The Stratigraphy of the Dyvikvågen Group, Stord: A Revision

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A revision of the stratigraphy of the Upper Ordovician to Lower Silurian Dyvikvågen Group is presented. This group of sediments rests with primary stratigraphic unconformity upon a substrate of basaltic greenstones cut by basic dykes (Nonshaug Formation) and underlying gabbros and serpentinites. This magmatic complex, which is inferred to represent a dismembered ophiolite fragment, was deformed and eroded prior to Upper Ordovician (Ashgill) times. From base to top the Dyvikvågen Group contains: the Limbuvik Formation (local basal conglomerates, sandstones, siltstones, limestones and calcareous phyllites), the Vikanes Formation (graptolitic shales) and the Utslettfjell Formation (polymict conglomerates). The revised stratigraphy of the Dyvikvågen Group and substrate is briefly discussed in terms of the association of obducted and deformed ophiolite fragments with a unconformably overlying Upper Ordovician to Lower Silurian cover sequence, a common feature in the allochthonous Caledonides of western Norway.

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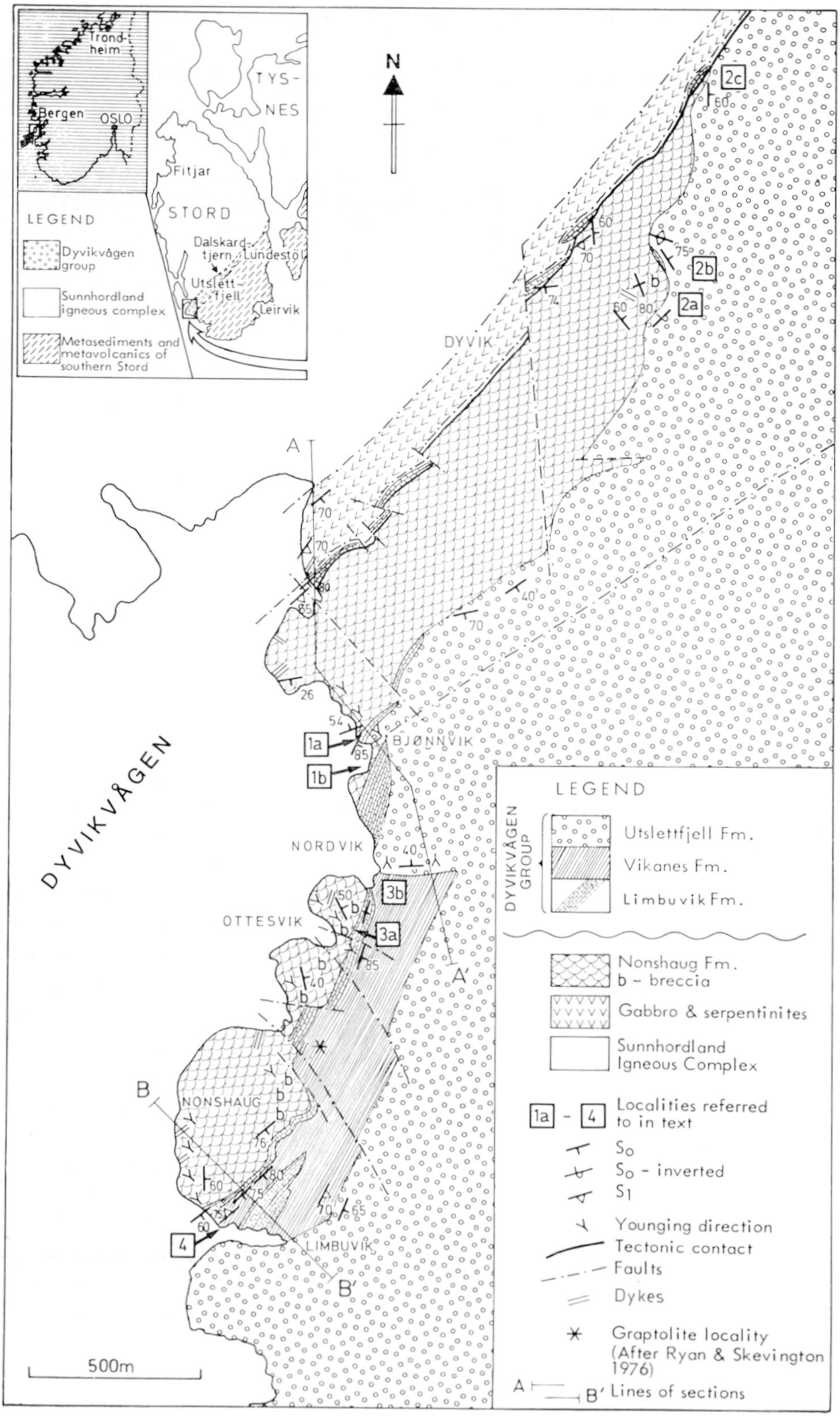
Introduction

