The Deglaciation of the Coastal Area NW of Svartisen, Northern Norway

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Rasmussen A. 1981: The deglaciation of the coastal area NW of Svartisen, northern Norway. *Norges geol. Unders. 369*, 1–31.

Late Weichselian glacial events, marine fauna and shore-lines in the coastal area NW of Svartisen are described. During the oldest glacial event (Vassdal event), marginal moraines were deposited near the mouths of the fjords. A Bølling or Older Dryas age is deduced for this event. A comprehensive Allerød deglaciation was followed by a re-advance of local glaciers in early Younger Dryas (the Glomfjord event). As a result of strong frost-shattering along the shore and a relative stable sea-level, a distinct shore-line corresponding with the Glomfjord event was formed along the sides of the fjords during the period 11.600–10.500 years B.P. The transition from arctic to boreal conditions in the fjords occurred later than 10.800 years B.P., but before 9.200 years B.P.

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Introduction

AREAL DESCRIPTION

The strongly dissected landscape within the investigated area is characterized by deep glacial valleys, fjords and cirques (Fig. 1). The main fjords and valleys are separated by montaineous areas with numerous alpine peaks 800 m to 1500 m high, whereas the coast is dominated by a 10–15 km wide strand-flat lying between 50 m b.s.l. and 100 m a.s.l. The highest mountains are presently glaciated, and the largest glacier, Svartisen, consists of two plateau glaciers, together covering an area of 369 km² (Østrem et al. 1973). North of these are several small plateau, cirque and hanging glaciers, the largest being Glombreen with an area of ca. 8 km².

The limit of glaciation is defined as the lowest altitude at which glaciers can be formed (Andersen 1968). By means of the 'peak method' described by Partsch (1882) and Enquist (1916), this has been calculated at 4 localities within the investigated area (Fig. 2). These calculations indicate that the present glaciation limit rises from ca. 1100 m a.s.l. near the head of Glomfjorden to ca. 1200 m a.s.l. in the eastern part of the area. This is in relatively good accordance with earlier calculations carried out by Østrem (1964) and Andersen (1975). Assuming that the glaciation limit slopes in a westerly direction at about the same gradient as in adjacent areas (Andersen 1975), the modern glaciation limit in the coastal district is roughly 1000–1050 m above the present sea level.

The climate in the coastal area NW of Svartisen is humid maritime. The average annual precipitation and temperature at Glomfjord is ca. 1900 mm and 5.0 °C (1901–1960) respectively, whereas the average january and july tem-

Fig. 1. Location map of the investigated area. Present glaciers are shown in black.

peratures in the same period were $\div 0.6°$ and $13.3°C$, respectively (Bruun 1967).

The pre-Quaternary rocks in the area are mainly Precambrian granodioritic and monzonitic gneiss, Eocambrian–Ordovician mica-schists, quartzite and marble, and intrusive granites and ultrabasic rocks of Caledonian age (Hollingworth et al. 1960, Rutland et al. 1960, 1965, Holmes 1966, Wilson et al. 1973).

PREVIOUS WORK

Rekstad (1910, 1912, 1915, 1929) studied the Quaternary geology in the Svartisen area and mapped many terminal moraines and raised shore-lines. He collected fossil shells from raised marine deposits and concluded that 'glacial' conditions prevailed at the time that the end moraines were deposited and the highest shore-lines were formed. Since many of the moraines were deposited in the sea, Rekstad thought that the interior of the country must have been covered by a continuous ice-sheet. However, glacial striae and erratic boulders suggested that this ice-sheet had not crossed the mountain area now occupied by Svartisen. According to Rekstad, the ice movements were deflected northwards to Saltfjorden or southwards to Ranafjorden east of the mountains.

Grønlie (1940) claimed there were traces of two ice-ages in Nordland. In the oldest of these, which correlated with Saale, almost all the land and most of the continental shelf were glaciated. According to Grønlie the ice was less extensive during the youngest ice-age, and he thought that the deflection of

the ice east of Svartisen occurred during this period. Based on studies of shore-lines and moraines, Grønlie (1940, 1951) demonstrated several re-advances during the deglaciation which followed the maximum extent of the last ice-sheet. During the most pronounced re-advance, the Tromsø/Lyngen event, a considerable local glaciation occurred west of the ice-sheet. However, Grønlie did not find any shore-lines west of Svartisen which corresponded to this event, and he therefore thought that this part of the coast was entirely ice-covered during the Tromsø/Lyngen event.

This opinion was opposed by Marthinussen (1962). On the basis of shore-lines, he concluded that most of the fjords west of Svartisen were ice-free during the Tromsø/Lyngen event. This conclusion was supported by two radio-carbon dates on *Portlandia arctica* shells found in glaciomarine clays to the north and to the south of Svartisen. The shells gave ages of 10550 ± 250 B.P. and 10300 ± 250 B.P. respectively, corresponding fairly well with dates for the Tromsø/Lyngen event in northern Norway (Andersen 1968).

Page (1968) studied the stratigraphy in an end moraine at Glomen near the head of Glomfjorden. Organic material from an isolated pocket of peaty sand at the base of a freshly-cut section into the moraine on a hillside, gave a radio-carbon age of 4550 ± 170 B.P. Page supposed the peat was formed at the same time as the moraine, and he therefore believed in an extensive Atlantic/early Sub-boreal glaciation both in northern and southern Norway. However, this idea was rejected by Griffey (1977) who demonstrated that there were no extensive Holocene glaciers in the Okstindan area, and he concluded that an extensive Holocene glaciation in the Svartisen area was very unlikely.

Andersen (1975) studied the glacial geology of the Saltfjord area and the area to the north of this fjord. He mapped marginal moraines near the mouth of the main fjords, and correlated these with the Tromsø/Lyngen event. According to Andersen, these moraines correspond with a marine molluscan fauna with *Portlandia arctica*, and with a Main Shore-line (P12). Andersen presumed that a marginal moraine-zone near the mouth of Saltfjorden, i.e. at Straumøy and Sandhornøy (Pl. 1), was deposited during the Tromsø/Lyngen event, and that the *Portlandia arctica*-clay at Bodø var deposited immediately outside the ice-front during this event. A radiocarbon date on *Portlandia arctica* from this clay, gave an age of 10.930 ± 200 B.P.

As a part of a degree thesis in Quaternary geology at the University of Bergen, a field investigation was carried out by the present author along the coast NW of Svartisen during the period of 1976–1978. The main object of the investigation, which is a contribution to I.G.C.P. project 73/1/24 'Quat-ernary Glaciation in the northern Hemisphere', was to trace the Late Weich-selian deglaciation history. Some preliminary results were summarized by Andersen et al. (1979).

Ice movements

The ice movements were deduced from directional elements as defined by Vorren (1979). The features which were used most frequently are glacial
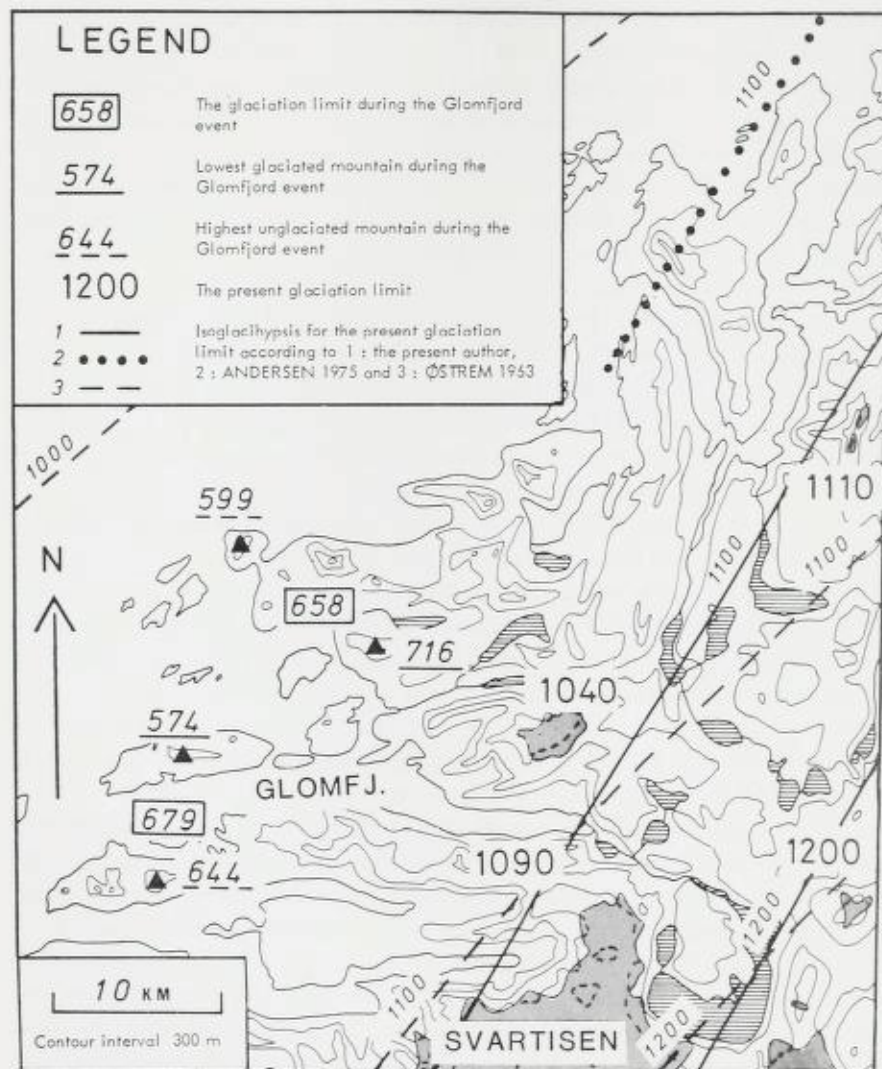
Fig. 2. Modern and Glomfjord glaciation limits calculated by means of the peak method. Altitudes in meters above present sea level.

striation, furrows, grooves and crescentic gouges. Most of the observations were made in the shore-zone where the directional elements are generally well preserved. At higher levels directional elements are often obliterated by weathering. Nevertheless, the observed directional elements give a fairly complete picture of the ice movements.

