Tectonic Succession of the Caledonian Nappe Front in the Haukelisæter—Røldal Area, Southwest Norway

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Naterstad, J., Andresen, A. & Jorde, K. 1973: Tectonic succession of the Caledonian nappe front in the Haukelisæter–Røldal area, Southwest Norway. *Norges geol. Unders. 292*, 1–20.

It is concluded from reconnaissance studies on Hardangervidda that a succession of 5 allochthonous units occurs above the Precambrian basement and its autochthonous/parautochthonous cover. The units are named from bottom to top: Holmasjø Formation, Dyrskard Group, Nupsfonn Complex, Kvitenut Complex and Revsegg Formation. Metamorphism in granulite facies (Kvitenut Complex) and subsequent amphibolite facies (upper 4 units) took place outside the present area. Movement between the units occurred in the Precambrian as well as during late Caledonian tectonic phases.

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CONTENTS

The investigations presented in this paper are limited to the area south of latitude 60°N, and north of highway E 76 between Prestegard, southeast of Haukelisæter, and Skare, 16 km south of Odda. The area is covered by the M 711 1:50,000 quadrangle sheets 1314 I Røldal and 1414 IV Haukelisæter.

The ground is rather rugged with variations in altitude from 300 m at Skare to over 1700 m on Sandfloeggi, and with most of the area well over 1000 metres above sea level. Consequently the effective field season is short, and restricted to late summer.

The investigations were started in 1968 by the senior author as an attempt to obtain supplementary information for his work on the nappe structures of the Hardangerfjord area. In 1969 A. Andresen started field work north of Haukelisæter, and in 1970 K. Jorde joined the team to help tackle problems in the area between Seljestad and Røldal. The rather general results presented in this paper are based on joint work aimed at obtaining a basis for subdivision of the rock units, and studying their relationships as a background for more detailed work. Consequently the following account must be considered as a progress report.

The first relatively detailed investigations in the area were made by W. C. Brøgger (1893) between Odda and Røldal. In 1900 Reusch, Rekstad & Bjørlykke mapped the greater part of Hardangervidda, and in NGU 34 (1902) they presented a remarkably accurate geological map on the scale of 1:400,000, and an account of the expedition. This work has since been the main source of information on the geology of this area.

Rekstad continued the work on Hardangervidda and in 1903 published a paper on the geology between Haukelisæter and the mountains of Hemsedal accompanied by a map on the scale 1:400,000, which also covers parts of our area. In 1913 Reusch published the description of NGU's 1:400,000 geological map of the Sunnhordaland–Ryfylke area. Werenskiold (1912) added to this a geological account and a map on the same scale of the area between Setesdal and Ringerike. Both these last two maps cover parts of the present area.

In 1911 Goldschmidt presented a map showing the deformation of the Precambrian peneplain. This map was later provided with new and more detailed data by Liestøl (1960).

Regional setting

The area under investigation covers a small but important section through the central Norwegian Caledonian nappe system (Fig. 1). This section crosses the part of the nappe system that lies east of the 'Faltungsgraben' of Goldschmidt (1912) onto the edge of the Baltic shield, and is involved in fundamental problems of the geology of Norway. Possible ages and root zones of the supposed allochthonous rock masses are problems of first importance, and have been vigorously debated. The evolution of the early ideas and the discussion that followed are well summarized in Strand's review papers (1960, 1972) and will not be repeated here. With a few exceptions the dominating interpretation of the eastern part of the nappe system over the last 50 years has been that of a major three-fold division: a relatively stable Precambrian basement unconformably overlain by a sequence of autochthonous Cambro–Ordovician sediments of foreland facies, which is again overlain by extensive thrust sheets of crystalline rocks. The overthrust masses are considered to have arrived at their present position from some unknown root zone to the northwest. However, current literature and oral discussions reflect a search for new solutions along widely differing paths of thought. The old interpretations are challenged by

