# The Upper Ordovician–Lower Silurian rocks in the Os area, Major Bergen Arc, Western Norway

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Ingdahl, S. E.: The Upper Ordovician–Lower Silurian rocks in the Os area, Major Bergen Arc, Western Norway. *Norsk Geologisk Tidsskrift*, Vol. 69, pp. 163–175. Oslo 1989. ISSN 0029–196X.

The two younger Ashgillian–Llandoverian sedimentary sequences in the Os area, the Holdhus and the Ulven Groups, have been correlated and are now collectively named the Os Group. The group is divided into five formations: the Skarfjell, Vaktdal, Hegglandsdal, Valla and Moberg Formations. No structural/metamorphic break is found between any of the formations, and the Os Group is claimed to represent a continuous sedimentary sequence related to transgression and regression in a shallow marine to beach environment.

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The investigated area (Fig. 1) is located in the southwestern part of the Scandinavian Caledonides and is a part of the Bergen Arcs, which have previously been discussed several times in the geological literature (Reusch 1882; Kolderup & Kolderup 1940; Kvale 1960; Sturt & Thon 1978 and refs. therein). The Bergen Arc System (Kolderup & Moncton 1911) consists of five arcuate belts containing rocks with different lithologies and tectonometamorphic histories (Kolderup & Kolderup 1940; Kvale 1960; Sturt & Thon 1978 and refs. therein). It is now established that the allochthonous Caledonian sequence within the Major Bergen Arc (MaBA) consists of two major complexes, the Gullfjellet Ophiolite Complex (GOC) (Furnes et al. 1982; Thon 1985; Ingdahl 1985) and the Samnanger Complex (Thon 1985; Ingdahl 1985 and refs. therein) separated from the overlying Holdhus and Ulven Groups by a major stratigraphic unconformity (Kvale 1960; Sturt & Thon 1976; Naterstad 1976; Færseth et al. 1977; Thon 1982). In the Os area the younger sequence is preserved in three large, modified synclinal structures (the Os, Hegglandsdal and Ulven Synclines) (Figs. 1 and 2).

The rocks within the Hegglandsdal and Os Synclines are termed the Holdhus Group (Færseth et al. 1977; Thon 1985; Ingdahl 1985) while the rocks within the Ulven Syncline are termed the Ulven Group (Ryan & Skevington 1976). In addition, the Moberg Formation appears in an F1 anticline at Hauglandsosen with the 'quartz-augen gneiss' forming a narrow zone in the core (Øvereng 1969; Ingdahl 1985). The stratigraphy of the Holdhus and Ulven Groups in various parts of the Os area has been correlated and is believed to belong to the Os Group (Figs. 1, 2).

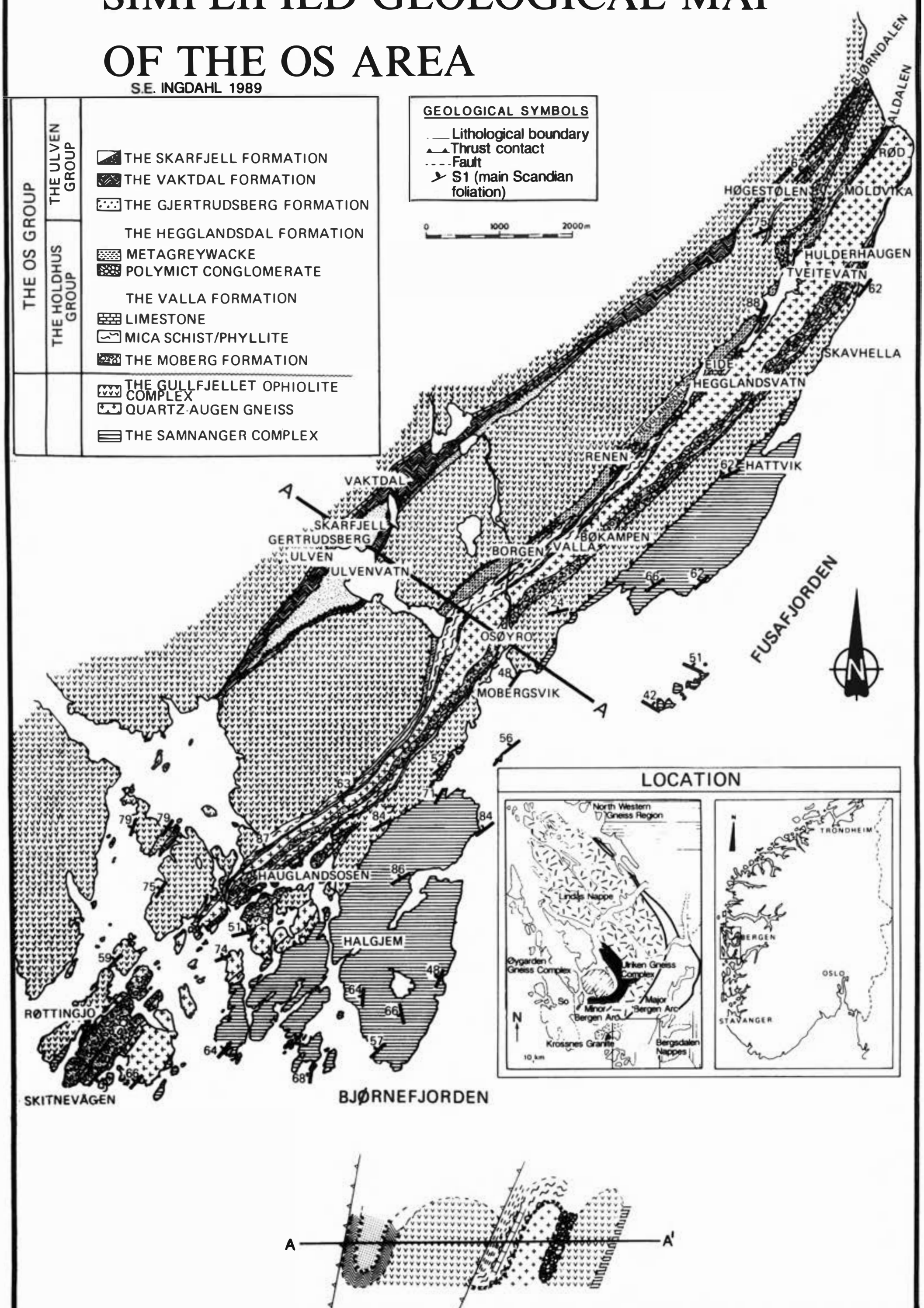
A structural/metamorphic unconformity has recently been postulated between the Skarfjell and Vaktdal Formations (Saltnes 1984; Sturt 1983). A discussion of the unconformity is incorporated in this paper. A syn- to post-kinematic event associated with D1 reached upper greenschist facies conditions indicated by the occurrence of almandine garnet and pargasitic hornblende (Ingdahl 1985; Fossen 1986, 1988).

