

The Skei Group, Leka: an unconformable clastic sequence overlying the Leka Ophiolite

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ABSTRACT

The sedimentary rocks of the Skei Group, of probable Ordovician age, make profound stratigraphic unconformity with the rocks of the Leka Ophiolite. Detailed mapping shows that the sediments were deposited on an irregular land surface, with considerable differences in topographic elevation. The Skei Group is an overall fining-upwards sequence, and its lower part is apparently dominated by deposits of alluvial fan and braided streams. The upper part of the Skei Group is probably a shallow marine sequence. At the basal unconformity, a palaeo-weathering profile is well preserved. This profile contains a major development of secondary carbonate, probably caliche, and horizons with such carbonate are also present in the braided stream deposits. This suggests that the lower part of the Skei Group not only developed in a continental milieu, but also that it was deposited under semi-arid climatic conditions. This leads to the suggestion that the rocks represented part of a former redbed sequence, and that their present coloration is an effect of the greenschist facies metamorphism.

Introduction

The sediments of the *Skei Group* comprise a series of well-preserved metasedimentary rocks of greenschist facies metamorphic grade. They occur within a complex, tightly pinched-in syncline above the Leka Ophiolite, and rest upon the latter with profound stratigraphic unconformity. In a number of papers (Prestvik 1974; Prestvik and Roaldseth 1978; Prestvik 1980), these rocks have been referred to as the Skei Formation, which was described as containing both sedimentary and volcanic rocks and considered to be a continuous cap-rock sequence to the Leka Ophiolite. Birkeland (1958), however, considered Leka to be composed of two distinct units: an older complex of volcanic and plutonic rocks, and a younger sequence of sedimentary rocks, dominantly clastic. We do not intend to discuss the Leka Ophiolite in this paper, but refer readers to the account given by Prestvik (1980) of its salient features.

The question of the stratigraphical position of the rocks of the Skei Group is of obvious importance

with reference to the geotectonic and palaeogeographical setting of the ophiolite, as pointed out by Furnes *et al.* (1980). In allocating the sediments to a younger sequence, Birkeland (1958) drew attention to the fact that the conglomerates contained cobbles of serpentinites and a clast population which included, in addition, undeformed and deformed gabbros, greenstones, and trondhjemites. Although not specifically stated by Birkeland, one may infer from these observations that a stratigraphical hiatus exists between the sediments of his 'younger sequence' and the substrate of mafic/ultramafic rocks. With this in mind we have remapped the Skei rocks on the scale of 1:5000, and found that there is a primary unconformity at the base of the sediments (Andersen *et al.* 1979) which is, in part, underlain by a distinctive weathering profile now preserved in the mafic rocks of the substrate.

We propose that the term *Skei Group* be applied to these rocks, and that they be divided into two formations: the *Stegaffell Formation* (lower), and the *Havna Formation* (upper). The top of the group is nowhere seen, and direct correlations with the main-

