroxenite veins (see also Furnes et al. 1988), or by gabbroic dykes. In some of the cumulate ultramafic horizons, flattened folds similar to those in the harzburgite are developed, whereas in the layered gabbro only certain horizons show ductile layer-parallel foliation, though a strong mineral lineation parallel to the banding is more prevalent. The isotropic gabbro, and in part the layered gabbro, displays narrow high-temperature and ductile shear-zones with blastomylonitic textures. That some of these shear-zones were essentially 'syn-magmatic' is seen from evidence of small-scale anatexis, producing rootless-topless veins and irregular patches of leucocratic gabbro pegmatite, associated with such zones.

At higher levels in the LOC pseudostratigraphy, lower-temperature mineralised (sulphide-bearing) shear-zones, commonly folded, are observed and may well be related to ocean-floor metamorphism, particularly as a number of these can be observed to be cut by metabasaltic dykes.

This plethora of structural features reflects conditions operative during the formative phase of the ophiolite rather than with orogenic deformation either associated with obduction/in-thrusting of the complex or occurring later. In the gabbros, dykes and lavas, on the other hand, obvious polyphasal orogenic strains are reflected in a sequence of foliations and diaphthoretic greenschist-facies metamorphism (see also Furnes et al. 1988).

The entire outcrop of the Skei Group lies in the overturned limb of a large-scale N-S trending Z-fold. No evidence of this structure can be clearly discerned in the LOC, which probably behaved as a more rigid block in the core of this fold. Tight, large-scale folding in the layered ultramafic segment has been determined from way-up criteria rather than structural observation (Furnes et al. 1988) and does not appear to be matched in the structure of the overlying Skei Group. The shearing and diaphthoresis which can be attributed to post-Skei Group deformation in the LOC is not related to this folding, and appears to post-date it.

In southern Leka, the layering of the gabbro unit has a mainly ENE-WSW strike and a variable but predominantly steep southeasterly dip (Fig. 8b). In some situations a strong foliation is developed sub-parallel to this banding. The earliest post-Skei Group deformation (D1) is represented by a suite of mesoscopic to macroscopic shear zones, a few centimetres to several tens of metres thick, which can locally become a prominent feature of the fabric. These range from narrow and sharply defined to broad and more diffuse zones, characterised in the latter case by phyllonitic cleavage. On the basis of orientation these shear-zones can be differentiated into two families (Fig. 8a), with a common intersection plunging towards ENE, parallel to their mutual intesection with the igneous layering (Fig. 8). On the cliffs of Horrfjell in SE Leka the shear-zones define the margins of conspicuous large lenticles in which the original fabric is still preserved. In some instances the sense of displacement on the shears can be determined from the deflection of the steep igneous layering