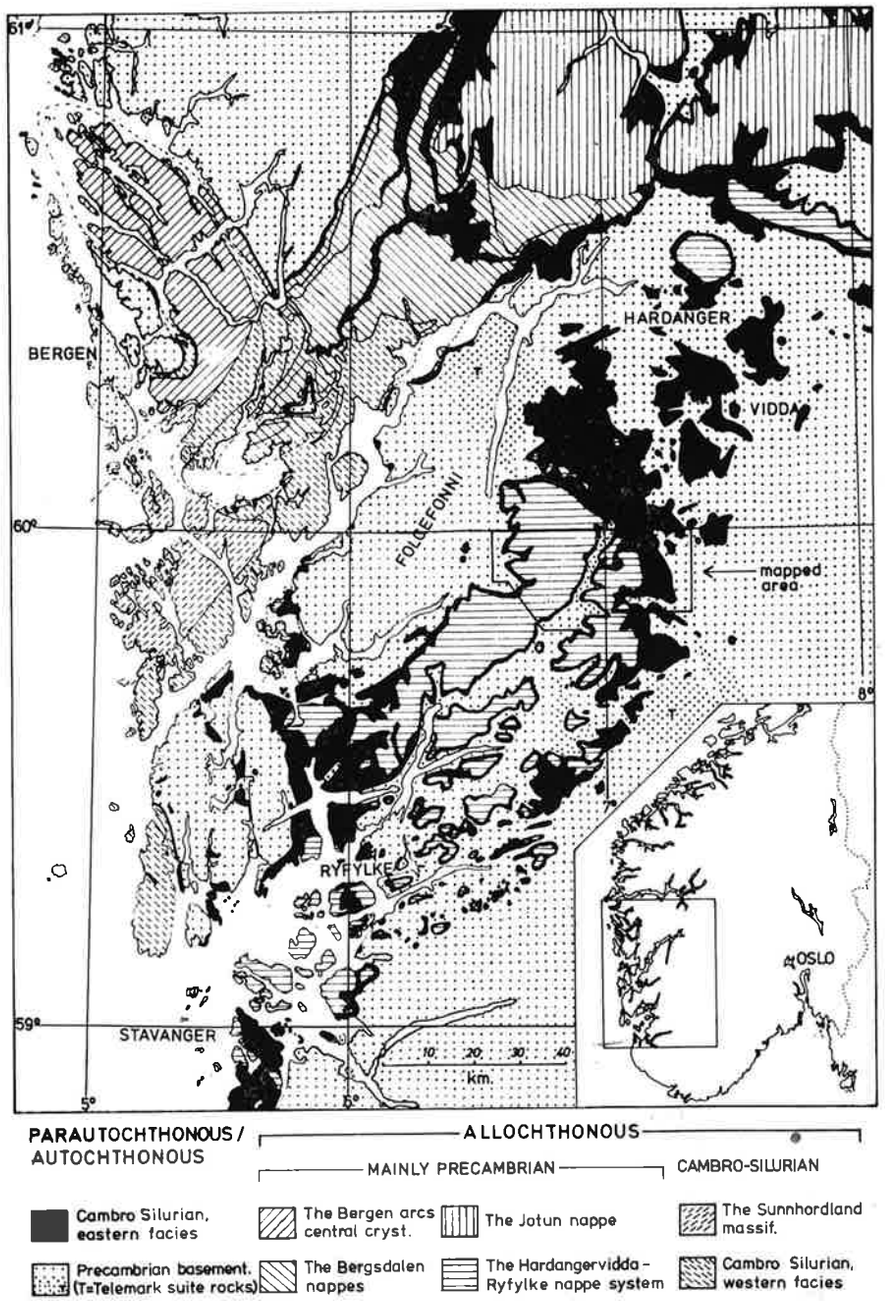

Fig. 1. Map showing location of the studied area and distribution of the main tectonic elements of the Caledonides of Southwest Norway. Redrawn from Holtedahl & Dons: Geological map of Norway 1 : 1 000 000.

ideas based on new geophysical and mineralogical work in neighbouring nappe areas. Geophysical investigations (Smithson & Ramberg 1970) have indicated that the root zone for the crystalline Jotun Nappe might well be located within the 'Faltungsgraben' itself, and this appears to be supported by conclusions drawn from the mineralogy of corona textures found in some nappe rocks (Griffin 1971).

To the southwest of our area, Müller & Wurm (1969, 1970a, 1970b) have collected new data on field relations, structures and petrography in the Stavanger area. They have rejected Goldschmidt's (1920) idea of parautochthonous sequence of 'injection'-metamorphosed Cambro–Silurian supracrustals in favour of a regionally metamorphosed autochthonous series of Cambro–Silurian sediments and volcanics. An allochthonous origin for the crystalline rock units above the basement seems, to Müller & Wurm, unworthy of discussion, in spite of the fact that the main tectonic and petrographic elements of the area strongly resemble those found northeastwards to Hardangervidda.

Description of the tectonic units

As a first subdivision, the rocks of the area can be grouped into one autochthonous/parautochthonous sequence comprising the Precambrian basement and the slightly metamorphosed Cambro–Ordovician sediments above it, and one allochthonous sequence comprising the more strongly deformed and metamorphosed schists and gneisses which constitute the higher ground of the region (Fig. 2). This principal division and interpretation is in good agreement with the earlier views expressed on this specific area, referred to above.

Fig. 2. The nappe front north of Ulevåvatn, northeast of Dyrskard.

We have now been able to make a further subdivision of the main units, and short descriptions of these subdivisions are presented below. The units and subunits are as follows:

Allochthon	Gneisses and schists of uncertain age. Probably mostly Precambrian.	Revsegg Formation Kvitenut Complex Dyrskard Group Nupsfonn Complex Holmasjø Formation
Autochthon/ parautochthon	Cambro–Ordovician sedimentary rocks	
	Precambrian basement rocks	Younger intrusives. Supracrustal rocks of the Telemark suite. Old gneiss complex.

The grouping of the Holmasjø Formation with the allochthonous rocks might turn out to be the most uncertain part of the above scheme. On all earlier maps of the area, it has been included with the parautochthonous Cambro–Ordovician rocks. Our field evidence, however, so far suggests that it must be considered as allochthonous in relation to this latter sequence. Whether the formation is of Precambrian or younger age is still uncertain. This problem will be considered in more detail below.

It should be noted here that the 5 units of the allochthon are tabulated above as a tectonic succession. Indications of the age of the rocks in each unit are given in the subsequent descriptions.

TERMINOLOGY

In recent literature the allochthonous part of the area has been referred to simply as 'The nappe on Hardangervidda' (Strand 1960). In his review of the Norwegian Caledonides, Strand (1972) uses the name 'The Hardanger Nappe'. Considering the geographical setting and the geological complexity of the area, the present authors would propose the name 'Hardangervidda Nappe System' as a better one. Previous work, however, suggests that this nappe system also extends southwestwards to the Ryfylke area. Should this be the case, the name 'Hardangervidda – Ryfylke Nappe System' would probably be preferable.

At the present stage of work we do not propose that the names used for the various tectonic units in this paper should be considered as formal designations. Further knowledge about vertical and lateral extension of the units may possibly require their renaming. The names adopted, however, seem to be the most suitable at present for the mapped area.