## The Holdhus Group

Sediments of Upper Ordovician age have been described both in the Os and the Samnanger–Osterøy area within the Major Bergen Arc (Reusch 1882; Kolderup & Kolderup 1940; Færseth et al. 1977). Within the Samnanger area these sediments were divided into two formations: the Grasdalen Formation and the Moberg Conglomerate, making up the Holdhus Group (Færseth et al. 1977). Within the Os area these rocks have traditionally been divided into chlorite sparagmite with conglomerate, mica schist with limestone and polymictic coarse conglomerate (Reusch 1882; Kolderup & Kolderup 1940). Kvale (1960) and Thon (1985) suggested that both the chlorite sparagmite and the Moberg Conglomerate were older than the Ashgillian lime-

# SIMPLIFIED GEOLOGICAL MAP OF THE OS AREA

S.E. INGDAHL 1989



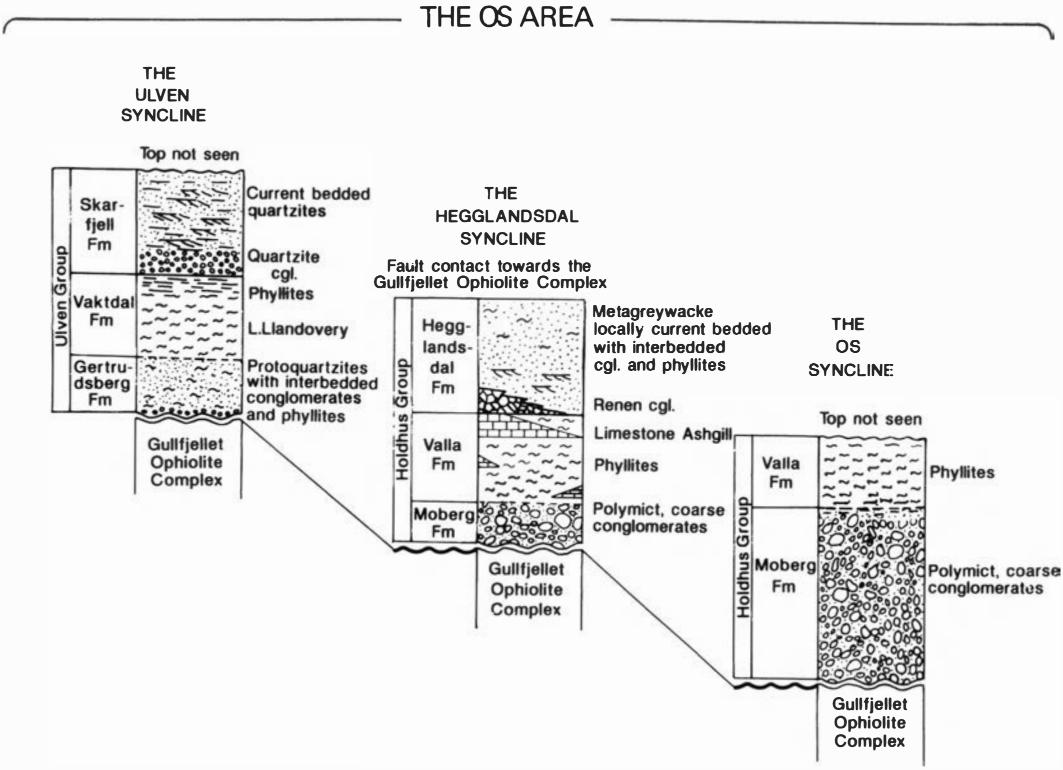



*Fig. 2.* Stratigraphy of the Upper Ordovician/Lower Silurian cover sequence to the GOC in the Os area, Major Bergen Arc.

stone. The present author suggests a subdivision of the Holdhus Group into the Hegglandsdal, Valla and Moberg Formations, supporting the stratigraphy of Kolderup & Kolderup (1940). In the Hegglandsdal Syncline, thrusting of older rocks (the GOC) above younger rocks (the Holdhus Group) along the inverted western limb has cut out several units of the Holdhus Group, making the Hegglandsdal Syncline into a half syncline where mainly the eastern part remains (Ingdahl 1985).

## *The Moberg Formation*

The Moberg Formation (the Moberg Conglomerate of Reusch 1882) within the Major Bergen Arc can be traced from the Os area in the south through the Samnanger area to Osterøy in the north (Reusch 1882; Kolderup & Kolderup 1940; Færseth et al. 1977; Henriksen 1981). The Moberg Formation is made up of coarse, polymict conglomerate with minor amounts of granular conglomerate to pebble sandstone, sandstone and phyllite. The coarse conglomerate is immature both compositionally and texturally and contains clasts of both igneous and sedimentary origin in a matrix of medium-grained lithic and feldspathic greywacke. Primary structures other than stratification and grading are scarce, but channelling and truncation of sandstone beds by conglomerate units are observed locally. The cobbles in the conglomerate unit reflect the underlying basement rocks with cobbles solely from the GOC. Greenstone, amphibolite and phyllite/mica schist cobbles/pebbles are generally strongly stretched and occur either as lenses or bands. They are generally difficult to differentiate from the matrix due to the similar colours and the strain state. Previous authors on this subject have reported quartzite clasts in the conglomerate (Reusch 1882; Kolderup & Kolderup 1940; Kvale 1960; Færseth et al. 1977). This is supported by the present author, but all quartzite clasts are interpreted as metachert, which indicates erosion of a formerly

*Fig. 1.* Simplified geological map of the Os area.

marine environment closely related to the Gullfjellet Ophiolite. Kolderup & Kolderup (1940) reported both limestone and marble boulders. They further point to the possibility of an older marble horizon now eroded. Kvale (1960) identified two types of limestones – one grey type occurring within the Middle Phyllite (Valla Formation) and an older white one, supporting the observations of Kolderup & Kolderup (1940). Kvale (1960) claimed that only the white one occurs as pebbles in the conglomerate. This author supports the observation that limestone/marble boulders/pebbles occur within the Moberg Formation. It is not possible, however, to relate these to any certain horizon. They may well represent an older horizon now eroded, but they may also represent erosion of more or less synsedimentary limestones eroded from nearby areas as intraformational limestone pebbles/cobbles occur locally towards the top.

