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Glacial Geology of Western Troms, North Norway

By

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Contents.

Illustrations:
Three plates, 29 figures and 7 tables.

Abstract.

A moraine chronology was established for western Troms. Altogether six main glacial phases were recognized. Several of the phases were radiocarbon dated. Observations were made of the corresponding shore lines, the marine fauna and the snow lines.

The maximum extent of the ice sheet. Numerous glacial features on the submarine shelf off the coast of western Troms show that the shelf was covered by the ice sheet. However, the available information is insufficient to show whether or not small parts of the outermost shelf or of the highest mountain peaks were ice-free during the Würm Maximum.

The Egga moraines represent the late part of middle Würm, possibly including the Würm Maximum. They are large submarine ridges on the shelf. Two or three successive ridges exist. The corresponding shore levels were probably 80 m—110 m below the present.

The Island I moraines are the oldest moraines deposited by local glaciers on the outermost islands. Submarine thresholds near Hekkingen could be corresponding end moraines deposited by the continental ice sheet.

The Skarpnes moraines are probably of Older Dryas age, or possibly slightly older. They are large moraine ridges near the mouths of the fiords. The glacial conditions during the Skarpnes event were similar to those described for the following Tromsø—Lyngen event. The Skarpnes shore lines lie 7 m to 10 m above the distinctive Main shore line near the moraines.

The Tromsø—Lyngen moraines correspond with the Younger Dryas period, and the ice fronts were located at or behind the position of these moraines also during most of the Allerød period, possibly also during the Older Dryas period. They are the most distinctive large moraines in Troms. Frequently two parallel moraine ridges exist suggesting two glacial advances. The Main shore line corresponds to these moraines, and a cold water *Yoldia* fauna characterized by the mollusk *Portlandia arctica* lived in the sea near the ice fronts. A more Boreo-Arctic type marine fauna lived further from the ice fronts. The latter fauna was the most dominant in Allerød time. The Tromsø—Lyngen snow line and glaciation limit were about 475 ∓ 50 m below the modern.

The Stordal moraines are of Pre-Boreal to early Boreal age. As many as three successive moraines lie in some valleys. They are generally considerably smaller and less distinctive than the Tromsø—Lyngen moraines. The Stordal snow line (glaciation limit) was

about 200 ± 50 m below the modern, and the Stordal sea level was 5 m—10 m below the extended Main shore line near the moraines. A Boreo-Arctic type marine fauna lived at the Stordal ice fronts.

The waning phase that followed the Stordal events corresponds approximately with the early part of the Boreal phase. The climate probably was very similar to the present-day climate, and the melting was rapid. Melting features of various kinds dominate the valleys upstream from the Stordal moraines. Ice-contact outwash terraces and indistinct moraines lie in scattered localities.

Small recent moraines close to the existing glaciers probably date from the early part of the 18th century and from younger phases.

Introduction.

Troms County in North Norway (Fig. 1) is characterized by deep narrow fjords between high mountainous peninsulas. Deep valleys lead from the heads of the fjords up to a high mountain plateau near the Swedish border. Many mountainous islands lie offshore, and a narrow, shallow submarine shelf follows the coast outside the islands.

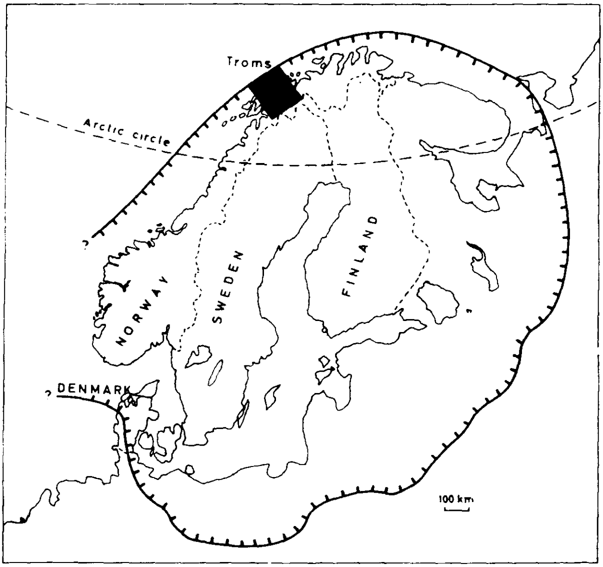

Fig. 1. Index map.

Western Troms, shown in black.
The extent of the Weichsel (Würm) ice sheet is outlined.

Vestlige Troms, sort ramme.
Utbredelsen av innlandsisen i Weichsel (Würm)-istiden er angitt.

Although Troms lies well above the Arctic Circle, its climate is humid-temperate. At Tromsø the mean annual temperature and precipitation are respectively 2.3 °C and 940 mm (Hansen, 1960, p. 46). Glaciers cover the highest mountains, and the snow line lies at altitudes between 800 m and 1200 m.

Most of Troms is underlain by metamorphosed, Cambro-Silurian, sedimentary rocks. These were folded during the Caledonian orogeny and uplifted in Tertiary time. Precambrian rocks, mainly red granite, are exposed near the Swedish border. Many of the islands along the coast are underlain by gneiss and granite of uncertain age. Raised marine shore lines and end moraine ridges are very striking Quaternary features in Troms. Shoreline studies were done by Pettersen (1884), Helland (1899), Grønlie (1940; 1951), Undås (1939) and others. Relatively little attention was paid to the study of the moraines. Helland (1889, p. 71) recognized the large moraine on Tromsø. Later Grønlie (1918, 1931) described several moraines, particularly in Balsfjord. A glacial origin for the submarine ridges (Egga-moraines) on the continental shelf was indicated by O. Holtedahl (1940, p. 14). Lind (1955) and Undås (1939), too, described moraines. Brief reviews of the moraines observed by the writer were published on two maps showing end moraines in Norway (Holtedahl and Andersen, in Holtedahl 1953, Pl. 16; 1960), and in Andersen (1965, 1965 b). The moraine chronology for Ullsfjord was established by Holmes and Andersen (1964).

When the investigations presented here started during the summer of 1951, many of the moraines in western Troms were unknown, and several of the known moraines were so poorly described that their origin was questioned. The investigations started as a study of the Tromsø—Lyngen glacial event. The hope was to give detailed descriptions of the Tromsø—Lyngen glacial conditions, the composition and the distribution of the Tromsø—Lyngen moraines, the age of the event, the climate including the altitude of the glaciation limit, the fauna, and the shore lines that corresponded to the event. Numerous observations of moraines and of other glacial features that represented older and younger glacial events were done as the field work progressed. Therefore, the scope of the study gradually changed to include these features also and to establish the complete moraine chronology for western Troms. However, most time was spent on the study of the Tromsø—Lyngen event, which is therefore described in more detail than the others.

THE MAXIMUM EXTENT OF THE CONTINENTAL ICE SHEET DURING THE PLEISTOCENE GLACIATIONS

A shallow submarine shelf lies along the west and north coasts of Norway, including the coast of Troms. The extent of the Pleistocene ice sheet on this shelf has been much debated. Most scientists seem to agree that the shelf was covered by the ice sheet during the Mindel and Riss glaciations, but there has been no general agreement on the extent of the Würm ice sheet. For instance, H. Holtedahl (1955, p. 195) favoured the opinion that a considerable part of the continental shelf near Ålesund could have been covered by the Würm ice sheet, while Dahl (1954, p. 21) thought that most of that shelf was ice-free during the Würm glaciation.

Conclusions on the Pleistocene ice cover were based mainly on studies of the submarine shelf topography. Numerous trough-shaped depressions that resemble glacial troughs, and ridges that look like marginal moraines were found. For instance, Helland (1875) recognized the glacial origin of some of these features. Later particularly O. Holtedahl (1929, 1940, 1953 p. 59) advocated a glacial origin for the submarine troughs and ridges on the shelf, while Dahl (1955, p. 167) thought that they could be of non-glacial origin.

Several of the features on the shelf in Troms are rather striking and many of them have been described by several scientists, Nansen (1904, p. 39), Shephard (1931, p. 349), Holtedahl (1935, 1940 p. 14), Evers (1941, p. 143), Andersen (1965) and others. The glacial origin of the features was discussed in most of the papers, but only O. Holtedahl gave a more detailed description. Holtedahl's interesting analysis will be discussed later.

Rather accurate bathygraphic maps from parts of the shelf in Troms, in addition to echograms and numerous samples of the sea floor sediments permit a more detailed analysis here. The shelf is only 30 km wide in the southwestern part of Troms, and the width increases to more than 60 km in the northeastern part. Characteristic for this shelf are the flat shallow banks between deeper submarine channels (drowned fjords) that cross it. The outer edge of the shelf is called Egga, and it lies generally 100 m to 250 m below sea level. The continental slope outside Egga slopes steeply down to a deep-sea floor, 2500 m to 3000 m below sea level (fig. 2). Shallow channels parallel to the coast along the inner margin of the shelf most likely represent eroded fault lines, as indicated by O. Holtedahl (1940).

Most of the morphological elements typical of a glacially sculptured landscape can be recognized on the shelf. In fact, these elements occur in abundance, and they are so well developed that much of the submarine shelf can be classified as a glacially sculptured landscape. For instance, the floors of all the submarine channels (fjords) are trough-shaped (fig. 2). The deepest part of the Andfjord-trough lies

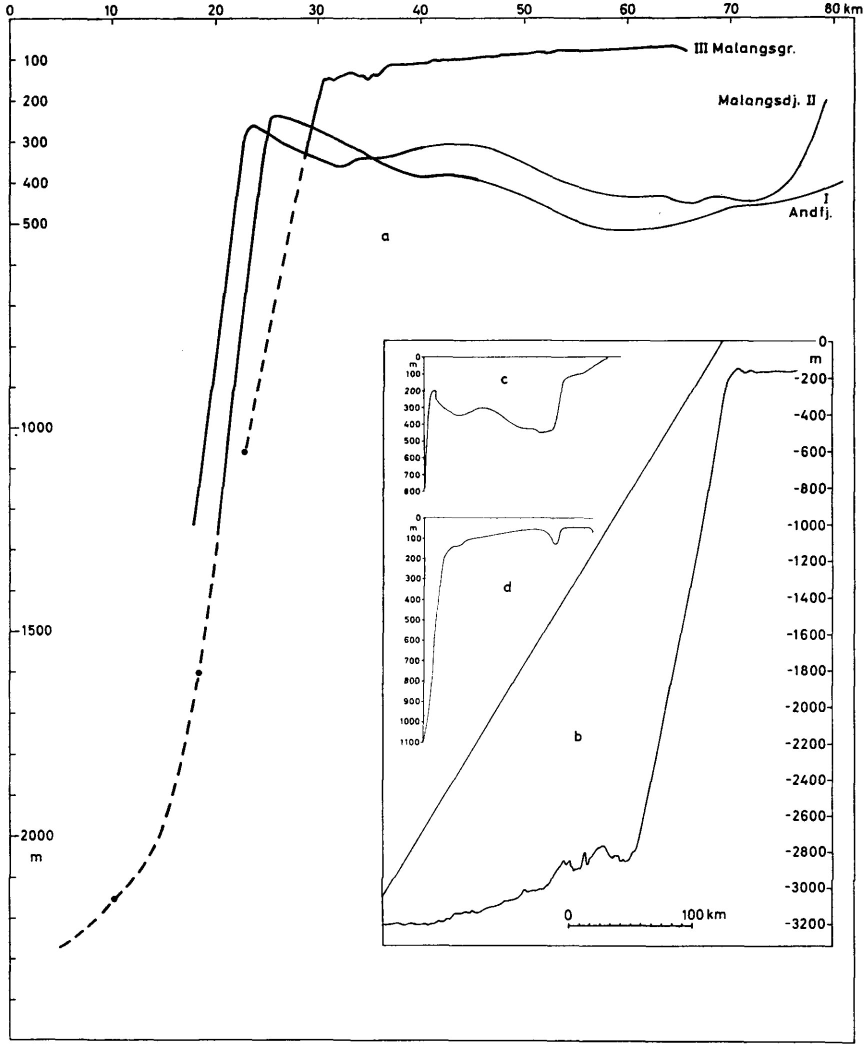

Fig. 2. Profiles perpendicular to the coast at the continental shelf in western Troms.

a) Andfjord I, Malangsdjupet II, and Malangsgrunnen III.
Thick lines are echo-profiles made by the Royal Norwegian Navy.
Dots are single observations.

b) Echo profile from immediately north of Malangsgrunnen, made by Sjøfarts-direktoratet.
From H. Holtedahl 1955.

c) and d) Profiles from Andfjord and Malangsgrunnen respectively.
From O. Holtedahl 1935.

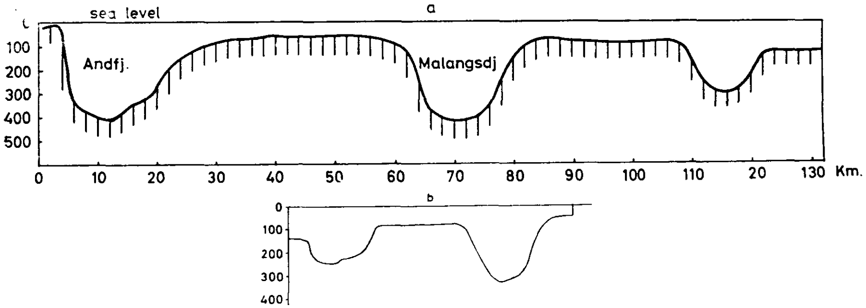

Fig. 3. Profiles parallel to the coast across the deep channels on the continental shelf in western Troms.

- *a) Constructed by the writer.*
- *b) From O. Holtedahl 1935.*

Tverrprofil av de dype rennene på kontinentalhyllen i vestlige Troms.

- a) laget av forfatteren.
- b) fra O. Holtedahl 1935.

about 500 m below sea level, while the threshold at its mouth is only 250 m below sea level. All cross profiles of the submarine channels (fjords) are characteristically U-shaped (fig. 3), and tributary channels hang with respect to the main channels.

In addition to the glacial erosion features, features that are characteristic for glacial sediments can be recognized. For instance, many large submarine ridges are shaped like end moraines and lateral moraines. A glacial origin for these ridges is supported also by the character of the sea-floor sediments (p. 15). Striking features are the large projecting parts of the shelf at the mouths of the three main submarine channels, particularly at the mouths of Andfjord and Malangsdjupet. They look like huge delta-fans extending down the continental slope to the deep-sea floor. Nansen (1904, p. 40) observed the

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Tverrprofil av kontinentalhyllen i vestlige Troms.

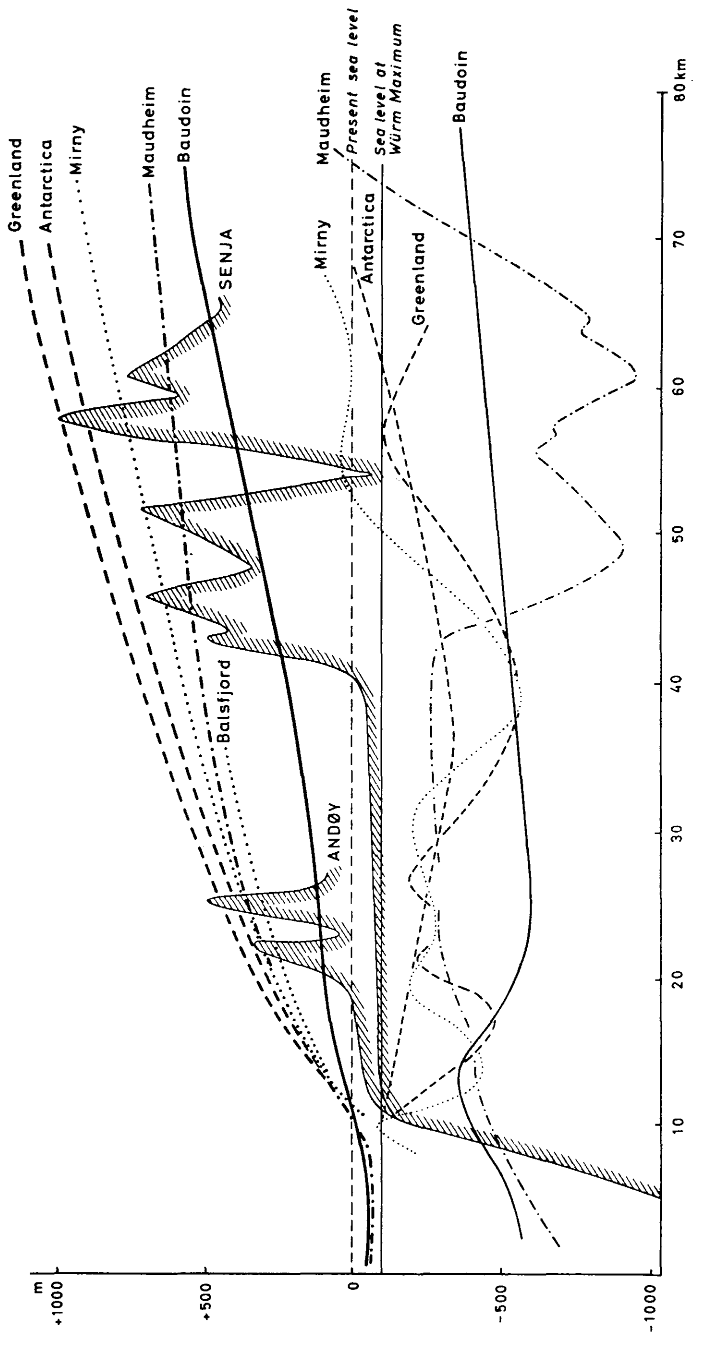
- a) Andfjord I, Malangsdjupet II og Malangsgrunnen III.
  Tykke linjer: ekkoprofil tatt av Den Norske Marine.
  Prikker: enkle observasjoner.
- b) Ekko-profil av et område like nord for Malangsgrunnen, tatt av Sjøfartsdirektoratet. Fra H. Holtedahl 1955.
- c) og d) Profiler av respektive Andfjorden og Malangsgrunnen.
  Fra O. Holtedahl 1935.

fans, and indicated that they were possibly "glacial deltas." However, Nansen was mainly interested in the valleys between the fans. He favoured the opinion that these valleys were formed by stream erosion, and therefore the fans were most likely erosion remnants between stream eroded valleys. Nevertheless, the location of these valleys in addition to information that will be presented in the following, clearly indicate that they were most likely formed by the same agent as the fans. The fan surfaces are very smooth and the angle of slope is regularly 12° to 16° as shown both by the echograms (fig. 2) and the bathygraphic map (pl. 1). The same angle of slope is very common for the fan (foreset) beds within the submarine end moraines along the coast of Norway (the writer's observation). Bottom samples from the fan surfaces show that coarse-grained sediments (sand to boulders) are usual, and clays cover only parts of the surfaces even at depths below 500 m. Nicely curved end moraine ridges follow the upper rims of the fans (p. 14). Located at the mouths of trough-shaped channels, the fans can not be ordinary stream deltas. The location and the regular shape also indicate that they are not rock promotories. In fact, there is only one reasonable explanation for them. They must be of glacial origin, deposited in the sea at the fronts of glaciers. They probably have a composition similar to most of the submarine end moraines, which consist of drift that was pushed by the ice or washed down from the ice front, and of outwash transported by the glacier streams. The fans can probably be classified as marine, morainic, outwash fans. The immense size of the fans suggests a deposition of enormous quantities of sediments, and they possibly contain drift from several glaciations. In fact, drift from the various

Fig. 4. Profiles across the shelf at Andøy and Senja; and longitudinal profiles of the glacier surfaces and the glacier floors for various glaciers in Greenland, Antarctica and in Norway.

Maudheim, Antarctica: Robin (1958), Hoppe (1959).
Mirny, Antarctica: Shumskiy (1959, 1962).
Badoin, Antarctica: Picciotto (1961).
Antarctica: Robin 1962, p. 141.
Greenland: Robin 1962, p. 141.
Balsfjord: see fig. 10.

Tverrprofil av kontinentalhyllen ved Andøya og Senja sammen med lengdeprofil av breoverflater og breunderlag fra forskjellige breer på Grønland, i Antarktis og i Norge.


Greenland
Antarctica
Mirny
Maudheim
Baudoin
SENJA
Balsfjord
ANDØY
Maudheim
Present sea level
Sea level at Würm Maximum
Mirny
Antarctica
Greenland
Baudoin
m
+1000
+500
0
-500
-1000
10
20
30
40
50
60
70
80 km

Pleistocene glaciations very likely occurs in abundance on the shelf, particularly on the outermost part.

An obvious conclusion to the previous discussion must be that the ice sheet covered the continental shelf in Troms. When did this happen? Evidence presented in a following section shows that the Egga-moraines along the outer edge of the shelf are of Würm age (p. 25). Therefore, the Würm glacier covered the shelf, possibly with the exception of small parts between the glacier lobes. In all parts of the world where the extent of the Pleistocene ice sheets are well known, the Mindel and the Riss ice sheets were considerably larger than the Würm ice sheets. Most likely this was also the case on the continental shelf off Troms, which was probably completely covered by the Mindel and the Riss glaciers. Belts of floating shelf ice could have covered parts of the deep-sea area outside the continental shelf during all of the Pleistocene glaciations. To illustrate the most likely conditions on the shelf during such phases the profiles of several modern ice sheets were plotted together with cross-sections of the shelf in Troms (fig. 4). Some of these ice sheets grade into floating shelf ice on open coasts similar to that in Troms.

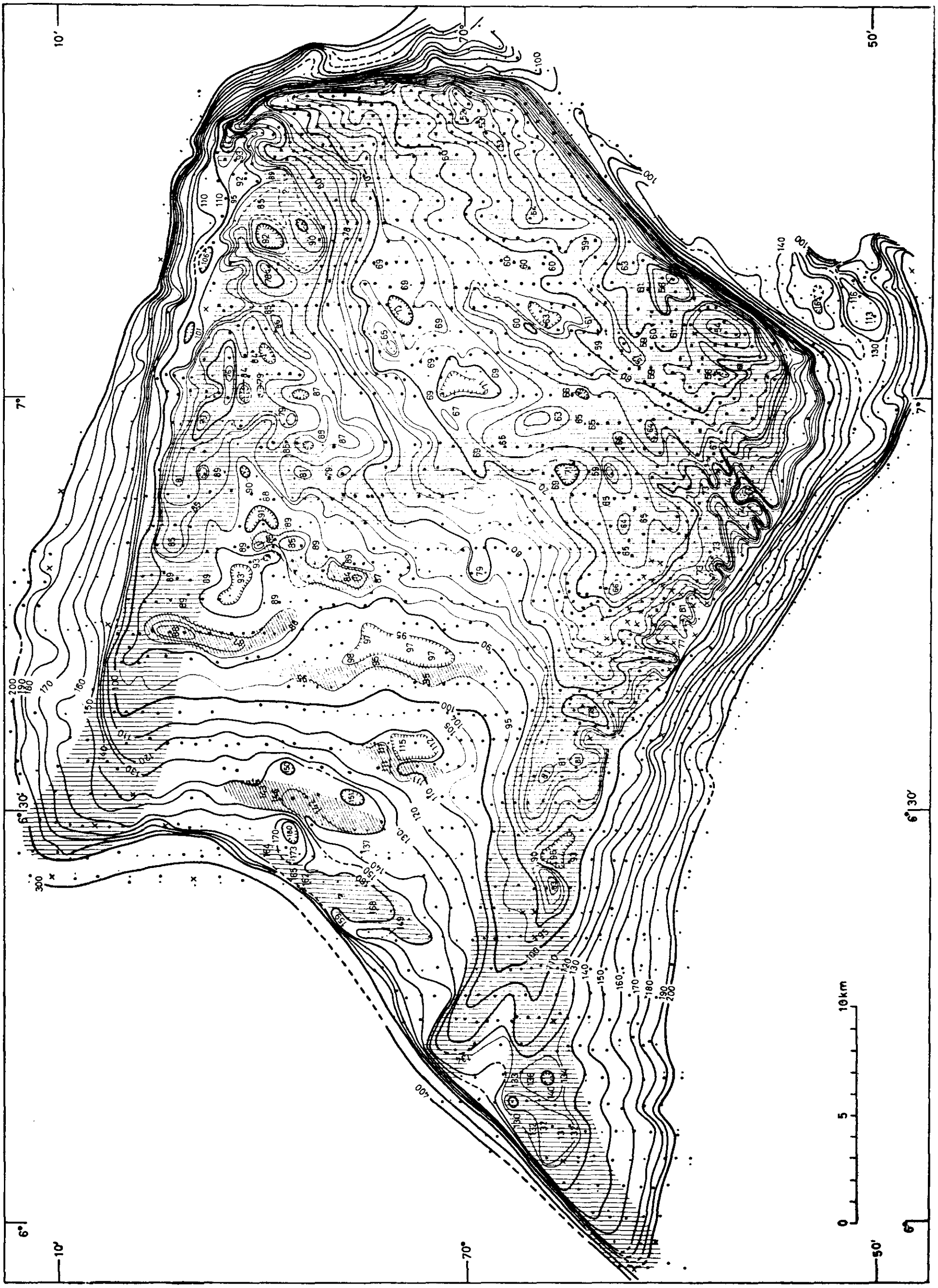
THE EGGA MORAINES

The bathygraphic map (pl. 1) shows large submarine ridges on the continental shelf in Troms. The nicely curved ridges at the mouths of the submarine main channels have been mentioned above. They continue into ridges on the shallow banks between the deep channels. Most of these ridges were observed by O. Holtedahl (1940, p. 14), who suggested that they could be marginal moraines. Some of them were plotted as questionable marginal moraines on the Glacial Map of Norway by O. Holtedahl and B. G. Andersen (in Holtedahl 1960). Evers (1941, p. 143) considered the shallow banks to be "Delta moränen", and he supported O. Holtedahl's suggestion that the ridges along the sides of the banks are most likely lateral moraines. In a preliminary report, Andersen (1965) described the submarine ridges as marginal moraines.

The shape of the ridges at the mouths of Andfjorden and Malangsdjupet is typical for end moraines; for instance, they are characteristically looped and they rise gradually towards the sides of the fjords where they pass into lateral ridges. Also, their location at the outer edge of a shallow area, and the 12° to 16° angles of their distal slopes are usual for many marine end moraines. Bottom samples from the ridges show that their surface sediments are sand, gravel and cobbles (fig. 5). The inclination of their crests indicates that they are not beach ridges. In fact, only the glacial theory satisfies and explains the observed features. The ridges are no doubt end moraines.

The map (pl. 1; fig. 5) shows broad ridge-shaped belts across the shallow banks, Malangsgrunnen and Sveinsgrunnen. The belts grade into the ridges described above at the mouths of the deep channels. Thus most of the large ridges on the outer part of the shelf are connected in a ridge-system that has a shape and a location characteristic for marginal moraines. Holtedahl (1940, p. 14) described the ridges at Malangsgrunnen and Sveinsgrunnen: "Main features of both banks are the examples of ridge-like lateral elevations especially in the outer part of the banks. An important detail is the bipartition of the southwestern ridge outwards in Malangsgrunnen, for such a feature supports strongly the idea that we are dealing with old lateral moraines laid up by the ice-tongues during a time of much lower relative sealevel. At the north-eastern corner of both banks (especially distinct in Malangsgrunnen) relatively small, but very marked peripheral ridges (probably also lateral moraines) are seen." Many other interesting features can also be seen on the bathygraphic map (fig. 5). For instance, the broad ridge-belt along the northern side of Malangsgrunnen consists of numerous small hills, ridges, and closed depressions. Bottom samples from the ridge-belt were of sand, gravel and boulders. This irregular topography resembles a subdued dead-ice topography. Holtedahl mentioned a ridge at the north-eastern corner of Malangsgrunnen. This is relatively steepsided, about 12 km long and it grades into a broader ridge towards the south. A regular gentle inclination of the ridge together with the location along the upper part of a steep slope suggest that it is a lateral moraine. About 30 samples collected from the ridge surface were sand, gravel and boulders (fig. 5), which supports this conclusion.

As many as three parallel main ridges lie within the described morainal belts. They probably represent successive glacial phases which were called the Egga phases, since the moraines lie close to the outer edge (Egga) of the continental shelf (Andersen 1965, 1965 b). Ridges


10'
70°
50'
7°
6°30'
6°
100
110
120
130
140
150
160
170
180
190
200
300
400
0
5
10 km

on the westernmost part of Malangsgrunnen could be end moraines representing still older phases.

Some of the features within the discussed ridge-belts are probably of nonglacial origin. For instance, bedrock or boulders have been recorded within small areas at Malangsgrunnen (fig. 5) and within larger areas at Sveinsgrunnen. (Boulders could not be distinguished from bedrock by the sampling method used.) Therefore, some of the ridge-belt topography could reflect the topography of the bedrock. Several small ridges within the belts have nearly horizontal crest-lines, and they are very likely beach-ridges. However, the dominant features of the ridge-belts resemble those of glacial accumulation features, and there can be little doubt about their glacial origin. The character of the sea floor sediments, too, supports this conclusion (fig. 5).

The sea level.

A thorough analysis of the sea-floor topography and sediments leads to the problem of the sea level that corresponded to the Egga phases. Holtedahl (1940, p. 14) discussed the problem of low sea levels, and he wrote: "The map of Malangsgrunnen shows at several levels, at about 150—160, 140—145, 110 and 95 m, low ridges in front of shal-

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Fig. 5. Bathygraphic map of Malangsgrunnen, with suggested moraine ridges and beach ridges.

Narrow shaded ridges: probably beach ridges
Broad „ „ : „ marginal moraines
Large dots: gravel to cobbles
Small dots: sand
xx: boulders or bedrock
Contour interval 10 m (5 m, dotted lines).
Bathygraphy: from O. Holtedahl 1940.
The location of most of the moraines was indicated by O. Holtedahl (1940).
The map is based on unpublished information from Norges Sjøkartverk.

Bathygrafisk kart av Malangsgrunnen, med morenerygger og strandvoller.
Smale skraverte rygger er sannsynligvis strandvoller
Brede „ „ „ „ randmorener
Store prikker: grus og stein
Små „ : sand
xx: blokker eller fjellgrunn
Ekvidistanse : 10 m (prikkede linjer, 5 m)
Dybdekurver: Fra O. Holtedahl 1940.
Beliggenheten av de fleste morenene ble angitt av O. Holtedahl (1940).
Kartet bygger på upubliserte opplysninger fra Norges Sjøkartverk.

low basins. These ridges may best be explained as drowned shore bars". "In Sveinsgrunnen is seen on the north side a lagoon-like depression, and south of it several contour lines show a marked curving towards the south. A fluvial channel, deformed and smoothed at varous levels by the sea at corresponding periods of relative standstill in the transgression of the sea, would produce a similar topography. The contour lines between 70 and 80 m form on the south side of Malangsgrunnen a very striking pattern. It looks like a coast with rocks of varying hardness striking into the sea and differentially cut back through abrasion". In general, Holtedahl's interesting analysis and conclusions agree very well with the writer's. However, the suggested origin of the above mentioned ridges at depths below 110 m on the westernmost slope of Malangsgrunnen is more questionable. Their crest lines seem to be inclined, and the echogram (fig. 2) shows an irregular topography which possibly reflects an irregular bedrock surface or a morainic topography. They could, therefore, be bedrock ridges or end moraines. The broad 7 km to 10 km long ridges with horizontal crest lines that lie 95 m, 85 m, and 86 m to 88 m below sea level on the western part of Malangsgrunnen look more like beach ridges (fig. 5); and many features that strikingly resemble shore features exist at approximately the same depths. For instance, many relatively steep-sided moraine ridges change to broad ridges or terraces below the 80 m to 100 m depth. This is particularly true for the ridge described on the northeastern slope of Malangsgrunnen, which terminates in a terrace between 95 m and 110 m below sea level. Another ridge at 76 m to 85 m depth along the north side of Malangsgrunnen becomes very broad below the 88 m contour line. Distinctive ridges on the north slope, and the large moraine ridge along the southwestern side of Sveinsgrunnen also change to broader ridges below the 80 m to 90 m depth, or they stop at that depth (see the map in Holtedahl 1940, pl. 4). These changes can best be explained as caused by changes in the depositional environment. Marine moraines are generally broader than terrestrial moraines, and broad terraces are commonly formed where lateral moraines reach sea level.

The topography on the south slope of the moraine ridge along the south side of Malangsgrunnen is very irregular. A part of this topography is probably morainic, but several small V-shaped depressions could be ravines. The irregular topography, including the suggested ravines, stop abruptly at a horizontal line about 90 m below sea level.

Two explanations seem possible for this abrupt change. The horizontal line represents either a shore line or a hard surface (bedrock?) on which the sediments rest.

The central western part of Malangsgrunnen is a wide plain that slopes gently seawards from about 70 m—80 m to 100 m—120 m below sea level, see echo-profile in fig. 2.

Bottom samples from the plain consisted mainly of gravel to cobbles and some sand. Both the topography and the sediments suggest that this could be an outwash plain graded to a sea level somewhere between 90 m and 120 m below the present. A wide portion of the northeastern part of the plain lies about 89 m below sea level. Closed depressions in this part look like shallow kettle holes, or lagoons. Several ridges, a few metres high, shown on the echo-profile of Malangsgrunnen (fig. 2) could be beach ridges. Evers (1941, p. 143) also was of the opinion that Malangsgrunnen in part represents an outwash plain.

The features described suggest that when the Egga moraines were deposited, sea level was somewhere between 80 m and 110 m lower than today. In that case the sea must have transgressed across Malangsgrunnen and Sveinsgrunnen during a following phase. This transgression was rapid or else the entire morainic topography would have been completely levelled by wave abrasion. O. Holtedahl (1940, p. 15), too, arrived at this conclusion. However, some of the morainic features, such as the depressions, could have been formed by melting of buried ice after the transgression. Still the moraines on the shallow banks must have been considerably levelled by wave abrasion. This is indicated, too, by the subdued topography of the moraines there. The angles of the steepest moraine slopes seem to be less than 6°, (unfortunately the scale of the available maps was too large (1 : 100,000) for accurate measurements).

Considering the steep slopes of many terrestrial moraines, there is good reason to assume that the moraines at Malangsgrunnen and Sveinsgrunnen were levelled very much by marine abrasion. The most usual sea-floor sediment is sand in the depressions, and gravel to boulders on the ridges (fig. 5). This could indicate that the sediments were washed and sorted by waves in the shore zone. However, some sorting and transportation of the sand probably occur even under the present-day conditions on this shelf. According to H. Holtedahl (1955, p. 137), both water movement associated with surface waves and bottom currents could move sand at considerable depths on the shelf. For instance, Helland-Hansen (1907) measured bottom current velocities of 23 m per sec. about 65 m below sea level on the shelf in western Norway. Therefore, the transport of sand on the shelf in Troms could be partly of recent age.

A rapid transgression of the sea across the shelf following the Egga phases seems necessary to explain the relatively well preserved morainic features on Sveinsgrunnen and Malangsgrunnen. Other lines of evidence also suggest that the transgression happened rapidly. For instance, the highest-lying shore lines at Andøya Island on the outer part of the shelf, lie about 50 m above sea level (Marthinussen, in Holtedahl 1960, p. 418, and the writer's observations). This shore line is the oldest on Andøya, and was probably formed immediately after the deglaciation of the shore zone, which again must have happened shortly after the Egga phases. Therefore, the sea level rose probably from 80 m—100 m below present sea level during the Egga phases to 50 m above present sea level shortly after them, at the outer part of the shelf.

More theoretical calculations of the sea level changes also suggest a rapid transgression of the sea across the shelf. This can be shown by a theoretically calculated graph for the shore line displacement at the outer part of the shelf near Andøya, fig. 6. The shore line displacement is the net effect of the isostatic changes of land and the eustatic changes of sea level. Therefore, a graph showing the shore line displacement can be constructed when the graphs for the isostatic changes and the eustatic changes are known.

The eustatic changes of sea level correspond with the shore line displacement in areas where no isostatic or orogenic movements took place. Several scientists have tried to find the Pleistocene shore line displacement in such areas. Graphs of the eustatic sea-level changes have been constructed, based partly on radiocarbon-dated shore levels. Shephard (1961) and Kenney (1964) presented good reviews of these observations, which are unfortunately still too few to construct the exact eustatic graph for the Würm glaciation. Theoretical calculations of eustatic changes have been attempted, too, based on calculated ice volumes. Several of the calculations suggest that the eustatic lowering of sea level during Würm Maximum was at least 100 m, and Donn (1962) indicated about 120 m. The graph or rather the belt for the eustatic changes presented in fig. 6 agrees with most of the accepted

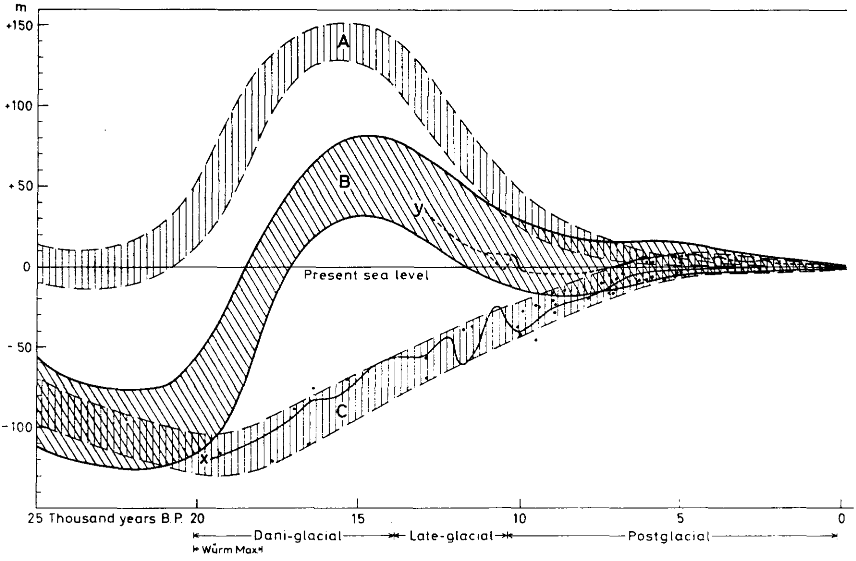


Fig. 6. Shore-line displacement near the outer edge of the continental shelf in western Troms, roughly calculated.