PRECAMBRIAN BASEMENT

The basement rocks can be divided roughly into three major groups:

Granitic intrusives
Supracrustals of the Telemark suite
The old gneiss complex.

The old gneiss complex crops out below autochthonous Cambro–Ordovician sediments and overthrust masses in the west-southwestern and east-northeastern parts of the mapped area. The main rock type is a coarsely foliated granitic to granodioritic gneiss. It varies in texture from coarse augen-gneiss to a more even-grained gneiss. Large xenoliths or remnants of an even older complex appear to be floating in the gneiss. The xenoliths consist of metabasites of uncertain origin, although some appear to be metasupracrustals. The mineralogy of the main gneiss is characterized by quartz, microcline, plagioclase, biotite and some muscovite. The gneiss is intensely brecciated and mylonitized in wide zones. This is perhaps most conspicuous along Røldal, where the tectonized zones strike parallel to the youngest NE–SW trending Caledonian folds and faults.

Supracrustals of the Telemark suite. Overlying the gneiss complex with what we interpret to be a primary depositional contact, is a sequence of metasediments and metavolcanics. In accordance with older views this is correlated with the Telemark suite of rocks in the Telemark area proper (Dons 1960).

The limited amount of detailed work carried out on the basement rocks by the present authors does not justify too conclusive statements, but as no data have been published on rocks of the Telemark suite from this area a short review will be given.

According to our interpretation, the supracrustals occur in a north-northwest trending synclinorium with depositional contact to the older gneisses in the southwest and northeast. The southwestern border of the synclinorium is well exposed in the nearly dried-out river bed beneath Nyastøl bridge (see map, Pl. 1). The northeastern boundary is exposed in Trossovdalen and at Uleåvatn. At the latter locality the contact between the old gneiss complex and the metasupracrustals is camouflaged by a younger granite intrusive. In Trossovdalen, however, a thorough search for a direct contact may prove fruitful.

As a first approximation the supracrustals are divided into three major divisions:

A lower division composed mainly of acid volcanics, with a few basic volcanics and epiclastic rocks;

a middle division of mainly basic volcanics with extensive sheets of almost monomictic quartzite conglomerate and some quartzite bands; and

an upper division of purely epiclastic sediments, quartzites and quartz schists, partly calcareous.

At Nyastøl bridge *the lower division* can be seen to start with some metres of quartzitic sediments. The quartzitic rocks show graded bedding and cross bedding, and contain gravel conglomerates and a single, thin, calcareous band. Graded bedding and erosion surfaces indicate 'right way up' for the sequence, although strong folding and other deformation reduce the reliability of such indications. The brecciation that can be seen to cross the boundary between the old gneiss complex and the supracrustals can be ascribed to the young, NE–SW-striking, fault system (see map).

Above the epiclastic basal sediments is a pile of acid volcanics: lavas, ignimbrites, agglomerates and possibly tuff deposits. Primary depositional structures, such as flow banding in the lavas, and eutaxitic and flame structures in the ignimbrites, are well preserved. Intrusives in this division are granite, granite pegmatite and a few bodies of gabbro.

The basic volcanics of the *middle division* are exposed in three separate belts crossing Valldalen. The central belt is interpreted as the core of an anticline. The rocks are mainly metabasalts, lavas and tuff. Structures interpreted as scoria zones, porphyritic and amygdaloidal textures, etc., have been found.

Layers of epiclastic quartz-rich sediments, as well as zones of almost monomictic quartzite conglomerate associated with thin calcareous sandstone layers, occur within the basaltic series. Intrusive bodies of gabbro are present. In the Dyrskard area the metabasalt is cut by the younger granite.

The *upper division,* consisting entirely of epiclastic quartz-rich sediments, feldspathic quartzites and quartz schists, is exposed in what is interpreted as two synclines crossing Valldalen. Locally, the quartz schist is rich enough in mica to deserve the name phyllite. Calcareous layers appear in the quartz sandstone. In places, thin disrupted layers of almost pure limestone appear. Conglomerates have not yet been observed in this division.

Sedimentary structures, such as graded bedding and cross bedding, are frequently seen, but the use of these structures to indicate facing is problematic due to the tight to isoclinal folding. Intrusives have not yet been found in this division.

The details of the structural pattern of the rocks of the Telemark suite have not yet been studied, and the authors are aware that such studies may necessitate changes in the geological picture presented above.

The metamorphism of the supracrustal rocks corresponds to the greenschist facies. A slightly higher grade metamorphism may be found in the northeastern part of the supposed synclinorium, where the number of younger granite intrusions is greater.

AUTOCHTHONOUS/PARAUTOCHTHONOUS CAMBRO-ORDOVICIAN SEQUENCE

A tectonically disturbed depositional contact exists between this sequence and the basement. The sequence is separated from the overlying Holmasjø Formation by a thrust, and the apparent thickness is 75–100 m. This autochthonous/parautochthonous series is found mainly in the northeastern part of the area, northeast of a NW-striking line (see map, Plate 1). Southwest of this line only small wedges and pockets of these rocks are found below the Holmasjø Formation.

The stratigraphy and structures of these rocks have been described by Brøgger (1893), Reusch et al. (1902) and Rekstad (1903). We can add only a few new data on these rocks, which, in our area, are strongly disturbed by local folding and thrusting.

In the basal sediments, consisting of conglomerate and quartzite, we have found traces of unidentified body and trace fossils north of Hellevassbu, the first to be reported within the area. In the basal arkose at Haukelisæter, just outside the map area, we have observed the galena impregnation that characterizes this contact in so many other places in southern Norway (Skjeseth & Vokes 1957). The primary sedimentary layering in the series is disturbed by folding and thrusting. Locally, the black shale (the 'Alum Shale' of previous authors) has been completely removed by thrusting, and the higher bluish quartzite rests with tectonic contact directly on the basement. The marble above the quartzite grades upwards into a green chlorite schist, the stratigraphically highest member in the autochthonous series.

