Glacial geology of Middle and Inner Nordfjord, western Norway

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Marginal moraines have been mapped and the course of deglaciation reconstructed, supported by studies on terraces and shorelines and by radiocarbon datings. The following glacial events have been recognised: 1. Davik stadial, age unknown, glacier front somewhere in the outer fjord area. 2. Vardehaug stadial, of early Younger Dryas age (10.700—10.600 years B.P.), glacier front at Naustdal, Eidsfjorden. 3. Nor stadial, later half of Younger Dryas, glacier front at Nor (Nordfjordeid), Anda and Rygg. The Nor stadial is by far the most marked late glacial event in Nordfjord, both with regard to the thickness of the deposits as well as to their distribution and continuity, and is correlated with the main Younger Dryas readvance in Norway. This stadial is completely reconstructed, and a paleogeographic map is presented. 4. Vinsrygg stadial, early Pre-Boreal, characterized by active glaciers, glacier front in the fjord outside Stryn. 5. Eide stadial, of Pre-Boreal age (> 9400 years B.P.), front of valley glaciers near the heads of the innermost fjord branches.

Local moraines, primarily in front of cirques, are numerous and frequently reflect several stadials, although Nor moraines dominate.

The Nor raised marine shoreline is a prominent feature in greater parts of the area, and an isobase map for Nordfjord and Sunnmøre is presented.

The Younger Dryas lowering of snow lines and glaciation limits is estimated at approximately 450 m.

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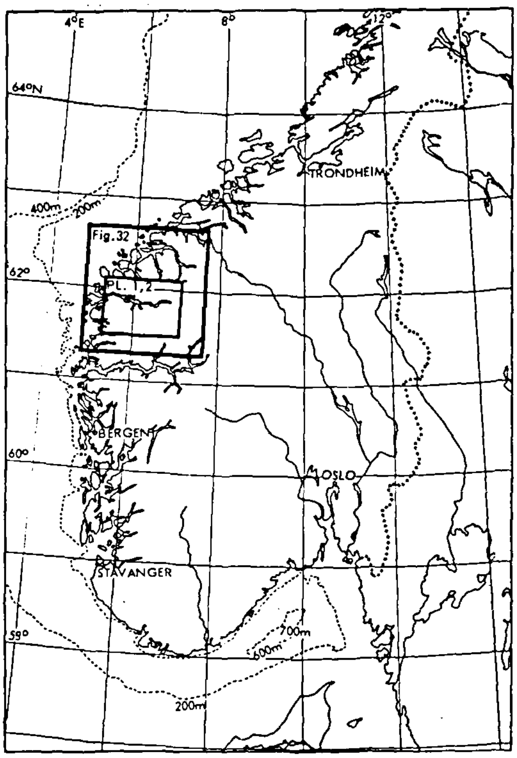


Fig. 1. Location map of the investigated area.

Preface

As will be apparent from the following review of literature, knowledge of the Quaternary geology of Nordfjord has been rather deficient until relatively recent time. Consequently, the main aim of the thesis (Fareth 1970) which forms the basis of the present paper, was to provide a regional survey of the main features of the glacial geology in the area, notably the course of the ice recession and the position of the Younger Dryas ('Ra') ice margin. The main field work was carried out during field seasons from 1964 to 1967. During later years, only short occasional visits have been made in the field.

The investigated area (Fig. 2) includes most of middle and inner Nordfjord with the exception of the easternmost part (Oppstryn-Loen and adjacent mountain areas). Fieldwork in Hyen was confined to the lower parts of the main valleys.

As with my thesis (1970), the present paper must be considered primarily a reconnaissance study, leaving much work to be done in the future, in particular the detailed mapping and interpretation of the sediments in the valleys. This work is now in progress under the œgis of N.G.U.

Review of literature

One of the first to publish observations on the Quaternary geology in the Nordfjord area, was Helland (1876, 1901 a, b), who recognised the deposits in front of some of the lakes as glacier marginal features. A.M. Hansen (1891) measured the altitudes of marine levels at several localities and constructed the first shoreline diagram for the area. Later, Rekstad (1906) made some measurements of terrace altitudes and other observations, particularly concerning the mollusc fauna. Until recently the only more comprehensive investigations carried out were by Kaldhol (1910, 1912), who made extensive measurements of terraces and shorelines and thorough studies on the Quaternary fossils. However, as his work was mainly confined to the fjord and the lower-lying major valleys, he probably knew little about the marginal deposits of the intervening areas, and his conclusions, therefore, about the course of ice recession are mostly unreliable.

During later years, until recently, the major work in the area is that of Rye (1963, 1965), who made detailed studies on the deposits and morphology of the main valley of Gloppen - Breim, including Våtedalen and Myklebustdalen. However, as his work, too, was concentrated on the valleys proper, the only information available about the mountain areas concerns two or three of the most prominent marginal moraines, which were drawn on the glacial maps of Norway (Holtedahl & Andersen 1953, 1960).

Summarising, very little was known about the glacial geology of the area at the beginning of the field work in 1964, and even less about the region between the Bergen area and Nordfjord, with the exception of the investigations of Carlsson (1950, 1960), Viken (1960) and Undås (1963). In Sunnmøre, to the north, the only modern investigations were made by Holtedahl (1955) and Reite (1963, 1967), in addition to older papers by Kaldhol (1930, 1941, 1946) and others.

During later years, studies of the glacial geology in the neighbouring regions have seen considerable progress, both in the area between Bergen and Nordfjord (Mangerud 1970, Aarseth & Mangerud 1974, Holm-Larsen 1982, Klakegg 1981, Kleiven 1976, Kræmer 1977, Rye 1976,

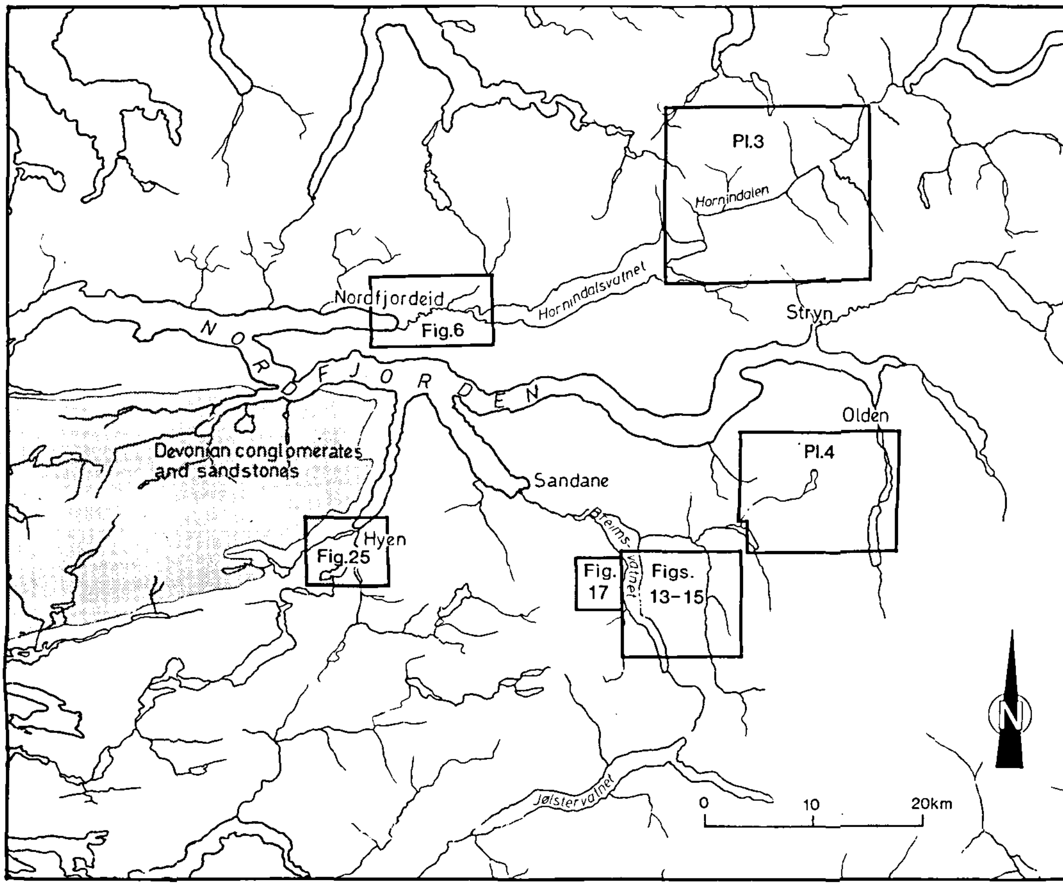


Fig. 2. Key map of the investigated area.

Aa & Mangerud 1981), and in the coastal areas of Nordfjord and Sunnmøre (Mangerud et al. 1981, Larsen & Mangerud 1981, Lie & Lømo 1981, Lie et al. 1983, Sollid & Sørbel 1979, 1981, Sollid & Reite 1983). The results obtained for the most part support this author's former conclusions and make correlations with the adjacent areas more reliable.

It should be mentioned that parts of the maps from Fareth (1970) were incorporated by Rye (1978), and many of the moraines from the same work are marked on a map published by Sollid & Sørbel (1981).

Recently the sediments in some of the lower-lying valleys have been mapped by NGU, mainly with respect to sand and gravel deposits of economic interest (NGU reports nos. 1560/3, 1560/21, 1560/22, 1806/1 and 1813).

Furthermore, NGU is presently working on the Quaternary geological map 1218 I Nordfjordeid (1:50,000), and in some more detail (1:20,000) in the Sandane area. This work has provided useful supplementary information to the present paper.

Geomorphology and bedrock

Geomorphologically the Nordfjord landscape bears the stamp of intensive glacial erosion, by which the fjord, the deep fjord lakes and valleys, most of them characterised by a clean-cut U-profile, were mainly excavated. Apart from these incisions, however, the topography is dominated by smooth, rounded curves and often plateaulike mountain forms, notably in the inner part. In some areas, particularly furthest north, the landscape is somewhat dissected by cirques, but not sufficiently to create truly alpine land forms, such as those found in parts of Sunnmøre. Generally, the Nordfjord landscape con-

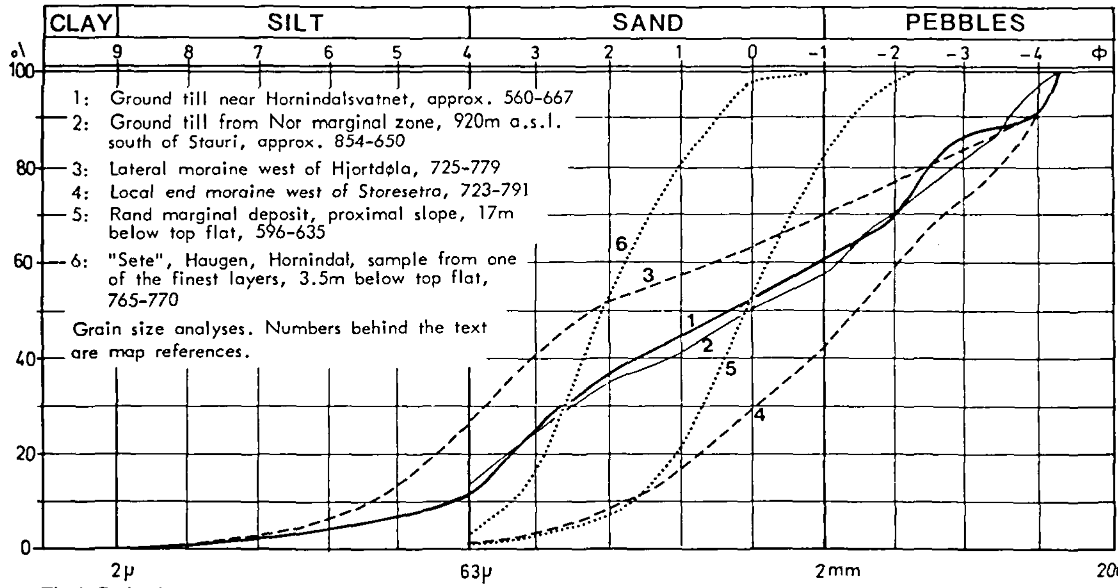


Fig. 3. Grain-size analyses.

veys the impression of a young, mainly glacial valley topography cut into an old, 'mature' land surface.

Bedrock structure is characterised by a dominant E-W strike, and most of the fjord and the major fjord valleys mainly follow that trend. Shorter stretches of the main fjord, and some of the tributary fjords and valleys, are excavated along NNW-SSE or N-S-trending joints in the bedrock, e.g., the neighbouring N-S valleys of Oldedalen, Myklebustdalen, Våtedalen and the middle part of Breimsvatnet-Myklandsdalen.

Most of Nordfjord is part of the northwestern gneiss region (Bryhni & Grimstad 1970, Kildal 1970), whereas the southwestern areas include the eastern part of the Hornelen Devonian basin (Fig. 2). The Devonian rocks are hard and resistant, and the Devonian complex forms an area of high relief, covered in part by plateau glaciers. The Devonian rocks, both the polymict conglomerates and the green, at times bluish or red sandstones, are easily distinguishable from all other rocks in Nordfjord and have proved very useful as indicator erratics.

Glacial geology — Introduction

As stated earlier, the present paper is primarily a reconnaissance survey of the glacial geology of the area. Consequently, descriptions of sediments are mainly confined to deposits related to the various glacial stadials and associated marine levels. However, nearly all thick glacigenic deposits in Nordfjord are more or less closely associated with the Nor (Younger Dryas) glacier margin. The following account will concentrate on the various stadials which are represented in the area. The term stadial as used here means a period of some duration, during which the glacier margin remained approximately at the same position, although minor oscillations may have occurred. Shorter intervals are termed phases. The terms glacier margin zone or only marginal zone are used for the zone of glacier margin features formed during one stadial. Concerning the various types of marginal features, the terminology of Andersen (1960, p. 15-17) is adopted.

Distribution and character of sediments

Most of the till is concentrated in the marginal zones. Greater thicknesses (some tens of metres) only occur in rather few areas, notably in some tributary valleys more or less transverse to the main valley, where a minor glacier tongue fell into the tributary valley from the main valley glacier. Hereby, flow velocity was sufficiently lowered such that much of the moraine material was deposited.

Apart from the marginal zones, the bulk of sediments occur below the marine limit in the

Fig. 4. Lateral moraine along the northern side of Sigdestadnakken, Ålfoten, looking westwards from the distal side.

main valleys and, not least, in the valleys of former ice-dammed lakes (e.g. Hornindal and Breim). Particularly in the latter areas the character of the sediments is highly variable and their origin rather complex. These problems will not be dealt with here.

In the mountain areas the cover of superficial deposits is generally rather sparse. The few grain-size analyses (Fig. 3) are considered fairly representative regarding the composition of the till. The rather low content of finer fractions ($<65\ \mu$) is probably due to the fairly coarse-grained gneisses from which the tills are mostly derived (Jørgensen 1977). Comparable curves were obtained by Reite (1967, p. 269) from the Sula-Sykkylven area, which is characterised by similar bedrock.

The Davik Stadial

The oldest marginal moraines, found in the fjord area, are the Davik moraines, which can be traced for slightly less than 2 km along the southern side of the fjord east of Davik, where they slope from about 580 m a.s.l. in the easternmost part to a little below 500 m at the western end just east of the Davik bay. For the most part this concerns a fairly continuous single ridge. The glacier front must have been situated somewhere in the outer fjord area. No other deposits corresponding to these moraines have been found.

The Vardehaug Stadial

Introduction

The next oldest stadial, the Vardehaug Stadial, is represented by only scattered marginal moraines in the mountain areas, particularly to the south and southeast. Mutual correlation of these marginal features is to a certain degree based on their position relative to the Nor moraines, but generally the moraine fragments conform to a pattern which suggests that most of them must be parts of the same marginal complex.

Earlier (Fareth 1970)I used the name 'Blåfjell' for the deposits ascribed to this complex, a term later adopted by Anundsen (1972) for a younger stadial in the Ryfylke-Sunnhordland area. To avoid confusion, therefore, the terms Vardehaug stadial and Vardehaug moraines — referring to a locality west of Breimsvatnet — will be used in the following.

Locality descriptions

Generally the Vardehaug moraines are smaller and less distinctive than those of the Nor stadial. This is clearly demonstrated on the gentle northwestern slope of Blåfjell, where both moraines occur. Here the marginal zone of the Vardehaug stadial is developed into a belt including several parallel moraine ridges, but these ridges are in no way so prominent as those of the Nor stadial further downslope. The distal relief, if any, does not exceed 1.5 m, and the vertical extent of the marginal zone is confined to some 50 m. In the zone between the distal Nor moraine and the proximal part of the Vardehaug marginal belt the cover of superficial deposits is usually very sparse, both here and in other areas.

The most prominent features belonging to the Vardehaug marginal zone are found in the southwestern area, for example, the up to 9 m-high boulder moraine curving along the edge of the mountain plateau south of Vardehaugane. In the Jardalen valley, two large parallel moraine ridges occur, of which the proximal (northern) one attains a maximum relief of 17 m. These ridges ascend more than 100 m from the valley bottom towards the steep mountain side to the west, gradually disappearing in the upper part and curving northwesterly into disorderly boulder mounds. A similar marginal zone crosses the Breidalen valley further to the west.

In Ålfoten a prominent nunatak moraine occurs along the northern side of Sigdestadnakken (Fig. 4) with a maximum distal relief of 7 m, accompanied by some more obscure boulder mounds and ridges at a corresponding level on the southern side. The moraine slopes eastwards in its eastern part, clearly demonstrating that the glacier was moving in that direction, in accordance with the youngest striae in the Ålfoten fjord. This fits well with a glacier front on the threshold at the mouth of this fjord. However, the age of the Sigdestadnakken moraine is somewhat uncertain, and it may possibly be contemporaneous with the Nor moraines.

The marginal moraines occurring on the slope below the northwestern corner of the Myklebustbreen glacier (Plate 4) are of particular interest concerning glacial conditions during the Vardehaug stadial. These undisturbed moraines, situated only 150 m below the subrecent (most likely Little Ice Age) moraines of the present glacier, are nearly horizontal or gently sloping towards the southwest. Their shape and course clearly indicate deposition by a valley glacier; showing that the Myklebustbreen glacier probably did not extend beyond the Little Ice Age moraines in late glacial times at this particular place. On the other hand, farther east, in the Svartebotn area, the Myklebustbreen must have joined the valley glacier complex.

South of Lyngvollen in upper Hornindalen, a prominent series of marginal moraines occur (Plate 3). These moraines, arching across the lower part of the Terdalen valley and continuing northward on to the rim of the Hornindalen valley, were clearly deposited by a valley glacier entering Hornindalen from the east. This glacier must be older than the deposits of Lyngvollen and cannot as yet be correlated with other marginal deposits in Hornindalen. Probably this glacier merged with a similar valley glacier entering Hornindalen from the west, possibly during the Vardehaug stadial.

Location of the glacier front

Eidsfjorden

Scattered fragments of lateral moraines found along the southern valley side at altitudes decreasing westwards from about 580 m a.s.l. south of Nor to 330 m a.s.l. above Taklo are probably of Vardehaug age. This suggests a glacier front in the Naustdal area, which agrees well with topographic conditions and with the existence of a glaciofluvial terrace at Naustdal corresponding to a marine level well above that of the Nor stadial. The resultant gradient of the outermost 13 km of the glacier surface is 40 m/km, which appears reasonable.

The main fjord

No Vardehaug marginal moraines have been found in the fjord area west of Anda. Judging from topographic conditions and fjord bathymetry, the ice margin could have been located at Krokeneset. This would imply a surface gradient of 32 m/km calculated from Anda to the glacier front, which is about the same as for the fjord glaciers of the Nor stadial. However, contributing supplies of ice, particularly from the ice-cap covering the Devonian area to the south and southwest may complicate the picture. Surface gradients of the Vardehaug glacier complex are shown in Fig. 20.

The Nor Stadial

Introduction

The Nor stadial is synonymous with the Main Stadial, which was the designation originally used (Fareth 1970). The present term — first adopted by Mangerud et al. (1979) — refers to the type locality at the western end of Hornindalsvatnet. The Nor stadial is by far the most marked Late Weichselian event in Nordfjord, both with regard to the thickness of the deposits as well as to their distribution and continuity. To the south of the main fjord in particular, the marginal moraines can be followed continuously for long distances. Consequently, the glacier margin of this stadial can be nearly completely reconstructed (Plate 2). In the adjacent areas of Jølster and Førde the paleogeographic map is based on the investigations of Rye (1976), Kræmer (1977) and Klakegg (1981). The map shows the maximal extent of the Nor glaciers, and the corresponding time is referred to as the Nor maximum. However, this maximum was not necessarily synchronous throughout the whole area.

Locality descriptions

Stryn and Hornindal

The easternmost traces of the Nor glacier complex are found on the southern side of the Stryn valley, where distinct lateral moraines occur, in part one, or two or more closely spaced ridges. The uppermost, distal moraine constitutes a very sharp upper limit of the thick till cover on the slope below. Slides originating from this steep morainic slope have several times caused severe damage to the farm of Stauri at the foot of the slope, the most recent occurring in 1966. No traces of the glacier margin have been recognised along the mostly steep northern side of lake Strynsvatn. A former outlet glacier moving northwards across the relatively low water divide of Floskaret (540 m a.s.l.) is indicated by certain marginal deposits along the sides of the valley leading down to Hellesylt. The paleogeographic map (Plate 2) indicates the glacier front to have been situated about 4 km northeast of Hellesylt, where a submarine moraine ridge nearly 100 m high crosses the fjord. This ridge was probably deposited by a glacier moving northeastwards (Giskeødegaard 1983).

Further to the west, on the northern side of the Stryn valley and on both sides of the Markane depression, the topographic conditions are more favourable for the formation of lateral moraines, but the moraines are mostly small and the cover of superficial deposits is generally rather sparse.

The main glacier has followed the deep depression of lake Hornindalsvatnet to the west. Contemporaneously, an outlet glacier, branching from the main ice stream, entered the Hornindalen valley to the northeast, damming up a lake in the upper part of the valley (Plate 3). The marginal moraines are distinctive in the valley east of Grodås, especially the 6-7 m-high distal ridge. Further east, near Seljeset, a well defined lateral moraine slopes to the east along the southern valley side. This moraine is obviously connected with the ridge on which the farm of Seljeset is situated. In a former gravel pit in the northern part of the main ridge at Seljeset stratified sediments occur, mostly sand and gravel, with strata dipping mainly towards the northeast, i.e., up-valley. A few large ice-rafted blocks occur on the surface of the ridges, further confirming that these ridges were deposited in water.

Further east in the valley, at Lyngvollen, near the water divide, a rather thick lateral deposit slopes longitudinally downwards to the northeast, where it is sharply delimited against the glacial lake terrace to the east. This terrace can also be followed westwards as a narrow ledge on the steep, nearly 30 m-high proximal slope. The surface topography of the deposit is fairly irregular with kettle holes up to 120 x 70 m. It is also somewhat modified along the distal side by lateral erosion. To the southwest the accumulations grade into the valley slope at about 420 m a.s.l.

The marginal deposits at Lyngvollen do not appear correlable with the distal Nor moraine east of Grodås. The corresponding slope of the glacier surface — 200 m for a stretch of 10 km — seems to be far too low for an outlet glacier of this type. A somewhat questionable marginal deposit higher up in the Kirkhorn valley may possibly correlate with the Lyngvollen deposit, which was probably formed during downmelting preceding the Nor stadial.

The Lyngvollen accumulations were described by Kaldhol (1910, p. 13-15) and interpreted as a series of glacial lake terraces, but the only clear terrace corresponds to the present watershed.