THE OLDEST ICE MOVEMENTS

The oldest directional elements demonstrate ice movement in a westerly to northwesterly direction (Fig. 3A). The variations within this sector indicate that the ice movements was influenced to some extent by the underlying topo-
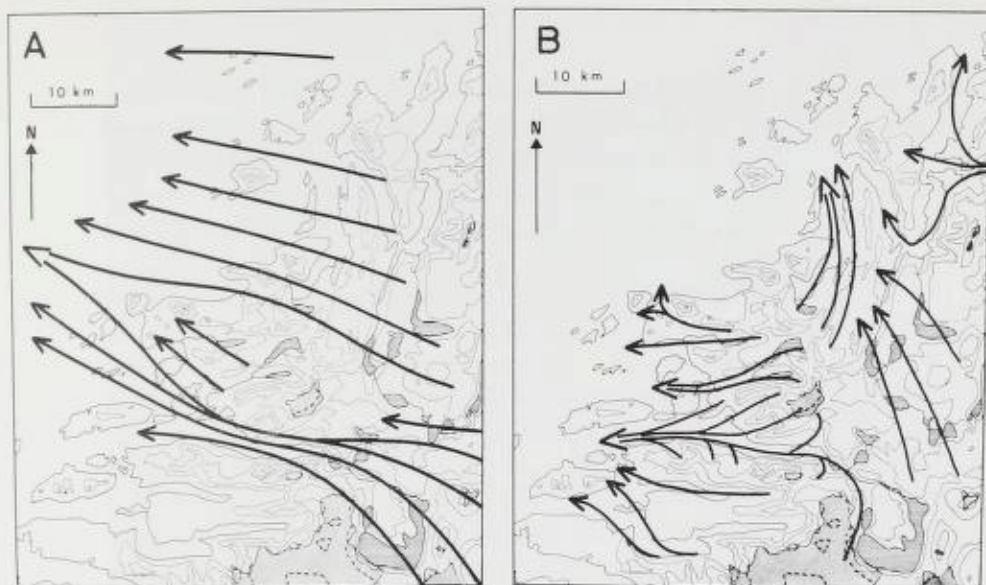
Fig. 3. Two ice-movement phases in the coastal area NW of Svartisen. A: Ice movements corresponding with maximum glaciation. B: Younger ice movements directed by topography. Shaded areas show the location of present glaciers. Contour interval 300 m.

graphy. Control by the topography seems reasonable, as the average relief of the coastal area northwest of Svartisen is 1200–1400 m. Topographically independant ice movements would require an ice thickness of at least 3600–4200 m, which is unlikely only 180 km from the edge of the continental shelf (Aseev 1968, Nye 1952).

YOUNGER ICE MOVEMENTS

The younger directional elements generally parallel the main fjords and valleys, and demonstrate that these were important drainage channels for the glaciers during younger glacial events (Fig. 3B). During the latest glacial phases, fjord and valley glaciers were dispersed from local ice culminations at Svartisen and Glombreen.

Glacial events

Most of the ice-marginal deposits in the coastal area northwest of Svartisen consist of distinct terminal moraines close to the present sea level (Plate 1). These moraines represent several *glacial events*, which are defined as *periods in which glaciers either stagnated or advanced.*

The correlation of moraines from different glacial events is based on moraine sequences, raised marine shore-lines, glaciation limits and radiocarbon dates.

THE VASSDAL EVENT

Description of moraines

On the mountain slopes southwest of Vassdal, near the mouth of Glomfjorden, a lateral moraine can be traced for about 3 km from the northern slope of Osafjell to a position north of Storalstind about 360 m above sea level. There it consists of a ca. 200 m wide moraine belt. The location of this lateral moraine shows that its eastern part was deposited by a cirque glacier which was a tributary of the glacier in Glomfjorden.

The corresponding terminal moraine lies in Åmnessund at the northern part of Åmøy, about 8 km west of Vassdal. It is a 200 m long, 100–200 m wide and 20 m high ridge projecting into the sound. Extensive glaciomarine deposits on the southern and eastern parts of Grønnøy, immediately to the north of the moraine, were probably deposited close to the ice-front.

The average gradient on the surface of the end 6 km of the fjord glacier during this event was ca. 44 m/km. This corresponds with gradients for other Late-Weichselian fjord glaciers in the northern Norway (Andersen 1968).

In the Kunna/Bolden area about 20 km north-northeast of Åmøy, there are two parallel moraine ridges. The westernmost moraine is represented by a 800–1000 m long ridge situated along the foot of the steep southeastern slope of Kunna. As a result of strong marine abrasion, the ridge is entirely covered by large, rounded boulders. The most distinctive moraine lies at Bolden 1–2 km east of Kunna where it forms a ridge 10–20 m high, 200–300 m wide, and stretching for approximately 1 km across the valley. Several gravel pits in the ridge show bouldery glaciofluvial gravel and sand beds dipping in northwest direction, as well as sections of till (Fig. 4). This demonstrates that the ridge is a terminal moraine deposited in the sea by a glacier moving from the southeast.

In the upper part of the valley between Skjeggen and Breitind, 4–5 km east of the marginal deposits at Kunna and Bolden, there is another large terminal moraine. Short stretches of lateral moraine along the mountain slopes, about 250 m above sea level, to the southwest of the terminal moraine, show that it was deposited by a glacier tounge which moved up-valley from southwest. These moraines probably correspond with the terminal moraines at Kunna and Bolden, implying a surface gradient of approximately 50 m/km for the outermost 4 km of the glacier.

Age

Since the marginal deposits in the Vassdal/Åmøy area and the Kunna/Bolden area are separated by several fjords and islands where no marginal deposits have so far been found, it cannot be excluded that they represent two glacial events of different age. However, both moraines are situated near the mouths of fjords at approximately the same distance from mountain areas, and no other marginal deposits have been found which could possibly correspond with them.

In order to obtain a minimum age for the Vassdal event, marine molluscs, collected from glaciomarine sediments along the sides of fjords to the east of

Fig. 4. Gravel pit at Bolden showing glaciofluvial ice-front deposits.

Table 1. Radiocarbon dates

Locality and sediments	Altitude	Dated shell	Age	Laboratory reference number
VASSDAL, lodgement till	15 m	*Mya truncata*, fragments	$34330 \pm {}^{1630}_{1410}$	T–2670
BRATSBERG, glacial clay	20 m	*Macoma calcarea*	11740 ± 100	T–2669
ENGAVÅGEN, glacial clay	5 m	*Macoma calcarea*	11720 ± 200	T–3080
NÆVERDAL, glacial clay	40 m	*Mya truncata*	11610 ± 140	T–2672
SANDÅ, glacial clay	10 m	*Astarte elliptica, Mya truncata* and *Macoma calcarea*	11050 ± 120	T–2372
SÆTVIK, glacial silt	3 m	*Mya truncata, Chlamys islandica* and *Hiatella arctica*	10860 ± 150	T–2374
FURUMO, diamicton	10 m	*Mya truncata*, one complete valve and fragments	10640 ± 70	T–3079
SÆTVIK, resedimentated silt	4 m	*Littorina littorea, Buccinum undatum, Gibbula ceneraria* and *Arctica islandica*	9240 ± 120	T–2373
SÆTVIK, marine sand	4 m	*Arctica islandica*	7340 ± 110	T–2671
INNDYR, marine sand	25 m	*Ostrea edulis*	4390 ± 80	T–3269

the moraines, have been radiocarbon dated (Table 1). One of the samples was collected at Engavågen ca. 4 km east of the terminal moraine in Åmnessund. In a road-cutting 5 m above sea level, a glaciomarine, boulder-bearing, silty sand contains shells of *Chlamys islandica, Macoma calcarea, Hiatella arctica* and

Mya truncata. Fresh complete valves of *Macoma calcarea* with preserved *periostrakum* gave a ¹⁴C-age of 11.720 ± 200 years B.P. Fossiliferous, glaciomarine sediments were also found at Næverdal, about 13 km north-east of Engavågen. At this locality a 0.5–1 m thick silty clay with boulders and dropstones overlies a sandy till in a ditch 40 m above sea level. The clay contains both complete valves and fragments of *Astarte elliptica*, *Chlamys islandica*, *Hiatella arctica*, *Macoma calcarea*, *Mya truncata*, *Anomia* sp. and *Balanus* sp. The fauna is dominated by large and thick-walled shells of *Macoma calcarea* and *Mya truncata*. Fresh, paired valves of *Mya truncata* with preserved *periostrakum* gave a ¹⁴C-age of 11.610 ± 140 years B.P.

These dates show that the Vassdal event is older than 11.600–11.700 years B.P. Since Glomfjorden is relatively deep on the inner side of the Vassdal moraines, the retreat from the moraines was probably rapid. Therefore, an Older Dryas or late Bølling age of the Vassdal event is considered to be most likely.

At Bratsberg about 6 km form the head of Sørfjorden, a glaciomarine silty clay containing many well-preserved, large and thick shells of *Macoma calcarea*, *Astarte elliptica*, *Astarte borealis* and *Mya truncata* was found in a river bank 10 m above sea level. Paired valves of *Macoma calcarea* gave a ¹⁴C-age of 11.740 ± 100 years B.P., which corresponds with the age of the glaciomarine sediments at Engavågen and Næverdal. Sørfjorden must therefore have been ice-free in the early Allerød.

The above-mentioned dates compares well with a date on *Macoma calcarea* and *Mya truncata* from a glacial clay on the southern side of Skarsfjorden about 7 km S–SW of Engavågen, which gave an age of 11.700 ± 150 years B.P. (T–3270). According to F. Bøen and P. N. Vallevik (pers. comm.), who collected the shells, they probably date the deglaciation of the site.

THE GLOMFJORD EVENT

Description of moraines

Glomfjorden

In Spilderdalen, Næverdalen and Selstaddalen on the northern side of Glomfjorden, distinctive terminal moraines were deposited by valley glaciers which flowed out-wards from the Glombreen area.