The Dyvikvågen Group as defined by Færseth & Ryan (1975) contains an Upper Ordovician (5a, Oslo sequence) shelly fauna (Kiær 1929) and a graptolite fauna of Lower Silurian (L. Llandovery) age (Elles, in Kiær 1929, Ryan & Skevington 1976). Structurally the Dyvikvågen Group lies in fault contact on either side (Fig. 1) between a southeastern series of metasediments and metavolcanics of supposed Lower Palaeozoic age (Skordal 1948) and the basic to acidic Sunnhordland Igneous Complex to the northwest (Kvale 1937, Færseth & Ryan 1975, Lippard 1976). Since Reusch's (1888) first description of these rocks and their faunal assemblage, considerable discussion has taken place concerning the stratigraphy and structure of the Dyvikvågen–Limbuvik area. Reusch (188), Kiær (1929), Skordal (1948) and more recently Strand (1972) assumed that the oldest rocks occur in the southeast with successively younger sequences to the northwest. Kolderup (1931), however, stressed the tectonic complexity of the area, and suggested that the preservation of a primary stratigraphic succession was unlikely. Recently Færseth & Ryan (1975) named the volcano–sedimentary sequence the Dyvikvågen Group and divided it into four formations (from top to bottom):

Utslettfjell Fm.	1000 m polymict conglomerates (Færseth & Steel 1978).
Nonshaug Fm.	Max. 220 m basaltic greenstones with ocean-floor tholeiitic geochemical characteristics (Furnes & Færseth 1975, Færseth & Ryan 1975).


Trondheim
Bergen
OSLO
TYSNES
Fitjar
STORD
Dalskard-tjern
Lundestöl
Utslett-fjell
Leirvik
LEGEND
Dyvikvågen group
Sunnhordland igneous complex
Metasediments and metavolcanics of southern Stord
N
2c
2b
2a
DYVIK
A
A'
BJØNNVIK
1a
1b
DYVIKVÅGEN
NORDVIK
OTTESVIK
3b
3a
B
B'
NONSHAUG
4
LIMBUVIK
500m
LEGEND
DYVIKVÅGEN GROUP
Utslettfjell Fm.
Vikanes Fm.
Limbuvik Fm.
Nonshaug Fm.
b – breccia
Gabbro & serpentinites
Sunnhordland Igneous Complex
1a - 4 Localities referred to in text
So
So - inverted
S1
Younging direction
Tectonic contact
Faults
Dykes
Graptolite locality (After Ryan & Skevington 1976)
A — B' Lines of sections

Vikanes Fm.	10–105 m graptolitic shales of L. Llandovery age (Elles, in Kiær 1929, Ryan & Skevington 1976).
Limbuvik Fm.	Min. 25 m limestones and phyllites with a shelly marine fauna of Ashgill age (Kiær 1929).

The early debate was centred on the stratigraphic position of the thick conglomerates of the Utslettfjell Formation. Earlier workers (Reusch 1888, Kiær 1929, Skordal 1948 and Strand 1972) placed the Utslettfjell Formation below the fossiliferous sequence on the basis of lithostratigraphic correlations with the Bergen and Trondheim regions. The presence of fossil-bearing clasts in the conglomerates, caused Kolderup (1931) to place the conglomerates above the limestones (Limbuvik Formation). Kiær (1929), following Reusch (1888), also mentioned the fossil-bearing limestone clasts in the conglomerate as an anomaly, in his discussion of the stratigraphy. Recently, Færseth & Ryan (1975) have shown that the thick sequence of conglomerates occurs at the top of the Dyvikvågen Group and thus cannot be older than Lower Llandovery.

