# Ordovician stratigraphy in the western Helgeland Nappe Complex in the Brønnøysund area, North-central Norway

TOM HELDAL

Heldal, T. 2001: Ordovician stratigraphy in the western Helgeland Nappe Complex in the Brønnøysund area, North-central Norway. *Norges geologiske undersøkelse Bulletin 438*, 47-61.

In the western part of the Helgeland Nappe Complex, a small ophiolite fragment (the Bolvær Complex) and a metasedimentary succession (the Brønnøysund Group) are exposed on several islands to the west of Brønnøysund. The Bolvær Complex was emplaced, uplifted and subject to subaerial weathering and erosion prior to the deposition of the Brønnøysund Group. The unconformity defines an irregular topographic surface which was gradually filled with sediments during a regional transgression, probably influenced by active tectonics. The sedimentation of the Brønnøysund Group initially started with the build-up of a coastal setting, delivering coarse and fine clastics into a shallow-marine environment (Risøy Formation). This formation is stratigraphically overlain by calcareous turbidites (Torgnes Formation), pelites (Aspøy Formation) and carbonate rocks (Toftsund Formation). The Brønnøysund Group is correlated with several cover sequences above ophiolites in the Helgeland Nappe Complex, and deposition in Early to Middle Ordovician time is suggested. The clast populations in conglomerates and the composition of finer clastic sediments show an exotic, ensialic source for the detritus, in addition to the ophiolite. This ensialic source consisted essentially of psammites and schists, deformed and metamorphosed prior to the deposition of the Brønnøysund Group.

*Tom Heldal, Norges geologiske undersøkelse, 7491 Trondheim, Norway.*

## Introduction

During the 1980s and early 1990s, several investigations focused on the complex tectonostratigraphy in the western part of the Helgeland Nappe Complex (HNC). Important discoveries were made, such as the recognition of a number of ophiolite fragments and a primary, angular unconformity between the ophiolites and metasedimentary cover sequences. The ophiolite fragments were correlated with other Late Cambrian-Early Ordovician ophiolites in the Caledonides, including the Leka Ophiolite Complex (Fig. 1). Several of these ophiolites have yielded ages of 500-485 Ma (Dunning & Pedersen 1988). Other metasedimentary rocks in the area include migmatite (mica) gneiss, calc-silicate gneiss and marble interpreted to represent remnants of a Neoproterozoic continental margin sequence.

Both sedimentary successions have been affected by pervasive deformation and medium-grade metamorphism, and primary features are, in most areas, totally obliterated. However, on some small islands to the west of Brønnøysund, the contact relations between an ophiolite fragment and the cover sequence, as well as sedimentary structures in the latter, are excellently preserved. Unlike at most other places within the western part of the HNC, a detailed study of the stratigraphy of the cover sequence and even an interpretation of the palaeoenvironment during its deposition was possible (Heldal 1987). In the author's opinion, this particular area may be of significance for a better understanding of the structure and stratigraphy of the pile of nappes and thrust sheets forming the western part of the HNC, and act as a type area for correlations within and between them. In addition, the area has one of the best preserved and exposed unconformities in the Norwegian Caledonides.

## Regional geology

The Helgeland Nappe Complex, which forms the dominant part of the Uppermost Allochthon in the Central Scandinavian Caledonides (Gee et al. 1985, Stephens & Gee 1985, Stephens et al. 1985), comprises a series of nappes and thrust sheets, predominantly composed of medium-grade metamorphosed sedimentary rocks. These are intruded by plutonic rocks, ranging in composition from olivine gabbro to leucogranite, the *Bindal Batholith* (Nordgulen & Schouenborg 1990, Barnes et al. 1992, Nordgulen & Sundvoll 1992, Nordgulen et al. 1993, Birkeland et al. 1993). Mafic and ultramafic rocks of ophiolitic affinity occur at several tectonostratigraphic levels, predominantly in western areas (Fig. 1). In the east, the HNC rests with a thrust contact upon the Rödingsfjället Nappe in the northeast, and the Gjersvik Nappe in the southeast. In the southwest, the HNC is separated from basement gneisses and inferred Seve Nappe supracrustal rocks by the Devonian *Kollstraumen Detachment Zone* (Braathen et al. 2000).

In the western, coastal part of the HNC (Fig. 1), it is fairly well established by field relationships (Gustavson 1975, Riis

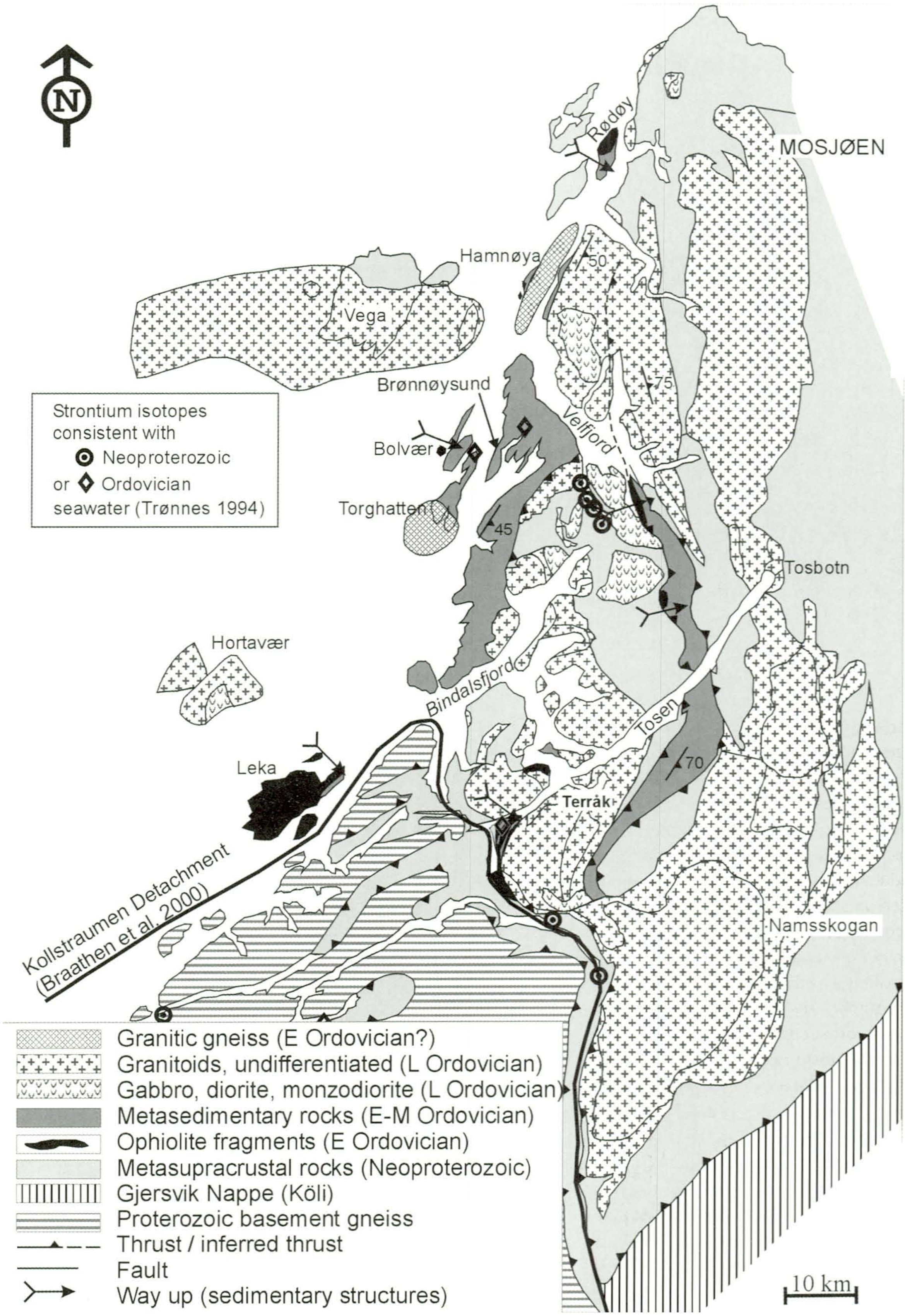


Fig. 1. Regional geological map of the western part of the Helgeland Nappe Complex; modified from Nordgulen et al. (1993).

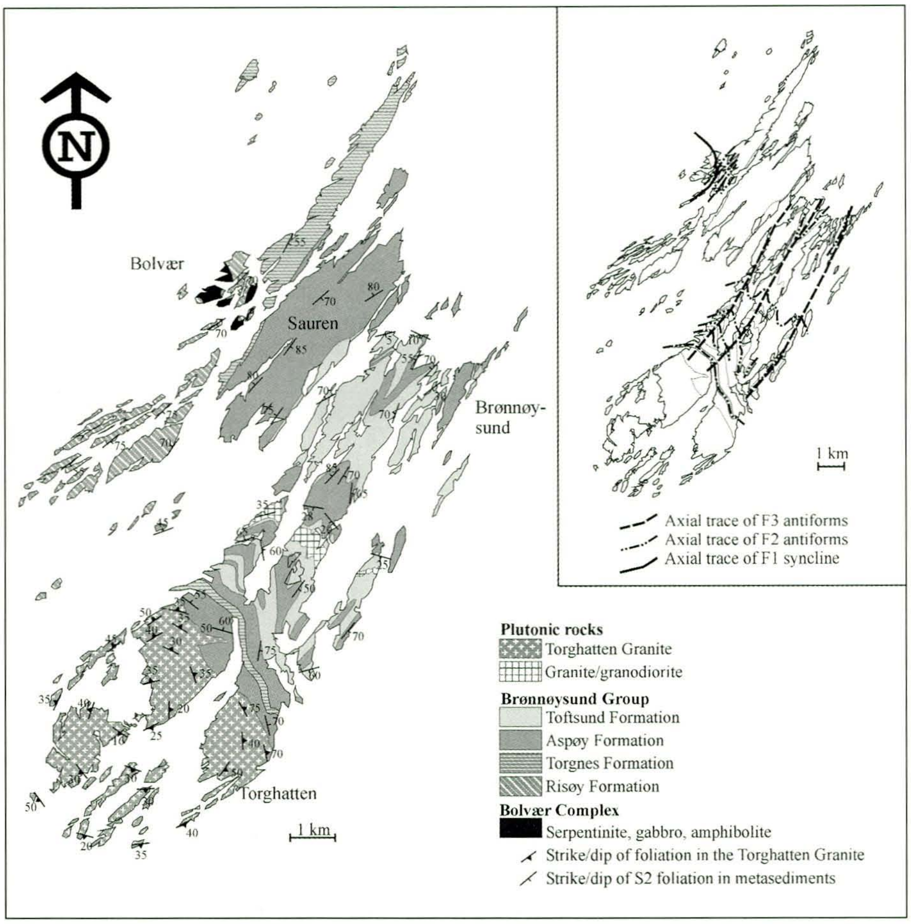


Fig. 2. The geology of the Brønnøysund – Bolvær – Torghatten area, showing the distribution of the Bolvær Complex, the four formations within the Brønnøysund Group and the Torghatten Granite. In addition, fold interference patterns between F2 and F3 in the vicinity of the Torghatten Granite are shown in the inset (right). From Heldal & Hjelmeland 1987.