The terminal moraine near the mouth of Spilderdalen is about 400 m wide, and the crest of the moraine lies about 60 m above sea level. A 20–25 m high river section through the moraine shows mainly bouldery till in the eastern part of the moraine, and a thick sequence of glaciomarine silt in the western part.

In Næverdalen, about 3 km east of Spilderdalen, an arcuate end moraine lies in the inner part of the valley. The moraine, which is about 200 m wide, is very boulder-rich and has a 30 m high distal slope and a 4–5 m high proximal slope. The crest of the ridge is 95–100 m above sea level. Lateral moraines corresponding to the terminal moraine are most pronounced along the south-eastern side of the valley, where there are up to two distal ridges as much as 4 m high, and one proximal very boulder-rich ridge, 40 m high.
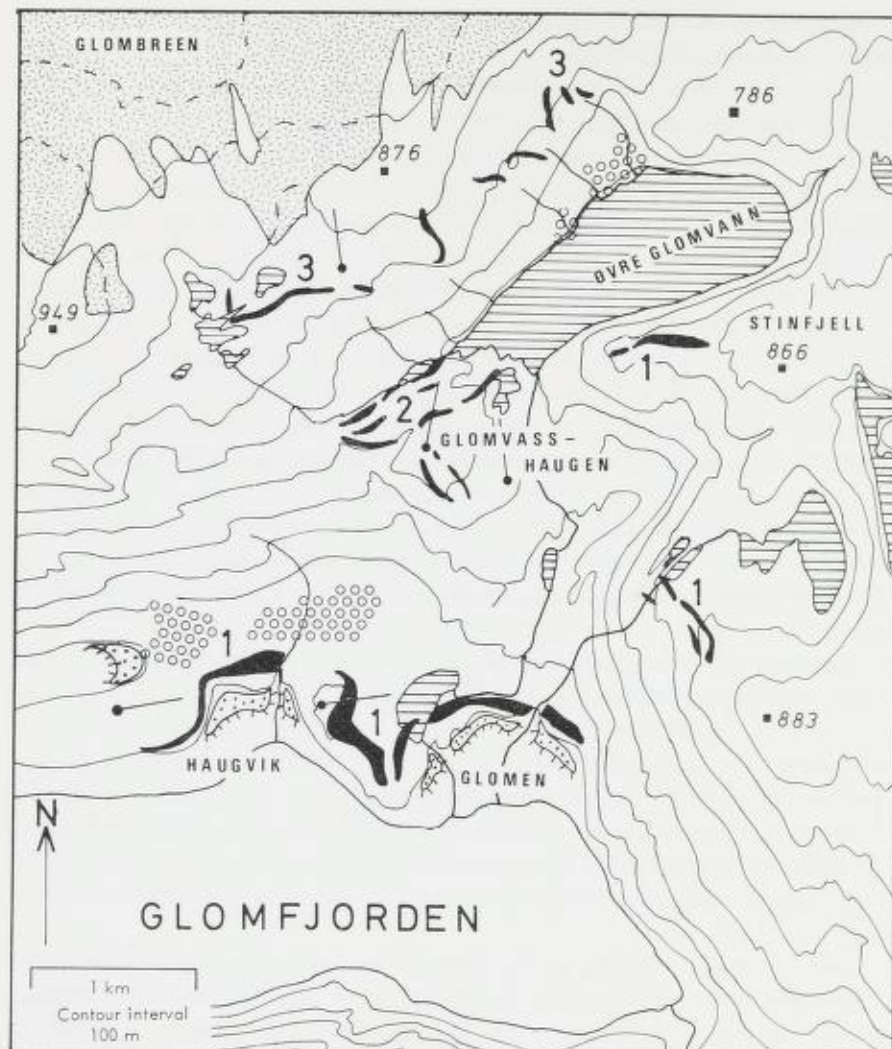
The terminal moraine at the mouth of Selstaddalen, 2–3 km south of Næver-dalen, is approximately 500 m wide and rises steeply from the fjord towards its crest about 55 m above sea level. The proximal side slopes gently towards a lake which is dammed up by the moraine 46 m above sea level.

A very distinct raised marine shore-line, characterised by terraces cut into solid rock, can be seen immediately outside the terminal moraines in Selstad-dalen, Næverdalen and Spilderdalen. This shore-line, termed the *Main shore-line* in the following, represents the marine limit in this area. At the mouth of Spilderdalen it lies about 90 m above sea level, in Næverdalen 92–95 m and in Selstaddalen 95–98 m above sea level. The Main shore-line is not present further up the valley from the terminal moraines in Spilderdalen and Selstad-dalen. Therefore, the moraines must be younger than, or contemporaneous with the Main shore-line. However, vague shore-lines and marine accumulations at approximately same height as the Main shore-line are present in these valleys. This suggests that the sea level must have also been at about the same level as the Main shore-line after the deposition of the moraines. The correspondance in shore-line development in the valleys supports correlation of the distinctive moraines described above. The corresponding glacial event will be called the Glomfjord event.

At the eastern side of Næverdalen two distinct cirque moraines are situated below a mountain which reaches an altitude of 882 m above sea level. This is about 200 m higher than the glaciation limit during the Glomfjord event, but lower than the glaciation limit during younger events (see p. 12). It is sug-gested that these moraines correspond with the Glomfjord event. Likewise, a cirque moraine on the south-western slope of Sætertind, near the head of Spilderdalen, was probably also formed during this event. It follows that the sharp-pointed mountain-tops of Sætertind and Kvittind must have been nuna-taks during this period.

At Glomen and Haugvik on the northern side of the head of Glomfjorden, there are also several distinctive terminal moraines (Fig. 5). The oldest is about 1 km long and up to 100 m wide, and lies about 110 m above sea level at Haugvik. The position of this moraine shows that it was deposited from the south by a glacier which occupied the innermost part of the fjord. A 200–300 m long bouldery ridge on a hill between Haugvik and Glomen, and a 400–500 m long lateral moraine on Stinfjell about 3 km north-east of this hill, probably corresponds to the moraine at Haugvik. A younger end moraine, approximately 800 m long and 100 m wide, is situated at Glomen. This moraine describes a wide arc with its convex side facing north. The crest of the moraine slopes from about 150 m above sea level in the east to 120 m above sea level in the west. Since the moraine lies above the marine limit, which is about 103 m above sea level at Glomen, its arcuate course shows that the moraine was deposited from the south by an outlet glacier from the Svartisen area.

The exact altitude of the shore-level that corresponds with the Glomen and Haugvik moraines has not been determined, but it is higher than 98 m above sea level, and is probably close to the extrapolated altitude of the Main shore-

Fig. 5. Map of the Haugvik–Glomen area showing the location of the Glomfjord, Glomvasshaug and recent moraines.

line, about 103 m above sea level. Rekstad (1912) and Grønlie (1951) reported the marine limit at Glomen to be 108 m and 101.5 m above sea level, respec-

tively. Therefore the moraines at Haugvik and Glomen very probably correspond with the Glomfjord event. The glacier that deposited the Glomen moraine was slightly smaller than the glacier that deposited the Haugvik moraine, and a correlation of these moraines with a late and early phase of the Glomfjord event is suggested.

South of Stinfjell these are some cirque moraines 600–700 m above sea level. These were probably deposited during the Glomfjord event, since the mountain east of the moraines is higher than the glaciation limit during this event (see page 12).

At Vassdal, on the southern side of Glomfjorden near the mouth of the fjord, there is a distinctive cirque moraine. The highest shore-level at Vassdal is represented by the Main shore-line, which is cut onto the distal slope of the moraine, and by glaciofluvial out-wash sediments which lie at the same height as the Main shore-line in front of the moraine (Fig. 6). This shows that the cirque moraine at Vassdal corresponds with the Main shore-line, and it is therefore included in the Glomfjord event. A smaller cirque moraine further up the valley was probaby deposited during a late phase of the Glomfjord event.

Other distinctive moraines deposited by local glaciers on the south side of Glomfjorden are also correlated with the Glomfjord event. They correspond with the Main shore-line, and the mountains behind the moraines rise to altitudes well above the glaciation limit during the Glomfjord event.

Sørfjorden

A distinct cirque moraine is situated on the north-western slope of Bjellåtind near the head of Sørfjorden. The Main shore-line is present immediately outside the moraine, but does not continue onto or behind the moraine. This might suggest that the moraine is younger than the Main shore-line. However, the mountain top at Bjellåtind is 882 m high, approximately 200 m over the glaciation limit during the Glomfjord event, but lower than the glaciation limit during younger events (see p. 12). It would seem probable that the moraine was deposited during the Glomfjord event.

Bjærangsfjorden, Holandsfjorden and Nordfjorden

The Main shore-line can also be traced along the sides of the fjords in the southern part of the area. This shows that these fjords were not glaciated during the Glomfjord event. On the southern side of Holandsfjorden and Nordfjorden there are several terminal moraines and cirque moraines (Fig. 7). The mountains south of these fjords reach altitudes even higher than the present glaciation limit, and some of the moraines are only a few km from existing glaciers. Some of these moraines were probably deposited during glacial phases from the Glomfjord event to recent times. The terminal moraine in front of the Engabreen glacier was deposited in historic time (Rekstad 1921, Theakstone (1964). But since no older moraines have been found in association with this glacier, and since the Main shore-line is present only a few km outside the

Fig. 6. Wave-cut terrace 85–93 m a.s.l. at Vassdal. The terrace, which is equated with the Main shore-line, is cut into the Glomfjord cirque moraine behind the barn.

existing moraine, Engabreen was probably not much larger during the Glom-fjord event than it has been in historic time.

Coastal mountains

Cirque moraines are present on several mountains on islands, and on other isolated mountains in the coastal district. One of the moraines lies on the northern side of Blåtind, about 10 km southeast of Kunna. The moraine lies to the east of moraines deposited during the Vassdal event, and it must be younger than this event. Since the Blåtind mountain is 716 m high, more than 300 m below the modern glaciation limit (see p. 1), the moraine probably was deposited during the Glomfjord event.