The coarse, polymictic conglomerate is generally interbedded with 5 to 100 cm thick massive, grey to green sandstone beds. The compositions of these sandstones are similar to the conglomerate matrix and consist of quartz, plagioclase, biotite, hornblende, epidote and chlorite as the essential constituents. Quartz and albite also occur as secondary minerals (along with hornblende, biotite, white mica, epidote and chlorite. White mica, calcite, opaques, sphene, tourmaline, clinozoisite, apatite and zircon occur as accessory minerals. Dark grey to black phyllite beds, 0.5–5 cm in thickness, consist of quartz, white mica, biotite and chlorite as the essential minerals. Accessories are albite, sphene and calcite.

A monomictic, granular conglomerate to pebble sandstone generally occurs below or is interbedded with the coarse, polymictic conglomerate. It consists of quartz clasts in a matrix containing white mica, epidote and chlorite. The quartz clasts are generally subangular to subrounded, and vary in diameter from 1 to 15 mm. The rock is greyish green in colour due to the presence of chlorite and epidote. The sandstone has a higher content of white mica and chlorite, and fewer quartz clasts than the conglomerate. In addition, it contains altered feldspar grains.

### *The Valla Formation*

The Valla Formation constitutes phyllite/mica schist, marble and fossiliferous limestone of Ashgillian age. The limestone has been traced from the Os through the Samnanger to the Osterøy area (Færseth et al. 1977). In the Samnanger area all the rocks above the Moberg Formation were collectively named the Grasdalen Formation (Færseth et al. 1977). The Grasdalen Formation has also been used synonymously with the Valla Formation (Ingdahl 1985). As the name was already in use in Finnmark (Siedlecka & Siedlecki 1971), it was suggested by the Norsk Stratigrafisk Komite that the name should be replaced; subsequently Valla was chosen as the new formation name. This formation conformably overlies the Moberg Formation. At several localities, however, the contact is tectonized. In Samnanger the limestone shows interfingering relationships with the conglomerate of the Moberg Formation.

The phyllite consists of quartz, white mica and chlorite as essential minerals; biotite, albite, clinozoisite, epidote, opaques, apatite, sphene, zircon, tourmaline, graphite and garnet as accessories. A gradual change from conglomerate through sandstone into limestone or calcareous phyllite, which reflects a sedimentary transition, is locally observed. In most places, however, either limestone or phyllite has sharp and sheared contacts against the conglomerate. The limestone/marble generally forms discontinuous beds occurring as limestone lenses of variable size arranged parallel to the regional strike. A more continuous outcrop of the limestone occurs in central Hegglandsdal. The limestone, which consists of calcite with quartz, albite, biotite, white mica, clinozoisite, opaque, sphene and graphite as accessories, generally shows a red-brown colour on weathered surfaces and a white to bluish colour on fresh surfaces. The purest limestone is generally converted to marble. The more impure varieties with thicker beds of pelitic material are less recrystallized and deformed, probably due to the pelite taking up most of the strains. It is generally within these less-deformed limestone beds that fossils are found. Within the phyllite, sandstone horizons occur at several places and some are large enough to be mapped. Thinner sandstone horizons are generally boudinaged and are in addition partly transposed. Others, occurring in major fold closures, are tight to isoclinally folded. When Reusch described the fossils from the Ulven and Os areas in 1882, it was quite a sensation, as they were among the first ever described from metamorphic rocks. At that time it was also generally believed that all mica schists were of Precambrian age. Fossils are found in several places within both the Hegglandsdal and the Ulven synclines. The fauna is not very rich and individual localities show limited assemblages. All previous authors on the subject (Reusch 1882; Kiær 1929; Kolderup & Kolderup 1940) agree in correlating the fauna within the Hegglandsdal Syncline with the gastropod limestone in the Oslo area (stage 5a, Ashgillian).

### *The Hegglandsdal Formation*

Within the Hegglandsdal Syncline this formation represents the uppermost part of the Holdhus Group. Because of faulting and increased excision along the inverted western limb the formation thins both northward and southward. The Hegglandsdal Formation comprises a sandstone sequence with minor amounts of conglomerate and mica schist. Locally it contains a basal, polymictic conglomerate which has a sharp contact with the underlying limestone or greywacke. The contact with the overlying greywacke is not exposed. This conglomerate reaches its maximum thickness of 30 m in the central part of Hegglandsdalen. The conglomerate is generally clast-supported with minor greywacke matrix. The cobbles are well rounded and consist of epidosite, greenstone, 'quartz-augen gneiss', trondhjemite/tonalite, diorite and gabbro. In addition, pebbles of vein quartz are frequent. During the D1 deformation they have been extensively stretched with the long axes in the 2–30 cm range and short axes about 1/2 to 1/5 of the long axes. This conglomerate resembles that of the Moberg Formation, but is based on structural observations thought to represent a higher stratigraphical horizon. Along the contact between the GOC and the sandstones, conglomerates correlated with this conglomerate crop out. The western zone of conglomerate is discontinuous and is only locally found between the GOC and the overlying sandstones. This is probably due to a combination of palaeotopography and tectonic effects. At Borgen the conglomerate has its maximum apparent thickness of about 40 m.