& Ramberg 1981, Bang 1985, Heldal 1987, Husmo & Nordgulen 1988, Thorsnes & Løseth 1991), radiometric dating (Nissen 1986) and dating by C and Sr isotopic data from marbles (Trønnes 1994, Trønnes & Sundvoll 1995) that the metasedimentary rocks belong to at least two different successions. An inferred Neoproterozoic succession comprises migmatites/micaceous gneiss, calc-silicate gneiss and marble. Based on correlations with the Leka Ophiolite (Prestvik & Roaldseth 1978, Sturt et. al 1984, Furnes et al. 1985), which has a minimum age of 497 +/- 2 Ma (Dunning & Pedersen 1988), a Late Cambrian to Early Ordovician age for the ophiolite fragments has been suggested, separating the Neoproterozoic succession from younger metasedimentary rocks (metasandstones, conglomerates, schists and marbles), such as the Brønnøysund Group (described in the present paper). The latter rocks were deposited unconformably on top of the ophiolites, and can be correlated with the sequence lying above the Leka Ophiolite – the Skei Group (Sturt & Ramsay 1994). Rocks similar to the inferred Neoproterozoic-age metasedimentary succession, in addition to the ophiolitic rocks, formed the source for the clastic sediments in the cover sequence. A minimum age for the younger sequence is given by the 444 +/- 11 Ma dating of the Heilhornet pluton (Nordgulen & Schouenborg 1990) and 447 Ma dykes in the Andalshatten Pluton (Nordgulen et al. 1993) in the Bindal Batholith, both postdating D2 structures in the metasedimentary succession. The possible existence of syn-D2 granites (granite gneisses, see Fig. 1) in the area (Hjelmeland 1987), earlier interpreted as basement windows, would push the minimum age even further back. Thus, the obduction of the ophiolitic rocks, uplift, erosion, deposition of the cover sequence and the major episodes of deformation all seem to have occurred within the Ordovician period.

The ophiolite fragments within the western HNC occur at two tectonostratigraphic levels, defining an eastern belt from Terråk to Velfjord (Nordgulen & Husmo 1988, Thorsnes & Løseth 1991) and a western belt from Leka to Rødøy (Prestvik 1980, Bang 1985), including the Bolvær Complex described in the present paper. In addition, relics of a possible middle belt can be seen in the Bindalsfjord area (Fig. 1). All major contacts are dipping eastward, and sedimentary structures defining way-up in the cover sequence are facing the same direction. The unconformity between the ophiolitic rocks and the cover off metasedimentary rocks is exposed at a number of localities in this area, and in several places it can be shown that the cover sequence onlaps onto a highly irregular palaeotopography formed by subaerial erosion and weathering of the ophiolitic rocks.

## Stratigraphy and tectonometamorphic development in the Brønnøysund area

The western, coastal belt of ophiolitic rocks and its cover sequence can be observed west of Brønnøysund. The rocks can be divided into three main units (Fig. 2). In the westernmost areas, around the island of Bolvær, there is a small ophiolite complex composed of peridotites, layered metagabbro and amphibolites, named the *Bolvær Complex* (Heldal 1987). Lying unconformably upon the ophiolite is a succession of metasedimentary rocks, occupying most of the studied area - the *Brønnøysund Group*. The third unit is the *Torghatten Granite*, forming a dome centred at the Torghatten mountain, enveloped by the upper part of the Brønnøysund Group. Hjelmeland (1987) suggested that the granite intruded the metasedimentary rocks simultaneously with the D2 deformation episode.

The Brønnøysund Group is divided into four formations. The *Risøy Formation* makes up the lower part of the group, comprising metasandstones, conglomerates and schists onlapping the unconformity (Fig. 3). This is overlain by calcareous metasandstones of the *Torgnes Formation*, which is followed by mica schists (the *Aspøy Formation*) and marbles with schists and calc-silicate rocks (the *Toftsund Formation*). The latter continues eastward to the eastern part of Brønnøysund, and is structurally overlain by mica schists and psammites. It is uncertain whether these schists lie stratigraphically above the Toftsund Formation or if they represent a structural repetition of the lower formations. Furthermore, the eastern limit of the Brønnøysund Group is not known. However, marbles and mica gneisses in the Velfjord area somewhat farther to the east belong to the Neoproterozoic metasedimentary succession mentioned above.

The Brønnøysund Group has experienced polyphasal deformation, and structures relating to four deformation episodes have been recognised. Upper amphibolite-facies metamorphism was attained during the second (D2) event, which, as mentioned above, probably took place prior to emplacement of the Heilhornet Granite and dykes in the Andalshatten Pluton. Two later episodes (D3 and D4) of deformation most likely represent Scandian (or even younger?) deformation related to the final amalgamation and thrusting of the Helgeland Nappe Complex.

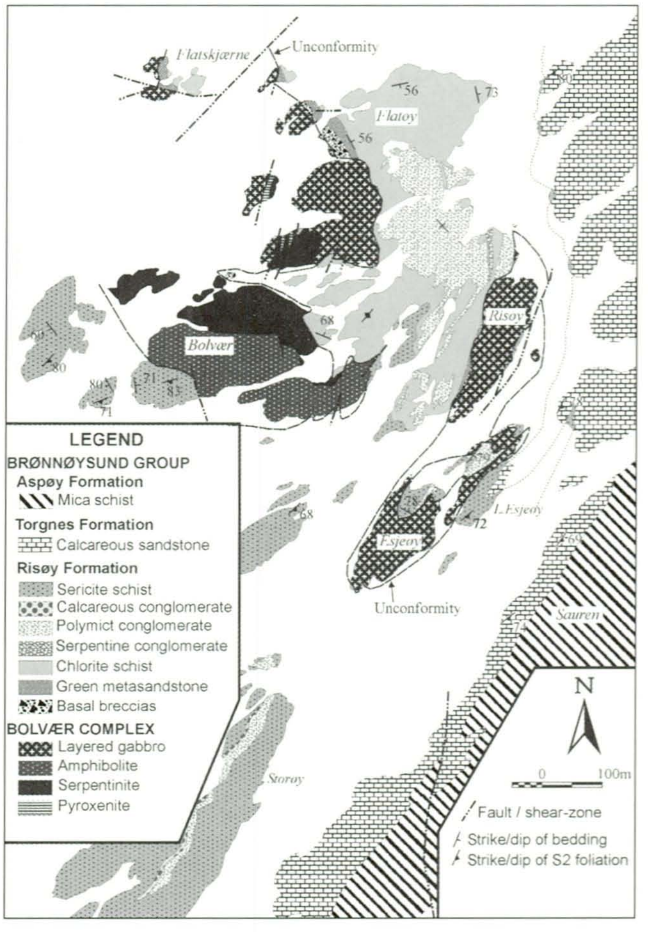


Fig. 3. Geological map of the Bolvær area.

## The Bolvær Complex

The Bolvær Complex comprises serpentinite, layered gabbro, clinopyroxenite with serpentinite layers and amphibolite (Fig 3). The complex shows evidence of polyphasal deformation pre-dating the unconformity that was probably related to an early oceanic crust stage and to a later stage when the ophiolite was emplaced onto a continental margin (Heldal 1987). The serpentinite contains relics of olivine and orthopyroxene, reflecting a primary harzburgitic composition of the peridotite. Indications of non-orogenic, ocean-crust deformation are seen in several generations of pyroxenite veins that were progressively deformed simultaneously with the injection of new veins. Together with the lithological composition of the Bolvær Complex, this provides evidence for a correlation with the dated Leka Ophiolite Complex farther south. The layered gabbro occupies most of the outcrop area of the Bolvær Complex. Evidently, large-scale, monoclinal fold structures and a mineral lineation pre-date the unconformity.

A small body of amphibolite occurs to the south of the serpentinite. The contact is subparallel to the early harzburgite foliation and to a penetrative, pre-unconformity foliation in the amphibolite. Since the amphibolite does not fit clearly into an ophiolite pseudo stratigraphy, and shows strong pre-unconformity deformation, it is suggested that it may represent a metamorphic aureole to the obducting ophiolite, with the contact to the serpentinite representing the actual plane of obduction. Unfortunately, no relict metamorphic parageneses pre-dating the amphibolite-facies metamorphism in the cover sequence have yet been found, leaving the question still open.

## The unconformity – palaeoweathering, morphology and basal breccias

The unconformity between the ophiolitic rocks and the overlying metasedimentary succession is exposed at a number of localities in the HNC (Bang 1985, Husmo & Nordgulen 1988, Heldal 1987, Thorsnes & Løseth 1991), and in several places it has been shown that the cover sequence onlaps an irregular palaeotopography formed by erosion and weathering of the ophiolitic rocks. A striking feature of the Bolvær area, however, is the excellent state of preservation of the unconformity, leaving it virtually undeformed over a large area, even though it is situated in the core of a F1 syncline, modified by a series of F2 step-folds with NE-SW trending axial planes (Fig. 2). The unconformity is exposed on the islands and islets around Bolvær over a 1000 metre section (Fig. 3). The best place to view the unconformity and regolith is at Esjeøyene (Fig. 4).

At the time of deposition of the Brønnøysund Group, the unconformity probably climbed towards south-southeast, with a vertical change in altitude of at least 100 metres within the distance of the outcrop area. This is shown by the onlapping deposition of the different members of the Risøy Formation onto the underlying Bolvær Complex. The irregular topography is also seen at outcrop scale (Fig. 5), where the angular difference between the sedimentary layering in the Risøy Formation and the unconformity surface can vary from 0 to 60 degrees.