A: isostatic changes, roughly calculated.
C: eustatic changes.
Line x is a graph presented by Kenney (1964, p. 206).
B: shore-line displacement, constructed by adding the graphs A and C arithmetically.
Dashed line (y): shore-line displacement at Andøya (Marthinussen 1962, p.67).

Strandforskyvningskurve for områder nær ytterkanten på kontinentalhyllen i vestlige Troms, beregnet omtrentlig.

A: den isostatiske forskyvningen, beregnet omtrentlig.
C: den eustatiske „ „ „
Linje x er en kurve laget av Kenney (1964, s. 206).
B: strandforskyvningskurve (belte) laget ved aritmetisk addisjon av kurvene A og C.
Stiplet linje: strandforskyvningskurve for Andøya (Marthinussen 1962, s. 67).

calculations for the sea level changes. Most of the mentioned radiocarbon-dated shore levels and the available graphs for the eustatic changes lie within the belt, for instance a graph presented by Kenney (1964, p. 206). Therefore, the correct graph for the eustatic changes of sea level most likely lies within the belt.

The construction of a graph for the isostatic changes at the outer part of the shelf in Troms is considerably more problematic, and it must be based on assumptions that can not be easily supported. Evidence from other glaciated areas suggests that the Würm ice sheets expanded rapidly during the period following 25,000 years B.P. to reach a maximum extent between 18,000 years B.P. and 20,000 years B.P. The stay of the ice fronts at their outermost positions was of short duration and it was followed by phases of rapid retreat (Flint 1955, p. 252). The following discussion is based on the assumption that the changes of the ice sheet in Troms followed approximately the same pattern. From about 25,000 years B.P. to about 20,000 years B.P. the ice sheet most likely advanced across the shelf. The isostatic down-warping of the outermost part of the shelf was probably very small during this period, and it is even possible that this part was slightly raised. The weight of the overlying water was small because the sea level was eustatically lowered, and the sub-crust transport of material from the isostatically lowered, ice-covered areas too, could have caused a small uplift. The shelf was probably completely overridden by the ice sheet about 20,000 years B.P.; and the ice reached its maximum thickness about that time. This must have caused a very rapid down-warping of the outermost shelf areas. At that time, the ice load was at its maximum, and the shelf crust was farthest from the equilibrium position. Since the ice front probably stayed for a very short period at its outermost position, the shelf crust can not have reached its down-warped equilibrium position before the glacier retreat started. Therefore, the isostatic down-warping of the shelf probably continued during the first phases of glacial retreat. The rate of down-warping gradually decreased because of the decreasing ice load and because the shelf crust approached the equilibrium position. This position was finally reached when the weight of the ice corresponded roughly with the weight of the replaced viscous material below the shelf crust. At that time the shelf was at its deepest, isostatically down-warped position. When did this happen, and what was the amount of the down-warping? The exact time can not be fixed, but it must be older than Late-glacial time since the deglaciation of the shelf area was completed before that time (p. 137). A rough calculation of the amount of maximum isostatic down-warping at Andøya Island was attempted. As mentioned before, the shores of this island were probably deglaciated shortly after the Egga phases. They were, therefore, most likely ice-free at the time of maximum isostatic down-warping, and the highest-lying shore line, about 50 m above sea level, was probably formed at that time. According to the graph (fig. 6), the corresponding eustatic lowering of the sea level was about 70 m to 110 m (90 m ± 20 m). Therefore, the maximum isostatic down-warping at the outermost part of the shelf near Andøya was most likely in the order of 140 m (50 m + 90 m) ± 20 m.

The rapid deglaciation of the shelf which probably followed, caused a rapid decrease of ice load and a rapid isostatic uplift. This uplift decreased gradually as the shelf crust approached the equilibrium position. The graph presented here for the isostatic changes was made as a very broad belt to indicate the many problems in the construction (fig. 6).

A graph or belt showing the shore-line displacement at the outer part of the shelf in Troms was made by adding arithmetically the values presented by the graphs for the isostatic and the eustatic changes. This shore-line displacement graph (belt) does not pretend to be accurate. However, it probably shows the general trend, and the correct graph for the shore-line displacement will most likely lie within or relatively close to the belt. This conclusion is supported also by the fact that a graph for the late shore-line displacement at Andøya, constructed by Marthinussen (1962, p. 67), lies entirely within the belt (fig. 6). That graph was based on studies of the shore-lines, of which some were radiocarbon dated. A striking feature of the present graph-belt is the very steep part suggesting a very rapid rise of the shore level, from about 80 m below the present sea level to about 20 m above it. This again probably explains the indicated rapid transgression across Malangsgrunnen and Sveinsgrunnen. Another suggestion, too, can be made based on the shore-line displacement graph. If the shore level during the Egga phases was 110 m to 80 m lower than at present, then the graph suggests that the Egga moraines are not much younger than the Würm Maximum.

The glacial conditions.

The westward, convex end moraines at the mouths of the deep channels, Andfjorden and Malangsdjupet, were probably deposited 150 m to 200 m below sea level. Similarly shaped end moraines deposited at about the same depths lie at several places along the coast of Norway, for instance, at the mouths of Lysefjord and Jøsenfjord in southwestern Norway (Andersen, 1953). The shape of these end moraines suggests that they were deposited by very active glaciers. The deep troughs of Andfjord and Malangsdjupet indicate also that these channels were occupied by very active glaciers. They were main outlet channels for the ice sheet that covered the mountains to the southeast. Little of the ice from this sheet could pass across the alpine islands of Senja, Kvaløy and Ringvassøy, and most of the ice flow was diverted towards the sounds between the islands and to the above mentioned deep channels.

The crests of the lateral moraines along the sides of Malangsgrunnen and Sveinsgrunnen slope very gently. For instance, the slope of the moraine ridge along the southern side of Malangsgrunnen is only 90 m in 30 km. The moraine was probably considerably levelled by marine abrasion, but still, the original moraine and corresponding glacier surface along the southern side of Malangsgrunnen could not have been very much steeper. Therefore, the continental shelf was most likely covered by a gently sloping piedmont glacier during the Egga phases. The Egga moraines on the eastern part of Sveinsgrunnen lie only 15 km to 25 km from the 700 m to 1,000 m high mountains on Senja Island. These mountains must have been nunataks during the Egga phases. However, they lie considerably above the altitude of the Egga glaciation limit, and were therefore, at least in part, covered by local glaciers, which merged with the continental ice sheet.

The available information permits no accurate determinations of the Egga firn line or glaciation limit. Based on studies of the glaciation limits in Troms, the Tromsø—Lyngen (Younger Dryas) glaciation limit was calculated to have been less than 400 m above the present sea level at Andøya (Pl. 2). Therefore, the glaciation limit during the Egga-phases was probably considerably below 400 m. The Egga firn line must have been little or no higher than the present sea level, since the firn lines lie at a lower altitude than the glaciation limits (p. 120).

The age of the Egga moraines.

As mentioned before, there is no full agreement among scientists on the extent of the Würm ice sheet on the shelf in western and northern Norway. The age of the Egga moraines has not been discussed in print, except in recent papers by Andersen (1965, 1965 b). Therefore, a more thorough discussion of this subject seems necessary.

No distinct local moraines older than about 12,300 years B.P. and no old Dani-glacial shore lines were found on the islands along the coast of Troms (p. 137). This indicates that the islands, and most of the coast, were covered by the Würm ice during the oldest glacial phases (see fig. 6). Since the distance from the outermost islands to the closest Egga moraines is only 5 km to 10 km, there is reason to believe that these moraines were deposited by the Würm ice sheet. The location of the local moraines on the islands show that the islands were heavily glaciated even as late as 10,000—12,500 years B.P., (see later discussion). Outlet glaciers from the large continental ice sheet reached points only 50 km from the Egga moraines during the Younger Dryas (Tromsø—Lyngen) event, about 10,500 years B.P. Compared with the differences in extent of the ice sheet in southern Fennoscandia during various glacial events, the ice sheet in Troms was only a little larger at Egga time than at Tromsø—Lyngen time. The distances between successive end moraines in Troms that are younger than 10,500 years B.P. are only slightly less than the distances between corresponding end moraines in southern Fennoscandia. However, the distance between the approximately 10,500 year old Tromsø—Lyngen moraines and the Egga moraines is 15 times less than the distance between the approximately 10,500 years old Ra-Salpausselkä moraines and the Würm Maximum (Weichsel) moraines in Denmark-Germany (fig. 7). This comparison too strongly suggests that the Egga moraines are of Würm age. Only an immence obstacle could have prevented the Würm ice from reaching the location of the Egga moraines. Deep open water could be such an obstacle. However, the water is shallow on the shelf, and much of the shelf area was probably dry land when the Würm ice sheet advanced across it. Therefore, the Würm ice sheet most likely reached and deposited the Egga moraines.

Late-glacial and Post-glacial end moraines in Troms are of approximately the same size as end moraines of corresponding age in southern Fennoscandia. This indicates that the older Würm moraines (Dani-glacial moraines) in the two areas are most likely of approximately the same size also. Considering the large size and the distinctiveness of the Dani-glacial end moraines in Denmark and Germany the corresponding end moraines in Troms too are probably large and distinct. This description fits the Egga moraines very well.

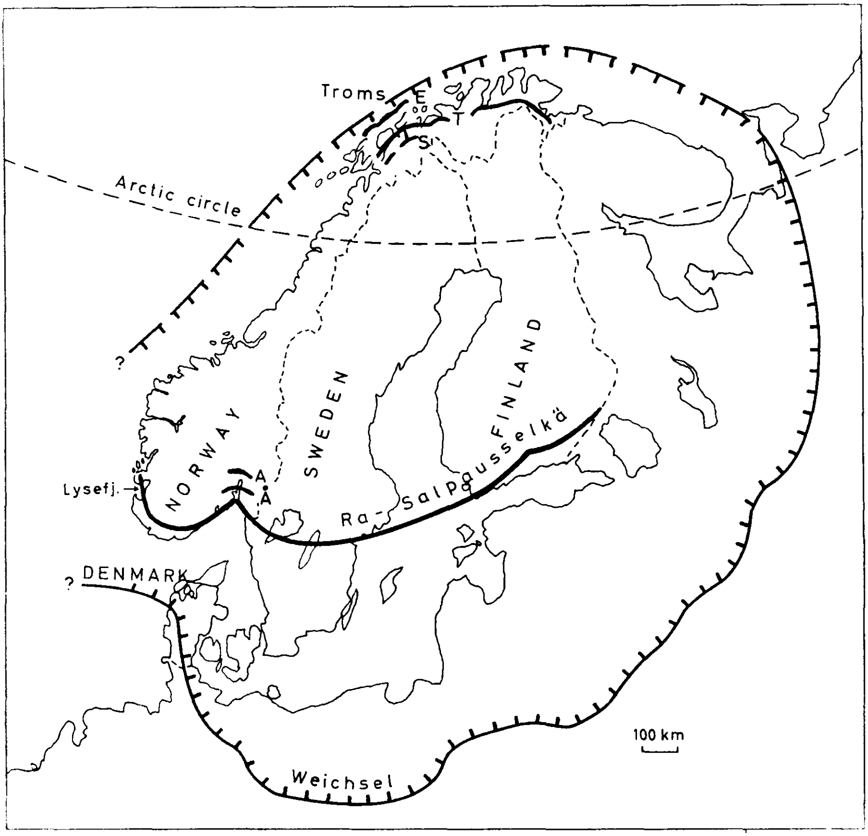


Fig. 7. End moraines in Troms and in southern Fennoscandia.

Troms: *E: Egga moraines*
T: Tromsø—Lyngen moraines (Younger Dryas)
S: Stordal moraines (Pre-Boreal)

Southern Fennoscandia:
Weichsel moraines (Würm Max.)
Ra-Salpausselkä moraines (Younger Dryas)
Å—A Ås—Ski and Aker moraines (Pre-Boreal)

Endemorener i Troms og sydlige Fennoskandia.

Troms: E: Egga morainer
T: Tromsø—Lyngen morener (Yngre Dryas)
S: Stordal morener (Pre-Boreal)

Sydlige Fennoskandia:
Weichsel morener (Würm maksimum)
Ra-Salpausselkä morener (Yngre Dryas)
Å—A: Ås—Ski og Aker morener (Pre-Boreal)

The short distance between the Egga moraines and the Tromsø—Lyngen (Younger Dryas) moraines could indicate that the Egga moraines are considerably younger than Würm Maximum. In that case, the Würm Maximum ice sheet probably extended outside the shelf area as a floating shelf ice. However, the suggested low Egga sea level indicates that the Egga moraines represent phases that are not much younger than Würm Maximum. Unfortunately the available information allows no more precise age determination. The Egga moraines probably correspond with most of the Dani-glacial moraines, possibly with the exception of the Würm Maximum moraines.

Questionable end moraines in the area between the Egga moraines and the Skarpnes moraines.

The rising sea level that followed the Egga phases must have been an important factor in a rapid retreat of the ice sheet from the 40 km to 60 km wide belt between the Egga moraines and the Skarpnes moraines. No clearly defined end moraines have been found within this belt. Some of the submarine thresholds could be end moraines, but they could as well be bedrock ridges. It is difficult to distinguish between the two types of thresholds, since the sea floor sediments are unknown and no characteristic morainic features have been found. Undås (1939, p. 152) suggested that two thresholds inside Andfjord are end moraines. He wrote that it looked as though a small end moraine crosses Vaagsfjord from Engenes to Stonglandet; and a threshold across the sound between Sandøy and Lemmingvær must be a good sized end moraine (pl. 1). However, Undås presented no particular information in favour of this conclusion. The threshold between Sandøy and Lemmingvær is parallel to the bedrock strike, and the contact between sedimentary rocks and igneous rocks (gneiss, granite) lies very close. Therefore, the threshold is most likely of igneous rocks, and the deep southern part of the sound was eroded into softer sedimentary rocks. The threshold in Vaagsfjord is a broad ridge that starts at Stonglandet and continues south-westward. The ridge does not cross the Vaagsfjord, and there seems to be no very good reason to postulate an end moraine between Stonglandet and Engenes.

Numerous small islands that represent the "strandflat" lie in a belt along the inner margin of the shelf outside Senja and Kvaløy (pl. 1). They are all bedrock islands with almost no sediments, except on a few small islands where slightly more beach sediments occur, for instance at Musvær and Sandøy. The submarine channels that lead through the main sounds between the large islands to the shelf are very shallow where they cross the "strandflat" belt. For instance, the Malangen channel has a marked threshold about 200 m deep north of Hekkingen, while it is more than 400 m deep both outside and inside that area. The shape of this threshold indicates that it could be an end moraine. However, the location near the mouth of a deep narrow sound is typical for many bedrock thresholds, and more information is needed to draw definite conclusions as to its origin. If the above mentioned thresholds are end moraines, then they most likely correspond to the Island I local moraines (p. 92).

Scattered morainic promontories, such as those in the sound between Reinøy and Ringvassøy, could be parts of end moraines. Therefore, more detailed studies of the promontories and of the sea floor could possibly reveal scattered end moraines within the belt between the Egga moraines and the Skarpnes moraines.

THE SKARPNES EVENT

Marginal moraines representing the Skarpnes event are generally the first large and well developed moraine ridges inside the submarine Egga moraines. Both end moraines across the fjords and sounds, and lateral moraines along the sides of the fjords and sounds exist. They were deposited by outlet glaciers from the continental ice sheet which covered the mountain districts to the south and south-east. The Skarpnes fjord glaciers were slightly longer than the fjord glaciers of the following Tromsø—Lyngen event. However, the size of the local glaciers that covered the highest parts of the islands and the peninsulas between the fjords was about the same for both the Skarpnes and the Tromsø—Lyngen event. This indicates that the climate was much the same during the two events. Moraines deposited by the local glaciers will be described in a later section.

Most of the Skarpnes moraines are slightly smaller and less distinctive than the Tromsø—Lyngen moraines, and they are usually not as continous as the Tromsø—Lyngen moraines. In some areas no Skarpnes moraines were found. The Skarpnes end moraines generally lie 4 km to 6 km outside the Tromsø—Lyngen end moraines.

Locality descriptions.

Ullsfjord—Sørfjord. The Skarpnes end moraine and lateral moraines in Ullsfjord were described by Holmes and Andersen (1964), and the following description is based on their observations. Prominent lateral moraines lie on both sides of the fjord. The one on the east side is more than 8 km long. It lies about 450 m above sea level and 150 m above the Tromsø—Lyngen lateral moraine at the southern end. The west side of the fjord is very steep, and only a very short lateral moraine ridge was seen in a shelf-like area on Nakkehylla. The ridge is steepsided and 10 m—15 m high, the northern end lying only 120 m above sea level immediately above the end moraine. Profiles of the lateral moraines show that the surface of the corresponding fjord glacier sloped steeply near, and gently at some distance from the terminus (fig. 10). A branch of the Sørfjord glacier entered the Nakkevann valley where it deposited a distinctive end moraine on the north side of Lake Nakkevann, together with large lateral moraines.

The end moraine in Ullsfjord is a very sharp, double ridge, about 40 m high, on the fjord bottom between Nakkehylla and Svensby. The ridge was found by echo soundings. Both the size, the shape and the location of the moraine indicate a correlation with the Skarpnes moraine north of Tromsø (p. 30). A relatively wide marine terrace at Svensby on the eastern side of Ullsfjord lies immediately outside the Skarpnes end moraine (Pl. 1). Small exposures along gullies in the front slope of the terrace show that it is composed mainly of fine-grained sediments, blue clay, sand and silt. An approximately 1 m—2 m thick sheet of gravelly outwash covers the terrace plain. The northern, highest-lying part of this plain was measured at 68 m—72 m above sea level, and the southern part at about 63 m—65 m above sea level. However, the weather was very bad when the northern part was measured, and the indicated altitude for that part could be slightly wrong. A distinct Main shore line was abraded into the front of the terrace, 60 m—62 m above sea level. Fossiliferous glacio-marine clays were exposed at two different localities on the front slope of the terrace. One lies 45 m above sea level at the mouth of a gully about 200 m north of Svensby pier, and the other about 20 m above sea level in an excavation for a house a short distance south of the pier (locality 1, Pl. 1). Both exposures showed glacio-marine blue clays that contained scattered stones and shells of *Mya truncata, Macoma calcarea* and *Hiathella arctica.* Unfortunately, the exposures are small, and the stratigraphic position of the clays is not clear. However, they were evidently deposited either at the Skarpnes ice front or during the following glacial retreat. Fresh-looking shells (many paired) from respectively the northern and the southern locality were radiocarbon dated at 11,200 ± 190 years B.P. (T-509, collected by Holmes and Andersen) and 11,090 ± 190 years B.P. (T-332). The dates suggest that the clays were deposited shortly after the Skarpnes event (p. 35).

Balsfjord. The east side. A low lateral moraine ridge near Krokelv on the east side of Tromsøysund lies about 300 m above sea level. The ridge slopes gently towards the north, about 20 m/km during the first 3 km south of Ruglfjell. Grønlie (1931, p. 267) recognized this lateral moraine together with a few short segments of the lateral moraine on the west side of the sound. However, Grønlie believed that the lateral moraines were almost horizontal, and he expected the corresponding end moraine to lie far north of Skarpnes.

The lateral moraine ridge continues steeply down the slope of a small valley north of Ruglfjell, and it grades into a broad morainic belt across the floor of this valley. The belt dams up Lake Movikvann. Apparently, a small steep branch of the Balsfjord glacier entered the Movikvann valley and deposited the above mentioned moraines. The moraine continues northward across Tuva and down the hill slope north of Tuva. There the ridge is steeply inclined, sharp and 10 m—15 m high. The end lies immediately above a set of marine terraces at Skarpneset end moraine. The highest-lying terrace is about 40 m broad, and rises gradually from a gently sloping outer part, 50 m—54 m above sea level, towards a higher, more irregular, inner margin. A beach ridge, 51 m—53 m above sea level, follows parts of the outer edge. The terrace and the ridge probably correspond approximately to the Skarpnes event. They lie about 10 m above the distinct Main shore line which crosses the Skarpnes moraine and continues inside the moraine along both sides of the sound.

The end moraine. Skarpneset is a broad ridge that projects far into the sound. Many large erratics lie at the surface of the ridge, and shallow exposures showed a gravelly till underlying beach washed sediments. Bedrock was exposed immediately above sea level in a small area on the proximal slope of the ridge, near the sea. The sediment, in addition to the location, clearly shows that Skarpneset is an end moraine deposited on top of a bedrock promontory. A submarine ridge continues across the sound from Skarpneset. The eastern segment of the ridge lies almost at sea level, and a part of the crest is exposed as a narrow, gravel-to-boulder island at low tide. The ridge lies deeper closer to Kvaløy, Pl. 1. Krakneset, on the west side of the sound, is a morainic promontory that represents the western segment of the end moraine.

The west side. Only short segments of the lateral moraine were seen on the west side of the sound, north and west of Tromsøy. The longest segment lies across the mouth of Finnvikdal, about 150 m above sea level. No Skarpnes lateral moraines lie further to the south on the west side of Balsfjord.

Fig. 10 shows the longitudinal profile of the Balsfjord glacier as indicated by the location of the lateral moraines.

The coast southwest of Tromsø. Only short segments of the Skarpnes marginal moraines were found along the coast southwest of Tromsø, despite an intensive search. The segments that were seen, have about the same location relative to the Tromsø—Lyngen moraines as the Skarpnes marginal moraines in Ullsfjord and Balsfjord. However, the moraine ridges in most of the segments are less distinctive than those in Ullsfjord and Balsfjord.

A Skarpnes lateral moraine about 6 km long lies along the south side of Kvaløy. The moraine is ridge-shaped in some places, but in general it forms a morainic belt with no sharp ridges. The eastern end lies 300 m—350 m above sea level, which is about 100 m higher than the western end. The hill slope west of the western end is covered by till, but no good lateral moraine was recognized, except for two very short ridges near Engenes. Considerable amounts of gravel with boulders lie in the shore zone near Engenes and Bakkejord. Engenes is a morainic promontory, and the Skarpnes end moraine most likely crosses the sound at the shallow part between Engenes and Tennskjær. Undås (1939, p. 221), also, suggested an end moraine across the sound at this point. A shore line cut in bedrock lies immediately west of the lateral moraine at Engenes, about 48 m above sea level. The shore line probably corresponds to the Skarpnes event. A small delta-fan with its front about 47 m above sea level must also have been graded approximately to the same sea level as the shore line. The Main shore line is the most dominant both west of and east of the Engenes moraine, and it lies about 38 m above sea level.

About 5 km south of Jøvik on the west side of Malangenfjord, there is a 4 km long, lateral moraine ridge, which lies about 100 m higher than the very distinctive Tromsø—Lyngen lateral moraine, and was, therefore, correlated with the Skarpnes moraines. The high altitude of this lateral moraine indicates that the corresponding fjord glacier sent a small glacier branch across the water divide towards Kaarvik in Gisundet. Low morainic ridges at the proximal part of a large gravelly and bouldery outwash delta at Kaarvik probably represent the end moraine deposited by this glacier. The delta plain outside the ridges lies 57 m—59 m above sea level, and corresponds in altitude with a shore line abraded into bedrock north of the delta. This is probably the Skarpnes shore line. A distinct shore line at about 10 m lower altitude represents the Main shore line (p. 59).

Slettnes in Gisund is a moraine ridge which projects into the sound. Numerous large erratics lie at the surface of the ridge. The Sletnes ridge, together with a shallow part of the sound, probably represents an end moraine. The location of the moraine, about 8 km outside the Tromsø—Lyngen moraine (p. 59), suggests a correlation with the Skarpnes event.

A lateral moraine ridge, 1 km long, on the south side of Solbergfjorden, and a similar ridge on the southwestern side of Gratangenfjord both lie about 100 m above large lateral moraines that were correlated with the Tromsø—Lyngen event. Therefore, the two ridges probably represent the Skarpnes event.

A broad moraine ridge projects into Astafjord at Langnes. The ridge is 10 m to 20 m high, and numerous erratics lie on the surface. Roldnes on the opposite side of Astafjord is a similar morainic ridge. Langnes and Roldnes, together with a broad indistinct submarine ridge between the two promontories, must be an end moraine. The location of this end moraine, about 5 km outside the Tromsø—Lyngen moraine (p. 63), suggests a correlation with the Skarpnes event. Undås (1939, p. 152), also, marked this moraine on his map.

Thick glacio-marine deposits lie at Sandstrand immediately outside the moraine ridge at Langnes. A shore deposit exposed in a gravel pit along the road to Sandvann (locality 13, Pl. 1) is of particular interest. The pit lies only 500 m from the Langnes moraine, and 70 m to 78 m above sea level. A section, shown in fig. 8, was exposed in the pit. A well sorted sand (A) overlies a poorly sorted bouldery gravel and sand with marine shells (B), and a sand with scattered

Fig. 8. Gravel pit in shore deposits near the Skarpnes end moraine at Langnes.
A: sand, well sorted.
B: gravel, poorly sorted with large erratics and numerous shells of Mya truncata *and* Macoma calcarea.
The shells were radiocarbon dated at 12,000—12,500 years B.P. (T-490 a, b, c).
C: sand, stratified with scattered boulders.
Scale: large boulder in "B" is 1 m.
The pit lies 70 m—78 m above sea level, immediately above the Main shore line.

Grustak i strandavsetninger ved Skarpnes-endemorenen på Langnes.
A: godt sortert sand
B: dårlig sortert grus med store flyttblokker og mange skjell av *Mya truncata* og *Macoma calcarea.* Skjellene har en C-14-alder av 12 000—12 500 år før nåtid (T-490 a, b, c).
C: lagdelt sand med spredte flyttblokker.
Målestokk: stor stein i "B" er 1 m.
Grustaket ligger 70—78 m o.h. og like over Hovedstrandlinjen.

boulders (C). Some of the boulders in the stratified sand (C) are striated. They are probably ice rafted and dropped in the sand near the shore. Boulders in the sand and gravel (B) are erratics too. Several of the boulders are large, some are striated, and they have the characteristic shape of erratics. The abundance of erratics in the sand and gravel suggests a considerable dropping from ice bergs. Therefore, a correlation with the ice front that deposited the Langnes moraine seems probable, although a correlation with a phase immediately before or after this event is also admissible. Numerous ice bergs from the ice probably became stranded in the shore zone immediately outside the ice front and dropped erratics there. The upper part of the marine sand (A) lies about 78 m above sea level, which corresponds approximately to the highest shore level in this area. No distinct Main shore line exists here, but the Main shore level was calculated at 68 m —70 m above sea level (Pl. 3).

Many shells of *Mya truncata* and *Macoma calcarea* lie in the till-like bed (B). Several of the shells were unbroken and some paired. The shells, therefore, must have lived when the erratics were dropped, and they most probably date the Langnes moraine. A sample of fresh looking shells were dated at 12,340 ± 160 (T-490a, outer fraction), 12,470 ± 160 (T-490b, middle fraction), 12,110 ± 160 (T-490c, inner fraction). The Langnes moraine, therefore, is probably 12,000 —12,500 years old, possibly slightly older or younger.

Marthinussen (1962, p. 46), also, collected shells from the glaciomarine deposits at Sandstrand, and five of the shell samples were radiocarbon dated. Shells which he correlated with the Langnes moraine were dated at 12,300 ± 250 years B.P. (T-269). Marthinussen gave the following description of the shell deposit; «Shells of *Macoma calcarea* near the lake Sandstrand, Skånland, Troms. Found near the surface of a small deposit of sandy clay (or clayey sand) at an altitude of 69.0 m." He mentioned that the shore lines corresponding to the Younger Dryas (Tromsø—Lyngen) time and the Older Dryas time probably lie respectively 68 m—70 m and 73.5 m—80 m above sea level at Sandstrand. Unfortunately, Marthinussen's description is so brief that it is impossible to see how he made the correlation between the shell deposit and the Langnes moraine. Another sample was dated at 11,700 ± 250 years B.P. (T-316), and Marthinussen gave the following description; "Shells of *Mya truncata* (fragments only) near the Lake Sandvatnet, Sandstrand, Skånland, Troms. Found imbedded in a layer of shore gravel 25 cm thick at 73.2—73.4 m a.s.l. Comment: The age coincides with the Allerød period of the standard timetable, and the altitude of the shells seems to point to a corresponding shore level at about 73.0 to 73.5 m a.s.l. The S_1 line, assumed to be of Allerød age, is here about 71 to 72 m a.s.l.". The third sample was shells of *Mya truncata* which were radiocarbon dated at 11,400 ± 250 years B.P. (T-214). The shells were found in a transition layer between a blue clay and a sand in a clay pit about 30 m above sea level. The blue clay is 5 m to 8 m thick and it rests on the sand. Scattered specimens of *Portlandia arctica* and a whale skeleton (Balaena mysticetus) lie in the clay that Marthinussen first correlated with the Younger Dryas phase. Later the protein fraction of the whale bones and shells of *Mya truncata* were radiocarbon dated at respectively 11,480 ± 260 years B.P. (T-378) and 11,430 ± 260 years B.P., and Marthinussen suggested an Allerød age for the clay (Nydal 1964, p. 283). Information that the writer obtained suggests that a sandy clay with pebbles to boulders underlies the described sand layer and the Allerød clay. The sandy clay is clearly glacio-marine, and it probably corresponds with the Langnes end moraine. Therefore, the Langnes moraine is most likely of Older Dryas age or slightly older, and the Allerød clay was probably deposited in the following waning phase.

The age, the climate, the fauna and the shore lines corresponding with the Skarpnes event.

The radiocarbon dates of deposits near the Langnes moraine suggest that the Skarpnes event is about 12,000—12,500 years B.P. old. The event can not be younger than early Allerød time, since deposits of this age lie at the Tromsø—Lyngen moraines about 4 km to 6 km inside the Skarpnes moraines. A Bölling age (12,000—12,400 years B.P.) or an Older Dryas age (11,900—12,100 years B.P.) are the most likely for the Skarpnes event.

Generally, the Skarpnes local moraines lie within the same moraine complex as the Tromsø—Lyngen local moraines (p. 94). Therefore, the glacial conditions and the climates of the two events were probably very similar (p. 126). The glaciation limits and the firn lines probably lay about 475 ± 50 m below the modern glaciation limits and firn lines.

Only shells of *Mya truncata* and *Macoma calcarea* were found within sediments that probably represent the Skarpnes event. Today the two species live in Arctic to Boreal waters. However, more observations are necessary to be able to draw definite conclusions about the Skarpnes faunas and sea-water conditions (see p. 69).

The observed Skarpnes shore lines lie 7—10 m above the Tromsø—Lyngen shore lines in areas close to the Skarpnes end moraines, that is, in areas where the Tromsø—Lyngen shore line (the Main shore line) lies 40 m to 70 m above the present sea level. The Skarpnes shore line must be of approximately the same age as the S_3—S_4 shore lines in western Finnmark (fig. 27). Marthinussen (1961, p. 133) correlated the S_3—S_4 shore lines with the Repparfjord moraines that lie a short distance outside the Tromsø—Lyngen moraines in Finnmark. He also suggested a correlation of the moraine at Langnes with the S_3—S_4 shore lines (Marthinussen 1962, p. 46).

THE TROMSØ—LYNGEN EVENT

The end moraines deposited during the Tromsø—Lyngen event cross several of the main fjords in Troms and are the largest and most prominent end moraines in Northern Norway. Two well known examples of the Tromsø—Lyngen moraines are the very large end moraines in Ullsfjord and Lyngenfjord. The supramarine parts of these two moraines are long, ridge-shaped promontories which project into the fjord from its steep sides (fig. 9). The Lyngenfjord and the Ullsfjord moraines and also an end moraine at Tromsø have been described by several scientists. The Tromsø moraine was described as early as 1889 by Helland (1889, p. 71). Later, O. Grønlie (1931) made a more thorough study of it and the corresponding lateral moraines in Balsfjord. Grønlie (1940) also tried to correlate end moraines in the districts to the west (southwest) of Balsfjord with the Tromsø—Lyngen moraines, but most of these moraines lie a considerable distance inland from the true Tromsø—Lyngen moraines (pl. 1). Grønlie based the correlations mainly on studies of the shore lines which, he believed, corresponded to the moraines. However, a field check of Grønlie's observations showed that many of the postulated high-lying Tromsø—Lyngen shore lines are probably not marine, and that the true Tromsø—Lyngen shore line was at lower altitudes than he had suggested (p. 144).

A Tromsø—Lyngen moraine along the southeastern side of Andørja was described by Lind (1955); and some of the postulated submarine end moraines which were plotted on a map by Undås (1939, p. 152) are of the same age. Holmes and Andersen (1964) made a thorough study of all moraines in Ullsfjord. Most of the moraines in Troms were plotted on two maps showing moraines in Norway (Holtedahl and Andersen, *in* Holtedahl, 1953, Pl. 16; 1960). Information on these moraines was primarily based on the research presented in the present paper. A review of the moraines in Troms was given by Andersen (1965, 1965b).

Distinctive Tromsø—Lyngen end moraines and lateral moraines lie in all fjords along the coast of Troms. They were deposited by outlet glaciers from the continental ice sheet which covered the high-lying mountain districts to the south and southeast of the fjords. The montainous peninsulas between the fjords were locally glaciated during the Tromsø—Lyngen event, and many of the local glaciers merged with the large fjord glaciers. Therefore, in general, the Tromsø—Lyngen marginal moraines are discontinuous and do not cross the mountains from one fjord to the next. As the distances across the mountains from one fjord to the next are usually short, the correlation of the moraines generally causes no serious problems. The following criteria were used in correlating the moraines.

1) The Tromsø—Lyngen end moraines and lateral moraines are generally the largest and most prominent moraines within each fjord district.
2) The locations of the moraines are very similar in each fjord. The end moraines generally lie 3 km to 6 km inside the Skarpnes end moraines. More or less distinct Skarpnes lateral moraines commonly lie at altitudes from 100 m to 150 m higher than the Tromsø—Lyngen lateral moraines.
3) Relatively large moraine ridges were deposited by small local glaciers during the Tromsø—Lyngen event. These moraines are the youngest part of a complex called the Island II moraines (p. 94). They occur abundantly in areas outside the Tromsø—Lyngen end moraines, and in areas at higher altitudes than the Tromsø—Lyngen lateral moraines. No Island II moraines exist in areas which were covered by the Tromsø—Lyngen ice sheet and its outlet glaciers (p. 94).
4) The Main shore-line belt (p. 137) corresponds with the Tromsø —Lyngen event. A possible exception is the lowest-lying, young-

est part of the shore-line belt, which seems to represent the first part of the melting phase that followed the event. Shore features that lie slightly above the Main shore lines probably represent the oldest parts of the Tromsø—Lyngen event.

5) Shells from marine deposits within the marine parts of the Tromsø—Lyngen end moraines, or from marine deposits that are closely related to these moraines, were dated at 10,200 years B.P. to 11,900 years B.P. by the C-14 method.

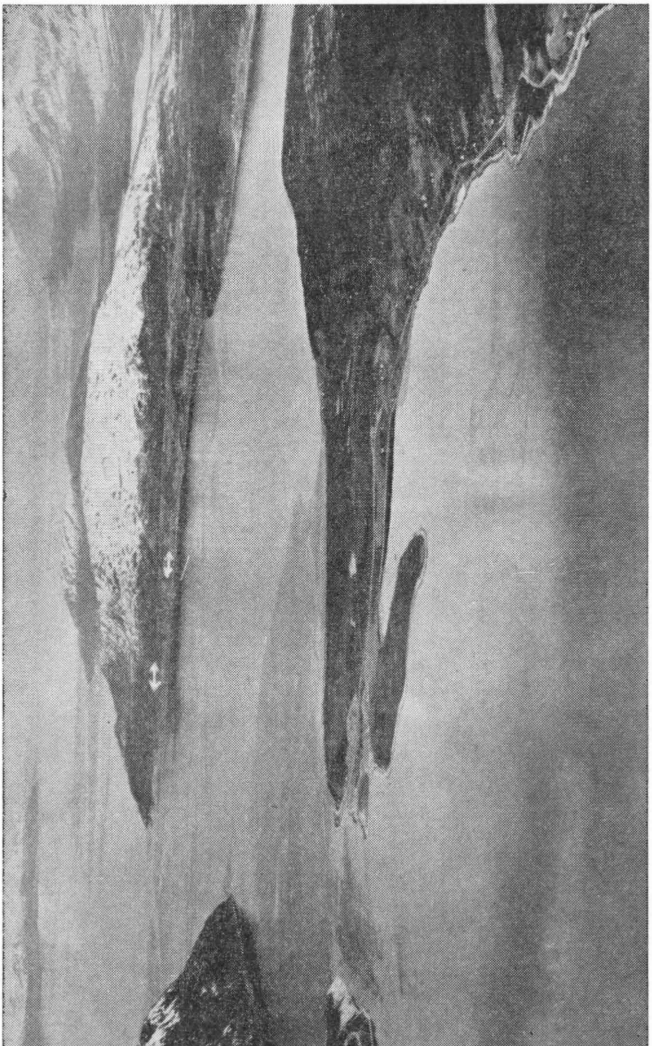
Preliminary correlations of the Tromsø—Lyngen moraines were based mainly on the criteria cited in paragraphs 1 and 2. Based on these preliminary correlations, further studies were undertaken, and the data cited in paragraphs 3, 4, and 5 was collected and later used to verify the earlier correlations.

Locality description.