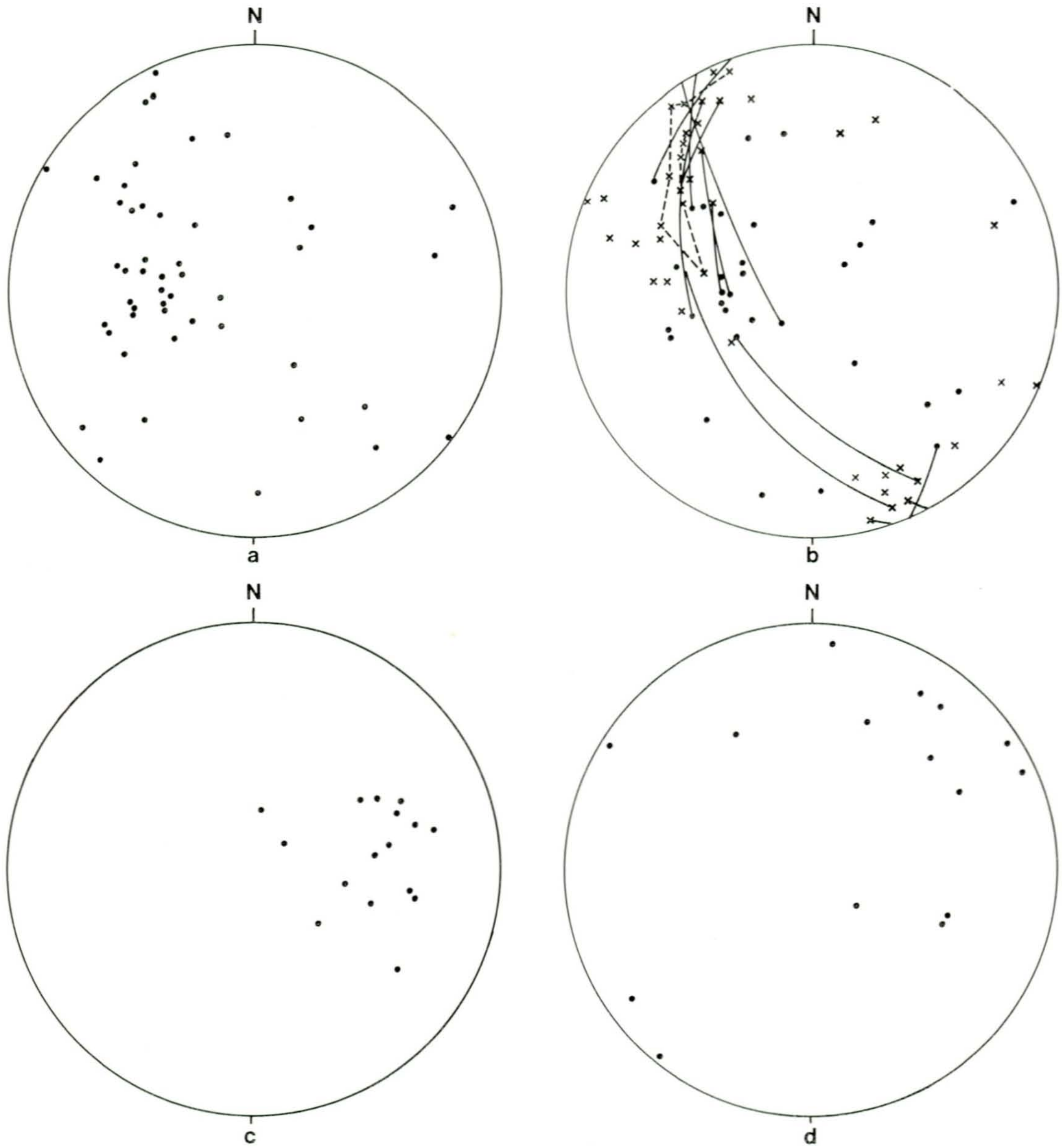


Fig. 8. Structural data of post-Skei Group shears in the LOC of southwest Leka. (a) - poles to foliation in shear-zones; (b) - poles to banding in gabbro (crosses), with tie lines to associated shear-zones (dots). (c) - Lineation of amphiboles and feldspars in the shear-zones; (d) - Fold axes (D2) superimposed on shear-zone foliation.

at the margins of the zones. On Horrfjell, for example, this exhibits a conjugate pattern of small dextral and sinistral offsets. Indeed, there is no evidence of large displacement on any one of the shears; rather, the bulk strain in the gabbro is the sum of small offsets along the many shear-zones.

In their formation these shear-zones were attended by considerable reconstitution of the original fabric and mineralogy. At the margins there is progressive thinning and sharpening in the definition of the deflected gabbroic layering, emphasized inwards by the development of a platy schistosity, coa-

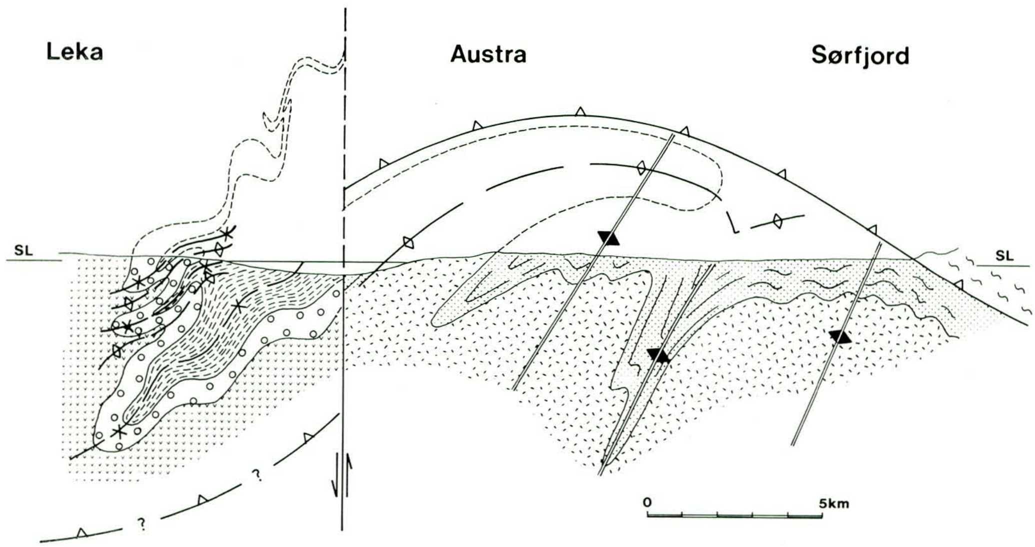


Fig. 9. Diagrammatic cross-section illustrating the relationship of D2 folding on Leka to the folding on the mainland.