Basal breccias are locally developed along the unconformity, reflecting the character of the rocks beneath the contact. Thick deposits of *short-transported breccias* are seen on northern Flatøy, Risøy, Bolvær, Esjeøy and Lille Esjeøy (Fig. 4). On Flatøy and Risøy, the breccias have an asymmetric lenticular shape with their southern flanks steeper than their northern, and are fining upwards and northwards, away from steep slopes in the palaeoterrain. In northern Flatøy and on Bolvær, the most proximal and coarse breccias are very poorly sorted and clast-supported, and these were probably deposited as talus beneath a scarp (Fig. 6a). Otherwise, the breccias occur as matrix-supported beds ranging from 0.5 to 6 metres in thickness, with a positive cor-

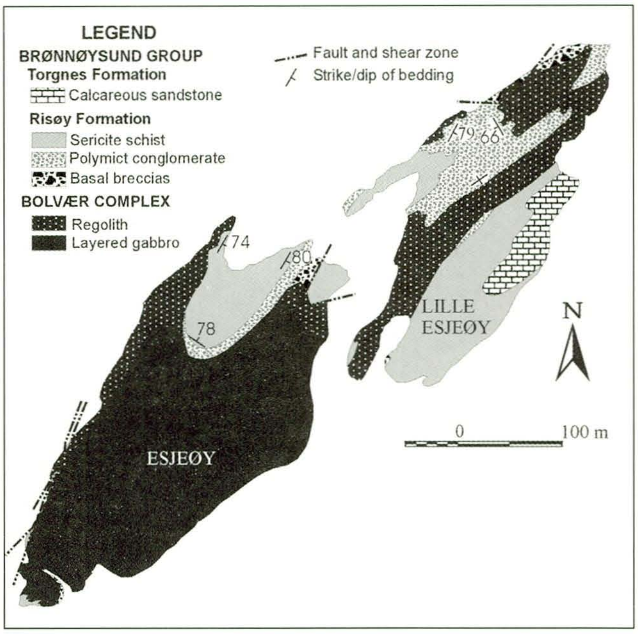


Fig. 4. Geological map of Esjeøyene.

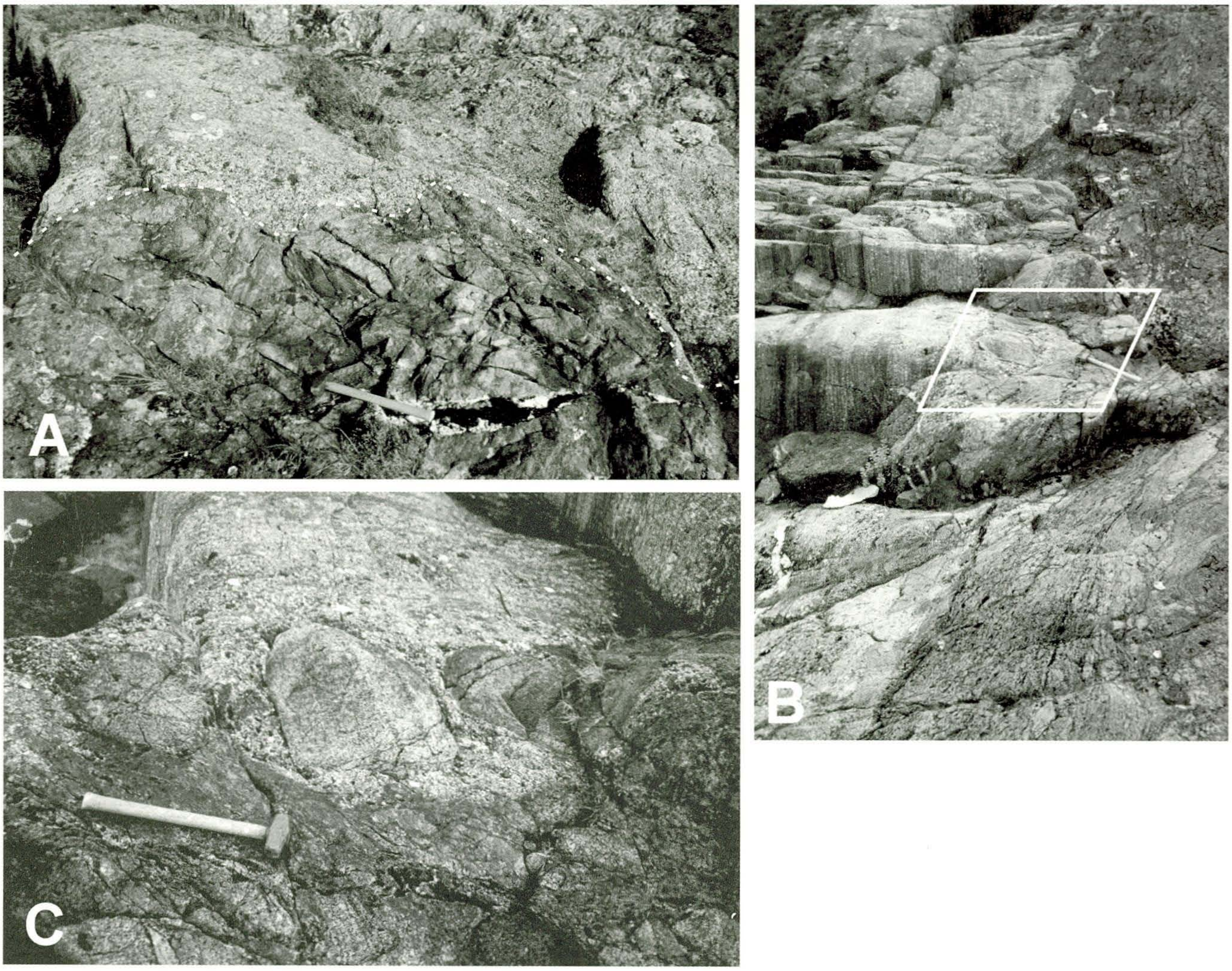


Fig. 5. The unconformity. A) Irregular erosional surface (white dotted line) on Lille Esjeøy. Gabbro (lower part) in contact with conglomerates of the Risøy Formation (upper part). B) Erosional surface in regolith (right) on Esjeøy, filled by the upper part of the Risøy Formation. C) Detail of area in B) (white square). Note large, rounded boulders of gabbro along the contact.

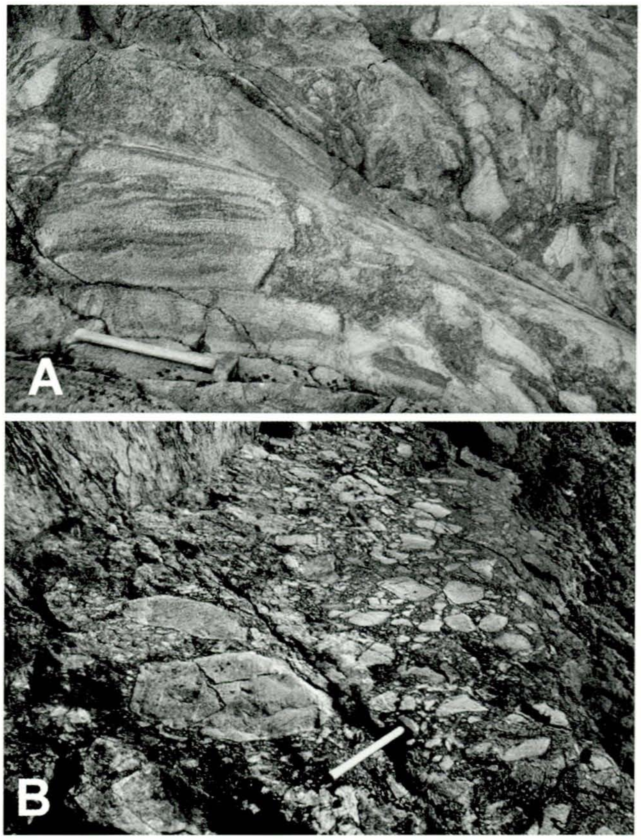


Fig. 6. Basal breccias immediately above the unconformity. A) Boulders of amphibolite in basal breccia at Bolvær, showing a pre-unconformity folded and transposed foliation. B) Viscous mass-movement deposit on Lille Esjeøy; large boulders of gabbro (left part) have cracked during transport.

relation between maximum boulder size and bed thickness. Commonly, the largest boulders are concentrated in the central parts of the beds (Fig. 6b). Besides the bed thickness/boulder size correlation, boulders fractured during transport, sheared bases and lack of reworking by waves indicates that these breccias represent highly viscous, subaerial mass-movements (Nemec & Steel 1984). On Flatøy, the scarp that defines the southern limit of the basal breccias is seen continuing as a fault below the unconformity, suggesting that syn-sedimentary faults played an important role in the shaping of the palaeotopography.

*In situ weathering breccia*, or regolith, is present in the southern part of the area, e.g. in the higher levels of the palaeotopography. On Esjeøy, such brecciation of the layered metagabbro extends down to 10 metres beneath the unconformity (Fig. 4 and 5), and is characterised by rounded gabbro fragments surrounded by anastomosing chlorite veins. The only feature showing the in situ character of the brecciation is the consistent modal layering of the gabbro. Accompanying the brecciation is an enrichment of iron-carbonate in the upper part of the fossil weathering profile, as irregular patches, crack fillings and individual grains replacing mafic minerals in the gabbro. Such carbonate enrichment in a weathering profile is characteristic of weathering in hot and arid- to semi-arid climates; the higher up the caliche develops, the more arid is the climate (Blatt et al. 1980). In addition to the carbonate enrichment, the fossil weathering profile is characterised by an upward increasing content of biotite, chlorite and even kyanite, a decreasing content of amphiboles and plagioclase and a breakdown of the ophitic texture of the gabbro. The change in mineralogy reflects the chemical alteration of the deeply weathered gabbro, such as growth of kyanite during later amphibolite-facies metamorphism in the Al-enriched, upper part of the regolith. Furthermore, biotite would be expected to grow at the expense of clay minerals, and leaching of Ca from plagioclase contributed to the carbonate enrichment.

The occurrence of a deep, fossil weathering profile mainly restricted to the higher levels of the palaeotopography suggests that these parts were exposed to subaerial weathering for a significantly longer period of time than the lowermost levels. This is supported by the common occurrence of clastic grains from the weathering profile in the lower members of the Risøy Formation.

The weathering profile in the Bolvær area shows striking similarities to those described from other Early Ordovician ophiolites in the Scandinavian Caledonides. Both the high palaeorelief and a carbonate-enriched regolith are found in the ophiolites at Otta (Bøe et al. 1993), on Leka (Sturt & Ramsay 1994) and on Rødøy (Bang 1985). An example of a younger unconformity within the Norwegian Caledonides, where field relations are quite similar to those described here, has been reported by Bøe (1989).