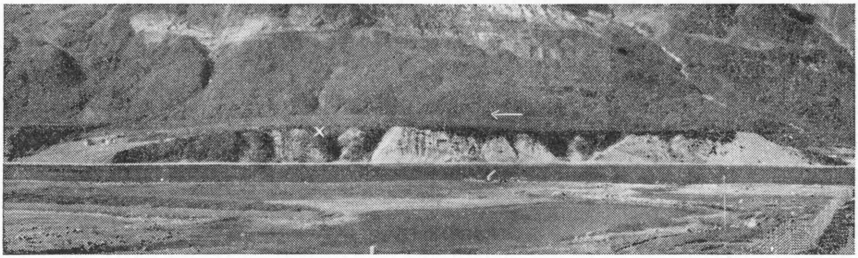
Lyngenfjord. The Lyngenfjord lies to the east of the area studied, but some observations were made on brief reconnaissance trips. A Tromsø—Lyngen moraine, probably the largest of all end moraines in Troms, crosses the fjord at a promontory called Spaakenes. This is the supramarine part of the end moraine, and it projects far into the fjord from the eastern side. Corresponding lateral moraines lie along the eastern fjord side to the south of Spaakenes. The Lyngen moraine was first described by Vogt (1913), and later R. W. Feyling-Hanssen studied the moraine (personal communication). Information on the composition of the moraine is sparse. Marthinussen (1962, p. 45) collected *Portlandia arctica* shells from a marine clay at Slottet immediately outside the Spaakenes moraine. The shells were radiocarbon dated at 10,350 ± 300 years B.P. (T-187), and Marthinussen gave the following description of the shell locality; "Shells of *Portlandia arctica* from Slottet, about 1 km north of Djupvik, Lyngen, Troms. Found at altitudes between 4.5 and 9.0 m a.s.l. in a clay deposit, the maximum thickness of which above the present sea level is about 11 m. The clay is partly overlain by Post-glacial shellbeds. The locality is situated outside an important terminal moraine (at Spaakenes) belonging to the substage in question (Marthinussen, 1960, p. 418). Comment: Assumed date 10,000—10,500 years. The date obtained probably indicates the minimum age of the said moraine and seems to coincide with the closing phase of the Younger Dryas period. The contemporaneous shore level represented by the Main line, S_0 (P_{12}) is at this locality 65–66 m a.s.l."

Ullsfjord. Ullsfjord is the easternmost fjord within the area studied. A large dominant end moraine ridge, called the Skardmunken moraine, crosses the mouth of Sørfjord, a branch of Ullsfjord (fig. 9), and is correlated with the Tromsø–Lyngen moraines. J. Vogt (1914) first described the moraine; later it was described by Grønlie (1931) and by Holmes and Andersen (1964). The following description is based on observations made by the latter authors.

The Skardmunken moraine ridge is breached by a narrow and shallow inlet near the western side of the fjord. The eastern moraine segment has a wide irregular top surface which rises gradually towards the fjord side. Two parallel moraine ridges were distinguished on this surface. They are broad and clearly influenced by marine abrasion below the 65 m–66 m altitude. The distal ridge passes into a sharp ridge above the 65 m–66 m altitude. There it curves towards the fjord side, where it grades into a lateral moraine. The apex of a fan-shaped outwash delta lies in the lateral channel between the moraine and the fjord side. The delta plain is very bouldery and steep near the apex, and it passes into a wide gently sloping distal part, 66 m to 67 m above sea level. This is the altitude of the distinctive Main shore line immediately outside the moraine. A series of marine terraces and shore bars were formed on the steep front-slope of the outwash delta. The highest-lying shore bar lies on the delta front about 65 m –66 m above sea level, and it continues into the moraine ridge. Both the altitude of the outwash delta and of the other marine features observed on the moraine ridge clearly indicate that the sea level was about 66 m–67 m above the present when the Skardmunken moraine was deposited. This is the altitude of the Main shore line which, therefore, corresponds to the Skardmunken moraine. Viewing the moraines and the shore lines from a distance, it looks as though the distinctive Main shore line crosses the moraine and continues a short distance inside it. However, the measurements suggest that the shore line immediately inside the moraine lies about 1 m below the Main shore line (fig. 28), or represents a low-lying part of the Main shore-line belt. Further south from the moraine no distinctive shore lines exist, and



9 a



9 *b*

Fig. 9a. The Tromsø—Lyngen end moraine at Skardmunken in Ullsfjord. View is north. Notice the distinctive Main shore line (upper arrow) and the Tapes shore line (lower arrow) on the peninsula behind the moraine.

Photo: Royal Norwegian Airforce.

Tromsø—Lyngen endemorenen ved Skardmunken i Ullsfjord (sett mot nord. NB den markerte Hoved-strandlinjen (øvre pil) og Tapes-strandlinjen (nedre pil) på halvøya bak morenen.

Foto: Det Norske Flyvåpen.

Fig. 9b. Cross-section of the Tromsø—Lyngen end moraine at Skardmunken. View is west.

A: Foreset beds of gravel and sand.
X: Laminated clay with shells dated at 10,390 ± 200 years B.P. (T-333).
The arrow points to the Main shore line.

Tverrprofil av Tromsø—Lyngen endemorenen ved Skardmunken (sett mot vest).

A: Skrålag av grus og sand.
X: Lagdelt leire med skjell som ble C-14 datert til 10 390 ± 200 år før nåtid (T-333).
Pilen peker på Hovedstrandlinjen.

the highest-lying shore features lie at altitudes below the extended Main shore line.

A cross section through the supramarine part of the Skardmunken moraine (fig. 9 b) was exposed in a sea bluff on the moraine segment at the west side of the fjord. The distal part of the section consists of foreset beds that dip 20°—25° northwest. The sediments in most of the beds are well sorted, and vary from sand to cobbles. Apparently, this part of the marine moraine is of a deltaic or fan type.

In the upper portion of a gully on the proximal part of the sea bluff there is a section of glacio-marine, partly laminated, silt and clay, 4 m thick, that overlies stratified, well sorted sand (locality 2, Pl. 1). The silt and clay beds dip westward, except the southern part of the beds which are folded and lie almost vertically. Scattered shells and pebbles lie throughout the silt-clay section, but many shells and pebbles to cobbles lie in the relatively thick beds of sandy clay in the upper part of the section. Both broken and unbroken shells of the following species were seen: *Macoma calcarea, Hiatella (Saxicava) arctica, Mya truncata* and *Similipecten greenlandica (Pecten groenlandicus)*. Shells collected by Holmes and Andersen (1964, p. D 163) were radiocarbon dated at 10,390 ± 200 years B.P. (T-333). The clay-silt section is clearly younger than the foreset section which is truncated by the former. The location of the clay-silt section on the proximal side of the moraine suggests that the ice was not in close contact with the moraine where this section was deposited. However, the character of the sediments indicates that they were deposited near an ice front, and the folded beds suggest that the ice front pushed into the moraine subsequent to the deposition of the silt and clay. The folding of the clay beds could possibly be the result of slumping (sliding), but this seems less likely, as the distal part of the folded beds shows no sign of disturbance. Therefore, the dated shells are most likely from a phase prior to a late advance of the ice front to the Skardmunken moraine position, and subsequent to a phase when the main part of the moraine was deposited.

The corresponding lateral moraine on the eastern side of the fjord can be traced from the end moraine to a point almost 10 km further to the south. For most of the distance the lateral moraine forms a distinctive ridge which is breached only on the steepest slopes. The west side of the fjord was generally too steep for accumulation of a lateral moraine. A branch of the fjord glacier entered the Nakkevann valley and deposited moraines to the south of Lake Nakkevann. Further to the south, the fjord glacier deposited a lateral-moraine ridge, about 3 km long, across the mouth of Sennedal valley. The southern end of this ridge lies about 500 m above sea level. The longitudinal profile of the Sørfjord glacier (fig. 10) was constructed by using the location of the lateral moraines as a base.

Radiocarbon dated shells from Oldervikdal valley in northern Ullsfjord are of particular interest in connection with the age of the Main

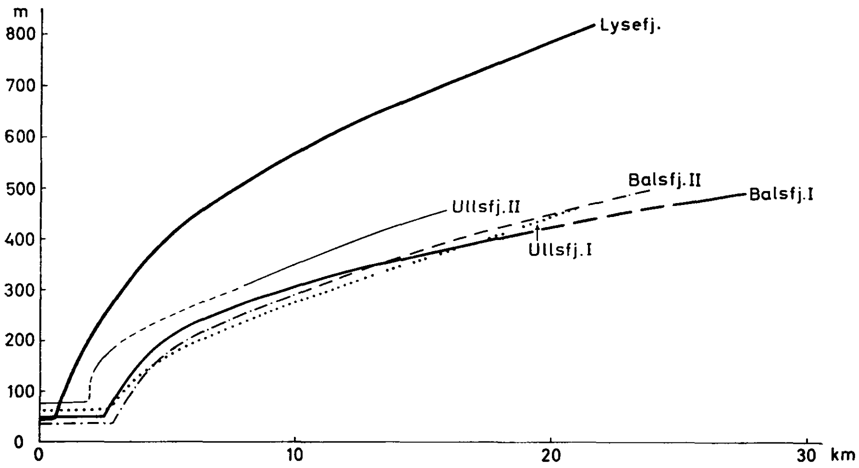


Fig. 10. Longitudinal profiles of the Tromsø—Lyngen and the Skarpnes fjord glaciers in Ullsfjord and Balsfjord, with the corresponding shore lines.
I: Tromsø—Lyngen glaciers.
II: Skarpnes glaciers.
The profiles were based on the projected lateral moraines. The profiles of the glaciers in Ullsfjord were modified from Holmes and Andersen (1964). A profile of the corresponding glacier in Lysefjord, SW Norway is from Andersen (1954).
Lengdeprofil av Tromsø—Lyngen og Skarpnes fjord-breer i Ullsfjorden og Balsfjorden, med korresponderende strandlinjer.
I: Tromsø—Lyngen breer.
II: Skarpnes breer.
Profilene ble konstruert på grunnlag av projiserte sidemorener. Profilene av breene i Ullsfjord er modifisert fra Holmes og Andersen (1964). Profilet av den tilsvarende breen i Lysefjord i sydvestlige Norge er fra Andersen (1954).

shore line and the Tromsø—Lyngen moraine at Skardmunken. The shells lie in a glacio-marine blue clay at the foot of a marine terrace about 2 km west of Oldervik village (locality 3, Pl. 1). About 4 m of unstratified blue clay with scattered pebbles and cobbles was exposed in a road-cut. The clay is overlain by sand and gravel, but no good exposures existed in the sand-gravel section. The top of the terrace lies about 52 m—54 m above sea level, which is 1 m to 3 m above the Main shore line. Numerous large shells of *Mya truncata, Hiathella arctica, Macoma calcarea* and *Balanus* sp. lie in the clay. Fresh-looking shells were radiocarbon dated at 11,550 ± 190 years B.P. (T-631). This is a mid-Alleröd age. Therefore, the sea level was probably 1 m

–3 m above the Main shore line in about mid-Alleröd time, or possibly slightly later. This again indicates that the Main shore line and at least the latest part of the Tromsø–Lyngen event are probably younger than Alleröd time.

Balsfjord. The Tromsø–Lyngen glacier in Balsfjord deposited two end moraines on the Tromsø Island and lateral moraines along the fjord sides. Helland (1889, p. 71) mentioned the end moraine on Tromsø, and later Grønlie (1931) studied this moraine and the corresponding lateral moraines. The dotted lines on Grønlie's map (fig. 11) suggest the location of the lateral moraines. These lines correspond quite well with the observed lateral moraines in the northern part of the fjord, but lie below the lateral moraines in the south.

A Tromsø–Lyngen end moraine ridge lies along the southwestern side of Lake Prestvann on Tromsø Island. The ridge curves northward and continues down the hill to the west and northwest of

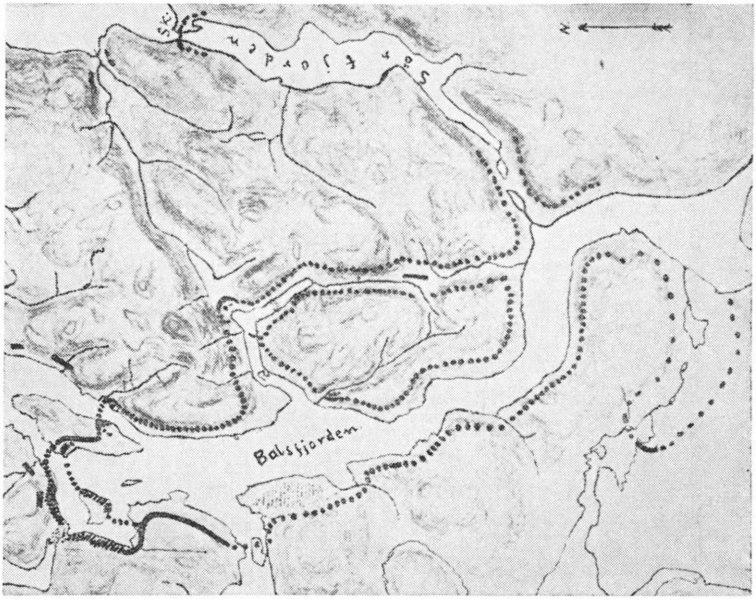


Fig. 11. Grønlie's map of the moraines and the reconstructed margins of the glacier in Balsfjord (Grønlie 1931).

Grønlies kart av Balsfjordbreens morener med rekonstruerte randlinjer (Grønlie 1931).

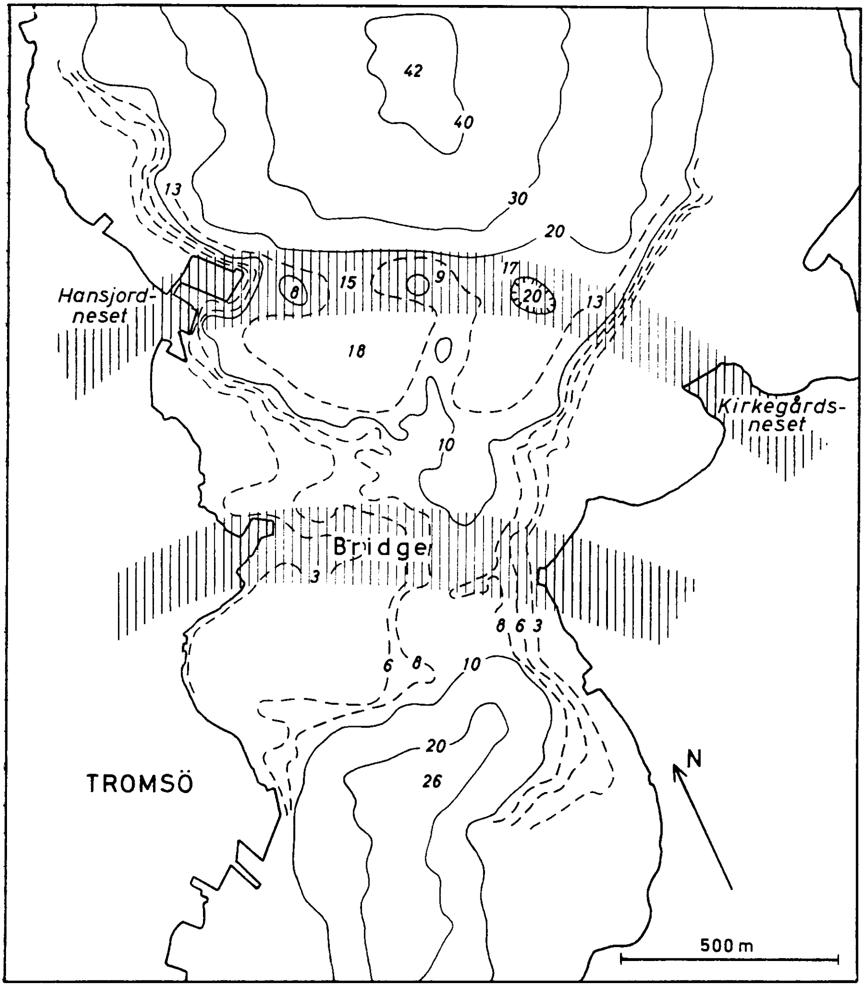


Fig. 12. The two Tromsø—Lyngen end moraines across Tromsøsund.

Bridge: Tromsøsund Bridge.
Depths in metres.
Bathygraphy is based on unpublished information from Norges Sjøkartverk.

De to Tromsø—Lyngen endemorenene i Tromsøsund.

Bridge: Tromsøbrua.
Dyp er angitt i meter.
Dybdekurvene er konstruert på grunnlag av upubliserte opplysninger fra Norges Sjøkartverk.

Prestvann. The height of the ridge varies between 5 m and 10 m, and both the distal and the proximal slopes are very steep. At the foot of the hill, the ridge curves westward and finally disappears in the bog near Langnes. A bouldery and gravelly point at Langnes probably corresponds to the moraine. On the east side of Prestvann, the moraine ridge is low and broad where it crosses the churchyard and continues down the hill towards Hansjordnes (fig. 12).

A parallel and less distinct moraine ridge lies on the proximal side of the one just described. The western segment of this moraine is a steep, broad ridge on the slope west of Prestvann. Giæverneset which is a ridge-shaped gravelly and bouldery promontory probably corresponds to this proximal Tromsø moraine, but there is no direct connection between the two ridges. The structure of the ridge at Giæverneset was described on p. 47. An eastern segment of the proximal Tromsø moraine is a broad indistinct ridge which lies down the hill slope towards the Tromsøsund Bridge on the east side of the island (fig. 12). The moraine crosses Tromsøsund at the bridge which was built on the morainic sediments. A corresponding, broad, gravelly moraine ridge continues from the bridge up the slope towards a lateral moraine on the east side of the sound. The distal Tromsø moraine crosses the Tromsøsund as a low submarine ridge between Hansjordneset and Kirkegaardsneset. The corresponding moraine on the eastern side of the sound is a sharp 5 m to 10 m high ridge which curves from Kirkegaardsneset towards the lateral moraine just mentioned (fig. 14). The sound on the west side of Tromsøy is also very shallow where the moraines cross from Giævernes and Langnes on Tromsø to the northern part of Håkøy and to Kvaløy. The crest of a submarine moraine ridge rises above sea level in the narrow, gravelly Duken Island between Håkøy and Kvaløy.

Several pits in the supramarine end moraine ridge west of Prestvann show a gravelly to bouldery till with no stratification. The structure of the marine deposited moraine ridge at Giæverneset was studied in two gravel pits (fig. 13 a; locality 7, Pl. 1). The ridge has a relatively flat top at 10 m to 15 m above sea level. The sea level was about 45 m higher than to day (p. 52) when the moraine was deposited. A coat of beach washed gravel (A) including several large boulders covers the surface of the ridge. This gravel overlies a bed of till (B) and beds of very poorly sorted glacio-fluvial gravel (C). Marine sediments (D-D_1-E-F) were exposed in the lower parts of the two sec-

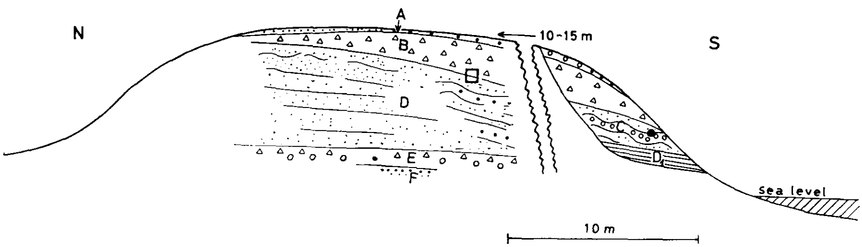


Fig. 13a. Cross-section of the proximal Tromsø—Lyngen end moraine at Giævernes on Tromsø, exposed in two gravel pits.

A: *Beach-washed gravel with several large erratics.*

B: *Bouldery till with some clay.*

C: *Glacio-fluvial gravel and sand, strongly folded beds in upper part. Scattered fragments of* Astarte elliptica, Chlamys islandicus, Mya truncata, Macoma calcarea, Hiatella arctica *and* Balanus *sp. lie in this section. They were radiocarbon dated at 11,500 ± 350 years B.P. (T-112).*

D: *Stratified marine sand, well sorted. The upper beds are folded.*

D_1: *Stratified silt and clay, about ½ m, with unbroken shells of* Portlandia arctica, Leda pernula, Thyasira flexuosa *and* Nucula tenuis. *Section D_1 is probably younger than bed E.*

E: *Glacio-marine blue clay with scattered cobbles and shells of the same species that were found in bed C. The shells were mostly unbroken.*
They were radiocarbon dated at 11,480 ± 150 years B.P. (T-436 B).

F: *Medium sand.*

Filled circles: stratigraphic positions of radiocarbon dated samples.
Frame: Beds in fig. 13 b lie within the frame.

Tverrprofil av den proksimale Tromsø—Lyngen endemorenen ved Giæverneset på Tromsø, vist i to grustak.

A: Strandvasket grus med mange store flyttblokker.

B: Blokkrik morene med noe leire.

C: Glacifluvialt grus og sand, sterkt foldete lag i øvre del. Spredte fragmenter av *Astarte elliptica, Chlamys islandicus, Mya truncata, Macoma calcarea, Hiatella arctica* og *Balanus* sp. ble funnet i lagene. De ble C-14 datert til 11 500 ± 350 år før nåtid (T-112).

D: Lagdelt marine sand, godt sortert. De øvre lagene er foldet.

D_1: ½ m lagdelt silt og leire, med hele skjell av *Portlandia arctica, Leda pernula, Thyasira flexuosa* og *Nucula tenuis*. Seksjon D_1 er sannsynligvis yngre enn lag E.

E: Glaci-marin blåleire med spredt stein og skjell av de samme arter som i lag C. De fleste skjellene var hele. C-14 alderen på skjellene er 11,480 ± 150 år før nåtid (T-436 B).

F: Middelskornig sand.

Store prikker angir den stratigrafiske beliggenhet av C-14 daterte prøver.
Rammen angir beliggenheten av utsnittet på fig. 13 b.

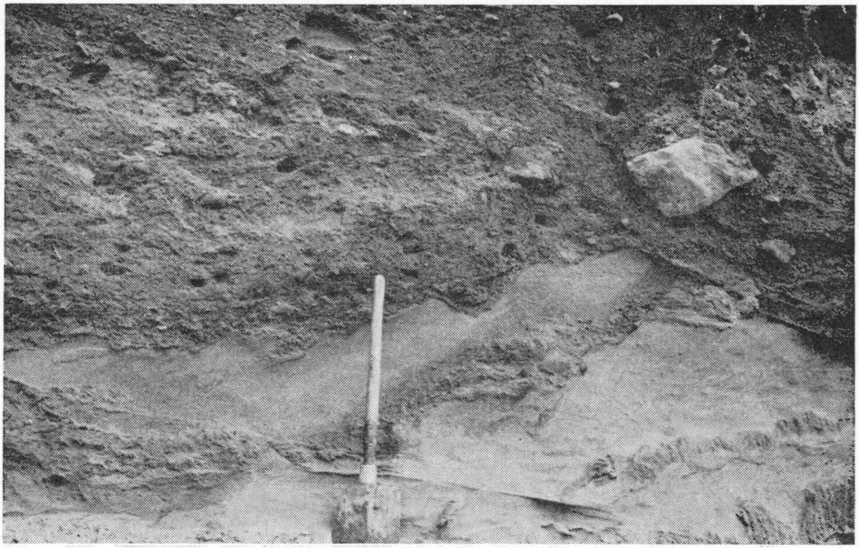


Fig. 13b. Till overlies folded marine sand in the proximal Tromsø—Lyngen end moraine at Giævernes on Tromsø (see frame in fig. 13a). The ice moved towards the left.

Morene over foldete lag av marin sand i den proksimale Tromsø—Lyngen endemorenen ved Giævernes på Tromsø, (se rammen på fig. 13a). Breen beveget seg fra høyre mot venstre.

tions. The upper marine beds are strongly folded (fig. 13 a), and most of the marine sediments are well sorted sands. A section (½ m thick) of laminated silt with some clay (D_1) contained shells of *Portlandia arctica, Leda pernula, Thyasira flexuosa* and *Ennucula tenuis,* and a cold water foraminifer fauna (p. ???). Unfortunately, the exact correlation of the laminated section (D_1) with the marine beds in the other gravel pit is not clear, but seems to correspond with a part of section D. A bed of very poorly sorted, bouldery glaciomarine clay (E) was exposed at the base of the largest pit. This clay contained many broken and unbroken shells of *Astarte elliptica, Chlamys islandicus, Mye truncata, Macoma calcarea, Hiathella arctica* and *Balanus* sp. Most of the specimens were large, and this, in addition to the abundance of shells, suggests favourable conditions at the time of deposition. The shells were radiocarbon dated at 11,480 ± 150 years B.P. (T-436 B, inner fraction) and 9,950 ± 130 years B.P. (T-436 A, outer fraction). The extraordinary high age difference between the two fractions must be the result of a considerable contamination of the shells by ionic exchange (p. 146). The date of the outer fraction is definitely much too low. Even the 11,480 ± 150 years B.P. date of the inner fraction could be too low. Small fragments of shells found in the glacio-fluvio-marine sediments (C) were dated at 11,500 ± 350 years B.P. (T-112). All of the fragments found were of large specimens of the same species as those found in the clay (E). Therefore, the fragments most likely represent shells from the glacio-marine clay (E) that were picked up and redeposited by a glacier stream. Thus both the date T-112 and T-436 B suggest a mid Allerød age or possibly an early Allerød age for the glacio-marine clay (E), and the entire section of well-sorted, marine sediments is most likely of Allerød age. This indicates that the ice front was located inside (south of) the Giævernes area during much of Allerød time, and the till (B) must have been deposited during a following glacier advance, when the Tromsø moraine was formed. The oldest (distal) Tromsø moraine could be older than the marine sediments (D-E-F). In that case, the oldest phase of the Tromsø—Lyngen event is probably of early Allerød or Older Dryas age (table 4). But there is also the possibility that the till (B) represents both a ground moraine corresponding to the oldest Tromsø moraine and a part of the youngest Tromsø end moraine. In that case the entire Tromsø—Lyngen event must be younger than about mid-Allerød age.

A bog which lies in a kettle hole on the distal Tromsø moraine ridge on the south side of Prestvann, consists of peat and lacustrine gyttja (locality 6, Pl. 1). A grey sandy clay, at least 20 cm thick, underlies the organic section. A Hillers peat sampler was used to collect a sample from the base of the organic section which is about 4 m deep. The sample was taken from the lowest 5 cm of a brown gyttja (mud) immediately overlying the inorganic sediments. Much care was taken to prevent contamination of the sample which was radiocarbon dated at 11,680 ± 170 years B.P. (T-51). To check this date a new sample of gyttja (mud) was collected some years later and dated at 9,610 ± 250 years B.P.

Unfortunately, the weather was very poor when the latter sample was collected, and there is a slight possibility that the sample was contaminated. If the first-mentioned date is the correct, then the oldest Tromsø moraine must be older than approximately 11,700 years, and an early Allerød or Older Dryas age for it seems most likely. How-

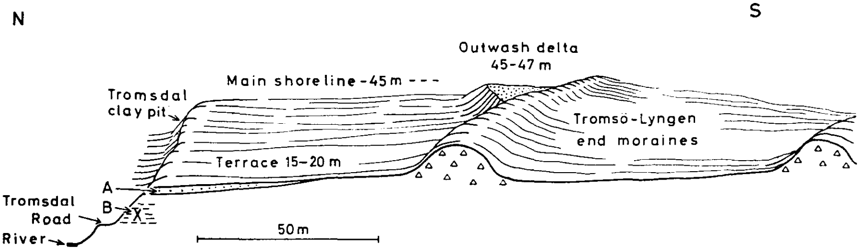


Fig. 14. Sketch of the two Tromsø—Lyngen end moraines and the marine terraces on the eastern side of Tromsøsund.

A: Sand (½ m—1 m) with shells of Mya truncata *and* Macoma calcarea.

B: Glacio-marine clay with scattered pebbles to boulders and shells of Macoma calcarea, Macoma torelli, Nucula tenuis, Yoldiella (Portlandia) lenticula, Yoldia hyperborea *etc. About 4 m of clay was exposed. Shells from the middle part of the section (x) were radiocarbon dated at 10,200 ± 350 years B.P. (T-113).*

Altitudes in metres above sea level.

Skisse av de to Tromsø—Lyngen endemorenene og de marine terrassene på østsiden av Tromsøsundet.

A: ½—1 m sand med skjell av *Mya truncata* og *Macoma calcarea.*
relli, Nucula tenuis, Yoldiella (Portlandia) lenticula, Yoldia hyperborea etc. Omlag 4 m med leire var blottet. Skjell fra midten (x) av den blottede leireseksjon har en C-14 alder på 10 200 ± 350 år før nåtid (T-113).

Høyder er angitt i meter o. h.

ever, there is a possibility that old (inactive) carbon could have been incorporated in the gyttja (mud), and that, therefore, the apparent radiocarbon age of the collected sample is too high. Incorporation of inactive carbon in gyttja (mud) is not unusual, and the apparent radiocarbon ages of many bogs are too high. For instance, the radiocarbon ages of several bogs in Finland (Tauber 1964, p. 216), in England (Godwin et al, 1964, p. 119) in Sweden (Østlund 1959, p. 39) are definitely too high. Therefore, the possibility can not be excluded that the oldest Tromsø moraine is younger than indicated by the radiocarbon date.

Another radiocarbon dated shell sample was collected from a glaciomarine bluish-grey clay in a low-lying terrace north of the oldest moraine ridge on the eastern side of Tromsøsund (fig. 14, locality 5, Pl. 1). The surface of the terrace lies at an altitude of 15 m—20 m. The clay was exposed 10 m to 14 m above present sea level in a small gully close to the Tromsdal-River Bridge. Scattered pebbles an cobbles lie throughout the clay section which is in part laminated. Shells of the following species were seen: *Macoma calcarea, Macoma torelli, Ennucula tenuis, Yoldiella (Portlandia) lenticula, Yoldia hyperborea, Bathyarca glacialis, Similipecten greenlandica (Pecten Groenlandicus), Balanus balanus* and *Mytilus edulis.* The two latter species lie only in the higher part of the clay section and *Yoldia hyperborea* only in the lower part.

Today all of the species cited above live in Arctic waters. *Yoldia hyperborea* lives only in Arctic waters, while *Mytilus edulis* generally lives in more favourable Boreal waters. The fauna is an *Arca* fauna, and it indicates a change from typical Arctic to Boreo-Arctic conditions when the clay was deposited. Fresh-looking shells from the middle part of the clay section were radiocarbon dated at 10,200 ± 350 years B.P. (T-113), which is the approximate age of the Younger Dryas—Pre-Boreal transition. Several of the collected shells were paired and therefore of the same age as the clay. Sandy beds were exposed in a ditch on top of the terrace. Numerous shells, particularly *Mya truncata* and *Macoma calcarea,* lie in this sand.

In the same low-lying terrace, about 50 m to 60 m from the section just described, was the old Tromsdal clay pit, 8 m to 12 m above sea level. H. Kiær (1902, p. 18) studied the stratigraphy and the fossils in this pit. He recognized the following stratigraphy: a thin layer of sand with numerous shells of *Mya truncata* and *Macoma calcarea* overlies a grey clay with small and large stones. In the upper part of the clay he found shells of *Mya truncata, Chlamys islandicus, Arctica islandica, Astarte elliptica, Macoma calcarea, Hiatella (Saxicava) arctica, Neptunea despecta, Balanus porcatus* and a few other species. In the lower part of the clay, there were shells of *Similipecten greenlandica, Portlandia arctica, Yoldiella lenticula, Astarte elliptica, Macoma calcarea, Lyonsia arenosa, Mya truncata, Natica clausa, Modiolaria migra, Ennucula tenuis* and *Leda pernula.* This latter fauna is a typical *Yoldia* fauna. The basal part of the *Yoldia* clay lies about 2 m below the basal part of the exposed *Arca* clay in the gully. Therefore, the *Yoldia* clay is most likely slightly older than the *Arca* clay.

The *Arca* and *Yoldia* faunas, the pebble and boulder content and the lamination of parts of the clays, suggest that they were deposited in cold slightly brackish water close to a glacier. A correlation between the clay and the Tromsø moraine seems likely since the clay lies immediately outside this moraine. The *Yoldia* clay most likely corresponds with the main phase, and the radiocarbon dated *Arca* clay to a slightly later phase of the Tromsø—Lyngen event, or to the waning phase immediately following this event.

The Main shore line is very distinctive along the sounds immediately outside the Tromsø moraines. There the shore line lies 43 m to 46 m above sea level. However, no Main shore line occurs on the fjord sides or along the sounds inside the Tromsø moraines, with the possible exception of a shore line formed in the sediments immediately inside the moraine. The highest-lying shore deposits further inside the moraine lie at lower altitudes than the extended Main shore line. This indicates that the Main shore line corresponds with the Tromsø moraines and probably with the first melting phase at the end of the Tromsø—Lyngen event also. A small outwash delta lies between the distal Tromsø—Lyngen moraine ridge and the steep hill slope on the east side of Tromsøsund (fig. 14). The apex of the delta plain is located in the lateral channel outside the lateral moraine, and the delta was probably deposited by a lateral stream during the Tromsø—Lyngen event. The distal part of the delta plain lies 45 m—47 m above sea level, which corresponds well with the altitude of the Main shore line. Therefore, both the altitude of the outwash delta and the location of the Main shore line suggest that this shore line corresponds with the Tromsø moraines.

Grønlie (1940, pl. 3) correlated the Tromsø moraines with the considerably higher-lying g-shore line. However, Grønlie's own observations hardly supported this correlation. The measured shore features are plotted on the diagram in fig. 27, and discussed on p. 144.

The eastern side of Tromsøsund—Balsfjord. The distal end moraine ridge on the eastern side of Tromsøsund grades into a lateral moraine ridge that can be traced only a short distance to the south of the end moraine. The fjord side is very steep further to the south and no clear lateral moraine was seen until Ramfjord, a branch of Balsfjord. Along both sides of Ramfjord there are large lateral moraines. The one on the west side of the fjord forms two sharp parallel ridges or terraces, one lying slightly above the other. The lateral moraines rise from 250—300 m in the north-western part to about 450—500 m in the southern part of the fjord. A corresponding lateral moraine on the east side of Ramfjord continues into

Breidvikeid valley, where it grades into an end moraine that lies across the floor of the valley.

The end moraine at Breidvikeid and the corresponding outwash plain were described by Holmes and Andersen (1964). The following section is based mainly on their observations. The end moraine is a sharp 4 m to 6 m high ridge which spans the wide Breidvikeid valley and grades into lateral-moraine ridges on both sides. A terrace on the proximal (southwestern) side of the end moraine is very bouldery, and is clearly an ice-contact terrace. A wide, raised outwash plain (valley train) covers the valley floor north-east of the moraine. The plain is almost undissected near the moraine, where a pattern of braided stream channels occurs. Further to the north-east, the streams cut deeply into the sediments, and only remnants of the plain exist mainly along the valley sides. The grain size of the material on the outwash plain grades from boulders near the moraine to fine-sand in the north-easternmost part. The altitude of the plain is 72 m to 74 m at the moraine, about 62 m 3 km to 4 km north-east of the moraine, and 59 m to 60 m about 10 km from the moraine.

The distal part of the plain is nearly horizontal, and it grades into the distinctive Main shore line, 59 m to 60 m above sea level. A thick section of marine clay, silt, and sand underlies the outwash. Gravel pits near the moraine show that the sheet of outwash gravel is at least 6 m thick. At Stormo, about 6 km from the moraine, the outwash sheet is only 3 m—4 m thick and consists of flat-lying beds of sand and pebble-to-cobble gravel. Small exposures on the river bluffs in the Stormo area show that the outwash gravel and sand overlie an at least 4 m thick, laminated marine clay section. The laminated clay overlies a section of stratified sand and silt at least 15 m thick, which in turn overlies marine clays near river level, 35 m—40 m below the outwash plain. All of the observed beds were flat-lying. The upper 4 m of the laminated clay section was exposed at Stormo, near a pit in the outwash gravel (locality 4, Pl. 1). The clay is glacio-marine and bluish-grey, with scattered pebbles and cobbles, and a *Yoldia* shell fauna. The shells lie scattered in the clay, and only *Macoma calcarea* (few) and *Portlandia arctica* (several) were found. The foraminifer fauna in the clay is typical for *Yoldia* clays (p. 73), suggesting a cold slightly brackish water environment. The lamination of the clay also suggests slightly brackish conditions, although lamination can be formed by turbid marine currents. Fresh-looking shells were ra-

Fig. 15. Tromsø—Lyngen lateral moraine at Høgbakken. View is south. Lateral channel in the foreground. The ice-contact slope on the other side of the ridge is steep also.

Tromsø—Lyngen sidemorene på Høgbakken (sett mot syd).

Lateral-renne i forgrunnen.

Baksiden av ryggen er iskontakt siden, og den er også bratt.

diocarbon dated at 11,500 ± 400 years B.P. (T-110), and are most likely of Allerød age.

The outwash at Stormo undoubtedly corresponds to the Tromsø–Lyngen moraines. Therefore, the laminated clay probably represents a phase immediately prior to the Tromsø–Lyngen event. However, the laminated clay could be bottomsets corresponding to an older part of the Tromsø–Lyngen outwash that lies close to the moraine.

The Tromsø–Lyngen lateral moraine on the *west side of Balsfjord* and on Kvaløy commonly consists of sharp ridges 5 m to 15 m high. At several places, the moraine branches into two parallel ridges. The most prominent ridges lie on Høgbakken on Kvaløy (fig. 15) and on Langåsen south of Ryøy. A shallow part of the sound west of Ryøy is a submarine end moraine connecting the moraine on Kvaløy with that on Langåsen. The moraine at Langåsen consists of two parallel, steeply inclined ridges. The inclination of the ridges shows that the surface of the corresponding glacier branch in the Ryøy sound sloped about 60 m/km. The Main shore line is distinctive along both sides of the sound to the west of the end moraine near Ryøy, and lies 42 m—43 m above sea level (Pl. 3). No corresponding shore lines were seen in the eastern part of the sound, which was covered by the Tromsø—Lyngen glacier.

The west side of Balsfjord to the south of Langåsen is generally very steep, and the Tromsø—Lyngen lateral moraine occurs only in some of the least steep parts. For instance, a low gently sloping moraine ridge on the eastern slope of Slettind lies about 500 m above sea level at the southern end. A longitudinal profile of the lateral moraines (fig. 10) indicates that the corresponding glacier had a gently sloping surface and a steep front.