The mountain of Skjeggen, about 8 km north-west of Blåtind, was outside the glacier margin during the Vassdal event. The cirque moraine on the north side of this mountain may therefore be older than the Vassdal event or con-temporaneous with it. However, since the mountain-top reaches an altitude of 903 m, almost 200 m higher than Blåtind, it must have been glaciated during the Glomfjord event, and the moraine is believed to belong to this event. The other cirque moraines in the coastal districts are similarly equated with the Glomfjord event since they lie on mountains of about the same height as Blåtind, or higher.

The glaciation limit

The glaciation limit during the Glomfjord event has been calculated in the same way as for modern glaciations, i.e. by means of the peak method (Fig. 2). The lowest-lying mountain peak with a Glomfjord cirque moraine is presumed to have been the lowest glaciated peak during the Glomfjord event, and the highest mountain without any cirque moraine is presumed to have been the highest unglaciated peak at this time. Before carrying out the calculations, the topographic conditions were evaluated as described by Andersen (1968). For instance, two mountains south-west of Sørfjorden have no cirque moraines, in spite of the fact that they reach altitudes of 819 m and 1045 m above sea level. However, this is explained by the fact that these south-west to south-east facing
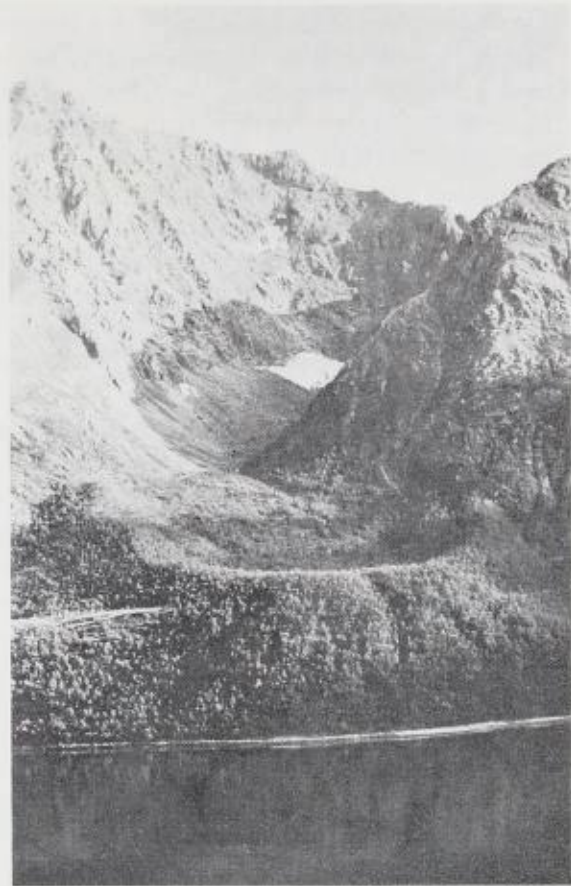
Fig. 7. Cirque moraine at Nordfjorden.

summits are surrounded by precipitious slopes which prevented snow-accumulation above the equilibrium line.

The glaciation limit during the Glomfjord event was thus about 450–500 m lower than at present. A similar, or slightly lower glaciation limit has been reported for the Tromsø–Lyngen event in northern Norway (Andersen 1968, 1975). In southern Norway calculations of Late Weichselian glaciation limits and equilibrium lines have shown that these were 400–500 m lower in Younger Dryas time than they are today. These calculations were summarized by Andersen (1975, p. 58–60). It is concluded that the glaciation limit during the Glomfjord event was as low relative to the recent glaciation limit, as during the Tromsø–Lyngen event in northern Norway and the Younger Dryas in southern Norway.

Age

At Sætvik, about 5 km from the head of Glomfjorden, a 2 m thick section of glaciomarine clayey silt with dropstones and an arctic fauna underlies 0.5 m of marine sand, 0.7 m of clayey silt and 0.5 m of shore gravels. Stratigraphic studies of these sediments show that the glaciomarine silt (Sætvik Silt) repre-

sents the last phase of glacial sedimentation in Glomfjorden (see p. 18). Deposited only about 2 km from the terminal moraines at Haugvik and Glomen, the Sætvik Silt must correspond to the Glomfjord event. Shells of *Mya truncata, Chlamys islandica*, and *Hiatella arctica* from the Sætvik Silt were radiocarbon dated at 10 860 ± 150 years B.P.

More than 5 m of glaciomarine clayey silt with numerous dropstones underlies about 0.5 m of shore gravels in a ditch 10 m above sea level at Sandå, about 6 km north-west of Sætvik. Located only 2 km from the Glomfjord terminal moraine in Næverdalen, the glaciomarine silt probably corresponds with the Glomfjord event. Shells of *Astarte elliptica, Mya truncata*, and *Macoma calcarea* from the glaciomarine silt were radiocarbon dated at 11 050 ± 120 years B.P.

On the evidence of the radiocarbon dates, an early Younger Dryas or late Allerød age is suggested for the Glomfjord event. At Furumo on Åmøy, 1 km west of the Vassdal moraine in the Åmnessund, 2–3 m strongly consolidated silty clay with numerous pebbles and boulders showing glacial striae, underlies about 3 m shore gravels.. The clay, named Furumo diamicton, also contains numerous broken shells of *Mya truncata* and many complete valves of *Lepeta caeca*. Well preserved, large fragments of *Mya truncata* gave a radiocarbon age of 10 640 ± 70 years B.P. If the Furumo diamicton is interpreted as a lodgement till, this either indicates a re-advance of the ice-sheet to Åmøy after 10 640 B.P., or an advance of a local glacier on Åmøy. There are, however, no local moaines on the eastern part of Åmøy, and a re-advance of the ice-sheet to Åmøy at that time is opposed by all other evidence. Therefore, the strong consolidation of the Furumo diamicton must either be caused by another process than glacial pressure, or the date must be wrong.

This would suggest that a re-advance should not be postulated on the evidence of only one radiocarbon date, or based on the degree of consolidation of sediments.

Paleogeography

Terminal moraines at Straumøy and Sandhornøy near the mouth of Saltfjorden have been correlated with the Tromsø/Lyngen event (Andersen 1975). Radiocarbon dates indicate an early Younger Dryas age for these moraines, and they may also be correlated with the Glomfjord event (Andersen et al. 1979). This indicates that there was no delay between the local glaciation and the re-advance of the ice sheet in this area. The paleogeographic reconstruction of early Younger Dryas is shown in Fig. 8. The ice margin and the contours on the glaciers is deduced from the marginal deposits and glacial striations shown in plate 1. No distinct terminal moraines have been found between Laksådalen and Morsdalsfjorden. However, the glacier must have lain in this area, and the position indicated is that considered to be most likely. The absence of moraines in this area is possibly related to the fact that the area lay in the zone between the ice sheet and the local glaciers. The ice sheet did not cross the mountains east of Glomfjorden during Younger Dryas. This suggests that the Svartisen

Fig. 8. Reconstructed paleogeography during the Glomfjord event about 10 800 years B.P. Shaded areas show the extent of glaciation, arrows indicate ice movements. Areas below the marine limit and the isobases for the Main shore-line is shown in black.

area acted as a physical hindrance which forced the ice to flow in a north-western direction.

THE GLOMVASSHAUG EVENT

In Spilderdalen, Selstaddalen and Sundsfjorddalen there are several small ice marginal deposits further up the valley than the Glomfjord moraines. Most of these correspond to a shore-level which lies at about the same altitude as the Main shore-line, and they were possibly deposited shortly after the Glomfjord event.

At Glomvasshaugen, about 2 km north of the head of Glomfjorden, there are several parallel ridges of moraine deposited by a glacier tongue from Glombreen (Fig.5). On the steep mountain slope above the head of Selstaddalen, the are further moraines deposited by Glombreen. These moraines were deposited in the Glomvasshaug event of uncertain age.

Holocene glacial variations in northern Scandinavia have been discussed by several authors (Theakstone 1964, Karlén 1973, Worsley & Alexander 1975,

Karlén & Denton 1976, Griffey & Worsley 1978, Karlén 1979). Several periods of glacial advance occurred in the Holocene, but the sizes of the glaciers were approximately the same in each of these periods. The Glombreen glacier, however, was significantly larger during the Glomvasshaug event than during the youngest Holocene event, since the moraines deposited during these two events are separated by 0.7–1 km. Accordingly, it would seem probable that the Glomvasshaug event occurred during the late Younger Dryas or Preboreal.

Marine fossils

PRE-LATE WEICHSEL

Till containing shell fragments has been found at two localities NW of Svartisen, at Vassdal near the mouth of Glomfjorden, and at Åmøy.

The Vassdal Till, about 15 m of grey, bouldery lodgement till, is exposed in a road cutting 5–20 m a.s.l. at Vassdal. The till contains scattered fragments, 1–20 mm long, of shells, some of which can be identified as *Mya truncata* and *Balanus* sp. Most of the fragments are, however, too abraided to be identified. The shell-bearing Åmøy Till is exposed in a 1–2 m high roadcutting at about 20 m a.s.l, SW of Skarsvatn on Åmøy. The till is very similar to the Vassdal Till, but shell fragments are much more frequent. 23 fragments from *Mya truncata* and 1 from *Balanus* sp. were identified. The other fragments were eroded, but many of them were thick-walled and possibly from *Mya truncata*. Shell fragments from the Vassdal Till gave an ^{14}C-age of 34 330 $\pm$ $^{1575}_{1410}$ years B.P. If this date is correct, then the outer parts of Glomfjorden at least were ice-free during the Mid-Weichsel, and the molluscs which lived in the fjord at this time were subsequently transported by glacier ice.

The shell fragments from the Åmøy Till have not been dated, and it is not possible to say whether this is of same age as the Vassdal Till. If the fjord was ice-free at Vassdal it must also have been ice-free at Åmøy, and a Mid-Weichselian age for the shell fragments in the Åmøy Till is therefore not unlikely.