We concur with recent workers as to the stratigraphic position of the Utslettfjell Formation, but suggest that the Nonshaug Formation, as defined by Færseth & Ryan (1975), should not be included as a part of the Dyvikvågen Group. In the present paper, evidence indicating that the basaltic rocks of the Nonshaug Formation were deformed (folded with local reorientation and flattening of pillows in the cleavage) prior to the deposition of the Dyvikvågen Group sediments is presented. We thus interpret the contact between the Nonshaug Formation and the Dyvikvågen Group as a major stratigraphic unconformity and suggest a redefinition of the Dyvikvågen Group as follows:

Utslettfjell Fm. Vikanes Fm. Limbuvik Fm.	} Dyvikvågen Group
————————	Major stratigraphic break
Nonshaug Fm.	

The Nonshaug Formation greenstones, which display clear ocean-floor tholeiitic geochemical characteristics, are together with an underlying slice of gabbros and serpentinites cut by basic dykes, tentatively interpreted as part of a fragmented ophiolite.

The evidence for the revision of the stratigraphy of the Dyvikvågen Group is presented below together with a brief discussion of the evidence for an ophiolite fragment in the area. A more detailed study of the stratigraphy, paleontology and structure of the rocks of the Dyvikvågen area is in progress.

Substrate to the Dyvikvågen Group

The Nonshaug Formation crops out along the eastern shore of Dyvikvågen from Nonshaug in the south to north of Bjønnvik, and the northernmost unit

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Fig. 1. Geological map of the Dyvikvågen area. Partly after Færseth & Ryan (1975).

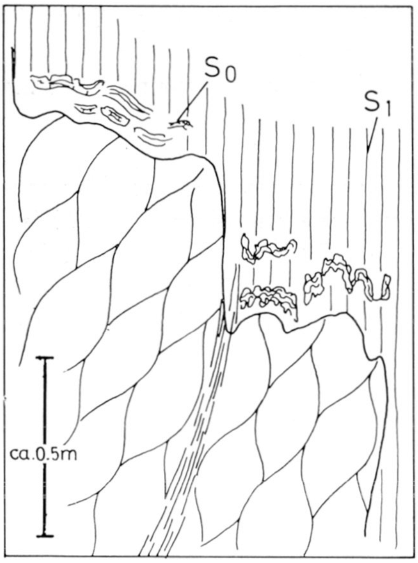

Fig. 2. Sketch of the angular unconformity between the Nonshaug Formation (lower part) and the Limbuvik Formation at Bjønnvik, locality la (Fig. 1).

can be traced 1.4km northeastwards where it is unconformably overlain by the conglomerates of the Utslettfjell Formation (Fig. 1). Færseth & Ryan (1975, Fig. 1) show five isolated outcrops of this formation, but our mapping indicates that the three southernmost disconnected outcrops are in fact continuous.

The Nonshaug Formation consists of basaltic volcanics which locally display good pillow structures, best seen in the wave-washed cliff-sections. The lavas are cut by basic dykes which can be shown to represent feeders to the lavas (a good example can be seen on the small headland 300 m northwest of Bjønnvik, Fig. 1). The dykes vary in thickness from 0.15–0.80 m, have variable trends from NE–SE (030°) to NW–SE (126°) and are generally steep. No dykes have been observed to cut the rocks of the Limbuvik or Vikanes Formations. Towards the top of the lava sequence several distinct units of hyaloclastite and isolated pillows occur, but lenses of hyaloclastite have also been observed lower down in the volcanic pile. Characteristically the pillow lavas are variolitic and non-vesicular, features suggestive of eruption at a water depth of at least 1500–2000 m (Furnes 1973). Bedding is shown by layers of red jasper-bearing sediments and mudstone (0.3–0.5 thick) in the northernmost unit (Figs. 1 and 3). A crude primary layering is also present in the pillow lavas shown by alignment of lenses of hyaloclastite. In some outcrops a planar orientation of pillow long axes and epidote lenses is seen; we would interpret this as an early deformation feature associated with folding and cleavage development in the rocks of the Nonshaug Formation. This plane and the S_0 in the pillow lavas are cut by the interface between the Nonshaug Formation and S_0 in the Dyvikvågen Group sediments (Figs. 2 and 3). In thin-sections, recrystallized tests, probably of radiolaria, have been observed.

Geochemically the Nonshaug Formation basalts display clear ocean-floor tholeiitic characteristics (Furnes & Færseth 1975) and it may thus be speculated that the volcanics form part of a fragmented ophiolite assemblage. The lower part of an ophiolite pseudostratigraphy may be represented in the northern part of the area (Fig. 1) where serpentinites and gabbros are cut by basic dykes and trondhjemites. Locally the gabbros have developed a marked foliation prior to the intrusion of basic dykes. The gabbros and serpentinites are tectonically separated from the Nonshaug Formation by thin disconnected slivers of Ashgillian phyllites and limestones. Since the discovery of the Karmøy Ophiolite (Sturt & Thon 1978a), ophiolitic rocks have also been reported from the nearby island of Bømlo (Amaliksen 1979, Nordås 1979) and the rocks of the Dyvikvågen–Limbuvik area can indeed be traced southwestwards across to Bømlo.