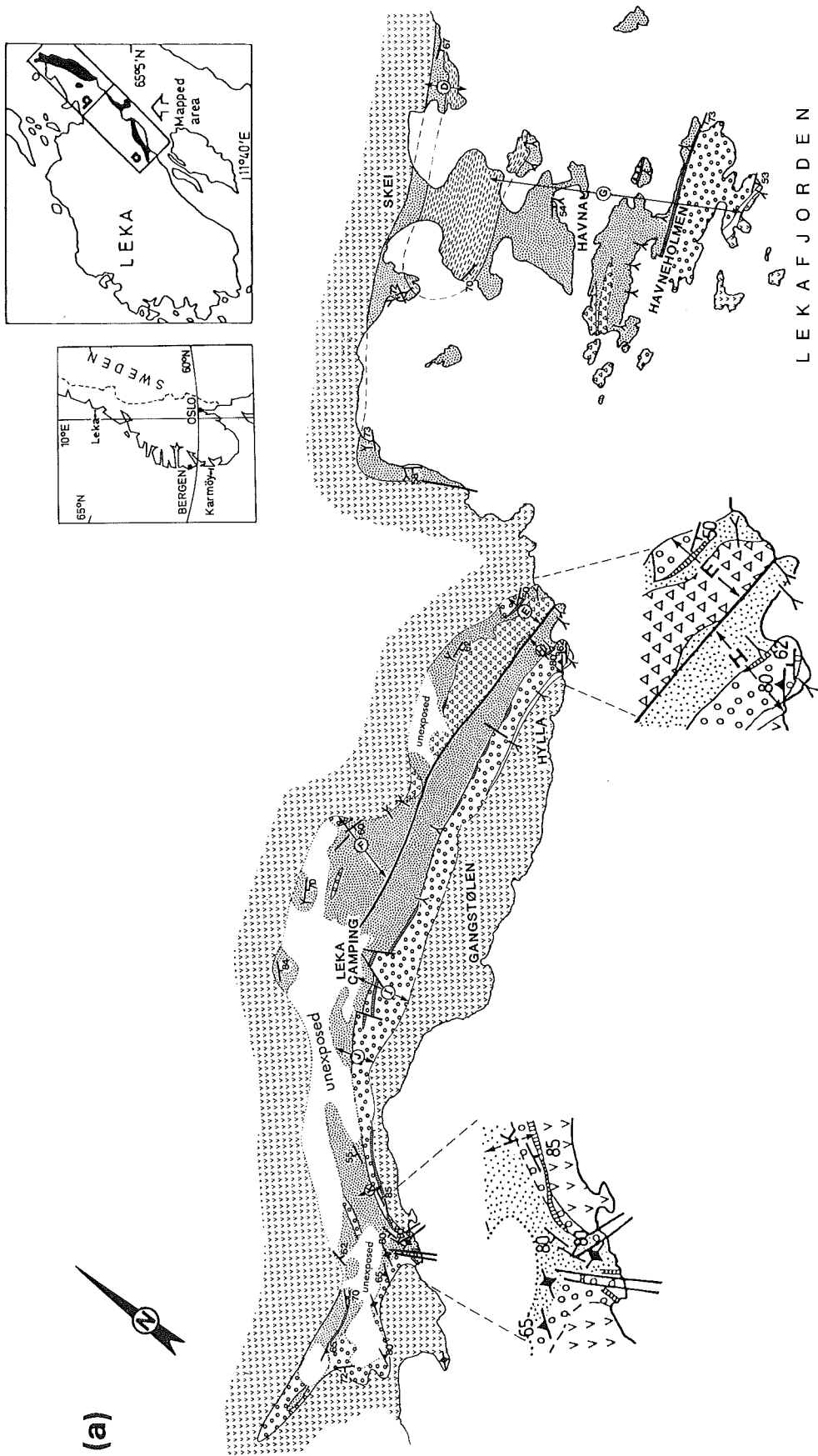




Fig. 1. Geological map of the Skei Group, Leka

land cannot be made owing to faulting along Leka-fjorden. Furthermore no fauna has yet been recovered from the rocks of the Skei Group, and so a biostratigraphic position for the sequence has not been determined. Traditionally, however, they have been correlated with the Lower Hovin Group of the Trondheim area (Prestvik 1974), a volcano-sedimentary succession of early Ordovician age.

It is pertinent to comment briefly on the structures which control the distribution of the Skei Group on Leka. The sediments are chiefly preserved in three main F_1 synclines. Two of these have their hinges partly preserved at Havna and northeast of Våtvik (Fig. 1), and they show a reclined fold geometry. The outcrop pattern in the southern part of the mapped area is controlled by a tight overturned F_1 syncline, which has a non-cylindrical geometry, but with a generally horizontal axis. The interference pattern caused by a second fold phase (F_2) is seen at the scale of mapping by the refolding

in the hinge zone of the F_1 syncline northeast of Våtvik (Fig. 1).

As a detailed structural study has not yet been completed, we shall deal principally with the lithostratigraphy of the Skei Group, the main purpose of this account being to draw attention to the unconformity at the base of this unit.

The Unconformity

The unconformity at the base of the Skei Group can be mapped with confidence though the precise contact is seen only in a few localities i.e. Skeineset, Våtvik, C, Havneholmen, Hylla, F, and K (letters refer to localities at the base of stratigraphic profiles shown in Fig. 2 and located on Fig. 1).

At the Havneholmen locality it is continuously exposed over a 200 m section, and at Hylla it is well to intermittently exposed along a 400 m section.