LATE WEICHSEL

The Late-Weichselian marine shell faunas were dominated by large and thick-walled *Macoma calcarea* and *Mya truncata* together with variable proportions of *Chlamys islandica*, *Astarte elliptica* and *Hiatella arctica* (Fig. 9). Similar faunas are found today in the fjords of eastern Greenland, Svalbard and in the eastern part of the Barents Sea (Ohdner 1915, Brotskaja 1930, Spärck 1933, Thorson 1933, 1934, 1958). These areas are part of the mid- and high-arctic zoogeographic region, whereas the coast of Nordland is within the mid-boreal region (Feyling-Hanssen 1955). Ths may indicate that the arctic zoogeographic regions were displaced more than 2000 km southwards in early Allerød and Younger Dryas time. However, Atlantic water probably had acess to the Norwegian Sea in the Allerød, and it is likely that arctic marine faunas could thrive along the Norwegian coast because of the existence of steep ecological gradients between calving glaciers and the open sea (Mangerud 1977).

LOCALITY		BRATSBERG	ENGAVÅGEN	NÆVERDAL	SANDÅ	SÆTVIK	FURUMO
¹⁴C-DATING		11 740 ± 100	11 720 ± 200	11 610 ± 140	11 090 ± 120	10 860 ± 150	10 640 ± 70
YOLDIA HYPERBOREA							
CHLAMYS ISLANDICA							
MACOMA CALCAREA	(x)						
MYA TRUNCATA	(x)						
HIATELLA ARCTICA	(x)						
ASTARTE ELLIPTICA							
ASTARTE BOREALIS							
LEPETA CAECA							
ANOMIA SP.							
BALANUS SP.							

FREQUENT   (x) LARGE AND THICK-WALLED SPECIES
LESS FREQUENT

Fig. 9. Late Weichselian marine shell-faunas from the coastal area NW of Svartisen.

Macoma calcarea is the most frequent bivalve in the glaciomarine sediments along the fjords NW of Svartisen. Investigations in the fjords on Greenland and Svalbard have shown that this species dominates in the depth-zone occupied by so-called 'fjord-water', i.e. surface-water with a low salinity and generally above-zero temperatures (Thorson 1933, 1934, Ohdner 1915). Below the 'fjord-water' there is a high-salinity zone with permanently below-zero temperatures in which *Bathyarca glacialis* is the most frequent species. Since *Bathyarca glacialis* has not been found among the Late Weichselian molluscs NW of Svartisen, whereas *Macoma calcarea* is frequent, the upper 50–100 m of the sea in the fjords at this time was probably occupied by 'fjord-water'.

Portlandica arctica has been found many places along the coast of Nordland, commonly just outside ice-marginal deposits of Late Allerød or Younger Dryas age (Rekstad 1925, Marthinussen 1962, Andersen 1975). However, along the fjords NW of Svartisen this species has not been found. This suggests that the ecological conditions were, for unknown reasons, unfavourable in these fjords for this species. Spjeldnes (1978) pointed out that *Portlandia arctica* is more easily devoured by predatory gastropods (*Naticidae*) than the thick-walled *Macoma calcarea*. Accordingly, *Portlandia arctica* occurs in abundance only where conditions are unfavourable for predatory gastropods, such as in lowsalinity water with high content of suspended matter. Such conditions undoubtedly prevailed beside the fronts of the large fjord glaciers which existed in many places in Nordland during the Younger Dryas. However, in most of the fjords NW of Svartisen there were no such glaciers, and the fjords probably contained slightly more saline 'fjord-water' with less suspended matter. *Portlandia arctica* may have been out-competed by *Macoma calcarea* in these fjords due to gastropod predation, and is therefore only found in glaciomarine sediments deposited close to large fjord glaciers. The fact that most of the *Macoma calcarea* found had bore-holes from *Naticidae* support this deduction.

THE LATE WEICHSEL/HOLOCENE TRANSITION

The transition from Late-Weichsel to Holocene is demonstrated in a sequence of marine sediments exposed in a river-bank 2–6 m a.s.l. at Sætvik, approximately 5 km from the head of Glomfjorden. The sediments consist of 4 units. The lower-most unit, the Glomfjord Silt, is over 5 m thick. This is overlain by the 0.5 m thick Sætvik Sand, the 0.7 m thick Sætvik Silt and about 0.5 m of well-rounded gravels (Fig. 10).

The Glomfjord Silt contains many subrounded to angular pebbles and blocks some of which show glacial striae and demonstrate the glaciomarine origin of the sediment. The silt also contains *Chlamys islandica*, *Mya truncata*, *Hiatella arctica*, *Macoma calcarea* and *Yoldiella hyperborea*. This fauna indicates cold, arctic conditions and medium depths (Nordsieck 1969).

The foraminifera in Glomfjord Silt is grouped into two assemblage zones as defined by Hedberg (1976). The *Virgulina schreibersiana* zone (F1), which occupies the greater part of the unit, is dominated by *Virgulina schreibersiana* (21–54%), *Cassidulina reniforme* (25–35%), and *Elphidium excavatum* f. *clavata* (14–31%). Based on the present and fossil distribution of these species, (Loeblich & Tappan 1953, Risdal 1964, Nagy 1965, Todd & Low 1967, Feyling-Hanssen 1974, Sejrup & Guilbaut 1980), it can be concluded that the foraminifera in most of the Glomfjord Silt is arctic.

The *Cassidulina reniforme – Elphidium excavatum* zone (F2) forms the upper 10 cm of the Glomfjord Silt. The zone is dominated by the arctic species *Cassidulina reniforme* (41%) and *Elphidium excavatum* f. *clavata* (24%). The transition from the *Virgulina schreibersiana* zone is characterized by a strong decline in the content of *Virgulina schreibersiana* (from 54% to 9%), and by the appearance of *Cibicides lobatulus* and *Trifarina angulosa*. The recent distributions of the latter species is cosmopolitan and low-arctic to lusitanian, respectively (Sejrup et al. 1980). Although the fauna in this zone is dominantly arctic, the occurrence of *Cibicides lobatulus* and *Trifarina angulosa* indicates a change to slightly warmer conditions.

The Glomfjord Silt has been radiocarbon dated using fresh shells of *Mya truncata*, *Chlamys islandica* and *Hiatella arctica*. These gave an age of 10.860 ± 150 years B.P., indicating an Younger Dryas age for the Glomfjord Silt.

The relatively well sorted Sætvik Sand overlying the Glomfjord Silt is very rich in shells and shell fragments. This, and the occurrence of scattered pebbles with barnacles, worm tubes and bryozoans, indicates clearwater conditions and a low sedimentation rate. 15 different molluscs were found in the Sætvik Sand. 8 of these have a boreal-lusitanian recent distribution, 4 a boreal-arctic distribution and 3 species are cosmopolitan. The most frequent species are *Arctica islandica*, which forms a shell bank in the middle of the sand, *Lucinoma borealis*, *Cardium echinata* and *Cochlodesma praetenue*. Many shells were found in their position of growth. The high content of boreal-lusitanian species indicates that the water temperature during deposition of the Sætvik Sand were at least as high as today.

The foraminifera in the Sætvik Sand may be grouped into two assemblage

zones. The *Cibicides lobatulus–Trifarina angulosa* zone (F3) forms the lower 20 cm of the sand. This zone is separated from the underlying *Cassidulina reniforme – Elphidium excavatum* zone by a rapid increase in the content of *Trifarina angulosa* and *Cibicides lobatulus*, whereas *Cassidulina reniforme* and *Elphidium excavatum* f. *clavata* strongly decline. This and the occurrence of thermophile species, such as *Gavelinopsis praegeri* and *Bulimina marginata*, demonstrates that the water temperature increased considerably when sand deposition started. The uppermost 30 cm of the Sætvik Sand is within the *Bolivina pseudoplicata* zone (F4). The boundary with the zone below is defined by an increase in *Bolivina pseudoplicata*, which together with *Cibicides lobatulus* and *Trifarina angulosa* dominates the fauna. The high content of boreal–lusitanian species, and the occurrence of southern species like *Planorbulina medittarensis*, indicates relatively high water temperatures. The occurrence of *Cassidulina reniforme* and *Elphidium excavatum* f. *clavata* in the sand is probably a result of resedimentation.

Fresh, paired shells from *Actica islandica* collected from the shell bank in the middle of the sand gave an radiocarbon age of 7.340 ± 110 years B.P. According to this date, most of the Sætvik Sand was deposited in the Holocene.

The Sætvik Silt is poorly sorted and contains variable amounts of gravel, sand and clay. The silt also contains boulders and pebbles, particularly in its uppermost part, which might suggest a glaciomarine origin. However, since the silt overlies Holocene marine sand, this is considered unlikely. More probably, the Sætvik Silt consists of a mixture of older glaciomarine and marine sediments transported by an avalanche or clay slide.

The Sætvik Silt also contains many shells and shell fragments, but these are not as frequent as in the Sætvik Sand, and no paired shells ware found.

Characteristic of the mollusc fauna is the occurrence of thick-walled *Mya truncata*, *Macoma calcarea* and *Astarte elliptica* together with *Littorina littorea*, *Gibbula ceneraria* and *Buccinum undatum*. This mixture of boreal–lusitanian and arctic species, and of species inhabiting different depth zones, could only have been caused by resedimentation.

The foraminifera in the Sætvik Silt constitute the *mixed fauna* zone (F5). The lower part of the zone is dominated by the arctic species *Cassidulina reniforme* and *Elphidium excavatum* f. *clavata*, but also contains high percentages of the boreal–lusitanian species *Bolivina pseudoplicata* and also *Cibicides lobatulus*. In the upper part of the zone *Cassidulina reniforme*, *Virgulina schreibersiana* and *Cibicides lobatulus* are most important, but also here there are significant amounts of boreal–lusitanian foraminifera. The occurrence together of arctic and boreal–lusitanian foraminifera demonstrates that the zone does not contain a normal fossil assemblage, but a mixture of different fauna communities.