The Dyvikvågen Group is separated from the supposed Lower Palaeozoic metasediments and metavolcanics to the southeast by a fault (Færseth & Ryan 1975). To the north the Dyvikvågen Group and the possible ophiolite fragment are in fault contact with the rocks of the Sunnhordland Igneous Complex (Kvale 1937, Lippard 1976) which is thought to be of Lower Palaeozoic age. The latter is also thought to have been uplifted along the fault, and to have been the source rocks of the upper part of the Utslettfjell Formation conglomerates (Færseth & Steel 1978). A Rb/Sr whole rock isochron of 445 m.y. (λ Rb^{87} = $1.42 \times 10^{-11} y^{-1}$) on rhyolites within this complex (Priem & Torske 1973) indicates an Upper Ordovician age following the time scale by Ross et al. (1978). Recently, however, Råheim & Thon (in prep.) have obtained a Rb/Sr whole rock isochron of 664 ± 102 m.y. on granodiorites/granites intruding deformed gabbros west of Fitjar (Fig. 1), northern Stord, indicating the presence of Late Precambrian (Cadomian) plutonic rocks within the Sunnhordland Igneous Complex.

Contact relations between the Nonshaug Formation and the Dyvikvågen Group (see Fig. 1 for numbered localities)

1a. WEST OF BJØNNVIK (Figs. 2 & 3)

The contact with the overturned, eastward-younging, Nonshaug Formation basalts and a 10 m-thick development of the Limbuvik Formation is well exposed at this locality (Fig. 2). This contact is interpreted as a primary stratigraphic unconformity between the Nonshaug Formation and the overlying Limbuvik Formation although it is somewhat sheared. This zone of sediments was shown on Reusch's (1888) original map, but not on the map by Færseth & Ryan (1975), Fig. 1). In the Nonshaug Formation adjacent to the contact, pillows and epidote lenses are clearly oriented in a plane trending at 054°/54°NW, i.e. overturned (Fig. 2). Directly overlying the lavas is a 70 cm-thick reddish-green siltstone followed by 4.3 m of white limestone (Fig. 3), both units containing a rich shallow-marine Ashgill fauna (crinoids, corals, brachiopods and gastropods).

The interface between the Nonshaug Formation and the sediments is eastward dipping, and where bedding, S_0, is seen in the siltstone it is parallel to the contact with the Nonshaug Formation and thus clearly cuts the orientation