## Lithofacies of the Brønnøysund Group

### The Risøy Formation

The Risøy Formation comprises a variety of sandstones, schists and conglomerates, filling and onlapping the irregular topography formed by erosion of the Bolvær Complex. The thickness varies from 5 to at least 100 metres, reflecting the irregular surface beneath. Although the metasedimentary rocks have undergone middle amphibolite-facies metamorphism, with staurolite, kyanite and sillimanite as index minerals, sedimentary structures are remarkably well preserved in parts of the studied area. The reason for this is thought to be decreasing strain in the cover sequence towards the unconformity due to a shadowing effect by the Bolvær Complex under the pervasive D2 deformation, allowing interpretation of the depositional environment within parts of the Risøy Formation. Furthermore, the F1 syncline described above provides an additional contribution to the preservation of primary structures. The outcrop pattern of the Risøy Formation is, however, complex, due to both the rapid lateral changes in lithology and thickness and to a complex interference pattern between F1 and F2 folds.

The Risøy Formation shows a south-southeastward onlap to the Bolvær Complex, and is subdivided into 4 members: green metasandstone, chlorite schist, sericite schist and

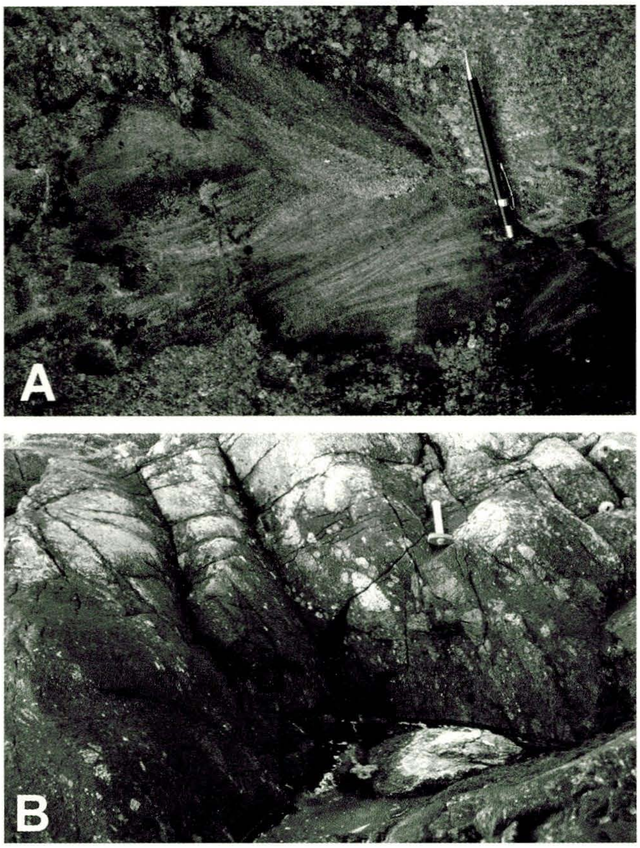


Fig. 7. The green metasandstone (Risøy Formation) on Flatskjær. A) Cross-bedding and a high-angle scour. B) Conglomerate layers, single-pebble layers and scattered pebbles (pebbles are all of layered gabbro).

polymict conglomerate. The green metasandstones, occurring predominantly in the northern part of the area, are entirely derived from the ophiolitic basement. The chlorite schists and the conglomerates occur in the central part of the formation, and reflect a mixed source of ophiolitic and quartzofeldspathic detritus, while the sericite schist member (which occurs in the upper part of the formation) is essentially derived from a quartzofeldspathic source.

The type area for the lower part of the Risøy Formation is at the northern tip of Flatøy, while the upper part is excellently exposed on Esjeøy and Lille Esjeøy (Fig. 4).

## Green metasandstone

The lowest member of the Risøy Formation occurs predominantly in the lowermost part of the paleotopography, e.g. in northern Flatøy and the small islets to the north. The thickness varies from 0 to 20 metres, thinning towards the scarp in northern Flatøy described above. In the southern part it overlies the basal breccias, while farther north it rests directly on the weathered gabbro. The contact towards the breccias is characterised by a narrow transition zone where the breccias are reworked and filled with sand. Upwards, the green sandstone gradually changes in character and colour, into the greyish green, planar bedded siltstone and sandstone of the overlying member.

The mineralogy of the green sandstone mirrors that of the gabbro beneath, with actinolitic amphibole and plagioclase, and alteration products such as clinozoisite and epidote, as the major constituents. Furthermore, pebbles of the gabbro are common in conglomeratic beds.

The green metasandstone displays a variety of sedimentary structures. In the lower part of the member, low-angle cross-strata and trough cross-strata are the most common sedimentary structures, while horizontal lamination and symmetrical ripples dominate in the upper part. Low-angle, undulatory lamination, reminiscent of hummocky strata, are found in the middle part. Conglomerates and layers with scattered pebbles are common. In the southern part of the member (northern Flatøy), channel-shaped, upward-fining grits are followed by a few metres of thick, poorly sorted conglomeratic channel deposits, matrix- to clast-supported. Farther west (Flatskjær), conglomerates occur as several matrix-supported beds (<60 cm) with the largest pebbles concentrated in the middle of the beds. Between these conglomerates, single, continuous, pebble layers and isolated pebbles in the metasandstone occur quite commonly, indicating strong reworking of the conglomerates.

## Chlorite schist

The upward fining of the green sandstones marks the transition to the overlying member. Generally, this consists of planar and thin-bedded, fine-grained sandstone, siltstone and schist, characterised by a generally high content of Mg-chlorite. In the central part of the area, the member rests directly upon the Bolvær Complex or basal breccias, while it is absent in the southern part, e.g. on the palaeotopographic highs. Its occurrence in the core of the Flatøy syncline, combined with F2 refolding and lateral variation hinders an exact calculation of the thickness, but the member reaches a minimum thickness of at least 60 metres. Upwards, it grades into pelites and semipelites of the sericite schist member. Several conglomerate lenses occur in the chlorite schist, and these are treated separately below.

Sedimentary structures are well preserved in the lower part of the member, but upwards and away from the unconformity the bedding is increasingly transposed by the penetrative S2 foliation. The lower part of the member mineralogically reflects the rock compositions of the Bolvær Complex, with plagioclase and amphibole as common clastic grains, and Mg-chlorite and biotite as metamorphic minerals. As the clay layers are totally recrystallised to coarse-grained biotite and chlorite, a metamorphic inversion of the grain-size has occurred, demanding care in the interpretation of the sedimentary structures. However, the general appearance of the member is that of a well-bedded deposit, with sandstone and siltstone beds of 5 to 50 cm in thickness (Fig. 8a). The beds are generally massive, normally graded in the lower parts and planar or convoluted in the upper part with intercalations of clay material. Thus, the A, B, C and E subdivisions of classical Bouma sequences are recognised. Load casts (Fig. 8b) and flame-, ball- and-pillow and other escape-struc-

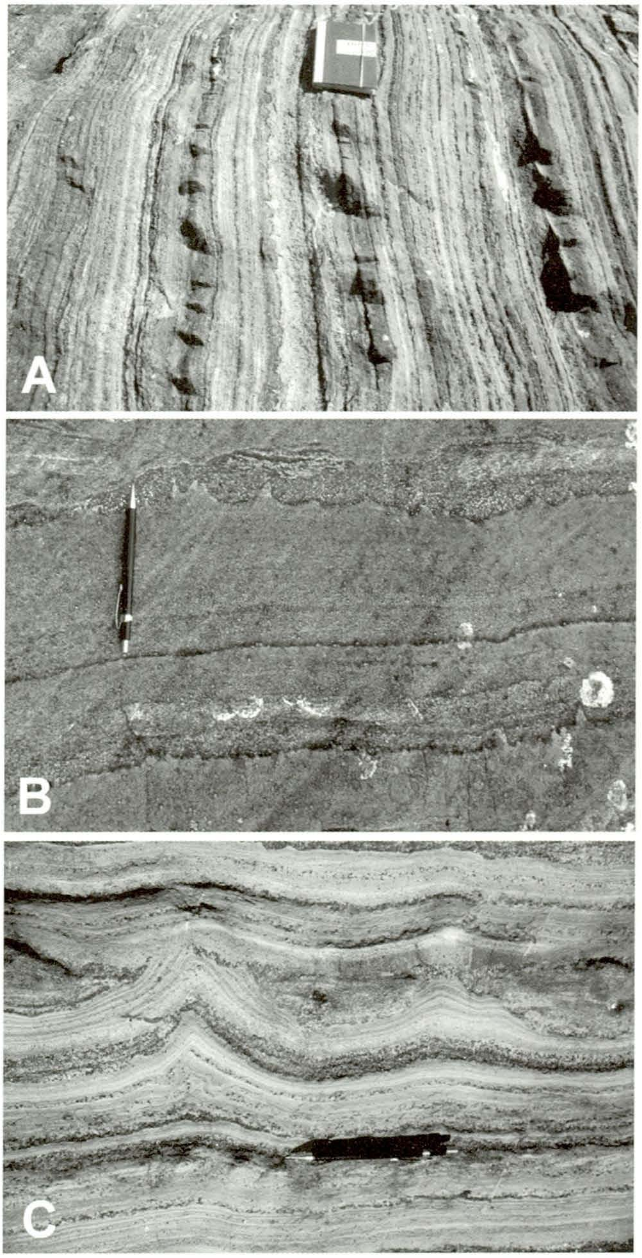


Fig. 8. Chlorite schist member (Risøy Formation) on Flatøy. A) Typical appearance of a well-preserved part of the chlorite schist member. Way up towards the left of the photograph. B) Load casts and planar laminated beds. The small round spots are garnet porphyroblasts. C) Planar laminated siltstone and sandstone and eroded escape structures.

tures indicating rapid deposition and burial are common. In several places, erosional bases are seen, cutting through escape-structures (Fig. 8c).

In the upper part, the content of quartz, garnet, staurolite and sericite increases, reflecting an increasing input of detritus from an ensialic source. Sedimentary structures are completely or partly obscured by S2, but generally a vague planar layering with interchanging sandy and clayey layers is seen. Isolated gabbroic clasts are sporadically present, and in northeast Flatøy a chaotic conglomerate lens, surrounded by slump folded siltstone, is present. Several smaller conglomerate lenses associated with slumping in the surrounding schist also occur, indicating down-slope sliding of poorly consolidated conglomerate bodies.

## Sericite schist

This member is a semipelitic schist, locally with sandy facies, especially close to the unconformity and conglomerates. In the southern part of the area it rests directly upon the unconformity, while in central and northern areas it shows a transition to the underlying chlorite schist member. The contact is defined where sericite replaces chlorite as the main flaky mineral. The member is about 10 m thick on Lille Esjeøy. Towards the west and southwest its thickness probably increases considerably, but a lack of continuous exposures makes this difficult to assess. Sedimentary structures are only common close to the unconformity and/or conglomerates; elsewhere, S0 is completely transposed by S1/S2.