The Malangenfjord. Parts of the eastern side of Malangenfjord are very steep, and therefore, the lateral moraines occur only in a few localities. The most distinctive lateral moraines lie on the west slope of the Slettind mountain massif. There, two parallel lateral moraine ridges or kame terraces exist, one slightly above the other. Their northernmost parts are clearly kame terraces that lie 350 m above sea level. These seem to correspond to the lateral moraine on the north-eastern side of Slettind. Therefore, the Balsfjord glacier and the Malangen glacier probably joined in the valley on the north side of Slettind. A broad moraine ridge across this valley is most likely a medial moraine deposited at the junction of the two glaciers. The glacier entered the Sandselv Valley and blocked the south-flowing drainage there. Shore lines and thick lacustrine sediments in the northern part of the valley show that an ice-dammed lake existed. Two sets of shore lines lie at approximately the 280 m and the 300 m altitudes. The corresponding outlet channels occur across the divide at Bakkebyskardet.

Two parallel lateral moraines on the mountain slope south of Bakkebyskardet grade north-westward into a broad indistinct morainic belt across the mouth of Bakkebyskardet 250 m to 300 m above sea level. A small end moraine crosses Bakkebyskardet a short distance to the east of this belt. The shape of the moraine shows that is was deposited by a glacier from the Sandselv valley. The moraines in Bakkebyskardet represent either the Tromsø—Lyngen event or the Skarpnes event. If they represent the former, then the ice-dammed lake just described in Sandselv valley was formed during the waning phase that followed this event.

Two short, terrace-like lateral moraines near Ansnes at the mouth of Malangenfjord lie about 130 m and 150 m above sea level. The corresponding end moraine must be located at the mouth of the Malangenfjord near Ansnes. There, a broad, submarine threshold crosses the fjord between the northern part of Ansnes and Tennskjær. However, no distinct end moraine was recorded on the bathygraphic map.

A long lateral moraine ridge on the west side of Malangenfjord ends at Tennskjær. This moraine must correspond to the moraines just described on the east side. A series of marine terraces and beach ridges lie at Tennskjær. The highest-lying terraces and ridges at the moraine lie 43 m—48 m above sea level. They probably correspond to the Main shore line and to slightly higherlying shore levels (Pl. 3). However, a more detailed study needs to be done at Tennskjær.

The lateral moraine on the west side of Malangenfjord is usually a sharp ridge, 5 m to 20 m high, that often branches into two parallel ridges. For instance, two steepsided parallelled moraine ridges lie on the north slope of Jøvikhaug near Tennskjær. The lateral channels between the ridges and the hill slope are more than 10 m deep. The crests of the ridges dip about 100 m/km, which shows that the front of the Malangen glacier was very steep. The average dip of the lateral moraine is about 30 m/km in the next 2 km south of Jøvikhaug, and only 8 to 10 m/km in the following 6 km. Several small lakes are dammed by the moraine. A good example is Langbakkvann, a long narrow lake lying in the lateral channel formed by the 15 m to 25 m high, steep-sided moraine ridge.

A lateral moraine ridge lies on the peninsula to the east of Rossfjordvann. The north-western end of this ridge is about 300 m above sea level and corresponds approximately in altitude with the lateral moraine on the west side of the lake. The high mountain massif on the east side of Rossfjordvann must have been a nunatak when the Tromsø—Lyngen glacier deposited these moraines.

Sollidalen on the west side of Rossfjordvann was occupied by a branch of the glacier in Rossfjord-Malangenfjord. The lateral moraine on the west side of Rossfjordvann passes into a ridge that continues steeply down the northern valley side of Sollidal, where it branches into two parallel ridges. Two steeply inclined, closely spaced lateral moraine ridges on the south side of the Sollidal valley correspond with this moraine. An end moraine zone, 1 km wide, crosses

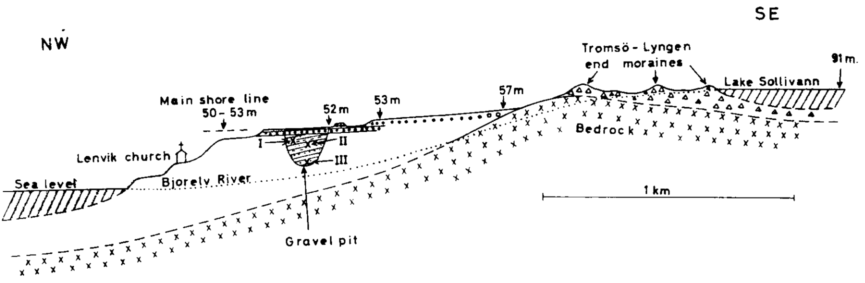


Fig. 16. Cross-section of the outwash delta at Bjorelv.

Beds exposed in the gravel pit:

2 m topset beds, mainly of gravel with boulders.

20 m foreset beds, mainly of well sorted sand. However, beds of poorly sorted bouldery sand to gravel exist particularly 6 m—10 m below the exposed part of the topset beds. The foreset beds dip 20°—25° NW. Unbroken shells of Macoma calcarea *and* Mya truncata *lie within several beds. I, II and III show the statigraphic positions of collected shell samples radiocarbon dated at respectively 10,500 ± 400 years B.P. (T-50), 11,250 ± 319 years B.P. (T-511 B) and 11,200 ± 500 years B.P. (T-174).*

Altitudes in metres above sea level.

Tverrprofil av brefront-deltaet ved Bjorelv.

Lag som er blottet i grustaket:

2 m topplag, vesentlig grus og stein.

20 m skrålag, vesentlig godt sortert sand, men lag med dårlig sortert steinførende sand og grus finns også, spesielt 6 m—10 m under topplagene. Skrålagene heller 20°—25° mot nordvest. Hele skjell av *Macoma calcarea* og *Mya truncata* finns i flere lag.

I, II og III viser den stratigrafiske beliggenhet av skjellprøver som har C-14 aldre på henholdsvis 10 500 ± 400 år (T-50), 11 250 ± 319 år (T-511B) og 11 200 ± 500 år (T-174).

Høyder er angitt i meter o. h.

the valley northwest of Lake Sollivann. Several distinct moraine ridges lie in this zone and they grade into the lateral moraines just mentioned.

A large marine outwash delta at Bjorelv was deposited in front of the Sollidal glacier (fig. 16). Postglacial rivers cut deeply into the delta, but mainly the northern half of it is well preserved. The proximal part and the distal part of the outwash delta plain lie respectively 57 m—58 m and 52 m—53 m above sea level. River channels on the plain about 1½ m deep continue into a slightly lower-lying plain, 50 m—52 m above sea level. Both plains were graded to sea levels that corresponded approximately with the Main shore line, which is very distinct along the sound near Bjorelv at about 50 m—53 m altitude. The highest-lying plain was possibly graded to a level slightly above the Main shore line. Large boulders cover the proximal parts of the delta plain, and the grain size decreases to cobbles in the distal parts.

The structure of the delta was exposed in a gravel pit on the steep river bluff at Bjorelv River (fig. 16; locality 9, Pl. 1). Topset beds, 2 m thick, of cobble-to-boulder gravel overly a thick foreset section, of which the upper 20 m—25 m were well exposed. The dip of the foreset beds is 20°25° NNW. The upper 6—8 m of the foreset section consist of well sorted sand, silt, and some gravel beds. Shells of *Macoma calcarea* lie in several of the silt beds. Unbroken, fresh-looking shells (some paired) from about 4 m—6 m below the topset beds were radiocarbon dated at 10,500 ± 400 years B.P. (T-50).

Poorly sorted gravel beds together with better sorted sand and silt beds dominate the middle part of the foreset section. Some of these beds contained large boulders. A till-like gravel bed of irregular thickness (1—2 m) lies within this part. Shells of *Mya truncata* (many) and *Macoma calcarea* (few) were found in silty pockets in the till-like bed. Many of the shells were unbroken and paired. Very fresh-looking shells were radiocarbon dated at 11,250 ± 319 years B.P. (inner fraction, T-511 B) and 11,330 ± 280 years B.P. (outer fraction, T-511 A). The lowest-lying part of the foreset section consists of well sorted sand, silt, and gravel beds. Some unbroken shells of *Macoma calcarea* lie in the silty beds. Their apparent radiocarbon age is 11,200 ± 500 years B.P. (T-174). Unfortunately, so few shells were found that the total shell sample had to be used for the radiocarbon dating, which was therefore rather inaccurate, (p. 147).

The radiocarbon dates show that the outwash delta is most likely of Allerød and Younger Dryas age. The outwash plain and the topset beds must be younger than the youngest radiocarbon dated shells. Therefore, a Younger Dryas age seems most likely for this part and the corresponding part of the Sollidal moraines. The section of poorly sorted foreset beds corresponds to an older glacial phase, presumably a phase represented by an older part of the Sollidal moraines. The radiocarbon dates suggest that this phase is of approximately late Allerød age. There is a possibility that these beds and the lower-lying beds could represent the deglaciation period prior to the Tromsø—Lyngen event. Therefore, the following two interpretations seems possible: 1) the exposed topset and foreset beds all correspond to the Tromsø—Lyngen moraines in Sollidal, and the moraines are therefore most probably of Younger Dryas and Allerød age; 2) only the highest-lying part of the exposed foreset section corresponds to the Tromsø—Lyngen moraines, which are, therefore, of Younger Dryas age and possibly, also, of late Allerød age.

The lateral moraines on the south side of Sollidal valley extend south-eastward to a point where they reach about 400 m altitude. No lateral moraines lie on the steep slopes further to the south. Only short sections of the lateral moraine were found on the east side of Gisund. The corresponding end moraine crosses Gisund between Leiknesodden (fig. 17) and Laksenes which are both morainic promontories. Two broad, parallel moraine ridges lie on both Leiknesodden and Laksenes. The sound is very shallow between the two promontories. The Main shore line was eroded into bedrock along both sides of Gisundet to the north of the moraine. There, the shore line is very distinct, particularly on the east side of the sound immediately north of the moraine, where it lies about 55 m above sea level (fig. 17).

The moraine ridge at Laksenes grades into a lateral moraine which is an almost unbroken ridge across the south-eastern part of Senja. The ridge which is usually steep-sided, is in places more than 20 m high, and is commonly branched. A submarine threshold across Solbergfjord between Vangsvika and Tennes, must be a corresponding end moraine, as recognized by Undås (1939, p. 121). Tennes is a morainic promontory covered by thick morainic and glacio-marine deposits, including many large boulders. A lateral moraine along the south side of Solbergfjorden is a sharp ridge 5 m to 20 m high. The ridge is low where it crosses the mountain between Solbergfjorden and Skøelv valley. Most of the valley slope on the west side of Skøelv valley is steep, and only fragments of the lateral moraine exist. Two steeply inclined, parallel, lateral moraine ridges lie on the gentle slopes to the north of Skøvatn, about 400 m above sea level. One lies at a slightly higher altitude than the other. The ridges are lacking further to the west on a steep part of the slope. Still further to the

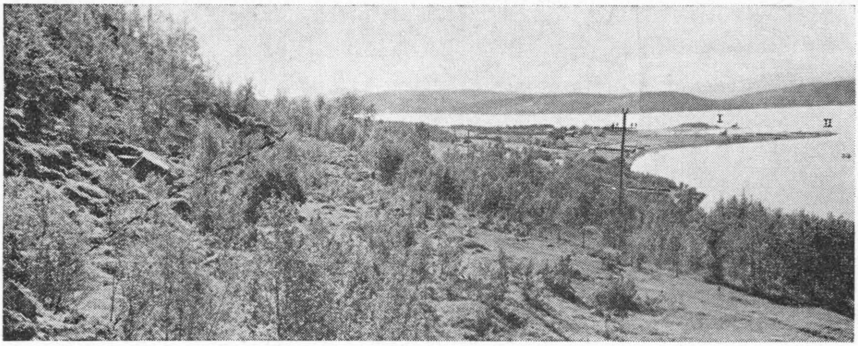


Fig. 17. The Main shore line and the Tromsø—Lyngen end moraines at Leiknesodden in Gisundet. View is southwest.

I and II: Promontories corresponding with the two moraine ridges at Leiknesodden.

Dashed line: The Main shore line.

Hovedstrandlinjen og Tromsø—Lyngen endemorenene på Leiknesodden i Gisundet (sett mot sydvest).

I og II: Nes som svarer til de to endemoreneryggene på Leiknesodden.

Stiplet linje: Hovedstrandlinjen.

west, the lowest-lying moraine again forms a ridge that grades into an end moraine ridge across the valley. The highest-lying lateral moraine is less distinct. However, the corresponding lateral moraine on the south side of the valley and the end moraine in Bjørkebakk valley are two steep-sided ridges, generally 5 m to 15 m high. The snout of the glacier that entered the Bjørkebakk valley pushed against the western valley side. There, the glacier deposited an end moraine approximately 3 km long and generally 3 m—8 m high. The moraine grades into ridges across the floor of the Bjørkebakk valley at both the downstream and the upstream ends. The upstream end branches into two moraine ridges which continue as two lateral moraines. A raised marine outwash delta covers the valley floor north of the northern end moraine ridge. The altitude of the outwash delta plain is about 64 m—68 m at the moraine, where it is very bouldery. The plain grades northwards into the Main shore line along the eastern valley side, about 62 m above sea level. A road cut in the distal part of the terrace, about 1 km from the end moraine, exposed the following section (locality 10, Pl. 1):

4 m	outwash gravel and sand as flat-lying topset beds.
2—3 m	marine silt and clay as flat-lying laminae and thicker beds.
5 m	marine bluish clay, in parts stratified, with a few silt and sand laminae, and scattered pebbles, to cobbles and shells. Shells of *Portlandia arctica* (many), *Macoma calcarea* (few), and a typical *Yoldia* clay foraminifera fauna (p. 73) were identified. The shells were radiocarbon dated at 10,150 ± 500 years B.P. (T-173).

The fauna in the clay, together with the lamination of the glaciomarine sediments, suggest that they were deposited close to an ice front (p. 69). Unfortunately, the collected shell sample was so small that all of it had to be used for the radiocarbon dating. Therefore, the apparent radiocarbon age obtained could be younger than the true one (p. 147).

A bog, 4 m deep, at Blindfinnvann, between the proximal and distal end moraine ridges in Bjørkebakk valley just described, was radiocarbon dated at 10,720 ± 240 (T-53; locality 11, Pl. 1). The bog consists of gyttja and peat, and rests on a grey clayey sand. The radiocarbon dated sample was collected from the lowest 10 cm of a brown, slightly sandy gyttja at the base of the organic section. The deposition of organic sediments in this bog must have started after the formation of the oldest (distal) end moraine, but it could have started before the formation of the youngest (proximal) moraine. Therefore, at least the oldest Tromsø—Lyngen moraine must be older than 10,720 ± 240 years B.P., if the radiocarbon date is correct (see p. 50).

The lateral moraine on the southwestern side of Skøvatn is a low ridge along the east slope of the Rundfjell massif, 400 m to 500 m above sea level. The corresponding glacier must have entered the southern part of Bjørkebakk valley. Here a very bouldery end moraine belt with several low ridges crosses the valley floor. An outwash plain covers the flat valley floor on the north side of the moraine. The end moraine belt grades into lateral moraines on both sides of the valley. The lateral moraine on the south side rises steeply from about

110 m above sea level at the end moraine to 300 m above sea level about 3 km from the moraine. Further to the south, the lateral moraine is gently inclined. Only small remnants of moraine exist on the steep fjord side north of Salangen. A short moraine ridge crosses Isfjellet at about the 300 m altitude, and a similar moraine ridge lies at about the same elevation on Andørja on the south side of Mjøsundet. A broad submarine ridge between Aarbostad and Slaatta must be the corresponding end moraine. Undås (1952, p. 152), too, considered this ridge to be an end moraine. The eastern part of the ridge lies only 3 m to 10 m below sea level, while the deepest part lies about 80 m below sea level. The depths are more than 150 m immediately inside and outside the ridge. Thick gravel deposits including many large erratic boulders lie both at Aarbostad and at Slaatta.

Lind (1955, p. 17) described the lateral moraine along the southeastern side of Andørja Island. This moraine is a low ridge on a shelf-like part of the fjord side, 350 m to 400 m above sea level. The moraine grades into a steeply inclined lateral moraine that has a direction towards Aanstad on the south-west side of the island. Morainic promontories at Aanstad, and at Vik on Rolla Island together with a very shallow threshold across the sound between the promontories must be the corresponding end moraine. Numerous large erratics lie on the promontories. Lind (1955, p. 18), too, recognized this end moraine, but he found no lateral moraine on Rolla Island. Therefore, he suggested that the corresponding ice margin followed the shore zone south of Vik and crossed the Astafjord near Vik. However, the bouldery sediments that Lind found south of Vik are probably the proximal part of the end moraine at Vik—Aanstad, and no evidence was found suggesting an end moraine across Astafjord at Vik. A lateral moraine exists on the steep hill slope south of Vik. The southern part of this lateral moraine is a distinct ridge 250 m—275 m above sea level. Long narrow bogs lie in the lateral channel adjacent to it.

The southern side of Rolla Island is very steep and only small segments of a lateral moraine exist. The moraine dips very gently westward, and the westernmost end, at Hamran, lies 150 m—180 m above sea level. A lateral moraine on the opposite side of Astafjorden, east of Elvebakken, probably corresponds with this moraine. The moraine near Elvebakken lies about 115 m above sea level and is a sharp ridge, 5 m to 15 m high. The western part of this moraine is parallel to an end moraine ridge which curves into Rensaa valley, and was clearly deposited by a glacier from that valley. The crest of the Astafjord lateral moraine was pushed up to an altitude of about 120 m above sea level where the two moraines lie in closest contact. The westernmost part of the lateral moraine is steeply inclined and it stops 100 m—90 m above sea level. This was only 30 m above sea level at the time of deposition. A submarine ridge across Astafjorden between Elvebakken and Agnneset must be the corresponding end moraine. Thick glacio-marine deposits, including large boulders at Elvebakken represent a southern segment of this end moraine.

The glacier that deposited the moraines on Rolla Island and on Andørja Island also deposited distinct lateral moraines along the sides of the small fjords south-east of these islands. The north sides of the fjords are steeper than the south sides. Therefore, the lateral moraines lie mainly on the south sides, on the most gently sloping parts. They form morainic belts with ridges that are generally no more than 5 m to 10 m high. The lateral moraines on the south sides of Lavangenfjord and Gratangenfjord are respectively 8 km and 6 km long. Their eastern ends lie 600 m above sea level, and the gradient of the moraines is 12 to 13 m/km. A part of the west side of Grovfjord is so low that a branch of the Grovfjord glacier passed across the mountains and entered the Rensaa valley. A lateral moraine along the west side of the valley must have been deposited by this glacier (p. 109). The moraine is an almost unbroken ridge for about 8 km, the southern end lying about 450 m above sea level. The northern part is steeply inclined and grades into a broad end moraine ridge across the mouth of Rensaa Valley. Lake Rensaavann is dammed up by this moraine, and the outlet stream from this lake has breached the end moraine ridge. The top of the moraine is a wide terrace 66 m to 68 m above sea level, on the south side of the stream. Marine terraces were abraded into the moraine at about the same altitude on the north side too, and no higher-lying marine terraces exist. Therefore, the moraine was deposited probably when the sea level was about 68 m above the present. This is the approximate altitude of the Main shore line, which, in this area, is less distinctive than usual for Troms.

The structure of the Rensaa end moraine was exposed in a gravel pit and in a section on the steep bluff by the Rensaa River (fig. 18; locality 12, Pl. 1). The gravel pit lies on the distal slope near the top of the moraine. A 15 m thick foreset section with beds dipping 15°—

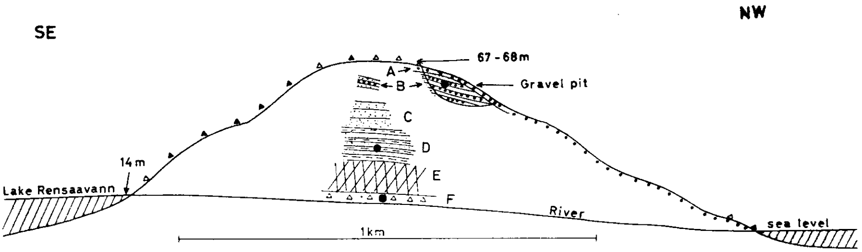


Fig. 18. Cross-section of the Tromsø—Lyngen end moraine at Rensaa.

A: Beach gravel, ½ m—1½ m.

B: Foreset beds, mainly gravel with large boulders.
The beds dip 15°—20°.
Shell fragments of the following species lie scattered within the beds: Mya truncata, Hiatella (Saxicava) arctica, Chlamys (Pecten) islandicus, Arctica (Cyprina) islandica *and* Astarte elliptica. *The shells fragments probably originate from older beds. They were radioarbon dated at 11,100 ± 300 years B.P. (T-111) and 11,650 ± 220 years B.P. (T-437 B).*

C: Stratified marine sand and silt.

D: Interbedded silt and clay, with scattered pebbles and cobbles. Shells of Portlandia arctica *lie in some of the beds. The shells were radiocarbon dated at 11,100 ± 800 years B.P. (T-175).*

E: Marine blue clay, well sorted with no stratification.

F: Glacio-marine clay, 2 m exposed. Numerous pebbles to cobbles and unbroken shells exist. The shells were of the same species as the shells in section B. They are large, and their radiocarbon age is 11,700 ± 210 years B.P. (T-438 B); 11,990 ± 250 years B.P. (T-438 A).
Filled circles: radiocarbon dated samples.

Tverrprofil av Tromsø—Lyngen endemorenen ved Rensaa.

A: ½—1½ m strandgrus.

B: Skrålag, vesentlig av grus med store flyttblokker.
Lagene heller 15°—20°.
Skjellfragmenter av følgende arter ligger spredt i lagene: *Mya truncata, Hiatella (Saxicava) arctica, Chlamys (Pecten) islandicus, Arctica (Cyprina) islandica* og *Astarte elliptica.* Skjellfragmentene skriver seg sannsynligvis fra eldre lag. De har en C-14 alder på 11,100 ± 300 år (T-111) og 11,650 ± 220 år (T-437 B).

C: Lagdelt marin sand og silt.

D: Silt og leir-lag med spredte stein og skjell av *Portlandia arctica* ligger i noen av lagene. De ble C-14 datert til 11,100 ± 800 år før nåtid (T-175).

E: Marin blåleire, godt sortert og ikke lagdelt.

F: Glaci-marin leire med meget stein og hele skjell. Ca. 2 m leire var blottet. Skjellene representerte de samme artene som ble funnet i seksjon B. De er store og har en C-14 alder på 11,770 ± 210 år (T-438 B), 11,990 ± 250 år (T-438 A). Store prikker angir den stratigrafiske beliggenheten av C-14 daterte prøver.

20° seaward was exposed. The beds consist of mainly sand and gravel with several boulders more than 1 m^3. Shell fragments of *Mya truncata, Hiatella (Saxicava) arctica, Macoma calcarea, Chlamys (Pecten) islandicus, Arctica (Cyprina) islandica* and *Astarte elliptica* lie particularly in silty parts of the foreset section. A shell sample collected from various parts of the section was radiocarbon dated at 11,100 ± 300 years B.P. (T-111). Shell fragments collected from a silty bed at about the middle part of the foreset section were dated at 11,650 ± 220 years B.P. (inner fraction, T-437B) and 10,830 ± 180 years B.P. (outer fraction, T-437A). The crusts of most shells were relatively soft and powdery, but the submitted samples consisted of the hardest parts of the most fresh-looking shells. Still, the great difference in apparent age between the two fractions of sample T-437 suggests a considerable contamination (p. 147), and the correct age of the sample is most likely 11,650 ± 220 years B.P. or possibly older. Sample T-111 could also have been contaminated. Therefore, the age of this sample could be higher than 11,100 ± 300 years B.P., and possibly as old as sample T-437. If, therefore, the shell fragments are of the same age as the host sediments, then the upper part of the Rensaa moraine is probably of Allerød age. However, the fragments were most likely reworked from older sediments, since no unbroken shells were seen, and numerous shells of the same species lie in the deeper, older part of the Rensaa section. Therefore, the foreset section is very likely younger than the shells.

The foreset beds were exposed in the upper part of the bluff at Rensaa River also (fig. 18). There, an approximately 40 m thick marine (glacio-marine) section with flat-lying beds underlies the foreset beds. The flat-lying beds consist of sand in the upper part (C), interbedded (laminated) silt and clay in the middle part (D), and bluish clay with no clear stratifaction in the lower part (E and F). Most of the beds are well sorted except for a few clay beds in the middle part of (D) and the clay bed (F) at the base of the bluff. Scattered pebbles, cobbles and shells of *Portlandia arctica* lie in the clay beds (D). This, together with the lamination, suggest that the beds were deposited near an ice front. Unbroken, shells of *Portlandia arctica* were radiocarbon dated at 11,100 ± 800 years B.P. (T-175). Unfortunately, the shell sample was so small that the entire sample was used for the radiocarbon dating. The date suggests that the glacio-marine beds are of Younger Dryas or Allerød age.

The clay in bed (F) is a typical glacio-marine clay with numerous pebbles and boulders. A fabric analysis showed that 60 % of the pebbles and cobbles had vertically or nearly vertically (max. 30° deviation) oriented long axes. Unbroken, many paired and freshlooking shells lie in abundance in the clay. Most of the shells are large. The following species were identified; *Mya truncata, Chlamys (Pecten) islandicus, Astarte elliptica, Macoma calcarea* and *Arctica (Cyprina) islandica.* These were radiocarbon dated at 11,770 ± 210 years B.P. (inner fraction, T-438 B) and 11,990 ± 250 years B.P. (outer fraction, T-438 A). Therefore, the clay is probably of early Allerød or possibly of Older Dryas age. The fauna and the stratigraphic position of the glacio-marine clay (F) is very similar to that of the glacio-marine clay (E) at the base of the Giæverneset moraine at Tromsø (p. 47). The radiocarbon age of the two clay beds, too, is about the same. The abundance of pebbles and boulders within the clays suggests that they were deposited near the ice front. However, the fauna indicate relatively favourable water conditions, which are difficult to correlate with the conditions at the front of the glacier during a cold phase of the Tromsø—Lyngen event. Therefore, these beds could represent a warmer phase prior to the latter event. The radiocarbon dates show that this phase was during early Allerød to Older Dryas time. At that time, the ice front was located at or behind the position of the Tromsø—Lyngen moraines. The deposition of the thick section (B, C, D, E) of mostly well sorted fine-grained sediments must have taken a considerable time, probably most of Allerød time. The ice front at that time could have been located far behind the position of the Tromsø—Lyngen moraines. Section (A) represents a following ice advance, most likely of Younger Dryas age. According to this interpretation only section (A) corresponds to the Tromsø—Lyngen event. However, the possibility can not be excluded that all of the glacio-marine beds (A), (D) and (F) represent cold phases of the Tromsø—Lyngen event.

Conclusion and discussion.

Moraines and longitudinal profiles of the fjord glaciers. Large and distinct moraine ridges were deposited at the margins of the Tromsø—Lyngen glaciers in each of the fjords in

Troms. The correlation of these moraines from one fjord to the next is generally clear.

Longitudinal profiles of the fjord glaciers in Ullsfjord and Balsfjord were constructed by using the location of the lateral moraines as a base (fig. 10). The profiles of the Tromsø—Lyngen and the Skarpnes fjord glaciers were very much alike. They show that the fjords were occupied by long gently sloping glaciers, whose surface gradients were 12 m/km—14 m/km in areas lying 10 km—30 km from the snouts. This is about the same slope as that calculated for the Tromsø—Lyngen glaciers in the Lavangen and Gratangen fjords. The glacier surfaces sloped steeply near their fronts, generally 60 m/km—80 m/km, which indicates that they were very active.

Andersen (1954, p. 321) presented longitudinal profiles for the Younger Dryas fjord glaciers in south-western Norway. They are steeper than the profiles just mentioned for the corresponding glaciers in Troms (fig. 10). For instance, the surface of the Lysefjord glacier sloped 75 m—80 m/km (between 0 km and 5 km from the front), 34 m/km (between 5 km and 15 km from the front), and 20 m/km (between 15 km and 25 km from the front). This indicates that the Younger Dryas glaciers in south-western Norway were more active than the glaciers in Troms. A considerable difference in precipitation between Troms and south-western Norway can probably explain much of this difference in glacier activity. The modern annual precipitation is between 1500 mm and 3000 mm in the area studied in south-western Norway, and between 500 mm and 1500 mm in the coastal districts of Troms (Wallén 1960, map 5). A similar difference in precipitation probably existed during the Younger Dryas phase also.

The Structure of the moraines. The terrestrial moraines consist of mainly gravelly and bouldery till. No stratification was seen within these, and well rounded stones are very rare. The marine end moraines are ridges composed of stratified sediments. Exposures in the moraines at Giæverneset and at Rensaa gave the most complete picture of the structure in this kind of moraine. They consist of, 1) an upper section of marine deposited ice-contact drift, 2) a middle section with flat-lying beds of mainly well sorted marine sand, silt and clay, 3) a low-lying section of glacio-marine clays with shells and numerous pebbles and boulders.

The ice-contact drift section at Rensaa is dominated by foreset beds of sand and gravel to boulders, including large erratics. The beds dip 15° to 20°. At Giæverneset, the corresponding section is dominated by a till bed. Both drift sections were deposited during a glacier advance in about Younger Dryas time. This advance represents either a late phase of, or all of the Tromsø—Lyngen event. The well sorted marine sediments below the ice-contact drift were deposited probably in Allerød time when the ice fronts were located inside the positions of the Tromsø—Lyngen end moraines. The low-lying glacio-marine clays are of early Allerød or Older Dryas age. They represent either an earl yTromsø—Lyngen advance or a melting phase prior to the Tromsø—Lyngen event. The stratigraphic position of the glacio-marine clays and the Boreo-arctic fauna in the clays favour the last mentioned interpretation. However, if the radiocarbon date of the bog on the moraine at Tromsø is correct, then the glacio-marine clays most likely represent an early Tromsø—Lyngen phase.

The marine ice-contact outwash deltas. Several raised, marine, ice-contact, outwash deltas lie in contact with the Tromsø—Lyngen moraines. The outwash delta plains are generally covered with large boulders near the moraines, and the grain size of the sediments gradually decreases in a distal direction. The slope of the delta plains also decreases in a distal direction. The proximal parts commonly slope as much as 4 m to 8 m per km, while the distal parts of the longest plains are nearly horizontal. Andersen (1960, p. 66) described similar profiles of the outwash delta plains in southern Norway. He found that the distal gently sloping parts of the plains were deposited at about sea level. This is true for the outwash delta plains in Troms also. The distal parts of the Tromsø—Lyngen delta plains lie at about the same altitude as the corresponding Main shore line, although the most distal parts, at the delta fronts, usually lie slightly below this shore line.

The structure of the outwash deltas generally fall within two categories; 1) deltas with steeply inclined foreset beds, 2) deltas where the foreset beds are either very gently inclined or they are lacking.

The outwash deltas that were deposited in deep water are of the first-mentioned kind. Their foreset beds dip usually between 15° and 25°, and they consist mainly of coarse grained sediments, as do the topset beds. Deltas of the second type were formed in shallow water.

The outwash unit rests conformably on beds of fine grained marine sediments. Apparently, the Tromsø—Lyngen ice fronts advanced into shallow water, and the water from the glacier streams continued as marine currents across the shallow sea floor. Therefore, the sediments dropped out gradually as the current velocity decreased, and no steeply inclined foreset beds were formed (Andersen 1960, p. 69).

The shore lines. The Tromsø—Lyngen moraines correspond to the Main shore line and to slightly higher-lying shore levels. This is shown by the facts that, 1) the raised Tromsø—Lyngen outwash plains correspond in altitude to the Main shore line and to slightly higher-lying levels, and 2) the Main shore line stops approximately at the Tromsø—Lyngen moraines.

The Main shore line is a zone or belt rather than a sharp line. A low-lying part of this zone seems to continue a short distance inside the Tromsø—Lyngen moraines, and represents the melting phase at the end of the Tromsø—Lyngen event (see discussion on p. 144).

The marine fauna. A review of the marine shell faunas is presented in table 1. The suggested ages of the faunas were based on the radiocarbon dates. They could be slightly inaccurate (p. 145). Included in the table there are also shells from deposits that are older and younger than the Tromsø—Lyngen event. They are described in detail in other sections.

The faunas found in the oldest sediments, of Bølling and Older Dryas age in Troms consist of species that live in Arctic to Boreal waters. This Boreo-Arctic type fauna resembles the Bølling (Oldest Dryas) fauna found near Lillesand in southern Norway (Andersen 1960, p. 61). Most of the shells were large and occurred abundantly, suggesting favourable sea-water conditions at the time of deposition. A similar Boreo-Arctic type fauna dominates most of the Allerød sediments, also, particularly the mid- to early-Allerød sediments. However, shells of a High-Arctic *Yoldia* fauna, including *Portlandia arctica* lie in several sediments of supposedly Allerød age. *Macoma calcarea* and *Mya truncata* that lie together with *Portlandia arctica* were generally small. This fauna thrived in cold, brackish water near the ice fronts (Andersen 1954, p. 328). The occurrences in connection with glacio-marine laminated (varved) clays also suggest that

<table>
<tr><th>Locality</th><th>Pre-Boreal</th><th>Younger Dryas</th><th>Allerød</th><th>Older Dryas</th><th>Bölling</th></tr>
<tr><td>Slottet
in
Lyngenfjord</td><td colspan="2"><i>Portlandia arctica</i></td><td></td><td></td><td></td></tr>
<tr><td>Olderdal
in
Ullsfjord</td><td></td><td></td><td><i>Mya truncata</i>
<i>Hiatella arctica</i>
<i>Macoma calcarea</i>
<i>Balanus</i> sp.</td><td></td><td></td></tr>
<tr><td>Svensby
in
Ullsfjord</td><td></td><td></td><td><i>Macoma calcarea</i>
<i>Mya truncata</i>
<i>Pecten groenlandicus</i>
<i>Nucula tenuis</i></td><td></td><td></td></tr>
<tr><td>Skardmunken
in
Ullsfjord</td><td colspan="2"><i>Macoma calcarea</i>
<i>Saxicava arctica</i>
<i>Mya truncata</i></td><td></td><td></td><td></td></tr>
<tr><td>Tromsdal</td><td><i>Bathyarca glacialis</i>
<i>Macoma torelli</i>
<i>Nucula tenuis</i>
<i>Pecten groenlandicus</i>
<i>Balanus balanus</i>
<i>Yoldia hyperborea</i>
<i>Portlandia lenticula</i></td><td colspan="2" rowspan="2"><i>Portlandia arctica</i> 1)
<i>Portlandia lenticula</i>
<i>Leda pernula</i>
<i>Nucula tenuis</i>
<i>Modiolaria nigra</i>
<i>Pecten groenlandicus</i>
<i>Astarte elliptica</i>
<i>Macoma calcarea</i>
<i>Mya truncata</i>
<i>Lyonsia arenosa</i>
<i>Natica clausa</i></td><td></td><td></td></tr>
<tr><td>Stormo
in
Balsfjord</td><td><i>Mya truncata</i>
<i>Macoma calcarea</i></td><td></td><td></td></tr>
<tr><td>Giæverneset
on
Tromsøy</td><td></td><td colspan="2"><i>Portlandia arctica</i>
<i>Nucula tenuis</i>
<i>Leda pernula</i>
<i>Thyasira flexuosa</i></td><td></td><td></td></tr>
</table>

			Astarte elliptica *Mya truncata* *Balanus* sp. *Hiatella arctica* *Chlamys islandicus*		
Bjorelv		*Macoma calcarea*	*Mya truncata* *Macoma calcarea*		
Brøstad		*Potrlandia arctica*			
Rensaa			*Astarte elliptica* *Chlamys islandicus* *Mya truncata* *Potrlandia arctica*	*Astarte elliptica* *Chlamys islandicus* *Mya truncata* *Hiatella arctica* *Macoma calcarea*	
Sandstrand			*Mya truncata* *Portlandia arctica*		*Mya truncata* *Chlamys islandicus* *Astarte* sp.
Gratangsbotn	*Macoma calcarea* *Mya truncata* *Chlamys islandicus*				
Breidvikeid			*Potrlandia arctica* *Macoma calcarea*		

[1]) From Kiær 1902.

Table 1. The approximate ages of marine shell-faunas in western Troms (Based on radiocarbon dates).
De omtrentlige aldre på marine skjell-faunaer i vestlige Troms (Basert på C-14 dateringer).

the Allerød *Yoldia* fauna lived in brackish water near the ice fronts. Shells of the High-Arctic *Yoldia* fauna are dominant within the Younger Dryas sediments. In addition to *Portlandia arctica*, the High-Arctic mollusk *Yoldia hyperborea* lived probably in Younger Dryas time in Troms. The Boreo-Arctic type Younger Dryas faunas at Bjorelvnes and Skardmunken were characterized by relatively small shells suggesting unfavourable sea-water conditions at that time.

Bathyarca glacialis lived near Tromsø probably at the Younger Dryas—Pre-Boreal transition. The *Arca* fauna lived under slightly better sea-water conditions than the *Yoldia* fauna. In the Oslofjord area, also, an *Arca* fauna succeed the *Yoldia* fauna about the Younger Dryas—Pre-Boreal transition.

Numerous and large shells of a Boreo-Arctic fauna lie within most of the fossiliferous Pre-Boreal sediments. This indicates relatively favourable sea-water conditions at the time of deposition.

Apparently, a High-Arctic *Yoldia* fauna lived in the muddy, slightly brackish and cold water near the Tromsø—Lyngen ice fronts. At the same time, a Boreo-Arctic type fauna lived further from the ice fronts. The *Yoldia* fauna was replaced by an *Arca* fauna and a Boreo-Arctic fauna at the end of the Tromsø—Lyngen event.

The foraminifera. The fossil foraminifer faunas were studied in samples from five localities (table 2). All samples are between 10,200 and 11,600 years old, according to the radiocarbon dates. The recorded faunas are cold-water faunas dominated by *Elphidium incertum clavatum*. The small differences between the faunas could have been caused by local environmental differences rather than differences in age and climate. The sedimentation rate, grain size of the sediments, concentrations of nutrients and trace elements, and the water type are some of the most important environmental factors influencing the foraminifer faunas (Feyling-Hanssen 1964, p. 13). Many of these factors could have varied considerably within short distances near the ice fronts.