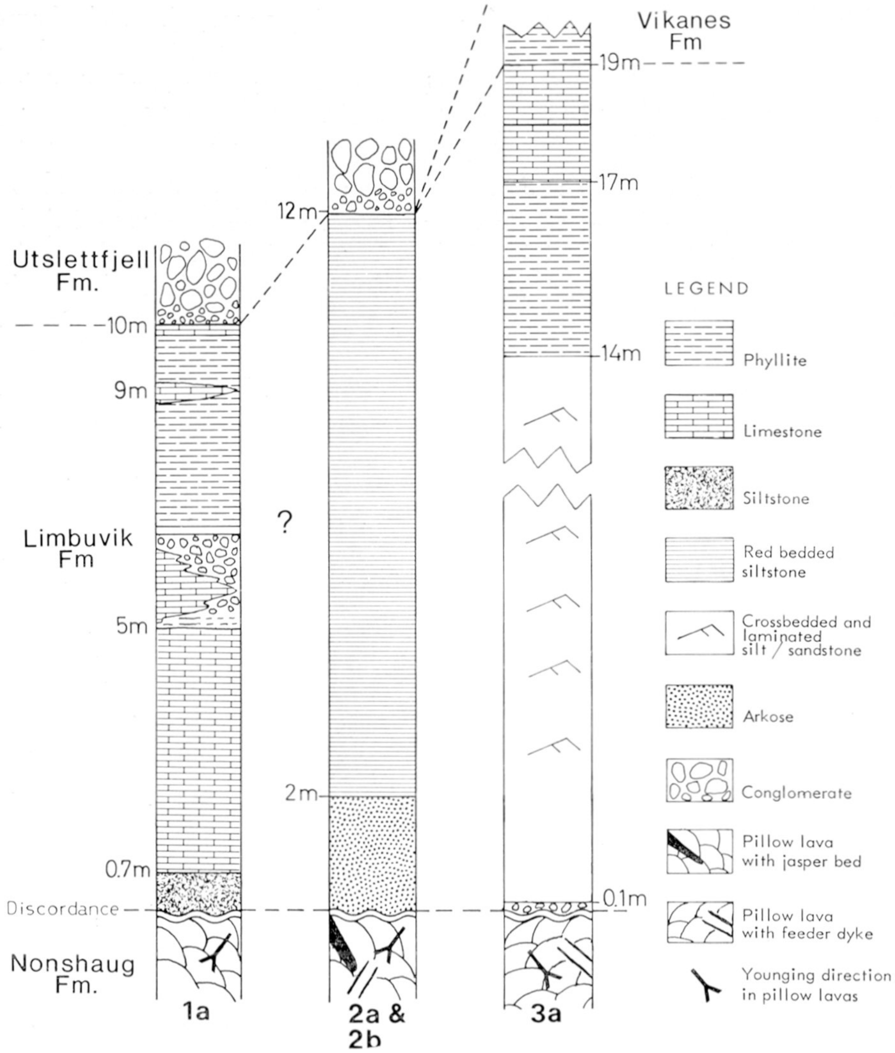

Fig. 3. Stratigraphical logs illustrating the contact relations between the Nonshaug Formation and the Limbuvik Formation and the base of the Limbuvik Formation. For location of logs 1a, 2a–b and 3a see Fig. 1.

of long axes of pillows and epidote lenses (Fig. 2). The sediments are strongly cleaved and S_0 is often transposed in the steep S_1 cleavage. When the S_1 cleavage is traced into the underlying pillow lavas of the Nonshaug Formation it develops into discrete shear zones cutting the orientation of pillows and epidote lenses (Fig. 2). Above the limestone there are phyllites (5 cm), limestone (1 m) and a pebbly conglomerate with a total thickness of 1.5 m (Fig. 3). The pebbles in the conglomerate are mainly greenstone, limestone and jasper. The conglomerate is overlain by 3 m of reddish slates and thin limestone beds (3 cm), and then by the conglomerates of the Utslettfjell Formation (Fig. 3). The clasts in the lowest part of this formation are of pebble size, but their size increases rapidly upwards into conglomerates with coarse granitic boulders typical of the granite conglomerate of Færseth & Steel (1978). Channels in the conglomerate indicate younging upwards from the Limbuvik Formation.

Isolated rugose corals are found in the Limbuvik Formation and clasts containing corals and crinoids occur in the lowest parts of the Utslettfjell Formation.

At sea-level the thickness of the Limbuvik Formation is about 10 m, but it thins rapidly to the north where the conglomerates of the Utslettfjell Formation directly overlie the Nonshaug Formation.

1b. SOUTH OF BJØNNVIK

Here the greenstones of the Nonshaug Formation crop out in a narrow belt along the coast. To the east, there is a series of highly sheared limestone lenses in a brownish calcareous phyllite, representing the Limbuvik Formation. In the phyllites and limestones abundant Ashgill fossils are found (corals, crinoids and brachiopods).

In the area north of Bjønnvik the contact between the Nonshaug Formation and the Dyvikvågen Group sediments is exposed at several localities.

2a. 500 M ENE OF DYVIK (Fig. 3)

The pillow lavas here show a layering, S_0, defined by beds of jasper-bearing sediments, oriented at 150°/90°NE. Basic dykes trend at 110°/90°. The primary contact with the conglomerate is sharp and S_0 in the conglomerate is oriented at 054°/80°NW; i.e. overturned, but clearly cutting the bedding and dykes in the Nonshaug Formation.

2b. JUST NORTH OF 2a (Fig. 3)

The lava sequence at this locality is weathered at the top. The lowest Limbuvik sediments are coarse arkoses, green at the base and becoming reddish upwards. The arkose is overlain by 10–15 m of well bedded siltstone and fine-grained sandstone (S_0–315°/75°N, S_1–110°/90°S). In the siltstone traces of bioturbations are found. The contact with the overlying conglomerate is sharp and primary.