The top of the basement has also been affected by thrusting, and in many places wedges of basement gneiss are present within the shale unit. The oldest folds that we have been able to distinguish have axes concentrated towards 150^g. (Compass directions are given as azimuths based on the 400^g scale.) In the quartzite, these folds are fairly open and overturned to the northeast, whereas the more incompetent black shale may show a more intricate style of folding. These structures are affected by quite open, undulating, younger folds with axes directed towards ca. 45^g.

The transection of this series by the NW–SE striking thrust plane underlying the Holmasjø Formation seems to be synchronous with the formation of the 150^g folds.

The mineralogy of the rocks suggests a metamorphism in the lowest part of the greenschist facies. No intrusives have been found in this sequence.

The Cambro-Ordovician age is confirmed by the fossil finds (Brøgger 1893).

ALLOCHTHONOUS SEQUENCE

Holmasjø Formation

The Holmasjø Formation rests tectonically on all rock types of the autochthonous Cambro-Ordovician sequence, as well as on the Precambrian basement. Its upper boundary with the Dyrskard Group is identical with the major thrust plane recognized by earlier authors. The boundary is clearly tectonized, and it marks an abrupt change in lithology, structural style and degree of metamorphism. The thickness of the Holmasjø Formation varies from 5 m to 250 m, most of this variation being ascribed to tectonic deformation.

The dominating rock type is a strongly deformed quartz schist, rich in white mica and chlorite. In places the rock may be called a phyllite or mica schist, and numerous pods and lenses of quartz are conspicuous. Layers of feldspathic quartz sandstone or quartzite are present.

The two sets of folds occurring in the autochthonous/parautochthonous sequence are also present in the Holmasjø Formation, and with the same age

Fig. 3. Foliation and cleavage in schist of the Holmasjø Formation. South of Holmasjøen.

relationship. In addition, minor folds occur which appear to be older, but their general trend has not been determined. In most places two secondary foliations are conspicuous: an older, generally flat-lying, penetrative foliation; and a younger, crenulation or fracture cleavage with a fairly constant moderate dip to the southeast over the whole area (Fig. 3). The relationship between the obviously late cleavage and the folding is as yet unknown, but it is tempting to relate the formation of this cleavage to the formation of the 45^g late folds. This late southeast-dipping cleavage also affects the autochthonous sediments.

Chlorite, white mica and albite indicate a low grade of metamorphism in the Holmasjø Formation, but relics of chloritized garnets and biotite, and epidote minerals clouding the albite, are indicative of an earlier, slightly higher grade metamorphism.

The age of the Holmasjø Formation is difficult to ascertain. Brøgger's (1893) view, accepted by Reusch et al. (1902), was that these rocks were autochthonous and continuous with the underlying Cambro-Ordovician rocks. The observed thrust contact between the Holmasjø Formation and all underlying rocks, and the irregular appearance of the autochthonous Cambro-Ordovician rocks, indicate that Brøgger's simple solution must imply the existence of a disconformity between the Holmasjø Formation and the sediments below. This, however, does not help to solve the problem of the seemingly higher degree of metamorphism and deformation in the Holmasjø sediments as compared to that in the autochthonous rocks. Another solution, and in our opinion a more likely interpretation, could be that the Holmasjø sediments were deposited outside the Hardangervidda area and were thrust in

front of and below the advancing higher nappe units. This places the age of deposition of the Holmasjø sediments within the wide time span from Precambrian to Silurian. The present authors consider an Eocambrian to Ordovician age to be most likely.

Nupsfonn Complex

The rocks of the Nupsfonn Complex occur as a local wedge between the underlying Holmasjø Formation and the overlying Dyrskard Group. The wedge is bounded by thrust planes (see map).

The bulk of the Nupsfonn Complex is composed of various gneisses, both paragneisses of assumed metasedimentary origin and orthogneisses of granitic to granodioritic composition. Locally, the gneisses have a rather migmatitic appearance. Low down in the Nupsfonn Complex, immediately above the thrust plane that separates it from the Holmasjø Formation, a sequence of metasupracrustal rocks is present. These comprise quartzites and quartz schists with amphibolite layers, rocks that in many respects resemble those of the Dyrskard Group. Calcareous rocks are also found. The metasupracrustals are neither thick nor continuous along the base of the complex.

Lithologically, the Nupsfonn Complex strongly resembles the overlying Kvitenut Complex. The fringe of quartz-rich sediments along its base is probably equivalent to the rocks of the Dyrskard Group, and has been mapped as such.

The rocks of the Nupsfonn Complex display throughout evidence of a brittle cataclasis. The minerals show little or insignificant recrystallization subsequent to this cataclastic deformation.

At least 3 episodes of folding can be recognized. The fold styles, trends of fold axes, and the age relations between the tectonic episodes are the same as those described for the Dyrskard Group, below. The mineralogy is indicative of metamorphism in the almandine-amphibolite facies, before cataclasis.

The Nupsfonn Complex is tentatively interpreted as a wedge of rocks that belonged originally to the Kvitenut Complex and to the Dyrskard Group. If so, it must have been cut away from its original position in the allochthon and subsequently overridden by the overlying part of the nappe, thereby acquiring its cataclastic texture and tectonic position.