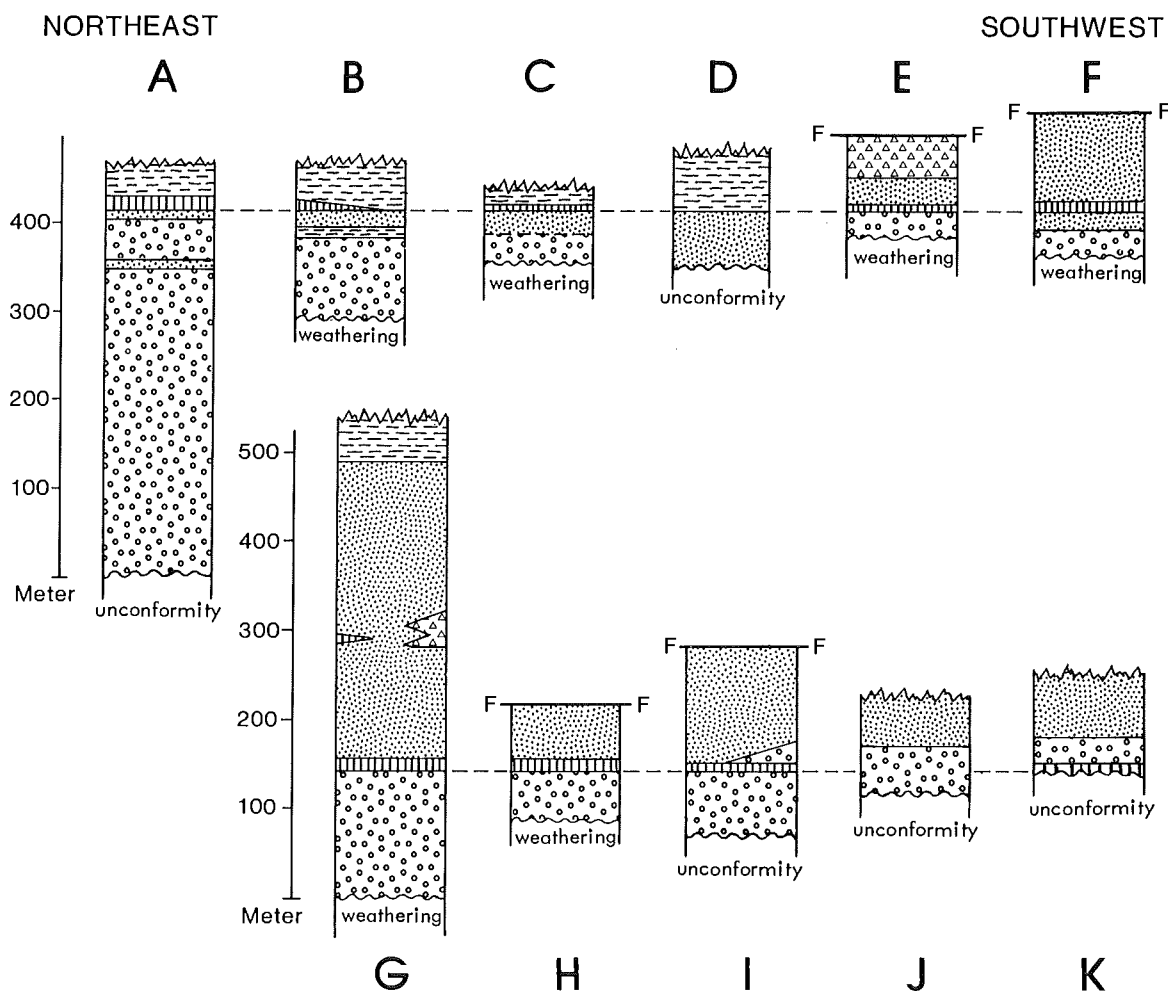


Fig. 2. Stratigraphical profiles (A–J shown in Fig. 1) from the Skei Group. A thin, impersistent limestone is considered to represent a palaeohorizontal time plane. The variation in stratigraphic thickness beneath this plane is chiefly explained by the palaeorelief in the rocks underlying the Skei Group

Evidently the sediments of the Skei Group were deposited on an irregular topography; this is indicated at the unconformity by the observation that different members of the Skei sequence make direct primary contact with the underlying rocks of the Leka Ophiolite. At Skeineset, Våtvik, C, Havneholmen, Hylla, Leka Camping, and J the conglomerates of the Stegafjell Formation (letters refer to Figs. 1 and 2) occur at the base of the succession. Along the northwest margin of the syncline, in the Skei area, the rocks of the Havna Formation directly overlie the ophiolite (Figs. 1 and 2).

We will first describe the unconformity at the Havneholmen and Hylla localities. At these sections a series of coarse sandstones and conglomerates, which show considerable lateral and vertical variation, directly overlie the rocks of the underlying ophiolite. These sediments show features indicating that they probably represent braided stream deposits, and can be observed to overstep markedly upon the ancient land-surface. Fig. 3 illustrates this