Hornindal glacial lake

During the Nor stadial a glacier-dammed lake was formed in upper Hornindal, with its outlet at the present watershed. The water level is marked by several prominent shorelines and terraces, as already pointed out by Kaldhol (1910, 1912). Thus the conspicuous shoreline or 'sete' along the northern valley side (Fig. 5) is continuous from Hjortdøla east to Haugen, i.e., for a stretch of 4 km, varying in width from 10 m to more than 60 m. Near its eastern end, just opposite the Seljeset ridge, a section well over 15 m high in the front of the 65 m-broad, horizontal terrace shows stratified, mainly rather coarse gravel, partly bouldery, especially in the upper 2 m and near the bottom. The intervening zone contains finer gravel and coarse sand (Fig. 3). The stones and boulders are poorly rounded, though more so than normal till pebbles. The strata dip steeply (25° to 30°) outwards from the valley side. Seen in association with the Nor marginal deposits at Seljeset and west of the Hjortdøla river, it is striking that this prominent terrace is developed exactly across the intervening stretch and seems to consist of reworked till. This agrees very well with the conclusions of G. Holmsen (1915) who made comprehensive studies on the glacier-dammed lakes of Østerdalen in eastern Norway. He regarded the 'sete's' to be mainly erosional terraces, cut in the pre-

Fig. 5. The shore terrace of the glacial lake, above Engebø, Hornindalen.

sent till, which he thought was originally deposited in lateral lakes between the glacier and the valley side.

During the Nor stadial some of the numerous local glaciers of the mountain areas on both sides of Hornindalen extended far down towards the main valley, thus causing a considerable increase in the sediment supply. These sediments were to a great extent deposited as terraces in the glacier lake. The outlet of Hjortedalen was blocked by the valley glacier, and consequently the sediments were deposited in the valley depression just inside. Later, most of the material has been removed by erosion, leaving a series of erosional scarps and terraces. The accumulations at the mouth of Rokkedalen (Honndalssetra) and Knutsdalen were deposited directly in the glacier lake. South of Honndalssetra, remnants are left of a sandur delta, which sloped gently outwards from its central, proximal part, reaching the lake level in the outmost, distal parts. Thus the SE-trending 'sete'-like terrace on the eastern side of the river drops down some 3 m over a stretch of 200 m.

The prominent terraces at the mouth of Knutsdalen represent the remaining proximal parts of a similar accumulation, but in this case without the same close connection to the feeding local glacier or glaciers. The deposits, therefore, are better characterised as the remnants of a glaciofluvial fan.

In addition, thick sediments occur further up along the lower part of the Knutsdalen valley. This may indicate the existence of a glacier-dammed lake in Knutsdalen at some earlier time, possibly while the glacier terminus was situated near the watershed (Lyngvollen). Sections just north of Knutsdalen seter reveal stratified sediments at a level nearly 100 m higher than the glacial lake terraces in the main valley. On the intervening stretch the river has cut deep into the loose deposits and left a steep erosional slope along its eastern side about 30 m high.

The level of the main glacial lake is rather conspicuous in the field also at Lyngvollen, where a continuous, in places more than 100 m-wide terrace extends from the lateral deposit here northeastwards to the Honndøla river at an altitude corresponding to the present watershed (389 m). The water divide is situated on a bog more than 100 m wide and 2 m deep, resting on bedrock, just east of the county border. A little further east, the bog becomes narrower and deeper (Kaldhol 1910, p. 15), indicating erosion by a former stream, i.e. the outlet river from the Hornindalen glacial lake.

Frontal deposits at Nor

On the mostly steep slopes along the northern side of the lake of Hornindalsvatnet no evidence of the glacier margin has been found, except for a minor ridge north of Heggjabygda.

The frontal deposit at the western end of the lake was originally described by Helland (1876, p. 58, 1901a, p. 317) and later by, among others, Kaldhol (1912, pp. 19, 46) (Fig. 6). It has generally been supposed to be of 'Ra', i.e. Younger Dryas age, an assumption which now seems to be confirmed. Although talking about 'Nor moraines', no real moraine ridge is found at the type locality. Instead, a large outwash deposit has been built up. The accumulation extends some 3 km to the west, furthest in the

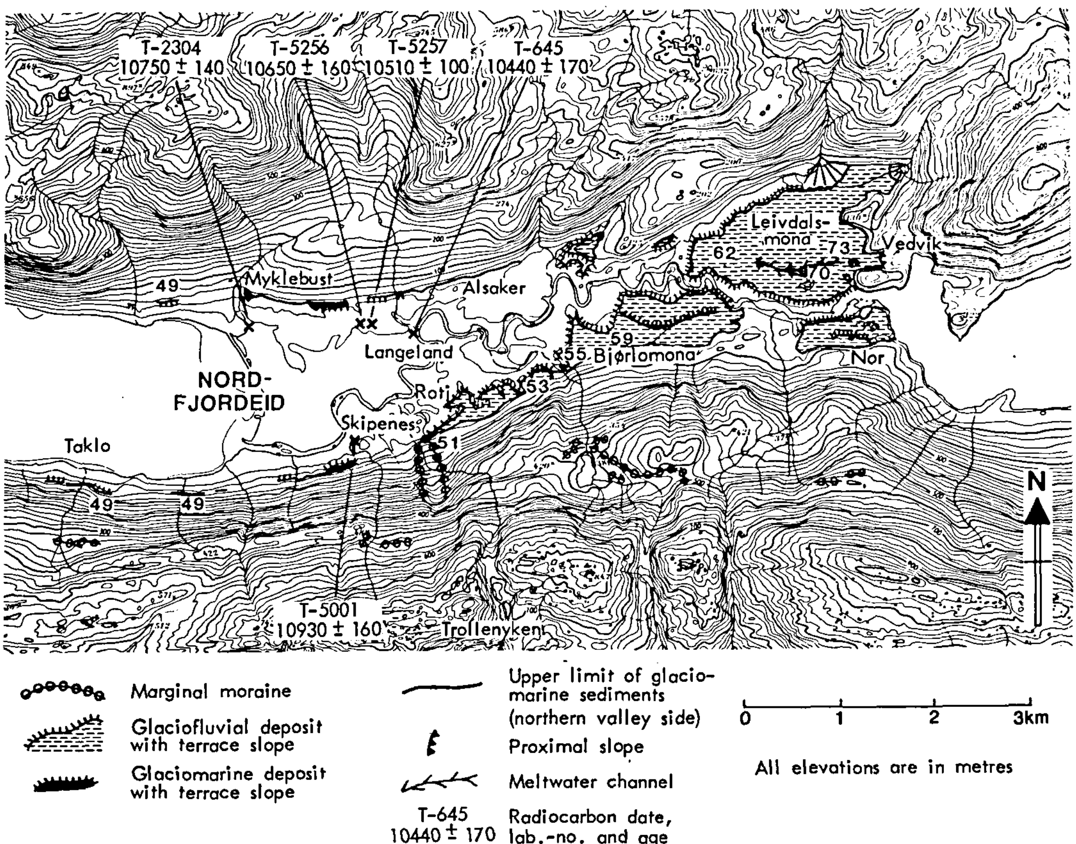


Fig. 6. Map of the Nordfjordeid area.

southern part, where it gradually merges distally into a prominent narrow marine terrace along the valley side.

The surface altitude of the frontal deposit decreases gradually westwards from a maximum of 73 m a.s.l. some 400 m west of the proximal edge at Vedvik (Fig. 7) to 53 m at the westernmost edge of Bjørlomona. Sections show predominantly horizontal, fairly regular beds of sand and gravel, relatively well sorted. The upper 2 m are generally coarser and more bouldery. Consequently, the Nor frontal deposit must be considered a sandur or a sandur delta, being mainly supramarine. The sands and gravels are underlain by glacio-marine clay, which, in the western part of the valley, overlies till probably of Vardehaug age. Fossils have been found in both the clay and the till, and several datings are now available. The present distal limit of the sandur is marked by high and steep erosional slopes. In particular, much of the material seems to have been removed in the middle of the valley. During the later part of the Nor Stadial it appears that the accumulation cannot have extended further to the west than the present western edge of Bjørlomona. Below this high, steep slope, several boulders of Devonian sandstones and conglomerates have been found. These boulders must have been deposited during the Nor stadial by drifting ice from the west, running aground here. Such boulders are generally not found proximally to the Nor marginal zone.

About 800 m west of the proximal edge at Vedvik, a conspicuous, somewhat asymmetrical cone-shaped and 16 m-high mound has now been nearly totally removed by gravel exploitation. This structure must have been a kame, older than the surrrounding sandur layers. Sections revealed stratified, bouldery and badly sorted gravel with some lenses of sand, and layers mainly oriented parallel to the surface. Kaldhol (1912, p. 19, 46) considered this mound as a morainic remnant.

Two kettle holes occur some 250 m west of Vedvik, and several (at least 5) shallow glaciofluvial channels are fanning out westwards from

Fig. 7. The proximal slope at Vedvik, looking northwest.

the highest part of the sandur. These channels, 1-2 m deep and 10-50 m wide, can be traced for several hundred metres.

Southern side of Hornindalsvatnet

On the steep mountain slopes facing the southern side of Hornindalsvatnet, no lateral deposits can be expected to exist. The marginal zone appears south of Holmøyane, where the Nor glacier has extended above the edge of the mountain plateau and deposited moraines which in part can be intermittently traced around the whole of this mountain area and over to the northern side of the main fjord. Despite the rather large distance between the frontal deposit at Nor and the lateral moraines south of Holmøyane (16 km), the correlation must be considered reliable. The corresponding surface gradient of the glacier nearly equals that for the glacier in the main fjord, which occupies a very similar basin (Fig. 20).

The marginal zone on the mountain south of Holmøyane is a few hundred metres wide in its northern part, here including two or three parallel ridges, rarely more than 2 m high. The till cover is rather sparse, and bedrock is commonly exposed between the ridges. In addition, the distal border of the marginal zone is less distinctive than usual elsewhere. Further to the east some more prominent single lateral ridges occur.

Northern side of the main fjord (Utfjorden)

The lateral moraines along the northern side of the main fjord are also relatively small in the eastern areas and the till cover outside the ridges correspondingly sparse. The only exception is the large proximal moraine in the valley bottom east of Bergsetnakken. In this area the vertical extent of the marginal zone approaches 100 m, which accords with that on the southern side of the fjord.

Along the southern slope of Bergsetnakken and Heida the marginal zone is partly developed into a series of gently sloping terraces (maximum 4 or 5), because the moraines have to some degree been superficially modified and reworked by laterally flowing streams.

Further to the west, near the mouth of the Tvinna valley, a conspicuous morainic remnant, up to 20 m high, projects from the southern valley side just west of the road tunnel entrance. A large moraine probably once extended across the valley.

At the mouth of the next tributary valley, the Randadalen, a similar ridge, nearly 50 m-thick in its central part, remains almost entirely intact. This moraine, the largest in Nordfjord, forms a barrage curving across the outer part of the valley, only breached in the middle by the river.

Inside (distally to) the moraine a glacier-dammed lake probably existed, since the material in the marginal moraine partly must have been deposited in stagnant water. This is clearly demonstrated in a minor section on the proximal slope, ranging from 15 to 20 m below the level of the sportsground on top of the moraine. The

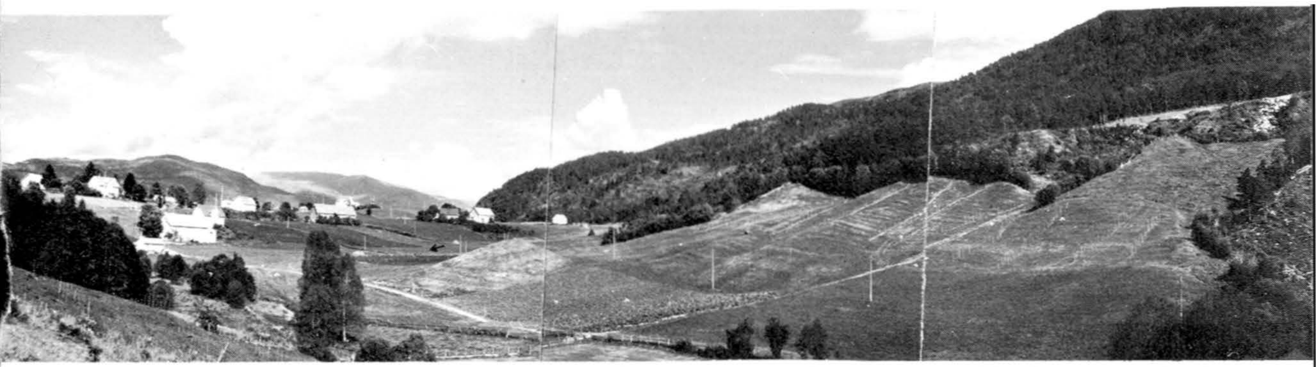


Fig. 8. The Føleide moraine, seen from the distal (western) side. The depression between the Føleide ridge and the thick till accumulations further west (right-hand part of the picture) is probably erosional.

section reveals sorted and bedded gravel with some layers of finer sand (Fig. 3). The beds dip towards south-southeast, i.e. obliquely up-valley. In the upper part of the section typical till also occurs.

No terraces indicating former lake levels have been observed, most likely because the lake level was not sufficiently stable, owing to the lack of any controlling outlet pass. For some time the lake drained across the northwestern part of the moraine, where a former river course can be seen some 200 m west of the sportsground.

In addition, some minor kettle holes occur along the proximal slope of the moraine.

On the western side of Hoplandsskaret the glacier margin can be traced in the field for only about 1 km. The deposits here are not ridge-shaped, but merely plastered on to the slope as a morainic belt, within which two marginal steps seem to exist, the upper one lying 25 m above the lower.

Southern side of the main fjord (Utfjorden)

During the Nor stadial the glacier front in the main fjord was situated at Anda, as the threshold here marks the only natural line of repose in this area. Inside Anda the prominent Nor shore level has not developed, and Devonian boulders carried by drifting ice are entirely lacking, except for the nearest 3 or 4 km, where a few may occur.

According to Giskeødegaard (1983) most of the present Anda ridge is made up of till, which accounts for about 220 m of the relief. The real relief of the rock threshold, however, is not more than some 100 m.

Following the southern side of the main fjord eastwards, the greater part of Føleide Farm is situated on top of a prominent moraine ridge which constitutes the watershed between the main fjord and Gloppenfjord (Fig. 8). This moraine was first described by Kaldhol (1912, p. 47) and interpreted as a lateral moraine deposited by the glacier in the main fjord. The meltwater from this area drained southwestwards to Gloppenfjord, where it built up a large gravel fan at Vereide.

Considerable morainic accumulations occur on the southeastern side of the valley (leading down to Vereide), and to some extent also on the northwestern side, remnants of more extensive deposits which probably filled the valley. These remnants, extending up to more than 270 m a.s.l. in the westernmost part, tend to project bastion-like from the southern valley side and suggest a former maximum moraine thickness in the middle of the valley of some 100 m. The bulk of these sediments, however, appear to be rather hard-packed basal till of pre-Nor age. Most of the erosion which has taken place was probably caused by meltwater rivers during the Nor stadial.

Continuing eastwards, the steep fjord side has mostly prevented the formation of lateral moraines, until 7 km further to the east, where the glacier extended beyond the plateau margin. Southeastwards from here the lateral moraines, among which the distal, most prominent ridge partly constitutes the tree line, can be traced continuously to the mountain pass of Utvikfjellet, ascending by only 150 m for a stretch of 13 km. This results from the curving of the fjord glacier, whose surface slope was dispersed over a longer stretch along the outer side of the bend (Fig. 9).

At Utvikfjellet (pass elevation 640 m) the

Fig. 9. Lateral moraine belonging to the Nor marginal zone NW of Tistam, looking north from the distal side. The moraine is broken through by lateral drainage in the direction shown by the arrow.

glacier in the main fjord received an additional supply of ice from the Breim glacier. The surface of the latter lay some 200 m higher, causing the ice-flow to run northwards in the pass area. The moraines of the two glaciers are nearly connected on the eastern side of the pass.

From Utvikfjellet eastwards the lateral moraines of the fjord glacier are generally large and conspicuous (Fig. 10). The marginal belt usually includes 2-3, in places 4, parallel ridges, which are generally continuous for long stretches. In some places the ridges dam up bogs and minor lakes. As a rule, the distal moraine, being the most prominent, constitutes a very sharp upper boundary of the locally rather thick till cover within the marginal belt, whereas the external area is generally very sparsely covered with sediments and in many places is quite bare.

In Myklebustdalen, however, (not to be confused with Myklebustdalen in Breim), thick morainic accumulations extend further up-valley, being limited by the marginal moraine of the Vardehaug stadial. The river, eroding its course through these deposits — probably basal till of mainly Vardehaug age — has formed high cuttings, up to 45 m. Such large moraine thicknesses generally occur on slopes or in tributary valleys situated somewhat to the leeward of the main ice flow.

During the Nor Stadial, the glacier tongue in the upper part of Sanddalen, on the Breim side, just reached the pass point towards Myklebustdalen, so that the meltwater from this glacier drained northwards. The upper part of the valley depression leading down to Myklebustdalen, was flushed more or less bare by the water, and further down-valley a canyon was eroded (Fig. 11, Plate 4). This canyon, which is virtually dry at present, is about 300 m long with nearly vertical walls, up to 15 m high, on the western side. The outlet is on a level with the valley floor of Myklebustdalen. The existence of this canyon together with the total lack of evidence for any glacier-dammed lake, show that the meltwater discharge from Sanddalen drained subglacially beneath the ice in Myklebustdalen.

The vertical extent of the marginal zone increases eastwards, reaching some 100 m on the gentle northwestern slope of Blåfjell and 170 m furthest to the east north of Skarsteinfjell. The most conspicuous lateral moraine is the distal ridge on the northwestern slope of Skarsteinfjell, which forms a continuous wall 10 to 11 m high. In the eastern part of this area the moraines are almost entirely made up of boulders, many up to 5 m in size, and nearly all of them are a locally derived characteristic augen gneiss.

Further east, and southwards, the steep slopes have prevented the formation of lateral moraines, but on the plateau on the southern side of Skarsteinfjell there are two ridges which are the highest-lying late glacial moraines in Nordfjord (situated at 1170 m a.s.l.). To the south only moraines of recent age occur, indicating that the present cirque glaciers on the western side of Oldedalen, including the glaciers north and south of Sisiliekruna, merged into the main valley glacier during the Nor Stadial.

Fig. 10. The distal moraine just east of the pass area at Utvikfjellet, looking west. Distal slope to the left.

Fig. 11. The pass area between Myklebustdalen, Utvik (foreground) and Sanddalen, looking south. Meltwater drainage in the direction shown by the arrow, i.e., towards the canyon. Note erosion scarp in the thick till cover of Myklebustdalen (left). The marginal moraines in the pass area, i.e. those deposited from Sanddalen, are shown dotted.

Myklebustdalen and northern side of Breimdalen

The easternmost northbound tributary glacier feeding the main Breimdalen glacier was that of Myklebustdalen. South of Vora, this glacier has left a lateral moraine on the very rim of the 700 m-high precipice towards the Myklebustdalen valley floor. It is evident from the curving of the ridge along the eastern bank of Nonselvvatnet that it could not have been deposited by any local cirque glacier.

Further to the north the glacier has entered the outer part of the wide paleic valley above Sanddalsfossen and deposited large marginal moraines, which completely dominate the area (Plate 4). The vertical extent of the marginal zone — mostly including 2-4, maximum 6 parallel ridges — amounts to 100 m, and the morainic belt is continuous and quite undisturbed, proving that the Myklebustbreen did not reach these moraines during the Nor stadial. Further up-valley, however, a complicated system of marginal moraines occur, which must be at least in part deposited by the latter glacier (see below).

The thick till cover of Sanddalen is essentially caused by the marginal moraines, and the river has formed erosional slopes 10 to 20 m high. The ridges proper mostly range from 6 to 10 m, maximally 15 m.

From the pass area north of Sanddalssetra the distal moraine, which here is very large and prominent, ascends evenly towards the southwest, the proximal one somewhat steeper, nearly reaching the distal ridge on top of the slope NW of Sanddalssetra. The rather gentle slope of the Sanddalen glacier tongue — 30 m/km when calculated from the southernmost edge northwards to the passpoint area (4 km) — must be due to the wide valley floor of Sanddalen and to the fact that the local direction of movement did not essentially differ from the main ice-flow direction.

Further westwards, the moraines are generally smaller and less distinctive, in part merely indicated by lines of boulders which, locally, may be difficult to distinguish from the frost-shattered bedrock. West of Utvikfjellet very few traces of the Nor glacier margin have been found along the northern valley side.

Våtedalen

Southeast of Strand the tributary valley glacier of Våtedalen has deposited marginal moraines arching across the outer part of a hanging cirque. The marginal zone, including 3 or 4 parallel ridges, here extends for a vertical distance of more than 160 m west of the river. The conspicuous distal moraine descends steeply i.e. >90 m in a 600 m stretch on to the river flat. At the valley floor it widens and obtains a maximum height (above river flat) of 18 m. On the other side of the valley it gradually rises to the north until it disappears beneath the talus slope west of Vora. The steep slope of this glacier tongue (more than 150 m/km in the central part of the lobe) is probably an effect of its orientation as compared with the main ice-flow direction in Våtedalen. Similar gradients, related to comparable glacier lobes, have been reported by, amongst others, Anundsen & Simonsen (1968, p. 26), who found a gradient of 162.5 m/km, 0-1.2 km from the terminus.

The area between Våtedalen and Breimsvatnet

During the Nor maximum, the valley glacier in Våtedalen merged with the Breimsvatn glacier in the area between Blåfjellet (Rådafjellet) and Daurmål. The distal marginal moraines deposited by the two northward-flowing glaciers meet both south and north of the pass area (Figs. 13-15). From the points of coincidence the moraines rise noticeably as they separate into different directions. The northern point lies at a level 20 m below the southern one. At an early stage in the course of down-melting of ice following the Nor maximum, the mountain ridge between Årdalen and Våtedalen emerged from beneath the glacier. Thereby the connection was broken between the two glaciers, which from then onwards deposited marginal moraines separately from each direction. These moraines form a somewhat complicated pattern. Figs. 13-15 suggest how the down-melting of the ice is considered to have taken place.

The various phases of down-melting are demonstrated on the morainic slope north of Daurmål (Fig. 12). In the Botnavatn area the vertical range of the marginal zone attains a maximum of not less than 250 m. As elsewhere, the distal moraine is the most prominent, here constituting a rather sharp boundary between the very sparsely covered area to the south and the morainic slope to the north. The upper moraines slope gently westwards, whereas the lower ones are inclined to the east and, consequently, must have been deposited by the Breimsvatn glacier. The main reason why all the moraines are referred to the Nor stadial is the continuity of the morainic series throughout the whole vertical range.

Correlations between individual moraines in the pass area and the corresponding ones west of Blåfjellet (Rådafjellet), further to the north, may be somewhat uncertain, as moraines are lacking in the intervening area. The western slope of Blåfjellet is rather steep in its southern part, and the marginal zone is best developed just north of Rådavatnet, here including at least 6 morainic steps having a total vertical range of 150 m.

In the southern, lowermost part of this slope, a lateral moraine curves down to Nigarsvatn, continues along the eastern bank of the lake and afterwards surprisingly ascends again north to Rådavatn, an upward rise of not less than 40 m. Its rather strange course may possibly be due to a locally increased rate of down-melting in front of the dark, SW-facing mountain wall east of Nigarsvatn.

The morainic belt along the western side of Rådavatnet also shows a somewhat atypical morphology, having a rather sinuous and irregular course associated with kettle holes. These deposits correspond to the last phases of the Nor stadial.

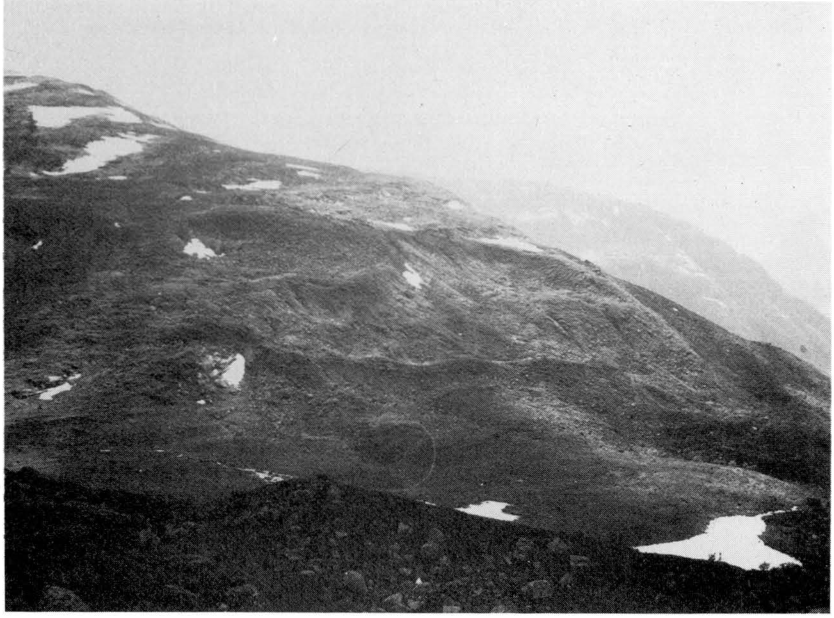


Fig. 12. The northern slope of Daurmål, Botnavatnet (right). The proximal side of the moraine 915 can be seen in the foreground (Fig. 14).