The sandstones constitute a fining-upward sequence of greywacke comprising plane parallel bedding and graded beds. Its maximum apparent thickness is 200 m in central Hegglandsdal. The greywacke consists of quartz, feldspar and rock fragments as essential constituents. Accessories are biotite, chlorite, epidote, calcite, white mica, clinozoisite, garnet, apatite, sphene, zircon, tourmaline and rock fragments. Garnet, hornblende, biotite and epidote frequently occur as porphyroblasts. Rock fragments have been identified as diorite, trondhjemite/tonalite, greenstone, epidosite and 'quartz-augen gneiss'. The carbonate content decreases upwards. Calcareous greywacke beds occur in the lower part of the sequence either directly overlying the conglomerate or partly interfingering with or overlying the limestone/phyllite. The calcareous greywacke shows both incomplete and complete graded beds. The thicker graded beds fine upwards from coarse to very fine sand. Each unit is often capped by a fine sandstone bed. Small-scale trough cross-bedding and climbing ripples are frequently seen in this facies. Rip-up clasts are also common and some of the sandstone beds also contain larger fragments of epidote. The plane parallel bedded greywacke unit forms 0.5–2 m thick units of fine to medium-grained lithic and calcareous greywacke. Each unit is made up of several minor beds which vary from 5 to 30 cm in thickness, usually separated by well-sorted finer-grained sandstone or pelite laminae. Locally the interbeds are missing, and bedding planes are marked by abrupt changes in grain size. The contacts between the different beds, however, are always sharp.

## The Ulven Group

Sediments of Lower Silurian age appear in a syncline between ophiolitic rocks (Reusch 1882; Kolderup & Kolderup 1940; Ryan & Skevington 1976). The Ulven Syncline (Kolderup & Kolderup 1940) is a tight to isoclinal fold which appears as an open fold within the quartzite in the central part around Ulvenvatn. This syncline becomes tighter both northwards and southwards and here the quartzite in addition approaches an isoclinal configuration. The rocks within the Ulven Syncline are termed the Ulven Group (Inderhaug 1975; Ryan & Skevington 1976).

### *The Gertrudsberg Formation*

The Gertrudsberg Formation (Ryan & Skevington 1976) consists of greywacke with polymictic conglomerate and phyllite. Sometimes quartz siltstones and irregular bands of conglomerate occur at or near the lower contact. The conglomerate, denoted the Ulven Conglomerate by Kolderup & Kolderup (1940), is composed of flattened fragments lithologically identical to underlying rocks such as greenstones, diorites, epidosites, trondhjemites, gabbros and quartzites in a matrix of quartz, feldspars, amphiboles and occasionally garnets overgrown by amphibole (hornblende) and chlorite. The greywacke shows rare cross-bedding. The clast size is between 1 and 4 cm in length and they are normally flattened and elongated subparallel to the contact. Most fragments are fairly angular. The conglomerate only covers a narrow and short zone with a thickness of less than 5 m on average. The conglomerate grades into a protoquartzite sandstone with white mica, chlorite and opaques defining the main (S1) cleavage, which is commonly subparallel to the layering (S0). The protoquartzitic sandstones are interlayered with phyllitic horizons (Inderhaug 1975).

### *The Vaktdal Formation*

This formation consists primarily of phyllites, but metasandstones, carbonate and siltstone beds as well as graphite-rich schists are found. The formation has a maximum thickness of 125 m on the northwest limb and 105 m on the southeast limb of the Ulven Syncline. At its base, the contact between the phyllites of this formation and the conglomerates or metasandstones of the Gertrudsberg Formation (Inderhaug 1975; Ryan & Skevington 1976) is sharp. In the northwest, 50 m above the base, a graptolite fauna has been obtained (Ryan & Skevington 1976). The top 10 m of this formation contains rare beds of quartz siltstone (0.1 m) and flattened corals (Ryan & Skevington 1976). The fauna in the Ulven Syncline has recently been re-investigated and found to belong to the *M. gregarius* Zone (Ryan & Skevington 1976), which can be correlated with the lower part of stage 6b, Middle Llandoverian in the Oslo area. According to the new subdivision of the Silurian sequence in the Oslo Region (Worsley et al. 1983), the Vaktdal Formation should correlate with the Sælabonn and/or the Solvik Formations. In the southeast, limestone bands (1–2 cm), separated by phyllites (2–4 cm), occur in the top 2 m. Reusch's etage 6c fauna probably came from the top few metres of the Vaktdal Formation (Ryan & Skevington 1976).

### *The Skarfjell Formation*

The Skarfjell Formation (Ryan & Skevington 1976) represents the uppermost part of the Os Group and occupies the hinge of the Ulven Syncline. The thickness of the formation varies from 0 to 230 m. It was deposited on the Vaktdal Formation and locally the two formations are interbedded. The Skarfjell Formation is divided into two members, the conglomerate member and the sandstone member. The formation generally starts with a basal conglomerate followed by a much thicker sandstone sequence. The conglomerate is generally found directly above the phyllite, but locally it is either missing due to lateral thinning or to a thin layer of sandstone occurring between the two. Pebbles of quartzite locally occur within the Vaktdal Phyllite close to the contact with the Skarfjell Formation. The conglomerate is clast supported with both reverse and normal grading. The conglomerate consists of well-rounded and oblate cobbles of white to grey quartzite in a quartzitic matrix. Cobbles of serpentinite, sandstone, phyllite, trondhjemite/tonalite and calcareous material make up about 15% of the total amount of cobbles in places. The cobbles show a fairly well defined preferred planar and linear orientation. Both normal and shear fractures are seen, and locally the individual parts of the cobble are distorted. The conglomerate at the base contains 50% or more by volume of rounded clasts of pure white quartz (1–15 cm along the longest axis, 5–10 cm most common) set in a quartzite matrix. The conglomerates vary in thickness up to a maximum of 55 m and often contain thin intercalations of quartzite (0.3–0.5 m). Where the conglomerate is absent at the base of the formation, the basal 2 m of quartzite is often calcareous, containing up to 15% by volume of calcite and occasional shelly fossils (Ryan & Skevington 1976). The conglomerate grades into the overlying sandstone with several cobble beds in the transition zone. The contact between the conglomerate and the sandstone beds is sharp. The matrix of the conglomerate is composed of fine-grained quartz and minor amounts of sericite/white mica and biotite and locally, carbonate. The sandstone overlying the conglomerate consists of about 90% medium-grained quartz, 5% biotite and white mica and about 5% feldspar, opaques and calcite. Small quartzite clasts (2–7 cm) occur irregularly in the lower 100 m of this formation. Primary structures, such as cross-bedding and slumping, are frequently seen. In the upper half of this formation rare bands of quartz siltstone (1–3 cm) and shale (1–30 cm) occur.