ted with coarse phacoidal chlorite, in a diaphthoretic assemblage of actinolite, chlorite and albite. In this new foliation a prominent mineral lineation of actinolite and feldspar may be present, sub-parallel to the intersection of igneous banding and shear-zone. (Fig. 8 c). Where several of these zones come close together or intersect, a more general reconstitution has occurred and relics of the protolith are sparse. The diaphthoretic greenschist-facies metamorphism reflected in this mineralogy is isogradic with the prograde assemblages of the Skei Group.

The steep attitude of layering in the LOC within the core of the anticlinal compliment of the D1 Leknes Syncline may relate, in part, to this folding, but may also be a relic of some pre-Skei Group attitude. While the highly anisotropic Skei Group deformed by congruous folding on a wide range of scales, the more massive gabbro yielded by formation of multiple shear-zones, which effected a bulk shear flow into the core of the anticline.

The second phase of deformation, D2, in the gabbro can only be recognised within the strongly anisotropic shear-zones, where it is expressed as tight angular, upright to conjugate folds of the schistosity, associated with a rude crenulation cleavage. Under the influence of the original attitude of the shear-zones these fold axes are somewhat dispersed between N-S and NE-SW (Fig. 8d).

Widespread small- and large-scale faulting is a prominent feature of the fabric of the island, in both the LOC and the Skei Group. This is attended by brittle shearing but no mineral reconstitution is developed. The larger faults of this system juxtapose the various levels of the LOC in a number of well-defined blocks. Although no dating is yet available, it is possible that this faulting equates with the prominent Mesozoic block-faulting which affected much of coastal Norway.

Pre-Skei Group orogenesis

Prior to the unconformity at the base of the Skei Group the LOC already possessed a tectonic fabric, probably dating back to the formation of the complex. This is generally a strong foliation and folding within the cumulate mafic and ultramafic horizons, but it can locally be a mylonitic foliation in high-temperature shear-zones. These structures bear no geometric or spatial relationship to a regional structural pattern. As mentioned earlier, Sturt et al. (1985) recorded relict amphibolite-facies mineralogy in this sequence, overprinted by a low-mid greenschist facies, isogradic with the prograde metamorphism of the Skei Group. They regarded the higher grade as representing an older pre-Scandian regional metamorphism.

In the coarse flood breccias of the lower part of the Stegafjell formation, at the western end of Havnaholmen (Fig. 2), angular and irregular clasts are derived from several members of the ophiolite pseudostratigraphy, especially those levels now poorly represented, due to the depth of erosion. Despite two phases of Scandian deformation there is no evidence of mechanical reorientation or shape distortion of these clasts. The presence of an internal tectonic fabric in many is a significant pointer to the tectonothermal state of the LOC prior to erosion. Mindful of the ambiguous status of tectonic fabrics in the plutonic members of the ophiolite, the search for evidence of older orogenic deformation focused on greenschist pebbles. Cobbles with a randomly orientated schistosity, relative to clast shape and external foliation, or with a folded schistosity (Fig. 10), provide clear evidence of polyphasal orogenic strains prior to the formation of the conglomerate. A number of psammite pebbles with pre-pebble fabrics were also observed. In being exposed to sub-aerial erosion the LOC must already have been elevated to high topographic levels and had experienced tectonic strains and greenschist-facies metamorphism prior to the deposition of the cover sequence. Large-scale, pre-unconformity folding of Group 1 ophiolites has already been recorded from elsewhere in the Helgeland Nappe Complex, e.g. Rødøy (Bang 1985), in the Lyngen Nappe in Troms (Minsaas & Sturt 1985), in the Vågå-Otta area (Sturt et al. 1991) and on Bømlo in Southwest Norway (Brekke 1983, Nordås et al. 1985).