The area west of Breimsvatnet

To the western side of Breimsvatnet, the main valley glacier was in contact with cirque glaciers in the area west of Myklandsdalen, but the relationship between these glaciers has not been investigated in detail.

Further to the north, on the eastern side of Øykjeheia, the slope only locally has allowed for the deposition of lateral moraines. The most prominent one, being mostly 4-5 m high and consisting virtually of large boulders, is situated on the very rim of the precipice towards Breimsvatnet (Fig. 16).

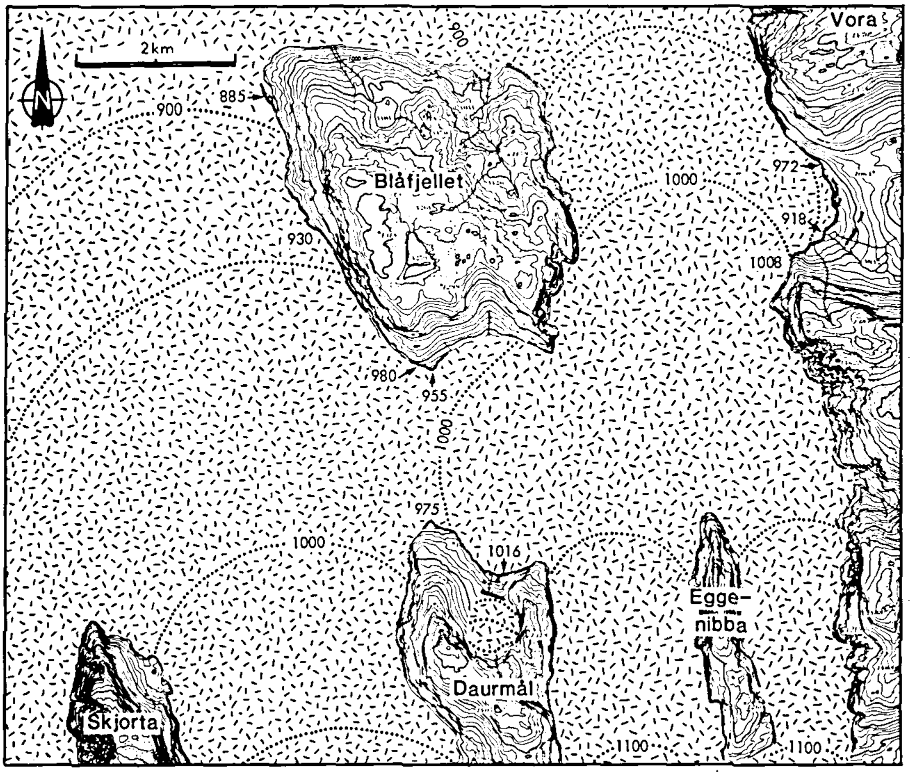
During the Nor stadial, the main valley glacier obviously coalesced with a tributary valley glacier emerging from the Botnafjell area through Sørsendalen, because no moraines deposited from outside exist in the upper part of this valley (Fig. 17).

The conditions further to the north support this view. The Nor moraines are well developed both on the slope northwest of Kandalssetra and along the eastern side of Ryssdalshorn. As elsewhere, the marginal zone, attaining a vertical range of 200 m northwest of Kandalssetra, has a sharp upper limit in both areas, and, moreover, it is situated at approximately the same level, 800 m a.s.l. But for the additional supply of ice from a tributary glacier in Sørsendalen, a westerly slope of the main valley glacier could have been expected.

The rather extensive Breim valley glacier complex was virtually drained through the relatively narrow passage of Vassenden at the northwestern end of the lake, which caused an increased rate of flow and a correspondingly increased drop of the glacier surface level in that area. This is well demonstrated by the lateral moraine on the eastern side of Jardalen, which drops more than 160 m down on to the valley bottom, i.e., over a very short distance. The extremely high inclination of this moraine — as much as 30° — can also partly be attributed to the direction of the Jardalen valley as compared with that of the main ice flow. In its upper part, the moraine coincides with the very edge between Jardalen to the west and the main valley to the east.

Deposits of the inner Gloppenfjord area

North of Jardalen the valley glacier broadened and flattened out in the wide basin at the head of the Gloppenfjord. The deposits of the terminal zone are primarily found in the Rygg—Gimmestad area (Fig. 18). At Gimmestad two minor moraine ridges occur, which can be traced some 100 m towards the northwest before disappearing below the marine sediments. The much more prominent distal ridge at Rygg ('ridge'), further to the west, protrudes crest-like from the surrounding marine sediments, reaching a maximum relative height of 10 m.



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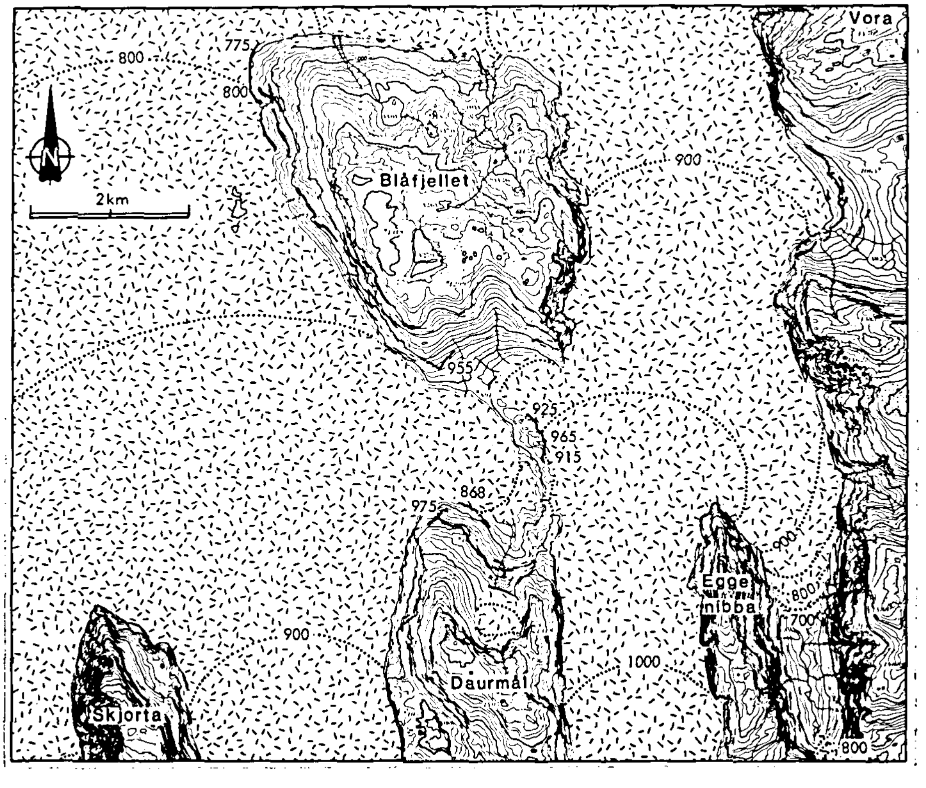

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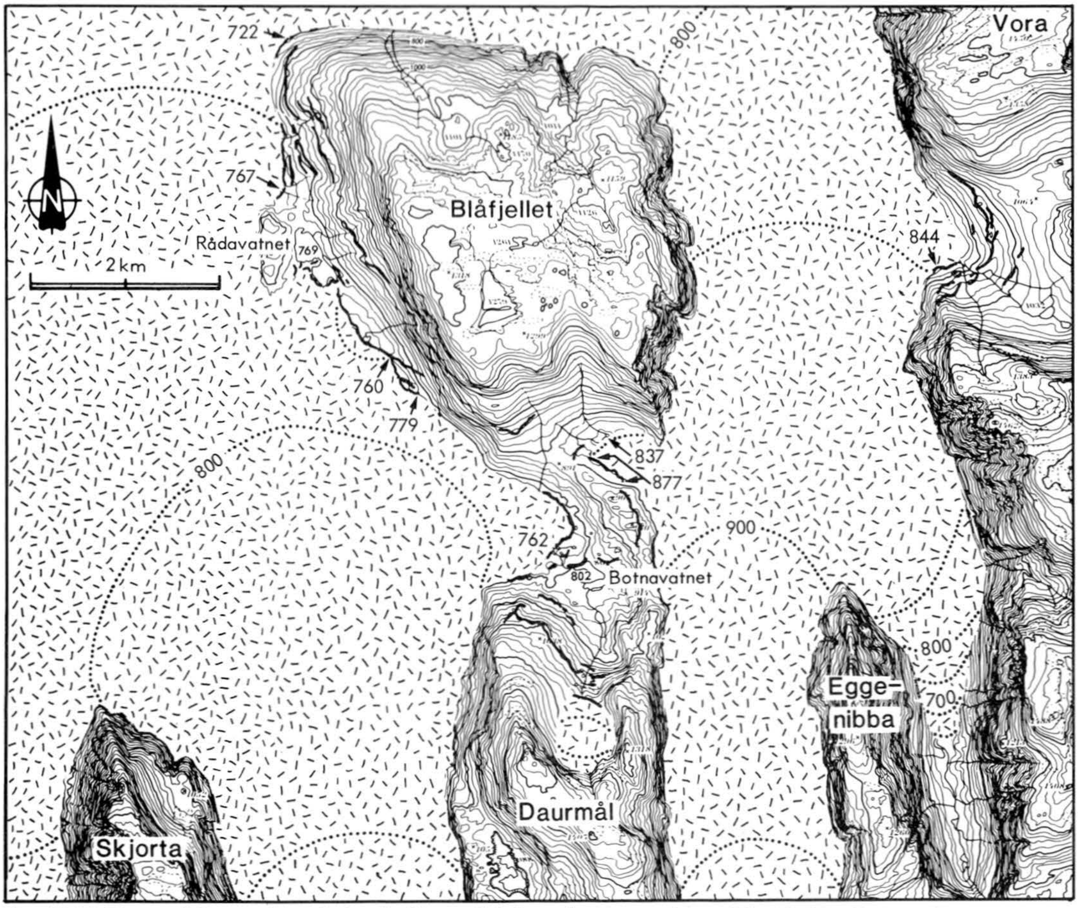

Figs. 13-15. Phases of down-melting during the Nor stadial, from the Nor maximum (Fig. 13). Marginal moraines are marked. All elevations are in metres.

Fig. 16. The distal marginal moraine at Øykjeheia, seen from the distal side. The large boulder on top of the moraine is nearly 5 m high.

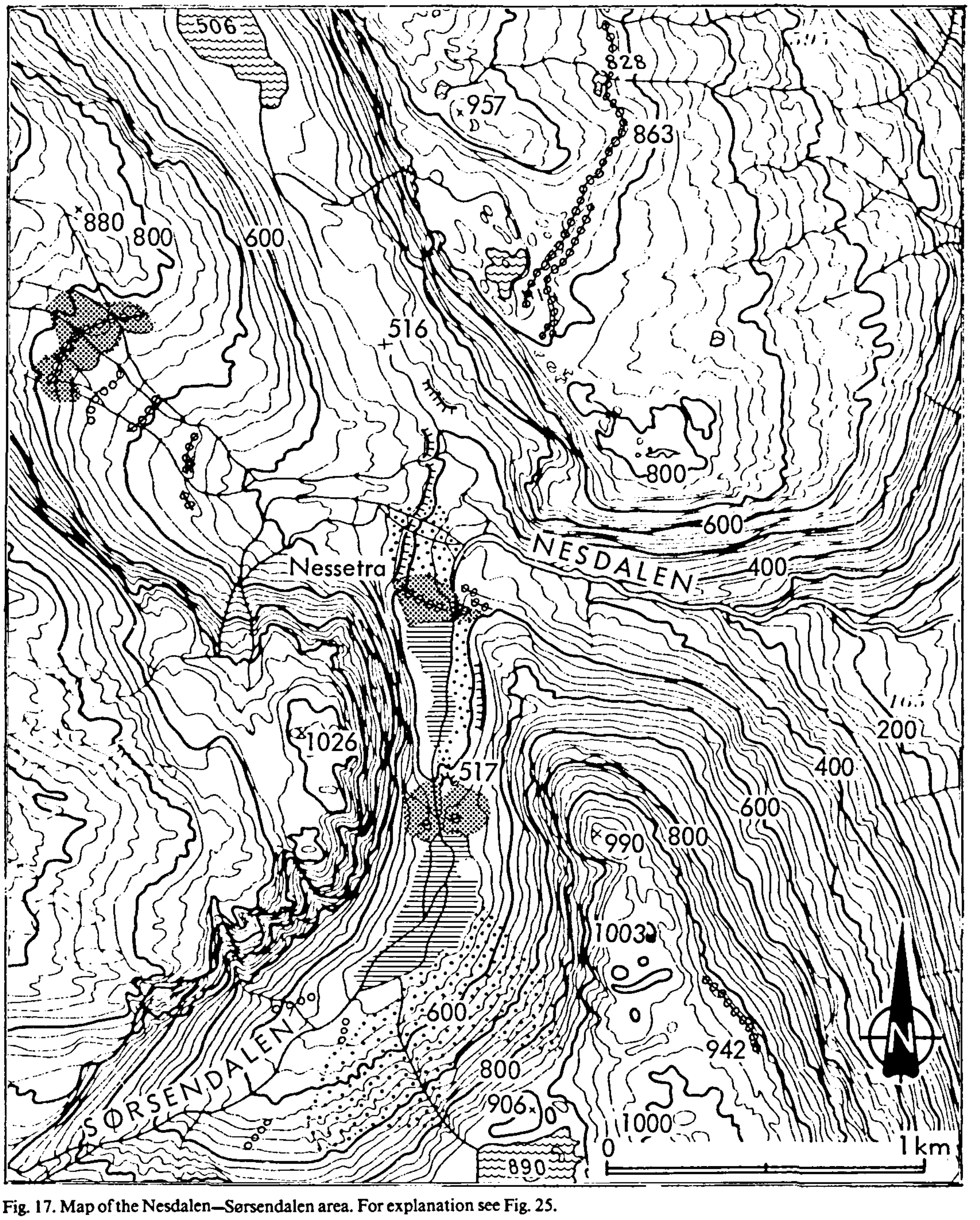

Fig. 17. Map of the Nesdalen—Sørsendalen area. For explanation see Fig. 25.

Most of the relief is probably hidden below the marine deposits (Fig. 19). The present shape of the ridge is partly due to erosion caused by the river from Traudalen. Along the proximal side there is a strikingly sharp boundary between the cultivated marine sediments and the wooded moraine, which is almost entirely made up of boulders, in part rather large (2.5 m).

The marine sediments form rather broad flats in the Rygg - Gimmestad area, and the marine

Fig. 18. View of the Rygg—Gimmestad area, looking south. The marginal moraines of Gimmestad (left) and Rygg are dotted, and the fossil localities at Rygg are also marked. Numbers refer to measurements of the Nor sea-level. R — Rygg, G — Grov. (Photo Fjellanger—Widerøe A/S). The letter R is unfortunately misplaced. It should be positioned ca. 1 cm to the left of the number 64 in the middle of the photograph.

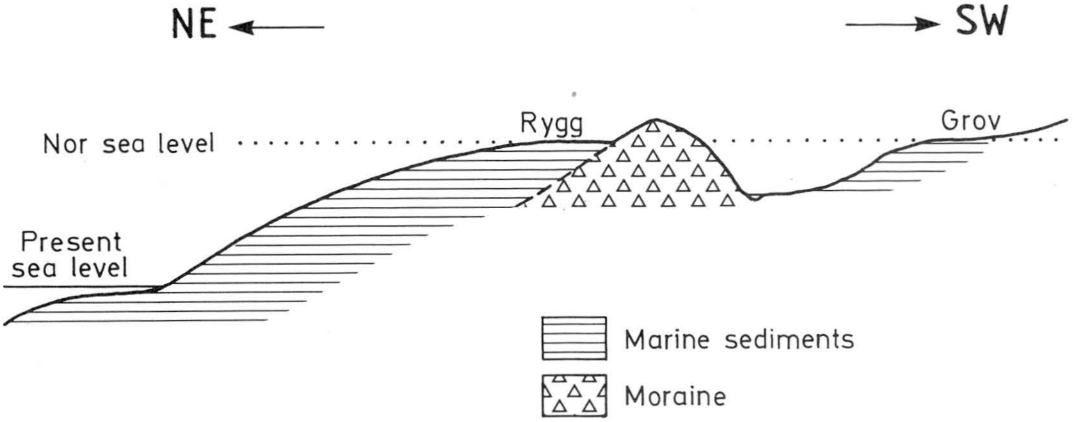

Fig. 19. Schematic profile across the Rygg area.

limit is very clear along the entire proximal side of the Rygg moraine and corresponds to the level at the distal side. A minor section furthest to the northwest, on the upper part of the erosion slope towards the river, reveals a typical glaciomarine clay: a rather hard, coarse sandy clay with some pebbles, up to 10 cm, irregularly interbedded with thin sand layers. In the deeper part of this section, 6 m below the surface, which is here about 58 m a.s.l., the beds are more regular and no pebbles seem to occur. Fossils in the form of mollusc imprints were found at 2-3 m below the surface, and the following species were recognised: *Portlandia arctica, Mya* *truncata, Hiatella arctica,* and *Macoma calcarea.* In addition to these, Rekstad (1906, p. 26-28) and Kaldhol (1912, p. 74-75) found imprints of leaves at a nearby locality, less than 100 m to the southeast, and at the same level. The species reported were *Salix polaris, Betula nana, Betula alpina* and *Juniperus communis.* The character of the sediment as well as the fossils indicate deposition near a glacier margin, as earlier suggested by Kaldhol. However, the deposits must be younger than the Rygg moraine and therefore most probably refer to the later part of the Nor stadial, when the glacier made its retreat to the marginal deposits at Gimmestad and Kleivedam. During this period there was a rather large supply of sediment to the area immediately outside the glacier terminus, probably to a great extent by drifting ice. In addition, a considerable reworking and redeposition of the finer fractions of the marginal moraines — particularly the large Rygg moraine — took place, and much of these sediments probably accumulated in the terrace on the proximal side of the moraine. The additional supply of sediments from Traudalen—Breidalen, caused by local glaciers, must also be taken into account.

No marginal deposits have been found outside the Rygg moraine, which therefore probably represents the distal limit of the Nor glacier in this area. This location of the glacier terminus fits well with considerations of glacier surface slope (Fig. 20) and fjord bathymetry. The Rygg moraine corresponds exactly to a buried submarine ridge which crosses the fjord in this area. The real relief of this submarine moraine ridge is about 60 m, and the basin on the proximal side was later filled up with sediments just sufficiently to hide the ridge (Giskeødegaard 1983). In addition, ice-rafted Devonian boulders are relatively common (about 10%) in the fjord area outside Rygg, whereas such boulders rarely occur within this limit. No corresponding marginal features are found on the northeastern side of the fjord.

At Kleivedam, just above the village of Sandane, a somewhat younger outwash deposit occurs. This accumulation, which was thoroughly described by Rye (1963, p. 108-110, 114), has been built up to a level of 74 m, whereas the marine limit was estimated by Rye to be 70 m, corresponding to the foremost edge. This corresponds to the Nor marine level. The whole accumulation forms a sandur delta of the same kind as the Nor frontal deposit. It seems obvious that the Kleivedam deposit must correspond to some of the lower, proximal Nor moraines further inland, although no accurate correlation can be made as yet.

Review

During the Nor stadial, the inland valley glaciers formed a more or less continuous glacier complex, from which long outlet glaciers extended westwards through the deep fjord and lake channels. The longest was that of the main fjord, attaining a length of 31 km when calculated from a line between Hogademma and Skarsteinfjell westwards to Anda. Next comes the Hornindalsvatnet glacier with 24 km, here too calculated from the point of coincidence at Hogademma. Surface slopes at the Nor maximum appear in Table 1 and the profiles are given in Fig. 20. These are based on the lateral features situated nearest to the middle of the fjord or valley channel, whereas Andersen (1954) by the construction of the Lysefjord glacier profile used a kind of levelled average curve. To make the curves more compatible, the diagram of Andersen has been slightly modified in Fig. 20 by constructing a smooth curve based on the maxima of his graph. This does not affect the average gradient in any perceptible way.

As evident from the table and the diagram, surface slope gradients of the Hornindalsvatnet and the main fjord outlet glaciers, respectively, are about the same as those of comparable fjord glaciers, even though considerable individual variations may occur. It may be noticed that the glacier of the main fjord, unlike most other glaciers, tends to flatten near its terminus, owing to the possibility of lateral expansion in this area.

Regarding the somewhat diverging profile of the Breim - Gloppen glacier, it must be mainly due to different topographic conditions, which have already been dealt with as far as the outer part is concerned. This made the glacier terminate further inland than the two other outlet glaciers, despite the fact that the Breim glacier surface at Utvikfjellet lay considerably higher than that of the main fjord.

The lack of any significant down-valley surface slope in Breimdalen is due to the contributing supply of ice from the tributary glaciers to the south.

Locally, much higher gradients may occur, but these always apply to minor glacier lobes branching out from the main ice stream into tributary valleys. The steep slopes of some

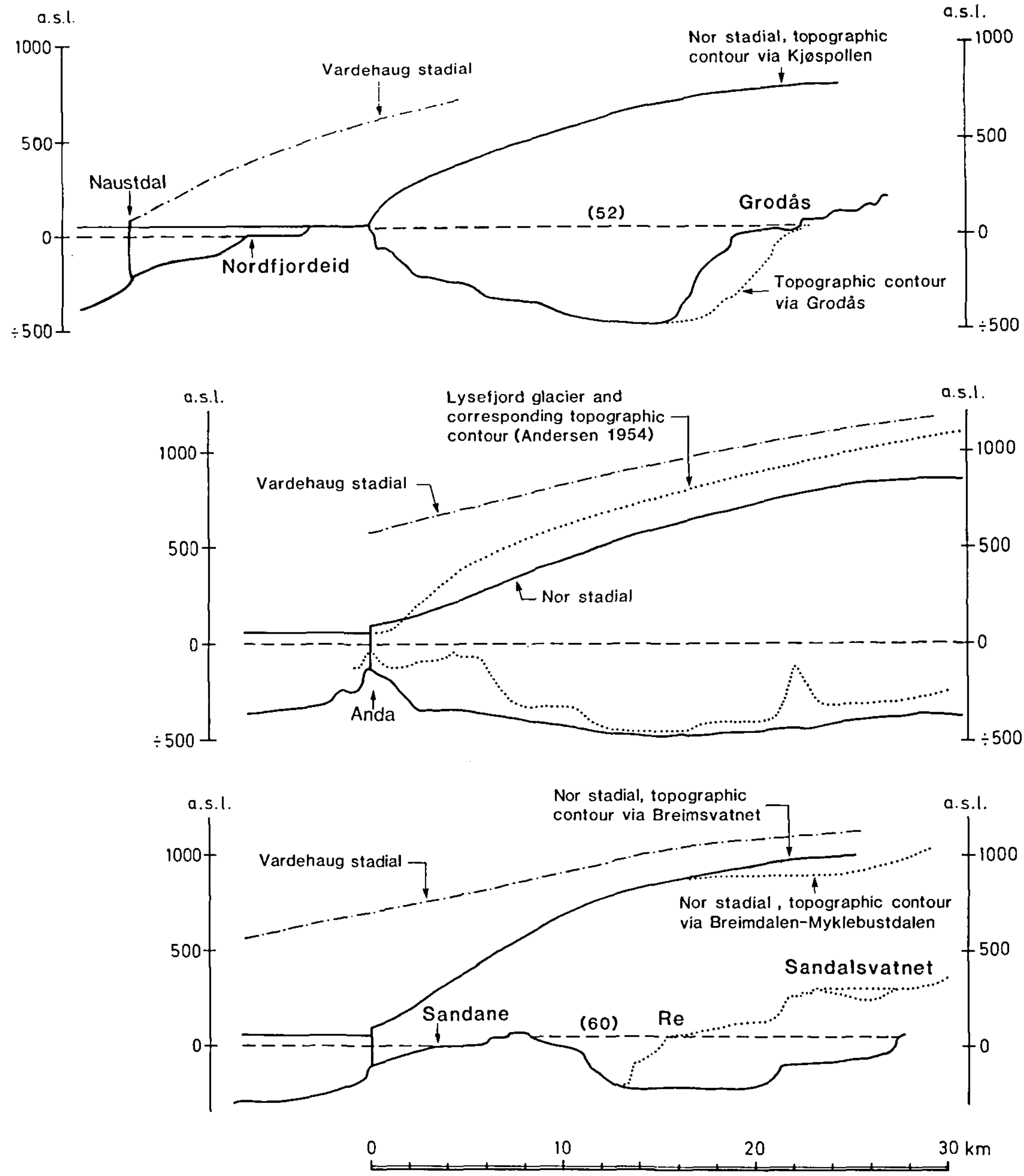

Fig. 20. Longitudinal profiles of some valley and fjord glaciers.

indicate a rather high rate of flow of the main valley and fjord glaciers.