2c. 1 KM NE OF DYVIK

In the very northernmost outcrop of the Nonshaug Formation the contact with the overlying conglomerate trends at 160°/90° and is sharp and primary. The conglomerate above the Nonshaug Formation (exposed 1 m) contains greenstone pebbles (1–5 cm) and some 1 cm pebbles of jasper in a reddish arkosic matrix.

3a. EAST OF OTTESVIK (Fig. 3)

Here the angular unconformity between the Nonshaug Formation and the Dyvikvågen Group sediments has been recently exposed by quarrying. The Nonshaug Formation here consists of well developed pillow lavas and hyaloclastites cut by porphyritic dykes. Layering, S_0, in the eastward-younging lavas is disposed at 340°/50°E and the dykes trend NNE and are vertical. The contact with the overlying Limbuvik Formation sediments is oriented at 020°/90°E. At the base of the sequence there is a local pebble size conglomerate up to 10cm thick (Fig. 3) with clasts of greenstone. This is overlain by a 14 m-thick series of well bedded, often lenticular, and internally laminated fine-grained sandstones and siltstones. Typically this consists of light, fine-grained, sandstone layers (1–10 cm thick) alternating with darker, silty, laminated layers (1–5 cm thick). The sediments contain abundant sedimentary structures (ripple drift, scours, sharp lower contact and normal grading) indicating younging to the east. Overlying this sequence is a 3 m-thick unit of dark phyllites followed by 3 m of micritic limestone. The limestone is mostly unfossiliferous, but in a thin (5 cm), bedded, calcareous siltstone, Upper Ordovician brachiopods and trilobites are found. We have assigned these sediments to the Limbuvik Formation. Above the limestones follows an unmeasured sequence of dark shales which we have assigned to the Vikanes Formation.

On tracing the contact between the Nonshaug Formation and the Limbuvik Formation southwards from this locality the 14 m-thick sandstone unit almost disappears and fossil-rich limestones containing abundant corals occur immediately above the Nonshaug Formation. It thus appears that the Limbuvik Formation has a much wider development than indicated on previous maps.

3b. EAST OF NORDVIK

East of the Nonshaug Formation basalts there is limestone of 3 m minimum thickness, but the precise contact is not seen. Lenses of limestone occur along the contact with the Utslettfjell Formation, and in the lowest conglomerates there are clasts of limestone with crinoids and corals indicating erosion of the Limbuvik Formation. Channels and normal grading indicate a right way up succession.

4. LIMBUVIK

Here the angular unconformity is again indicated, although the relationships are not as clear as further north. In the Nonshaug Formation, pillow lavas with lenses of hyaloclastite cut by steeply dipping basic dykes are well exposed along the steep cliffs, best seen from a boat. A crude layering dips 50–70° to the east. The contact with the fossiliferous Limbuvik Formation limestones is steep. The limestones are overlain by dark shales assigned to the Vikanes Formation. The shales occupy an F_1 syncline (Fig. 4, B–B′) and the thick (25 m) limestones of the Limbuvik Formation reappear further to the east in the core of an F_1 anticline, as indicated by Færseth & Ryan (1975). From this locality a rich Ashgill fauna has been described (Kiær 1929). Most of the fossils occur in loose blocks on the beach and their stratigraphic position is therefore somewhat uncertain.

In the northern part of the area slices of calcareous phyllites containing a shallow-marine Ashgill fauna separate the Nonshaug Formation from the gabbros and serpentinites. These slices or lenses may be traced discontinuously along the contact between the gabbros and the Utslettfjell Formation, and at Dalskardtjern, 3 km to the northeast (Fig. 1), a rich shallow-marine fauna and flora of Ashgill age have been found (Kvale 1937, Breivik 1975). We assign these rocks to the Limbuvik Formation.

Evidence for deformation of substrate prior to deposition of the Dyvikvågen Group sediments

In the previous section the contact relations between the Nonshaug Formation and the sediments of the Dyvikvågen Group have been described. At Bjønnvik the actual angular unconformity is preserved in spite of the strong tectonic deformation. In other localities (2a–b., 3a and 4, Fig. 1) the general orientations of volcanite layering and dykes close to the interface are clearly cut by the S_0 of the Dyvikvågen Group sediments. If we restore the bedding, S_0, in the Dyvikvågen Group sediments back to horizontal on a stereographic net and rotate the structures in the Nonshaug Formation by a similar amount, we would then arrive at an approximate measure of the state of deformation and attitude of layering in the Nonshaug Formation prior to the deposition of the Dyvikvågen Group sediments.