The foraminifer faunas described in Troms correspond relatively well in age and composition with those in the *Yoldia* clays near Oslofjord (table 2). They all have a very high percentage of *Elphidium incertum clavatum* and most of them have a high percentage of *Cassidulina crassa*. However, differences between the faunas within the two regions exist, and a detailed correlation seems difficult. For in-

	Tromsdal *Arca* clay	Bjorelv *Macoma* silt	Giævernes *Yoldia* clay	Breidvikeid *Yoldia* clay	Brøstad *Yoldia* clay	E Postglacial clays, Oslofjord *	B-C-D Arca clays, Oslofjord *	A Yoldia clays, Oslofjord *
Elphidium i. clavatum	55,5	58,5	44,3	97,1	8,2	10—40	10—100	40—100
Cassidulina crassa	9,2	14,2	38,9	0,3	3,6	5—10	5—40	10—40
Virgulina sp.	5,3	0,4	1,5					
Buccella frigida	11,5	3,9	8,1	0,3		0—1	0—1	
Buccella inusitata	8,2		1,5					
Elphidium orbiculare	5,9	0,4	1,1					
Elphidium subarcticum	0,8	0,8	0,3	0,3	3,6	0—1	0—1	0—1
Nonion labradorium	1,3	0,4	1,6			0—1	10—40	10—40
Triloculina trihedra	0,2		0,2			0—1	0—1	0—1
Cassidulina teretis	0,3		1,1					
Guttulina dawsoni	0,3			1,7	7,2	0—1		0—1
Fissurina lucida	0,2					0—5	0—5	0—1
Cibicides lobatulus	0,2	0,8	0,3		1,8	0—5	0—5	0—1
Pyrgo williamsoni	0,3		0,2			1—5	0—10	0—10
Astrononion gullowayi	0,7	1,2	0,4			0—1	0—1	0—5
Lagena sp.	0,2							
Discrotbis sp.	0,2							
Elphidium i. *incertum*		18,1		0,3		10—40	0—40	0—5
Elphidium excawatum		0,8				0—1		
Pyrgo cf. *simplex*		0,4						
Virgulina loeblichi		0,4	0,2			1—5	1—40	0—10
Globigerina bulloides		0,2				0—1		0—1
Angulogerina fluens		0,2						0—1
Guttulina lactea			0,2			0—1		0—1
Bolivina pseudoplicata			0,2			0—1	0—1	0—1
Quinqueloculina seminulum			0,2		1,8	1—5	0—5	0—1

Table 2.

Foraminifera faunas in Troms and near Oslofjord in southern Norway.
Figures: Percentages.
**: From Feyling-Hanssen (1964).*
A . . E: Foraminiferal zones.

Foraminifer faunaer i Troms og ved Oslofjorden.
Tallene angir prosent.
*: Fra Feyling-Hanssen (1964).
A . . E: Foraminifer soner.

stance, the faunas at Tromsdal, Bjorelvnes and Langnes resemble the cold water Pre-Boreal *Arca* fauna in the Oslofjord region also. The foraminifera analyses were all done by Dr. Feyling-Hanssen, (p. 154).

The radiocarbon dates. Altogether 18 samples of organic deposits that are closely related to the Tromsø—Lyngen moraines were radiocarbon dated. All of these dates lie between approximately 10,100 years B.P. and 12,000 years B.P. Therefore the age of the Tromsø—Lyngen event must lie somewhere within this age bracket. This conclusion is also supported by the radiocarbon ages of older and younger glacial events in Troms (pp. 35, 87). A list of the radiocarbon dates and the most important information on the dated samples are presented in table 3. In reading the list it must be kept in mind that several of the dates could be rather inaccurate, see discussion on p. 145.

The date T-51 (11,680 ± 170 years B.P.) of the bog on the oldest Tromsø—Lyngen moraine at Tromsø suggests that the oldest Tromsø—Lyngen phase is of early Allerød or Older Dryas age. This date corresponds well with the dates of the glacio-marine beds at Rensaa (T-438 B) and at Giævernes (T-436 B). However, the stratigraphic positions of the glacio-marine beds indicate that they could be older than the Tromsø—Lyngen event. Therefore, the evidence in favour of an old Tromsø—Lyngen phase is questionable. The dates at least show that the ice front was located close to the position of the Tromsø—Lyngen moraines in about early Allerød time. A main part of the Tromsø—Lyngen outwash was deposited during a later advance. This outwash overlies marine (glacio-marine) sediments of about Allerød age (T-110, T-175, T-174). Therefore, the advance most likely occured in Younger Dryas time. The date (T-333) of the advance at Skardmunken and the date (T-50) of the outwash at Bjorelvnes support this conclusion. An older part of the outwash at Bjorelvnes was dated at 11,250 ± 310 years B.P. (T-511 B), which indicates that the glacier advance possibly started in late Allerød time. The date T-113 (Tromsdal valley), in addition to T-187 and T-333, suggests that the final phase of the Tromsø—Lyngen event was about 10,200 ± 300 years B.P., i.e. at the transition between Younger Dryas and Pre-Boreal time (see table 4).

Lists of the mentioned dates have been published previously by R. Nydal (1959, 1960, 1962 and 1963). Based on the radiocarbon dates,

Locality	Occurrence	Dated material	Laboratory numbers	Locality numbers **	Radiocarbon age (B.P.)	Correlation with phases of Tromsø—Lyngen event
Brøstad	Outwash delta: Glacio-marine clay (overlain by outwash)	*Portlandia arctica*	T—173	10	10,150 ± 500 *	Early or before
Tromsdal valley	Low-lying terrace: Glacio-marine clay	*Bathyarca glacialis* etc.	T—113	5	10,200 ± 350	Late or after
Spaakenes in Lyngenfjord	Outside end moraine: Glacio-marine clay	*Portlandia arctica*	T—187[1]	—	10,350 ± 300	Late
Skardmunken in Ullsfjord	End moraine: Glacio-marine clay (truncates "foreset" beds)	*Macoma calcarea* etc.	T—333[2]	2	10,390 ± 200	Late advance
Bjorelv I	Outwash delta: Silt, in highest part of foreset section	*Macoma calcarea*	T—50	9	10,500 ± 400	Late
Bjorelv II	Outwash delta: Silt, in lowest part of foreset section	*Macoma calcarea*	T—174	9	11,200 ± 500	Early or before
Bjorelv III	Outwash delta: Silt, in middle part of foreset section	*Mya truncata*	T—511 A T—511 B	9	11,330 ± 280 (outer fraction) 11,250 ± 310 (inner fraction)	Middle or early
Rensaa I	End moraine: Silt and sand in foreset beds	Shell fragments, *Mya truncata, Chlamys islandicus*, etc.	T—111 T—437 A T—437 B	12	11,100 ± 300 10,830 ± 180 * (outer fraction) 11,650 ± 220 (inner fraction)	Before or early?
Rensaa II	End moraine: Glacio-marine clay, in middle part of marine section	*Portlandia arctica*	T—175	12	11,100 ± 800	Before or middle
Rensaa III	End moraine: Glacio-marine clay, at the base of marine section	*Mya truncata, Chlamys islandicus, Astarte elliptica* etc.	T—438 A T—438 B	12	11,990 ± 250 (outer fraction) 11,770 ± 210 (inner fraction)	Before or early
Breidvikeid	Outwash delta: Glacio-marine clay, overlain by outwash	*Portlandia arctica* *Macoma calcarea*	T—110[2]	4	11,500 ± 400	Before or early
Giævernes I on Tromsøy	End moraine: Outwash sand and gravel, overlain by till	Shell fragments, *Mya truncata, Chlamys islandicus, Astarte elliptica* etc.	T—112	7	11,500 ± 350	Before or early?
Giævernes II on Tromsøy	End moraine: Glacio-marine clay, at the base of the moraine	*Mya truncata, Chlamys islandicus, Astarte elliptica* etc.	T—436 A T—436 B	7	9,960 ± 130 * (outer fraction) 11,520 ± 150 (inner fraction)	Before or early
Blindfinnvann	Bog: Gyttja from the base of a bog between two end moraines	Gyttja	T—53	11	10,720 ± 240	After early phase
Prestvann I on Tromsøy	Bog: Gyttja (gel mud) from the base of a bog on the oldest end moraine	Gel mud and gyttja	T—51	6	11,680 ± 170	After early phase
Prestvann II on Tromsøy	Bog: Gyttja (gel mud) from the base of a bog on the oldest end moraine	Gel mud and gyttja	T—167	6	> 9,610 ± 250 *	After early phase
Oldervikdal valley	Marine terrace above the Main shore line: Glacio-marine clay	*Mya truncata*	T—631	3	11,550 ± 190	Before or early

Table 3.

Radiocarbon dated samples from Tromsø—Lyngen end moraines and outwash deltas, and from deposits that are closely related to the Tromsø—Lyngen event.

1) Collected by Marthinussen (1962, p. 45).
2) Collected by Holmes and Andersen (1964).
All other samples collected by the writer.
** Most likely contaminated.*
*** Refer to numbers on Pl. 1.*

C-14 daterte prøver fra Tromsø—Lyngen endemorener og brefront-delta, og fra avsetninger som har nær sammenheng med Tromsø—Lyngen trinnet.

1) Prøven ble tatt av Marthinussen (1962, s. 45).
2) Prøven ble tatt av Holmes og Andersen (1964).
Alle andre prøver ble tatt av forfatteren.
* Sannsynligvis forurenset.
** Svarer til lokalitetsnummer på Pl. 1.

the age of the Tromsø—Lyngen event was supposed to be, 1) between 10,200 years B.P. and 11,600 years B.P. (Andersen, in Nydal 1959, 1960), 2) Younger Dryas (Marthinussen, in Holtedahl 1960, p. 418), 3) Younger Dryas and possibly a late part of the Allerød phase (Holmes and Andersen, 1964), 4) Younger Dryas, a late part of Allerød and possibly also an early part of Allerød or Older Dryas phases (Andersen, 1964, 1965).

The local glaciation and the snow lines. Small local glaciers covered the highest mountains on the islands and peninsulas outside the Tromsø—Lyngen fjord glaciers. The local glaciers deposited numerous ridges that dominate the Island II moraine complex (p. 94).

The corresponding snow lines and glaciation limits were about 475 ± 50 m below the altitudes of the present-day snow lines and glaciation limits. See the description and discussion in the following sections (p. 126).

Correlation of the Tromsø—Lyngen moraines with moraines outside Troms.

Large marginal moraines which correspond to the Tromsø—Lyngen moraines have been found in Finnmark county to the east of Troms. The Main shore line was correlated with these moraines (Marthinussen, 1961).

In southern Fennoscandia the Ra-Middle Swedish-Salpausselkä moraines have a similarly dominant position as the Tromsø—Lyngen moraines in northern Norway. Attempts were made to date the Ra-Salpausselkä event, and most of the obtained dates correspond well with the dates of the Tromsø—Lyngen moraines. The Ra moraines in south-eastern Norway were deposited in the sea. Altogether 4 samples of marine shells from the Ra ridges were radiocarbon dated (Nydal 1962, p. 170; and three unpublished dates of samples collected by Andersen and Holmes). The radiocarbon ages of the samples are (in years B.P.), 11,000 ± 250 (T-261), 10,760 ± 200 (T-424), 10,650 ± 150 (T-426), and 10,080 ± 160 (T-425). According to Andersen and Holmes (unpublished), the stratigraphic position of the last-mentioned sample (T-425) indicates that it was deposited during a very late phase or the waning phase of the Ra glacier. Samples of shells from the *Yoldia* clay immediately outside the Ra-moraine, too,

Y. Dryas | Pre-Boreal	Younger Dryas	Y. Dryas | Allerød	Allerød	Allerød | O. Dryas
10,264 ± 350[3]	10,325 ± 215[3]	11,480 ± 150[2]	11,845 ± 190[2] Q-359	11,950 ± 190[2]
Q-151	Q-153	Q-365	12,090 ± 190[2] Q-361	Q-358
10,500 ± 350[4]	10,835 ± 185[3]	11,030 ± 200[1]	11,390 ± 190[2] Q-362	
K-111	Q-144	K-110; K-102;	11,450 ± 190[2] Q-363	
10,170 ± 193[3]		K-103	11,770 ± 190[2] Q-364	
Q-152		10,970 ± 300[4]	10,705 ± 207[3] Q-147	
10,336 ± 215[3]		K-110	11,300 ± 140[5] K-552	
		10,845 ± 185[3]	11,350 ± 245[11] Q-102	
		Q-144	11,930 ± 225[11] Q-101	
		10,700 ± 207[3]	11,400 ± 300[11] Q-100	
		Q-147, Q-148	11,620 ± 140[5] K-553	
			11,700 ± 140[5] K-547	
			11,880 ± 340[8] K-106	
			11,800 ± 410[8] K-410	
			10,990 ± 240[8] K-104	
			10,850 ± 230[11] Q-104	
			11,140 ± 235[11] Q-103	
10,350 ± 150	Younger Dryas	10,950 ± 150	Allerød	11,950 ± 150

1) Ruds Vedby Denmark (Tauber 1960, p. 6).
2) Roddan's Port, Northern Ireland (Godwin and Willis, 1964, p. 117).
3) Scaleby Moss, British Isles (Godwin and Willis, 1959, p. 64; 1959, p. 208).
4) Bølling, Denmark (Tauber, 1960, p. 6).
5) Usselo, Netherlands (Tauber 1960, p. 14).
6) Witow, Poland (Tauber 1962, p. 28).

Table 4.
Radiocarbon dates of Late-glacial deposits from some of the best studied stratigraphic sections in northern Europe.

Older Dryas	O. Dryas | Bølling	Bølling	Bølling | O. Dryas	Oldest Dryas
12,110 ± 190[2]	11,900 ± 180[6]	12,200 ± 140[5]	12,410 ± 140[5]	12,440 ± 140[5]
Q-360	K-706	K-543	K-544	K-545
11,770 ± 140[5]	11,825 ± 120[10]	12,100 ± 140[6]		12,530 ± 140[5]
K-541	Gro-926	K-708		K-546
11,680 ± 140[7]		12,260 ± 140[6]		12,240 ± 230[6]
K-962		K-707		K-709
11,780 ± 180[7]		12,330 ± 120[9]		
K-963		GrN-3049		
		12,340 ± 120[9]		
		GrN-3052		
		12,460 ± 140[9]		
		GrN-2458		
		12,355 ± 170[10]		
		Gro-927		
		12,300 ± 260[12]		
		H 77/54		
Older Dryas	12,050 ± 200	Bølling	12,400 ± 200	Oldest Dryas

7) Nørre Lyngby, Denmark (Tauber 1966, p. 214).
8) Ruds Vedby, Denmark (Gross 1958, p. 178).
9) Ekeren, Belgium (Vogel et al. 1964, p. 367).
10) Usselo, Netherlands (Vries et al. 1958, p. 131).
11) Garral Hill, England (Godwin, 1959, p. 203).
12) Gaterslebener Sees (Firbas et al. 1955, p. 509).

C-14 dateringer av senglaciale avsetninger fra noen av de best undersøkte stratigrafiske profil i Nord-Europa.

were radiocarbon dated (Nydal 1962). This *Yoldia* clay was correlated with the Ra-moraines and the first part of the waning phase immediately after the Ra-phase (Feyling-Hanssen 1964, p. 175). The following are the obtained radiocarbon dates (in years B.P.); 11,200 ± 200 (T-223), 10,700 ± 300 (T-315), and 10,200 ± 220 (T-178).

The Norwegian Ra-moraines can be physically traced into the Middle Swedish moraines. Therefore, the two moraine complexes undoubtedly correspond. Varve-datings from Sweden suggest an age between approximately 10,100 years B.P. and 10,900 years B.P. for the Middle Swedish moraines (J. Lundqvist 1965, p. 168). A map of varve dated ice-front positions in Sweden, was presented by G. Lundqvist (1961, p. 85). According to this map, an ice-front position 11,200 years old, corresponds to the position of the oldest Ra-moraines in Norway. The good correspondance between the radiocarbon dates of the Ra-moraines, the varve dates of the Middle Swedish moraines and the radiocarbon dates of the Tromsø—Lyngen moraines (at least the youngest part) suggests a correlation of the corresponding three glacial events.

The Ra-Middle Swedish moraines were generally correlated with the Younger Dryas event, which is the youngest cold phase of the Würm Glaciation. Numerous radiocarbon datings have been done of Younger Dryas organic deposits from pollen-analyzed sections in different parts of northern Europe. Most of the dates, from the best sections, are shown in table 4. They suggest that the age of the Younger Dryas phase is from 10,350 ± 150 years B.P. to 10,950 ± 150 years B.P., which again corresponds well with the dates of the Ra-Middle Swedish moraines and the dates of the Tromsø—Lyngen moraines.

The age of the Salpausselkä moraines in Finland is slightly more problematic. Varve datings done by Sauramo suggest that the Salpausselkä moraines correspond with the Middle Swedish moraines (Donner 1965, p. 229). However, many Finnish geologists arrived at conflicting results for the age of the Salpausselkä moraines, based mainly on pollen analysis of bogs and on correlation of shore levels (see review in M. Okko, 1962, p. 136). Many of them believed that the oldest part of, or possibly all of the Salpausselkä moraines are of Allerød or Older Dryas age, while some favoured a Younger Dryas age for the moraines.

A correlation of the oldest Salpausselkä moraine with an early part of the Allerød phase or the Older Dryas phase corresponds well with the indicated possible age for the oldest Tromsø—Lyngen moraine. The ice fronts in Troms were at least located close to the positions of the Tromsø—Lyngen moraines in early Allerød time. A radiocarbon date of shells from a locality near Lillesand suggests that the ice front there, too, was located very close to the area of the Ra-moraine during the early Allerød and Older Dryas phases. The shells lie only 8 km outside the Ra-moraines, and they were dated at 12,550 ± 200 years B.P. (T-168, Andersen 1965, p. 115). However, varve dated ice-front positions in Sweden suggest that the ice front there was located far south of the Middle Swedish moraines during the Older Dryas and most of the Allerød phases. Apparently, the retreat of the ice front in Sweden occurred slowly during the phases mentioned, while it probably happened rapidly in an early phase on most of the Norwegian coast, and possibly also in Finland. A main reason for the differences in glacier retreat could be differences in calving. In Sweden the ice front retreated in shallow water or on dry land south of the Middle Swedish moraines, while the corresponding retreat in Norway and in Finland occurred partly in deep water. Both the Allerød and the Bölling climates were more favourable than the Younger Dryas climate (p. 132). Therefore, the ice fronts could have retreated to, or behind, the positions of the Younger Dryas moraines in early Allerød or even Bölling time within areas where the ablation and calving was very rapid, i. e. where the ice fronts were located in deep water. This is clearly demonstrated on several island in Troms, where the Island II moraine complexes represent the Younger Dryas, the Older Dryas and possibly still older events (p. 96).

THE STORDAL EVENTS

Scattered end moraines lie in the districts that were covered by the Tromsø—Lyngen glaciers. Most of the moraines are small and indistinctive, and many lie on topographic thresholds where the ice fronts were well protected against calving. Therefore, the existence of several of these moraines could be the result of favourable topographic conditions rather than climatic changes. However, the moraines that represent the Stordal events and the Recent events are generally distinct. Since these moraines lie in most fjords (main valleys), they must correspond to climatic fluctuations.

From one to three successive Stordal end moraines lie in some valleys (fjords), suggesting as many as three Stordal glacial events. The moraines generally lie at the heads of the fjords, or short distances upvalley from the heads. Some of the moraines are small. Considering the variable size, shape and number of Stordal moraines in the different fjords (valleys), they most likely represent glacial events caused by minor climatic fluctuations. Several of the supposed Stordal moraines, too, lie on topographical thresholds, and they could have resulted from a decrease in calving rather than a change in climate. This complicates correlation of the moraines from one fjord district to the next, and no attempts were made at detailed correlation. Radiocarbon dates suggest that the Stordal events fall within the 9,000 years B.P. to 10,000 years B.P. time bracket. The Stordal firn lines were only about 200 ± 50 m below the altitude of the modern firn lines (p. 130), and the Stordal shore lines lie 5 m to 10 m below the extended Main shore line.

Locality description.

The Ullsfjord District. Holmes and Andersen (1964) described Stordal moraines deposited by local glaciers in the tributary valleys of Ullsfjord–Sørfjord. No corresponding end moraines deposited by the fjord glacier were seen, and the fjord was probably ice free during the Stordal phases. The Stordal local moraines in the Ullsfjord–Sørfjord area were described in the section on Island III moraines (p. 106). An outwash terrace outside the Stordal moraine was graded to a sea level 71 m–73 m higher than the present, which is only about 5 m below the extended Main shore line (fig. 28).

Small gravel deposits connected with a bedrock threshold at Skognesodden in the middle part of Sørfjord could represent an end moraine older than the Stordal phases.

The Balsfjord District. The first good end moraine inside the Tromsø moraine in the Balsfjord district probably lies at Skjævelnes, about 10 km from the head of Balsfjord. There, a submarine ridge crosses the fjord, and thick gravel deposits lie on the fjord side at Skjævelnes. A corresponding outwash delta terrace lies at the mouth of a small valley 1 km west of Skjævelnes. Projecting ridge-shaped parts of the delta terrace probably represent the ice-contact zone. Three small segments of a lateral moraine lie on the east side of the fjord, 5 km–9 km south of Skjævelnes. The segments are low ridges, the southern and the northern ends respectively 350 m and 250 m above sea level. The lateral moraine probably corresponds to the Skjævelnes end moraine and the oldest Stordal event.

A large end moraine (outwash delta) lies at Stormo—Høgmo, about 2½ km south of the head of Balsfjord. Two valleys join there, and the moraine lies at the mouths of the two valleys. Most of it was deposited in the sea. The eastern segment, at the mouth of the eastern valley, is a wide morainic zone. The proximal part of the zone has typical dead ice topography with irregular ridges and kettle holes. Gravel with large boulders is exposed at the surface. Grønlie (1918, pl. I) recognized this end moraine. The western segment, at the mouth of the western valley, is a flat-topped ridge with a steep distal slope and a more gentle proximal slope. A deep river gorge breaches the ridge, which is in fact an outwash delta, fig. 19. The flat topsurface (outwash plain) is 500 m—600 m wide and lies 75 m to 77 m above sea level. This corresponds approximately to the altitude of the highest-lying raised marine level in this area. Large boulders cover in particular the proximal part of the outwash plain. The structure of the outwash delta was shown in several small exposures (fig. 19). A thin section of coarse-grained marine outwash overlies a thick section of well sorted marine clays, silts and sands. The contact between the two sections was not exposed, but the outwash section was probably no more than 10 m to 15 m thick. Exposures on the river bluff show that the lowest-lying section is about 30 m thick and consists of flatlying beds of, 1) marine blue clay near river level, 2) laminated silt and clay at higher levels and 3) stratified silt and sand near the top. The marine outwash section was exposed in two gravel pits, one on the distal slope and the other on the proximal slope of the delta. Bouldery topset beds (1 m—2 m) overlie foreset beds of sand and gravel dipping about 20° (?) north. Irregular south-dipping sand and gravel beds lie on the proximal slope. These beds were probably deposited by uphill-flowing subglacial streams close to the ice front.

Shells lie in the clay of the river bluff about 200 m north of the described delta ridge (fig. 19; locality 8, Pl. 1). There, the river has cut into a terrace 30 m to 50 m above sea level, and exposed a 1 m thick gravel bed on top of a 20 m thick section of marine silt and clay. The silt-clay section consists of unstatified blue clay in the lowest part and stratified clay and silt, including laminated (varved) units, in the higher parts. Numerous large shells of *Macoma calcarea* and

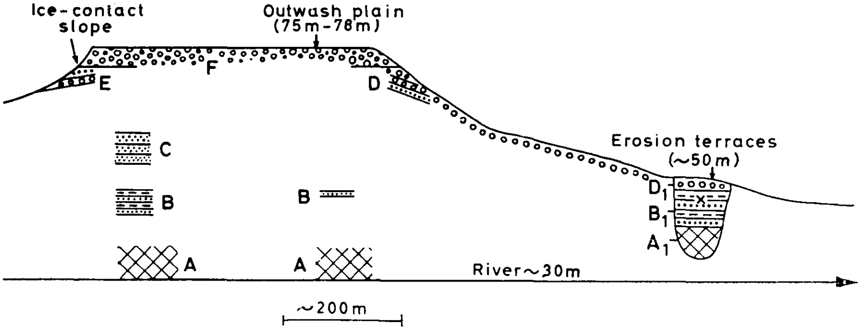


Fig. 19. Cross-section of the ice-contact outwash delta at Stormo in Balsfjord (rough sketch).

A: Marine blue clay, mostly unstratified.
B: Marine silt and clay, partly laminated.
C: Marine silt and fine-sand, stratified.
D: Foreset beds of sand and gravel.
E: South-dipping sand and gravel beds.
F: Topset beds of gravel with large boulders.
A_1: Marine clay, mostly unstratified.
B_1: Marine silt and clay, partly laminated, with shells of Macoma calcarea *and* Mya truncata.
D_1: Gravel.
x: Location of shells radiocarbon dated at approximately 9,150 years B.P. (T-510 A, B).
Altitudes in metres above sea level.

Tverrprofil av brefront-deltaet ved Stormo i Balsfjord (skisse).

A: Marin blåleire, vesentlig uten lagdeling.
B: Marin silt og leire, delvis laminert.
C: Marin silt og finsand, lagdelt.
D: Skrålag av sand og grus.
E: Grus- og sand-lag som heller mot syd.
F: Topplag av grus og stein.
A_1: Marin leire, vesentlig uten lagdeling.
B_1: Marin silt og leire, delvis laminert, med skjell av *Macoma calcarea* og *Mya truncata.*
D_1: Grus.
x: Beliggenheten av skjell som er C-14 datert til omlag 9 150 år før nåtid (T-510 A, B).
Høyder er angitt i meter o. h.

Mya truncata lie in some of the clay beds. The shells were all unbroken and many were paired. Freshlooking shells were radiocarbon dated at 9,100 ± 150 years B.P. (inner fraction, T-510 B) and 9,190 ± 160 years B.P. (outer fraction, T-510 A). The fossiliferous silt-clay section corresponds in altitude to the silt-clay section below the outwash delta just described, and the exposures of the two sections lie only 300 m—400 m apart. Therefore, they are most likely of the same age, although it is possible that a part of the fossiliferous section could be bottomset beds corresponding to some of the foreset beds in the outwash delta. The shells therefore, date a phase immediately before the deposition of the delta, or they date the delta itself.

Raised outwash deltas that probably correspond to the Stormo—Høgmo moraine lie at Storsteinnes and Melbakken, respectively north-west and north-east of Stormo—Høgmo. The two deltas lie at the mouths of small valleys. Both have bouldery outwash plains. The distal part of the outwash plain at Storsteinnes consists of an undulating area 74 m—77 m above sea level, and a very flat area at a slightly lower level. The delta at Melbakken is small, and the proximal part of the outwash plain slopes steeply, while the distal part is gentler, 78 m—80 m above sea level. Melbakken is closer to the center of isostatic uplift than Høgmo and Storsteinnes. Therefore, the outwash plains at the head of Balsfjord correspond well in altitude. They were graded to sea levels 75 m—80 m higher than the present, which is about 10 m below the extended Main shore line (fig. 29).

The Malangen district. A sharp submarine ridge across the fjord at Målsnes looks like an end moraine. However, no corresponding supramarine moraine was seen. Therefore, the ridge could be a continuation of the Målsnes bedrock ridge. If, however, it is an end moraine, then it is probably older than the Stordal events.

Thick gravel deposits that cover the Aspenes promontory near the head of Malangenfjord represent an end moraine. Grønlie (1931) considered this moraine to be of Tromsø—Lyngen age. However, the Aspenes moraine lies on a bedrock promontory and is small. No corresponding lateral moraines lie along the gentle fjord sides. Both the size, the shape and the location of the moraine suggest a correlation with the Stordal events rather than the Tromsø—Lyngen event. Grønlie based his conclusion mainly on observations of high-lying, supposedly marine terraces that he correlated with the Aspenes moraine and the Tromsø—Lyngen moraines. However, a field check of the terraces indicated that they were most likely not marine, and the highest-lying positively identified marine terraces near Aspenes lie below the extended Main shore line (fig. 30).

A steeply inclined low lateral moraine ridge lies on the valley slope near Bardufoss in Maalselv valley. The direction of the ridge suggests that the corresponding ice front was located close to Bardufoss. A large outwash terrace at Bardufoss probably corresponds with the moraine. Gravelly terrace-promontories about 3 km east of Bardufoss almost block the Maalselv valley. These promontories probably represent the ice contact zone of an outwash terrace.

The Solbergfjord area. A low, broad ridge of glacio-marine deposits including gravel with large boulders dams Lake Reisvatn. The ridge is most likely an end moraine, and a correlation with the Aspenes moraine and an old phase of the Stordal events seems probable. The highest-lying, raised marine terraces near Reisvatn lie below the extended Main shore line (pl. 2). On the east slope of Matfjell, south-east of Reisvatn, there is a low lateral moraine ridge. This is steeply inclined, 400 m to 250 m above sea level. A low ridge in combination with an outwash terrace across the valley floor at Fugleli is probably the corresponding end moraine. The moraine must represent a late Stordal phase. Two small moraine ridges on the valley floor in Gumpedal to the west of Fugleli most likely correspond with the Fugleli moraine.

The Sagfjord, Lavangenfjord and Gratangenfjord areas. The moraines in the Sagfjord area were described by Grønlie (1918) and by E. Løkse (1952). They both recognize an end moraine at the mouth of Sagfjord and two at the head of this fjord. All moraines were deposited in the sea. The southern part of the first mentioned moraine is a sharp ridge that dams up a lake at Rotvik. Salangen church lies on the oldest of the two moraines near the head of the fjord. This moraine is a broad ridge. The youngest moraine lying between the two lakes Øvervatn og Nervatn is small and indistinct. The moraines probably represent different Stordal phases, although the moraine at the mouth of the fjord could represent a phase between the Tromsø—Lyngen and the Stordal events.

Grønlie (1940, pl. III) suggested that a broad submarine ridge across the mouth of Lavangenfjord could be an end moraine but the origin of this ridge is uncertain. About 2 km up-valley from the head of the Lavangenfjord, there is a terraced ridge projecting into the valley from the eastern valley side. Several boulders lie on the flat top-surface, about 74 m above sea level. Small exposures in the steep river bluff showed gravelly to bouldery outwash overlying marine sands, silts and clays. The terraced ridge represents a marine end moraine or an ice-contact outwash delta. No marine terraces lie at higher altitudes than 74 m at this locality. However, the valley is narrow here, and higher-lying terraces could have been removed by stream erosion. Wide terraces about 83 m above sea level lie at the mouth of a tributary valley near Lavangen church, 4 km from the head of Lavangenfjord. They represent the highest-lying marine terraces in this fjord, and are only about 7 m below the extended Main shore line (Pl. 3).

Grønlie (1940, pl. III) and Lind (1955, p. 17) suggested that the Tromsø—Lyngen end moraine crosses the Gratangen fjord between two promontories near the mouth of the fjord. However, the two promontories are of bedrock and no clear end moraine was found. Lind and Grønlie also indicated that this moraine is problematic. Lind recognized one end moraine at Aarstein and two near Gratangsbotn at the head of Gratangen fjord. The one at Aarstein is a good gravel ridge that crosses the fjord on top of a bedrock threshold. The two end moraines near Gratangsbotn were deposited in the sea. The oldest moraine is represented by a gravel ridge at Moen on the north side of the valley, and an ice-contact terrace projecting into the valley from the south side, near Fjellhøgda. Large boulders lie at the surface of the ridge at Moen which has a crest about 80 m above sea level near the contact with the valley side. The youngest moraine is a short, low ridge which rises above the flat marine outwash terrace near Dalsletten, about 800 m up-valley from the Moen-Fjellhøgda moraine.

The highest-lying marine terraces near the moraines lie at the 82 m to 83 m altitude. Lind (1955, p. 16), too, considered these terraces to represent the highest-lying, raised, marine features at the moraines. The calculated altitude of the extended Main shore level is about 90m at the head of Gratangen fjord (Pl. 3).

The terrain 100 m—200 m inside (east of) the Moen moraine ridge slopes steeply from high-lying terraces 70 m—75 m above sea level towards the river about 25 m above sea level. Several small exposures

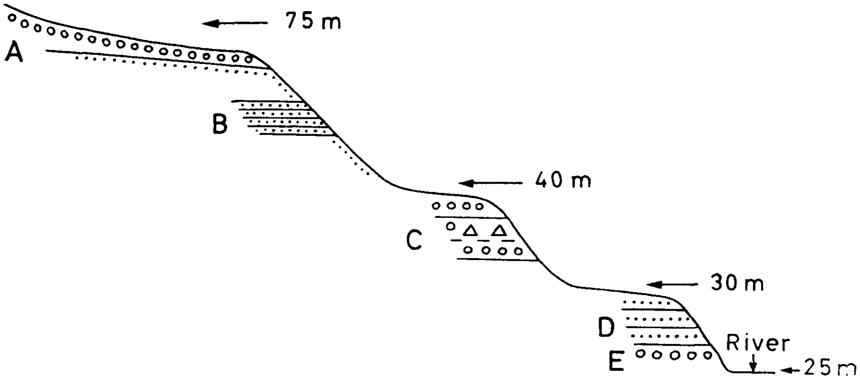


Fig. 20. Cross-section of the terraces immediately inside (east of) the moraine at Moen in Gratangen Fjord (rough sketch).

A: Sand and gravel.

B: Silt and fine-sand, stratified with scattered pebbles. Small shells of Mya truncata *and* Macoma calcarea *were collected and radiocarbon dated at 9,520 ± 190 years B.P. (T-630).*

C: Bouldery gravel, poorly sorted, in parts till-like, with many large striated erratics.

D: Stratified silt and sand, about 4 m. Pebbles and cobbles lie in some of the sand beds, particularly in one bed which is very fossiliferous. Shells of Macoma calcarea, Mya truncata, Hiatella (Saxicava) arctica, Chlamys islandicus *were collected and radiocarbon dated at 9,740 ± 160 years B.P. (T-512 B).*

E: Bouldery gravel, 1 m.

Altitudes in metres above sea level.

Tverrprofil av terrassen like innenfor (østenfor) endemorenen ved Moen i Gratangen (skisse).

A: Sand og grus.

B: Lagdelt silt og finsand med spredte stein og små skjell av *Mya truncata* og *Macoma calcarea*. Skjellene har en C-14 alder på 9 520 ± 190 år (T-630).

C: Blokkrikt, dårlig sortert grus, delvis morenelignende, med mange store isskurte blokker.

D: Omlag 4 m med lagdelt silt og sand. Stein ligger spredt i noen av sandlagene, spesielt i et fossilførende lag. *Macoma calcarea, Mya truncata, Hiatella (Saxicava) arctica* og *Chlamys islandicus* ble funnet. De ble C-14 datert til 9,740 ± 160 år før nåtid (T-512 B).

E: 1 m steinførende grus.

Høyder er angitt i meter o. h.

on this river slope gave the following information on the structure of the terraces (fig. 20; locality 14, Pl. 1). Beds of gravel and sand (A) at the top of the terraces overlie a section of silt and fine-sand (B), poorly sorted till-like sediments (C), stratified silt and sand (D), and gravel (E) at river level. The approximately 8 m thick section of poorly sorted till-like sediments (C) consists mainly of poorly sorted gravel with many large erratics. The section was probably deposited during the glacier advance to the Moen moraine. Small shells of *Macoma calcarea* (many) and of *Mya truncata* lie in silt beds within section B, and large shells of *Macoma calcarea, Mya truncata, Hiatella (Saxicava) arctica* and *Chlamys islandicus* lie in section (D). Many of the shells were unbroken and paired. They must therefore, be of the same age as the host sediment. Fresh-looking shells from both sections (B) and (D) were radiocarbon dated at respectively 9,520 ± 190 years B.P. (T-630), and 9,560 ± 170 years B.P. (T-512 A, outer fraction) and 9,740 ± 160 years B.P. (T-512 B, inner fraction). The radiocarbon dates show that the till-like section (C), and probably the Moen moraine, must be about 9,500 years to 9,600 years old.

Conclusion.

The Stordal moraines described represent at least three different phases of Pre-Boreal to early Boreal age; a young phase probably about 9,000 years B.P. to 9,300 years B.P. (Stormo—Høgmo in Balsfjord), a middle phase about 9,400 years B.P. to 9,700 years B.P. (Moen—Fjellhøgda in Gratangen), and an older phase that probably corresponds with the type Stordal moraine in Ullsfjord. Shells collected by R. W. Feyling-Hanssen from a marine terrace at Birtavarre in Lyngenfjord were radiocarbon dated at 9,880 ± 240 years B.P. (T-125, Nydal 1960, p. 86). The terrace is an ice-contact outwash delta that lies about 35 km inside the Tromsø—Lyngen moraine. The delta must correspond to a Stordal phase, probably an early one.

The Stordal outwash deltas were graded to sea levels that were slightly lower than the extended Main shore line, about 5 m lower at the head of Ullsfjord and 8 m to 10 m lower at the heads of Balsfjord and Gratangenfjord. This indicates that the Stordal outwash deltas in Ullsfjord are slightly older than the last mentioned outwash deltas. The morainic sequences near the heads of Balsfjord and Gratangenfjord also suggest that the outwash deltas described there represent later Stordal events than do the moraines in Ullsfjord.

The fauna, the climate and the glaciation limits corresponding with the Stordal events were discussed on pages 72, 133 and 130 respectively.

Areas upvalley from the Stordal moraines.