By extrapolating the glacier profile further inland from the innermost fjord areas (Olden—Loen), the resulting altitude becomes about 500 m too low as compared with the level of the present glacier plateau of Jostedalsbreen. Consequently, there must have been a marked break in the glacier profile, as shown on the paleogeographic map. This rather surprising fact will, however, not be further discussed here.

The marginal zone itself is usually developed into a belt including 3-4, sometimes more, parallel moraine ridges, among which the distal

Table 1. Glacier surface slopes.

Area	Outlet glacier	Peripheral part of inland ice
Hornindalsvatnet	Nor-Hogademma, 0-24 km from terminus: 30 m/km	Hogademma-Middagshaugen (15 km inward from Hogademma) 16 m/km *)
Main fjord	Anda-Tistam, 0-13 km: 33 m/km; Tistam-Blåfjell, 13-26 km: 21 m/km } Anda-Blåfjell, 0-26 km: 27 m/km; Anda - line betweeen Hogademma and Skarsteinfjell, 0-31 km: 24 m/km	
Breim-Gloppen	Rygg-Ryssdalshorn, 0-12 km: 56 m/km, Ryssdalshorn-Daurmål, 12-25 km: 18m/km	
Lysefjord glacier (Andersen 1954, pp. 318-323)	0-30 km: 34 m/km	20 m/km
Balsfjord glacier, Troms (Andersen 1968, p. 43)	0-28 km: 16 m/km	
Sermiligarssuk glacier, Greenland (recent)	0-24 km: 32 m/km	
Porsanger-Altafjord (Marthinussen 1961, pp. 125, 134)		10-12 m/km (Repparfjord stadial) 8-9 m/km (Main stadial)

*) Break in the profile further inland, see text.

moraine is nearly always the most prominent one. Besides, this ridge usually forms a sharp upper limit of till. Thus, the morainic material of the marginal zone was pushed together during several oscillations of the glacier margin, and the shape and course of the marginal moraines clearly show that the Nor glaciers were highly active, in particular during the maximum phase. Glaciofluvial erosional and constructional forms are usually of only minor importance, except at the termini of the long outlet glaciers, where meltwater from wide areas was concentrated. Here, large outwash deposits were built up, whereas real end moraine rigdes are lacking. Similar conditions have been described, among others, by Martinussen (1961, p. 139).

As pointed out earlier, the vertical range of the marginal zone increases eastwards, showing that a considerable down-melting took place in the inland areas at a time when the glacier termini still remained at their distal positions. At least, this was the case with the glaciers occupying Hornindalsvatnet and the main fjord. Flattening of the glaciers' length profile must be regarded as an expression of a somewhat reduced glacial activity.

The Nor moraines can be traced up to an altitude of nearly 1.100 m above the sea level of the time. Probably this is close to the real Nor snowline, as will be discussed later.

In the mountain areas not covered by the continuous fjord and valley glaciers, a comprehensive local glaciation took place at that time, which will also be dealt with in a following section.

Retreat of glaciers subsequent to the Nor stadial

Hornindalsvatnet and the main fjord

Hornindalsvatnet and Hornindalen

Scarcely any traces of the glacier retreat following the Nor stadial are found along the sides of Hornindalsvatnet. Probably this retreat occurred very rapidly by calving in the deep lake basin. Contemporaneously, the Hornindalen glacial lake at first expanded westwards at the expense of the shrinking glacier, thereby allowing the deposition of glaciolacustrine sediments constantly further to the west (Plate 3). This sedimentation obviously went on during the subsequent lowering of the lake level as the lake was drained westwards. In the greater part of Hornindalen, therefore, the Quaternary deposits are almost entirely made up of more or less stratified sediments. These may be of varying character, mostly sand and gravel, but also finer fractions, often folded and disturbed and mixed with till, indicating glacier oscillations during down-melting. The sorted sediments may be interpreted as partly washed and reworked till and partly glacial lake sediments, in some cases forming terraces assumed to indicate short intervals during the successive lowering of the lake level. Thus, small terraces occur at altitudes of 337 and 335 m a.s.l. just east of Hjortdøla, and a somewhat greater one, 193 m a.s.l., at Fannemel. 4-6 m high sections in this terrace show predominantly horizontal, undisturbed sand and gravel beds. Pebbles and boulders are usually relatively well rounded. Locally, foreset beds and well preserved flow structures occur, both indicating flow mainly towards west and northwest. The terrace was undoubtedly built in shallow waters, as already suggested by Kaldhol (1912, p. 49, 1910, p. 17).

The only deposit in the lower part of Hornindal which may possibly be interpreted as a marginal feature, is the moraine accumulation at Svor, just south of the eastern end of Hornindalsvatnet. If so, it may be about the same age as the upper terrace level at Otterdal, on the northern side of the lake. This level, which is well defined both east and west of the river, is so high (89 m) that it cannot be marine, but must refer to some minor ice-dammed lake of local origin.

Continuing southeastwards, no marginal moraines or other evidence of glacier retreat seem to exist in the rather barren Markane area, despite the report of Kaldhol (1912, p. 46).

The main fjord
No marginal deposits younger than the Nor moraines are found along the main fjord east of Anda. Nor did the prominent Nor shore level extend into this area, with the possible exception of some proximal remnants of a glaciofluvial fan-delta at Utvik, which might have been graded to that level. Even though there are other indications that the Nor sea-level was maintained for some time after the beginning of glacier retreat, it appears that in the main fjord time was too short to allow for the building up of terraces higher than the Langvin shore level, which was somewhat lower than that of the Nor stadial. Obviously, the glacier terminus was resting on the threshold of Anda for a rather long time. As down-melting went on in the inland areas, this frontal position could not be maintained any longer, and a rapid retreat by calving occurred in a similar manner as in Hornindalsvatnet.

The Vinsrygg stadial
In Nedstryn, on both sides of the valley, occur some prominent moraines that are definitely younger than the Nor stadial. In the following account these are referred to as the Vinsrygg moraines, and the corresponding period as the Vinsrygg stadial. The name relates to a locality just west of the village of Stryn.

On the southern slope of the Stryn valley, just above Staurisetra, a distinctive boulder ridge, up to 6 m high, can be traced for some 120 m westwards; here grading into disorderly boulder heaps, which also occur further to the west at about the same altitude. The ridge (Fig. 21) lies on top of the thick till cover in this area, which was mainly deposited during the Nor stadial and earlier, and which here attains its maximum thickness (nearly 100 m).

On both sides of the mouth of the Rjupedalen cirque valley, lateral moraines, clearly differing from the otherwise rather thick (>5 m) till cover, slope 10° to 15° outwards, indicating flow of ice from the cirque onto the Vinsrygg valley glacier. Eastwards from here the moraine is almost continuous, winding across hills and descending into depressions in a way which must clearly be regarded indicative of glacier advance. In general, only one single ridge occurs, which is up to 10 m high on the eastern side of Brekkedalen. The moraine ends abruptly near the edge of the steep slope towards Strynsvatnet.

On the northern side of the valley the Vinsrygg glacier has deposited a narrow, sharp moraine ridge just above Ytreeide seter, and further to the west, a somewhat more extensive moraine belt curving across Vikadalen northwest of Stryn. From some 420 m a.s.l. the moraine winds down into the valley depression. where it partly separates into two parallel ridges. On the western side of the river, by approaching the main valley again, the moraine remains at about the same altitude — 320 m a.s.l. — for a rather long stretch before finally steepening and disappearing just above Vinsrygg. This suggests a fairly steep surface slope of the Vinsrygg glacier, confirming the impression of high glacial activity at that time.

Fig. 21. The boulder ridge above Staurisetra, looking north from the distal side.

There is no field evidence to indicate the position of the glacier terminus, but the glacier probably did not reach very far outside the Stryn bay, perhaps to a line between Lunde-Årholen, where fjord bathymethry seems favourable. The resultant glacier surface slope becomes 54 m/km on average, when calculated from the most easterly moraine, i.e., 0-17 km from terminus, whereas the medium slope west only to Vinsrygg seter, was 45 m/km.

However, the Stryn glacier may have merged with a glacier entering the fjord from the Loen-Olden area to the southeast. If so, the glacier terminus would probably have been situated further to the west, perhaps at Hildeneset, which seems to offer another suitable line of repose.

The Eide stadial

Apart from subrecent moraines, one of the youngest deposits indicating glacier advance or intervals during retreat is the Eide moraine between Oldevatnet and Floen (Olden). This moraine, which was submarine at the time of deposition, forms a ridge up to 12 m high both east and west of the river. On the eastern side only large blocks remain, as the finer fractions have been washed away.

In Nedstryn, the Øvreeide terrace may possibly be about the same age. This deposit, which is mainly made up of relatively well sorted sand and gravel layers, should probably be considered part of a large fan deposited by a tributary river from the north. Its distal, southwestern part forms a nearly horizontal ledge which can be traced 400 m westwards along the northern valley side. The altitude of its foremost edge, about 69 m, probably corresponds to the sea level of that time. At Kyrkjeeide, nearly 2 km further to the west, a 'sete'-like terrace can be traced another 300 m along the valley side at the same level (Fig. 22). Possibly both the Kyrkjeeide and the Øvreeide deposits were parts of the same terrace, which may perhaps be interpreted as a kind of kame terrace connected with the sea.

The Øvreeide deposits and the Eide moraine are probably about the same age, in the following being referred to as the Eide stadial.

Gloppen—Breim

Outer part

In the Gloppen-Breim area, conditions during glacier retreat succeeding the Nor maximum differed from those of Hornindalsvatnet and the main fjord. In the latter areas, the persistent flattening of the glacier surface finally caused a rapid retreat by calving, whereas in Gloppen-Breim the retreat largely proceeded across land or shallow water. In this area, too, a considerable down-melting of ice took place in inland areas during the Nor stadial, but here this process was accordingly accompanied by withdrawal of the glacier terminus, as indicated by the marginal deposits of Gimmestad, Kleivedam and Vassenden.

The accumulation of Vassenden, at the northwestern end of Breimsvatnet, is similar to that of Kleivedam and was described as such by Rye (1963, p. 111-112, 114). As at Kleivedam, the Vassenden deposit was not built very high above

Fig. 22. The 'sete'-like terrace at Kyrkjeeide, looking east.

the marine limit either, as the surface slopes only very gently — 2 m over a stretch of 800 m — in the distal direction. According to Rye, the marine limit, in conformity with the Kleivedam deposit, approximately corresponds to the foremost edge, and this fits in with the Nor shore level. Considering glacier gradients, however, it seems doubtful whether the Vassenden marginal deposit can be ascribed to the Nor stadial. More probably, the Vassenden deposit was contemporaneous with the distinctive marginal moraine at Nessetra, on the western side of Breimsvatnet, which is supposed to be a little younger than the real Nor stadial.

It should be noted that the present outlet of the lake, which is cut into solid rock near the southern valley side, is superimposed. In the central part of the valley the lake is dammed by the glaciofluvial deposits.

The above-mentioned Nessetra moraine (Fig. 17) is about 10 m high in its lower part and curves up-valley, clearly demonstrating that it was deposited by an outlet glacier descending into this valley from the main glacier in Breimsvatnet. Judging from the altitude of Nessetra — about 480 m a.s.l. — the surface level of the main glacier at the mouth of Nesdalen was probably approaching 600 m a.s.l. By assuming the glacier terminus to be at Vassenden, the resultant gradient becomes 53 m/km, which seems reasonable.

Nesdalen glacial lake

In the Nesseter area, well-defined shorelines ('setes') occur along the valley sides, proving the existence of a former glacier-dammed lake, which had its outlet towards the northwest through the valley west of Ryssdalshorn. Unlike the Hornindalen glacial lake, tilting of shorelines may be disregarded here as the total length of the lake was only 1800 m. Southwards the lake was delimited by a prominent marginal moraine which almost entirely blocks the valley 800 m south of Nessetra. This moraine was almost certainly deposited from Sørsendalen. On its northern slope the lake level is sharply marked by a nearly horizontal and almost 70 m-wide terrace ledge, northwards separated from the valley floor by a steep slope, 15 m high. Otherwise, the glacial lake terrace is best developed on the western valley side north of Nessetra, where the 'sete' can be traced continuously for about 700 m, varying in width from 20 to 7 m. In conformity with the Hornindalen glacial lake, the sete surface tends to become narrower and more sharply marked where the valley side is steeper.

The Nesdalen 'setes' are undoubtedly largely composed of till, although no sections exist in the area. The correlation between marginal moraines and the formation of 'setes' is even more evident than in Hornindalen. This is clearly demonstrated northwest of Nessetra, where

Fig. 23. Lateral deposit at Sanddal, looking east. The Sanddal river cuts through this deposit at X.

the 'sete' is developed on a morainic slope which forms the northward continuation of the Nessetra moraine.

Re moraines and Breimdalen glacial lake

At the mouth of Breimdalen, a little up the slope northwest of Re, there are two prominent moraine ridges which must probably be interpreted as marginal moraines. The lower parts of these ridges curve downslope in a way which clearly indicates deposition by a valley glacier flowing westwards in Breimdalen and not by a north-moving glacier in Breimsvatnet, as suggested by Rye (1963, pp. 98-103). Thick deposits, probably moraine, on the opposite side of the valley in the Råd-Seime area support this view. Moreover, the westernmost (i.e., distal) ridge borders on a fan-delta which was probably built by meltwater running along the northwestern side of the ridge. The foremost edge of this fan-delta is likely to correspond to the level of Breimsvatnet at that time.

The cover of sediments in Breimdalen and on the valley slopes, in particular the northern one, is generally rather thick, partly forming ridges, mounds and terrace-like deposits, largely of glaciofluvial and possibly glaciolacustrine origin in the lower areas. Some terraces bear evidence of deposition in contact with ice. According to Rye, (1966, p. 205) the highest terrace, that at Bø on the southern side of the valley, attains a height of 177 m a.s.l., a level which he associates with the pass level of an outlet gap on the northern valley slope northwest of Re, 179 m a.s.l. In Rye's opinion, the terraces of the Breim valley were built in an ice-dammed lake formed by a glacier in the Breimsvatnet basin. However, this assumption does not agree with the interpretation of the Re moraines as having been deposited by a glacier moving west in Breimdalen. In addition, the Bø terrace is the only one reaching the actual level, and the approximate accordance of levels may thus be accidental. The Breimdalen sediments may possibly have been built up to a certain degree in some minor ice-dammed lake or lakes, but then without connection with any pass level, in part contemporaneously, but mainly subsequent to the formation of the Re moraines.

The lowermost terraces are probably marine, and will be dealt with in a later section.

Deposits of the Sanddalsvatnet area

At the mouth of Myklebustdalen a considerable boulder field occurs, extending from the western part of Sanddalsvatnet almost down to Byrkjelo, covering a rather sharply limited area more than 3 km long and about 1 km wide. Most boulders are more than 1 m^3 in size, and many of them

Fig. 24. Aerial view including most of the Hornelen Devonian area and part of the Nordfjord, looking west. To the left the Ålfoten glaciers and (nearer) a minor part of Gjegnalundsbreen. The tributary fjord in the centre of the picture is the Ålfoten fjord. Arrows indicate ice-streams from Gjegnalund area during the Nor stadial. D — Daurmålsvatnet, G — Gjegnalunden, I — Isane, S — Sigdestadnakken. (Photo Fjellanger—Widerøe A/S).

even approach the size of houses. No boulders of such dimensions exist either up-valley or down-valley in the adjacent area.

Supporting the view of Rye, who gave the first description of this deposit (1963, p. 59-61, 1966, p. 211), it is considered impossible that such a boulder field could be formed by frost wedging or slides from the neighbouring mountain. On the other hand, the boulders might have slid down on to the surface of the valley glacier from the steep mountain walls bordering the southern part of Myklebustdalen, preferentially within a limited space of time, and then carried by the glacier to the present position. If so, the boulder field may be considered either a kind of ablation till, deposited in the marginal area of a slowly retreating glacier, or an end moraine. The latter is probably the most adequate term, especially when the boulder field is seen in association with the accumulations of Sanddal, which may be of about the same age. From the Sanddal river thick deposits extend terrace-like about 1.5 km westwards along the valley side, separated by an almost 50 m-high steep slope from the valley floor (Fig. 23). The terrace surface is relatively even and slopes gently towards the foremost edge.

East of the Sanddal river, surface topography is more irregular with depressions which may possibly be interpreted as kettle holes. No sections exist through the deposits, which also extend up-river to an altitude of nearly 450 m.

The Sanddal deposits are clearly lateral, originating partly from the glacier in Sanddalsvatnet and partly from the river, which probably carried large quantities of glacigenic material at that time. No conclusive correlations can be made as yet, but tentatively the Sanddal accumulations may be associated with the Eide stadial.

Local glaciation

Introduction

During the Late Weichselian, an extensive local glaciation took place in Nordfjord in the areas

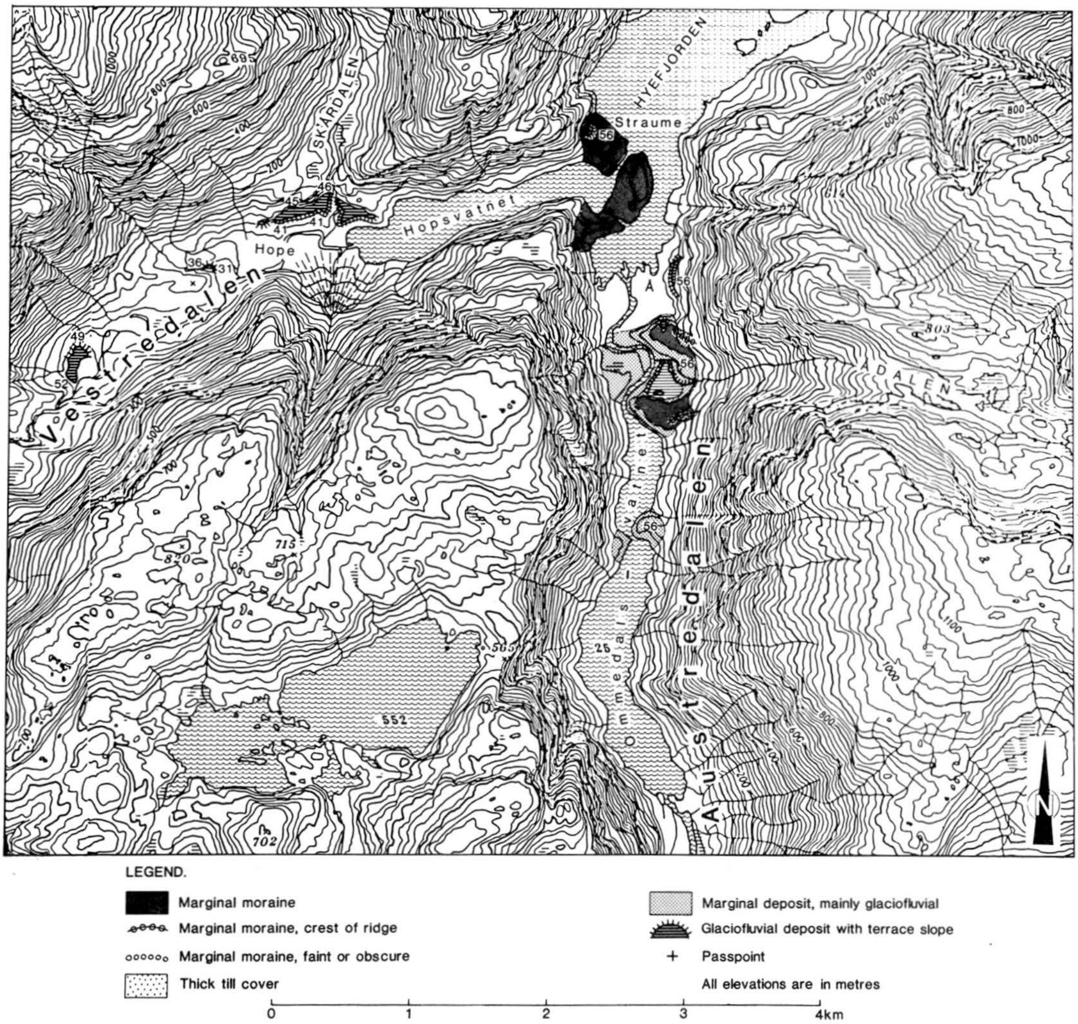

Fig. 25. Map of the Hyen area.

outside and above the continuous fjord and valley glaciers. These local glaciers were mostly of the cirque glacier type, but larger areas of coherent glaciers also existed, mainly plateau glaciers, from which small and large ice streams moved down the valleys. Local glaciers outside the Nordfjord area are not shown on the map (Plate 2).

Locality descriptions

Ålfoten—Gjegnalund—Hyen area

The most prominent centre of local glaciation was the high-lying Devonian massif on the southern side of the fjord, where the present Gjegnalund and the Ålfoten plateau glaciers are located (Fig. 24).

During the late glacial, the entire area was covered by a large, continuous ice cap from which outlet glaciers descended into the surrounding valleys. Some of these glaciers extended straight down to the sea-level of that time, allowing for the development of shorelines into the marginal moraines, which, accordingly, can be dated.

Up in the mountain above Yksnelvane, prominent marginal moraine belts show that two valley glaciers originating from the Gjegnalund area here extended out to the very edge of the plateau, 400 m a.s.l., from where considerable ice masses must have tipped over the edge down into the fjord. Most likely these moraine belts should be correlated with the Nor moraines.

Fig. 26. The frontal deposit at Å, Austredalen, just south of the head of Hyenfjorden (foreground), looking south. Marginal moraines bordering the deposit are dotted. (Photo Telemark Flyselskap A/S).

Further east, a small isolated local glacier seems to have existed beneath the steep, north-facing slope of Skjerdingane just above the farm of Skeistrand, and at the mouth of the narrow Skjerdalen valley there is a distinctive, curved marginal moraine terraced to the Nor marine level.

At the head of the Hyenfjord two major valleys meet, Vestredalen from the west and Austredalen from the south (Fig. 25). Both valleys are relatively narrow, and the valley sides mostly steep. The sediments, therefore, are mainly concentrated on the valley floors. At the mouth of Vestredalen a prominent, curved end moraine, on which most of the Straume settlement is situated, terminates the valley, thus blocking the Hopsvatn lake from the sea. Only in its northernmost part, near the mountain side, does the moraine extend above the sea-level of that time, which is here very clearly indicated by a narrow (25 m to 10 m) ledge eroded into the moraine. This altitude corresponds to the Nor sea level. In the central part much of the sediment has been removed by river erosion, by means of which the lake has acquired two outlets, one to the north and one to the south. The till contains many large boulders, mostly of Devonian rocks, as could be expected since the moraine was deposited by a valley glacier originating from the Devonian area to the north.