Dyrskard Group

As can be seen from the map, the lower thrust boundary of the Dyrskard Group brings the group into direct contact with the Precambrian basement, the Holmasjø Formation and the Nupsfonn Complex. The upper boundary of the Dyrskard Group is everywhere against the mylonite gneisses of the Kvitenut Complex or the cataclastic rock of the Nupsfonn Complex. This upper boundary is interpreted as an older thrust zone; the products of cataclasis that are found along it have all been recrystallized in the amphibolite facies.

Lithologically, the Dyrskard Group may be divided into three main units:

1) A lower unit comprises various banded gneisses of supracrustal origin

Fig. 4. Banded quartzite of the Dyrskard Group showing multiple folding. South of Trossovdalen.

(propably mixed volcanic and epiclastic rocks), quartzites and banded feldspathic quartz-rich gneisses. Feldspar augens are developed locally. An impure carbonate rock with a characteristic unevenly weathered surface occurs low down in this lower part of the Dyrskard Group. It is 3 to 5 m thick, and can be found over wide areas, often together with a zone of rather pure quartzite.

2) A middle unit of the Dyrskard Group is composed of amphibolites in a characteristic alternation with bands and zones of quartzite. Thicknesses of the amphibolite and quartzite layers vary from less than a centimetre to several metres. The total thickness of this middle unit is variable, probably due to both primary and secondary processes.

3) The uppermost part of the Dyrskard Group is dominated by quartzites and meta-arkoses, with a few horizons of black, quartz-rich schists.

A few gabbroic intrusives occur in the Dyrskard Group, but other intrusive rocks have not been found.

The most common folds in the rocks of this group are isoclinal structures with axes trending approximately 150g. Minor folds with amplitudes varying between 0.5 cm and 0.5 m are predominant (Fig. 4), but a single, recumbent fold of amplitude 15 m has also been found. Open folds, with axes trending 150g, occur locally.

Less common, and clearly younger, is a set of folds with axes trending approximately 40g, parallel to the major synclines and anticlines of the area. These structures are broad, open, flexural slip folds.

Traces of folds older than those with 150g axes have been observed, but it has not yet been possible to determine their axial trend.

In assigning an age to the Dyrskard Group, we have attempted a correlation with rocks from other areas in Southern Norway. Three groups of rocks come into focus: the Precambrian Telemark suite rocks, the Eocambrian sedimentary sequence and the Ordovician rocks of the Trondheim region. Of these, the rocks of the Telemark suite show by far the greatest lithological similarity, and this correlation, already suggested by Reusch et al. (1902 p. 11), is favoured for the Dyrskard Group.

Kvitenut Complex

The Kvitenut Complex lies above the Dyrskard Group with a strongly tectonized contact. The boundary against the overlying Revsegg Formation is interpreted as an erosional surface.

A thick zone of mylonite gneisses occurs in the lowermost part of the complex (Fig. 5), in places with tectonic pseudo-conglomerates. The mylonite gneisses and the tectonic conglomerates are recrystallized in the amphibolite facies, indicative of an old age for the tectonic movement along the lowermost contact of the complex. Above the mylonite gneisses, quartzo-feldspathic gneisses are the dominating rock type in the greater part of the area (Fig. 6). The composition of the gneisses varies from granitic in the lower part of the complex to dioritic in the upper part. Migmatites of dioritic composition occur in the upper part of the complex; in the northern part of the area, migmatites are present throughout the complex.

Numerous bodies of plutonic rocks have intruded into the gneiss and the migmatites. The compositions of these intrusives vary from granitic to dioritic,

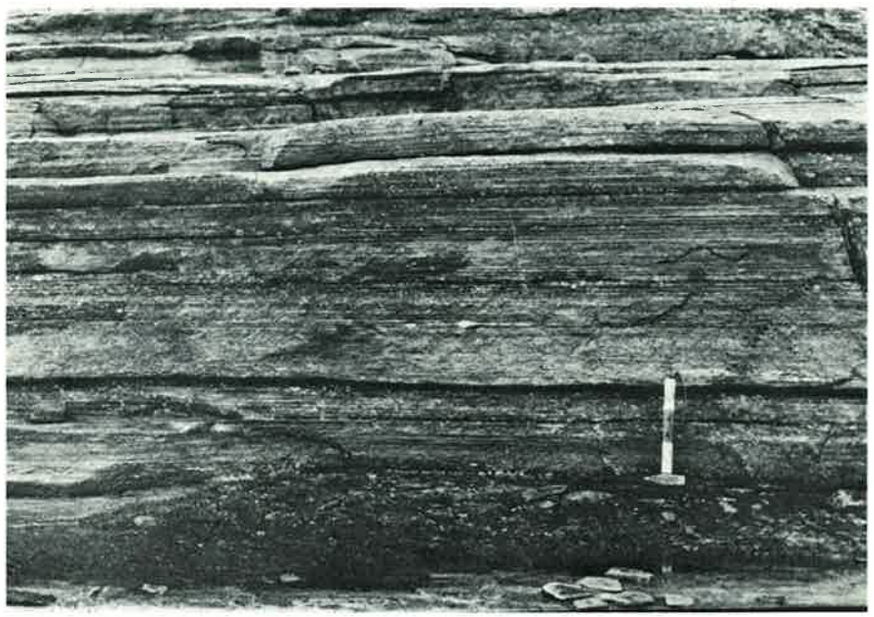

Fig. 5. Mylonite gneiss of the Kvitenut Complex. West of Kvitenuten.