No detailed mapping was done within the areas up-valley from the Stordal moraines. But reconnaissance mapping of the main features was done, and some of these were plotted on the map of Pl. 1. The down-stream parts of the main valleys generally slope very gently. Further upstream they become steep and narrow where they lead up to a mountain plateau near the Swedish-Norwegian border. This mountain plateau has wide, open valleys. The floors of the gently sloping downstream parts of the main valleys are covered by thick outwash sheets that commonly lie on top of marine deposits. The corresponding outwash plains (valley trains) were graded to sea levels 70 m—80 m above the present near the mouths of the valleys. Narrow, high-lying, terrace remnants along the valley sides usually represent the valley trains. The thick outwash sheets suggest an immense drainage through the valleys during the melting phase that followed the Stordal events. Numerous lateral erosion terraces and channels, kame terraces and small canyons on several of the upstream valley sides are good evidence of this drainage. The features are particularly striking along the sides of Dividal valley, where extensive kame terraces lie near its head. Most of these features were not mapped, and only some of the most dominant terraces, etc., on the west side of Dividal were plotted on the map of Pl. 1.

Drainage features near the Swedish border show that large areas of northern Sweden drained northward across the present water divide to the valleys described in Troms. For instance, long esker ridges pass across the water divide from Sweden to Norway. The Norwegian part of one of the ridges was mapped on short reconnaissance trips to the wide main valleys upstream from Dividal—Bardudal. The ridge follows Lejnavann (fig. 21), and ends near the wide kame terraces at the head of Dividal. The length of the Norwegian part of it is about 25 km. Sand, gravel and well-rounded cobbles to boulders lie at the

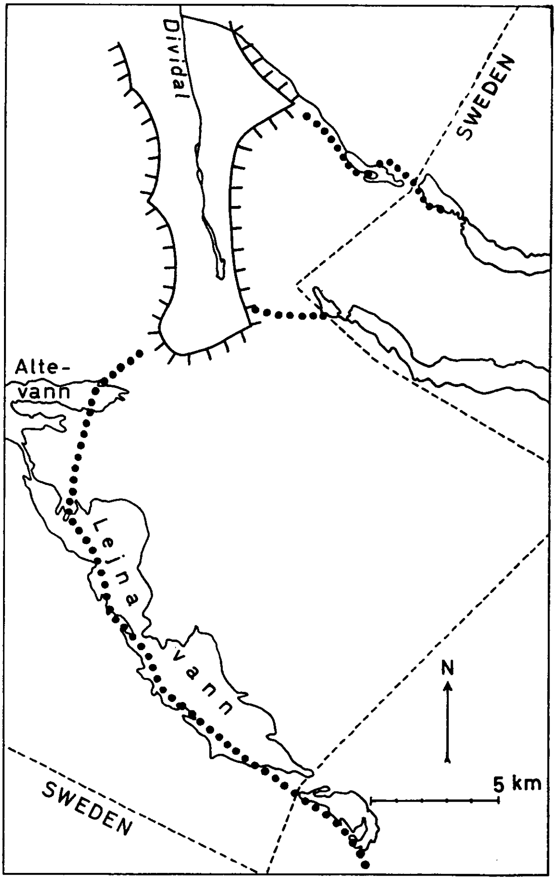


Fig. 21. Eskers on the plateau near the Norwegian-Swedish border.
Dotted lines: Esker ridges.
Dashed line: The Norwegian-Swedish border.
The line in Dividal valley indicates the approximate location of kame terraces.

Eskers på fjellplatået nær grensen mot Sverige.
Prikkede linjer: Eskers.
Stiplede linjer: Grensen mot Sverige.
Takket linje i Dividal angir den omtrentlige beliggenhet av kame-terrasser.

surface of the esker ridge, which is generally steepsided and 5 m—20 m high. Smaller eskers lie in several of the other plateau valleys, for instance, the esker system in Anjavassdal. This system falls within the limits of the map on Pl. 1, and it consists of an irregular pattern of ridges and hummocks which ends at the kame terraces near the head of Dividal.

The drainage features described indicate a rapid melting of the ice during the phases that followed the Stordal events. Ice-front features are generally indistinct upstream from the Stordal moraines, and it is uncertain whether or not they represent climatic fluctuations. Grønlie (1918) claimed to have found several end moraines within the valleys (pl. 1). Most of them were visited by the writer. Many were found to be projecting parts of kame terraces or outwash terraces and they possibly correspond with ice-front positions. Some of them are less distinctive moraine ridges. For instance, moraine ridges across the floor of Tamokdal valley are probably end moraines. Lateral erosion features and lateral moraines dip up-valley in this part of Tamokdal, and the corresponding glacier must have been a short glacier branch moving up-valley from the Dividal—Rostadal glacier. Lateral features (lateral moraines?) dipping up-valley lie at the mouth of the Svensborgdal too. The corresponding glacier dammed a lake in the upstream part of Svensborgdal. Lake terraces, slightly above the 400 m altitude are distinctive along the eastern valley side. They correspond in altitude to the water divide at the northern end of the valley.

Hummocky dead-ice terrain at Sætermoen and in a narrow part of the Bardu Valley, about 5 km south-east of Sætermoen, are probably ice-front deposits. An ice-contact outwash terrace dams Lake Rostavann, and a bouldery projecting part of a terrace at Kistefoss in Salangsdal is the ice-contact zone of an outwash terrace. However, no striking distinctive end moraines were seen in the valleys upstream from the Stordal moraines, except for the recent moraines near the existing glaciers.

Some of the numerous cirques and cirque valleys in the highest mountains near the heads of the main valleys were visited in the field and many others studied on aerial photographs. No good end moraines were seen in the cirques and cirque valleys, except for the recent moraines near the existing glaciers. This indicates that the cirques were not occupied by very active local cirque glaciers during the final deglaciation phases of the mountain districts. It indicates also that the highest mountains were covered by the ice sheet, or that the local glaciers from the mountains merged with the ice sheet, during the Stordal (Island III) events.

THE RECENT MORAINES

Small moraine ridges of recent age generally lie close to the fronts of the existing glaciers. The sparce vegetation on these moraines suggests a young age. They probably represent the well known early 18th century glacial advance. Two or three successive, closely spaced recent moraine-ridges exist near some glaciers. The youngest of these moraines could represent the 19th or the early 20th century advances, which have been recorded in other parts of Norway (O. Liestøl, in O. Holtedahl 1960, p. 487).

GLACIAL STRIATION

Glacial striation is striking on numerous valley and fjord sides. The striation shows that the main direction of glacier flow was towards the north-west along the main valleys and fjords, from the high mountains near the Swedish border towards the coast. However, the local topography strongly influenced the flow direction, at least during the latest phases of glaciation. This is indicated by striation parallel to the valleys and sounds, even when they are oriented at more or less right angles to the above mentioned main flow direction. Apparently, these valleys and sounds were occupied by glacier branches between the main glaciers. Some of the most important observed striation directions were plotted on the map (Pl. 1).

THE LOCAL GLACIATION

General discussion.

Numerous end moraines deposited by small local glaciers lie along the coast of Troms and, in particular, on the mountainous islands. Using several different methods, a correlation of these moraines was attempted. In general, by comparing the size, shape, and distribution of the moraines, together with an evaluation of the topography and the glaciation susceptibility of the valleys, it was possible to correlate the end moraines in one valley with the moraines in adjacent valleys (fig. 23). Raised shore lines and outwash deltas were helpful also in correlating the moraines. Through these methods together it was possible to identify local moraines from four different glacial main phases. They were named the Island I, II, III and IV Phases in this study. The Island II, III and IV Phases consist of several minor phases, and this is possibly the case for the Island I Phase also. However, no attempts were made at detailed subdivisions of the main Island phases.

In a few areas, the correlation of the local moraines is problematic, and question marks were added on Pl. 1 where the correlation of local moraines is most uncertain. Some of the local moraines could have been formed by more or less incidental advances of other ages than the Island I, II, III and IV events. In such cases, the suggested correlation on Pl. I is incorrect. However, in general, the correlations based on the above mentioned principles must be correct.

Strikingly, many of the large local moraines, particularly the Island II moraines, lie on the shore at the mouths of small, steep valleys. Apparently, the small, local glaciers which deposited the moraines were unable to advance into the deep water beyond the shore zone. As sediments were deposited in front of the glaciers, the water gradually became shallower and calving decreased. This decrease in calving could have caused small glacier advances on the shallowing part of the shore zone. Furthermore, it could have halted the retreat of glaciers during phases of minor climatic amelioration. Therefore, the ice fronts were more or less caught in the shore zone, and only minor fluctuations occured, unless the climatic changes were considerable. This would explain the large number of end moraines in the shore zone and their relatively large size. It explains, also, why most Island II moraines in the shore zone are single ridges, while many of the corresponding supramarine deposited end moraines consist of complexes of several smaller parallel ridges.

Moraines are missing, or unrecognizable, in some valleys which must have been glaciated during the Island Phases. However, such valleys are few in number, and they are of little importance to the following discussion.

The Island I Phase. Broad, mainly submarine ridges cross some of the small fjords on the outermost islands in Troms. The ridges, which lie only in the fjords on the outside (generally north-west side) of the islands, are probably end moraines. They are believed to be from an old glacial phase called the Island I Phase. During this phase, the areas inside the islands were most likely covered by the continental ice sheet, which probably merged with local ice sheets that covered the main parts of the islands. This conclusion is supported by the fact that some of the islands were in part covered by local ice sheets and the continental ice sheet even during the following Island II Phase. The moraines thought to be from the Island I Phase

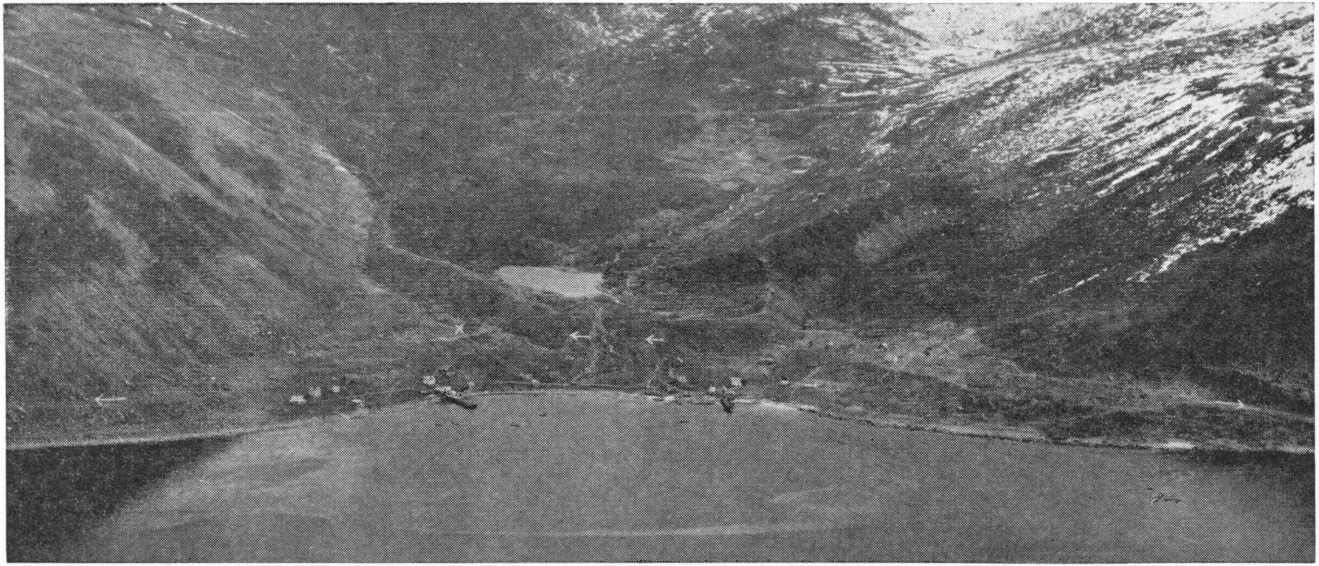


Fig. 22. Island II (Tromsø—Lyngen) end moraine at Rekvik on Kvaløy. Long arrows point at Main shore lines (terraces in bedrock); shorter arrows point at Main shore line on the distal slope of the end moraine; X shows outwash delta at Main level, deposited by a lateral stream. Tapes terraces at lower altitudes are less distinct.
Photo: Royal Norwegian Airforce.

Island II (Tromsø—Lyngen) endemorene ved Rekvik på Kvaløy. Lange piler peker på Hovedstrandlinjen som er skåret inn i fjell. Korte piler peker på en svak Hovedstrandlinje på morenen. X: Brefront-delta avsatt av lateral elv i Hovedstrandlinjens nivå. Mindre distinkte Tapes-terrasser ligger i lavere høyde.
Foto: Det Norske Flyvåpen.

could represent several glacial phases. The submarine ridges from a possible Hekkingen phase (p. 28) could correspond to the Island I moraines.

The Island II Phases. The largest and most distinct local moraines along the coast of Troms usually represent the Island II Phases (fig. 22). Generally, several closely spaced Island II end moraine ridges lie together as an end moraine complex. However, in some localities only one Island II end moraine ridge exists. The Island II moraines represent several glacial phases, during which the glacial conditions were very similar. Usually, the moraines that represent the youngest phase are the most dominant, and in some areas these moraines are the only ones present. In such areas, the youngest Island II glaciers were more extensive than the older Island II glaciers. The Island II moraines that lie immediately outside the Tromsø—Lyngen moraines represent only the youngest Island II Phase, since these areas were covered by the fjord glaciers during the earlier Island II Phases. The Island II moraines are generally so much larger and so much more prominent than all the other local moraines that they can be easily recognized. No sharply defined local moraines were seen outside the Island II moraines, apart from the few Island I moraines which are considerably less distinct. The younger moraines from the Island III Phases generally lie a considerable distance up-valley from the Island II moraines, and they are usually small.

Numerous Island II moraines were deposited in the sea, and the corresponding raised marine shore lines and terraces lie at altitudes between the Main shore line and the S_8 shore line (fig. 28). At localities where only one Island II moraine exists, the Main shore line is generally the highest that was eroded into the moraine. Outwash delta fans at these moraines were generally graded to the Main shore level or to slightly higher levels. Therefore, the youngest, most dominant Island II Phase corresponds to the Main shore line and to slightly higher-lying shore levels.

Correlation of the Island II moraines was based mainly on the above mentioned characteristics. During a later study, the altitudes of the Island II snow lines and glaciation limits were calculated to have been approximately 475 m lower than the modern snow line and glaciation limits (p. 123). This result was then used to verify the earlier correlations. A surface lying approximately 475 m (500 m) below the modern isoglacihypse surface (Pl. 2) was the isoglacihypse surface for the Island II Phase. Mountains with summits at higher altitudes than this surface were generally glaciated during the Island II Phases, and distinct Island II moraines lie on these mountains. Mountains with summits at lower altitudes were generally not glaciated during the Island II Phases, and no local moraines exist on them (fig. 23).

The size of the Island II glaciers depended mainly on the altitude and the size of the areas lying above the corresponding isoglacihypse surface. If, for instance, a mountain lay only slightly higher than this surface, then the corresponding Island II glacier was generally very small; if a large part of a mountain lay considerably higher than the surface, then the corresponding Island II glacier was generally large. Therefore, by determining a mountain's elevation above the isoglacihyps surface, the size of the Island II glaciers was roughly calculated (fig. 23).

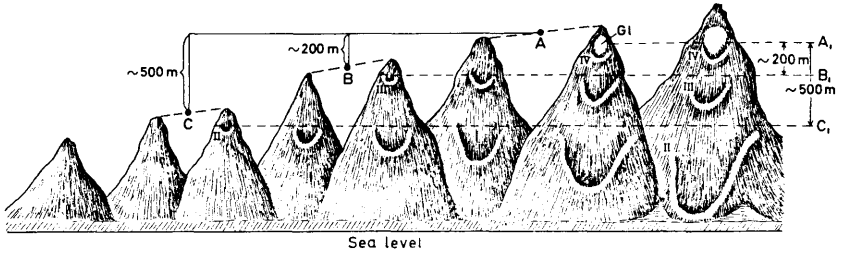


Fig. 23. Local glaciers and local moraines on an alpine island in Troms, generalized.

Gl: Glacier.

II, III and IV: Island II, III and IV moraines.

The top-method was used to calculate the altitudes of the glaciation limits for the Modern Phase (A), the Island III Phases (B), and the Island II Phases (C).

The upper ends of the lateral moraines were used to calculate the altitudes of the regional snow lines for the Island III Phases (B_1), and the Island II Phases (C_1).

A_1: The modern regional snow line.

Generalisert skisse av lokalbreer og lokalmorener på en alpin øy i Troms.

Gl: Bre.

II, III og IV: Island II, III og IV morener.

Topp-metoden ble brukt til å beregne høyden på glaciasjonsgrensene for moderne tid (A), Island III fasene (B), Island II fasene (C).

De øvre endene av sidemorenene ble brukt til å beregne høydene på de regionale snegrensene for Island III fasene (B_1) og Island II fasene (C_1).

A_1: Den regionale snegrensen i moderne tid.

Several lines of evidence show that the youngest, most dominant Island II moraines correspond with the large moraines deposited by the Tromsø—Lyngen fjord glaciers. For instance, 1) both the Tromsø—Lyngen moraines and the youngest Island II moraines correspond with the Main shore level, 2) the calculated altitudes for the Tromsø—Lyngen and the Island II firn lines are approximately the same (p. 127), and 3) the Island II moraines occur in abundance in the areas outside the Tromsø—Lyngen end moraines, but never in the areas inside these moraines. In areas where well developed Tromsø—Lyngen lateral moraines lie along the sides of the fjords, the Island II local moraines lie in many tributary valleys above and at the altitude of the lateral moraines. However, with two possible exceptions, the Island II local moraines never cross the Tromsø—Lyngen lateral moraines. Several of the youngest Island II moraines cross the Skarpnes lateral moraines and are, therefore, younger than the Skarpnes event. Shore lines corresponding to the Skarpnes event, and even higher-lying shore lines lie at some of the Island II moraines. This suggest that the oldest Island II Phases are of Skarpnes age and of still older ages.

The Island III Phases. The Island III moraines are generally small moraine ridges. When formed by large glaciers, they are commonly marked ridges, while those formed by smaller glaciers are often indistinct. The Island III moraines usually lie a considerable distance up-valley from the Island II moraines (fig. 23). As many as three successive small Island III moraines lie in some valleys. They represent three minor Island III Phases. However, one Island III moraine in each valley is most usual. The Island III regional glaciation limit lay approximately 200 m below the modern regional glaciation limit (p. 124).

When the modern isoglacihypse surface is known, then the approximate altitude of the Island III isoglacihypse surface can be calculated. Mountains lying below the Island III isoglacihypse surface generally do not have Island III moraines on them, while mountains rising above the isoglacihypse surface do. The largest Island III glaciers originated on the highest mountains (fig. 23). One of the observed Island III moraines was deposited at sea level. The altitude of the corresponding shore line is about 5 m lower than the Main shore line (p. 106).

Numerous Island III moraines lie in areas that were covered by the Tromsø—Lyngen glaciers, and Island III lateral moraines cross the lateral positions of the Tromsø—Lyngen fjord glaciers. Therefore, the Island III event is younger than the Tromsø—Lyngen event. This is indicated, also, by the low altitude of the Island III shore line. In particular, many Island III moraines lie in the highest mountains near the heads of the fjords. These mountains are located outside the areas covered by the continental ice sheet and the outlet valley glaciers of Stordal age. The highest mountains at some distance inside the heads of the fjords generally have no Island III moraines. These mountains were nunataks during the Stordal events. Since the Island III moraines occur in abundance outside the Stordal moraines, but not in areas that were covered by the Stordal continental ice sheet and outlet valley glaciers, the two glacial phases most likely correspond.

The Island IV Phases. The Island IV moraines are small ridges that lie very close to the existing glaciers (fig. 23). The moraines are fresh-looking with almost no, or very little, vegetation cover. They undoubtedly correspond with the recent moraines. Generally, one Island IV moraine lies in front of each glacier, but as many as three successive small ridges exist near some glaciers.

Locality description.

Ringvassøy. The highest mountains (900 m—1150 m) on Ringvassøy lie in the southern part of the island. Small glaciers occupy some of the cirques, and the modern regional glaciation limit was calculated at approximately 980 m above sea level (p. 114). Large, prominent end moraines lie in the shore zone at the mouths of several steep valleys on the southern slopes of the mountains. The moraines at Glimma and Ringvatn, for instance, are more than 50 m high ridges which dam up small lakes. The main parts of the end moraines were deposited in the sea, and many of them grade into steep, lateral moraine ridges. In some valleys, the moraines are complexes of several parallel and closely spaced ridges. The good correspondence in size, shape and location of the end moraines (moraine complexes) from one valley to the next shows that they must represent corresponding glacial phases. Several lines of evidence show that the moraines represent the Island II Phases.

1. The moraines are large and distinct ridges.

2. No moraines resembling the characteristic Island II moraines lie inside or outside the suggested Island II moraines. No good end moraines were seen in the areas outside these moraines, and moraines from two glacial phases lie in some of the valleys inside the moraines. The last mentioned moraines represent the Island III and Island IV Phases (see following discussion).

3. The moraines suggested as being Island II moraines lie on all mountains with summits above approximately 500 m, and they are absent on lower-lying mountains. Therefore, the corresponding regional glaciation limit was 450 m to 500 m below the modern regional glaciation limit. This is the expected difference between the Island II Phase and the modern phase.

4. The Main shore line was eroded into all of the supposed Island II moraines that lie in the shore zone. Outwash delta fans deposited by lateral streams were graded to the Main shore level or slightly higher-lying shore levels. For instance, a steep, small, outwash delta fan at the mouth of the lateral channel on the eastern side of the moraine at Storneset has a gently sloping distal part 38 m—41 m above sea level. A distinct Main shore line was eroded into the front of the moraine next to the fan, about 38 m above sea level. The delta fan must have been graded to the same level as the Main shore line, or to levels lying a maximum of 2 m to 3 m above it.

   A slightly larger outwash delta (delta fan) lies in front of an eastern segment of the large end moraine at Glimma. This delta (fan), too, was deposited by a lateral stream. Large erratics cover the delta (fan) plain which is steeply inclined next to the moraine, and has a more gently sloping distal part, 41 m —43 m above sea level. The total length of the plain is only 50 m—70 m. A distinct Main shore line eroded into bedrock next to the moraine was eroded into the front of the delta, 38.5 m above sea level. Therefore, the delta plain was graded to a sea level about 3 m to 4 m above the Main shore line. A western part of the described outwash delta was lowered by stream erosion, and a good sized delta plain was formed at a slightly lower level. This delta plain, too, was probably formed by a lateral stream. The distal, gently sloping part of the plain lies 38 m—40 m above sea level, and corresponds to the Main shore line.

All of the features described show that the large local moraines on Ringvassøy represent the Island II Phases. The high mountains on southern Ringvassøy were covered by a more or less continuous local ice field during these phases. The dashed line on the map on Pl. 1 indicates the approximate outer limit of this ice field.

Small moraines usually lie a considerable distance up-valley from the Island II moraines. They lie on mountains with summits higher than 800 m above sea level. Therefore, they were correlated with the Island III Phases.

Only small glaciers existed in the highest mountains during the Island III Phases.

Very fresh-looking, small end moraine ridges close to the existing glaciers must represent the Island IV Phases.

Rebbenesøy, Nordkvaløy, Grøtøy, Helgøy and Vanna were not visited, and all observations concerning these islands were made from aerial photographs. Large, end moraine ridges lie on each of the islands. The size, shape and location of the moraines show that they correspond in age, and are equivalent to the Island II Phases. The moraines lie on all mountains with summits at altitudes higher than 450 m—500 m, and on no lower-lying mountains. The 450 m—500 m altitude is 450 m—500 m below the modern isoglacihypse surface. This supports the conclusion that the moraines are from the Island II Phases.

A broad, submarine ridge at the mouth of Sørskardvågen on Nord-Kvaløy is probably from the Island I Phase. A submarine ridge across one of the other small fjords at Nord-Kvaløy could likewise be an Island I end moraine. Except at Vanna, no end moraines lie up-valley from the large Island II moraines. At Vanna Island, there are small moraine ridges a considerable distance up-valley from the Island II moraines. They lie only on the highest mountains, and must correspond to the Island III Phases. The three highest mountains at Vanna are glaciated today, and small moraines near the glaciers were correlated with the Island IV Phases.

Reinøy. Large end-moraine ridges on Reinøy must be from the Island II Phases. No older local moraines, and only one younger, exist there. The younger moraine is a small ridge up-valley from a large Island II moraine on Reinskardtind (884 m), the highest mountain on Reinøy.

Kvaløy. The glacial geology of Kvaløy is very similar to that of Ringvassøy. The highest mountains are glaciated, and the altitude of the modern regional glaciation limit is approximately 1000 m (p. 115). Numerous, large, local, moraine ridges exist, many of them in the shore zone. Some of the moraines consist of several parallel ridges. No prominent moraines lie outside the large moraines (moraine complexes), and up-valley there are moraines only on the highest mountains. These latter moraines are small and generally lie a considerable distance up-valley from the large moraines. The location, size and shape of the large moraines, therefore, suggest a correlation with the Island II Phase. All of the Island II moraines lie on mountains whose summits are higher than approximately 500 m, which is the calculated altitude of the Island II regional glaciation limit. The Main shore line was abraded into all of the Island II moraines lying in the shore zone. Outwash-delta plains at several Island II moraines were graded to the Main shore level or to slightly higher levels. An example is the outwash delta at the Rekvik moraine on northwestern Kvaløy (fig. 22). The delta lies in contact with a nicely curved, Island II end-moraine ridge, at the mouth of the lateral channel on the northern side of the moraine. No stream follows this channel today, and the delta must have been deposited by a lateral stream from the same glacier that formed the Rekvik moraine. The distal part of the delta plain lies 22 m—23 m above sea level, which must be the approximate altitude of the corresponding sea level. At the same altitude, there is a distinct Main shore line cut into bedrock both on the north side and on the south side of the moraine, while a weak Main shore line was abraded into its front. No higher-lying shore lines exist in the moraine. The outwash delta and the Rekvik moraine, therefore, must correspond with the Main shore line. A crude, narrow, very bouldery terrace, 40 m to 43 m above sea level, lies at the foot of a steep hill slope north of the outwash delta. The terrace is possibly marine, and corresponds in altitude approximately with the S_8 shore level (fig. 29). Grønlie (see Pl. 3) measured the Rekvik shore lines (terraces) at

23,5 m and 44 m. The high-lying shore features immediately outside the Rekvik moraine indicate that the local glacier at Rekvik was as small as the Island II glacier even in early Late-glacial time.

Features very similar to those at Rekvik exist near a large Island II moraine complex at the head of Kattfjord. A rather extensive marine terrace about 56 m above sea level lies along the fjord side immediately outside the moraine. The terrace corresponds in altitude approximately with the S_8 shore line. A wide outwash delta in front of the moraine has a steeply inclined outwash plain littered with erratics. The distal, more gently sloping parts of the plain lie 36 m—38 m above sea level. A gravel pit in the terrace front showed 2 m of flat-lying, very bouldery topset beds on top of sandy and bouldery foreset beds. A small fan-shaped outwash delta at the mouth of the lateral channel on the southwestern side of the moraine also has a gently sloping distal part, 36 m—38 m above sea level. The delta must have been graded to a sea level at about this altitude, which is slightly above the altitude of the Main shore line (Pl. 3).

Of particular interest are the Island II end moraines on the southeastern side of Kvaløy. They were deposited near the mouths of several small valleys at an altitude less than 100 m above present sea level. The moraine at the mouth of Skitnskardsdalen consists of two parallel ridges. The proximal ridge is about 10 m high and dams up a small lake, 60 m above sea level. Most of the distal moraine was destroyed by stream erosion, but a segment near the southwestern valley side is clearly ridge-shaped. There, the end moraine grades into a lateral moraine. An outwash delta outside the distal moraine has a gently sloping distal part, 45 m—48 m above sea level. A distinct shore line down-valley from the delta lies 42 m—43 m above sea level. This shore line was supposed to represent the Main shore line. However, the reconstructed Main shore line in the diagram (fig. 29) lies about 45 m above sea level for this locality. Therefore, the outwash delta plain that corresponds to the oldest moraine at Skitnskardsdal was probably graded to a sea level slightly above the Main shore level.

The lateral moraine deposited by the Skarpnes fjord glacier (p. ??) lies about 300 m above sea level near the mouth of Skitnskardsdalen.

The lateral moraine deposited by the Skarpnes fjord glacier (p. 31) Therefore, this glacier covered the areas where the Island II moraines lie. Consequently, the Island II moraines in these places must be younger than the Skarpnes event. An Island II moraine at the mouth of Finnvikdal northwest of Tromsø also lies at a lower altitude than the Skarpnes lateral moraine. This indicates that the youngest, most dominant Island II moraines are younger than the Skarpnes event, and they most likely correspond with the Tromsø—Lyngen event.

Several small moraines on the highest mountains, generally a considerable distance up-valley from the Island II moraines, were correlated with the Island III Phases. Fresh-looking end-moraine ridges close to the present glaciers represent the Island IV Phases.

Senja. The photo coverage of parts of Senja, particularly in the north and northwest, is very poor. As most of the local moraines shown on the map in Pl. 1 were plotted from aerial photographs, the map does not, in general, show moraines in areas where they do not appear on the photographs. Very few mountains on Senja have summits higher than 900 m. Breitind, the highest summit, lies only 1010 m above sea level. The modern regional glaciation limit was calculated at about 950 m above sea level for Senja (p. 115). As a consequence, very few Island III and Island IV moraines exist on this island. Broad submarine ridges near the mouths of several small fjords on the north and northwest coast are probably end moraines. They were tentatively correlated with the Island I Phase.

A large number of mountains on the west coast have summits between 500 m and 900 m above sea level. Well defined moraine ridges lie on all of the mountains with summits above 500 m—550 m that were studied on the aerial photographs or in the field. The resemblance in size, shape, and location between these moraines and the Island II moraines on the other islands is so striking that there can be little doubt about the correlation. Large mountain districts of more subdued topography in central parts of Senja lie at altitudes between 500 m and 900 m. These districts must have been glaciated during the Island II Phases, as they lie at higher altitudes than the calculated Island II regional glaciation limit. The corresponding end moraines lie at the mouths of several main valleys with heads in the central parts of Senja, and on some of the peripheric low-lying mountain plateaus. The end moraines at the mouths of the two valleys, Anderelv valley and Kaperdal valley, for instance, are nicely looped moraine ridges. A corresponding moraine ridge lies at the 300 m—400 m altitude on the plateau between the two valleys. The moraines were clearly deposited by a large local ice sheet that covered the central parts of Senja.

The approximate extent of this ice sheet is indicated on the map, Pl. 1. No other local moraines that could have been deposited by Island II glaciers lie within the area covered by this ice sheet. Immediately outside this area, there are numerous, relatively large Island II moraines. Therefore, the local ice sheet described must be of Island II age.

Small marine terraces 18 m—20 m above sea level lie in contact with good sized Island II moraines at Gryllefjord; and weak shore lines were abraded into the moraines at this altitude. No good outwash deltas exist, but the above mentioned shore features probably correspond with the moraines. A distinct shore line along the north side of Gryllefjord appears to lie at the same altitude, which is the approximate altitude of the Main shore line. Grønlie (Pl. 3) measured shore features about 23 m above sea level at Gryllefjord, and the writer, too, observed weak marine terraces with sorted gravel and sand at this altitude. The terraces lie close to the moraines.

Blyfjord in south-western Senja faces the open sea, and shore lines (terraces) were abraded into the hill slopes below the 56 m altitude. The highest-lying shore line, about 56 m above sea level, appears to continue into the distal part of an Island II end-moraine complex. Therefore, the oldest part of the Island II moraine at Blyfjord probably corresponds with the 56 m shore line, which lies approximately at the altitude of the S_8 shore line (fig. 29).

Andørja and Rolla. The highest summits on Andørja lie between 1100 m and 1300 m above sea level. Several mountains are glaciated, and the modern regional glaciation limit was calculated at about 1150 m above sea level (p. 116). Numerous relatively large moraine ridges, that were correlated with the Island II Phases, lie on mountains with summits higher than 700 m. However, Island II moraines are absent in the steep valleys on the eastern side of the island. There, the Island II local glaciers joined the Tromsø—Lyngen fjord glacier. A Tromsø—Lyngen lateral moraine across the mouth of these valleys is typical of the pattern described in section D-2 on page 105. Small moraines that were correlated with the Island III and Island IV Phases lie on the highest mountains.

The peninsula between Ullsfjord and Balsfjord. Most of the moraines on the peninsula between Ullsfjord and Balsfjord were mapped by Holmes and Andersen (1964), and the moraines in Pl. 1 were plotted, in general, from their field maps. A detailed correlation of the moraines is very difficult in parts of this area, and some of the correlations suggested in Pl. 1 could be wrong.

The mountains in the northern part of the peninsula between Ullsfjord and Balsfjord are relatively low, with the highest summits between 1100 m and 1150 m above sea level. The modern regional glaciation limit lies at approximately 1100 m altitude (p. 116). A few small, local moraines on the highest mountains display all of the characteristics of Island III or IV moraines. Well developed end moraine ridges on all mountains with summits above 600 m were correlated with the Island II Phases. Big, tongue-shaped rock piles along the east side of Oldervikdal are probably remnants of rock glaciers formed during the Island II Phases. An Island II moraine at the mouth of a steep valley on the north side of Ullstind lies in the shore zone. A weak Main shore line was abraded into this moraine. A broad, more indistinct moraine damming Lake Trollvann is probably older than the Island II Phases.

The mountains in the southern part of the peninsula between Ullsfjord and Balsfjord are high. Local glaciers cover the highest mountains, whose summits lie between 1100 m and 1400 m above sea level. The recent regional glaciation limit was calculated at about 1200 m above sea level (p. 116). Tromsø—Lyngen fjord glaciers covered the lower parts of the fjord sides. Therefore, the Island II local moraines were deposited more or less in contact with the fjord glaciers. This phenomenon is typical of all of the areas to be described in the following sections, and in each it assumed one of the following patterns.

Pattern A:	The Island II end moraines were deposited up-valley from the Tromsø—Lyngen lateral moraines. This is usual in areas where the Tromsø—Lyngen lateral moraines cross the valleys at low altitudes, e.g. areas close to the Tromsø—Lyngen end moraines.
Pattern B:	The Island II end moraines were deposited in contact with the Tromsø—Lyngen lateral moraines. Both moraines are generally well developed ridges that lie in contact with each other.
Pattern C:	The Island II end moraines were deposited in very close contact with the Tromsø—Lyngen lateral moraines. The two moraines form a combined moraine complex

where elements of both moraines are mixed and often difficult to distinguish. These moraines are generally large.

Pattern D: The Island II glaciers joined the Tromsø—Lyngen main glaciers.

1. No Island II end moraines exist, and no Tromsø—Lyngen lateral moraines lie across the tributary valleys that the Island II glaciers occupied. This is usual in valleys where the glaciers joined at altitudes higher than the Tromsø—Lyngen firn line.
2. No Island II end moraines exist, but laterally accumulated Tromsø—Lyngen moraines cross the mouths of the tributary valleys. This situation is rather common in valleys that were occupied by small Island II glaciers which joined the fjord glaciers at altitudes below the Tromsø—Lyngen firn line. Apparently, the erosive power of the tributary glaciers was too small to remove the material accumulated along the side of the large trunk glaciers. The accumulation could have taken place mainly during a late part of the Island II—Tromsø—Lyngen event, when some of the tributary glaciers became less active, while the trunk glaciers remained very active. The Tromsø—Lyngen "lateral" moraines are usually indistinct and small, although a few of them are surprisingly large and well developed.

Pattern E: In two localities the local moraines, originally correlated with the Island II Phases, lie slightly below the Tromsø—Lyngen lateral moraines. In these cases, the local glaciers overrode the Tromsø—Lyngen lateral moraines. Both of the local moraines are small and lie on steep mountain slopes. Therefore, they could represent incidental advances slightly younger than the Island II event.

All of the described patterns exist on the peninsula between Ullsfjord and Balsfjord. In the southern-most and eastern parts, where the heads of the tributary valleys lie in 1200 m to 1400 m high mountains, Pattern D-1 is most common. No end moraines that could be correlated with the Island II Phases exist. Pattern A is most common in areas lying further to the north near the Breidvikeid. There, numerous moraine ridges correlated with the Island II Phases lie in the small valleys. A good example of Pattern B was seen in the valley north of Durmålstind, where a part of a sharp Island II end moraine ridge is curved up-valley at the contact with the Tromsø—Lyngen lateral moraine. Pattern E was found in the valley on the north slope of Tverrbotnfjell.

Small, fresh-looking, Island IV moraine ridges lie close to the fronts of the existing glaciers on the Ullsfjord—Balsfjord peninsula. However, some lie as much as several hundred metres from the glaciers, which indicates that the glacier fronts fluctuated considerably in recent time. This must be a result of the special topography there. The glaciers occupy parts of plateaus, and small changes in the altitude of the firn lines caused considerable changes in the accumulation areas. This, in turn, resulted in considerable fluctuations of the glacier fronts.

Small moraine ridges, generally a short distance down-valley from the Island IV moraines, are all well covered with vegetation. The size and location of these moraines suggest a correlation with the Island III Phases. In some of the valleys, there are two or three successive and closely spaced, small Island III ridges, suggesting two or three minor Island III Phases. These phases probably represent very small climatic fluctuations since the topographic conditions made the glaciers very sensitive to climatic changes.

Of particular interest is the moraine at the mouth of Stordal valley. There, a distinctive lateral moraine grades into an end moraine which was deposited in the shore zone. The lateral moraine is a double ridge. Holmes and Andersen (1964, p. 162) described the Stordal moraine in the following manner; "Here is a small but distinct end moraine, at an elevation of about 70 metres, well below the projected level of the Skardmunken glacier and at about the same level as the oldest raised shoreline in the inner part of the fiord. Similar moraines occur behind terrace-dated Skardmunken moraines in the northeastern corner of the mapped area. The outwash delta from the type Stordal moraine, graded to the oldest elevated marine terrace in the inner part of the fiord is only about 5 m below the 'main beach level'.

Thus this advance occurred shortly after the Skardmunken glaciation and is possibly Pre-Boreal in age." The first end moraine up-valley from the Stordal moraine is a small fresh-looking moraine ridge, 200 m—300 m from the glacier. This moraine must be from the Island IV Phase. The location of the Stordal moraine, therefore, suggests a correlation with the Island III Phase, a conclusion which is supported by the evidence presented by Holmes and Andersen. The Island III glacier in Stordal was large, undoubtedly due to the large accumulation area on the high-lying plateau, up-valley from Stordal.