Accordingly, it is clear that during the Nor stadial, glaciers from the Devonian area reached the sea at least in two places, i.e. Straume and Skjerdal, and possibly also in the Ålfoten fjord. In addition, a considerable icefall from the plateau above Yksnelvane must be taken into account. Consequently, the fjord at that time received ample supplies of drifting ice carrying Devonian rocks.

Devonian boulders are common along the shores of Gloppenfjorden and Eidsfjorden, particularly in the outer part of Eidsfjorden. They are found up to the Nor shore level, notably just below that level, but never above it, except for the areas further to the west, where direct transport by moving glaciers was also possible.

In the Austredalen valley, the northernmost marginal deposit, at Å, is the most prominent (Fig. 26). This accumulation was deposited by a local glacier originating from Ådalen, a hanging cirque in the mountain on the eastern side of the valley. The deposit almost completely blocks the valley just south of the head of the fjord and is separated from the valley floor to the north and the Ommedalsvatnet lake to the south by high, steep slopes. Laterally the deposit is bounded by distinct moraine ridges, which are particularly clear in their upper parts near the mountain side. The levelling by fluvial erosion and deposition of the gently sloping moraine flat between the marginal moraine ridges probably took place immediately after the glacier had retreated from its distal position, while sea level was still unchanged (56 m, corresponding to the Nor sea level). The similarity of this deposit to that described by Reite (1967, pp. 268-269), from Riksheim, Sykkylven, is striking, except for the lack of a delta outside the moraine.

Further to the south in Austredalen another frontal deposit stretches across the valley, nearly dividing the Ommedalsvatnet into two parts. According to a section on the southern side, showing a 2 m-thick, rather coarse and unsorted topset bed underlain by gravel layers dipping 30° northwards, this accumulation must be considered as a frontal terrace deposited by a valley glacier moving north. The marine limit (56 m, corresponding to the Nor sea level) is well defined on the rather even, very gently sloping surface, where also many boulders, including Devonian rocks, are seen. These boulders must have come from the north, transported by drifting ice. This frontal deposit must be somewhat older than the Å moraine, because it appears improbable that any valley glacier from the south could have extended as far north as this during the Nor stadial.

Except for the northeastern part, the reconstruction of the ice-cap covering the Devonian area must be considered highly tentative, being based solely on the interpretation of moraines from aerial photographs combined with evaluations of the topographic conditions. Some of the moraines may possibly be older or younger than the Nor stadial.

The area north of Eidsfjorden and Hornindalsvatnet

In the area north of Eidsfjorden and Hornindalsvatnet local moraines are relatively scarce, probably in part due to a general lack of loose deposits. This seems to be the case particularly in the mountain areas north of Hjelmelandsdalen, where cirque topography is rather well developed, but where moraines are few. The most prominent moraine in this area is that north of Ljøsureggja, with three closely spaced proximal ridges immediately inside the long, sharp-crested, 15 m-high distal ridge. Further east, the similar high boulder moraine north of Kviteggja and the prominent, horseshoe-shaped moraine ridge 'Kyrkjegarden' on the southern side of the same mountain must be mentioned. A lateral moraine along the southern side of a steep, gully-like western tributary to Otterdalen shows that even minor depressions in some cases could have been the sites of small, independent glaciers during late glacial times.

Northern side of Hornindalen

In this area the mountains attain considerable altitudes, and cirque topography is fairly well developed. All the cirques around the Hjortedalen depression were certainly occupied by glaciers during the Late Glacial, and most of them have left marginal moraines, commonly with several behind each other (Plate 3).

In the central part of the Hjortedalen depression both Bruasetra and Storesetra are situated upon prominent morainic walls of which the latter, because of its curvature, seems to have been deposited by a glacier coming from Guridalen-Lisjedalen. Concerning the Bruasetra moraine, which lies 400 m south of Storesetra and 700 m north of the lateral moraine from the Nor stadial, the direction of glacial transport is not clear.

Just west of the river, a curved marginal moraine descends from 630 m a.s.l. at its northern end towards the valley floor, and then ascends again towards the southwest. In some places a couple of more proximal ridges occur inside the sharply marked distal ridge. Sections, the largest one 10 m high and situated directly opposite the Storeseter ridge, show homogeneous till, consisting mainly of gravel and sand with numerous boulders and with a very low content of silt and clay (Fig. 3). This is a common till type in Nordfjord.

The site of the glacier that deposited this moraine is somewhat unusual: an east-facing gently sloping and only slightly concave valley side, without any connection to a possible higher-lying accumulation area. Indeed, the entire glacier seems to have been situated below 750 m a.s.l., indicating that it could have been determined by a lower glaciation limit than the other local glaciers in the area. However, the moraine must be younger than the Storeseter ridge, and according to its position it cannot be very much older than the Nor stadial. It is, therefore, highly probable that this moraine, too, is more or less contemporaneous with the Nor moraines, whereas the Storesetra moraine is older.

In the Blåbredalen valley the till cover is mostly sparse and marginal features are rather insignificant. By contrast, in upper Hjortedalen, i.e. the northeastern continuation of the main valley, there is an even, in part relatively thick till cover, including several marginal moraines. These marginal features do not differ from the general till cover in any perceptible way, but are easily recognised on aerial photos and seem to represent at least three clearly separated phases or stadials. The outermost moraine belt (1, Plate 3) is not very distinct, whereas the middle one (2) is the most pronounced. This complex consists of three or four ridges forming a lobate pattern and is tentatively correlated with the Nor stadial.

A minor sand-pit on the slope just above Hjortedalssetra, 480 m a.s.l., reveals rather fine-grained bedded sediments (sand-silt), which may be indicative of an ice-dammed lake caused by the Hornindalen valley glacier during some pre-Nor stage.

In the uppermost part of Hjortedalen the youngest (phase 3) marginal moraines (Plate 3) are cut on their southern side by a still younger and slightly larger moraine ridge (4), deposited by a tongue-shaped glacier in the northwestern slope of Sandfjellet. This glacier was not localised to any real cirque, thus resembling the glacier on the slope west of the Storeseter ridge, although conditions north of Sandfjellet were much more favourable for glacier formation. Both may be interpreted as fairly spontaneous reactions to climatic deteriorations which did not last long enough to affect the larger cirque glaciers sufficiently to allow them to expand down into the valleys. The two glaciers in question were not necessarily synchronous. The marginal moraine north of Sandfjellet may perhaps be considerably younger than the Nor stadial.

In Rokkedalen, further to the east, there is only one moraine, namely the 15 m-high ridge upon which Honndalssetra is situated. However, the lower part of the corresponding lateral moraine, which can be traced up to an altitude of 525 m before disappearing on the increasingly steeper slope, is in part divided into up to four closely spaced parallel ridges. The valley inside the moraine is extremely barren, particularly northwards from the Blåvatn threshold.

The mountain area between Hornindalen and Stryn

The landscape on the southern side of Hornindalen is almost equally characterised by cirque glacier activity as the northern mountain areas, and distinctive marginal moraines occur in front of all the cirques lying north of the watershed between Hornindalen and Stryn. These are generally divided into two or more morainic steps.

The marginal moraines in front of Botnavatn (Seljesetvatn) at the head of Knutsdalen probably represent at least two separate stadials, because of the rather great difference in altitude — nearly 100 m — between the upper and the lower lateral ridge on the northeastern valley slope, where only these two moraines are recognisable. In the valley bottom there are other, in part rather prominent, moraine ridges which may possibly represent interveening phases. South of Botnavatn a narrow, but distinctive marginal moraine must be indicative of a still younger stadial. At the mouth of the Nattakupen cirque two prominent marginal moraines are found. In addition, a more distal, marginal line curving almost down to the valley floor of Knutsdalen, and a proximal one just south of the northern end of the lake, possibly exist, but are not indicated on the map.

In Litlekupane there is evidence of at least two clearly different stadials. The whole area within the proximal marginal line is dominated by boulders in ridges and heaps, which in part conform to a pattern which may suggest the further retreat of the glacier front. However, no clear marginal lines can be distinguished. The proximal line mentioned mainly appears as a very sharp outer limit of this boulder area, whereas the zone between the two marginal lines does not differ particularly from the evenly moraine-covered area outside the distal moraine.

Further to the west, on the northeastern side of Gulekoppen, heaps and ridges of till, mostly boulders, form a marginal belt, probably including several phases or stadials. Individual moraines are difficult to distinguish. On the other hand, in the deep, narrow cirque northwest of Gulekoppen, two very distinctive marginal lines are seen.

Along the southern side of the mountain massif between Hornindalen and Stryn there is no reliable evidence of local glaciers during late glacial times, even though only the westernmost cirque — that just east of Gulekoppen — was lying slightly below the Nor valley glacier margin. This cannot be satisfactorily explained uniquely by the south-facing position of these cirques. In the Hjortedalen area, where the mountains are of about the same altitude, several local glaciers of similar orientation existed, in part at considerably lower levels. It is reasonable to propose that the difference to a great extent was due to different accumulation conditions. Thus, the present glaciation and firn limits drop rather steeply towards the coast in the Nordfjord area, even though the map of

Østrem & Liestøl (1964, pp. 324—326) must probably be considered somewhat inaccurate in this region.

South of the Stryn valley and Strynsvatnet the cirque glaciers coalesced with the valley glacier, and hence the local moraines found here are usually of sub-recent age (1750 or younger).

The area between Eidsfjorden—Hornindalsvatnet and the main fjord

With few exceptions (Glittereggja) the mountains are lower and cirques generally less developed than in Hornindalen and Stryn. The most remarkable feature in the western part of the area is a large boulder moraine which was deposited by a relatively small glacier close to the mountain Trollenyken (Fig. 6). This moraine extends down to the Nor shoreline at Roti and must have been deposited during the Nor stadial. This also applies to the cirque moraine north of the mountain 847 and to the curved, up to 12 m-high boulder ridge bordering the lake Kvanndalsvatnet further east. During the Vardehaug stadial the floors of these cirques were probably overrun by the fjord glacier of Hornindalsvatnet.

Concerning the moraines of Kalvegeilsbotnen and Klebergsvatnet, conditions are not quite clear, and the possibility that one or both of them were deposited by fjord or valley glaciers prior to the Nor stadial cannot be excluded.

Areas south of the main fjord

In this region the formation of local glaciers was to a greater extent dependent upon, and to some degree prevented by, the development of the late glacial fjord- and valley glacier systems than in the areas previously described. Marginal moraines deposited by local glaciers are found mainly above the distal limit of the continuous Nor glaciers and are less numerous than further to the north.

Along the southern side of the Innvik valley all stages of cirque development can be seen, ranging from narrow gullies furthest to the east, to the well-developed cirque of Storelogjen to the west. The thick moraine cover in front of the latter cirque is bordered by a marginal moraine attaining a maximum height of 20 m and flattening to a morainic plateau in its lowermost part, at an altitude only 50 m above the distal lateral moraine of the fjord glacier a little further downslope. Thus, the thick till accumulations extend continuously from the lake and nearly down to the floor of the main valley. The river from Storelogjen has formed a more than 20 m-high cutting through these deposits, showing exclusively homogeneous, non-sorted till of the common kind.

The distal cirque moraine, in conformity with the moraines below the two neighbouring cirques to the east, almost certainly corresponds to the Nor stadial. Between the distal moraine and the sub-recent ones in front of the small present-day glacier, at least two other moraines can be distinguished.

Turning to the western side of Breimsvatnet, the large marginal moraine south of Nessetra (Fig. 17) was probably deposited from Sørsendalen. This moraine must presumably be of about the same age as the Nesdalen glacial lake. In the western part of the Sørsendalen valley remnants of lateral moraines show that the Sørsendalen valley glacier extended just down to the western end of the present valley train at some later time. Most of the moraines further up-valley, however, but not necessarily all, are most likely to be of sub-recent age.

The cirque moraines in the mountain areas south and west of the Gloppen valley, leading from Breimsvatnet to the fjord, have been mapped mainly from aerial photographs. Further to the north, a prominent local moraine ('Langolen') descends downslope from a little more than 700 m to somewhat below 500 m a.s.l. on the western side of Gloppenfjorden. The size of this lateral cirque moraine, which for a long distance exceeds a height of 25 m, is remarkable when compared with the small dimensions of the cirque.

The Myklebustbreen area

Myklebustbreen forms a large continuous icecap over most of the plateau between Myklebustdalen to the west and Oldedalen to the east. Field investigations were confined to the northern margin of this plateau glacier, which at present covers an area of about 12 x 5 km.

During the Nor stadial Myklebustbreen did not reach the prominent marginal moraines (1, Pl. 4) deposited by the main valley glacier above Sanddalssetra, since they are quite undisturbed (p. 13). However, the most distal moraines (2) deposited by Myklebustbreen are found immediately to the east. The two westernmost ridges may possibly be interpreted as erosional forms, being bordered to the east by rather marked meltwater channels, whereas the western slopes are more gentle. If the ridges are marginal moraines, the westernmost one, at least, must be older than the distal Nor lateral moraine because it is cut by the latter at its lower end (near the tarn 859). The other ridges further east, which are higher and rise more prominently above the surroundings, are definite marginal moraines. The easternmost one (2a) attains a maximum height of 20 m with a marked steep proximal (east-facing) slope. These marginal moraines must have been deposited by a large glacier from the east which occupied the entire Svartebotn depression and are possibly related to the Nor stadial. In its eastern part this glacier probably received supplies of ice from the Myklebustbreen plateau, and most likely also from plateau glaciers along the eastern and northern sides of the Svartebotn basin, as tentatively suggested on the map (Pl.2).

It is, however, remarkable that, at its northwestern corner, the Myklebustbreen does not appear to have extended beyond the Little Ice Age moraines during late glacial times. Below these moraines, which stretch down to a level of about 1230 m, there are no moraines deposited from above; on the contrary, there are fragments of a lateral moraine deposited by the Vardehaug valley glacier complex. The fact that Myklebustbreen in this area did not extend very much beyond the limits of the present glacier during the late glacial, while it possibly completely filled the entire Svartebotn basin further to the east, must be due to an easterly displacement of the ice culmination as compared with present-day conditions. If there was no connection between Myklebustbreen and the glacier of Svartebotn, the former could not have extended very much further towards the north in its eastern part than it does at present. It is, however, well known that individual glaciers — in particular glaciers of quite unequal orders of size — may react rather differently to the same climatic fluctuations (p. 31). Examples illustrating this are reported also from other, neighbouring areas (Vorren 1973, p. 19). Consequently, it cannot be excluded that Myklebustbreen might possibly have been smaller during late glacial times than it was at about 1750. Much would depend on the initial configuration of glaciers immediately prior to each of the late glacial readvances, in particular that of the Nor stadial. It is not inconceivable that the high-lying plateaux of inner Nordfjord were almost ice-free even before the Nor stadial, whereas large glaciers were still occupying the valleys. In that case, a long time would be needed to rebuild a plateau glacier to the dimensions of Myklebustbreen during some new period of climatic deterioration. In this connection comparisons with the Ålfoten - Gjegnalund area, which during the Nor stadial was the site of a large continuous ice-cap much greater than at any later time, cannot be arbitrarily made. Even during present-day conditions the climatic difference between these two glaciers, as expressed by the firn limit, is rather large, about 250 m. Possibly this difference was even greater during late glacial times; particularly if the maritime influence was more pronounced at that time, because even a minor percentage increase in precipitation would probably affect the Ålfoten plateau to a much greater extent than the more continental areas further to the east. If the assumption that Myklebustbreen was relatively small during the Younger Dryas is correct, it may indicate that the Younger Dryas climatic depressions were characterised not only by lowering of temperature, but also by an increase of precipitation.

On the hill (1025) near the northern side of the valley, there is a prominent morainic ridge (3) of somewhat uncertain origin. Even though its present appearance, including the up to 5 m-high, steep eastern slope, may be in part erosional, the ridge may possibly be interpreted as a marginal moraine deposited by the Svartebotn glacier.

All the younger moraines were deposited from the south, directly by Myklebustbreen. The Little Ice Age moraine (7), a boulder ridge 3 m high, is rather prominent. This age cannot be doubted, because of the marked difference in vegetation and colour between the areas inside and outside the moraine. On the proximal side the fresh-looking basal till is characterised by a fluted surface pattern, which cannot be traced on the distal side. South of the river, several other, rather sharp-crested younger moraines occur (not shown on the map).

Outside the Little Ice Age moraine, somewhat higher on the gently rising slope, at least two much older marginal lines (4) appear, conforming to the same concentric pattern as the recent moraines. In particular the lower one — which is to a great extent composed of several parallel ridges — is fairly distinctive in its western part, and contrasts strikingly to the river plain inside by a steep proximal slope up to 8 m high. The age of these moraines is difficult to decide, apart from the fact that they must be younger than the moraines deposited from the east. The till cover inside the marginal lines cannot be visually distinguished from that outside, and, therefore, the moraines in question are most likely to be of early post-glacial age, even though a late Younger Dryas age cannot be excluded. At any rate, the considerable displacement of the ice culmination zone which occurred between the deposition of the moraines (2, 3) and (4) may possibly indicate a rather long interval.

The morainic ledge (5) which can be traced along the northwestern shore of the Svartebotn lake, although not ridge-shaped, should probably be interpreted as a marginal moraine of about the same age as the marginal moraine complex (6) north of Trollebotn and the moraines (4). The innermost moraine (8), bordering the northern shore of the lake 1083, may be of sub-recent age.

The marginal moraine (9) below the steep slope, a little further to the east, is deposited across some of the moraines (6) and consequently must be younger. Regarding the sharpness and the narrowness of the ridge and the fresh-looking character of the area inside, it is a fair supposition that it dates from the Little Ice Age.

The sub-recent glacial events, including the Little Ice Age readvance, are considered to be mainly beyond the scope of the present paper. It should be mentioned, however, that some historical information, primarily concerning the inhabitated areas, is available (Eide 1955).

Review

In comparison with the rather clear evidence of the deglaciation history revealed by the valley and fjord glaciers, the picture obtained by studying the local glaciers is somewhat more complicated. It seems certain that here, too, more stadials are present, perhaps 3 or 4. Most likely the Nor stadial is in most cases represented, but only a few local moraines can be referred to that stadial with certainty, notably those which can be correlated through some marine or lacustrine reference level (the moraines of Hyen, Skjerdal, Honndalssetra and south of Nordfjordeid). In some other cases the moraines, owing to their position, must be younger than the Davik stadial (Davik local moraines) or the Vardehaug stadial (marginal moraines of Storelogjen and cirques east of Storelogjen, in part also moraines in the lower part of Hjortedalen). Most of these moraines, too, are likely to be referred to the Nor stadial, even though they could theoretically be either younger or slightly older (Davik moraines). Inside and below the margin of the Nor valley and fjord glacier conditions were less favourable for the formation of local glaciers because of the rapid improvement of climate succeeding that stadial. In Sørsendalen, however, there is evidence for at least two stadials or phases older than the Little Ice Age and younger than the Nor stadial.

The most complete series of local moraines is found in Hornindalen where at least two clearly different phases are found everywhere, with the exception of Rokkedalen. The Hornindalen mountains were for a long time beyond the influence of the late glacial valley glaciers. This fact in itself indicates that the outer moraines in these cirques are older than the Nor stadial, and possibly contemporaneous with the Vardehaug stadial. This conclusion seems very probable regarding the outer moraines of Hjortedalen and Litlekupane.

All the marginal moraines previously described which, by some degree of certainty, may be referred to the Nor stadial, are very prominent. This also applies to the cirques of Hornindalen, where the second moraine when counted from outside, is generally the most distinctive one, again suggesting that the outer moraine is older. On that score, conditions are particularly clear in Hjortedalen, where there are also two pre-recent marginal belts younger than the Nor moraines.

Several features show that the stadials indicated by the fjord and valley glaciers may also be found in the cirques. However, these local marginal features need not necessarily be synchronous, neither relative to each other nor to the regional stadials. Local conditions were certainly highly variable, and additional investigations, preferably direct datings, are required in order to draw further conclusions.

Concerning the evidence from local glaciers as to firn limits, glaciation limits and climate, these subjects will be dealt with in a later section.

Glacial striae and ice-flow directions

Directions of ice movement are shown on the map and were usually determined by means of glacial striae (Fig. 27), in some places accompanied by crescentic gouges and/or crescentic marks. In two localities the directions were found solely from the latter features.

In many places directions of striae may be somewhat variable, and where the amplitudes exceed 15° both the extreme values and the

Fig. 27. Strong glacial striations at Haneholmen, trending SE-NW (NW towards the left).

main or medium direction have been plotted on the map, although all those striae are generally thought to be more or less contemporaneous. This even applies to the observations at Hamnnes, where the striated sector exceeds 60°, owing to the particular conditions here (merging ice streams from two fjords).

During the glacial maximum the area in question was probably totally glaciated. Striae on open positions in the mountain areas show that the main direction of the ice flow was towards NW or NNW, though in some areas it was closer to north or somewhat east of north. This agrees well with observations in adjacent areas, for example, those made by Holtedahl (1955) from the outer parts of Møre and by Klakegg (1981) from Jølster, just south of the investigated area. Consequently, the glacier surface was highest to the south and southeast.

In the deep valleys and fjords the ice streams were, as a rule, more or less strictly controlled by topography, notably during later phases such as the Nor stadial. However, examples are found showing glacier flow governed solely by the surface slope of the glacier and apparently independent of subglacial topography (southwesterly striae just north of Innvik).

Crossing striae referring to definitely separate phases of movement are found in some localities, and usually reflect an adjustment of the ice drainage pattern to topography during thinning of the ice sheet. As an example, this seems to be the case in the Randabygda area, where the southwesterly movement — recorded also on the southern slope of Glittereggja — most probably is an expression of glacial confluence towards the fjord during phases of down-melting.

At the mouth of the Ålfoten fjord the older, northwesterly movement was later replaced by an icestream out from this tributary fjord, possibly corresponding to the Vardehaug or perhaps to the Nor stadial.

Marine levels

Introduction

Nearly all the glacigenic deposits of any importance in Nordfjord are more or less closely related to the Nor glacier margin, which, at the same time, constitutes a decisive dividing line as regards the topography of the fjord bottom. Inside Anda the fjord bottom is only to a moderate degree covered by sediments, whereas outside it is extremely flat both in transverse and in longitudinal sections. This can only be explained by the filling up of sediments during the Nor stadial. The dominating position of the Nor stadial is emphasized still more by the correspondingly prominent series of terraces, which was given the designation 'the epiglacial step' by Kaldhol (1912, p. 33). This level is particularly conspicuous along the southern side of the fjord from Elde to Isane, at Nordfjordeid,

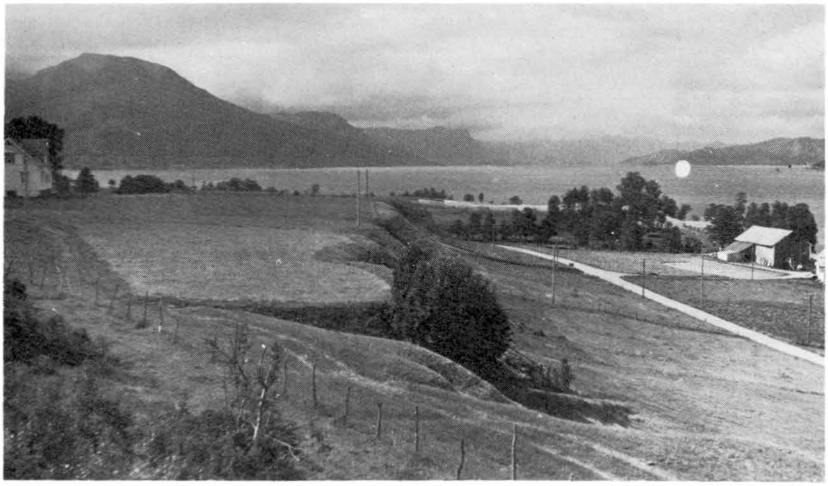

Fig. 28. The northern, distal part of the Elde fan-delta, including the transition between the fan proper and the lateral ledge stretching further northwards, i.e. to the right (foreground).

on both sides of the valley, and along the Gloppenfjord. Eastwards it comes to a stop against the Nor glacier margin. This series of terraces obviously represents a synchronous marine level, the only one (possibly with the exception of the Tapes level) which, with some degree of certainty, can be traced regionally and forms the basis of the construction of isobases.