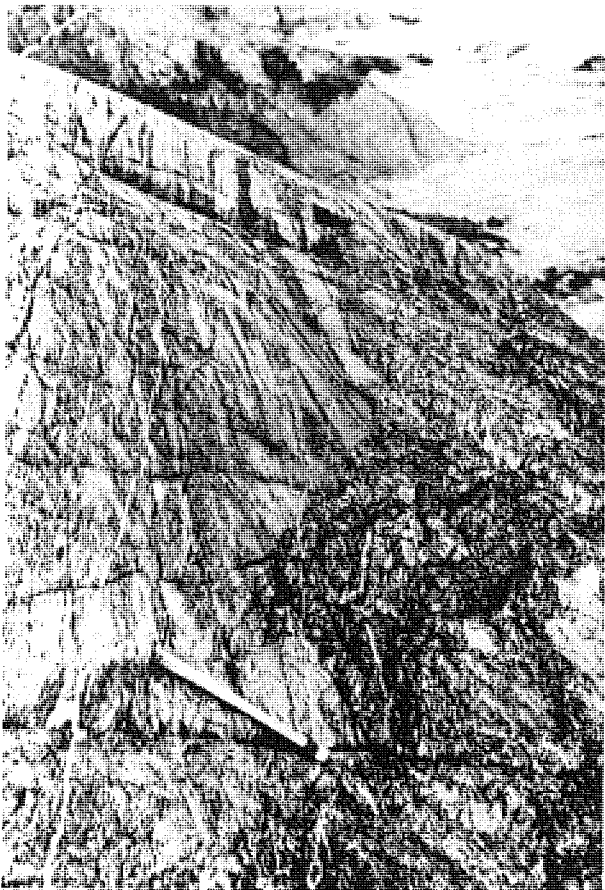


Fig. 3. Unconformity between bedded conglomerates and sandstones and weathered gabbro at Hylla. At this locality a palaeoslope of approximately 30° has been overstepped by the sediments. Note the strong alteration by palaeoweathering in the gabbro

overstepping. Here a series of conglomerates and sandstones are seen to overlap on the irregular surface of the weathered gabbro. Similar features can be observed on Havneholmen, Hylla, and at Våtvik. On a larger scale the progressive burial of the irregular topography is shown in Fig. 2, in which the sedimentary columns have been normalized with reference to a thin limestone. This limestone, where present, has been taken to define the base of the Havna Formation. There can be no doubt that the rocks of the Skei Group overlie all of the plutonic and volcanic rocks of Leka, and that the inclusion of certain volcanics within the Skei Formation was in error (Prestvik 1974).

One of the most interesting features of the unconformity is that it not only marks a highly irregular topography at the base of the Skei Group, but that also parts of a pronounced fossil weathering profile are preserved at a number of localities (Figs. 1 and 2, sections B, C, E, F, G, and H). The fossil weathering profile is best seen at the Havneholmen and Hylla localities where it is developed on gabbro intruded by diabase dykes. At Havneholmen the zone affected is some 25 to 30 m in depth, and the lowest levels are defined by the incipient breakdown of the good ophitic texture of the gabbro. At outcrop scale, the first alteration observed is the patchy breakdown of the igneous texture of the gabbro. Within such irregular zones a complete obliteration of the ophitic texture is noted at a level 10 to 15 m below the unconformity (Table 1). The textural change in the gabbro is accompanied by an increasing content of carbonate and more rarely quartz veining towards the unconformity. The diabase dykes remain virtually unaffected, and well-defined dyke margins can be traced in the altered gabbro (Fig. 4). Apart from transecting carbonate veins they show little of the effects of supragene alteration, and only in the upper few metres do they show conspicuous signs of breakdown. This is similar to that observed by Kalliokoski (1975) from a palaeoweathering zone of Precambrian age from Michigan.

In thin section, the first signs of alteration are observed in the mafic minerals of the gabbro, and this has been traced in a profile down to a level 25.6 m beneath the unconformity at Havneholmen. One of the most conspicuous features, of the initial alteration of the gabbro, is the progressive replacement of the mafic minerals by ankeritic dolomite, and such alteration may be found at relatively deep levels in the profile. Although complete replacement of the mafic minerals may have occurred, a palimpsest ophitic texture can still in some cases be discerned within the textural relationships of the less-altered plagioclase feldspars (Table 1). The detailed primary textural changes, however, are partly