In the more pelitic lithologies of the member, fine-grained quartz and sericite compose the matrix of the schists, while garnet, staurolite, plagioclase and kyanite are common porphyroblasts. In some samples, sillimanite is in equilibrium with kyanite, reflecting the syn-D2 metamorphic peak in middle to upper amphibolite facies. Where sedimentary structures are preserved, the lithofacies in the lower part resembles that of the underlying member, with rythmic, planar bedded sandstone interbedded with shale as the dominant type. Farther up, towards the contact with the Torgnes Formation, the member turns more pelitic in character. Close to the conglomerates, cross-bedded sandstone with grit layers are present, grading into foliated schists away from the contact.

## Conglomerates within the Risøy Formation

The conglomerates within the Risøy Formation are found in the upper part of the chlorite schist member and in the sericite schist member. Locally, they rest directly on the Bolvær Complex, as on Esjeøy, Lille Esjeøy and the western part of Risøy. They are generally polymict with a mixed clast population reflecting both the Bolvær Complex and a quartzofeldspathic source. A pure ultramafic conglomerate occurs on Risøy. In the polymict conglomerates, the matrix is essentially composed of quartzofeldspathic sandstone with biotite commonly defining the S2 foliation. Clasts are generally deformed and rotated into the same foliation, making interpretation of sedimentary clast morphology and imbrication difficult. However, in spite of the D2 deformation, sedimentary structures are still quite well preserved, making an interpretation of the depositional facies possible (Table 1, Fig. 9).

As shown in Table 1, four facies of conglomerates have been distinguished – interpreted as braided stream, subaerial mass-movement, subaqueous mass-movement, and beach gravels and conglomerates. The distribution of the different conglomerate facies varies within the area. On Risøy, braided stream conglomerates are most common. On

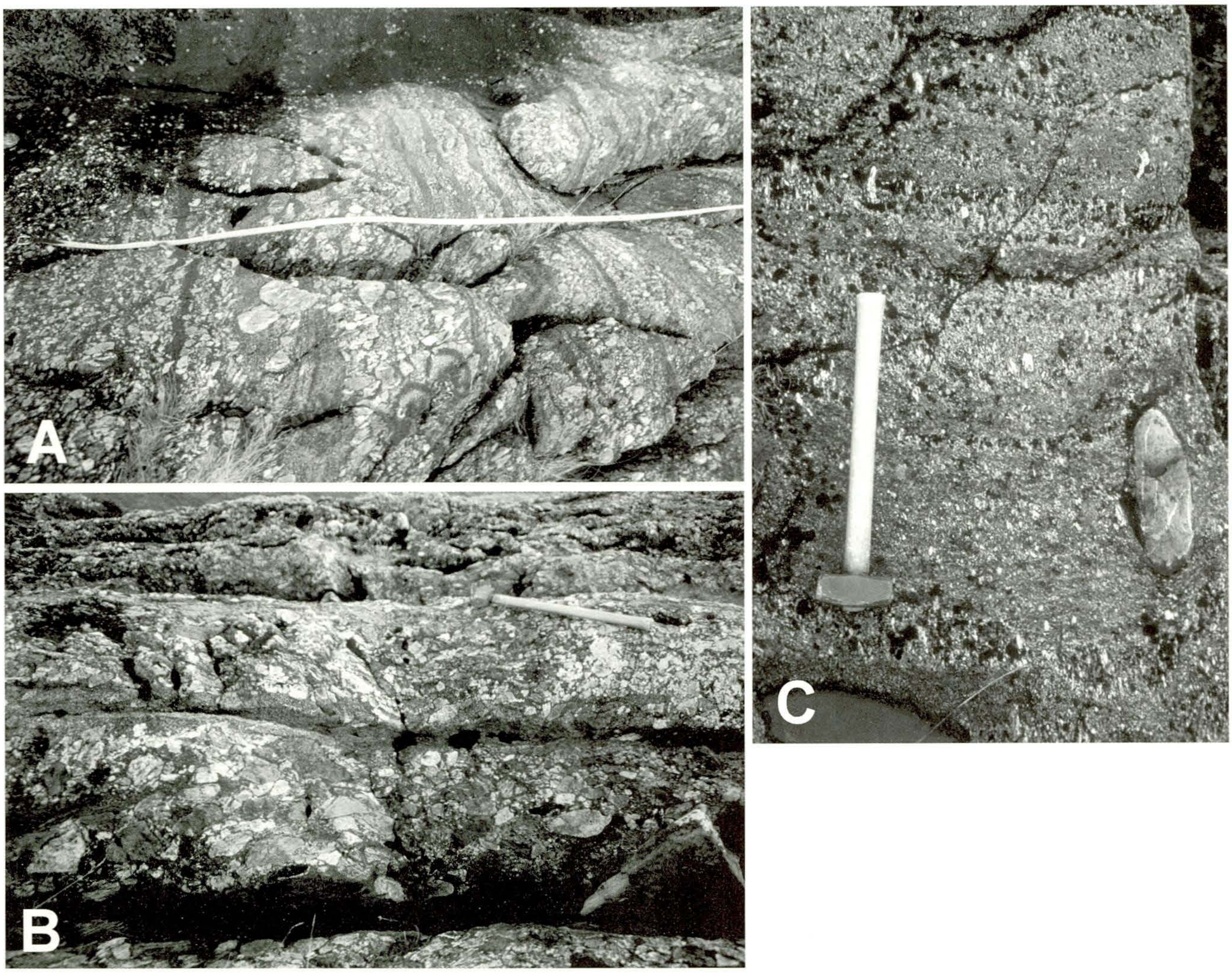

Fig. 9. Conglomerates in the Risøy Formation. A) Type 1 (way up towards the right); B) Type 3; C) Type 4 (Table 1). Note that clasts are rotated into the S2 foliation (N-S in the photograph).

Table 1. Conglomerate facies within the Risøy Formation.

| FACIES | DESCRIPTION | INTERPRETATION |
|---|---|---|
| Type 1 conglomerates | Clast-supported, packed, essentially medium to well sorted, upward- fining sequences towards intercalated sand and grit layers. Upward- coarsening beds are seen locally. Conglomeratic channels. The sandy and gritty subfacies are massive, crudely bedded or laminated, the latter in the upper parts of the sand layers. Unidirectional clast imbrications occur at the tops of some beds. | Braided stream conglomerates |
| Type 2 conglomerates | One 6-metre thick, lenticular bed which erodes underlying type 1 conglomerates. Clast to matrix-supported, poorly sorted, shows no obvious grading and contains isolated, large blocks up to 60 cm in diameter surrounded by cobbles and pebbles of varying sizes. | Highly viscous deposit, probably of subaerial mass-movement origin (Nemec & Steel 1984). |
| Type 3 conglomerates | Tabular conglomerate beds (<1 m) intercalated with sand and/or schist. Clast- to matrix-supported, poorly sorted, but commonly with increasing matrix content from bottom to top. Both upward fining and coarsening is seen (the latter is most common), and clasts are essentially angular. | Subaqueous mass-movement |
| Type 4 conglomerates | Gritty conglomerate, minor pebbly beds. Layers are well sorted (although single pebbles of larger size can occur), clast supported, packed and laterally persistent. Pebbles are essentially well rounded. Intercalated sand and pelitic layers are usually thinner or of the same thickness as conglomerate layers, commonly with clasts. No grading is seen. Upwards, this facies grades into conglomerates with carbonate matrix (no interpretation of sedimentary structures has been possible) or sericite schists. | Beach conglomerates (based on criteria described by Clifton (1973) and Kleinspehn et. al. (1984)) |

Table 2. Pebble population in polymict conglomerates at different localities in the Bolvær area. X = present, XX = abundant, XXX = frequent. * Ultramafics include actinolite-rich rocks.

| SOURCE | ROCK TYPE | NORTH FLATØY | SOUTH FLATØY | RISØY | LILLE ESJEØY | ESJEØY | STORØY |
|---|---|---|---|---|---|---|---|
| The Bolvær Complex and associated rocks | Ultramafics* | XX | | | XXX | XXX | |
| | Gabbro | XX | | XX | | X | |
| | Amphibolite | X | XX | | | | |
| | Chert | X | X | X | | | |
| Weathering profile | Magnesitic carbonate | | XX | X | X | X | |
| Meta-sediments | Psammite | XXX | XXX | XXX | X | XX | XX |
| | Quartzite | XXX | XXX | XXX | XXX | XX | XX |
| | Calc-silicate schist | X | | | | | |
| Other | Vein quartz | XX | XX | XX | XX | XX | XXX |

Lille Esjeøy this facies and possibly subaerial mass-movement conglomerates occur, while the third type is most common on Esjeøy. The beach-type conglomerates are seen on Storøy, where they grade laterally into coarser conglomerates of the former types.

In common with the fine-grained clastic sediments, the conglomerates are derived from several sources. A study of the pebble populations is summarised in Table 2.

Not surprisingly, the Bolvær Complex is commonly present in the pebble population. Additionally, clasts of 'coticule' chert containing very fine-grained, pink spessartine are quite abundant. These rocks are not observed in the Bolvær area, but similar rocks are found on the mainland farther to the east, occurring as thin bands in amphibolites (Heldal & Hjelmeland 1987), possibly representing an up-sequence part of the ophiolite pseudostratigraphy.

Pebbles of the metasedimentary rocks include psammite, biotite psammite, quartzite and calc-silicate schists. Evidently, these rocks were deformed and metamorphosed prior to deposition of the conglomerates, as shown by the occurrence of a pre-existing foliation and folded quartz veins in undeformed pebbles. This old basement of continental-derived metasedimentary rocks is not exposed in the area, but an obvious candidate would be the inferred Neoproterozoic, metasedimentary succession in the Helgeland Nappe Complex described above. The nearest location of such rocks is in the Velfjord area to the east of Brønnøysund. Furnes et al. (1988) stated that the Leka Ophiolite is resting on a basement of psammite, marble and schist, observed on the islands Solsemøyene.

## The Risøy Formation: source and depositional environment

The Risøy Formation gradually filled the irregular topography in the eroded Bolvær Complex. A reconstructed fence-diagram of the palaeotopography and the Risøy Formation is presented in Fig. 10, based on stratigraphic logs at five localities. The figure shows that sedimentary rocks at the base of the formation were deposited in topographic lows whereas highs were exposed to weathering. The different members of the formation show rapid lateral and vertical changes from fine-clastic sediments such as sandstone, siltstone and shale, to coarse conglomerates and breccias.