Fig. 6. Migmatitic gneiss of the Kvitenut Complex. Stavsnuten.

with monzonites and diorites predominating. The intrusive bodies are particularly common in the Kvitenut area. They occur as separate bodies with a gneissic texture that is discordant to that of the surrounding gneisses, indicative of post-emplacement transposition or breaking-up of larger plutons. Intrusive dykes of granitic composition are found in a few places; these are nowhere seen to be connected with the larger intrusive bodies.

The thickness of the Kvitenut Complex is normally 100–150 m, except in the northern area, where it increases to some 300 m or more. The complex is now metamorphosed in the amphibolite facies, but shows relics of an orthoclase–pyroxene–garnet assemblage indicative of an older metamorphism in the granulite facies. This indicates a Precambrian age for the complex.

The most conspicuous structural element in the gneisses of the Kvitenut Complex is a lineation trending approximately 140^{g}. This is parallel to the axes of tight to isoclinal folds. Tight folds with axes trending 160^{g} are commonly present. A set of irregular folds, younger than the former, occurs locally in the Kvitenut Complex. These folds are restricted to a few narrow zones low down in the quartzo-feldspathic gneiss. Their axial trend is rather variable, with 70^{g} as an approximate mean value.

As in the Dyrskard Group, broad open folds with axes trending 40^{g} are present in some places, these clearly representing the youngest fold episode in the area.

Fig. 7. Mica gneiss of the Revsegg Formation with amphibolite boudins and quartzo-feldspathic pods. Southeast of Kvitenuten.

Revsegg Formation

The highest member of the tectonic succession is the Revsegg Formation. The boundary with the Kvitenut Complex is normally quite sharp, and this appears to be a normal depositional contact with the Revsegg Formation sediments deposited on an erosion surface in the Kvitenut Complex. In most places, however, the contact is disturbed by tectonic movements. An upper boundary for the Revsegg Formation has nowhere been found.

The formation crops out only in the western part of the mapped area, where it has a minimum thickness of some 600 m. The Revsegg Formation consists almost exclusively of mica gneisses, a lithology that laterally is rather uniform. The lowermost part of the formation consists of a two-mica gneiss, rich in quartz and plagioclase pods (Fig. 7). The gneiss contains garnetiferous zones, as well as a zone rich in kyanite. The kyanite zone occurs extensively at a fairly constant distance above the contact with the Kvitenut Complex, and thus in the authors' opinion supports the interpretation that the boundary is of primary depositional character. The kyanite is often partially altered to muscovite. The two-mica gneiss has a well-defined schistosity, and in some places the rock grades into a mica schist.

Above the two-mica gneiss lies a hornblende–biotite gneiss which is more massive than the former. It also contains fewer quartz and plagioclase pods. Above this is another two-mica gneiss. Although this is very similar to the lowermost gneiss of the formation, kyanite has not yet been found in this unit. Then follows another hornblende–biotite gneiss, which, as far as we know at present, constitutes the uppermost part of the formation.

Large bodies of intrusive rocks have not been found in the Revsegg Formation within the mapped area. Thin bands of amphibolite are quite common, however, locally constituting some 30% of the formation thickness. These often have a high garnet content. It is not known whether the amphibolite bands are sedimentary layers, or have been intruded as sills. Nowhere have they been observed to cut the foliation of the gneisses. Minor bodies of granodiorite occur in places, transecting the amphibolites. The intrusive rocks, as well as the amphibolite layers, often show prominent folding and boudinage.

The rocks of the Revsegg Formation are now metamorphosed in the amphibolite facies. The main structural elements in the Revsegg Formation are isoclinal folds with axes trending 140g, and a moderately developed lineation trending 130g. The boudins, which grade into beaded structure, have long axes generally trending 80g. Contorted relics of fold closures are present, also with axes striking 80g.

The age of the Revsegg Formation has not yet been determined. Lithologically, the formation is similar to the Røros Group in the west of the Trondheim region, as described for instance by Hernes (1956), but a Precambrian age seems just as likely.

Evolution of the Haukelisæter—Røldal section

As mentioned previously, there has been much speculation as to how the nappe rocks have come to lie in their present position. The present work, while not comprehensive enough to provide a definite solution, does, however, supply sufficient data for the proposal of a more detailed theory of evolution than has previously been possible.

From the foregoing descriptions, it is noted that the Kvitenut Complex is considered to be the oldest part of the allochthon. This must have had a long and complex history reaching far back into the Precambrian, and in agreement with earlier views the scene for this evolution must be sought off the present coastline to the northwest. Our observations are thought to indicate some later episodes in the evolution of the complex: old migmatitic gneiss complexes have been eroded and overlain by supracrustals of both volcanic and sedimentary origin. The entire sequence and its intrusives were affected by granulite facies metamorphism.

Volcanics and sediments of the Dyrskard Group were then deposited in a region probably closer to the Hardangervidda area. Following this sedimentation, an orogenic episode resulted in the thrusting of the Kvitenut Complex above the Dyrskard supracrustals. The Dyrskard Group, the Kvitenut Complex and the rocks of the intervening thrust zone suffered amphibolite facies metamorphism. Relics of high grade rocks survived in the Kvitenut Complex. Then followed uplift and erosion, almost to peneplanation, of the Kvitenut/Dyrskard association. This was followed by deposition of the dominantly pelitic Revsegg sediments. The time for this sedimentation, whether late Precambrian, Eocambrian or early Paleozoic, is still uncertain, but a fairly complex period of de-

formation and an episode of intrusion of basic dykes or sills then ensued. The authors are inclined to connect a later episode of intrusion of quartz-dioritic to granodioritic sills, 'trondhjemites', with the last amphibolite-facies metamorphism of the Revsegg Formation, and to consider this as a possible Ordovician event.