Table 1. Petrography of fossil weathering profile

Sample nr.	Relics of primary texture	Mineralogy	Alteration effects	Distance from UC
HH 9	Ophitic	Act, sausplag, dol	Patchy growth of dol in the mafic minerals.	25.6 m
HH 8	Relic ophitic	Act, chl, ep, sausplag, dol	All originally mafic minerals contain abundant dol replacement.	17.2 m
HH 7	Not preserved	Ab, chl, act, dol, qtz	All primary mafic minerals replaced by dol. Plag is recrystallized ab/olig.	13.6 m
HH 6	Not preserved	Ab, chl, ep, dol, qtz, ore	The pre-metamorphic texture dominated by fine grained aggregates of dol, ab and qtz.	9.6 m
HH 5	Relics of ophitic texture	Ab, chl, ep, dol, qtz	The plag occurs as polygonal aggregates. The mafic minerals are altered to dol and chl. Veins of dol/qtz.	6.0 m
HH 4	Relics of ophitic texture	Ab, dol, chl, ep, bio, act, ser, qtz	All primary mafic minerals destroyed. The plag displays spherical alteration producing ser. The plag-rich domains coarser grained than the mafic.	5.2 m
HH 3	Relics of ophitic texture	Ab, chl, ep, ser, dol, qtz, bio, act	All mafic minerals replaced by dol and chl. Dol/qtz veins.	3.6 m
HH 2	Not preserved	Ab, chl, ep, act, dol, qtz	Fine grained, recrystallized matrix with plag, dol, chl overgrown by porphyroblastic act and ep.	1.6 m
HH 1	Not preserved	Ab, chl, ep, act, dol	Fibrous and non-fibrous plag and dol dominates the matrix overgrown by porphyroblastic ep, chl and act.	0.8 m

Abbreviations: act—actinolite, ab—albite, chl—chlorite, bio—biotite, dol—ankerite dolomite, ep—epidot, olig—oligoclase, plag—plagioclase, ser—sericite, sausplag—saussuritized plagioclase

blurred by the later imposed post-Skei Group greenschist facies metamorphism which caused recrystallization and new mineral growth in the weathered rocks. Thus the present mineralogy consists of a metamorphic assemblage superimposed on the alteration products formed by the ancient subaerial weathering.

The carbonate veining, replacement, and textural discontinuity in this zone is considered by the authors possibly to be the product of caliche development in a palaeoweathering profile, and as such is closely comparable to the sub-Cambrian caliche development claimed by Kalliokoski (1975) from Michigan. Many clasts of such carbonate are



Fig. 4. The palaeoweathering zone 3–4 m beneath the unconformity at Havneholmen. The ophitic texture in the gabbro has been destroyed by the dolomite replacement (left). The less altered diabase dyke (right) preserves its primary texture, and the alteration in this is chiefly seen as transecting dolomite and quartz veins

found in the lower parts of the overlying conglomerates, and occasional carbonate pebbles with relic gabbro texture have been observed. The conglomerates and sandstones in the lower part of the Stegafjell Formation also contain irregular layers and veins of a similar brown ankeritic dolomite, and sporadic plug-like, patchy cementation by such material is observed in some of the conglomerates. Such features resemble closely those observed in modern and fossil caliche profiles in fluvial clastic sequences (Gile *et al.* 1966; Steel 1974).

It is concluded that the sediments of the Skei Group lie unconformably upon an irregular topography carved by subaerial erosion from the Leka Ophiolite. The overstepping of different horizons of the Skei Group onto this irregular surface can be demonstrated both on the scale of the individual outcrops and on the scale of mapping. It is also obvious that the unconformity transgresses different parts of the ophiolite complex because at Havneholmen and Hylla the underlying rock is a gabbro with sporadic dykes, whereas at Våtvik the rocks are diabase dykes and trondhjemites.

The Lithostratigraphy and Sedimentary Features of the Skei Group

It is proposed that the Skei Group be divided into two formations. The *Stegafjell Formation* (lower) is dominated by gravel conglomerates with subordinate sandstones probably formed as braided stream deposits. The boundary to the overlying *Havna Formation* is taken to lie at the level of an impersistent limestone. The lower part of this formation is made up chiefly of sandstones giving way upwards to black shale (now phyllite) with minor sandstone and conglomerate bands. The maximum thickness of the Skei Group seen on Leka is approximately 530 m.

The Stegafjell Formation

This lower formation of the Skei Group shows a pronounced variation in thickness within the mapped area (Fig. 2), and it is considered that this is due to a pronounced palaeorelief in the topography cut into the underlying ophiolite. Where a continuous stratigraphic profile can be followed, the formation has its maximum development at Skeineset (Figs. 1 and 2) where the thickness is approximately 410 m (uncorrected for tectonic strains). Apart from a few medium to coarse grained sandstones in the upper part in the Skeineset area, the Stegafjell Formation is made up chiefly by conglomerates.

The conglomerates show a plethora of well-preserved sedimentary structures. They are most

commonly pebbly gravels with some cobbly varieties, and can be variably matrix and clast supported. The gravelly facies may be massive, but is most commonly crudely or well bedded. The crudely-bedded subfacies normally has a horizontal stratification. Equally common, however, are trough cross-bedded gravels which fill channels that cut into each other, both laterally and vertically. The rapid lateral facies changes resulting from the channelling makes it difficult to trace individual beds for more than a few metres along strike (Fig. 5). Commonly the scour and fill structures contain clast-supported and well-sorted pebbly conglomerates. Various types of grading (normal, reverse, and composite) are frequent, but have not been systematically studied.