Arctica islandica, *Littorina littorea*, *Gibbula ceneraria* and *Buccinum undatum* collected from the Sætvik Silt gave å radiocarbon age of 9240 ± 120 years B.P. These molluscs are almost 2000 years older than the middle part of the underlying Sætvik Sand, and the date confirms that Sætvik Silt is a product of resedimentation.
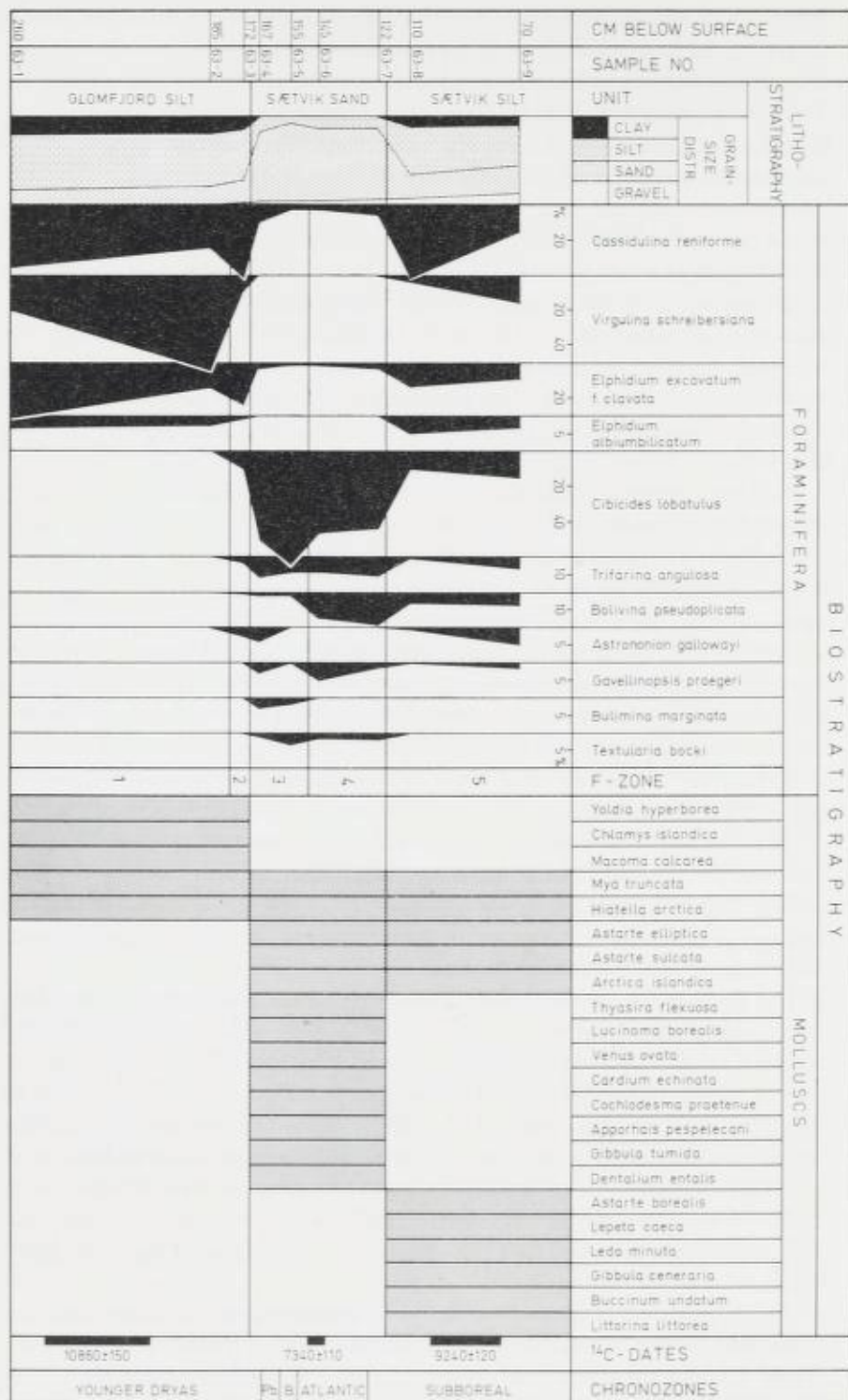
Fig. 10. Stratigraphy in marine sediments at Sætvik, Glomfjord.

The Glomfjord Silt represents the last period of glaciomarine sedimentation and arctic conditions in Glomfjorden. The last time glaciers calved in the fjord was during the Glomfjord event, and the Glomfjord Silt must correspond to this event. According to radiocarbon dating, the Glomfjord Silt was deposited about 10 800 ^{14}C-years B.P. When the glaciers retreated after the Glomfjord event, glaciomarine sedimentation in the fjord ceased. There was an important change in the hydrographic conditions in the fjord, which resulted in the de-position of the Sætvik Sand.

At the same time the marine fauna changed radically, and high- and mid-arctic species were succeeded by boreal–lusitanian species. In the foraminifera, this change in conditions is marked by an increase in the percentages of *Trifarina angulosa* and *Cibicides lobatulus*, whereas the arctic elements decline. Equivalent changes in lithology and fauna have been reported from several localities along the Norwegian coast in association with the transition from arctic to boreal conditions during deglaciation. (Sejrup et al. 1980, Løfaldi & Rokoengen 1980). According to Sejrup et al. (1980), the characteristic flour-ishing of *Trifarina angulosa* and *Cibicides lobatulus* probably occurred shortly after the Polar front passed on its way northwards as the Norwegian Sea became warmer. These relations indicate that arctic water in Glomfjorden was displaced by atlantic water at approximately the same time as glaciomarine sedimentation ceased. Since boreal–lusitanian molluscs lived in the fjord at ca. 9200 ^{14}C-years B.P., this displacement must have occurred within the period 10 800–9200 ^{14}C-years B.P.

A more accurate date for the transition may be obtained from considerations of the age of the Glomfjord event. Since this event most probably is of late Allerød to early Younger Dryas in age, the glaciomarine sedimentation in Glomfjorden had most likely ceased about 10 500 ^{14}C-years B.P. Accordingly, it is possible that the transition from arctic to boreal–lusitanian conditions in Glomfjorden occurred during late Younger Dryas time. This agrees wiht evidence from the continental shelf outside southern Nordland, where the transi-tion occurred about 10 400 years B.P. (Løfaldi & Rokoengen 1980).

According to radiocarbon dating, the middle part of Sætvik Sand was depos-ited about 7300 ^{14}C-years B.P. The lower 25 cm of the sand therefore rep-resents a minimum of 1900 years, possibly as much as 3000 years if the change from deposition of the Glomfjord Silt to Sætvik Sand took place in late Younger Dryas. Due to this low rate of sedimentation (0.08–0.10 mm/ year) the sand is very rich in shells and shell fragments.

The dates also indicates that the lower part of the *Bolivina pseudoplicata* zone (F4) coincides in part with the warm Atlantic and Sub-boreal chronozones. This is supported by the occurrence of thermophile species in this zone.

The Sætvik Silt was deposited by a slump or avalanche after 7300 ^{14}C-years B.P. If the upper part of the Sætvik Sand accumulated at the same rate as the lower part, the top of the bed was deposited within the period 5400–4300 ^{14}C-years B.P., which is the maximum age for the Sætvik Silt. The uppermost unit in the sequence consists of shore-gravels deposited during the Holocene regression.

Table 2. Holocene molluscs from the coastal area NW of Svartisen

Locality Approximate age B.P.	INNDYR 4400	DALEN 4500–5500	SÆTVIK 5000–10 000
Modiolus modiolus		x	
Ostrea edulis	x		
Thyasira flexuosa			x
Lucinoma borealis	x	x	x
Cardium echinatum			x
Cardium edule	x		
Arctica islandica		x	x
Dosinia exoleta		x	
Dosinia lincta		x	
Venus ovata			x
Venus gallina	x	x	
Venerupis pullastra	x		
Hiatella arctica		x	x
Mya truncata		x	x
Cochlodesma praetenue			x
Patella vulgata		x	
Gibbula ceneraria			x
Gibbula tumida		x	x
Littorina obtusata	x	x	
Littorina saxatilis		x	
Littorina littorea		x	x
Apphorhais pespelecani			x
Nucella lapillus		x	
Buccinum undatum	x	x	x
Dentalium entalis			x

HOLOCENE

Holocene molluscs have been collected from two localities in addition to Sætvik (Table 2). One of these is situated on a terrace 25 m a.s.l. near Inndyr at Sørfjorden. In a roadcutting showing 0.5 m–1 m of wellsorted marine sand, 7 different species were found. The fauna, which is dominated by large (4–5 cm long) species of *Cerastoderma edule*, closely resembles recent faunas found on sand between the tidal zone and a depth of a few metres (Tebble 1963, Bergan 1970, Nordsieck 1969, Ziegelmeyer 1957). The fauna must have lived at a time when the sea level at Inndyr was approximately 25 m higher than at present. An incomplete shell (longest axis 9.5 cm) of *Ostrea edulis* from Inndyr was radiocarbon dated to 4390 ± 80 ^{14}C-years B.P.

Holocene molluscs were also collected at Dalen ca. 4 km SE of Kunna. Here, a river-side exposure ca. 20 m a.s.l. of gravelly sands, 2–3 m thick, contains a great number of shells and shell fragments. The fauna is dominated by paired valves of *Venus gallina*, a species which according to Bergan (1970) and Lie (1971) occurs most frequently at depths less than 10 m, but is also common near the tidal zone. Since the fauna also contains three different *Littorina* species and *Patella vulgata*, it would seem that the fauna lived close to sea level. Most of the 17 different species which were found at Dalen have a boreal-lusitanian distribution, and some of them do not live further north than Lofoten. The fauna suggests water temperatures at least as warm as today.

Raised marine shore-lines

The main purpose of the shore-line investigation presented here was the use of raised shore-lines in the correlation of ice – marginal deposits, and to establish their relative ages. The highest shore-lines were judged to be most important, and only a few observations have been made at low levels.

THE MAIN SHORE-LINE

By far the most distinct of all raised shore features along the fjords NW of Svartisen is the shore-line corresponding to the Glomfjord event, the *Main shore-line*. Since no indisputable shore features have been found above the Main shore-line to the east of the Vassdal moraines, this is believed to represent the marine limit in this area (Fig. 12). The marine limits at Djupvik and Vassdal reported by Vogt (1904) and at Kjeldal reported by Grønlie (1940) are significantly higher than the Main shore-line, but the present author have not been able to confirm these observations. However, some of the islands have not been investigated in detail, and it is possible that the marine limit in the westernmost part of the area is higher than the Main shore-line.