Some time during the main Caledonian orogeny the three units were affected by further movement, this time on a thrust below the Dyrskard Group. Most probably they also carried, on top, a sequence of western facies, Cambro–Ordovician, eugeosynclinal sediments.

On Hardangervidda itself, long peneplanation during late Precambrian time was followed by deposition of the autochthonous sediments of Cambro–Ordovician age. During the late stages of the Caledonian orogeny the nappe pile closed up on this actual area, pushing in front of it, and overriding, a sheet of Holmasjø Formation sediments that must have occupied an area not too far to the northwest of their present position. The Holmasjø Formation rocks were metamorphosed in the greenschist facies. Some retrogression of the amphibolite facies mineralogy of the higher nappe rocks probably took place at this time, but relics of high grade rocks in the Kvitenut Complex still persist.

Movement of the nappes then slowly ceased, with imbrication wedges, like the Nupsfonn Complex, being sheared off and overridden by the main nappe. In these late stages of compression, the basement was also involved. The large, open, late, NE–SW striking folds were then formed – the 'Faltungsgraben' itself is considered to be one of these structures. The horst- and graben-like faulting, apparently closely connected with this last folding, developed as the stress in this part of the crust was relieved. The asymmetry of the late folds, and the southeast-dipping late cleavage of the Holmasjø Formation, are puzzling, unsatisfactorily explained features that perhaps indicate a late northwestward movement of the allochthonous cover rocks relative to the basement.

Some regional comparisons

Tectono–stratigraphic correlations along the southeasternmost front of the Caledonian nappes of Scandinavia are not easy to establish. The authors are convinced, however, that the nappe system of the Haukelisæter–Røldal area has much more than only local significance, and an attempt at making some regional correlations should therefore be fruitful.

Turning southwestwards to the northern and central Ryfylke area, the descriptive parts of all available literature (listed in Strand 1972) seem to suggest a main twofold division, with an autochthonous part comprising the Precambrian basement and overlying Cambro–Ordovician sediments, and an allochthonous part of varying lithology that is continuous through this area and via the Stavanger–Boknfjord region into the North Sea. Further subdivision of the allochthon on the basis of structural or metamorphic breaks has, in most cases, not been attempted. However, the descriptions frequently point out the fact that the lower section of the gneissic part of the allochthon consists of more

or less feldspathic quartzites, amphibolites and quartzo-feldspathic paragneisses metamorphosed in lower or middle amphibolite facies. The higher parts of the allochthon contain gneisses with a mineralogy consistent with a higher metamorphic grade, and various intrusives of charnockitic affinities.

The new geological maps and petrographic descriptions from the Stavanger–Boknfjord area (Müller & Wurm 1969, 1970a, 1970b) obviously need reinterpretation before direct comparisons can be made (Heier et al., 1973), but a study of the published reports, together with excursions to the area, have convinced us that the general tectonic succession in this region is comparable to that of the Haukelisæter–Røldal area.

The connection between the Bergsdalen Nappes to the northwest (Kvale 1948, 1960) and the Hardangervidda–Ryfylke Nappe System is broken by the Precambrian basement area of the Folgefonn peninsula, but lithological units equivalent to both the Holmasjø Formation and the Dyrskard Group are to be found within the Bergsdalen Nappes. Rocks of Kvitenut Complex type are less prominent within the Bergsdalen Nappes, but may have correlatives within the Upper sheet of the Upper Bergsdalen Nappe, and within the Jotun Nappe northeast of the Voss area. These connections are admittedly tentative and additional field studies are needed before more definite correlations can be proposed.

To the northeast, the old descriptions (e.g. Reusch 1908) from the Hardangerjøkulen–Fillefjell area indicate that rocks similar to those of the Holmasjø Formation, Dyrskard Group and Kvitenut Complex can be recognized above the autochthon, but a delineation of the different tectonic units is impossible at present. As for the area further to the northeast, a relationship between the rocks of the Kvitenut Complex and parts of the Jotun Nappe has already been indicated, but further similarities seem difficult to recognize, mainly because of the complications involving the autochthonous/parautochthonous Eocambrian sparagmite rocks to the southeast of the Jotun Nappe area.

In the extreme northeastern section of the Caledonian nappe front in southern Norway and in its continuation into Sweden, Swedish geologists have divided the overthrust masses into a series of tectonic units that are similar in many ways to some of those established for the Haukelisæter–Røldal area. The amphibolite facies rocks of the Kvitenut Complex showing relics of retrograded granulite facies metamorphism, together with the overlying Revsegg Formation, constitute a tectonic unit which might be comparable to the lower part of Kulling's (1972) Seve–Køli complex, part of the Upper thrust rocks of his Main Seve Nappe. In the Haukelisæter–Røldal area, however, none of the low grade eugeosynclinal Køli rocks of Cambro–Silurian age are present, but the belt of rocks of similar age along the Hardangerfjord from the Norheimsund area to the coast, and further southwards to Karmøy, could be interpreted as equivalents of Køli metasediments. These rocks occur in this area in an allochthonous position, folded into, and transported together with, rocks of the Bergsdalen Nappes; the latter, in lithology and possibly also in age, are comparable to those of the Dyrskard Group.

In east Norway and in Sweden the amphibolite facies rocks of the Dyrskard Group might find their counterparts within Kulling's (1972) Middle thrust rocks, in the Serv–Kvitvola Nappe. Kulling favours an Eocambrian age for most of the Serv rocks, whereas Asklund (1961) suggests that they are Precambrian. Asklund's (1960, 1961) suggested correlation between some of the Serv rocks and the rocks of the Telemark suite is consistent with our idea of the age of the Dyrskard Group.