Locality descriptions: Areas outside the Nor glacier margin

Southern side of the main fjord from Elde to Isane

As already mentioned, the Nor marine level is very prominent along the outer part of the southern side of the fjord, particularly at Elde, Endal, Davik and Dombestein, and at Isane. With the exception of Isane, these localities show many common features. All these accumulations can be characterised as very gently sloping fan-deltas. In their outer parts, they form large, nearly horizontal flats, where the foremost edge is marked by a prominent, steep slope (Fig. 28). Laterally, the fans pass into narrow, usually very sharply defined ledges, which in part may extend for a considerable distance to both sides.

At Elde and Endal, at least, these ledges evidently indicate a level of accumulation corresponding to the foremost edge of the central part of the fan-delta. In these two localities there is no question of erosion terraces as is probably the case on the eastern side of the Davik bay, where the Nor shoreline developed on a gentle morainic slope. At Elde and Endal the ledges are abruptly limited headward by barren or nearly barren rock. Although sections are small and few, it appears that these fan-deltas consist largely of rather coarse and unsorted, in part bouldery material, sometimes resembling till. Possibly, in some localities — such as Davik — the formation was to a certain extent conditional on nearby local glaciers.

In general, the Nor marine level probably corresponds to the altitude of the distal, horizontal part of the central area, or the headward limits of the ledges which form its lateral continuation. No reliable evidence of sea-levels higher than that of the Nor stadial has been recognised on the surface of these fan-deltas; possibly because during the Nor stadial supplies of sediment were so abundant and fan-building activity so great that any traces of former higher sea-levels were removed or buried, if they ever existed.

The 'upper terrace level', a term used by Rekstad (1906) and Kaldhol (op. cit.) and thought to correspond to the marine limit, cannot be verified in the field. In most cases the altitudes reported correspond approximately to the apices of the fan-deltas in question.

Further to the east, at Isane, conditions are different, because most of the prominent ledge on which nearly all the farms are situated is cut into the rock and only sparsely covered by sediments. The width of this 2.2 km-long shoreline, which is transverse to the strike, varies between 10 and 30 m.

Evidence of higher sea-levels

In some places at Isane somewhat questionable erosional notches are found in the rock which

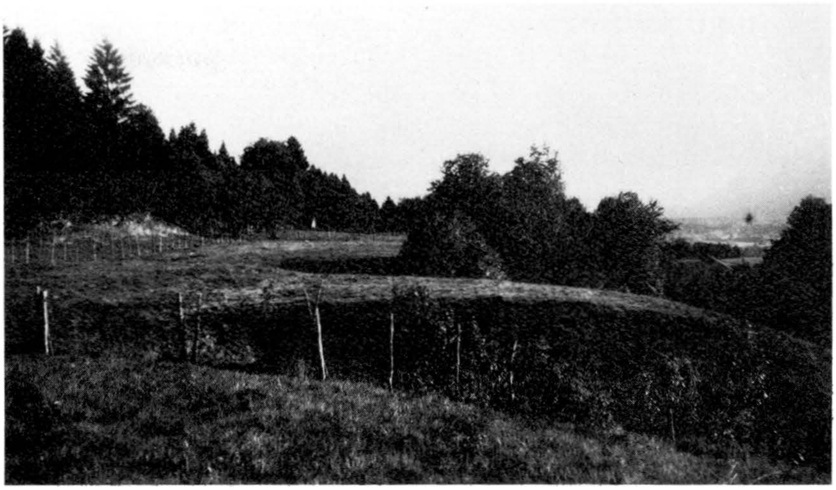

Fig. 29. The Nor terrace along the northern valley side at Myklebust, Nordfjordeid, looking east.

may possibly suggest a sea-level 5 to 7 m above that of the Nor stadial. A similar high level may be recorded at Førde, Ålfoten. However, the only reliable evidence of any former higher sea-level in the investigated area appears to be the upper terrace of Naustdal at the northern side of Eidsfjorden, which almost certainly must be marine. This terrace is quite flat and clearly separated by a distinctive, steep erosional slope from the neighbouring, well-defined terrace representing the Nor sea-level.

All the other statements by Kaldhol concerning higher terrace levels at several localities in Eidsfjorden, at Lote and in Gloppenfjorden are rather doubtful (op. cit. 1912, see also Rekstad 1906, pp. 9-11, 22-24 and Rye 1963, p. 114). The lack of evidence of former higher sea-levels may to a great extent be explained in the same way as for the Elde-Endal area, at least in places where supplies of sediments during the Nor stadial were abundant (in the Nordfjordeid, Lote, Hyen, Vereide, Rygg-Ravnestad areas).

Eidsfjorden

In Eidsfjorden the Nor terraces are fairly prominent at Stårheim, Naustdal and Løken on the northern side of the fjord, and in the Nordfjordeid area. Here the Nor level is very conspicuous on both sides of the valley, in particular the 20-30 m-wide, nearly horizontal terrace extending along the northern valley side from Myklebust to Alsaker, where it also constitues a very sharp upper limit of sediments towards the barren slope (Fig. 29). This terrace appears to have developed locally, in the same manner as the terraces at Elde and Endal, i.e., without any relationship to the Nor frontal deposit a few kilometres further to the east. The narrow ledge from Skipenes to Taklo on the southern side of the valley, however, must at least in part be characterised as an erosion terrace cut into till.

The surface level of the otherwise mainly supramarine Nor frontal deposit grades imperceptibly into the Nor marine level at Bjørlomona. Further westwards to Skipenes rather wide, flat terraces of the Nor altitude project up to 300 m outwards from the southern valley side, possibly indicating that the existing valley fill initially stretched nearly 1.5 km beyond the present western edge of Bjørlomona. It is possible that the easternmost part of the terrace on the northern side of the valley may also be considered as an erosional remnant of this continuous valley fill.

Below the Nor level, the proglacial sands and gravels have been removed, redeposited and thoroughly reworked. By these processes several secondary terraces at various levels and erosional remnants have developed, though not shown on the map. The underlying glaciomarine clay, which near the valley sides rises somewhat higher, close to the Nor level, is now exposed over a greater part of the valley floor.

Hyen and Gloppenfjord area

The deposits at Lote resemble those at Elde and Endal as regards surface topography, type of sediment and genesis. The Nor shore level is very distinctive both at the mouth (Eikenes (Fig. 30), Hestenesøyra, Skjerdal) and at the head of Hyenfjorden, and, above all, along the northern side of Gloppenfjorden. Here, a continuous

Fig. 30. The Nor shoreline at Eikenes.

terrace, with somewhat variable width and inclination, extends all the way from Hjelmeset in the northwest to Austrheim in the southeast, a distance of more than 6 km. The mode of formation appears comparable with that for the deposits at Elde and Endal and other similar localities.

It is particularly obvious that the terrace sections just north and south of Vereide constitute the unbroken lateral extensions of the large Vereide fan-delta. The very even surface of this fan-delta, which was mainly built by sediments of the meltwater from Føleide as previously mentioned, slopes at a very constant rate from its apex 104 m a.s.l. down to the edge of the steep slope towards the fjord, 67 m a.s.l.

In the eastern part of the terrace, the nearby position of the glacier front evidently played an important role, in conformity with the Rygg-Gimmestad area on the southern side of the fjord, where the Nor level is also very prominent.

Areas inside the Nor glacier margin

Hornindalsvatnet

Inside the glacier margin at Nor, terraces formed only locally, mainly for topographical reasons, even though the lack of terraces is not as complete as suggested by Kaldhol (1912, p. 20), at least not in the eastern part of the lake. Here, terraces are found at Holmøyane, Holmøyvik (two levels) and Otterdal (also two levels), in addition to those of Grodås, which have been previously described, among others, by Rekstad (1906, p. 11) and, in particular, by Kaldhol (1912, pp. 20-21). The "beautiful terrace line" mentioned by Rekstad forms a more or less horizontal, narrow terrace, which can be traced continuously along the valley side from the main road to the north to a little beyond the church to the south. It varies in width between 15 and 40 m, and has a height of about 73 m (Appendix); Rekstad recorded 76 m (locality unspecified). On the slope below, fossils in the shape of imprints of molluscs and leaves have been found at several localities at 68 m a.s.l., i.e. 16 m above the level of the present lake. The list of fossils embraces the following molluscs (Rekstad 1906, p. 30, Kaldhol 1912, pp. 72-74): *Mya truncata, Hiatella arctica (Saxicava pholadis), Macoma calcarea* and *Portlandia (Yoldia) arctica* (uncertain), and, in addition, leaf-imprints, probably *Salix phyllicifolia* and *Salix herbacea.*

The altitude of this terrace clearly corresponds to the terrace level at Holmøyane and the main level of Holmøyvik and Otterdal, and the fossils prove that this level must be marine. Consequently, the sea must have entered the Hornindalsvatnet basin subsequent to deglaciation (Fig. 31). At that time the sea level was still unchanged, since the terrace altitudes along the upper part of the lake fit perfectly with the Nor sea-level. The connection with the sea must have been broken shortly afterwards during land upheaval. The lower levels, such as the lower terrace of Holmøyvik, must then be lacustrine. The upper terrace in Otterdal probably formed in a little ice-dammed lake of local origin, as mentioned earlier, whereas the higher levels north of Grodås must be ascribed to various stages of the Hornindal glacial lake.

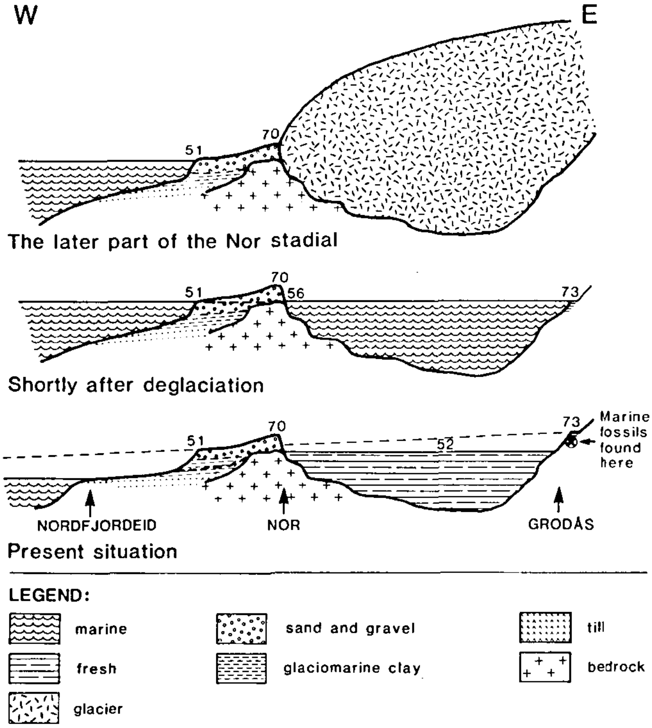

Fig. 31. Phases of development in Hornindalsvatnet during the deglaciation.

The main fjord

Inside the Nor glacier margin at Anda the fjord sides are generally rather steep and the quantities of superficial deposits mostly small, except for the Tistam - Utvik - Innvik area. Along the northern side of the fjord, no terraces are found between Lote and Stryn, with the exception of some very low terraces in Hennebygda (at 6 m and 14 m a.s.l.). The latter level is sharply marked also at Tistam (19 m), Utvik and Innvik, and may possibly be of Tapes age. In addition, each of the three latter areas is dominated by a large, sloping fan-delta of coarse sediments, gravel and boulders. The Tistam fan-delta has a break at 62 m a.s.l., though not particularly distinctive, from which there is a relatively steep slope down to the horizontal 19 m level. The foremost edge of the Utvik fan-delta, east of the present river, is probably not entirely primary; being marked by a 30 m-high steep slope facing the fjord. It reaches a level of 69 m at its most distal part in the north-east, which was possibly not very much above the contemporary sea-level. At Innvik, the large fan-delta on which the Langvin school of agriculture is situated, seems to indicate a sea-level of about 70 m, judging from the present surface, which, although somewhat irregular, slopes both downward along the river and laterally on both sides.

It thus appears that the large fan-deltas of Tistam, Utvik and Innvik were all graded to the same marine level, in the following referred to as the *Langvin level,* which is somewhat lower than the Nor marine level.

It is uncertain whether the Langvin level represents the highest marine level of the area. At Utvik the fan-delta corresponding to the Langvin level seems to be cut into an older, higher fan-delta. Possibly the latter was graded to the Nor sea-level, which here must have been at nearly 82 m. Most of the other levels reported by Kaldhol appear, on closer examination, to be either more or less arbitrary flattenings on sloping fans, not apparently related to any sea-level, or structurally determined rock platforms.

In the Olden area the mostly rather steep valley sides are dominated by large gravel cones which, at Sunde, almost separate the lake Oldevatnet into two parts. The only clear terraces are found in the valley south of the lake. The most prominent one is the rather large and flat Åbrekk terrace, although most of it has been removed by erosion. The remaining part rises nearly 30 m above the river plain, and further south at Åbrekk another terrace remnant can be traced as a narrow ledge along the valley side at the same altitude (84 to 86 m a.s.l.). This correponds to the Langvin level, and if these terraces are marine, the Langvin level must have been maintained for a fairly long period, or the ice recession must have proceeded rather quickly. However, there is also the possibility that an outlet glacier from Myklebustbreen or from plateau glaciers on the eastern side of the valley could have descended down to the Oldevatnet, thereby creating an ice-dammed lake in the southern part of the valley. The terraces at Myklebust (Appendix) are probably marine.

In Nedstryn the valley floor is totally buried beneath marine and fluvial deposits, but the only clear terraces at higher altitude are those of Øvreeide and Kyrkjeeide, which correspond to a level somewhat below the Langvin level.

Gloppen—Breim

In this area most of the terraces inside the Nor glacier margin have previously been described by Rye (1963, p. 113). The marine levels of Kleivedam and Vassenden and the altitude of the large Re terrace correspond exactly to the Nor sea level, and so approximately does the upper level of Førde, at the southern end of Breimsvatnet, even though this level (91 m) is perhaps a little too high. Consequently, the terraces of Re and Førde are probably marine. Rye correlated the Re level with the lower terrace at Førde and not the upper one; however, this does not fit in with the isobase map. In addition, a considerable fan-delta was built extra-laterally outside the westernmost moraine at Re (p. 26). This deposit extends nearly 400 m westwards, and gradually assumes the character of a relatively narrow terrace with a sharp outer edge. The surface slopes down evenly from 100 m at the apex to the foremost edge, where the altitude remains nearly constant (82 m near the river and 80 m furthest to the west, where the terrace disappears on the mountain slope). This corresponds to the Nor sea-level.

Accordingly, it appears that this level was still maintained during the deposition of the Re moraines, which, therefore, may be a little older than the Vinsrygg moraines. If, however, the upper fan-delta of Utvik is taken as proof of the existence of a Nor sea-level in the main fjord east of Anda, they may be of about the same age.

All the higher terraces of the Breimdalen valley most probably are to be referred to various glacial lake levels (p. 26). Along the western side of Breimsvatnet lower terraces occur at the mouth of Myklandsdalen and Nesdalen. The only clear level at the latter locality lies at 71 to 73 m a.s.l.

Hyen

Inside the marginal moraine at Straume there are several terraces or fan-deltas. The most prominent one is the large and very even fan-delta deposited in front of the tributary valley of Skårdalen at Hope (Kaldhol 1912, p. 23). This accumulation closely resembles those of the Nor level described previously. The altitude of the foremost edge of the lateral ledge is nearly constant here, too, but on account of the rather great width (50 m) the rear edge lies considerably higher, almost at the same altitude (45 m a.s.l.) as the apex of the fan (46 m). The sea-level during deposition was therefore probably somewhat higher than indicated by the foremost edge, i.e. possibly about 45 m.

Further to the west, sloping erosional remnants of two other terraces or fan-deltas at altitudes of 36 to 31 m, and 52 to 49 m, indicate that the marine limit of western Hyen is possibly not higher than 45 m, as compared with 56 m outside the Straume moraine. Thus, it appears that the outlet glacier of western Hyen remained in its distal position at Straume for a rather long time. However, since Devonian boulders are generally not found inside the Nor moraines anywhere in the fjord, this glacier, too, probably retreated at the same time as the other Nor glaciers.

Review

Levels higher than the Nor sea-level

As mentioned earlier, reliable evidence of any marine level definitively above that of the Nor stadial has been found only at Naustdal, possibly also at Isane and in the Ålfoten area. The main reason why traces of higher sea-levels have proved so difficult to recognise in the field, is most probably due to the fact that these traces have been buried beneath the large, submarine fan-deltas which were built during the Nor stadial. Moreover, shore features corresponding to higher sea-levels were probably for the most part only modestly developed.

As stated earlier, the upper Naustdal terrace probably corresponds to the Vardehaug stadial. In the main fjord, there is the possibility that the Vardehaug glacier did not reach Isane, and the upper shore level here — if reliably identified — need not be synchronous with the Naustdal terrace. This latter is indicated by the difference in altitude relative to the Nor sea-level at the two localities (5-7 m and 12 m, respectively).

The Nor sea-level

Earlier attempts to construct isobases showing land upheaval in the northern part of West Norway (e.g. Rekstad (1906), Undås (1942)) have not been convincing, mainly owing to the poor data available at that time and especially the lack of reliable time correlations. The first requirement when drawing isobases must be that the terraces and shorelines used were all formed at the same time. As already mentioned, the Nor shore features constitute just that kind of synchronous level, which in Nordfjord can be traced all the way from Elde in the west to the Nor glacier front in the east. Nevertheless, the Nordfjord area is too small to form a sufficient basis for constructing an isobase map, and, accordingly, adjacent areas must also be taken into consideration. In Sunnmøre, Reite (1967) found two prominent marine levels, the upper one of which coincides with a marked stage of

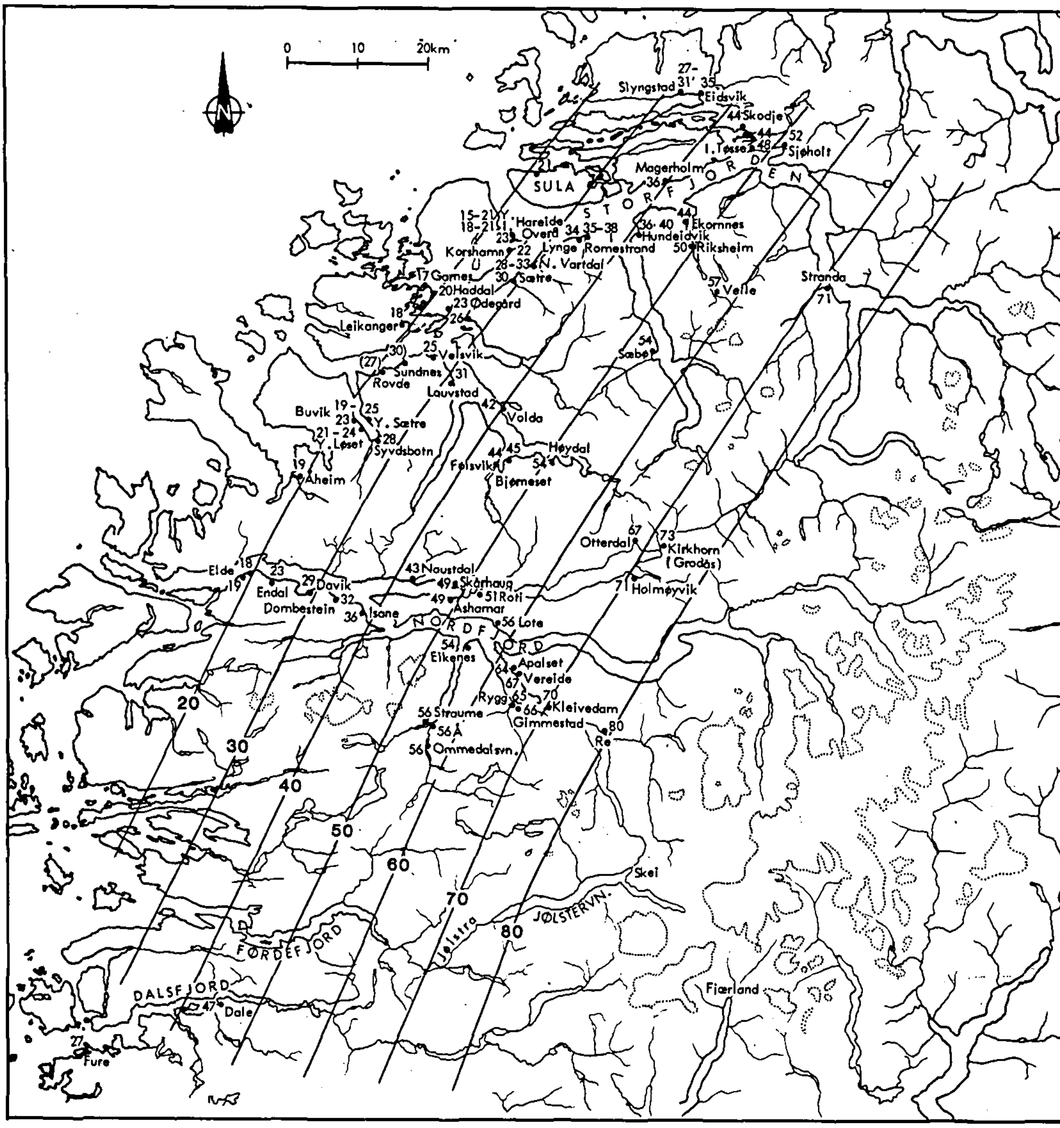

Fig. 32. Isobases showing the Nor (Main Younger Dryas) sea-level.

local glaciation, probably corresponding to the Nor stadial of Nordfjord. Outside the local moraines this upper level forms a very conspicuous abrasion terrace which can be followed continuously over long stretches. According to Reite, it is no doubt synchronous in the entire area that he investigated. Thus, the analogy to the Nor level of Nordfjord is striking, and together with the available datings, this gives reason to believe that it represents the same level. This level is prominent in most of Sunnmøre and appears to be identical with the marine level of the 'Third Ice age' (the 'Ra Time') of Kaldhol (1930). The isobase map (Fig. 32) is primarily based on the data given by Reite from the Ålesund-Sykkylven-Stranda area, and by the present author in Nordfjord. The observations of Kaldhol which are assumed to be the most reliable, notably in the inveening area, have also been used, i.e., measurements of 'Third Ice-age' terraces where the difference in altitude between the outer and inner edge does not generally exceed 2 or 3 m. With a few exceptions (shown in parentheses on the map)

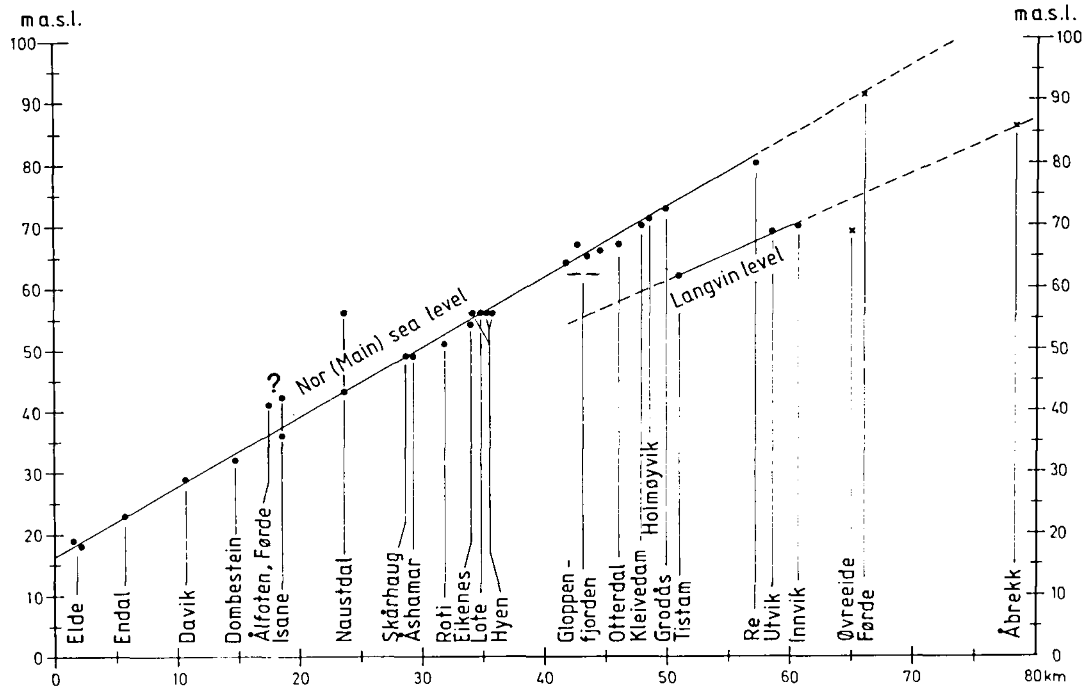

Fig. 33. Equidistant shoreline diagram for Nordfjord.

the altitudes of the latter fit very well with the isobases which can be drawn on the basis of the Nor terraces in Nordfjord and the terraces related to the local glaciation in the Sula-Sykkylven area. This strongly supports the view that all the shore features in question can be referred to the same synchronous level, i.e. the Nor sea-level.