The conglomerates contain interbedded sandstone units ranging in thickness from a few centimetres to a metre and are composed of fine to coarse sandstones, and the coarse varieties are frequently pebbly. The sand facies is dominated by horizontally bedded, trough cross-bedded and ripple cross-laminated sandstones. Some of the laminated, very fine-grained, silty sandstones may represent overbank deposits, but otherwise there is a conspicuous lack of a shale facies.

The pebble population of the conglomerates is dominated by ophiolite-derived material in the lower part of the formation. Brown dolomitic pebbles derived from the weathering zone in the ophiolite are typically common. The ophiolite-derived clasts in the Stegafjell Formation are chiefly greenstones, diabases, trondhjemites, isotropic gabbros characteristic of the upper parts of the ophiolite pseudostratigraphy; and only rarely are clasts of ultramafic rocks present. The clasts are normally well rounded and generally within the pebble range, but cobbles up to 20 cm in diameter occur locally. In the higher parts of the formation well-rounded, undeformed pink granites form an exotic suite of pebbles which were derived from a presently unknown source. Caledonian granitic rocks, however, occur in this region, and these clasts may have their origin in the Hortavær (Gustavson and Prestvik 1979) or from time-equivalent granitic complexes.

As mentioned previously, the Stegafjell Formation shows lateral variations in thickness from in excess of 400 m at Skeineset to zero at Skei (Fig. 2,D) and south of Leka Camping (Fig. 2,K). This is a primary feature and is a consequence of the palaeorelief in the topography underlying the Skei Group. By direct measurement of the angle of unconformity and the bedding of overstepping clastics, palaeoslopes of up to 30 degrees can be indicated, although these values are not corrected for tectonic strains.

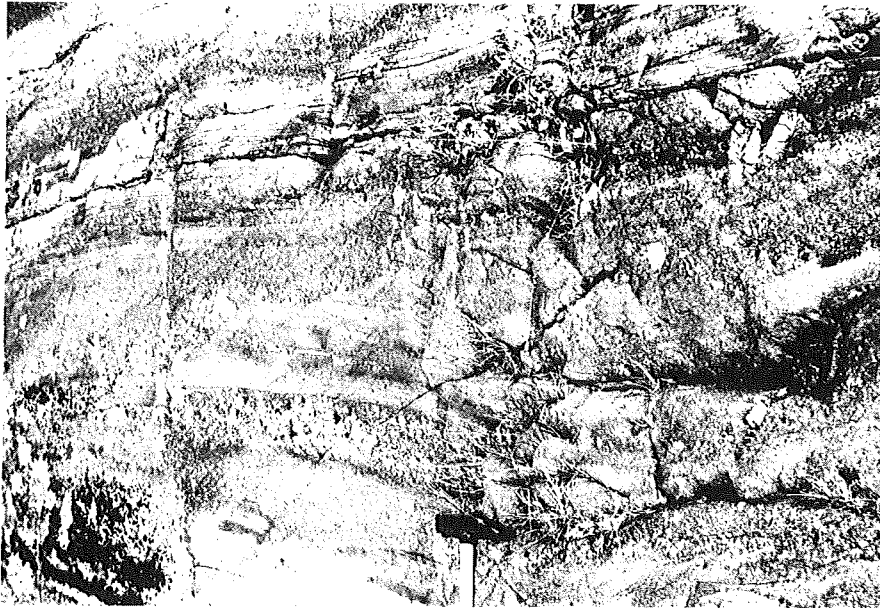


Fig. 5. Braided stream sediments in the lower part of the Stegafjell Formation at Våtvik. Channels are seen in both the lower, middle and upper part of the picture, giving rise to the rapid lateral and vertical facies variation



Fig. 6. Scour and fill structure with clast supported conglomerate in the Stegafjell Formation, Skeineset

The sedimentary features of the Stegafjell Formation taken together with the evidence for subaerial weathering and the irregular palaeotopography indicate that deposition commenced in a continental environment. The record of the sedimentary structures and of the facies in the Stegafjell Formation indicate that the sediments were probably deposited in a braided stream environment (Miall 1977), though more detailed work is required to provide a precise environmental interpretation. The presence of a deep weathering profile with carbonate replacement in the ophiolite rocks and the probable caliche development in the Stegafjell Formation would indicate deposition in an arid to semi-arid climate. The continental deposits in such an environment would be expected to be of red bed facies. Thus the possibility must be considered that the clastics of the Stegafjell Formation formerly represented a red bed association.