The lack of fossils, metamorphic recrystallisation and absence of continuous, vertical sections make it difficult to present a detailed interpretation of the sedimentary environment. However, there are several indications that the Risøy Formation represents partly continental and partly shallow-marine deposits in a coastal environment:

- In the green metasandstone member, sedimentary structures typical of shoreface associations (Burgois & Leithold 1984, Walker 1984, Johannesen et al. 1995, Fjellanger et al. 1996) are found, including low-angle cross-strata, small-scale trough cross-strata, high-angle scours and low-angle undulatory lamination. Furthermore, interchanging wave ripples and herring-bone strata could indicate interactions between wave- and tide-dominated environments (Hayes 1980). The conglomerates in the lower part of the member could represent channel-mouth deposits, varying from upward-fining, clast-supported channels to matrix-supported, tabular conglomerates, probably subaqueous mass-movements (Kleinspehn et. al. 1984). These conglomerates are, in part, strongly reworked, resulting in layers with isolated boulders and pebbles.
- The chlorite schists immediately above the green metasandstone could be interpreted as predominantly shallow-water turbidites. This is supported by the occurrence of slumped conglomerate bodies and boulders within them.
- The upper part of the Risøy Formation is characterised by pelitic sericite schist representing more finely laminated clay and siltstone, reflecting a complete drowning of the palaeotopography. Stratigraphically above these follow carbonate deposits of the Torgnes Formation, which are clearly of marine origin.
- The polymic conglomerates reflect a variety of facies – interpreted as braided stream, subaerial mass-movement, subaqueous mass-movement and beach, reflecting an interaction between fluvial, alluvial and subaquatic processes According to Houseknecht & Ethridge (1978) and Ethridge & Wescott (1984), these are important criteria for the recognition of fan-deltas in coastal environments. The vertical transition from subaerial deposits to the carbonate rocks of the Torgnes Formation, combined with the coarse, cyclic conglomer-

ates interchanging with possible shallow-water turbidites, are indicative of a shelf-type fan delta, according to Ethridge & Wescott (1984).

A striking feature of the Risøy Formation however, is the extreme bimodal character of the metasedimentary rocks: rapid transition from coarse conglomerates to clay, isolated boulders in fine-grained sandstone and siltstone, and slumped conglomerate bodies in the turbidites of the chlorite schist member. This could indicate either extreme storms and/or tectonism triggering a sudden influx of coarse clastic sediments. The observations of synsedimentary faults in the field are in favour of the latter. The transition from clastic sediments totally derived from the ophiolitic subsurface to sediments derived from a mixed and/or exotic, ensialic source occurs in the middle part of the formation, marked by the polymict conglomerates and the boundary between the chlorite schist member and the sericite schist member. At this stage, erosion had cut through the ophiolitic rocks and psammites and schists were exposed to weathering. These rocks then became the dominant detrital source. The sudden character of the change in source material, in the author's opinion, provides further support to syn-sedimentary faulting as an important factor controlling the deposition of the Risøy Formation. Fig. 11 shows a conceptual model summarising the interpretation of the Risøy formation.

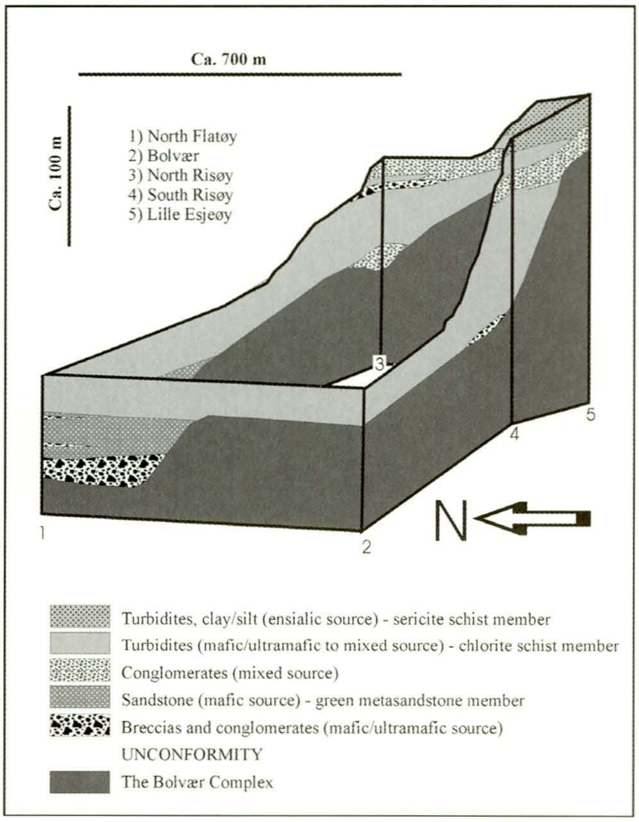


Fig. 10. Reconstruction of the palaeotopography and the Risøy Formation in the Bolvær area, based on logs from 5 localities (see Fig. 3).

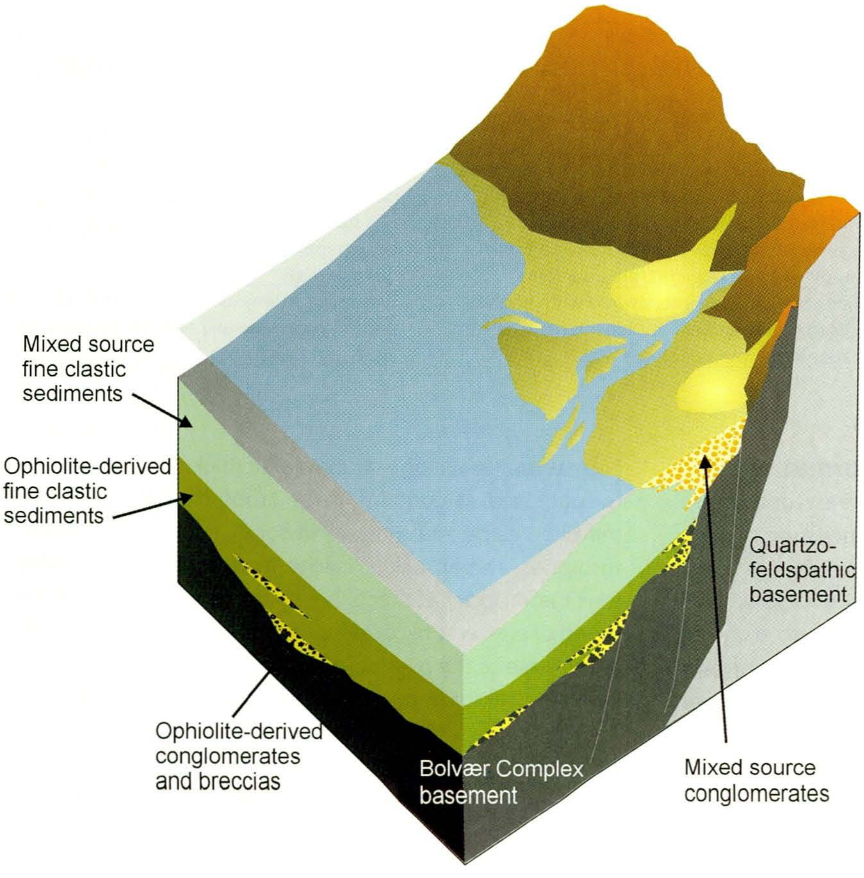


Fig. 11. Interpretation of the palaeoenvironment and the change of source area during deposition of the Risøy Formation.


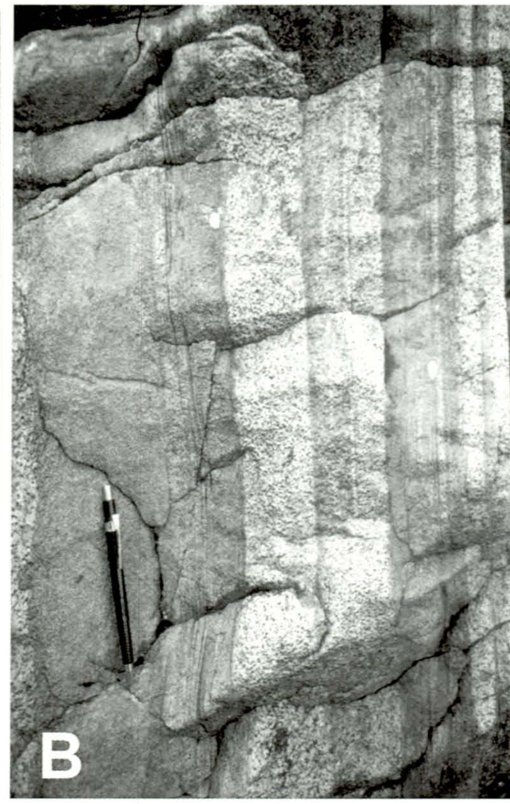


Fig. 12. Features of the Torgnes Formation. A) Folded (F2) sandstone layers intercalated with marble; B) Calcareous sandstone beds with normal grading and planar lamination in the upper part. Way up towards the right. The dark spots in the lighter coloured beds are biotite porphyroblasts.

Table 3. Lithofacies in the Torgnes, Aspøy and Toftsund Formations, and interpretation of depositional environments.

| FORMATION | LITHOFACIES | INTERPRETATION |
|---|---|---|
| Toftsund Formation | Marble conglomerate: pebbles and matrix of calcite marble | Intraformational limestone conglomerates |
| | Biotite schist | Marine silt- and sandstone |
| | Calcareous metasandstone: beds (<20 cm) intercalated with calcite marble | Marine, mixed clay and limy mud |
| | Calcite marble: banded, grey and white | Carbonate platform |
| Aspøy Formation | Biotite schist with minor layers and horizons of calcite marble, psammite, gritty conglomerate and clast-bearing schists | Marine silt with minor coarse clastic sediments and limestone (upper part) |
| | Garnet-mica schist | Predominantly marine clay |
| Torgnes Formation | Upper calcite marble: 15 metre-thick, yellow to grey marble with calc-silicate layers (only in the northern part of the area) | Hemipelagic, limy mud |
| | Calcareous metasandstone: planar beds of calc-silicate schist and calcareous sandstone with thin marble layers. Generally upward coarsening (increasing grain-size and bed thickness (<1 metre)). Decreasing carbonate content towards the contact to the overlying Aspøy Formation. Individual beds are normally graded, and the A, B and E sections of a Bouma sequence are abundant. | Calcareous turbidites ranging from distal (lower) to proximal (upper) part of a submarine fan. Intercalated by hemipelagic, limy mud deposited in quiet periods |
| | Lower calcite marble: grey, graphitic calcite marble interlayered with graphite schists (lower part) grades upwards to yellow and red marble intercalated with calc-silicate schists and intraformational, marble conglomerates. | Hemipelagic, limy mud, partly deposited . under hypersaline and reducing conditions (Bjørlykke & Olaussen 1981; Blatt et. al 1980) |

## The Torgnes, Aspøy and Toftsund Formations

The three remaining formations of the Brønnøysund Group occupy the area between Bolvær and Brønnøysund, younging towards the east. Sedimentary structures are much less common than in the Risøy Formation, and the rocks are isoclinally folded, and in some areas strongly sheared in the long limbs of F2 folds. Therefore, only a brief description and an attempt to interpret the lithofacies of these formations are included in the present paper.