Regional setting of the Leka sequences

Placing the LOC and its cover in a regional setting is complicated by the geographic isolation of the island. However, the association of ophiolite with an unconformable cover sequence containing polymict conglomerate horizons rich in ophiolite debris is typical of many nappes of the upper allochthons of Norway. This association occurs at many localities in the Helgeland area (Sturt et al. 1984, Thorsnes & Løseth 1991), with Leka as the largest single occurrence. The ophiolitic bodies are distributed in linear arrays which, on the one hand, delineate nappe boundaries and, on the other hand,

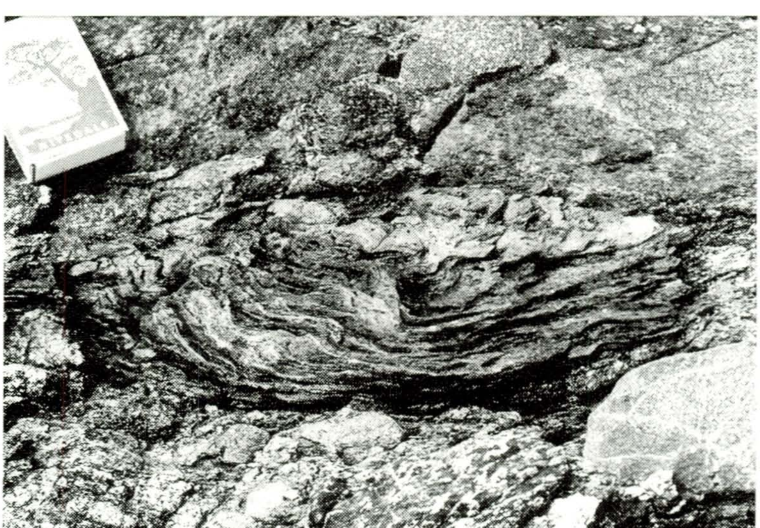


Fig.10.Boulder of folded, foliated greenstone with deformed epidote knots, Havna Formation, SW Havnaholmen.

partition nappes into substrate and cover sequences (Fig. 1). The unconformity is also a valuable datum plane for establishing the base of the cover sequences, the polarity of the sediments and the lithostratigraphy in each nappe.

In reviewing the tectonostratigraphic relationships and obduction histories of Scandinavian ophiolite terranes, Sturt & Roberts (1991) concluded that the obduction of the Group I ophiolites (Sturt et al. 1984) in the central part of the Caledonides was post-Tremadoc and pre-Middle Arenig in age. This postulate was based on a combination of faunal dating in cover sequences and U/Pb zircon dating of late components of the ophiolites. The Heilhornet Pluton (dated at 444±11 Ma), which intrudes the Terråk ophiolite fragment and its deformed and metamorphic cover sequence, provides an upper limit not only for the age of the cover sequence but also for its deformation and metamorphism. Nordgulen et al. (1993) have also provided a series of reasonably precise U/Pb zircon dates for other plutons in the Bindal Batholith in the range 447±7 to 430±7 Ma, i.e. during the period Ashgill-Early Llandovery.

The stage of tectonothermal development represented here, from approximately Mid Arenig to Mid Caradoc time, apparently coincides with deformation of the Arenig-Llanvirn sequence of Smøla, west-central Norway (Gautneb & Roberts 1989). It would thus appear to represent a regional event of some magnitude. For convenience, we will here refer to this informally as the *Terråk Phase.* Evidence for a Mid Ordovician orogenic event in certain nappe complexes or terranes in Central and SW Norway, broadly equivalent to the Taconian of the Appalachians, has indeed been presented by Hall & Roberts (1988). Isotopic data helping to identify this event also in the higher parts of the Upper Allochthon in Central Sweden have been reported by Stephens et al. (1993). There is, however, as yet little evidence for this event from the gneisses or amphibolite-facies supracrustals of the Vestranden region, though Dallmeyer et al. (1992) record an $^{40}Ar/^{39}Ar$ date from a hornblende concentrate from supracrustal rocks of the southeastern margin of Vestranden at 440±2 Ma which they interpret as a cooling age through c 500°C. The peak Caledonian metamorphism of the Vestranden gneisses is indicated by a Sm/Nd isochron of 432±6 Ma from high-pressure basic granulites of the Roan Window (Dallmeyer et al. 1992) and a U/Pb lower intercept age of 434±22 Ma from discordant zircons in a migmatite from Vikna in the northwestern part of Vestranden (Schouenberg et al. 1991). These dates are interpreted by Dallmeyer et al. (1992) to indicate peak Scandian prograde metamorphism. Uplift cooling ages, in Vestranden, are indicated at 419±2 - 393±3 Ma for hornblende concentrates and at 395±2 - 390±2 for micas (Dallmeyer et al. 1992). Unfortunately no $^{40}Ar/^{39}Ar$ ages are available from the HNC.