If this was the case, the grey-green colour of the Stegafjell Formation could be interpreted as a consequence of later imposed greenschist facies metamorphism. This would be analogous to the colour change in the Torridonian Sandstones of north-west Scotland in the section from Assynt to Kisborn (Barber *et al.* 1978).

The Havna Formation

The type area of this formation, in the Havna area, has a minimum stratigraphic thickness of

approximately 380 m (top not seen). It contains three main members: (1) the limestone member (lower), (2) the sandstone member (middle), and (3) the black phyllite member (upper).

The limestone member is impersistent and has a maximum thickness of 3–4 m (Havneholmen and Skeineset). It occurs above the conglomerates of the Stegafjell Formation. In a few localities, however, it is overlain and truncated by the erosional plane at the base of conglomerates similar to those that also underlie it. In such areas, the overlying conglomerates have abundant limestone pebbles (Fig. 1, Fig. 2, I and J). At one locality south of Leka Camping (Fig. 1 and Fig. 2, K) the limestone rests directly with a primary contact on the ophiolite.

On the northwestern limbs of the complex pinched-in syncline (Fig. 1) the stratigraphical development is somewhat different from that of the southeastern limb. The limestone in this case is often underlain by a calcareous sandstone (Fig. 1 and Fig. 2, A, B, C, and F), and is directly overlain by the black phyllites. Although no fauna has yet been recovered from this limestone, it is suggested that it probably marks an event of marine transgression, though in such an environment a non-marine perhaps lacustrine origin for the limestone cannot be excluded.

The middle member of the Havna Formation is a well-bedded sandstone with a maximum thickness of 310 m (Havna–Havneholmen area). It contains abundant primary sedimentary structures including grading, cross-bedding, ripples, dewatering structures, and clastic dykes, and probably represents a

shallow marine environment (Fig. 7). It is generally calcareous and, in the area 200–300 m northeast of Leka Camping (Fig. 1), the sandstone is interbedded with thin layers of impure limestone. On a small island close to Havneholmen (Fig. 1) a one metre thick limestone is locally developed and is overlain by a lens of pebbly sandstone which channels down into the limestone. At approximately the same stratigraphic level, on Havneholmen, the sandstone is abruptly truncated by coarse sedimentary breccias consisting predominantly of angular blocks of layered gabbro and ultramafic rocks, which are up to one metre across (Fig. 8). These breccias form fan-like bodies and also occur north of Hylla (Fig. 1). Internally they are generally massive, but in a few localities reworking of finer-grained matrix material gives distinct bedding. The layered gabbros and ultramafic rocks in the blocks show that at this stage deep erosion had unroofed the lowest part of the Leka Ophiolite, and the nature of the deposits indicate active syndepositional faulting close to or even within the sedimentary basin itself.

The highest stratigraphical level exposed on Leka is represented by the third member of the Havna Formation. This black phyllite (maximum observed thickness 65 m) in the northeastern part of the area forms a laterally persistent unit. It has abundant interlayered graded sandstones and grits, and locally contains conglomerates.

The black colour stems from a combination of carbonaceous material (possibly graphite) and disseminated iron sulphides, predominantly pyrite.

A precise model for the depositional environment

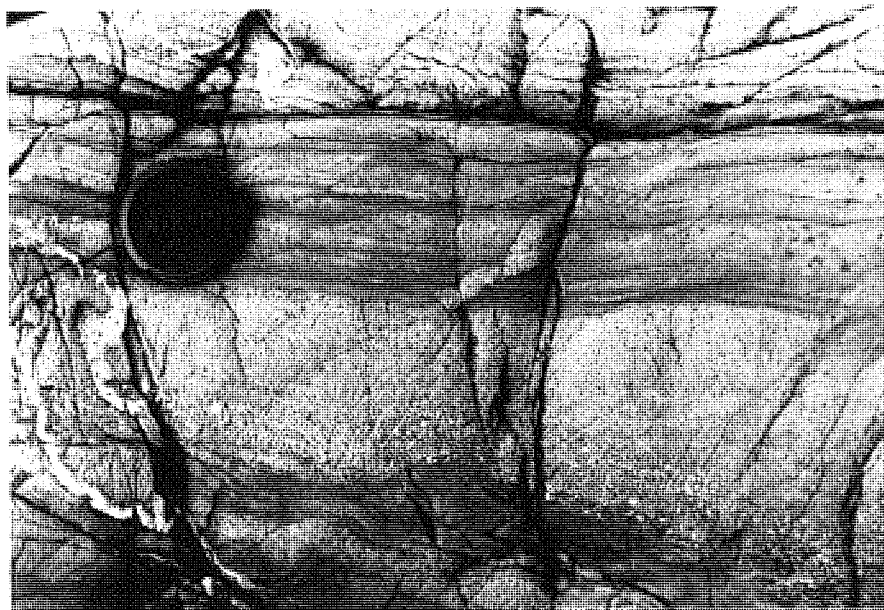


Fig. 7. Sandstones in the middle member of the Havna Formation at Skei, showing normal grading, a clastic dyke and a load structures