To the southwest, the isobases of Nordfjord-Sunnmøre can easily be connected with the Younger Dryas isobases drawn by Aarseth & Mangerud (1974, p. 17) in the area between Hardangerfjorden and Dalsfjorden.

In the Sula-Sykkylven area Reite (op. cit., p. 276) found the trend of the isobases to be N37°E, which is confirmed by Lie & Lømo (1981). The present map for this area has almost exactly the same result: N36°E. In Nordfjord the trend is N30°E, and the gradient perpendicular to the isobases is nearly constant, about 1.1 m/km (Fig. 33).

Recently, Sollid & Kjenstad (1980) published a small-scale map showing Younger Dryas isobases in Middle Norway, without specifying the localities used. Their isobases essentially do not differ from those of the present map in the overlapping area.

The observations available are insufficient to draw the 0 and 10 m curves, whereas the 80 m isobase is drawn mainly by extrapolation. As mentioned earlier, the most prominent marine terrace level in the eastern part of Hornindalsvatnet has a good fit with the Nor sea-level, indicating that the relative sea-level must have remained stable even for some time after the Nor stadial proper, at least until the Hornindalsvatnet had become deglaciated. In Breimsvatnet conditions are quite similar, since the dominating terrace level here — including the main Re level and the upper terrace at Førde — corresponds to the Nor sea-level and almost certainly must be marine.

The terraces of Hornindal and Breim are in place rather prominent, but they are by no means comparable to the shore features that developed at the corresponding level in the areas outside the Nor glacier margin. Here, the stability of relative sea-level prevailed over a much longer time span.

In the main fjord, east of Anda, no wholly reliable shore features corresponding to the Nor sea-level have been found, which possibly suggests that the fjord glacier here persisted somewhat longer than the neighbouring outlet glaciers of Hornindalsvatnet and Breimsvatnet, respectively. However, it appears more probable that the main fjord became deglaciated at least past the Innvik area at about the same time as Hornindalsvatnet and Breimsvatnet. The lack of terraces at the Nor level may have a similar explanation as in the outer part of the fjord where evidence of pre-Nor sea-levels is lacking (p. 76). The shore displacement curve (Lie & Lømo 1981) gives some support to the idea of a Nor sea-level being maintained during part of the subsequent deglaciation. This curve applies to the Ålesund area and indicates a fairly stable relative sea-level throughout the entire Younger Dryas chronozone and until about 9800 years B.P.

The Langvin level

As mentioned earlier, the large fan-deltas of Tistam, Utvik and Innvik are apparently determined by the same marine level — the Langvin level — which lies well below that of the Nor stadial. The reason why this level is distinctly developed only along the inner part of the fjord, may be that it just indicates a short interval in the relative upheaval of land. Besides, the supply of glacigenic material to the shores of the outer fjord areas was essentially over, whereas simultaneously the Tistam-Utvik-Innvik area was just deglaciated. The thick till deposits here were therefore particularly exposed to fluvial erosion and transport at that time, thus favouring fan-building activity in this area.

It appears reasonable to correlate the Langvin level with the Vinsrygg stadial. At any rate, the possible difference in age is probably rather insignificant.

The large, probably marine, Åbrekk terrace in Olden fits with the Langvin level, if one assumes isobases parallel to those of the Nor level. The Øvreeide terrace in Stryn lies well below the Langvin level and is thus younger.

Chronology

During the last decades much work has been done in southern and western Norway in elucidating the late glacial history of the various areas, notably the trend of the 'Ra' moraines (references in Mangerud et al. 1979, Aa & Mangerud 1981). The position of the 'Ra' ice border in western Norway, including the connection between the Bergen area and the Nor moraines of Nordfjord, now appears to be well established. These moraines are generally accepted to be of mainly Younger Dryas age, although there are relatively few radiometric (C^{14}) dating results. At present the discussion turns primarily on the precise dating of the Younger Dryas moraines. The deglaciation pattern probably differed from one area to another, indicating that not all Younger Dryas moraines are necessarily synchronous. In Nordfjord, C^{14} datings applicable to the Nor and possibly also to the Vardehaug moraines have been made at Langeland east of Nordfjordeid (T—645). The shell-bearing clay of Langeland was described by Rekstad (1906, p. 35) and later by Kaldhol (1912, pp. 58-59, 61-70), who classified it as Yoldia clay. The fossil assemblage includes the following: *Astarte elliptica, Balanus porcatus, Hiatella arctica (Saxicava pholadis), Lepeta caeca, Macoma calcarea, Mya truncata, Nucula tenuis* and *Portlandia (Yoldia) arctica.* The shells were found about 1.5 km west of the present distal edge of Bjørlomona, in a somewhat coarse, evidently primary, glaciomarine clay. This clay was deposited in front of the nearby Nor glacier. The dated sample, containing the species *Hiatella arctica, Macoma calcarea* and *Mya truncata,* was collected by Rekstad in 1904, and the age obtained was 10440 ± 170 years B.P. (Nydal et al. 1970). The shells at Langeland probably relate to an early phase of the Nor stadial, judging from the rather thick sequence of clay (minimum 10 m) which was subsequently deposited above them. Accordingly, the Nor stadial must be referred to the later half of the Younger Dryas chronozone. This agrees well with conditions in the Bergen area.

Recently, datings made on shells from the same stratigraphic unit and at about the same level in nearby localities have supported this interpretation (T—5256: 10650 ± 160 years B.P., T—5257: 10510 ± 100 years B.P.) (Klakegg & Nordahl Olsen, pers. comm. 1983.)

At Mel, Nordfjordeid, about 2 km west of Langeland, shells obtained from a sediment which was interpreted by Mangerud et al. (1979, p. 185) as till, have an age of 10750 ± 140 years B.P. Another dating, T—5001, on shells from till below marine sediments at Skipenes, 20 m a.s.l., yielded 10930 ± 160 years B.P. (Klakegg & Nordahl Olsen, pers. comm. 1984). The dominating species were *Mya truncata,* but *Chlamys sp.* and *Balanus sp.* were also found. These two datings imply a later short-lived re-advance across the area — probably about 10700 — 10600 B.P. — and this is tentatively

Table 2. Schematic survey of glacial stadials and associated marine or lacustrine levels in middle and inner Nordfjord (reservations for certain points, see text).

Stadial	Marine level	Location of glacier front			Age
		Hornindalsvatnet	Main fjord	Gloppen/Breim	
Davik stadial			Lateral moraines along the southern fjord side east of Davik, no frontal deposits known		Older Dryas?
Vardehaug stadial	Possibly evidenced at Naustdal (Isane, Ålfoten?)	Naustdal	Possibly at Krokeneset: lateral moraines along both sides of the fjord, no frontal deposits	Possibly at Krokeneset: Only lateral moraines	Early Y. Dryas 10600 — 10700 (T—2304, shells in till at Mel, Nordfjordeid: 10750 ± 140 yrs B.P., T—5001, shells in till at Skipenes, Nordfjordeid: 10930 ± 160 yrs B.P.)
Nor stadial	Nor level	Nor (Hornindalen glacial lake)	Anda	Rygg-Kleivedam Vassenden (Nesdalen glacial lake)	Younger Dryas (T—645, T—5256 and T—5257, in proglacial marine clay 4 km west of the glacier front at Nor, deposited in an early stage of the readvance: 10440 ± 170 yrs, 10650 ± 160 yrs, and 10510 ± 100 yrs B.P., respectively)
Vinsrygg stadial	Langvin level	Between Innvik and Stryn (lateral moraines on both sides of the Stryn valley, no frontal deposits)		Re (Breheimdalen glacial lake)	Early Pre-Boreal
Eide stadial	Possibly evidenced at Øvreeide (Stryn)	Øvreeide (Stryn), Eide (Olden), possibly Loen		Sanddal	Pre-Boreal (T—616, shells in marine clay 2 km proximally to the Eide moraine, and, consequently, younger than this moraine: 9390 ± 200 yrs B.P.)

correlated with the Vardehaug moraines. This agrees well with the impression obtained from these moraines, which are generally much less developed than those of the Nor stadial. Otherwise, the Vardehaug moraines must be older, perhaps of late Bølling or Older Dryas age, possibly corresponding, for example, to the Skarpnes moraines in Troms (Andersen 1968, pp. 74-75). If so, the readvance carrying the Nordfjordeid shells must be due to a more episodical early Younger Dryas event not represented by marginal moraines.

At Kråkenes, on the outermost coast of Nordfjord, datings obtained by Mangerud et al. (1979, p. 184) indicate that the Kråkenes cirque moraine must be exclusively of Younger Dryas age.

The only available dating from neighbouring areas is that from Kalvatn, Austefjord, giving an age of 11570 ± 110 years B.P. (T—3357). This only indicates that the area in question was ice-free at that time, as could also be expected.

Concerning the glacial events immediately after the Nor stadial, datings have been made on the lowermost part of a gyttja from Langeset, Markane (9340 ± 130 years B.P., T—5812 A) and on shells from Håheim, Olden (T—616). The shells, *Acanthocardia echinata (Cardium echinatum)* and *Arctica (Cyprina) islandica*, were for the most part unbroken and were found a little more than 1 m below the normal level of lake Oldevatnet in an assumed primary marine sediment. The dating was made on a large specimen of *Arctica islandica*, giving an age of 9390±200 years B.P.. As the shell-bearing clay is found 2 km south of (proximally to) the Eide moraine, it provides a minimum age for that moraine. On the other hand, the Eide moraine most likely post-dates the Vinsrygg stadial, which in turn must be considerably younger than both the Nor stadial proper and the Nor sea-level. As already indicated, the Vinsrygg moraines reflect a period of glacial readvance. Similar events at about the same time have been reported from several areas (references in Andersen (1975), see also Andersen et al (1981)), and an early Preboreal age of the Vinsrygg stadial thus appears reasonable. The Eide stadial, which offers the youngest evidence of dynamically active valley glaciers, is probably only slightly younger, according to C^{14}-dating T—616.

Some of the pre-recent local moraines in the mountain areas, notably in Svartebotn and north of Botnafjell, are probably still younger and may be of 'Neoglacial' age.

Snow lines and glaciation limits

Snow lines — definitions and present altitudes

In the following the term 'firn line' or 'snow line' means the annual maximum height of the local snowline (Andersen 1968, p.110) averaged over a period of years with constant glacial conditions. The height of the present snow line can be determined from aerial photographs, mass balance studies, by using the maximum height of fresh lateral moraines or by the method of Østrem & Liestøl (1964, pp. 324-326). Their map of the present snow line (op. cit., p. 326) is mainly based on their method, which, strictly speaking, gives the height of the steady-state equilibrium line (Vorren 1973, p. 33) and not the snow line. The steady-state equilibrium line coincides with the snow line as defined above only when the glaciers are in equilibrium, i.e., adjusted to the present climate. Spot tests made on aerial photographs taken July 19-21, 1966 (Widerøe, series 1833), when the mean level of the temporary snow line in Nordfjord was probably very near the real modern snow line, agree very well with the map of Østrem & Liestøl. Along the western and northern side of Myklebustbreen the level of the snow-line was found to be about 1510 m (Østrem & Liestøl: 1510 m), and on Tindefjellsbreen between Loen and Oppstryn 1520 m (1540 m), confirming the view that the Østrem & Liestøl map gives a fairly good approximation to the present snow line. In the following it is therefore used as a reference when calculating snow-line depressions during ice recession times.

Snow-line depressions during ice recession times

The *Vardehaug* moraines can be traced up to an altitude of 1115 to 1120 m above present sea-level on the slopes of Blåfjell and northwest of Myklebustbreen, which is about 1030 m above sea-level during deposition. No lateral moraines correlable with the Vardehaug complex are found either on the rather gentle slopes of Skarsteinfjell or on Daurmål. In both these areas the altitude of the glacier surface must have been some 1100 m a.s.l. of that time. This indicates that the snow-line during the Vardehaug stadial was situated lower than 1100 m, probably not very much more than 1030 m above the sea-level of that time. This implies a snow-line depression as compared with the present-day level of not less than 405-410 m and a maximum of 475 m, most likely about 450 m.

During the *Nor* stadial, the depression of the snow-line, as shown by the moraines southeast of Skarsteinfjellet, was as much as 440 m. Some local moraines may indicate a slightly lower value. Thus, the cirque moraine east of Storeggja can be traced up to an altitude of 855 m, which is about 815 m above the Nor sea-level. This implies a maximum depression of the snow-line of only 385 m. However, the altitude of the present snow-line may be slightly underestimated, and the moraine need not necessarily refer to the Nor stadial, even though this is very probable. In the Devonian area, just south of the main fjord, lateral moraines can be traced up to altitudes of 960 m, i.e. 910 m above the Nor sea-level, and even 1080 m (1030 m) just north of Gjegnalunden, giving a snow-line depression of only 350 m and 230 m, respectively. It should be noted, however, that these values may be inaccurate because of the steep seaward drop of the present-day snow-line in this area (nearly 10 m/km). In addition, the highest-lying moraines (1080 m) may possibly be younger than the Nor stadial. Further inland, the only local moraines approaching the critical altitude are those of Storlogbotnen, but here the Nor

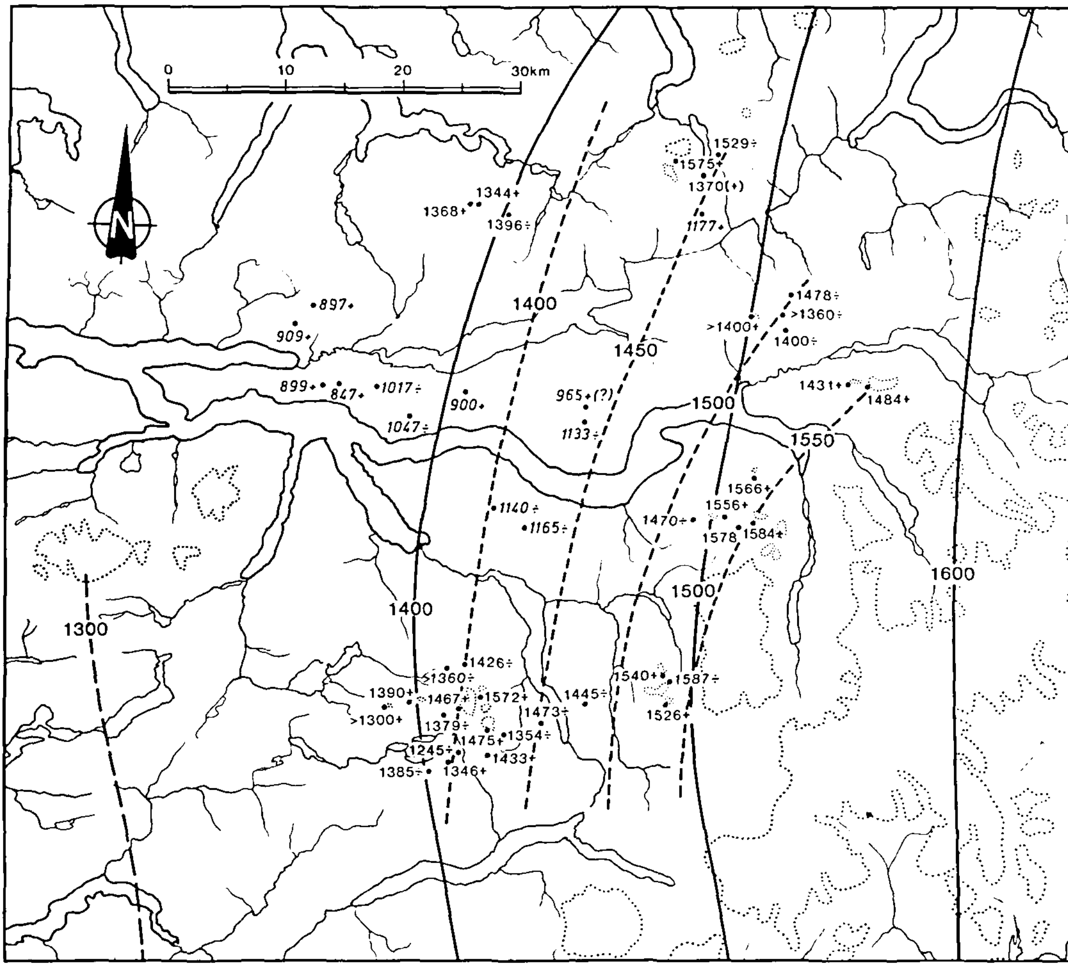

Fig. 34. Glaciation limits.
Heavy lines: (1300 dashed): altitude of the modern glaciation limit according to Østrem & Ziegler (1969.
Dashed: as above, according to the present author.
1566+: altitude of mountain precently glaciated
1354—: altitude of mountain presently not glaciated
899+: altitude of mountain glac'ated during the Vardehaug—Nor stadials.
847—: altitude of mountain not glaciated during the Vardehaug—Nor stadials.

moraine cannot be safely distinguished from younger ones.

Summarizing, it can be concluded that the Nor snow-line was not very much higher than that of the Vardehaug stadial, probably about 400 m below the present-day level. The very high depression (700 m) of the Younger Dryas equilibrium line recently reported by Larsen et al. (1984) from the outermost coast of Nordfjord — the extremely oceanic Vågsøy—Stad area — need not be contradictory to a lower value further inland. These 700 metres include a postulated difference of 100 m between the present climatic equilibrium line and the steady-state equilibrium line.

As regards the Vinsrygg stadial, nothing can be said for certain about the snow-line depression because, for topographic reasons, no lateral moraines are found at suitable altitudes.

Glaciation limits — definitions and present altitudes

According to the definition given by Enquist (1916), which has later been generally accepted, the glaciation limit represents the lowest altitude of a mountain at which glaciers can originate. The regional glaciation limit within an area may be calculated as the medium altitude of the glaciation limits for each mountain (the local glaciation limits), or it may be calculated by means of the summit method (Partsch 1882). Values obtained by the two methods appear to be nearly equal (Andersen 1968, p. 113). In addition, local topographic conditions must be taken into account, because the altitude of the glaciation limit does not depend only on climatic factors, but also to some degree on the shape of the mountains (op. cit., pp. 111-112).

In southern Norway, the altitude of the modern glaciation limit was last determined by Østrem (1964, p. 335, see also Østrem & Liestøl 1964, pp. 324-325), who used the summit method. The main features of his map, which is also reprinted in Østrem & Ziegler (1969, p. 33), appear to be correct, but since both maps and aerial photographs available now are much better than those existing in 1964, some adjustments have been made by the present author (Fig. 34).

North of the Stryn valley the regional glaciation limit can be determined by the summit method to about 1440 m, based on the mountains 1478 and 1400, but because both these summits are of the type D according to the classification of Andersen (1968), the real value may be somewhat higher, probably about 1500 m.

North of Hornindalen a little local glacier — at present probably only a perennial snowfield — existed in recent times on the mountain 1370, which, however, is also of type D, and the regional glaciation limit is certainly higher, presumably about 1450 m which is the value obtained by the summit method.

In the area between Loen and Stryn, too, the lowest glaciated mountains (1431 and 1487) are of type D, and the regional glaciation limit, therefore, must be higher and probably even higher than the level (1500 m) which can be calculated by using the summit method.

South of the main fjord, the glaciation limit at Skarsteinfjellet (1566), which carries a very small glacier and large perennial snowfields, can be estimated to some 1550 m, and the same value appears to be appropriate also for the area southwest of the Innvik valley. The map of Østrem gives some 1510 to 1520 m in these areas, and his values are possibly somewhat low also further to the southwest, in the area between Myklebustdalen and Våtedalen (some 1490 m), as compared with the 1540 m obtained by the summit method.

In the Botnafjell region the figures obtained from the new maps and aerial photos are not essentially different from those given by Østrem (about 1405 and 1420 m, respectively, at Botnafjell).

The late-glacial lowering of the glaciation limit

No local moraines of Vardehaug age have been recognised for certain without being complemented by Nor moraines in the same localities. In the following, therefore, these two stadials are treated together.

In the area between Eidsfjorden, Hjelmelandsdalen and Stigedalen several mountains occur at a level of about 900 m or slightly higher, among which only Blåsvednyken (909) and Kringlevassegga (897) were certainly glaciated. This implies a depression of the glaciation limit of about 475 m [1325 - (900-50)].

South of the western part of Hornindalsvatnet the regional glaciation limit can be determined by the summit method to (945—60)m = 885 m, assuming that Svarteggja (1047) was not glaciated (no moraines seem to exist); alternatively the limit would be 870 m if Sagetennene (1017) is considered to be highest unglaciated mountain. Both these values are likely to be a little too low because the lowest glaciated mountains are of the type D or E. The resulting depression of the glaciation limit compared with the present level (1350 m) was probably less than 500 m.

No marginal moraines are found at Bergsetnakken (1133), implying that the local glaciation limit here was higher than 1060 m (1133-75), at least during the Nor stadial, whereas the present level is about 1450 m. However, this mountain is of the type B, and the regional glaciation limit, therefore, was probably lower than 1060 m. If the moraine in front of Klebergsvatnet is interpreted as being deposited by a local glacier during the Nor stadial, this gives a glaciation limit as low as 965 m -75 m = 890 m. The regional glaciation limit determined by the summit method then becomes 975 m, i.e. the depression was 475 m.

South of the main fjord the landscape is characterised mainly by high-lying plateau mountains, and the only area suited for determinations of late glacial glaciation limits is that of the Svinestrand massif. No evidence of local glaciers is found here, even though a depression of the glaciation limit of less than 350 m [1425 - (1165-75)] should theoretically be sufficient. However, the local glaciation limit here was evidently higher than the regional one (mountain of the type A), so that even a depression exceeding 400 m was probably too small to create glaciers.

Summarizing, the late-glacial depression of the glaciation limit can be estimated to somewhere between 400 m and 500 m, most probably about 450 m. This conclusion applies to both the Vardehaug and the Nor stadial. Depressions of a similar magnitude, referring to Younger Dryas glacial events, are reported from various parts of western and northern Norway (Andersen 1975, with further references).

Marginal moraines that are definitely younger are found essentially in localities where the glaciation limits was not necessarily much lower than the present level. Consequently, little or nothing can be said about the lowering of glaciation limits during stadials subsequent to the Nor stadial. The only exception is the moraine north of Sandfjellet, Hornindal, which implies a depression of the glaciation limit of not less than 340 m [1450 - (1177-70)]. If the moraines (3) in Hjortedalen are tentatively correlated with the Vinsrygg stadial, the moraine in question (4, Pl. 3) must be younger than that. However, it need not be synchronous with any particular stadial as shown by the evidence from the valley and fjord glaciers.

Conclusions

In the Nordfjord area the various events during glacial regression are clearly recorded. The main features of the late glacial history of the area are summarised in Table 2.