The regional development of a major unconformity, commonly above ophiolite fragments, in the Scandinavian Caledonides has been stressed in a number of papers (Sturt et al. 1984, Thon 1985, Minsaas & Sturt 1985, Ramsay & Sturt 1986, Sturt et al. 1991, Sturt & Roberts 1991, Bøe et al. 1993); and particularly in earlier papers this has been assumed to represent an individual event horizon. However, it becomes apparent that such unconformities associated with major clastic wedges may be more spread in time than has previously been assumed. In the Trondheim Nappe Complex a major unconformity above ophiolitic material is pre-Mid Arenig in age (Sturt & Roberts 1991) whilst in SW Norway the major clastic wedge is essentially of Ashgill/Llandovery age (Thon 1985), and in part overlies the West Karmøy Igneous Complex dated in the range 480-470 Ma (Pettersen & Dunning, in press). Thorsnes et al. (in press) show how the Follafoss Pluton (near Malm), giving a U/Pb zircon age of 460±5 Ma, is unconformably overlain by a basal conglomerate. This situation is very similar to that in the Gjersvik Nappe where the basal conglomerates of the Limingen Group rest unconformably on the Møklevatn granodiorite which has yielded a U/Pb zircon age of 456±2 (Roberts & Tucker 1991).

Conclusions

The geology of Leka plays a significant role in deciphering the lithostratigraphic and tectonic patterns of the coastal part of the north-central Scandinavian Caledonides, where neither the Scandian nappe sequence nor its relationships with the cratonic basement are well understood. The importance of Leka stems from a lower level of deformation and metamorphic reconstitution than is generally the case. Leka also provided the first record of an ophiolite association in the region, which prompted the search for and subsequent identification of other fragments. These have assumed a significant tectonostratigraphic status by defining the outlines of the constituent nappes along the western margin of the Helgeland Nappe Complex. In the source areas of these nappes ophiolite formed the substrate for later Ordovician sedimentation and subsequently formed the 'basement' segment in each of the nappes, when penetrated by the Mid-Late Ordovician (Terråk) thrusts. The present discontinuous nature of the ophiolite levels in the region is due, in part, to high orogenic strains as well as primary pre-orogenic erosion.

The precise pattern of Scandian deformation and metamorphism in the Skei Group is not known. It is probable that D1 and associated metamorphism relate to the Terråk Phase and that Scandian deformation does not have a penetrative imprint. Clear evidence for pre-Skei Group deformation and metamorphism is, however, clearly seen by the truncation of fabrics by the unconformity and from cobbles in the conglomerates.

The low strains and well-founded lithostratigraphy of Leka afford a clearer insight into the morphology of the large-scale folds and the geometric patterns of associated macroscopic structures, than can be obtained elsewhere in the region. The whole outrop of the Skei Group defines the overturned limb of a large Z-fold with N-S axial trend. Although this is the first post-Skei Group deformation to affect Leka, it has the geometrical characteristics of D2 on the mainland, in both the nappes and the sub-HNC rocks, and no trace of the regional D1 phase is present.
The second phase of folding on Leka was superimposed on the overturned rocks of the Skei Group and the steep attitude of bedding controlled the orientation of fold axes, with the result that they consistently have steeper plunges than is normally encountered in the region. The larger asymmetrical step folds of this phase face eastwards, consistent with their being parasitic to the large Austra Antiform (D3) on the mainland, one of a system of upright periclines of regional development. The strain associated with each of these post-Skei Group phases is rather patchy in distribution and development, and D2 may be the oldest tectonic feature in some localities.

It has been widely assumed that deformation and metamorphism of the metasediments and ophiolites in Helgeland can be ascribed to the Scandian Orogeny, i.e. Mid-Late Silurian (Sturt 1984, Stephens & Gee 1985). In this, the nappes were viewed as coeval with the climactic nappe phase of the belt, whose effects extend all the way to the orogenic front. With the recognition of the Terråk Phase, however, it has become apparent that this pattern needs revision. Thus, by the Late Ordovician, the main tectonothermal events of the HNC were over and the nappes were already in contact with the sub-Helgeland assemblage. This has considerable implications for modelling the sequential evolution of the Scandinavian Caledonides and provides a caveat for correlation of events across major tectonic boundaries which may ignore the complexities of palaeogeographies, and of happenings at active plate margins which provide a diversity of tectonometamorphic processes at some sites whilst continuous sedimentation is occurring at others.

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