## Intrusives

Granitoid intrusive dykes are observed in the Moberg Formation. These have intruded pre- or syn-D1 and they have not been rotated completely into parallelism with the S1 foliation during this event. This is supported by the strong deformation of the granitoids with recrystallization of plagioclase and the development of a strong foliation. The sediments of the Ulven Group are cut by lamprophyres. At the quarry at Hjorthaug the intrusion is seen to cut the layering of the sandstone on the western limb of the syncline, while it is subparallel to the layering in the sandstone on the eastern limb. The analysis carried out by Inderhaug (1975) gives values within the alkaline field, both in the alumina-alkali and the alkali-silica variation diagram. The analysis is consistent with Kersantite, a plagioclase-bearing lamprophyre with biotite phenocrysts, which is genetically related to diorites.

## A discussion of the postulated unconformity between the Skarfjell and Vaktdal formations

A structural and metamorphic discordance has recently been claimed to be present between the Skarfjell Formation and the underlying Vaktdal Formation, based on observations of a recently excavated locality at the inverted western limb of the Ulven Syncline (Saltnes 1984; Sturt 1983). They claim that two cleavages in the phyllite of the Vaktdal Formation are truncated by the conglomerate of the Skarfjell Formation. Quartz veins developed parallel to the first foliation in the phyllite are folded by the second generation folds, which are truncated by the conglomerate. The present author rejects this interpretation, however, following instead that of Inderhaug (1975) and Ryan & Skevington (1976) of this being a continuous sequence. This is based on the following observations:

(1) Structures developed in the phyllite of the Vaktdal Formation and the sandstone conglomerate sequence of the Skarfjell Formation may be studied in the fold closure of the Ulven Syncline (within the industrial area) (Fig. 3). Here one can see two strong cleavages and one weak cleavage in the phyllite, while only a single strong cleavage is developed in the conglomerates and quartzites. Within the conglomerate, cobbles are orientated in the first foliation and some are deformed with the production of a penetrative cleavage. Pressure shadows are also developed at clast edges. This cleavage is the first one observed in the Skarfjell Formation. Within the Vaktdal Formation bedding (S0) is revealed by thin silty

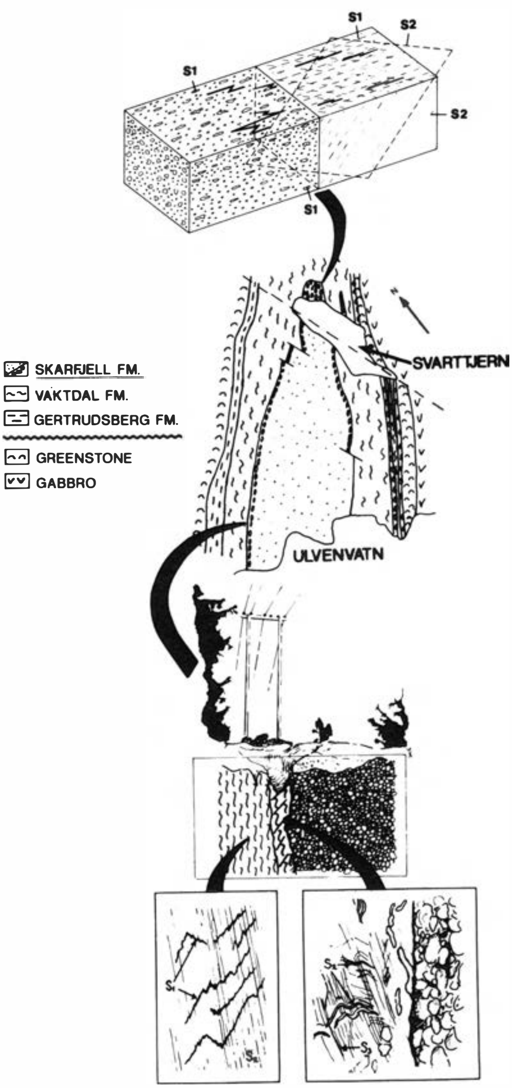



*Fig. 3.* Structural relationships observed at the excavated locality on the knoll just east of the Ulven camp (LM 023791).

laminae and is isoclinally folded. A slaty cleavage is axial planar to these folds and corresponds in orientation to the first cleavage in the Skarfjell Formation. The cleavage is further axial planar to the Ulven Syncline. A second cleavage of crenulation type affects the phyllite and dips towards the east throughout the closure of the Ulven Syncline, indicating that it must be later than the syncline. A corresponding crenulation cleavage is also weakly developed in the rocks of the Skarfjell Formation in the hinge of the Ulven Syncline. The third cleavage is a crenulation cleavage occasionally developed in the phyllite.

(2) At the excavated locality at Ulven on the steep to overturned northwest limb of the Ulven Syncline, two cleavages are well developed in the phyllite (Fig. 3). A slaty cleavage is folded around asymmetric, angular folds with an axial-planar crenulation cleavage. A further cleavage is developed in places, but generally only small, angular folds affect the earlier structures. A distinct crenulation cleavage is exclusively developed close to the base of the Skarfjell Formation in a zone about 0.5 m thick along the contact, which seems to represent a zone of intense deformation. None of the crenulation cleavages have orientations commensurate with an origin in connection with the development of the Ulven Syncline.

(3) The postulated unconformity is between phyllites and a thick sequence of conglomerates and orthoquartzitic sandstone. Across such contacts one would expect a marked competence contrast which would result in refraction of cleavages and variation in the degree of deformation. The S1 cleavage in the Vaktdal Formation has the same orientation and is coeval with the first cleavage observed in the Skarfjell Formation throughout the syncline.