The restored trends are:

1a. Plane of orientation of pillow lavas and epidote lenses 080°/90°.
2a–b. S_0 in pillow lavas oriented at 324°/84°NE, and basic dykes 150°/56°SW.
3a. S_0 in pillow lavas 060°/036°NW, and dykes 076°/20°E.
4. S_0 in pillow lava 048°/55°NW.

A restored structural section through the Nonshaug Formation thus indicates the presence of a syncline between the Nonshaug–Ottesvik area in the south-east and Bjønnvik prior to the deposition of the Dyvikvågen Group sediments .We would tentatively interpret the orientation of deformed pillows and epidote lenses (p. 4) as an axial planar cleavage to this syncline. In Fig. 3 we have shown the pre-Dyvikvågen Group structures within the Nonshaug Formation with the contact restored back to horizontal. Additional evidence for early deformation comes from the gabbros in the north-west which locally have developed a marked foliation cut by basic dykes.

Comments on tectonic structures

Two profiles (Fig. 4) from the same areas as those of Færseth & Ryan (1975, Fig. 1 profiles A–A′ and B–B′) are presented, and these clearly show differences in structural interpretation. This stems mainly from our recognition that the Nonshaug Formation basalts constitute the substrate on to which the Dyvikvågen Group sediments were deposited, and do not form an integral part of

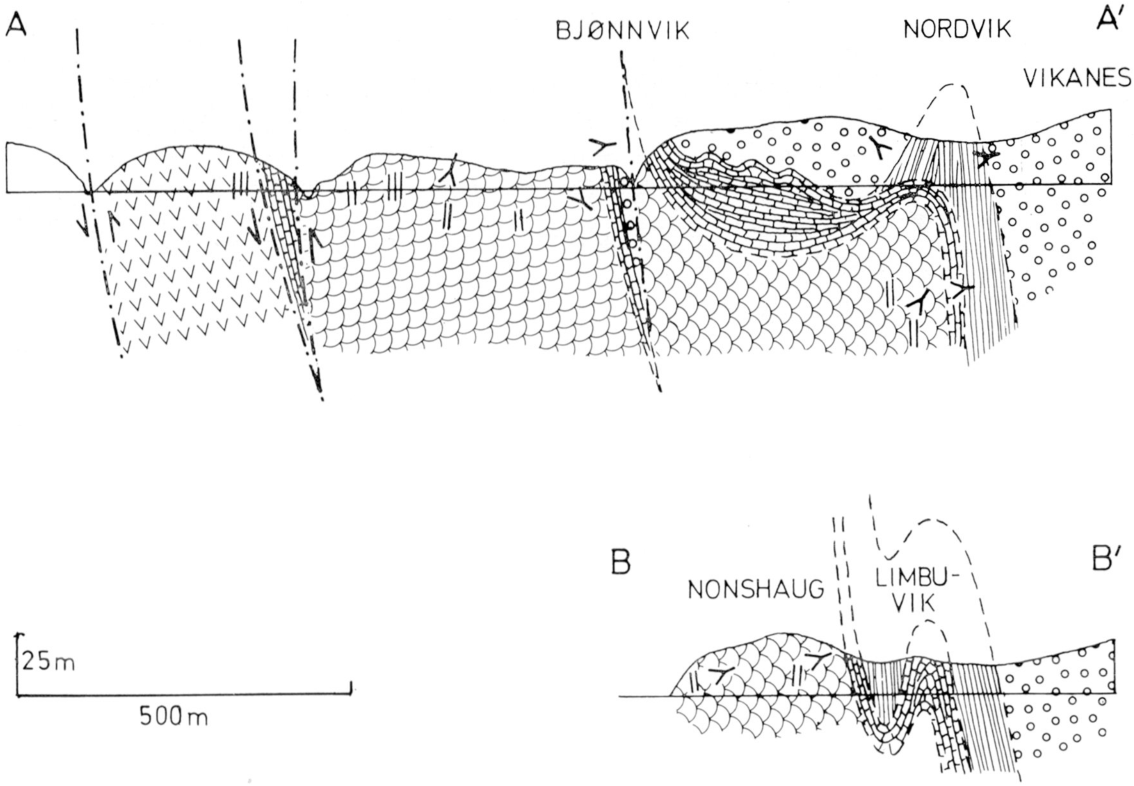

Fig. 4. Geological profiles across the Dyvikvågen Group. For location of profiles see Fig. 1.

a continuous stratigraphic succession. The main structural pattern of the Dyvikvågen Group comprises a series of large-scale, non-cylindrical, asymmetrical, close to tight F_1 folds with associated steep, NE–SW trending, axial planar cleavage (Færseth & Yan 1975). The megascopic fold axes have a shallow plunge towards NE, while the small-scale folds generally have steeply plunging axes. Within the less competent lithologies, the small-scale F_1 fold structures are isoclinal with transposition of S_0 into S_1. Small-scale F_1 folding is particularly well developed within the thin slices of Limbuvik Formation lithologies occurring between the Nonshaug Formation and the gabbros in the north. Here it appears that there has been an imbrication of the cover/substrate interface.