The peninsula between Balsfjord and Malangenfjord. The Tromsø—Lyngen fjord glaciers covered considerable parts of the peninsula between Balsfjord and Malangenfjord. Therefore, no Island II moraines lie in the high mountains on the southern parts of this peninsula, and only a few distinctive and large moraines that could be correlated with the Island II Phases lie in the northern parts. These moraines lie up-valley from the Tromsø—Lyngen lateral moraines, or in contact with them. Some of them are located in valleys outside the Tromsø—Lyngen end moraines. Two Island II moraines at the mouth of the valley west of Bentsjordtind lie in an area that was covered by the Skarpnes fjord glacier, and they are, therefore, younger than the Skarpnes event. A few small moraines in the valleys on the highest mountains probably represent the Island III and Island IV events.

The peninsulas west (southwest) of Malangenfjord — The highest mountains on the peninsula between Malangenfjord and Rossfjordvann were nunataks during the Tromsø—Lyngen event. Consequently, no Island II end moraines exist there. A few small lateral moraines that stop at the Tromsø—Lyngen lateral moraine probably represent the Island II Phases. Small end moraines on the highest mountains were correlated with the Island III or Island IV Phases. Two valleys on the north an west slopes of the highest mountain between Rossfjordvann and Gisund were not covered by the Tromsø—Lyngen fjord glacier. Large and sharp moraine ridges lie in these valleys. The oldest moraine in the valley, on the north slope, lies in contact with the Tromsø—Lyngen lateral moraine and must be an Island II moraine. As many as three small moraine ridges, which are probably Island III moraines, lie up-valley from this moraine.

The peninsula between Solbergfjord and Sagfjord. Several mountains at high altitudes on the peninsula between Solbergfjord and Sagfjord must have been glaciated during the Island II Phases. Two of the mountains in the western part of the peninsula are located outside the area covered by the Tromsø–Lyngen ice sheet. Unfortunately, the photo coverage of the two mountains is very poor, and little attention was given to the local moraines when the field study was done there. Therefore, no Island II moraines were identified. The photo coverage of some of the high mountains in the eastern part of the peninsula is better. Although there are definitely no local moraines on these mountains that can be correlated with the Island II Phase, small moraines that must be from either the Island III or Island IV Phases lie near some of the highest peaks.

The peninsulas between the fjords Salangen, Lavangen, Gratangen, and Grovfjord. The photo coverage of the Salangen–Lavangen peninsula is generally poor, but a few of the main valleys extending into the highest glaciated mountains have a good photo coverage. Several moraine ridges that must be Island IV moraines lie close to the existing glaciers. Less distinctive moraines at some distance from the glaciers were correlated with the Island III Phases. Only two moraines in a valley on the south side of the peninsula resemble the Island II moraines. Both lie immediately above the Tromsø–Lyngen lateral moraine. The lack of Island II moraines in the valleys examined on the north side of the peninsula suggests that the Island II glaciers joined the fjord glacier there. This would explain why the fjord glacier deposited no marked lateral moraine along this side of the peninsula.

The photo coverage of the peninsulas southwest of the Lavangen Fjord is good, and many of the moraines appearing on the photos were also studied in the field. Conditions at the Lavangen–Gratangen peninsula are very similar to those at the Gratangen–Grovfjord peninsula. The highest mountains on both peninsulas are glaciated, and several small moraines (Island IV) lie close to the glaciers. A few small moraines deposited by short glaciers at high altitudes were correlated with the Island III Phases. No evidence of Island II end moraines was found in the high mountains on the southeasternmost parts of the peninsulas. This shows that these mountains were nunataks or covered by the ice sheet during the Island II Phases. A few moraine ridges deposited by small local glaciers on the low-lying mountains in the northwesternmost parts of the peninsulas were correlated with the Island II Phases. All of these moraines lie at a higher altitude than the Tromsø—Lyngen lateral moraines deposited by the fjord glaciers. The southeastern sections of the long Tromsø—Lyngen lateral moraines were strongly influenced by the close contacts and junctions between the fjord glaciers and the local glaciers (cirque glaciers). Ridges clearly deposited by the cirque glaciers lie within the lateral moraines, which usually have very irregular patterns of hummocks and small ridges. This pattern is particularly striking where the lateral moraines cross the mouths of the small cirques. The lateral moraines are, therefore, good examples of Patterns C and D-2 (p. 105).

Mountains at the 1200 m—1300 m altitude on the southwest side of Grovfjord are glaciated today. Many distinctive Island IV moraines lie close to the existing glaciers, while relatively small moraines, a short distance down-valley from the Island IV moraines, probably represent the Island III Phases. A few good-sized moraine ridges deposited by cirque glaciers in the northern part of the area most likely represent the Island II Phases. One of them lies on a relatively low-lying mountain (1031 m) and stops at the Tromsø—Lyngen lateral moraine in Rensaa valley. The latter moraine crosses the mouth of Pungdalen valley, where it is a very broad ridge with an irregular pattern of hummocks and small ridges. This moraine must have been deposited at the contact between the main glacier in Rensaa valley and the local glacier in Pungdalen valley. Pungdalen heads into very high glaciated mountains, but it contains no local moraines that could be correlated with the Island II Phases. Therefore, the Island II glacier most likely filled the valley, and the moraine just described at the mouth of the valley was deposited by the Island II glacier and the Tromsø—Lyngen glacier. No Island II moraines exist in the high mountains in the southeastern part of this area.

SNOW LINES AND GLACIATION LIMITS

Several different kinds of snow lines and glaciation limits have been defined in geological literature, but, unfortunately, the definitions used by various scientists do not always agree. Since snow line and glaciation limit studies were used for relatively accurate calculations in the present study, the terms used had to be defined more precisely.

The snow lines.

Most scientists agree on the definition of the "temporary snow line" as the lower limit of the continuous winter snow cover at any given time (Ahlmann 1948, p. 41). The altitude of the temporary snow line varies considerably from winter to summer, and generally, the temporary snow line reaches its highest altitude in the early fall. This highest position of the temporary snow line during a year has frequently been called "the snowline" (Charlesworth 1957, p. 8). The altitude of "the snowline" varies from one locality to the next, and it is usually considerably higher on the north slopes than on the south slopes of mountains in northern latitudes. The term "local snow line" will be used rather than "the snowline" in the present paper. The local snow line is defined as the highest position of the temporary snow line at any given point during the year. Since the altitude of the local snow line varies from one year to the next, information about the local snow line must refer to a definite year, or to a period of several years with constant glacial conditions. On the glacier, the local snow line coincides with the firn line.

The "climatic snow line" has been given many different definitions, and it was frequently used synonymously with the term "regional snow line" (Charlesworth 1957, p. 11). In this paper only the term "regional snow line" is used, and it is defined as the median altitude of the local snow lines (firn lines) on glaciers of different exposures (facing in different directions, except to the south) within an area. Generally, the regional snow line was calculated as the median altitude of the firn lines on north-, east- and west-facing glaciers, or as the median altitude of the firn lines on glaciers in open positions. Approximately the same method was used by other scientists (Charlesworth 1957, p. 11).

The glaciation limits.

According to Enquist (1916, p. 11), the glaciation limit represents the lowest altitude at which glaciers can originate. The summits of the glaciated mountains lie at higher altitudes than this limit, and the summits of the unglaciated mountains lie at lower altitudes (fig. 23). The altitude of the glaciation limit often varies considerably from one mountain to the next, depending upon local topographic and local climatic factors. In the present paper, the glaciation limit for each mountain is called the "local glaciation limit," and the median altitude of the local glaciation limits within an area is called the "regional glaciation limit." In general, the latter corresponds best with the calculated glaciation limits presented in the literature.

Only rough estimates were made of the altitudes of the local glaciation limits, and they were made only on mountains that have glaciers or perennial snow fields. The summits of mountains that have very small glaciers or large perennial snow fields generally lie close to the altitude of the local glaciation limit. Therefore, the altitude of the local glaciation limit can be roughly estimated by studying the size of the glaciers and of the perennial snow fields in relation to the altitudes of the mountain summits. Although the calculations made in this manner are not very accurate, they were of help in the present study.

The altitudes of the local glaciation limits depend upon both climatic and topographic factors. The importance of the topographic factors in particular is briefly discussed below. Generally, the altitudes of the local glaciation limits vary little from one mountain to the next, and they usually lie at approximately the same altitude as the regional glaciation limit. However, on some of the mountains under consideration here, the local glaciation limits lie at exceptionally high or low altitudes, as much as 100 m to 150 m higher or lower than the calculated regional glaciation limits. Such variations are caused mainly by the varying shapes of the mountains, in addition to local climatic factors. Since most of the glaciers and snow fields in Troms lie on the north-facing or northeast-facing slopes, the shapes of these slopes are of particular interest. Altogether six different types of mountains were distinguished for the presented study (fig. 24):

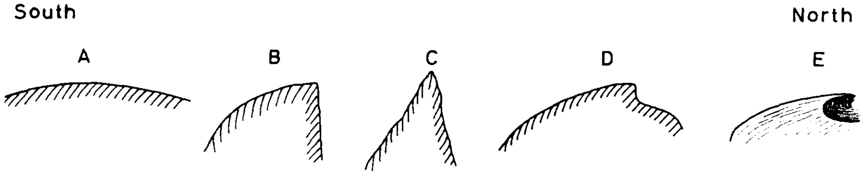


Fig. 24. North—south cross-sections through different types of mountain peaks discussed in the text.

Nord—Syd profil gjennom forskjellige fjelltyper som blir diskutert i teksten.

A. Mountains with very gentle north- and northeast-facing slopes often have high-lying local glaciation limits. The reason is probably that the insolation on such slopes is high compaired to the insolation on steeper north- and northeast-facing slopes. In addition, snow accumulation caused by wind eddies could be less significant on the gentle slopes.

B. Mountains with steep (vertical) and very high north- and northeast-facing slopes. The local glaciation limit is frequently very high-lying on these mountains. Most of the snow accumulates at the foot of the high, steep slopes at an altitude too low for glaciers to generate.

C. Pyramid- or needle-shaped mountains with high, steep north- and northeast-facing slopes. All of the exceptionally high-lying local glaciation limits were found on this type of mountains.

D. Mountains where only the highest-lying parts of the north- and northeast-facing slopes are steep. The snow that accumulates at the foot of the steep slopes is well protected against insolation and lies at high altitudes. In addition, the wind eddies on the steep slopes could cause a considerable snow accumulation. Therefore, the local glaciation limits generally lie at low altitudes on these mountains.

E. Mountains with deeply incised cirques and high-lying cirque floors on the north- and northeast-facing slopes. All of the lowest-lying, local glaciation limits were found on mountains of this type.

F. Other mountain types. The local glaciation limits on all mountains that fall outside types A—E generally lie close to the altitude of the regional glaciation limit.

Each of the mountain types described is referred to in the following discussion.

Regional glaciation limits.

The regional glaciation limit within an area was calculated as the median altitude of the local glaciation limits (herein referred to as the "median altitude method"), or it was calculated by means of the "summit method." The summit method was described by Partsch (1882), and has since been used by many scientists. Figure 23 illustrates the method. The lowest-lying glaciated mountain and the highest-lying unglaciated mountain are selected within a relatively small area. At a point midway between the summits of the two mountains, the regional glaciation limit has an altitude equal to the median altitude of the two summits. The regional glaciation limits calculated by means of the summit method generally lie at approximately the same altitudes as the median altitude of the local glaciation limits. Values calculated by means of the two methods usually differ less than 20 m, and 60 m is the highest difference found. The altitude of the regional glaciation limit depends mainly on regional climatic factors; the influence of local topographic factors is generally small. However, topographic factors can influence the calculations of the regional glaciation limits considerably, if the methods are not used with care (Ahlman 1948, p. 41). For instance, if the summit method is used, and the lowest-lying glaciated mountain and the highest-lying unglaciated mountain within the area are both of type C or of type E, then the values obtained can be exceptionally high or low, respectively. However, this situation was avoided in Troms by adjusting the size of the areas, so that each area in which the summit method was used contained several types of mountains with summits lying close to the altitude of the regional glaciation limit.

The regional glaciation limits, shown in Pl. 2, were calculated by means of the summit method. But calculations were made using the median altitude method also. If the values found by two methods differed more than 10 m, then the difference appears behind the summit-method value in Pl. 2. The difference can be considered a correction figure for the summit-method value. However, the generally good correspondence between the values calculated by the two methods, in addition to the excellent correspondence between the values in the different areas, is a good indication of the quality of the calculations.

Good topographic maps and, preferably, good aerial photographs are also essential for accurate glaciation limit determinations. Although most of the available topographic maps from Troms are good, many of them were constructed about 30 years ago when the glacial conditions were different from today. For instance, many of the glaciers shown on the maps no longer exist. Therefore, aerial photographs were used to correct the maps, and calculations were made only in areas where good aerial photographs are available. The photographs were taken between 1945 and 1960, and the term "modern" as used in the text refers to this period of time.

Modern glaciation limits.

Locality description. *Ringvassøy.* Two areas on Ringvassøy are well suited for calculations of the modern glaciation limits, one near Bjørnskardtind and the other near Nordfjell. Several 800 m to 1050 m high summits lie in the Bjørnskardtind area. A fair-sized glacier covers the northern slopes of the highest peak (1151 m), and a very small glacier lies in a cirque on the northeastern slopes of another peak (995 m). No glaciers exist on mountains with lower summits. The highest of these summits is 954 m above sea level. A medium sized perennial snow field lies on the mountain slope below that summit. The regional glaciation limit was calculated at approximately 970 m above sea level by means of the summit method. Two very small glaciers lie on the northeastern slopes of Nordfjell (988 m), while unglaciated mountains with summits as high as 954 m and 942 m lie close to it. A large perennial snow field exists on the slopes below the 954 m high summit. The altitude calculated by means of the summit method is approximately 970 m in this area also. The median altitude of the calculated local glaciation limits is 970 m to 980 m in both the Bjørnskardtind area and the Nordfjell area.

Vanna. Very small cirque glaciers lie on the northeastern slopes of Vanntind (1033 m), Vannkista (about 950 m) and Peppartind (898 m) on the southern part of Vannøy. The glacier at Peppartind is questionable, and could be the small remnant of a glacier. The highest summits of unglaciated mountains lie 891 m and 882 m above sea level. No perennial snow fields exist near these summits, which probably lie considerably below the local glaciation limit. Depending upon whether Peppartind or Vannkista was considered the lowest-lying glaciated mountain, the regional glaciation limits were calculated at respectively 895 m and 920 m above sea level. The latter result corresponds best with the median altitude of the local glaciation limits, this altitude having been calculated at approximately 920 m—940 m above sea level.

Kvaløy. The regional glaciation limit was calculated in three areas on Kvaløy; near Blåmannen, near Hollendaren, and in an area south of Ersfjord. Blåmannen (1044 m), the highest mountain on Kvaløy, is not glaciated. The unusually high local glaciation limit on this mountain is the result of its shape, that of a C-type mountain (p. 112). A small glacier covers the slope of a 1018 m high mountain near Blåmannen. Using the summit method, the regional glaciation limit was calculated at 1030 m above sea level. Hollendaren (1029) is glaciated, but the surrounding mountains with summits as high as 981 m above sea level are not, although several large snow fields lie on the highest. There, the regional glaciation limit was calculated at 1005 m above sea level. Several mountains with summits as high as 1000 m to 1043 m above sea level exist on the peninsula south of Ersfjord. However, the aerial photos of the peninsula are not good, and it is impossible to distinguish clearly between glaciers and snow fields. Glaciers seem to cover the slopes of the highest peaks, and snow fields the slopes of the lowest. Therefore, the regional glaciation limit was estimated at approximately 1010 m above sea level. The median altitude of the local glaciation limits was calculated at 1000 m to 1010 m on Kvaløy.

Senja. A very small glacier or remnant of a glacier exists in a cirque on the north-east side of a summit, 844 m high at Svanfjell on Senja. The glacier lies in an exceedingly well protected location on a type E mountain (p. 112). Therefore, the local glaciation limit on this mountain lies at an exceptionally low altitude. Other mountains with summits between 900 m and 1010 m above sea level are not glaciated. Large snow fields exist on several of these mountains. Breitind (1010 m), the highest mountain on Senja, is not glaciated, but it is a typical type C mountain, a fact which explains the high altitude of the local glaciation limit. Based on the altitudes of Breitind and Svanfjell, the regional glaciation limit was calculated at 930 m above sea level. The median altitude of the local glaciation limits on Senja was calculated at 940 m to 950 m.

Andørja. Several mountains on Andørja Island to the south of Senja are glaciated. Relatively large glaciers cover the slopes of mountains with summits at altitudes higher than 1200 m, and two very small glaciers lie on the slope north of a summit, 1193 m high. Lower-lying peaks, the highest of which is 1180 m above sea level, are not glaciated. The regional glaciation limit was calculated at 1185 m above sea level.

The peninsula between Ullsfjord and Balsfjord. Many small glaciers exist on the peninsula between Ullsfjord and Balsfjord. Using the summit method, the regional glaciation limit was calculated at several different localities (Pl. 2). A list of the results, together with names of the peaks used for the calculations, appears below.

1080 m,	the glaciated Ullstind (1067 m) and the unglaciated Stortuva (1090 m).
1130 m,	the glaciated Finnheimfjell (1148 m) and the unglaciated Nonstind (1111 m).
1225 m,	the unglaciated Tepphaugdaltind (1241 m) and glaciated mountains (1215 m) east of Tepphaugdaltind.
1205 m,	the unglaciated Durmålstind (1265 m) and a glaciated mountain (1156 m) southeast of Durmålstind.

The calculated median altitudes of the local glaciation limits within the different areas correspond well with the listed altitudes for the regional glaciation limits.

Calculations of regional glaciation limits in areas south of the Ullsfjord—Balsfjord peninsula gave the following results (Pl. 2):

1220 m,	the glaciated Henriktind (1219) and an unglaciated mountain (1224 m) northeast of Henriktind.
1440 m,	the glaciated Markenestind (1330 m) and the unglaciated Russetind (1527 m).

Russetind is a classic type C mountain, which explains the extremely high local glaciation limit. The median altitude of the local glaciation limits in the Russetind area was calculated at 1380 m to 1400 m above sea level.

Areas west (southwest) of Balsfjord. Very few glaciers exist in the areas west (southwest) of Balsfjord, and only a few regional glaciation limits were calculated. Following is a list of the results.

The peninsula between Balsfjord and Malangenfjord. 1130 m (the glaciated Bentsjordtind, 1169 m; and unglaciated mountains, 1100 m, close to Bentsjordtind).

The peninsula west of Malangenfjord. 1120 m (a glaciated mountain, 1203 m; and an unglaciated mountain, 1037 m). However, the median altitude of the local glaciation limits was calculated at 1170 m—1180 m on this peninsula.

South of Malangsfjord. 1350 m (the glaciated Blaatind, 1380 m; and the unglaciated Maarfjell, 1328 m).

South of Solbergfjord. 1250 m (the glaciated Snefjell, 1121 m; and the unglaciated Hjerttind, 1381 m). Snefjell and Hjerttind are classic type E and C mountains respectively.

Between Sagfjord and Lavlangenfjord. 1240 m (a glaciated mountain, 1241 m; and an unglaciated mountain, 1236 m).

South of Gratangenfjord. 1255 m (the glaciated Dudalstind, 1270 m; and an unglaciated mountain, 1243 m).

South of Grovfjord. 1220 m (the glaciated Sletfjell, 1167 m; and an unglaciated mountain, 1280 m, northeast of Sletfjell.

Several large snow fields and small glaciers exist in the latter two areas, and the median altitudes of the calculated local glaciation limits correspond well with the values obtained by means of the summit method.

Isoglacihypses. The isoglacihypses for the modern regional glaciation limits were constructed based on the above mentioned calculations (Pl. 2). The isoglacihypses were drawn as smooth lines. All of the calculated regional glaciation limits lie less than 60 m higher or lower than the isoglacihypse surface, and most of them lie less than 20 m higher or lower. Moreover, most of the calculated local glaciation limits lie at altitudes close to the isoglacihypse surface, and only two of them lie more than 100 m higher or lower. Therefore, the isoglacihypse surface must give a relatively accurate indication of the glacial conditions in Troms.

G. Østrem (1964, p. 334), in a study that covered most of Norway, used the summit method to calculate glaciation limits in Troms. He constructed isoglacihypses that are plotted on the map in Pl. 2. It can be seen from this map, that there are only small differences between Østrem's results and those of the present study within the northeastern part of the area studied. However, Østrem's isoglacihypse surface lies 100 m to 200 m below the one constructed by the writer within the southwestern part. Østrem's results within that part correspond well with the results obtained from calculations based on the glaciers which appear on the topographic maps. Since the photo coverage of the southwestern part of Troms is very incomplete, Østrem probably relied mainly on the available topographic maps in calculating the glaciation limits there. Enquist (1916, p. 13) presented a map of the isoglacihypses in northern Sweden. This map also included a small part of southwestern Troms. The isoglacihypses in the latter area were plotted in Pl. 2. They correspond well with those constructed by the writer.

Modern firn lines and regional snow lines.

Attempts were made to calculate the altitudes of the firn lines on the existing glaciers in Troms. As no observations of the firn lines were made in the field, all calculations were based on aerial photographs and topographic maps. Two different methods were attempted.

1. The firn lines usually show up as zones (belts) across the glaciers on photographs taken at the correct time in the fall. However, most of the available photographs were taken too early in the season, at times when the temporary snow line had not reached its highest position. In addition, most of the available topographic maps are not good enough for accurate measurements of the firn lines. Therefore, this method was used only in a few areas.

2. O. Liestøl (1963, p. 138) calculated a standard graph for the altitudinal variation in ablation on glaciers in a part of western

> Norway. He used this graph in combination with graphs of the aerial-height distribution of the glacier surfaces, to calculate the altitude of firn lines in western Norway. Unfortunately, no standard graph was calculated for Troms. However, attempts were made to calculate the altitude of the firn lines at several glaciers in Troms, based on Liestøl's graph for western Norway, and the results seem to be acceptable. Unfortunately, the maps of the glaciers in Troms are generally too inaccurate to make good graphs of the aerial-height distribution of the glacier surfaces. Consequently, most of the calculations made by this method were relatively inaccurate.

The altitudes of the firn lines depend on the climate and to some extent on topography. Glaciers on the north slopes of the mountains have lower firn lines than glaciers on the south slopes. The measured differences in altitude of the firn lines are as much as 350 m between some of the north- and south-facing glaciers east of Ullsfjord, and 200 m between some of the west- and northeast-facing glaciers. Therefore, the exposure of the glaciers must be considered when the altitudes of the firn lines are used to calculate the altitudes of the regional snow lines.

The best available maps and photographs are of the districts near Ullsfjord, where relatively accurate calculations were made in several areas. On the southern part of the peninsula between Ullsfjord and Balsfjord, the measured altitudes of the firn lines (local snow lines) generally vary between 850 m and 950 m above sea level on glaciers that lie on north-, west- and east-facing slopes. Altitudes calculated by means of Liestøl's method are approximately the same. For this area, the modern regional snow line lies about 900 m above sea level, which is as much as 300 m below the regional glaciation limit. Similar calculations were made in several areas on the east side of Ullsfjord (fig. 21). There, the modern regional snow lines lies between 250 m and 350 m below the regional glaciation limit. The firn lines on two glaciers at Ringvassøy lie between 750 m and 850 m above sea level, and the regional snow line approximately 830 m above sea level, which is only 150 m below the regional glaciation limit.

Less accurate calculations determined for glaciers in other parts of Troms gave the following results, Table 5:

Table 5:

	The altitude of the modern regional snow line	The difference in altitude between the modern regional snow line and the modern regional glaciation limit
Kvaløy	~ 850 m	~ 150 m
West of Malangenfjord	~ 900 m	~ 250 m
South of Gratangenfjord	~ 1000 m	~ 250 m
South of Grovfjord	~ 1000 m	~ 200 m
Andørja	~ 950 m	~ 200 m

The calculations listed, together with the calculations from Ullsfjord and Ringvassøy clearly show that the differences in altitude between the regional snow lines and the regional glaciation limits decrease with decreasing distance from the coast, and they also decrease from northeast towards southwest. The climate, too, changes in these directions. According to Wallén (1960, map 5), the annual precipitation increases from about 700 mm near the head of Ullsfjord to more than 1000 mm at Ringvassøy outside the mouth of Ullsfjord. A similar increase in precipitation occurs from Ullsfjord to Grovfjord in south-western Troms. This indicates that changes towards more maritime climate result in changes towards smaller differences in altitude between the regional snow lines and the regional glaciation limits. This is in good agreement with observations made in western Norway. There, Østrem and Liestøl (1964, p. 327) found that the glaciation limits lie 50 m and 150 m above the firn lines at, respectively, the outermost coast and at some distance from the coast. The precipitation in western Norway is considerably higher than in Troms, which explains why the differences in altitude between the regional snow lines and the regional glaciation limits are smaller in the former than in the latter area.

Regional glaciation limits during the Island II, III and IV Phases.

Numerous small moraines deposited by local glaciers during the four Island Phases of glaciation show which mountains were glaciated during each phase. Therefore, the glaciation limits corresponding to the Island Phases were calculated by studying the glacial conditions recorded by the moraines. In fact, the coast of Troms is ideal for this kind of study. The glaciation limits of the Island II Phases, for example, can usually be calculated with about the same accuracy as the modern glaciation limits.

Only areas located outside the continental ice sheet and outside the small local ice sheets on the islands were used for these calculations. In these areas, each local moraine was deposited by a local glacier that generally originated on one particular mountain. The moraine shows, therefore, that the mountain was glaciated; and the location of the moraine indicates the approximate size of the corresponding glacier. Unfortunately, the lack of local moraines on a mountain does not necessarily mean that it was not glaciated during the Island Phases. However, field observations indicate that most Island II local glaciers deposited distinctive end moraines. Apparently, the Island II glaciers were very active and existed for a long period. Therefore, the lack of Island II moraines on a mountain generally indicates that it was unglaciated during the Island II Phases. In each of the areas studied, mountains with summits lying higher than a certain altitude generally have Island II moraines, while mountains with summits below this altitude generally do not have Island II moraines. The altitudes found in this manner correspond well with the altitude of the Island II regional glaciation limits calculated by means of the "summit method" and the "median altitude method" (p. 113). Therefore, all the aforementioned methods were used to calculate the regional glaciation limits for the Island II Phases. The values presented in Pl. 2 were calculated by means of the summit method; the corrections listed behind these values were based on calculations made by the other methods.

Island III moraines are absent from a few of the mountains which were undoubtedly glaciated during that phase. Nevertheless, the summit method can be used to calculate the Island III regional glaciation limit in some areas. The altitudes of the Island III regional glaciation limits calculated by means of the summit method correspond well with the results obtained by the other methods. No attempts were made to calculate the glaciation limits for the Island I Phase; and the glaciation limits for the Island IV Phases were only slightly below (about 100 m) the modern glaciation limits.

All mountains on the coast of Troms lie at slightly higher altitudes today than during the several Island Phases, because of isostatic uplift. Consequently, for these phases, all the glaciation limit values cal-

Locality	The Island II regional glaciation limit	Calculations by means of the top method	Calculations by means of other methods	Reduction for isostatic uplift	Summits of the lowest-lying glaciated mountains	Summits of the highest-lying unglaciated mountains
Western Ringvassøy	525 (—15)	545	530	20	588	502
Northern Ringvassøy	490	510	510	20	526	492
Rebbenesøy—Nord-Kvaløy—Grøtøy	455 (+5)	465	470	10	482; 546	452; 432
Helgøy	445	465	470	20	444	487; 486; 455
Southern Vanna	465 (+30)	490	520	25	487; 590	490; 486; 481
Reinøy	570 (—30)	610	580	40	565; 596	655; 572
Western Kvaløy	560	600	600	40	641; 632	566; 549; 542
Northeastern Kvaløy	515 (+10)	550	560	35	505; 621; 632; 641	596; 577; 559
Southwestern Senja	460	500	500	40	469; 510; 521	525; 446
Western Senja	460		480	20	484; 510; 512	
Southwestern Andørja	650	710	710	60	758	660; 626
Ullsfjord—Balsfjord peninsula (northern part)	520 (+50)	570	620	50	579	554

Table 6.

The Island II regional glaciation limits. (Altitudes in m's above sea level).

Regionale glaciasjonsgrenser for Island II-trinnene. Høyder er angitt i meter o. h.

culated on the basis of modern maps must be reduced. The reduction corresponds with the shore-line displacement between the Island Phases and the present. The shore-line displacement since the Island II Phases is shown by the isobases for the Main shore line; the shore-line displacement since the Island III Phases is slightly less. Therefore, the isobases for the Main shore line (Pl. 3) were used to calculate the reductions for both the Island II and the Island III glaciation limits.

The Island II Phases. A list of the regional glaciation limits for the Island II Phases is presented in Table 6. The list includes the most important information used for the calculations.

The regional glaciation limits for the Island II Phases were plotted on the map in Pl. 2, and isoglacihypses were drawn as smooth curves. None of the calculated Island II regional glaciation limits lie at altitudes more than 40 m above or below the isoglacihypse surface. Therefore, this surface must give a relatively accurate expression of the glacial conditions during the Island II Phases. The isoglacihypses for the Island II Phases are nearly parallel with the modern isoglacihypses, and the differences in altitude between the two isoglacihypse surfaces are 430 m to 490 m. Many of the calculations of the modern and the Island II regional glaciation limits were made in about the same areas. The following figures show the calculated differences in altitude between these two regional glaciation limits in such areas; 535 m (Andørja), 485 m (Senja), 485 m (Kvaløy), 435 m (Vanna) and 520 m (the peninsula between Ullsfjord and Balsfjord). All of these differences except the one at Andørja, fall within the limits of 475 ± 50 m. Therefore, the regional glaciation limits for the Island II Phases must have been approximately 475 ± 50 m below the modern regional glaciation limit.

The Island III Phases. Relatively few Island III moraine exist. As a result, very few areas are well suited for the calculation of the Island III regional glaciation limits. Areas containing enough suitable mountains for each calculation were usually large. Therefore, most of the calculations were less accurate than those for the Island II Phases. A list of the results is presented in table 7.

Locality	The Island III regional glaciation limit	Calculated by means of the top method	Calculated by means of other methods	Reduction for isostatic uplift	Summits of the lowest-lying glaciated mountains	Summits of the highest-lying unglaciated mountains
Southern Ringvassøy and Reinøy	830	870	870	40	861; 876; 884; 903	874; 857; 790
Kvaløy	785(+25)	815	840	30	822; 827; 840; 866	804; 791; 785
Southwestern Senja	775	815	815	40	741; 742; 800; 813	886; 882; 800
The northern part of the Ullsfjord—Balsfjord peninsula	867(+53)	917	970	50	950; 1067	989; 966; 888; 882

Table 7

The Island III regional glaciation limits. (Altitudes in m's above sea level.)

Regionale glaciasjonsgrener for Island III-trinnene. Høyder er angitt i m o. h.

The regional glaciation limits for the Island III Phases were approximately 200 m ± 50 m below the modern regional glaciation limits; 180 m (Ringvassøy—Reinøy), 200 m (Kvaløy), 190 m (Senja) and 180 m (between Ullsfjord and Balsfjord).

The Island IV Phases. Most of the Island IV moraines lie near the fronts of the existing glaciers, suggesting only slightly lower glaciation limits (about 100 m) during these phases than during the modern phase.

The Island II and III firn lines.

The lateral moraines were deposited at lower altitudes than the corresponding firn lines. They were deposited immediately below the firn lines in the most favourable places. Many moraines in Troms are distinctive ridges that become gradually lower in an uphill direction. At their uphill ends, the ridges commonly grade into boulder (till) stripes which gradually disappear. If the dissappearance was not caused by such topographical features as very steep slopes, the altitudes at which the lateral moraine disappear generally lie close to the altitudes of the corresponding firn lines.

The upper ends of the best Island II lateral moraines within selected areas were plotted on height scales (fig. 25). The majority of the plots from each area lie below distinctive upper limits, as indicated in fig. 25. These limits must represent the approximate altitudes of the Island II regional snow lines. A few of the lateral moraines lie as much as 50 m to 100 m above the regional snow lines calculated in this manner. They are generally moraines on south-facing or west-facing slopes where the local snow lines lay at higher altitudes than the regional snow lines. To allow for the isostatic uplift, the values obtained were reduced by amounts that correspond to the altitude of the Main shore line.

The altitudes of most lateral moraines were not measured in the field. Therefore, the quality of the calculations depends on the accuracy with which the lateral moraines were plotted on the topographic maps, and on the quality of the maps, which is usually good. However, not all of the moraines could be plotted very accurately on the maps. Nevertheless, considering the large number of calculations and the relatively good correspondence between the results from each area, the quality of the calculations must be relatively good.

The Island II Phases. The upper ends of the best Island II lateral moraines at Ringvassøy, Rebbenesøy—Nordkvaløy, Vanna, Kvaløy, Senja and the peninsula between Ullsfjord and Balsfjord were plotted on height scales, and the Island II regional snow lines were calculated in the manner described (fig. 25). The results are plotted in Pl. 2. All of the calculated altitudes for the Island II regional snow lines lie between 375 m and 500 m below the altitudes of modern regional snow lines. This corresponds relatively well with the calculated depression of 475 ± 50 m for the Island II regional glaciation limits. Therefore, the altitudinal differences between the modern regional glaciation limits (snow lines) and the Island II regional glaciation limits (snow lines) must have been approximately 475 ± 50 m.

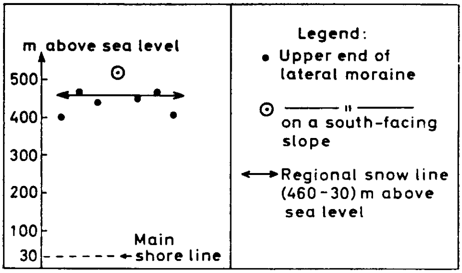


Fig. 25. Plotted altitudes of the upper ends of the Island II lateral moraines at Ringvassøy, and the calculated altitude of the corresponding regional snow line.

Høydene på de øvre endene av Island II sidemorener på Ringvassøy er plottet på en høydeskala og den tilsvarende regionale snegrensen er beregnet.

The Island III Phases. So few distinctive Island III moraines exist that it was impossible to make accurate calculations of the Island III firn lines and regional snow lines. In most areas, the highest-lying parts of the Island III moraines are probably at lower altitudes than the corresponding regional snow lines. The following is a list of the differences in altitude between the highest-lying Island III lateral moraines and the modern regional snow lines.

Ringvassøy (150 m—250 m).
Kvaløy (100 m—200 m).
Vanna (150 m—200 m).
Senja (150 m—200 m).

The differences vary between 100 m and 250 m. This corresponds relatively well with the calculated difference of 200 ± 50 m between the modern regional glaciation limits and the Island III regional glaciation limits.

The Tromsø—Lyngen event, regional glaciation limits, and regional snow lines.

The Tromsø—Lyngen event corresponds with a main part of the Island II Phases; therefore, observations and conclusions made on those phases generally apply to the Tromsø—Lyngen event. For instance, the difference in altitude between the modern regional glaciation limits (snow lines) and the Tromsø—Lyngen regional glaciation limits (snow lines) must be 475 ± 50 m. The altitudes of the Tromsø —Lyngen regional snow lines were also calculated using the lateral moraines of the Tromsø—Lyngen fjord glaciers. Only one pair of lateral moraines exists in each fjord. Therefore, no accurate calculations could be made for the Tromsø—Lyngen regional snow line in each fjord. However, the altitudinal differences between the modern regional snow lines and the highest-lying ends of the lateral moraines in each fjord were calculated and listed:

Ullsfjord: 450 m [900 m—(520 m—70 m)]
Balsfjord: 440 m [880 m—(500 m—60 m)]
Malangenfjord: 430 m [Maarfjell, 1100 m—(750 m—80 m)]
Lavangenfjord: 490 m [1000 m—(600 m—90 m)]
Gratangenfjord: 515 m [1000 m—(575 m—90 m)]

All of the differences lie between 430 m and 515 m. This suggests that the Tromsø—Lyngen regional snow lines lay that much below the modern regional snow line, a result in excellent agreement with results previously mentioned.

Younger Dryas snow-line depressions in other parts of Norway and in Europe.

Andersen (1954) studied the moraines of the Younger Dryas (Lysefjord) event in southwestern Norway. Using the altitudes of the highest-lying lateral moraines he calculated the firn line for the Lysefjord event to have been a minimum of 900 m—950 m above sea level. Recalculations, based on the same principles as those described for Troms, indicate that the Lysefjord (Younger Dryas) firn line and regional snow line was approximately 900 m—950 m above sea level. This is about 400 m—550 m below the calculated modern regional snow line, according to Andersen (1954, p. 324). Using more recent observations of the modern snow line, done by Østrem and Liestøl (1964, p. 326) and Pytte et al. (1965, p. 14; 1966, p. 8), the Younger Dryas snow-line depression was recalculated at 450 m—600 m. A Younger Dryas snow-line depression of about 450 m—600 m corresponds well with the Tromsø—Lyngen (Younger Dryas) snow-line depression in Troms. The difference in altitude between the Younger

Dryas and the modern firn lines (regional snow lines and glaciation limits) must have been approximately 475 ± 50 m along the northwest coast of Norway, and probably slightly more (525 ± 50) along the southwest coast.

If the altitude of the modern isoglacihypse surface is known on the coast of Norway, then the altitude of the Younger Dryas isoglacihypse surface can be calculated. Such calculations can be used to find which mountains along the coast of Norway were glaciated during the Younger Dryas time. The writer made several calculations of this kind for different areas on the coast, and the method seemed to work well. In fact, the calculations were a good help in the correlation of the moraines on the coast. The results of these studies will be published later.