Little is known as yet about the timing and extent of the Davik stadial, but an Older Dryas age is tentatively proposed. Concerning the next oldest stadial, the Vardehaug stadial, an Early Younger Dryas age (10700 - 10600 years B.P.) seems probable, on the basis of radiocarbon dates in the Nordfjordeid area.

The main Younger Dryas re-advance — corresponding to the Nor stadial — took place during the later part of this period, as was also the case in the Bergen area (Mangerud et al. 1979). The glacier front was situated at Nor, Anda and Rygg, approximately 15-20 km inland from the Vardehaug front. The Nor stadial is by far the most obvious late glacial event in Nordfjord, and almost all thick glacigenic deposits are closely related to the Nor glacier margin.

During the Nor stadial local glaciers extended from the Devonian area to the southwest to the fjord, and Devonian boulders transported by drifting ice are common along the shores of the fjord on the outer side of the Nor glacier front.

In upper Hornindalen an ice-dammed lake drained northeastwards across the present watershed. Several prominent shorelines and terraces correspond to this level.

The Nor marginal zone usually includes 3 or 4 parallel morainic ridges. The vertical extent of the marginal zone increases inland, to approximately 250 m, indicating vertical downmelting for a rather long time, while the glacier fronts were continuously resting on the thresholds of Nor and Anda. When these frontal positions could not be maintained, there was a rapid retreat by calving. In Gloppen-Breim the retreat proceeded across land or shallow waters, and some slightly younger sandurs were formed during the latest part of the Nor stadial (Kleivedam and Vassenden).

The paleogeographic map (Pl. 2), referring to the Nor maximum, shows a marked break in the glaciers' length profile towards the plateau of Jostedalsbreen.

The retreat of glaciers after the Nor stadial was interrupted by a marked re-advance, the Vinsrygg stadial, during which prominent lateral moraines were formed on both sides of the Stryn valley. This re-advance probably occurred in the early Pre-Boreal, and the glacier front was situated in the fjord just outside Stryn.

During the last stadial, the Eide stadial (>9400 years B.P.), the fronts of the valley glaciers were stationary for some time near the heads of the innermost fjord branches.

Local moraines, mainly in front of cirques, generally reflect several stadials, but the Nor moraines, where identifiable, are the most prominent. In Hornindalen, where the local moraines are most completely developed, the next oldest moraine are the largest and probably correspond to the Nor stadial.

The Nor raised marine shoreline is particularly prominent in areas outside the Nor glaciers. Together with data from Sunnmøre (Kaldhol 1930, Reite 1967) an isobase map (Fig. 32) has been constructed. The direction of the isobases is N30°E, and the gradient 1.1 m/km. Inside the Nor glacier margin the uppermost terraces along Hornindalsvatnet and Breimsvatnet, though less prominent than outside, correspond to the Nor sea-level. This indicates that the Nor sea-level was maintained for some time after the Nor stadial proper. The Langvin level, which is recorded along the main fjord east of Anda, lies somewhat below the Nor sea-level, and probably corresponds to the Vinsrygg stadial.

In the fjord outside the Nor glacier margin evidence of higher sea-levels has been found only at Naustdal; higher sea-levels possibly also occur at Isane and in Ålfoten. In most localities traces of former higher sea-levels were probably removed or buried beneath the large fan-deltas formed during the Nor stadial.

The lowering of the firn limits and glaciation limits during the Vardehaug and the Nor stadials is estimated at approximately 450 m, regardless of any possible difference between the climatic equilibrium line and the steady state equilibrium line. This is somewhat less than reported by Larsen et al. (1984) from the outermost coast of Nordfjord (Stad-Vågsøy). The existence of Vardehaug marginal moraines immediately below the sub-recent (Little Ice-Age) moraines on the northwestern side of Myklebustbreen, may indicate a precipitation shadow effect, caused by the large Ålfoten-Gjegnalund ice-cap. Thus the climatic difference between outer and inner Nordfjord, which is rather great at present, was possibly greater during the Late Glacial.

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Appendix

Marine levels

(some other observations closely connected with these levels are also included. f.e. — foremost edge; r.e. — rear edge).

Locality	Map reference	Description	Measurements m.a.s.l.	Corresponding sea-level: Lower levels	Nor marine level	Higher levels
Elde	105—694	The fan's apex, southern side of the river	22			
	104—694	Foremost edge of the fan, northern side	19			
	106—695	Westernmost part of the lateral ledge, here 10 m broad and horizontal, 25 m east of the transition to the fan proper	19		19	
	114—698	Northern end of the lateral ledge	18 (r.e.)			
Endal	146—689	Lateral ledge, here 20 m broad, r.e. measured on the lower side of the road	22 (f.e.) 23 (r.e.)		23	
Davik	189—667	Nearly flat area near the foremost edge of the fan, western side of the river, just above the quay	26			
		Somewhat obscure flattening higher up on the same fan, by the local road	30		29	
	195—669	Somewhat sloping erosional terrace in till, maximum 25 m broad, at the north-eastern corner of open grazing area east of easternmost farm	25 (f.e.) 29 (r.e.)			
Dombestein	236—667	Western side of the river, large flat	31 (f.e.) 32 (r.e.)			
	237—666	Between two brooks west of the old farm houses, rest of a flat	32		32	
	238—667	Just east of the river, by a farm road, flat area near the foremost edge	32			
Isane	273—665	Between the two northernmost farms, ledge 12 m broad and flat	35			
	274—652	40 m north of the northern river, a touch of flattening above the main level	42			
	274—649	30 m broad flat covered with some superficial deposits	35 (f.e.) 36 (r.e.)		36	42?
	274—647	South of the old school house, sharp rear edge measured on the road	35 (f.e.) 36 (r.e.)		(mean value applying to the central part of the area)	
	278—644	Measured on the road at a marked break in the profile (the flat is here somewhat sloping)	36			
		The same locality, a touch of flattening in solid rock	45 (f.e.)			

Locality	Map reference	Description	Measurements m.a.s.l.	Corresponding sea-level: Lower levels	Nor marine level	Higher levels
	281—636	South of the southernmost farm, north of the southern river, ledge 25 m broad	38 (f.e.) 39 (r.e.)			
		The same locality, a touch of flattening in solid rock	45 (f.e.)			
Ålfoten	246—605	r.e. measured just above the river	36 (f.e.) 37 (r.e.)			
		Upper level (the same locality) obscure, undulating surface, possibly rock determined	45 (f.e.)		37	
	249—608	Near little bridge crossing the northern brook	35 (f.e.)			
Ålfoten, Sigdestad	246—602	Nearly horizontal terrace, by a barn at the edge of the terrace	22	22		
Ålfoten, Førde	228—585	Foremost edge of large fan, by the road	42			41?
	228—584	as above, 100 m further south	40			
Naust-dal	353—696	Lower terrace, by the way down to the gravel pit	42 (f.e.) 43 (r.e.)			
		Upper terrace, the flattest part, at the churchyard entrance	53 (f.e.) 56		44	56
Løken	355—693	On the road, by the edge of the forest	46 (r.e.)			
Skårhaug	405—686	Just west of the brook	48 (f.e.) 49 (r.e.)		49	
Mel	409—686	300 m east of the Skårhaug brook, nearly horizontal erosional terrace, maximum width 20 m	48 (f.e.) 49 (r.e.)			
Taklo	402—667	Narrow abrasion terrace	48 (f.e.) 49 (r.e.)		49	
Åshamar	412—667	Narrow abrasion terrace	47 (f.e.) 49 (r.e.)			
Roti	436—672	Western end of narrow, horizontal terrace ledge which (eastwards) is connected with the Bjørlomona deposit, by the main road	51		51	
Bjørlo-mona	451—680	Foremost edge, north of former camping place	55			
Leivdals-mona	468—687	Western gravel pit, by cross-roads where the western road to Leivdal branches off from the main road	62	Supra-marine		
	474—685	120 m west of former kame	67			
	479—692	Highest part, by the eastern road to Leivdal	73			

Locality	Map reference	Description	Measurements m.a.s.l.	Corresponding sea-level: Lower levels	Nor marine level	Higher levels
Holmøyane	642—698	Holmøy working school, rear edge measured on the upper side of the houses	64 (f.e.) 71 (r.e.)		71	
Holmøyvik	663—701	Lower terrace, at the gravel pit	59 (f.e.) 61 (r.e.)	61 (lacustrine)		
		Upper terrace, the same locality, horizontal flat just east of the easternmost farm west of the river	71		71	
Otterdal	662—753	West of the river, 25 m broad terrace	88 (f.e.) 89 (r.e.)			
	663—750	East of the river, the terrace upon which the farms are lying, by the road up from the boathouses	67 (f.e.)		67	89 (lacustrine)
	663—753	East of the river, upper terrace	89			
Grodås	702—741	N—S-trending abrasion terrace along the valley side, measured less than 100 m south of a farm lying on the terrace, which is here 15 m broad and horizontal	73		73	
Hyen, Hope	332—478/480	The uppermost and westernmost fan, measured on the southern side of the road	49 (f.e.) 52 (r.e)			
	342—485	Rest of a fan, just above the westernmost farms	31 (f.e.) 36 (r.e.)			
	350—489 351—491	The fan at the mouth of Skårdalen, western side, by the river	41 (f.e.) 46 (apex)	45		
	348—489/490	Ditto, the lateral ledge, 300 m west of the river, 30 m east of rock promontory	41 (f.e.) 45 (r.e.)			
Hyen, Straume	370—395	10 to 25 m broad abrasion terrace in the Straume moraine (marine limit)	56			
Hyen, Å	376—483	Just above the boat builders' yard, r.e. measured on both sides of rock promontory, 40 m from f.e.	52 (f.e.) 56 (r.e.)		56	
Hyen, south of Å	375—477	Marginal deposit, measurement made on a 30 m broad horizontal area furthest to the west just south of the river from Ådalen	56			
Hyen, Ommedalsvatnet	373—465	Marine limit on marginal deposit	56			

Locality	Map reference	Description	Measurements m.a.s.*l.*	Corresponding sea-level Lower *levels*	Nor *marine* level	Higher *levels*
Eikenes	424—596	Narrow (10 m) terrace ledge, distally to and separated from the Hestenes fan	53 (f.e.) 55 (r.e.)		54	
	420—591 421	Prominent terrace ledge, separated from the preceding one, maximally 40 m broad	51 (f.e.) 53 (r.e.)			
Lote	465—632	Terrace maximally 100 m broad, forming the southern, distal part of a fan, r.e. measured just south of the road to Lotsberg, where the terrace is 60 m broad	52 (f.e.) 56 (r.e.)		57	
	465—635	Gravel pit just north of the river, top of topset layer	57 (f.e.) 58 (r.e.)			
	462—634	North of the river, minor terrace	23 (r.e.)			
Hjelmeset	474—591	Altitude of passpoint, ice-rafted Devonian boulder found here	60		62	
Apalset	492—571	Broad marine flat made up of sediments, inner part (30 m) nearly horizontal and sharply contrasting to the rock behind, f.e. not clearly marked (gradually increasing slope)	64		64	
Vereide	498—561	f.e. of Vereide fan, just south of the road down to the sea	67		67	
	503—568	The fan's apex	104			
Rygg	486—522	Marine limit proximal to the Rygg moraine, 150 m SE of crossroads	65		65	
	491—518	As above, 550 m SE of the preceding	65			
Gimmestad	496—518	Marine flat just west of the northwestern end of the distal Gimmestad moraine	66		66	
Re	625—480	Extralateral fan associated with Re marginal moraines, f.e. measured by the river	82		80	
	622—482	As above, f.e. measured at its north-western end, 400 m from the river	80			
Ytre Kandal (north of Nesdalen)	611—432	Just south of the river, somewhat sloping terrace	71 (f.e.) 73 (r.e.)			
Henne-bygda	542—620	Just east of the eastern river lower terrace	6			
		Just east of the eastern river upper terrace	12 (f.e.) 14 (r.e.)			

Locality	Map reference	Description	Measurements m.a.s.l.	Corresponding sea-level: Lower levels	Nor marine level	Higher levels
Tistam (Frøyset)	622—568	SE-corner of horizontal terrace, by the southernmost farm (the same level is found north of the river)	19			
	618—568	Foremost edge of large fan, by the gravel pit	62 (f.e.)	62		
Utvik	698—549	East of the river, erosional remnant of a fan, r.e. measured 0.5 m above the level of the local road	91 (f.e.) 93 (r.e.)			
	698—550	Large fan, nearly horizontal foremost part, r.e. measured just below f.e. of the upper fan	69 (f.e.) 84 (r.e.)	69		
Innvik	753—597	Langvin, large remnant of fan, f.e. furthest away from the river (from detailed topographic map)	70 (f.e.)	70		
Stryn, Kyrkjeeide	839—676	'Sete'-like terrace along the valley side, 40 m from western end, here 15—20 m broad	68 (f.e.) 70 (r.e.) 68 (f.e.)			
	842—676	As above, eastern end, here 40 m broad	69 (r.e.)			
Stryn, Øvreeide	860—680	Westernmost part of the Øvreeide terrace, 20 m broad horizontal area near f.e. just above gravel pit, rear edge at the base of the mountain	69 (f.e.) 72 (r.e.)			
Olden, Brynestad	850—568	Sloping gravel cone, f.e. not necessarily corresponding to any particular level	88 (f.e.)			
Olden, Åbrekk	844—408 845—408	Large terrace north of the farms, (70 m · 100 m)	84 (NW-corner) 86 (SE-corner)			
Olden Myklebust	839—413	Lower terrace level, f.e. measured furthest to the north, r.e. 40 m further south	59 (f.e.) 60 (r.e.)			
	839—412	Upper terrace level, flat, eastern corner, 60 m from the houses	71			

LEGEND

- Marginal moraines deposited by fjord or valley glaciers
- Marginal moraines deposited by local glaciers
- R Marginal moraines deposited by local glaciers, presumably of subrecent age (1750 or younger)
- Marginal moraine, faint or obscure
- E Esker
- Thick till deposit
- Extensive, continuous cover of till
- Boulder field
- Marginal deposit, mainly glaciofluvial, with terrace slopes, depositional or erosional
- Ice-contact slope
- Approximate location of the ice margin during Nor maximum
- Approximate location of Vinsrygg ice margin
- Terrace or fan with terrace slope, depositional or erosional
- Canyon
- Melt water channel
- P. Potholes
- Glacial striae, ice movement towards the observation point
- Glacial striae, direction of ice movement not decided
- youngest / oldest Crossing glacial striae
- Crescentic gouges
- Crescentic marks
- Fluted moraine
- 12 Percentage of Devonian boulders (among total number of boulders > 30cm)
- + Devonian boulders occur sparsely
- ÷ Devonian boulders not found
- × Locality of C^{14}-dated shells
- T - 616 9390 ± 200 Radiocarbon date, lab.-no. and age

Abbreviations:

- B. - Blåsvednyken
- Br. - Breidalen
- H. - Hestenesøyra
- Ka. - Kalvegeilsbotnen
- Ky. - Kyrkjeeide
- Ni. - Nigarsvatnet
- No. - Nonselvvatnet
- R. - Rjupedalen
- Ø. - Øykjeheia

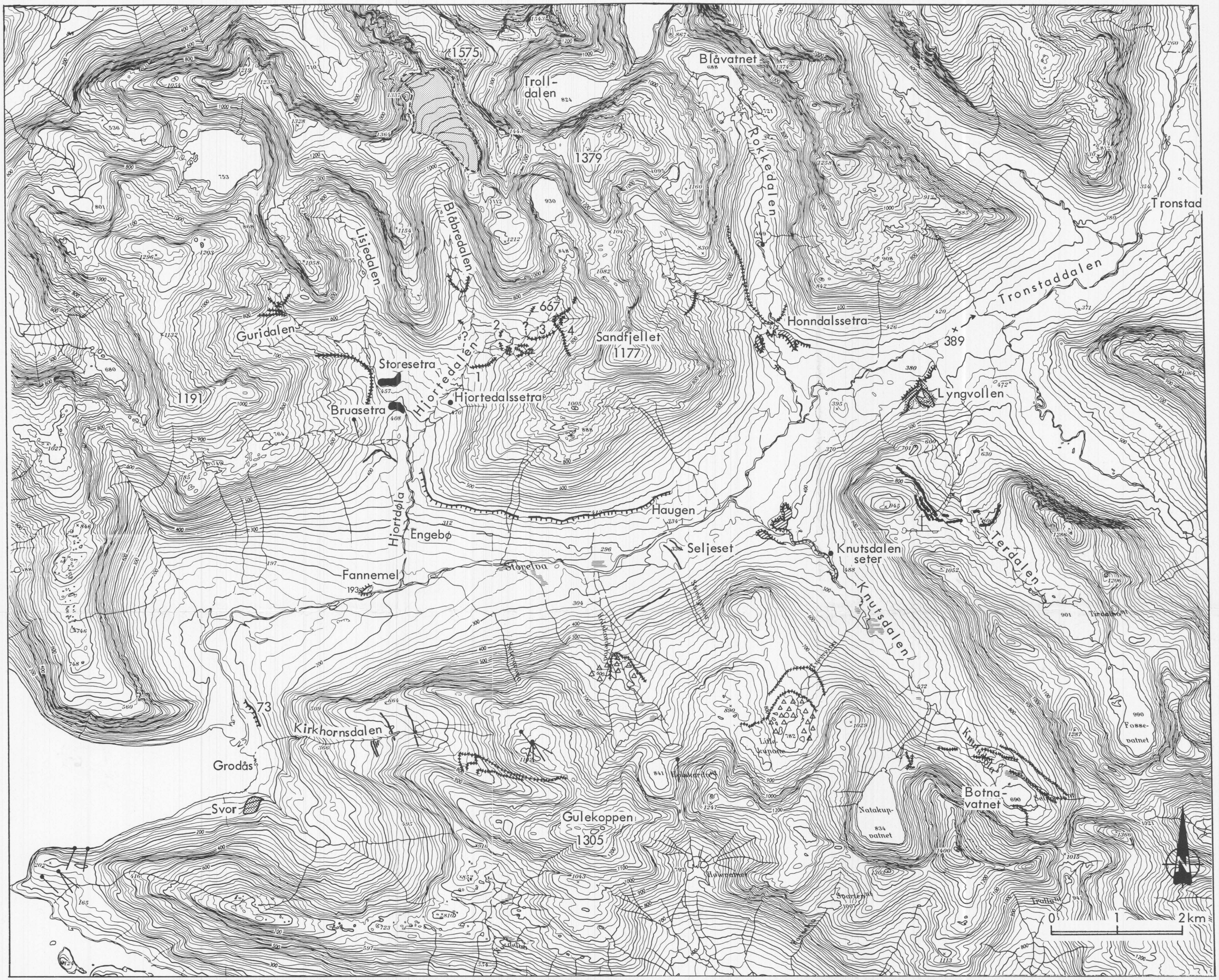
GLACIAL GEOLOGY OF MIDDLE AND INNER NORDFJORD

By Olav W. Fareth

Basic map: NGO Series M 1501
Contour interval: 100m (thicker contours: each 500m)
Subaequatic contours according to H. Mosby (unpublished), in the lakes according to Strøm (1933)

0 5 10 15 20km


Pl. 2
PALEOGEOGRAPHIC MAP OF THE NOR STADIAL
By Olav W. Fareth
Basic map: NGO Series M 1501
Contour interval: 100m (thicker contours: each 500m)
Altitudes in metres above present sea level
Subaequatic contours according to H. Mosby (unpublished)
Marginal moraine
Sandur
0 5 10 15 20 km
VOLDAFJORDEN
DALSFJORDEN
AUSTEFJORDEN
GEIRANGERFJORDEN
NORDFJORD
ISEFJORDEN
EIDSFJORDEN
HORNINDALSVATNET
STRYNSVATNET
Stryn
Loen
Olden
INNVIKSFJORDEN
UTFJORDEN
HUNDVIKFJORDEN
ÅLFOTEN
GLOPPENFJORDEN
HYEFJORDEN
Sandane
BREIMSVATNET
JOSTEDALSBREEN
Skei
JØLSTRAVATNET
GROVE-
BREEN
FØRDEFJORDEN
N



Present glacier

Marginal moraine, deposited by fjord or valley glacier

Marginal moraine, deposited by local glacier

Marginal moraine, deposited by local glacier, presumably of subrecent age

Marginal moraine, faint or obscure

Glaciofluvial deposit with terrace slope

Thick till deposit

Boulder field

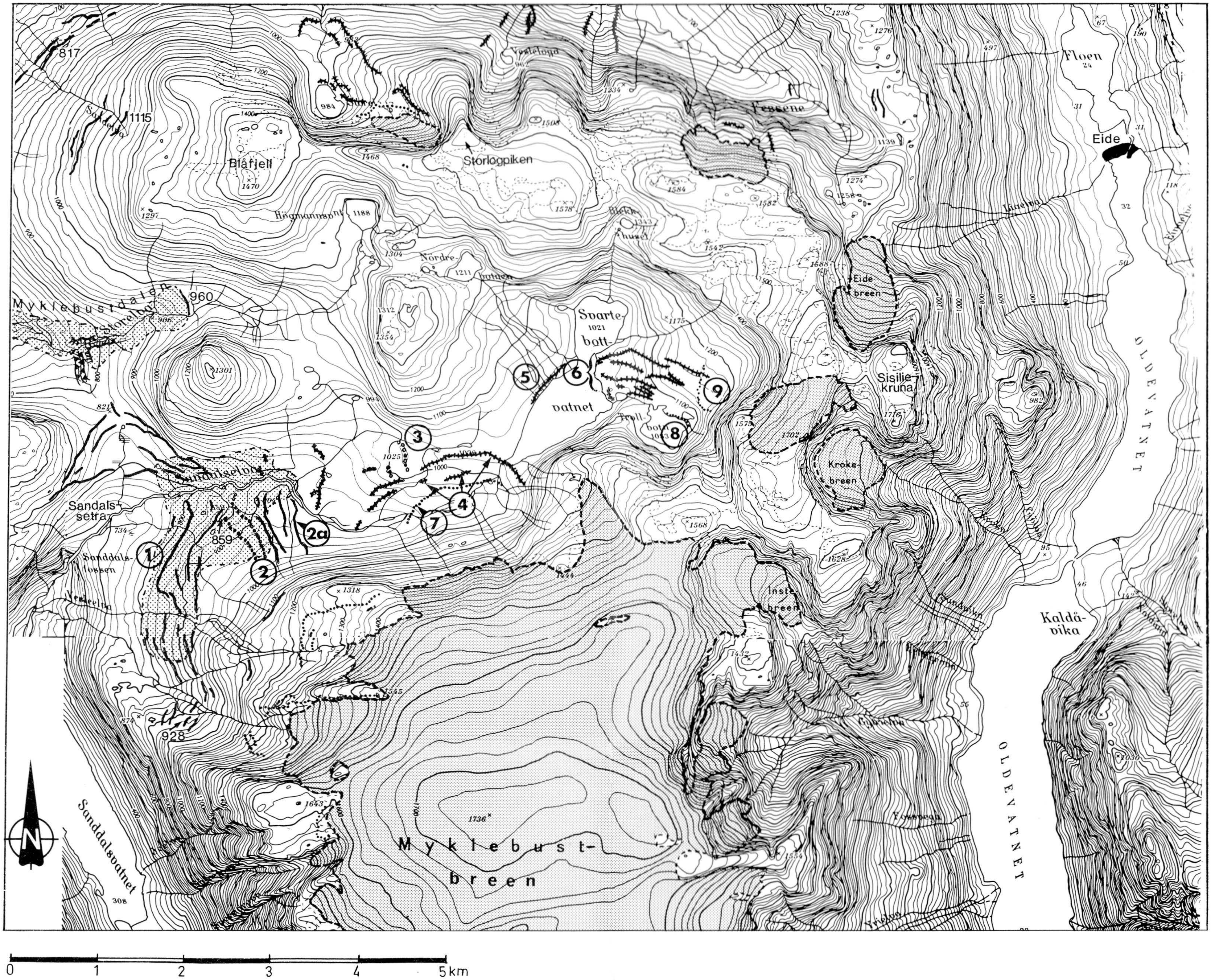
Canyon

Glacial striae

3 Numbers refer to text

Other numbers: metres above present sea level

Map of the Sandalssetra – Svartebotn area



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