Above the Risøy Formation follows a unit dominated by well-bedded, calcareous metasandstones; the Torgnes Formation. An average stratigraphic thickness of 200 metres is suggested. It contains three lithofacies: a lower calcite marble, a calcareous metasandstone (Fig. 12) interpreted as turbidites, and an upper calcite marble (Table 3). Both the lower and upper contacts are sharp, but no indications are found of any tectonic break within the succession. Grit layers at the base of the overlying Aspøy Formation may, however, indicate a minor depositional hiatus between the two.

The Toftsund Formation comprises calcite marble (Fig. 13), calcareous metasandstone, quartz-biotite schist and minor intraformational marble conglomerates. The last three lithologies are abundant in the lower part of the formation, marking a transition zone towards the subjacent Aspøy Formation, while the central and upper part is dominated by homogeneous, grey marble. One cannot exclude the possibility that the Toftsund Formation may represent a structural repetition of the Torgnes Formation, displaying a lateral change from turbidites to more proximal limestones. In that case, the Sauren island (outcrop area of the Aspøy Formation) would define an F2 syncline. Based on such considerations, the F2 fold pattern was carefully investigated for any indications of such a major syncline, without affirmative results. Thus, the author regards it as most likely that the Toftsund Formation is deposited on top of the Aspøy Formation.

## The Brønnøysund Group: Tectonism on a continental margin?

The unconformity at the base of the Brønnøysund Group clearly defines a highly irregular topographic surface exposed to subaerial weathering. This was probably filled with sediments during a regional transgression. The lower part of the cover sequence shows a great variety of depositional environments, from subaerial to shallow marine. By the time of deposition of the uppermost part of the Risøy Formation, the palaeotopography was completely drowned, and sedimentation was dominated by mud and fine-grained sand and silt. There are several indications of the deposition of the Risøy Formation being controlled by tectonism, e.g. the observation of a synsedimentary fault and the abrupt change in source material, reflecting a sudden, and not gradual, input of ensialic material.

The Torgnes Formation marks a change in the depositional pattern. The formation is interpreted to be mainly turbiditic, partly derived from a carbonate platform. During this period there was little influx of terrigenous detritus into the basin, which could have been due to diminishing tectonic activity. The Aspøy Formation, however, is essentially composed of terrigenous material, indicating either a new period of tectonism or a change to a more humid climate, increasing the sediment transport from the mainland. The Toftsund Formation again reflects a reduction in terrigenous detritus and/or transgression, leading to the development of a new carbonate platform.

The rapid changes in the Brønnøysund Group deviate from that expected in a transgressive sequence on a stable continental margin. The vertical change from terrigenous sediments to carbonates and back, indicates either strong climatic changes or a tectonically active margin. Given the clear indications of tectonism in the lower part of the group, the latter seems to be the most likely interpretation. Similar features have been described from cover sequences overlying the Lyngen Ophiolite in northernmost Norway (Minsaas & Sturt 1985), the Leka Ophiolite Complex (Sturt & Ramsay 1995) and the Vågåmo Ophiolite in south-central Norway (Sturt et al. 1991, Bøe et. al. 1993, Sturt et al. 1995). In the case of the Vågåmo Ophiolite, the cover sequence (lower part of the Sel Group) is interpreted as a series of fan-like deposits, relating to active fault scarps, at the margin of a Lower Ordovician back-arc basin.

## The stratigraphic problem of the HNC

For a further understanding of the history of the western HNC, *stratigraphy* could play an important role. In the present paper, it has been shown that the Brønnøysund Group was probably deposited on a tectonically active, continental margin. The area can serve as a type locality for the Lower Ordovician metasedimentary successions within the medium- to high-grade part of the western HNC, helping to define a stratigraphic and tectonostratigraphic framework for the region. The correlation between the Brønnøysund Group and similar cover sequences on Leka (Sturt & Ramsay 1994), at Terråk (Husmo & Nordgulen 1988), in the Velfjord-Tosen area (Thorsnes & Løseth 1991) and on Rødøy (Bang 1985) seems obvious. Additionally, rocks occurring on the myriad of small islets in the area between the mouth of Bindalsfjord and Vega can be correlated with the Bolvær

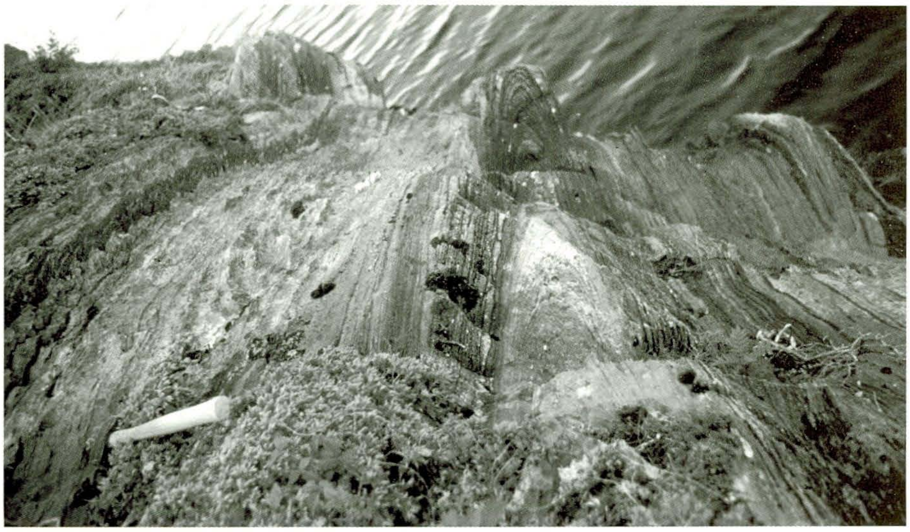

Fig. 13. Marble with folded (F3) layers of schist in the Toftsund Formation, eastern part of Sauren.

Complex and the Brønnøysund Group (Heldal & Hjelmeland 1987), breaking the pattern of thin, eastward-dipping, thrust sheets seen on the mainland. The relationship between the Brønnøysund Group and the *low-grade* successions to the northwest, in the Skålvær area (Gustavson 1975), remains to be investigated.

The conglomerate facies within the Brønnøysund Group and in similar ophiolite cover sequences in the HNC shows a *mixed source* of detritus, reflecting both the fragmented ophiolites, metamorphic quartzo-feldspathic sedimentary rocks and (at some locations) crystalline basement. Clearly, a candidate for the second group of clasts is the inferred Neoproterozoic succession found farther to the east in the HNC. However, no primary contacts between the old and the younger cover sequences have yet been found. This mysterious non-appearance of highly expected primary relations may be explained by a lack of systematic research on this subject, and the difficulties in locating primary contacts between two, comparatively similar, sedimentary successions in a high-strain area. The identification of such relationships and the further differentiation between the two metasedimentary units would be of great importance for our overall understanding of the tectonostratigraphy of the Helgeland Nappe Complex, and should therefore be a main target for future research in the region. Lately, it has been shown that isotopic dating of carbonate rocks (Trønnes & Sundvoll 1995) can be a suitable method of separating the 'older' and 'younger' successions in this region. Interesting results from such isotopic studies have recently been reported from areas farther to the north in the Uppermost Allochthon (Melezhik et al. 2000, 2001). Combined with sedimentological and structural work, these studies have added significantly to our knowledge of the orogenic development of this part of the Caledonides (e.g. Roberts et al., in press).

The Bolvær Complex was probably emplaced onto a continental margin some time after the formation of the Leka Ophiolite Complex (497 +/- 2 Ma; Dunning & Pedersen 1988); this was immediately succeeded by deposition of the Brønnøysund Group. Before emplacement of the Bindal Batholith (around 450 Ma), this margin was imbricated, deformed and metamorphosed in amphibolite facies. As described by several authors (Bang 1985, Heldal 1987, Thorsnes & Løseth 1991), this implies that the most significant part of the tectonometamorphic development of the metasedimentary successions took place during a major, pre-Scandian event. Hjelmeland (1987) interpreted the Torghatten Granite as a syn-D2 intrusion in the Brønnøysund Group, and not as a basement window, as indicated on geological maps. Dating of this pluton and the similar Hamnøy Granite farther to the north would clearly be of great importance for adding to our knowledge of the depositional and tectonometamorphic evolution of this region.

## Conclusions

It has been shown that the Bolvær Ophiolite Complex was emplaced, uplifted and subjected to subaerial weathering and erosion prior to the deposition of the Brønnøysund Group. The unconformity defines an irregular topographic surface, which was gradually covered by sediments during a regional transgression, probably influenced by active tectonics. The sedimentation of the Brønnøysund Group initially started with the build-up of a coastal setting, delivering coarse and fine clastics into a shallow-marine environment. This is stratigraphically followed by calcareous turbidites, mica schists and carbonate rocks.

The Brønnøysund Group is correlated with several cover sequences above fragmented ophiolites in the HNC, and an Early to Middle Ordovician depositional age is suggested. The clast population in conglomerates and the composition of finer clastic sediments show an exotic, ensialic source for the detritus in addition to the ophiolite. This ensialic source consist essentially of psammites and schists, deformed and metamorphosed prior to the deposition of the Brønnøysund Group.

The extremely well preserved unconformity and sedimentary structures in the Risøy Formation make the small islands in the Bolvær area an excellent target for field excursions. This could be of significant help in the interpretation of basement-cover relations in other, strongly deformed parts of the HNC; or just for the pleasure of studying primary, sedimentary features in rocks that were totally recrystallised in upper amphibolite-facies metamorphic conditions.

*Acknowledgements*

The author wishes to acknowledge the late Prof. Brian A. Sturt for supervision during fieldwork and for encouragement to start working on this paper. Likewise, Prof. Donald Ramsay is thanked for guidance and inspiration during the fieldwork. Many thanks also go to Reidulv Bøe, Stephen Lippard, Øystein Nordgulen and David Roberts for reading the manuscript and for offering constructive comments.

## References

Bang, N. 1985 : The stratigraphy and structural development of the Rødøy-Haltøy area, outer Vefsnfjord. Unpublished Cand. Scient. Thesis, University of Bergen, 247 pp.

Barnes, C. G., Prestvik, T., Nordgulen, Ø. & Barnes, M. A. 1992: Geology of three dioritic plutons in Velfjord, Nordland. Norges geologiske undersøkelse Bulletin 423, 41-54.

Birkeland, A., Nordgulen, Ø., Cumming, G. L. & Bjørlykke, A. 1993: Pb-Nd-Sr isotopic constraints on the origin of the Caledonian Bindal Batholith, central Norway. Lithos 29, 257-271.