Summary and discussion

We have presented evidence favouring a revision of the stratigraphy of the Dyvikvågen Group. Of prime importance in this interpretation is the recognition that the Nonshaug Formation was deformed prior to the deposition of the Upper Ordovician and younger sediments of the Dyvikvågen Group. We thus interpret the contact between the Nonshaug Formation and the base

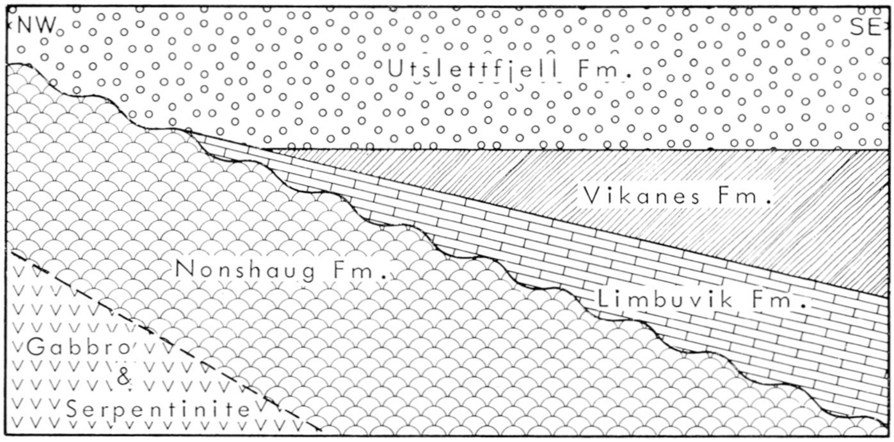

Fig. 5. Diagrammatic section through the Dyvikvågen Group sediments and their substrate illustrating facies variation from south–east to north–west. Not to scale.

of the Dyvikvågen Group as a major stratigraphic unconformity, separating two Caledonian complexes of markedly different geological development.

The Nonshaug Formation ocean-floor basalts with associated dykes and the underlying slivers of gabbros and serpentinites are tentatively interpreted as slices of a fragmented ophiolite. The general stratigraphical and structural development of the Dyvikvågen–Limbuvik area thus appears to correlate well with the geological history of other areas where Upper Ordovician and younger sediments occur along the coast of western Norway: i.e., from Sunnfjord, via the Bergen Arcs to Karmøy (Sturt & Thon 1978b). In all these areas, the fossil-bearing Upper Ordovician/Lower Silurian sequences are resting on a substrate containing obducted ophiolite fragments, and are separated from this substrate by a major stratigraphic unconformity (Furnes et al. 1979). The time of obduction is not precisely kown but is regarted as being of Lower to Middle Ordovician age (Furnes et al. 1979).

Despite the effects of the late, strong tectonic deformation we would suggest that there is a primary facies variation in the Dyvikvågen Group along a generalized profile from Bjønnvik to Limbuvik. At the type locality of the Limbuvik Formation, 25 m of locally conglomeratic limestone with phyllites are present while in the western and northern outcrops the Limbuvik Formation is represented by much thinner limestones interbedded with silt-stones, thin conglomerates and sandstones. In the north the Vikanes Formation is missing. The abundant pebbles derived from both the Limbuvik and the Nonshaug Formation in the lowest conglomerates of the Utslettfjell Formation indicate considerable down-cutting erosion.

A generalised reconstruction of the geology prior to folding is presented in Fig. 5. It is appealing to consider the depositional environment at the beginning of Limbuvik Formation sedimentation as a rocky shoreline of low elevation with small islands of the Nonshaug Formation in a shallow shelf sea. The thick conglomerates of the Utslettfjell Formation probably reflect rapid uplift in a nearby area along faults, possibly associated with tilting of the Limbuvik/Vikanes sediments. It is also clear that the original stratigraphical relationships have been complicated by the subsequent orogenic deformation.

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