The Main shore-line is characterised by wide terraces, frequently cut into solid rock, which are particularly well developed along relatively calm fjords and channels immediately adjacent to the Glomfjord moraines. The Main shore-line is particularly clear at the head of Sørfjorden, where it can be traced for approximately 6 km from Oterstranden to Laksådalen. Above Oterstranden it is a platform about 50 m wide cut into mica schist and bordered by an eroded 20–25 m high raised sea cliff (Fig. 11). Angular boulders and pebbles which have obviously collapsed from the cliff lie scattered on the platform. Rounding of these clasts, or any other indication of wawe action, was not noted. The landward edge of the terrace is 90–91 m above sea level, the outer edge about 85 m above sea level.

Well-developed platforms of the same type as the Oterstranden are present along the inner and middle stretches of Glomfjorden, Bjærangsfjorden, Holandsfjorden and Nordfjorden. They are excavated in a variety of rocks, but are in general widest in schists.

The formation of platforms cut in rock has been discussed by several authors (Nansen 1922, Bentham 1937, Joyce 1950, Feyling-Hanssen 1953, McCann & Carlisle 1972). They all agree on the importance of 'freeze and thaw processes' along arctic shores, and these processes are believed to be the main cause of rock terraces in arctic areas. The geographic distribution of the Main shore-line supports this belief: The Oterstrand-type shore-lines are most distinct along relatively calm fjords and channels close to the Glomfjord moraines which is not what should be expected if wave-action had been an important factor in their formation. There is, however, good accordance with the expected distribution if frost-shattering was the dominating process. Fjords adjacent to glacier fronts must have received large quantities of melt water which could give rise to a brackish surface layer. Such a surface layer was considered by Nansen

Fig. 11. The Main shore-line (marked by arrows) cut in rock 85–91 m a.s.l. at Oterstrand, Sørfjorden.

(1922) to be of prime importance for frost shattering on arctic beaches since the frequency of freezing is increased. A feature which may have contributed considerably to the formation of the Main shore-line, is the 'ice-foot'. Bentham (1937) defined this term in the following way: 'The ice-foot is that part of the sea-ice which is frozen to the shore and is therefore unaffected by tidal movements. It is separated from the sea-ice proper, which moves up and down with the tide, by the tidal crack'.

According to Bentham's investigations in NW Greenland, the ice-foot is best developed along calm shores, but is frequently absent in areas exposed to strong wave action. Since the distribution corresponds with the Main shore-line, and since an ice-foot is a common feature of arctic shores, it may be deduced that the shores along the fjords NW of Svartisen were to a large extent covered by an ice-foot during the Glomfjord event. If this was the case, an ice-foot have contributed to the formation of the Main shore-line since it protects the beaches from wave action for a major part of each year, and contributes to the removal of frost-shattered material when it breaks away in the summer.

Radiocarbon dates show that the Main shore-line formed between 11 700 and 10 500 years B.P. . The average rate of cliff retreat at Oterstranden was therefore at least 50 m/1200 years, or about 4 cm/year. This is of the same order as for modern coastal cliffs around Svalbard (Jahn 1961) and Younger Dryas shore terraces in Scotland (Dawson 1980). Studies in arctic areas have shown that frost shattering and 'ice-foot erosion' is most effective between mean and high tidal levels (Nansen 1922, Joyce 1950, Feyling-Hanssen

1953, McCann & Carlisle 1972). The inner-edges of shore terraces are therefore usually situated at about high-water mark. The inner edge of the Oterstrand terrace evidences a sea level which at flood tide was 90–91 m higher than the present day mean sea level. Assuming a tidal amplitude approximately the same as today, i.e. ca. 3 m (at Bodø, Gjevik 1978), the corresponding mean sea level was 88.5 m–89.5 m higher. The marine limit at Oterstrand is therefore 89 ± 1 m a.s.l. The marine limit has been calculated in this way for other localities where the Main shore-line is of the same type as at Oterstrand.

The Main shore-line at Vassdal is represented by a 50–70 m wide wave-cut terrace in till (Fig. 6). The inner-edge is bordered by and cuts partly into a Glomfjord cirque moraine. Large, well-rounded boulders can be seen a few meters from the inner edge of the terrace, but there is no trace of wave action above the inner edge. Along the outer shores of the fjords and around islands NW of Svartisen, the Main shore-line is represented by abrasional terraces in till, while rock platforms are small or absent. This indicates that frost shattering along the shore was less important in the outer coastal areas, whereas wave-action was of more importance. This was possibly caused by progressive mixing of the brackish surface layer at increasing distances from the glaciers because of waves and currents.

The outer coast was considerable more exposed to wave-action at this time than today, since most of the low strandflat areas outside the fjords were flooded by the sea.

Surf can also cause abrasion above high-water mark. Sollid et al. (1973) found that the inner edge of 35 abrasional terraces in unconsolidated deposits in Finnmark were on average 2.0 ± 4 m above mean sea level. However, this investigations only included fjords with limited fetches. The size of the terrace at Vassdal, and the large rounded boulders, suggests a considerable amount of marine abrasion, and it is concluded that the inner edge of this terrace lay more than 2 m above the marine limit. Since the inner edge of the terrace is 93 m above sea level, the marine limit at Vassdal is less than 91 ± 1 m a.s.l. Considerations of this type has allowed the calculations of the marine limit for different wave-cut terraces.

The isobases of the Main shore-line run roughly parallel to the coast in a NE direction (Fig. 8). All calculations of the marine limit carried out by the present author and reported in the literature, were plotted in an equidistant shore-line diagram (Fig. 12). The gradient of the Main shore-line is about 1.1 m/km.

LOWER SHORE-LEVELS

Many different shore-levels can be discerned below the Main shore-line. Rekstad (1929) distinguished 7 levels, whereas Grønlie (1951) increased this to 90. However, both authors noted that the Tapes levels in general are the most distinct.

One of the lower shore-levels investigated lies near Inndyr at Sørfjorden. Several littoral molluscs were found on a shore-terrace 25 m a.s.l. (see p. 22),
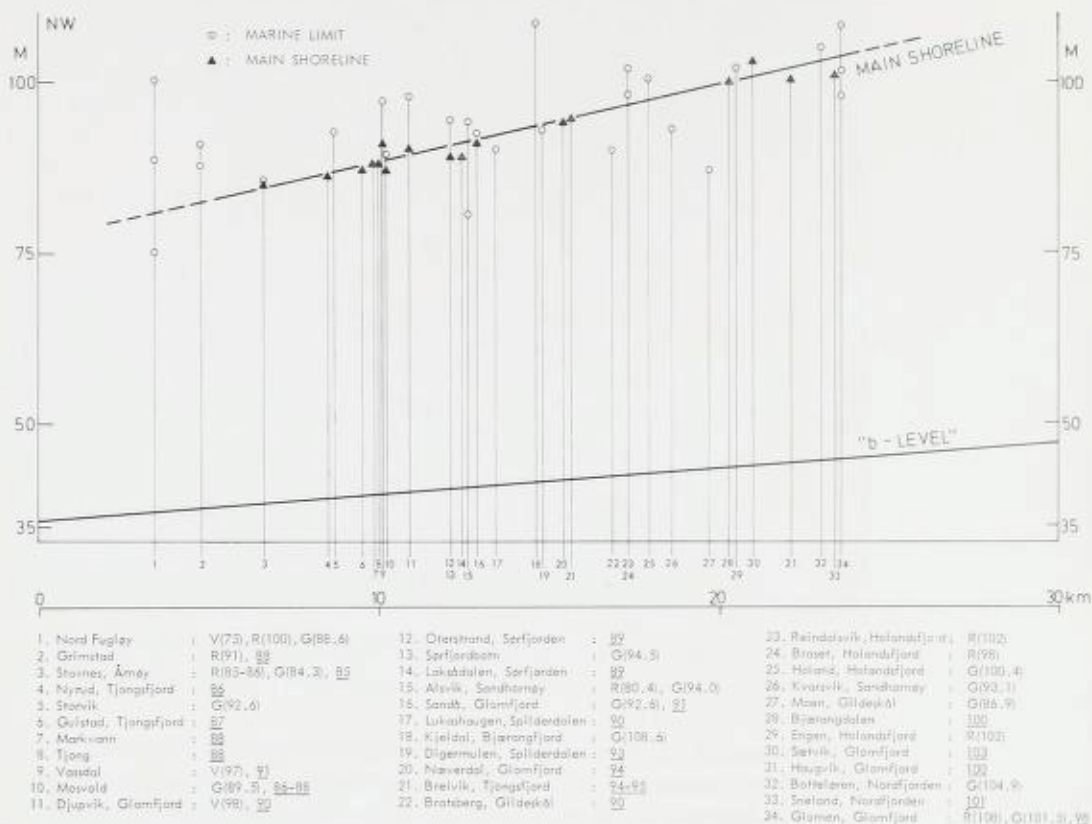
Fig. 12. Equidistant shore-line diagram for Glomforden. The field observations were made by Vogt 1890, 1904 (V), Rekstad 1910, 1912, 1915, 1929 (R), Grønlie 1940, 1951 (G), and the present author (underlined altitudes). The 'B-level' is according to Grønlie (1940, 1951).

and a shell of *Ostrea edulis* from this terrace gave a ^{14}C-age of 4390 ± 80 years B.P. This age corresponds with the Tapes IV level, which according to Marthinussen (1962) was formed about 4800–4500 ^{14}C-years B.P. Grønlie (1940) constructed isobases for the so-called 'b-level' in northern Norway, which he believed was formed in Sub-boreal time. However, at Inndyr the 'b-level' according to Grønlie is situated approximately 40 m a.s.l., and must therefore be older than Sub-boreal. In the inner fjords of Troms and Finnmark, the isostatic uplift has been approximately the same as the Sørfjorden, and the height difference between the Tapes I and Tapes IV levels is about 15 m (Marthinussen 1960). This indicates that the 'b-level' corresponds to the Tapes I level, which according to Marthinussen (1962) formed about 6600–6500 ^{14}C-years B.P.