Bjørlykke, A. and Olaussen, S. 1981 : Silurian sediments, volcanics and mineral deposits in the Sagelvvatn area, Troms, North Norway. Norges geologiske undersøkelse Bulletin 426, 1-38.

Blatt, H., Middleton, G. & Murray, R. 1980: Origin of sedimentary rocks. Prentice-Hall Inc., Englewood Cliffs, N.J. 782 pp.

Bourgeois, J. & Leithold, E. L. 1984: Wave-worked conglomerates – depositional processes and criteria for recognition. In: Koster, E. H. & Steel, R. J. (ed.) Sedimentology of gravels and conglomerates. Canadian Society of Petroleum Geologists, Memoir 10, 41-47.

Braathen, A., Nordgulen, Ø., Osmundsen, P. T., Andersen, T. B., Solli, A. &

Roberts, D. 2000: Devonian, orogen-parallel, opposed extension in the Central Norwegian Caledonides. Geology 28, 615-618

Bøe, R. 1989: A pre-Devonian pediment in the lowermost Old Red Sandstone Hitra Group, Western Norway. Norsk Geologisk Tidsskrift 69, 21-28.

Bøe, R., Sturt, B.A. and Ramsay, D.M. 1993 : The conglomerates of the Sel Group, Otta-Vågå area, Central norway : an example of a terrane-linking succession. Norges geologiske undesøkelse Bulletin 425, 1-24.

Clifton, H. E. 1973: Pebble segregation and bed lenticularity in wave-worked versus alluvial gravel. Sedimentology 20, 173-187.

Dunning, G.R. and Pedersen, R.B. 1988 : U/Pb ages for ophiolites and arc-related plutons of the Norwegian Caledonides: implications for the development of lapetus. Contributions to Mineralogy and Petrology 98, 13-23.

Ethridge, F. G. & Wescott, W. A. 1984: Tectonic setting, recognition and hydro-carbon reservoir potential of fan-delta deposits. In: Koster, E. H. & Steel, R. J. (ed.) Sedimentology of gravels and conglomerates. Canadian Society of Petroleum Geologists, Memoir 10, 217-235.

Fjellanger, E., Olsen, T. R. & Rubino, J. L. 1996: Sequence stratigraphy and palaeogeography of the Middle Jurassic Brent and Vestland deltaic systems, Northern North Sea. Norsk Geologisk Tidsskrift 76, 75-106.

Furnes, H., Roberts,D., Sturt, B.A.,Thon, A. & Gale,G.H. 1980 : Ophiolite fragments in the Scandinavian Caledonides.In : Panayioutou, A. (ed.) Proceedings of the International Ophiolite SymposiumCyprus 1979. Geological Society of Cyprus, Nicosia, 582-600.

Furnes, H., Ryan, P. D., Grenne, T., Roberts, D., Sturt, B. A., & Prestvik, T. 1985: Geological and geochemical classification of the ophiolite fragments in the Scandinavian Caledonides. In: Gee, D.G. and Sturt, B:A. (eds). The Caledonide Orogen- Scandinavia and related areas. John Wiley, Chichester, 657-669.

Gee, D.G. & Sturt, B.A. (editors) 1985 : The Caledonide Orogen - Scandinavia and related areas. John Wiley, Chichester. 1266 pp.

Gustavson, M. 1975: The low-grade rocks of the Skålvær area, S. Helgeland and their relationship to the high-grade rocks of the Helgeland Nappe Complex. Norges geologiske undersøkelse 322, 13-23.

Hayes, M. O. 1980: General morphology and sediment pattern in tidal inlets. Sedimentary Geology 26, 139-156.

Heldal, T. 1987 : Stratigrafi og Strukturell utvikling i Sauren-området, vest for Brønnøysund, Sydelige Nordland. Unpublished Cand. Scient. Thesis, University of Bergen, 293 pp.

Heldal, T. & Hjelmeland, H. 1987: Brønnøysund, berggrunnskart 1725-1, 1:50000, foreløpig utgave. Norges geologiske undersøkelse.

Hjelmeland, H. 1987: Tektonostratigrafi og strukturell utvikling i området Torgøya-Brønnøysund, Sørvestlige Nordland. Unpubl. cand.scient. thesis, University of Bergen.

Houseknecht, D. W. & Ethridge, F. G. 1978: Depositional history of the Lamotte Sandstone of south-eastern Missouri. Journal of Sedimentary Petrology 48, 575-586.

Husmo, T. & Nordgulen, Ø. 1988: Structural relations along the western boundary of the Helgeland Nappe Complex, north-central Norway. Institutt for geologi, Oslo, Interne Skrifter serie 54 (unpublished), 21-23 (abstract).

Johannesen, E. P., Mjøs, R., Renshaw, D., Dalland, A. & Jacobsen, T. 1995: Northern limit of the "Brent delta" at the Tampen Spur – a sequence stratigraphic approach for sandstone prediction. In: Steel, R. J., Felt, V. L., Johannesen, E. P. & Mathieu, C. (ed.) Sequence stratigraphy on the northwest European margin. Norwegian Petroleum Society Special publication 5, 213-256.

Kleinspehn, K. L., Steel, R. J., Johansen, E. & Netland, A. 1984: Conglomeratic fan-delta sequences, Late Carboniferous – Early Permian, Western Spitsbergen. In: Koster, E. H. & Steel, R. J. (ed.) Sedimentology of gravels and conglomerates. Canadian Society of Petroleum Geologists, Memoir 10, 279-294.

Melezhik, V. A., Heldal, T., Roberts, D., Gorokhov, I. M. & Fallick, A. E. 2000: Depositional environment and apparent age of the Fauske carbonate conglomerate, North Norwegian Caledonides. Norges geologiske undersøkelse Bulletin 436, 147-168.

Melezhik, V. A., Gorokhov, I. M., Fallick, A. E. & Gjelle, S. 2001: Strontium and carbon isotope geochemistry applied to dating of carbonate sedimentation: an example from high-grade rocks of the Norwegian Caledonides. Precambrian Research 108, 267-292.

Minsaas, O. & Sturt, B.A. 1985 : The Ordovician-Silurian clastic sequence overlying the Lyngen Ophiolite and its environmental significance. In: Gee, D.G. & Sturt, B:A. (eds). The Caledonide Orogen- Scandinavia and related areas. John Wiley, Chichester 379-394.

Nemec, W. & Steel, R. J. 1984: Alluvial and coastal conglomerates: their significant features and some comments on gravelly mass-flow deposits. In: Koster, E. H. & Steel, R. J. (ed.) Sedimentology of gravels and conglomerates. Canadian Society of Petroleum Geologists, Memoir 10, 1-31.

Nissen, A. L. 1986: Rb/Sr age determination of intrusive rocks in the southeastern part of the Bindal Massif, Nord-Trøndelag, Norway. Norges geologiske undersøkelse Bulletin 406, 83-92.

Nordgulen, Ø. & Sundvoll, B. 1992: Strontium isotope composition of the Bindal Batholith, Central Norwegian Caledonides. Norges geologiske undersøkelse Bulletin 423, 19-41.

Nordgulen, Ø., Bickford, M.E., Nissen, A.l. and Wortman, G.L. 1993 : U/Pb zircon ages from the Bindal Batholith and the tectonic history of the Helgeland Nappe Complex, Scandinavian Caledonides. Journal of the Geological Society, London 150, 771-783.

Nordgulen,Ø. & Schouenberg, B. 1990 : The Caledonian Heilhornet Pluton, north-central Norway: geological setting, radiometric age and implications for the Scandinavian Caledonides. Journal of the Geological Society, London 147, 439-450.

Prestvik, T. & Roaldseth, E. 1978: Rare earth element abundances in Caledonian metavolcanics from the island of Leka, Norway. Geochemical Journal 12, 89-100.

Riis, F. & Ramberg, I. B. 1981: The uppermost allochton, the Røddingsfjellet and the Helgeland Nappe Complexes in a segment south of Ranafjorden, Norway. Terra Cognita 1, 69.

Roberts, D., Heldal, T. & Melezhik, V. A. (in press): Tectonic structural features of the Fauske conglomerates in the Løvgavlen quarry, Nordland, Norwegian Caledonides, and regional implications. Norges Geologiske Tidsskrift.

Stephens, M.B. & Gee, D.G. 1985 : A tectonic model for the evolution of the eugeoclinal terranes in the central Scandinavian Caledonides. In: Gee, D.G. & Sturt, B:A. (eds). The Caledonide Orogen- Scandinavia and related areas. John Wiley, Chichester 953-978.

Stephens, M.B., Gustavson, M., Ramberg, I.B. & Zachrisson, E. 1985: The Caledonides of central-north Scandinavia - a tectonostratigraphic overview. In: Gee, D.G. & Sturt, B:A. (eds). The Caledonide Orogen-Scandinavia and related areas. John Wiley, Chichester 135-162.

Sturt, B.A. 1984 : The accretion of ophiolitic terranes in the Scandinavian Caledonides. Geologie en Mijnbouw 63, 201-212.

Sturt, B.A., Bøe, R., Ramsay, D.M. & Bjerkgård, T. 1995 : Stratigraphy of the Otta-Vågå tract and regional stratigraphic implications (Extended abstract). Norges geologiske undesøkelse Bulletin 427, 25-28.

Sturt, B.A. & Ramsay, D.M. 1994, The structure and regional setting of the Skei Group, Leka, north-central Norway. Norges geologiske undesøkelse Bulletin 426, 31-46.

Sturt, B.A., Ramsay, D.M. & Neumann, R.B. 1991 : The Otta Conglomerate, the Vågåmo Ophiolite - furthur evidence of Early Ordovician orogenesis in the Scandinavian Caledonides. Norsk Geologiske Tidsskrift 71, 107-115.

Thorsnes, T & Løseth, H. 1991 : Tectonostratigraphy in the Velfjord-Tosen region, southwestern part of the Helgeland Nappe Complex, central Scandinavian Caledonides. Norges geologiske undesøkelse Bulletin 421, 1-18.

Trønnes, R. G. 1994: Marmorforekomster i Midt-Norge: Geologi, isotopgeokjemi og industrimineralpotensiale. Norges geologiske undersøkelse Report 94.042, 53 pp.

Trønnes, R. G. & Sundvoll, B. 1995: Isotopic composition, deposition ages and environments of Central Norwegian Caledonian marbles. Norges geologiske undersøkelse Bulletin 427, 44-48.

Walker, R. G. 1984: Shelf and shallow marine sands. In: Walker R. G. (ed.) Facies models, second edition. Geoscience Canada, reprint series 1, 141-171.