(4) The occurrence of two strong and one weak cleavage in the phyllite and only one weak cleavage in the conglomerate is part of the evidence put forward for the existence of an unconformity (Saltnes 1984; Sturt 1983). The presence of two strong cleavages and one weak cleavage in the phyllite is considered incontrovertible. However, the present author would argue that locally there are also two cleavages in the Skarfjell Formation. At the excavated contact at Ulven (Saltnes 1984; Sturt 1983) the conglomerates and metasandstones seem almost undeformed. Pressure solution seems to be the only result of deformation. However, in a finer-grained, more calcareous sandstone bed in a knoll just to the north of the excavated locality there is a penetrative foliation. This one is crenulated and locally a crenulation cleavage is developed. The oldest of these cleavages is axial planar to the Ulven Syncline. The first cleavage, S1, is subvertical, while the crenulation cleavage, S2, dips 60° to the southeast and has virtually the same orientation as the S2 cleavage in the nearby phyllites. In the northern extension of the Ulven Syncline the same relationship is observed better and more frequently. Here the first deformation (D1) is stronger and subsequently the boulders within the conglomerate are more strongly deformed. The conglomerate here contains phyllitic horizons at the base. These phyllites show two cleavages very well developed (Fig. 4).

(5) The two major phases of folding observed in the Skarfjell and Vaktdal formations can be correlated with the two events, F1 and F2, observed in the rest of the Os area.

(6) A traverse through the Skarfjell Formation within the Ulven Syncline shows that because of competence contrasts between different lithologies the effect of D1 varies considerably. The S1 cleavage is only occasionally developed in less competent lithologies, usually rocks with a higher proportion of mica, while more competent lithologies are uncleaved.

(7) At the excavated locality the phyllite is juxtaposed with conglomerates with a sandy matrix containing little white mica which would make the development of a penetrative cleavage extremely difficult.

(8) Fossiliferous horizons within the Vaktdal Formation are symmetrically disposed around the Skarfjell Formation in the core of the Ulven Syncline (C. Magnus, pers. comm.).

## Sedimentological interpretation and discussion of the Os Group

The Os Group starts with the Moberg Formation, which is interpreted as an alluvial fan deposit related to fault scarps close to an ancient shoreline and in part reworked by shoreline processes (Fig. 5). The clasts are generally well rounded and,

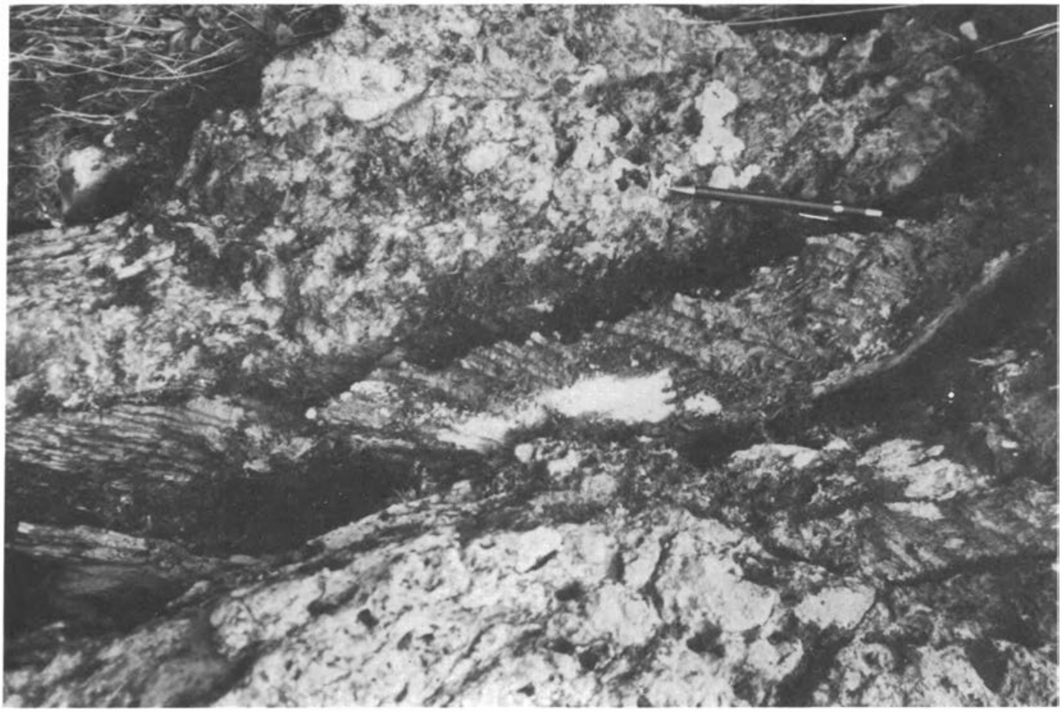


*Fig. 4.* A strong S2 crenulation cleavage developed in the phyllite bed near the base of the quartzite conglomerate of the Skarfjell Formation (LM 063815).