There are also extensive shore-terraces 20–25 m a.s.l. at Dalen E of Kunna. One of these contains a littoral molluscs fauna indicating conditions at least as warm as today (see p. 22). The 'b-level' at Dalen according to Grønlie (1940) is approxmately 35 m a.s.l., and indicates that these terraces correspond to the Tapes IV and III levels.
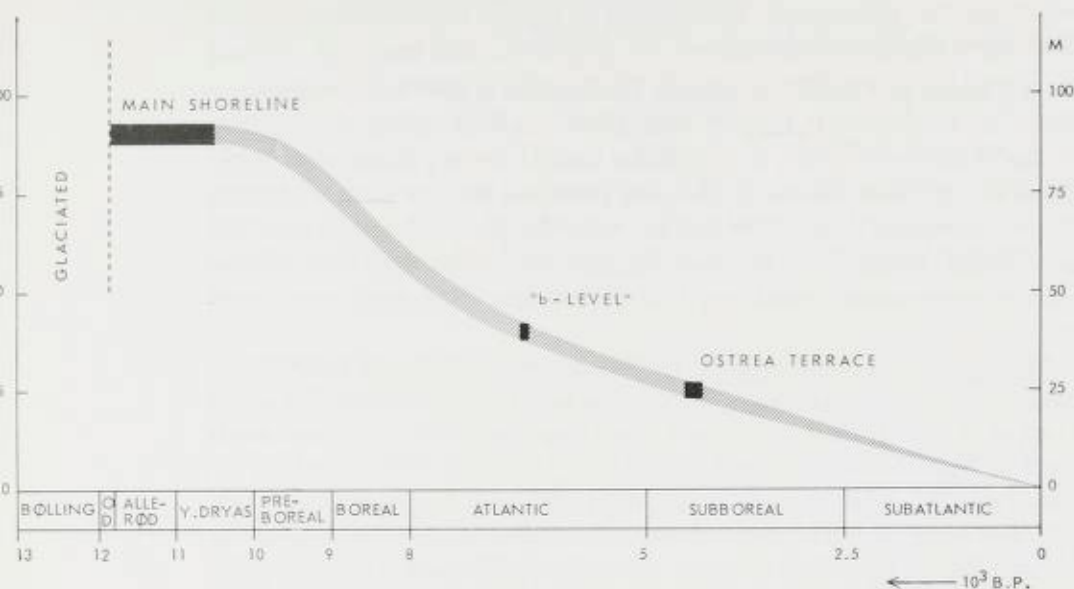
Fig. 13. Suggested trend of shore-line displacement at Inndyr, Sørfjorden. For explanation, see text.

In general, it can be concluded that most of the widespread shore-levels situated at heights of 10–40 m in the coastal area NW of Svartisen represent Tapes levels.

THE SHORE-LINE DISPLACEMENT

The wide Main shore-line rock platforms show that the relative sea level along the coastal area NW of Svartisen was relatively constant during a part of the Late Weichsel. The deglaciation of the fjords about 11 600–11 700 ^{14}C-years B.P., gives a maximum age for the formation of the shore-line. The fact that the Main shore-line is not present on the landward side of the Glomfjord moraines, gives a minimum age of about 10 500 years B.P. Accordingly, the time available for the formation of the Main shore-line is approximately 11–1200 ^{14}C-years, i.e. from 11 600–11 700 B.P. to ca. 10 500 B.P. However, were there no shore-line displacement during this time? Since the Main shore-line appears to represent the marine limit in these areas, there either were only very small changes in this period, or the Main shore-line is transgressional. Younger Dryas marine transgressions have been demonstrated in western Norway (Amundsen 1978, Stabell & Krzywinski 1979), but only in areas with much lower marine limits than in Nordland. It is considered most likely that there was a stable sea level between 11 600–11 700 ^{14}C-years B.P. and 10 500 ^{14}C-years B.P. in the fjords NW of Svartisen. By ca. 4400 ^{14}C-years B.P. sea level had sunk from about 95 m a.s.l to 25 m a.s.l. at Inndyr. If the isobases constructed by Grønlie (1940) are correct, the 40 m level at Inndyr was reached ca. 6600–6500 ^{14}C-years B.P. These two Holocene shore levels, and the Main shore-line suggest a possible trend for the shore-line displacement at Inndyr (Fig. 13).

Discussion and conclusions

The occurrence of a significant climatic amelioration in NW Europe at approximately 13 000 years B.P. has been established from both marine and continental data (Lowe et al. 1980). It is probable that the Bølling deglaciation of the coastal area of Troms (Vorren & Elvsborg 1979) and the NW parts of southern Norway (Mangerud et al. 1979) resulted from this climatic improvement. The same climatic change must also have occurred in Nordland and it is believed that the westernmost coastal area NW of Svartisen were deglaciated in the Bølling.

Deglaciation was interrupted by the Vassdal event. Although paleoclimatic evidence are somewhat equivocal concerning Older Dryas climatic oscillations (Lowe et al. 1980), a late Bølling or Older Dryas glacial advance is well established in Norway (Marthinussen 1961, 1974, Andersen 1960, 1968, 1975, Mangerud 1977, Anundsen 1977) and the Vassdal event is correlated with this.

During early Allerød time the deglaciation continued. The fjords were deglaciated and the ice-sheet retreated to a front east of Svartisen. To what extent local cirque and plateau glaciers persisted during this deglaciation is uncertain. Investigations in western Norway have demonstrated, however, that a Younger Dryas glaciation occurred here in areas not glaciated in the Allerød (Mangerud et al. 1979, Mangerud 1980). Therefore it may be supposed that local glaciers in the Svartisen area were much smaller during the Allerød than during the Younger Dryas.

During the late Allerød and early Younger Dryas a number of marginal moraines were deposited either by local glaciers which appeared in areas not glaciated during the earlier Allerød, or by the re-advance of older glaciers. Marginal moraines of Younger Dryas age are well-known in various parts of Scandinavia (Mangerud 1980). Although these moraines are not perfectly synchronous, they all are presumed to reflect a climatic deterioration which occurred in the late Allerød and Younger Dryas in NW Europe. This must also be the case for the moraines deposited during the Glomfjord event, since the extensive deglaciation which occurred during the early part of Allerød in this area was interrupted by an intense local glaciation during the early Younger Dryas.

The intense frost-shattering along the shores, the arctic marine fauna, and the low limit of glaciation show that the climate during the Glomfjord event was much colder than today. In the arctic, where the ice-foot is present for a major part of the year, the average annual and July temperature is normally well below 0°C and 8°C respectively (Orvig 1980). The ice-foot is, however, not present in northern-most Norway where the average annual and July temperature is about 1–3°C and 8–10°C, respectively (Bruun 1967). This suggests average annual and July temperatures below 0°C and 8°C during the Glomfjord event, which is at least 5°C colder than today. The level of glaciation during the Glomfjord event does, however, indicate a summer temperature only about 3°C lower than today assuming a vertical temperature-gradient of

0.65°C/100 m and no change of precipitation. Accordingly, it would seem probably that there was considerably less precipitation at this time than today.

The influx of atlantic water onto the continental shelf and into Glomfjorden was probably followed by a climatic improvement during the late Younger Dryas and the Pre-boreal. This may explain why the Main shore-line is not present inside the Glomfjord moraines. The Pre-boreal glaciation limit was, however, slightly lower than the present, (Andersen 1975, p. 58–60), and it is assumed that there existed local glaciers in the Svartisen area during the Pre-boreal.

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GLACIAL MAP OF THE COASTAL AREA NORTHWEST
OF SVARTISEN, NORTHERN NORWAY
BY ARNE RASMUSSEN

LEGEND

- Glacial striae, ice movement towards the observation point
- Crossing glacial striae, increasing number of ticks with increasing relative age.
- Glacial striae according to Rekstad 1910, 1912, 1929.
- Crescentic gouges.
- Marginal moraines.
- Assumed location of the glacier margin during the early part of Younger Dryas chronozone.
- N Assumed nunatak during the early part of Younger Dryas chronozone.
- Glaciofluvial ice-marginal delta.
- Kame terrace.
- Glaciolacustrine sediments.
- The main shoreline, cut into solid rock.
- The main shoreline, cut in unconsolidated deposits.
- 85 The marine limit.

- Glaciomarine sediments.
- Lodgement till containing shell fragments.
- Diamicton.
- 10860 ± 150 Radiocarbon date.
- 940 Mountain top.
- 370 Greatest depth.
- Present glaciers, distribution according to topographic maps surveyed 1895–1899.

All heights and depths in metres. Marginal moraines on the northern part of Sandhornøy and Straumøy according to Andersen (1975) and Andersen et.al. (1979).

0   5   10 km

Contour interval 150m

Place names and labels:

SALTFJORDEN · STRAUMØY · NORDFJORDEN · SANDHORNØY · SANDHORNET · BEIARN · SØR-FJORDEN · INNDYR · MORSDALSFJORDEN · HOLMSUNDFJORDEN · BEIARNTINDENE · SUNDSFJORD · SUNDSFJORDDALEN · ÅBSTADDALEN · SEGLVANN · FUGLØY · GLOMBREEN · GLOMFJORD · LAKSÅDALEN · VESTFJORDEN · KUNNA · BOLDEN · MØRSVDALEN · GÅSVÆRFJORDEN · MELØY · GLOMFJORDEN · MELØYFJORDEN · GRØNNØY · ÅMØY · ÅMNESSUND · ENGAVÅGEN · VASSDAL · BJÆRANGFJORDEN · BJÆRANGDALEN · SKARSFJORDEN · HOLANDSFJORDEN · NORDFJORDEN · SVARTISEN

Radiocarbon dates:
10540 ± 190 · 11740 ± 100 · 11050 ± 120 · 11610 ± 140 · 34330 +1630 −1410 · 10640 ± 70 · 11720 ± 200 · 10860 ± 150 · 11700 ± 150