Fig. 8. Coarse sedimentary breccia in the Havna Formation. The clasts are chiefly composed of gabbro, gabbropegmatite and ultramafics from the plutonic zone in the ophiolite. The preferred orientation of the clasts is a result of rotation into the S_1 cleavage

of the Havna Formation will not be given here although it appears to be a shallow marine sequence.

Discussion

It appears clear that the Skei Group was deposited unconformably upon a deeply-eroded ophiolite terrane. Evidence has been presented to show that the irregular surface beneath the Skei Group was subjected to subaerial weathering, and a deep weathering zone containing possible fossil caliche is preserved at a number of localities. The overlying Stegafjell Formation consists of sand and gravels, and deposition in a fluvial braided stream pattern has been indicated. The recognition of possible caliche development both in the weathering profile and sporadically within the Stegafjell conglomerates indicates that these sands and gravels originally may have been a red bed sequence. The present grey-green colour of the sandstones and conglomerates would thus be ascribed to the later pervasive greenschist facies metamorphism affecting the Skei Group. The Havna Formation is considered to have been deposited under shallow-water marine conditions. The Skei Group is folded in a complex manner into a tight pinched-in synclinal fold. The structural complexity is considered to result from a combination of the influence of the pre-Skei Group topography and refolding during F_2 .

It is now obvious that the Group I ophiolites (Furnes *et al.*, this volume; Sturt *et al.* 1983), to

which the Leka Ophiolite belongs, are capped by a major unconformity of Ordovician age within the belt-length development of the Scandinavian Caledonides (Sturt and Thon 1978; Minsaas and Sturt, this volume; Sturt *et al.* 1983). It has further been shown that the Finnmarkian metamorphic complex of the Kåfjord-Vaddas area is cut by a similar unconformity (Ramsay *et al.*, this volume). Generally the sediments, above the unconformity, are transgressive clastic-dominated sequences capping already obducted ophiolite fragments and deeply eroded Finnmarkian metamorphic complexes of Barrovian type. It is very difficult to place any precise age on such major unconformities. In the first instance unconformities are markedly diachronous in time, and in the second palaeontological control on the age of the post-unconformity sequences is very incomplete. In many cases it can only be stated that the unconformity is pre-Ashgill in age, based on the common presence of fossil bearing Ashgillian limestones in many of the sequences in western Norway (Thon, this volume), and beneath which are variable thicknesses of conglomerate dominated sequences of unknown age. In the case of the Støren Ophiolite, the capping unconformity can be dated as being pre-Late Arenig based on graptolite control (Ryan and Sturt this volume). On Bømlo, in Sunnhordland, a major unconformity separates the stratigraphically younger Siggjo volcanics from the already-folded Lykling Ophiolite (Nordås *et al.*, this volume). The latter involves ensimatic island arc volcanics dated at 535 ± 46 Ma, and the Siggjo vol-

canics have been dated at 464 ± 16 and 468 ± 23 Ma (Furnes *et al.* 1983), showing that the minimum age of the unconformity is middle Ordovician. As no fauna or age determinations are available from Leka, it is as yet impossible to place any age constraint on the Skei Group.

The major development of pre-Ashgill coarse clastic sequences, along the length of the belt, and the presence of highly irregular subunconformity topography, recorded from both Lyngen (Minsaas and Sturt, this volume) and Leka are indicative of major vertical uplifts. This fits well with the exotic clast population of undeformed 'granitic' plutonic rocks, acid volcanics, etc., perhaps corresponding with volcanic/plutonic arc development with rapid uplift and unroofing.

On Bømlø, in addition to the unconformity described above, evidence is also available for two further unconformities in the Ordovician and Silurian (Brekke 1983). These are respectively post-Siggjo volcanics—pre Ashgillian and post lowermost Llandovery. According to Brekke (1983) these are apparently related to block faulting and tilting with subsequent deep erosion. This attests to active tectonism during the Ordovician and early Silurian in the rocks of the higher western nappes.

The recognition of this belt-length pattern of unconformities must be of major importance in any attempt to model Caledonian geotectonic evolution.

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