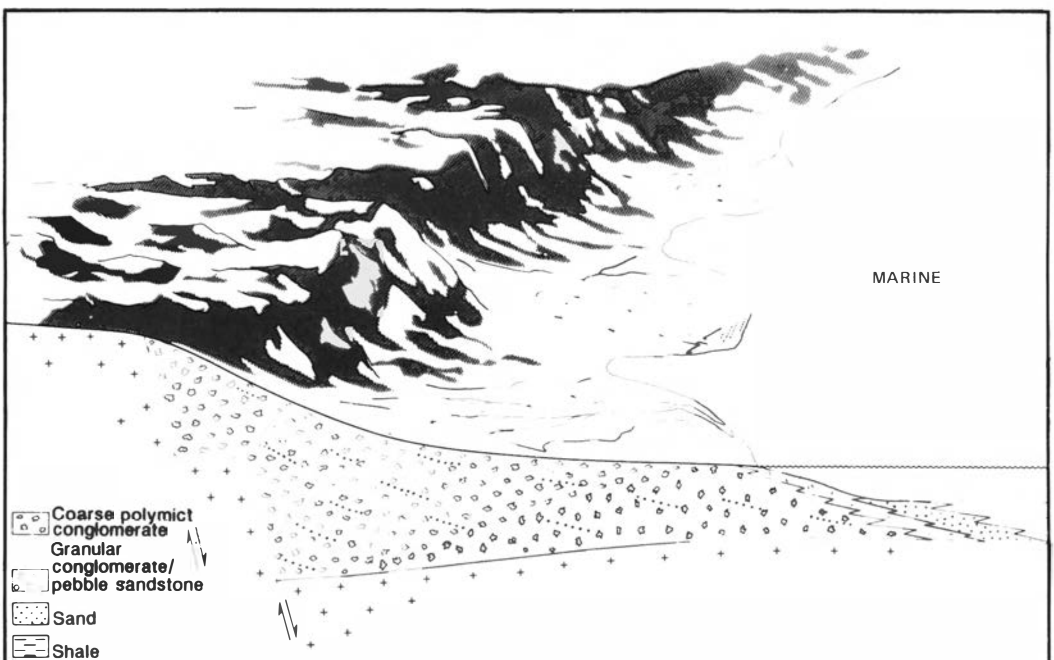



*Fig. 5.* Schematic, interpretative model for the Moberg Formation in Ashgill to pre-Ashgill times, representing large fans composed of cobbles, gravels and sand reworked by marine processes.

despite later tectonic strains, in less deformed areas this is believed to reflect their original shape, indicating either that the conglomerate was resedimented or was reworked by shoreline processes. The cobbles reflect the immediately underlying substrate, which suggests that transport was relatively short. The conglomerate was probably deposited on an uneven topography and in fault-bounded basins, as it varies considerably in thickness laterally.

Some of the sandstone beds are laterally persistent and may represent wave-worked shoreline deposits (Clifton 1973). As the contact between the Moberg Formation and the Valla Formation is transitional, shallow-marine fossils in the overlying Valla Formation also support a shallow-marine environment. The sandstones frequently form discontinuous lenses within the conglomerate, indicating alluvial reworking (Miall 1981, 1983) and/or fragmentation during deformation. Towards the top of the sequence, limestones frequently occur locally as clast material, suggesting reworking of limestones and a synsedimentary evolution of conglomerates and limestones. This is further supported by observations in the Samnanger area, where fossiliferous limestones are interbedded with conglomerates.

A granular conglomerate to pebble sandstone occurs locally between the GOC and the cobble conglomerate. The granular conglomerate to pebble sandstone is interpreted as more distal alluvial sediments, which during subsequent tectonic activity or transgression have been overlain by coarser conglomerates.

The precise age of the Moberg Formation cannot be determined, but as limestone overlying it contains shallow-marine fossils of Ashgillian age, the Moberg Formation must be Ashgillian or pre-Ashgillian. A maximum age for the formation is indicated by the recently published datings from a plagiogranite differentiate of the GOC giving an age of $489 \pm 3$ Ma and an arc-related trondhjemite pluton (the large 'quartz-augen' gneiss body) giving an age of $482^{+6}_{-4}$ Ma (Dunning & Pedersen 1988). A further indication of the age is given by the Moberg Formation equivalent on Bømlo (the Roaldsfjord Conglomerate), where underlying andesites and rhyolites from the Siggjo Complex give Rb/Sr whole rock ages of $464 \pm 16$ Ma and $468 \pm 23$ Ma (Furnes et al. 1983).

Thrusting/emplacement of both foreland and ophiolitic rocks has been claimed from various parts of western Norway. The increased rates of subsidence in Late Ordovician/Early Silurian times could be the effect of isostatic loading by nappes thrust towards the southeast during an early Caledonian orogeny, but the lack of evidence for such a model makes this highly speculative.

The Valla Formation is stratigraphically situated above the Moberg Formation. Locally it sits on the Moberg Formation with a primary depositional contact, but generally has a highly-sheared contact with the underlying rocks. The lithologies of the Valla Formation are interpreted as marginal-marine deposits. This is based on the occurrence of marine fossils and the overall stratigraphic context with a fining-upwards sequence from conglomerates in the Moberg Formation through sandstones and phyllites to interlayered impure limestones and phyllites with the local occurrence of purer limestones. The fine-grained, 'phyllitic' and silty sediments indicate a low-energy environment, while the interbedded sandstones probably represent storm deposits. The fining-upward trend could be due to diminishing sediment supply and fan retreat related to denudation of the source area and/or an increased distance to the fan apex related to backward faulting of the source area. Transgression and deposition of fossiliferous limestones in Ashgill time, indicate a tectonically quiet period and gentle topography in hinterland. Elevated domains underlain by resistant lithologies constituted shallow-water areas and islands favourable for carbonate sedimentation. This Upper Ordovician/Lower Silurian limestone horizon is found throughout western Norway and can be traced from Karmøy in the south to Lyngen in the north, indicating a major break in tectonic activity on a regional scale. In support of eustatic sea-level rises is the worldwide distribution of Llandoverian transgressive formations (Berry & Boucot 1973).

The Hegglandsdal and the Gertrudsberg formations have been correlated based on stratigraphical position and lithological composition. The Gertrudsberg Formation may represent a more distal facies of the Hegglandsdal Formation. The rocks of the Hegglandsdal Formation are interpreted as shallow-marine to shelf deposits, probably related to delta progradation in an active continental margin setting. Phases of delta progradation and subsequent transgression/abandonment may explain the observed alternations of conglomerate and carbonate beds. This model is based on the stratigraphical position above shallow-marine calcareous sediments and on sedimentary structures such as parallel lamination, sharp, planar to erosive bases, normal grading with a turbidite-like appearance and cross-laminated greywackes. Each sandstone bed is most probably the result of a single depositional event. The cross-laminated greywackes probably reflect local wave reworking. Planar-laminated sandstones are attributed to wave currents and storm-surge effects. The horizontal lamination may also reflect deposition of sand from suspension during storms (Dott & Bourgeois 1981; Hamblin & Walker 1979), i.e. as high-velocity, highly-turbulent flows. High-energy events are recorded in the thicker, laterally-persistent sheet sandstones. Trough cross-stratified sandstones reflect onshore waves and longshore currents. In central Hegglandsdal, the carbonate sedimentation (Valla Formation) was followed by a conglomerate which prograded into a marine environment. This conglomerate indicates that the transgression was discontinuous, with minor regressions resulting in influx of coarse material. Whether this was due to eustatic changes in sea level or active tectonism, however, is impossible to tell. The presence of conglomerates in a shallow marine succession may indicate a nearby high-relief source of terrestrial detritus. The conglomerates were probably transported by rivers and reworked into beach gravels. Fining-upward sequences of this type are generally attributed to transgressive cycles in which the rate of subsidence exceeds that of sedimentation, related to eustatic sea level changes and/or to backward faulting. The upward decrease in calcareous material is related to an increase in clastic input. The phyllite horizons occurring within the greywacke may represent variations in rate of sedimentation with time and of flow regime capacities.