Our Nupsfonn Complex has a tectonic position strikingly similar to the part of Kulling's (1972) Middle thrust rocks that has been called the Granite Mylonite Complex. We interpret the Nupsfonn Complex, however, as a severely crushed, imbricated wedge of rocks derived both from the Kvitenut Complex and from the Dyrskard Group.

The lowermost allochthonous unit, the low grade Holmasjø Formation, may be equivalent to some part of the Lower thrust rocks in Sweden (Kulling 1972). It is, however, uncertain whether the strongly phyllonitized, pelitic quartz-schist with layers of feldspathic sandstone is correlatable with some part of the Eocambrian sparagmite or with the overlying Cambro–Silurian sediments. Whichever is the case, the structures and metamorphic textures of the Holmasjø rocks are thought to be entirely of Caledonian age, in contrast to what has been demonstrated for the Dyrskard Group and the Kvitenut Complex.

Although these suggested correlations with other parts of the Caledonian nappe front in Scandinavia are admittedly only tentative, they are meant to illustrate our conclusion that the Haukelisæter–Røldal section fits into a tectonic reconstruction which, in its general pattern, is much the same along the front from northern Sweden to the North Sea.

Summary

The present paper is a report on reconnaissance mapping in the southern part of the Hardangervidda region in the central part of southwestern Norway. The old ideas of a threefold division of the rocks of the area into (1) a Precambrian basement overlain by (2) autochthonous/parautochthonous Cambro–Ordovician sediments and (3) an allochthonous complex of assumed far-transported crystalline nappes have been confirmed.

Within the Precambrian basement a series of supracrustals of the Telemark suite has been distinguished from an older gneiss complex. The contact between the two appears to be depositional. A series of younger granites penetrates both complexes.

The Cambro–Ordovician sedimentary sequence of earlier authors has been divided into two units. The highest unit in the mapped area, a greyish-green quartz-rich phyllite, is separated from the lower unit by a marked thrust plane and by a break in the structural style and metamorphic grade. This upper unit, the *Holmasjø Formation*, is tentatively mapped as a separate thrust sheet, and in the text has been grouped with the allochthonous rock masses. Uncertainty exists, however, as to its age and tectonic position.

The allochthonous rock masses are divided into three major units: the lowermost *Dyrskard Group* consisting of metasupracrustals of mixed sedimentary and volcanic origin, the *Kvitenut Complex* of heterogeneous ortho- and paragneisses, and the *Revsegg Formation* dominantly of mica gneisses considered to be a metasedimentary complex with disturbed depositional boundary to the Kvitenut Complex below. It appears that these allochthonous rocks moved together as one block into their present position at Hardangervidda, probably in late Silurian time. All these rocks are considered to be of Precambrian age, with the Kvitenut Complex as the oldest.

All the allochthonous rocks have jointly suffered amphibolite facies metamorphism somewhere outside and to the northwest of the Hardangervidda area. Domains with relics of granulite facies metamorphism are found within the Kvitenut Complex.

Complex structural patterns are found in most of the allochthonous rocks. This probably results from overprinting of Caledonian folds on several sets of Precambrian structures, although the details have not yet been worked out.

The oldest set of structures unravelled in the Cambro–Ordovician sequence is associated with folds with an axial trend of ca. 150g. These structures are refolded around relatively open folds trending 45g. The latter major folds affect all rocks of the area throughout the whole sequence from the Precambrian basement to the Revsegg Formation. A series of NE–SW striking normal faults is later than, but probably connected with, these major folds.

Finally, an attempt is made at some regional comparisons with other areas along the Caledonian nappe front in Scandinavia.

Acknowledgements. – We thank our colleagues at the University of Oslo for valuable discussions.

All field expenses have been paid by Norges geologiske undersøkelse, and Statens Vegvesen, Odda vegavdeling, has granted us the free use of their inspection cabins in the area. We thank both institutions for help and hospitality.

Dr. D. Roberts has kindly corrected the English text.

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LEGEND TO ROCK UNITS:

Allochthonous

- Revsegg Formation — Mainly mica gneisses
- Kvitenut Complex — Variable quartz-feldspar gneisses; Metasupracrustals and intrusives
- Nupsfonn Complex — As in Kvitenut complex, but strongly cataclastic rocks
- Dyrskard Group — Mainly basic metavolcanics; metaarkoses and quartzites
- Holmasjö Formation — Quartz-schist and metapelite

Autochthonous

- Autochthonous/parautochthonous Cambro-Silurian — Black shale and quartzite

Autochthonous — Rocks of the Telemark suite

- Quartzite and quartz schist
- Mainly metabasalt with metagabbro and zones of quartzite conglomerate
- Mainly acid volcanics lavas, ignimbrites and agglomerates
- Gneissic granite, younger than the Telemark suite
- Gneisses, mostly granitic older and younger than the Telemark suite

Numbers at map margin refer to UTM grid lines

Scale 1:100 000

0 1 2 3 km

OTHER SYMBOLS:

- Formation boundaries
- Thrust planes (T_4, T_3, T_2, T_1)
- D(own) / U(p) — Faults
- Other fracture zones
- Axes of late major folds: antiforms and synforms
- Major road with number (520)
- Minor road, possible to drive
- Glaciers, snowfields

NGU 292

Geology of the quadrangles 1314 I RØLDAL and 1414 IV HAUKELISÆTER north of highway E 76

Mapping by

JOHAN NATERSTAD, ARILD ANDRESEN and KNUT JORDE 1968 - 1971

Trykk: Asg. Bjærums Trykkeri, Trondheim - 1973