The Vaktdal Formation is interpreted as shallow marine deposits as it shows a sedimentary transition upwards into the Skarfjell Formation which represents beach to shallow marine deposits. The thin siltstones and sandstones are considered to be distal representatives of prograding fan deltas. These phyllites are probably at least partly equivalent to the Lower Llandovery graptolitic shales on Stord (Ryan & Skevington 1976). The Vaktdal Formation reflects transgression and deposition of clay-rich sediments of Llandoverian age. The transgression may be related to a remelting of the Upper Ordovician ice age.

A period of renewed faulting is indicated by the deposition of the coarse, reworked marine conglomerates and sandstones of the Skarfjell Formation. The Skarfjell Formation has an erosive base and overlies shallow-marine sediments with a slightly angular, stratigraphic unconformity. The Skarfjell Formation is tentatively correlated with the Utslettefjell Conglomerate on Stord, which shows the same relationship (Thon et al. 1980). The Skarfjell Formation is interpreted as beach to shallow-marine deposits following Inderhaug (1975) and Ryan & Skevington (1976). The idea that the Skarfjell Formation should be deposited by braided rivers (Saltnes 1984, and refs. therein) cannot be supported. A beach to shallow-marine environment for the Skarfjell Formation is based on the following observations in the Ulven area.

(a) The Skarfjell Formation contains mature sediments which are more likely in shallow-marine to beach environments than in braided rivers. The sediments are mature because the matrix in the conglomerate is very quartz-rich and well sorted. The conglomerate cobbles are dominated by quartzite, over 90% locally; they are of about the same size and are well rounded.

(b) Individual conglomerate beds show the lateral continuity typical for shallow-marine to beach environments rather than in braided rivers.

(c) Low-angle cross-bedding in quartzite. This indicates beach to shallow-marine environments. In braided rivers one would expect high-angle trough cross-bedding.

(d) Sharp contacts between conglomerate and sandstone beds. This can also be observed in braided-river deposits, but is normally associated with channelling. In the Skarfjell Formation erosional contacts related to channelling beds cannot be inferred.

(e) The conglomerate beds are texturally uniform.

(f) Normal grading occurs, but individual conglomerate beds are generally either ungraded or coarsening upwards. This is more typical for shallow-marine to beach deposits than for braided rivers.

(g) The quartzites are well sorted.

(h) The framework component is commonly well sorted in individual conglomerate beds, though successive beds may vary greatly in coarseness. Sand infill or small pebble infill locally cause bimodal textures.

(i) Local beds of finer material are always calcareous.

(j) The Skarfjell Formation overlies shallow-marine pelitic sediments of Llandoverian age (Ryan & Skevington 1976) without any major unconformity.

(k) Pebby sandstones probably result from shape filtering on gravel beaches causing pebble entrapment of sand beds (Bluck 1967).

(l) Absence of angular fragments in the conglomerate units. At least some angular fragments would be expected in most braided river environments.

(m) Extremely well-rounded clast material in the conglomerate beds.

In addition to the characteristics which favour a shallow-marine to beach environment, the Skarfjell Formation lacks some of the main characteristics of braided rivers which may separate them from shallow-marine to beach deposits, such as planar cross-bedding, upwards fining within beds, ripples, large-scale channels and fine-grained clastic sediments. The Skarfjell Formation overlies the Vaktdal Formation, which locally contains fossils of Llandoverian age (Ryan & Skevington 1976). This indicates that the deformation of the Os Group must be post-Lower Silurian in age.

## Conclusion

The two younger Ashgillian–Llandoverian sedimentary sequences in the Os area are preserved in F1 synclines. Both sequences have been correlated and collectively named the Os Group. The group is divided into five formations. In stratigraphic order these are: (1) The Skarfjell Formation (uppermost), comprising conglomerate and metasandstone. (2) The Vaktdal Formation, comprising phyllite, limestone and metasandstone of Llandoverian age. (3) The Hegglandsdal Formation, comprising sandstone and minor polymictic conglomerate. (4) The Valla Formation, comprising marble, phyllite and fossiliferous shallow marine limestone of Ashgillian age. (5) The Moberg Formation (lowermost), comprising monomict granule conglomerate to pebble sandstone, polymictic coarse conglomerate, metasandstone and minor phyllitic interbeds.

The Os Group represents shallow marine to beach deposits where alluvial sediments interfinger with tidal deposits because of several transgressive and regressive cycles. The coarse conglomerates at the base of the Holdhus Group were a response to faulting. Transgression and deposition of fossiliferous limestones in Ashgillian time indicate a tectonically quiet period and gentle topography. Elevated domains underlain by resistant lithologies constituted shallow-water areas and islands favourable for carbonate sedimentation. The shoreline to shelf deposits of the Hegglandsdal Formation indicate progradation of a delta. The calcareous sediments were drowned and overlain by boulders and sandstone. Transgression and deposition of clays of Llandovery age are only observed within the Ulven Syncline. A period of renewed faulting is indicated by the coarse, reworked marine conglomerate and sandstone of the Skarfjell Formation. No structural/metamorphic break occurs between any of the formations and the recently postulated structural/metamorphic break between the Vaktdal and Skarfjell formations is not supported.

*Acknowledgements.* – The author thanks Dr. B. Robins and E. Prestholm (Geology Institute/Dep. A, University of Bergen), and H. Fossen and K. G. Jacobsen (Statoil/Bergen) for their helpful advice and critical comments, which substantially improved the manuscript. The author also thanks an anonymous referee for critically reading an early draft of the manuscript and for the many suggestions towards its improvement. Statoil, Bergen is thanked for financial support for my attending the NGF meeting in Trondheim in 1986. Statoil's drawing offices in Bergen and Stavanger are acknowledged for help with the figures.

Manuscript received July 1987

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