Numerous calculations have been done in the Alps for the Lateglacial snow lines (Woldstedt 1958, p. 202). Rathjens (1954, p. 185) correlated the Younger Dryas phase with the Schlern glacial event whose snow line was 800 m—900 m below the present. However, other scientists correlated the Younger Dryas phase with several glacial events, including the Schlern event. The snow lines corresponding to these events lay between 900 m and 300 m below the present (Woldstedt 1958, p. 202; Gross 1958, p. 180). The Younger Dryas tree line depression was about 1000 m (Woldstedt 1958, p. 202; Rathjens 1954, p. 185). This information indicates that the snow line depression was 800 m to 900 m in the Alps, at least during a part of the Younger Dryas phase. This seems to be a rather large snowline depression compared with that in western and northern Norway.

Information presented by several scientists who discussed the Pleistocene snow lines in Europe suggests that the snow-line depression was large in Norway, at least south of the 65th parallel (Woldstedt 1954, p. 311—312). North—south profiles (fig. 26) of the modern snow line and the zone of maximum precipitation have been presented to show that, 1) the zone of maximum precipitation lies above the modern snow line to the south of the 65th parallel in Norway, 2) the modern snow line drops considerably in altitude immediately north of the 65th parallel, where it intersects the zone of maximum precipitation. The profiles described were published by V. Paschinger in 1923 (Woldstedt 1954, p. 311), and according to them, a drop in the temperature must bring the snow line down into the zone of maximum precipitation in areas south of the 65th parallel. The resulting increase in precipitation must cause a further depression of the snow line.

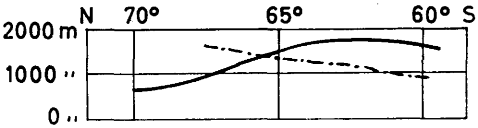


Fig. 26. The snow line (thick line) and the zone of maximum precipitation (dashed line) in Scandinavia, between latitudes 60° and 70°, according to Paschinger (in Woldstedt 1954, p. 310).

Snegrensen (tykk linje) og sonen med maksimal nedbør (stiplet linje) mellom 60° og 70° nordlig bredde i Skandinavia, ifølge Paschinger (Woldstedt 1954, s. 310).

Therefore, the scientists who relied on the profiles had reason to believe that the depression of the Pleistocene snow line was relatively large in Norway south of the 65th parallel. However, the profiles do not apply to the coast of Norway. There, the altitude of the modern snow line does not drop abruptly immediately north of the 65th parallel. The available information shows that the snow lines (isoglacihypses) lie nearly parallel to the coast both north and south of that parallel. In northwestern Norway, between the 65th and the 70th parallel, the snow lines lie only slightly lower than the snow lines in southern Norway, within areas at approximately the same distance from the coast.

Meteorological observations (Wallén 1965, map 5; Pytte et al. 1966) and glaciological observations (Østrem 1964; Pytte et al. 1966) show that the modern snow lines generally fall approximately within the zone of maximum precipitation along the coast of both southern and northern Norway. Therefore, a considerable drop in the temperature will bring the snow line down into zones of lower precipitation, and the resulting decrease in precipitation tends to diminish the depression of the snow line.

Another important factor is that temperature fluctuations tend to be smaller in areas with a maritime climate than in areas with a continental climate; and the climate along the coast of Norway is more maritime than the climate in the Alps. Several observations show that the Younger Dryas climate in the Alps was more continental than today, and observations from the southwest coast of Norway indicate that the Younger Dryas climate there was relatively maritime (p. 131). Therefore, the Younger Dryas temperature depression was probably smaller on the coast of Norway than in the Alps. Consequently, both the precipitation and the temperature conditions probably favoured smaller snow line depressions on the coast of Norway than in the Alps. A Younger Dryas snow line depression of 500 m to 600 m in western Norway seems compatible with an 800 m to 900 m depression in the Alps.

The Stordal events, regional glaciation limits and snow lines.

The Stordal events correspond with the Island III Phases; therefore, the conclusions and observations made in connection with the latter also apply to the Stordal events. For instance, the difference in altitude between the modern regional glaciation limits (snow lines) and the Stordal regional glaciation limits (snow lines) is generally 200 ± 50 m. The outlet glaciers from the continental ice sheet of Stordal age deposited only short segments of lateral moraines, and it is impossible to use them to calculate the altitude of the corresponding firn lines and regional snow lines.

Of interest in this connection is the calculated altitude of the snow line corresponding with the distinctive Pre-Boreal moraines at the head of Hardangerfjord in southwestern Norway. That snow line was about 200 m below the present according to Liestøl (1963, p. 138) and about 350 m below the present according to Anundsen et al. (1967, p. 5). This corresponds relatively well with the results from Troms. The firn lines, the regional snow lines and glaciation limits for the Pre-Boreal glacial events were probably approximately 200 ± 50 m and 300 ± 50 m lower than the modern ones along respectively the northwest and west coast of Norway. If, therefore, the altitude of the modern isoglacihypse surface is known, then the altitude of the Pre-Boreal isoglacihypse surface can be calculated. Calculations of this kind can be used to find which mountains were glaciated during the Pre-Boreal glacial events.

THE LATE-GLACIAL AND THE EARLY POSTGLACIAL CLIMATES

The Younger Dryas (Tromsø—Lyngen) climate.

The Younger Dryas isoglacihypses were approximately parallel to and 500 ± 75 m below the modern isoglacihypses along the west and the north coast of Norway. This indicates that the Younger Dryas climatic pattern was nearly parallel to that of today.

The altitude of the isoglacihypses depends mainly on the precipitation and the summer temperature. If we tentatively assume that the Younger Dryas precipitation was approximately equal to the present, then a rough calculation can be made of the Younger Dryas summer temperature. The vertical gradient for atmospheric temperature changes is usually 0.6°C—0.7°C/100 m along the coast of Norway (Andersen 1954, p. 325; Liestøl 1963). Therefore, an approximately 500 m depression of the snow line and isoglacihypses corresponds with about 3°C—3.5°C depression of the summer temperature. Consequently, the Younger Dryas summer temperature was about 3°C—3.5°C lower than the present if the precipitation was about the same. According to the calculated Younger Dryas snow-line depression of 450 m—600 m for southwestern Norway (p. 127), the Younger Dryas summer temperature there was about 3°C—4°C below the present, if the precipitation was the same as today. However, calculations from Denmark (Iversen 1954, p. 98) and southern Germany (Firbas 1949, p. 288) indicate that the Younger Dryas summer temperatures there were 5.6°C—7°C lower than today. These calculations were based on botanical evidence. The difference in the suggested temperature depressions between Denmark—Germany and western Norway seems to be rather large. Therefore, the assumption that the Younger Dryas precipitation in western Norway was about the same as that today could be wrong.

If the Younger Dryas precipitation was lower than the present in western and northwestern Norway, then the depression of the Younger Dryas summer temperature could have been more than 3°C—4°C. Numerous observations from various parts of Europe show that the precipitation was considerably smaller during Würm Maximum than it is today (Büdel 1951, p. 277). The Würm Maximum precipitation in Norway was calculated at only 30—40 % of the present (S. Klein, in Klute 1951, p. 277). Observations from the Alps show that the Younger Dryas climate, too, was drier than at present, (Klute 1951). Using botanical evidence, Iversen (1954, p. 104) suggested that the Younger Dryas climate in Denmark, also, was relatively continental. The mentioned observations could indicate that the Younger Dryas climate was drier than today on the west coast of Norway. However, the Younger Dryas glaciers in southwestern Norway were very steep and active (Andersen 1954). This indicates a considerable snow accumulation on the glaciers, and a precipitation that was probably not much lower than the present.

On the Folgefonn glacier in south-western Norway, the present winter snow accumulation at the firn line is about 200 cm (Østrem et al. 1964, Pytte et al. 1965). This value is probably representative for the Lysefjord area also, where the altitude of the Younger Dryas regional snow line was calculated at 450 m—600 m below the present. It is unlikely that the snow accumulation at the Younger Dryas firn lines in the Lysefjord area was less than 70 % of the present, i.e. less than 140 cm. A graph presented by Ahlman (1948, p. 48) indicates that a drop in winter snow accumulation at the firn line from 200 cm to 140 cm corresponds with a drop in the summer temperature at the firn line of about 1.5 °C. Therefore, the depression of the Younger Dryas summer temperature was probably maximum 3 °C + 1.5 °C to 4 °C + 1.5 °C, i.e. max. 4.5 °C to 5.5 °C. This is still less than the depression calculated for Denmark. However, a smaller temperature depression for the west coast of Norway than for Denmark is to be expected, since the climate is more maritime in Norway. Consequently, the Younger Dryas climate in western Norway was probably characterized by a precipitation slightly less than that of today and a summer temperature about 4 °C—5 °C below the present. But, it is possible that the precipitation was about the same as the present and the summer temperature about 3 °C—4 °C lower than the present. A similar conclusion can be made for the Younger Dryas climate in Troms.

The Bölling, the Older Dryas and the Allerød climates.

The fact that the Bölling, the Older Dryas and the Allerød local glaciers on several islands in Troms were no larger than the Younger Dryas (Tromsø—Lyngen) local glaciers, indicates that the climate was not significantly colder (or more rainy) during the three first mentioned phases than during the last mentioned. The presence of Boreo-Arctic type marine faunas during the earlier phases also suggests favourable conditions. The faunas indicate that the sea temperature was more favourable in mid. to early Allerød time in Bölling time and possibly in Older Dryas time, too, than it was in Younger Dryas time.

Iversen (1954, p. 94, p. 97, p. 98) calculated the summer temperatures for the Bölling, the Older Dryas and the Allerød phases in Denmark to have been respectively, slightly higher, slightly lower and considerably higher (2°C—4°C higher) than the Younger Dryas summer temperatures. This corresponds relatively well with the indicated climatic trends in Troms.

The Pre-Boreal climate.

The altitudes of the Pre-Boreal (Stordal) snow lines were about 200 m lower than the altitudes of the present ones. Therefore, the Pre-Boreal summer temperature was approximately 1.2°C—1.4°C lower than the present, if the precipitation was about the same as today. This indicates that the Pre-Boreal climate was not much colder than today.

THE MARINE SHORE LINES AND TERRACES

The coast of Troms is well known for its distinctive raised marine shore lines. Particularly the Late-glacial Main shore line and the Post-glacial Tapes shore line are dominant, almost unbroken lines along much of the coast. Raised marine deltas and less extensive shore lines exist at many different altitudes, the highest lying 80 m—85 m above sea level, at the heads of the fjords. However, in most areas the Main shore line and the Tapes shore line are the only ones easily recognizable. Helland (1899), for instance, recognized only these two shore lines in Troms. All of the raised shore lines are tilted, and the inclination of, for instance, the Main shore line is about 1 m/km.

In several publications, Pettersen (1880, 1884) described measurements of raised shore lines in Troms. He was, however, of the opinion that all shore lines were horizontal. Helland (1899) measured the altitudes of the Main shore line and the Tapes shore line at many different localities in Troms (Pl. 3). He arrived at the conclusion that they were both tilted, the Main shore line approximately 0.8 m/km to 1.2 m/km, and the Tapes shore line 0.2 m/km to 0.5 m/km. Although the tilt of the raised shore lines in Scandinavia was recognized by Bravais in 1838 (Andersen 1965, p. 123), Helland was one of the first to make an accurate study that provided a proof of this. O. Grønlie (1914, 1940, 1951) made the most extensive shore-line studies in Troms. He measured the altitudes of the raised shore lines and deltas at numerous localities (Pl. 3). Many of these observations were excellent, but some of the postulated highest shore lines were definitely not marine. Grønlie used the results of the shore-line observations to construct the isobases for both the Tapes shore level and the Main shore level (Pl. 3). He also plotted the observed altitudes of shore lines and terraces from most of northern Norway on a so-called "shore line relation diagram," the quality of which is in question, since the construction method is rather dubious (Andersen, 1965, p. 125). Grønlie made interesting attempts to correlate the Late-glacial shore lines with the end moraines on the coast of Troms. Many of Grønlie's observations and correlations will be discussed in later sections.

Undås (1939), also, made a few shore line observations on a short reconnaissance trip in Troms. He arrived at the conclusion that some of Grønlie's postulated highest shore lines were probably not marine, and he correlated several end moraines with lower-lying shore lines. The correlations made by Undås were much in line with those based on the present studies. Marthinussen (in Holtedahl 1960, p. 419) presented a map of the isobases for the Main shore line in northern Norway (Pl. 3). Apparently the construction of the Troms part of this map was based on the above mentioned observations by Pettersen, Helland, Grønlie and Undås, and on unpublished observations of his own. Through observations mainly from Finnmark, Marthinussen suggested a correlation of the Main shore line (P_{12}—S_0) with the Tromsø—Lyngen moraines. Shore lines in the Rolla—Gratangen area and in the Salangen area were studied by Lind (1955) and E. Løkse (1952) respectively. Holmes and Andersen (1965) arrived at the conclusion that the Main shore line in Ullsfjord corresponds with the Tromsø—Lyngen moraine at Skardmunken. In preliminary reports, Andersen (1965, 1965b) showed that the Tromsø—Lyngen moraines in Troms correspond with the Main shore line. H. P. Hansen (1966) studied the shore lines in eastern Troms. He, too, correlated the Main shore line with the Tromsø—Lyngen event. Some of the results from Hansen's studies are presented in Pl. 3 and they will be discussed in the following sections.

Most of the writer's shore line observations were made in connection with studies of the marine end moraines (see description in previous chapters). The main purpose of the observations was to distinguish the shore lines that correspond with the end moraines, particularly those corresponding with the Tromsø—Lyngen moraines. When the writer made these studies between 1958 and 1960 there were conflicting opinions on this correlation.

Field observations suggest that the sea regressed within the fjord districts of Troms during the entire deglaciation period. This agrees well with observations from similarly located fjord districts in Scandinavia (Marthinussen, in O. Holtedahl 1960, pl. 16; Andersen 1965, p. 125). Therefore, the highest-lying shore features within the fjords were formed immediately outside the retreating ice fronts, and can generally be correlated with ice-front positions marked by end moraines or other ice-contact deposits. A main objective for most scientists who have studied the shore lines has been to find the highest-lying shore features, the so called marine limit (ML), and to correlate this with the moraines. The published shore line observations in Scandinavia clearly show that it is difficult to find the exact altitude of the marine limit (ML). Features of more or less obscure origin were often considered to be marine. For instance, features of glacial origin, such as lateral erosion and deposition features, frequently look like marine terraces or shore lines. Andersen (1960, p. 86) discussed these problems in connection with a study of the shore lines in southernmost Norway. There, several of the older ML observations were based on lines and terraces of obscure origin, and similar lines and terraces often exist at considerably higher altitudes than the suggested ML. The writer arrived at the same conclusion for Troms. Several ML observations that Grønlie made were of the kind mentioned, and are therefore highly questionable.

The writer made the studies of the highest-lying shore levels (ML) in the following manner.

1) As many as possible of the ML observations made by other scientists were checked. Question marks were added in fig's 27—29 to the values that were based on obscure features or on clearly supramarine features.

2) Only the altitudes of clearly marine features were recorded. Obscure and indistinctive features were avoided. Particularly favourable localities were selected, and studied in detail. The highest-lying marine features at most of the selected localities were of the following types: A) marine outwash deltas, B) long abrasion lines

(terraces, ridges), usually eroded into moraines that have a constructional morainic topography above, C) fossiliferous marine sediments.

A. The marine outwash deltas were the highest-lying, clearly marine features in many observed localities. Several of the deltas lay in contact with the end moraines, and the outwash delta plains were graded to sea levels that corresponded with the moraines. As shown on p. 68, the relatively flat middle to distal parts of the deltas generally corresponded best with the sea level at the time of deposition. This agrees well with observations made in southern Norway (Andersen 1960, p. 86). However, several scientists have considered the steep proximal parts of the outwash delta plains in southern Norway to represent ML, and apparently some advocated this in Troms too. Question marks were added in fig's 27—29 to all ML-values that were found in the manner last mentioned.

B. Distinctive abrasion lines (terraces) exist on several moraines that lie well exposed to wave abrasion. Usually, a series of lines or terraces (ridges) exist up to a certain level, above which there is the unaltered constructional morainic topography, generally with till at the surface. On steep coasts facing open sea, wave abrasion occurs considerably above sea level. However, most of the observed abrasion lines (terraces) on the moraines in Troms lie in relatively narrow fjords and sounds where probably no very large waves were generated. Some of the lines lie on gentle slopes where the largest waves must have been stopped at breaker zones some distance away. Therefore, the altitudes of the abrasion lines probably correspond well with the sea levels at the time of deposition. This conclusion is supported by the fact that the distal parts of many outwash delta plains grade into the highest-lying abrasion lines.

A Paulin altimeter was used to measure the altitudes of the shore lines. Several readings were done at each locality, and all readings were corrected for temperature variations. Focus vesicularis was used as zero level. Several of the altimeter readings were checked by means of theodolite measurements. In general, the results obtained by means of the Paulin altimeter differed less than ± 1 m from the results obtained by means of the theodolites.

Review of field observations.

Details about the field observations of the shore lines and the terraces were presented in previous sections. Therefore, most of the following is an attempt to summarize the results and to discuss them in connection with the constructed isobases for the Main shore line and the shore line diagrams for Ullsfjord, Balsfjord and Malangen. Shore line observations made by other scientists will also be discussed in this section.

The oldest shore lines. The outermost part of the coast in Troms was the first area to be deglaciated. Therefore, the oldest shore lines must lie here. Marthinussen (in Holtedahl 1960, p. 418) showed that the highest shore lines on Andøya Island and on the coast of Finnmark correspond approximately with the S_{18} shore level (fig's 27—29). Accordang to the discussion on p. 21, the sea probably transgressed during the period prior to the formation of the highest shore line on Andøya. Therefore, the shore levels older than about S_{18} were probably at lower altitudes. The coast of Troms lies between Finnmark and Andøya, and the S_{18} shore line was probably the highest shore line that could be formed there, too.

The writer visited only a few of the outermost islands on the coast of Troms. But several of the other islands have been visited by other scientists. Many of the highest shore features recorded lie close to the S_8-line of Marthinussen's diagram, and only one of them lies above the S_{12}-line (fig's 27—29). The S_{18}-line in Marthinussen's diagram lies about 15 m above the S_{12}-line. The lack of the highest Würm shore lines on the coast of Troms clearly indicates that this coast was covered by the ice sheet during the older part of the Würm glaciation. This agrees well with observations mentioned in previous sections.

The shore lines corresponding with the Skarpnes event lie approximately 7 m to 10 m above the Main shore line at the Skarpnes moraines (see review on p. 36).

The Main shore line; shore lines corresponding with the Tromsø—Lyngen event. In many localities, the Main shore line is represented by terraces in bedrock (fig's 17, 22). These are generally widest along the sides of sounds, where they can be as much as 10 m to 20 m wide. The sheltered location indicates that they were not formed by ordinary marine abrasion. This conclusion was supported also by the fact that the rock debris on the terraces is commonly angular and the terrace surfaces, too, are generally rough and angular. Badly fractured rock surfaces, in part broken into large angular boulders, exist along the inner margin of several terraces. The general impression was that of frost shattering. Sea ice probably covered the sounds a considerable part of the year. This ice was frozen to the sides of the sounds, and was moved up and down by the tide, which here has a vertical range of about 2 m (Werenskiold 1943, p. 302). The constantly moving sea ice, together with freeze-thaw processes in the shore zone, probably shattered the rock. During the annual break-ups, the rock debris frozen to the ice was moved out from the shore zone. Ice-bergs from the ice fronts, too, probably aided this process. The fact that some of the best developed terraces lie immediately outside the Tromsø—Lyngen end moraines agrees well with this interpretation.

The Main shore line was plotted on the topographic maps particularly during boat rides along the coast line. The results of these studies are presented in Pl. 3. Parts of the outermost islands were not visited, but information from other scientists suggests that the Main shore line exist there also. The isobases for the Main shore line in Pl. 3 were drawn based on the writers observations and on observations by Pettersen (1880), Helland (1899), Grønlie (1951), Undås (1939), Lind (1955) and Hansen (1966). This was done mainly to check the isobases drawn by Marthinussen (in Holtedahl 1960, p. 419) and by Grønlie (1914, pl. I). Pl. 3 shows that the 3 sets of isobases correspond very closely. According to them, the tilt of the Main shore line is between 0.9 m/km and 1.1 m/km. This corresponds well with the results of studies done by Helland (p. 133).

The available measurements of the Main shore line were plotted on three shore-line diagrams, as indicated in fig's 27—29, and the Main shore lines were drawn based on the plots. All plots lie very close to the constructed Main shore lines, generally less than 2 m above or below. However, it would be more correct to construct belts rather than sharp lines for the Main shore line. The reasons for the above mentioned spread of the plots could be several, such as, 1) inaccurate measurements, 2) differences in the measuring methods used, 3) lines lying slightly above or below the Main shore line were measured, 4) the Main shore line is a belt rather than a sharp line.

The suggested reasons for the spread of the plots will be discussed briefly:

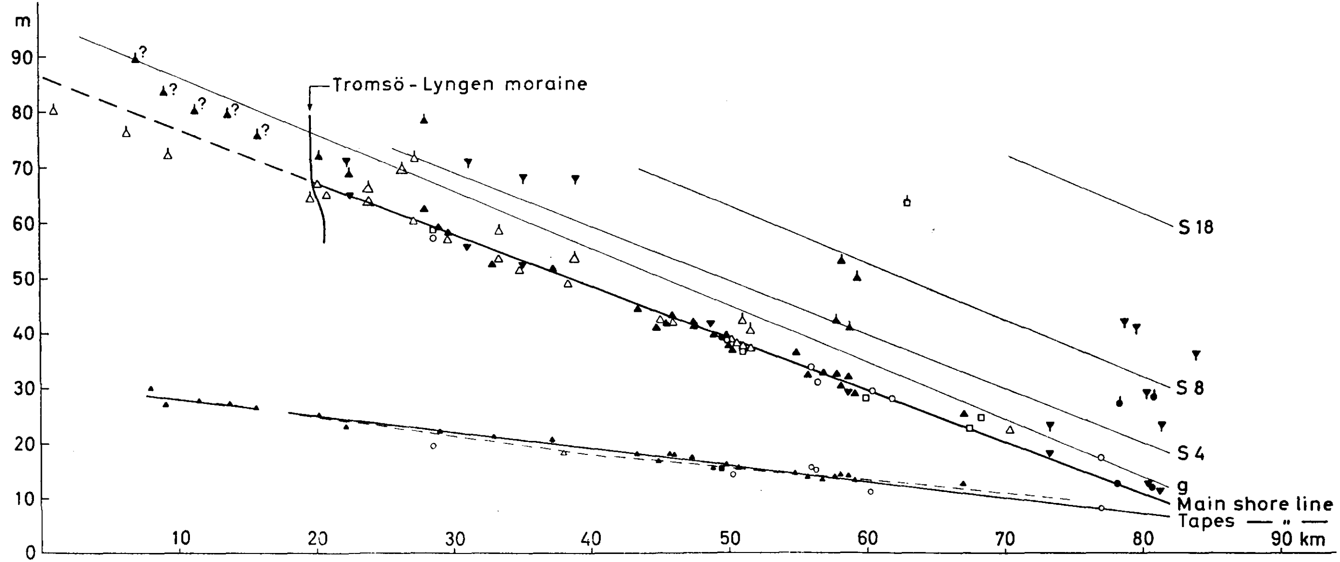
1) Theodolites were used to measure most of the presented altitudes, and the plots of the Paulin readings lie as close to the constructed Main shore lines as any of the other plots. Therefore, the spread of the observed altitudes can not be solely the result of inaccurate measurements.

2) The Main shore line frequently looked like a sharp line when it was viewed from a distance. However, a close study of the shore line generally revealed several irregularities. Most scientists probably measured the surface near the break at the inner margin of the terrace, as did the writer. But that break, too, is frequently a transition zone rather than a sharp line, and, to some degree, it is a matter of choice exactly where to measure. Therefore, different scientists could arrive at slightly different results depending upon which parts of the terraces they measured.

3) Some of the altitudes plotted in the diagrams were taken from lists that gave no detailed information on the shore lines. Therefore, some of the plots, supposedly of the Main shore line, could represent locally developed shore lines slightly above or below it.

4) In several localities the Main shore line is definitely a belt rather than a sharp line. Therefore, it most likely represents a complex of closely spaced shore levels. The Main shore line was measured in some localities by several different scientists who all arrived at exactly the same results, which indicates very accurate measurements. Still, some of the corresponding plots in fig's 27—29 lie as much as 1 m—2 m above or below the constructed Main shore line. This indicates that high-lying parts of the Main shore-line belt were best developed in some areas, while in other areas the low-lying parts were best developed.

The fact that the Main shore line in many areas is a broad bedrock terrace indicates that it was formed during a relatively long period of time when the changes in shore level were small. However, some isostatic tilting, and therefore some changes in shore level, must have occurred during such a long period. Therefore, the Main shore line most likely represents a group of intersecting shore levels. In that case, it was best developed where the shore levels intersect. This probably explains why it was best developed in areas where it lies at relatively low altitudes. The tide, too, must have had some influence on its development as a belt rather than a sharp line.

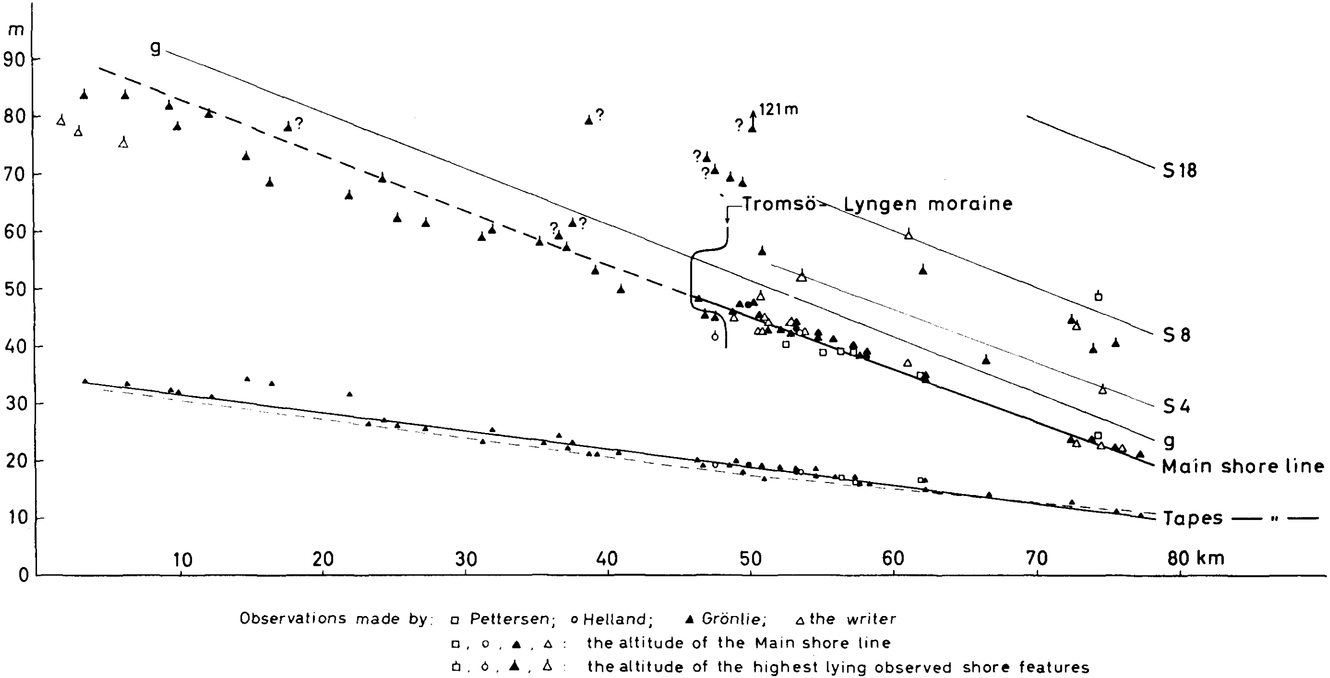


Observations made by: □ Pettersen; ○ Helland; ▼ Hansen; ▲ Grönlie; △ Holmes and Andersen

□, ○, ▼, ▲, △ : the altitude of the Main shore line

□, ○, ▼, ▲, △ : the altitude of the highest-lying observed shore features

Fig. 27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Main shore line
Tapes — " —
Observations made by: □ Pettersen; ○ Helland; ▲ Grönlie; △ the writer
□, ○, ▲, △ : the altitude of the Main shore line
□, ○, ▲, △ : the altitude of the highest lying observed shore features

Fig. 28

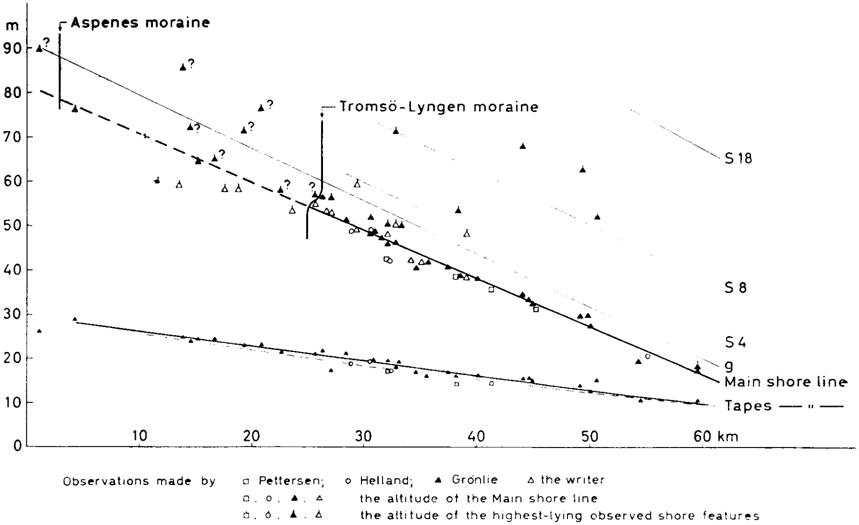

Fig. 29

Fig. 27. Equidistant shore-line diagram for the Ullsfjord area.
The projection plane is vertical to the isobases in Pl. 3.
Only the altitudes of the Main shore line, the Tapes shore line and the highest-lying observed shore features were plotted.
The field observations were made by Pettersen (1880, 1884), Helland (1899), H. P. Hansen (1966), Grønlie (1914, 1940, 1951), Holmes and Andersen (1964).
The lines S_{18}, S_8, S_4 and the dashed Tapes line represent shore lines in western Finnmark (Marthinussen, in Holtedahl 1960).
The g-line represents a shore line in Troms according to Grønlie (1940).
The "relation method" (p. 145) was used to transfer the last-mentioned lines to the Ullsfjord diagram. (The scales in Marthinussen's and Grønlie's diagrams were changed to make the Main shore lines exactly cover the Main shore line in the Ullsfjord diagram.)

Ekvidistant strandlinjediagram for Ullsfjord-området.

Projeksjonsplanet er vertikalt på isobasene i Pl. 3.
Bare høydene på Hovedstrandlinjen (Main shore line), Tapes strandlinjen og de høyestliggende observerte stranddannelsene er plottet.
Feltobservasjonene ble utført av Pettersen (1880, 1884), Helland (1899), H. P. Hansen (1966), Grønlie (1914, 1940, 1951), Holmes og Andersen (1964).
Linjene S_{18}, S_8, S_4 og den stiplede Tapes-linjen representerer strandlinjer i vestlige Finnmark (Marthinussen, i Holtedahl 1960).
g-linjen representerer en strandlinje i Troms ifølge Grønlie (1940).
De sistnevnte linjene ble overført til Ullsfjord-diagrammet ved hjelp av relasjonsmetoden. Hovedstrandlinjen ble brukt som styrelinje.

Holmes and Andersen (1964) presented a profile of the Main shore line in Ullsfjord. This shore line corresponds well with the one in fig. 27, which was expected, since they are both based on about the same field observations. Hansen (1966) constructed a shore line diagram based on observations in northeastern Troms, including parts of Ullsfjord. The correspondence is good between his observations and the writer's. The Main shore line (P_{12}) in Marthinussen's diagram from western Finnmark (p. 142) has a slightly gentler inclination than the Main shore line in the Troms diagrams. This shows a trend towards a steeper inclination for the Main store line in westerly profiles. This trend continues in Troms too, where the gradient for the Main shore line is about 0.90 m/km in the Ullsfjord area and about 1.00 m/km in the Malangenfjord area.

Description in previous sections clearly show that the Main shore line stops at approximately the Tromsø—Lyngen moraines, and that the Tromsø—Lyngen outwash deltas and outwash delta-fans were graded to that shore level or to slightly higher ones. This is best demonstrated at the Skardmunken moraine in Ullsfjord, the moraine near Tromsø, and the one at Bjorelv. The constructed shore lines in the shore line diagrams too, clearly show that the Main shore line stops approximately at the Tromsø—Lyngen moraines (fig.'s 27—29), not taking into account Grønlie's observations of the questionable highest shore levels.

The extended Main shore line lies only slightly above the highest-lying shore features a short distance inside the Tromsø—Lyngen mo-

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Fig. 28. Equidistant shore-line diagram for the Balsfjord area.
See information in fig. 27.
The field observations were made by Pettersen (1880, 1884), Helland (1899), Grønlie (1914, 1940, 1951) and the writer.

Ekvidistant strandlinjediagram fra Balsfjord-området. Se opplysningene på fig. 27. Feltobservasjonene ble utført av Pettersen (1880, 1884), Helland (1899), Grønlie (1914, 1940, 1951) og av forfatteren.

Fig. 29. Equidistant shore line diagram for the Malangenfjord area.
See information in fig. 27 and fig. 28.

Ekvidistant strandlinjediagram fra Malangenfjord-området.
Se opplysningene på fig. 27 og 28.

raines. In fact, at several localities, it looks as though a low-lying part of the Main shore-line belt crosses the Tromsø—Lyngen end moraines and disappears a short distance inside the moraines. Therefore, the lowest-lying part of the Main shore-line belt probably represents a very late phase of the Tromsø—Lyngen event, or possibly the first melting phase at the end of the event. No distinctive shore lines exist above the Main shore line between the Tromsø—Lyngen moraines and the Skarpnes moraines. However, in scattered localities the writer and other scientists also observed shore features at slightly higher altitudes than the Main shore line. These features lie below Grønlie's g-shore line (fig's 27—29) and some of them probably represent the oldest phases of the Tromsø—Lyngen event.

Grønlie (1940) correlated the Tromsø—Lyngen event with the g-shore line, but his own observations hardly support this correlation. Several of the features that he supposed to be marine lie at or above the g-line in the fjords, inside the Tromsø—Lyngen moraines. This is true for both Ullsfjord, Balsfjord and Malangenfjord. According to these observations, the moraines corresponding with the g-line should be located near the heads of the fjords, a long way inside the Tromsø —Lyngen moraines. Grønlie thought that the Main shore line continued to the heads of the fjords inside the Tromsø—Lyngen moraines. However, the observations which he presented show that he measured no shore line which could possible be the Main shore line in most of the localities studied inside the Tromsø—Lyngen end moraines, while he clearly measured the Main shore line at almost every locality outside these moraines. For instance, in the Balsfjord district, the highest-lying shore levels that he measured lie below the extended Main shore line in 12 of his 22 localities inside the Tromsø—Lyngen moraines. This supports the conclusion that the Main shore line stops approximately at the Tromsø—Lyngen end moraines.

Shore lines corresponding with the Stordal events lie 5 m to 10 m below the extended Main shore line near the heads of the fjords (see review on p. 87).

The Tapes shore line. The writer measured the altitudes of the distinctive Tapes shore line in only a few localities. Therefore, the construction of this shore line in the diagrams (fig's 27—29) was based mainly on the numerous measurements made by other scientists. According to Marthinussen (in O. Holtedahl 1960, pl. 16), the Tapes line in Finnmark is a bent line. The available observations in Troms are not accurate enough to reconstruct the very small bends indicated by Marthinussen. It was therefore, drawn as a straight line in the diagrams for Troms. A comparison between the shore lines in the diagrams from Troms and Finnmark by means of the "relation method" shows that the Tapes line in Troms corresponds very well in altitude with the bent Tapes line in Finnmark (fig's 27—29). The Tapes shore line was abraded during the Postglacial warm period, Tapes time, and it consists of a complex of shore lines.

Comparison of shore lines in different diagrams.

The comparison between the shore lines plotted in the shore line diagrams from different parts of northern Norway was made by means of the so-called "relation method" (Andersen 1965, p. 125). The horizontal scales in Marthinussen's and Grønlie's diagrams were changed slightly to give the Main shore lines in the two diagrams the same inclination as the Main shore line in the writers diagrams for Troms. Afterwards the shore lines were transferred to the Troms diagrams. This was done only for some of the most important shore lines (fig's 27—29). When the Main shore lines from Grønlie's and Marthinussen's diagrams exactly covered the Main shore lines in the diagrams from Troms, the altitudes of the other shore lines were compared. This comparison was discussed in the previous sections.

Radiocarbon dates of shells.

A few general remarks on radiocarbon dates of shells follows, since most of the dated samples from Troms were marine shells. Information in many publications indicates that radiocarbon dates of marine shells younger than about 15,000 years generally correspond well with the expected ages, and with the radiocarbon ages of charcoal and wood, which were correlated with the shells (E. A. Olson et al. 1959, p. 4; Ferrara et al. 1959, p. 103; Deevey et al. 1959, p. 157; Crane et al. 1960, p. 46; Kigoshi et al. 1962, p. 85; Stuiver et al. 1962, p. 251). Numerous radiocarbon dates of marine shells from the coast of Norway were published by R. Nydal (1960, p. 82, 1962, p. 160, 1964, p. 280). These dates, too, correspond well with the expected ages, and are consistent. The radiocarbon dates of the samples from Troms were done at the Trondheim Radiological Dating Laboratory. The dating procedure at this laboratory was described in the above mentioned publications by R. Nydal. All dates were based on the Libby value, 5,570 ± 30 years for the half life of C-14, and they were corrected for isotopic fractionation.

Possible sources of error have been discussed in the literature and will be briefly mentioned here.

1) Radiocarbon dates of molluscs that lived in hard-water lakes and rivers are frequently too high (Dyck et al. 1963, p. 45; Crane et al. 1963, p. 229). This is due to a recycling of older carbonate during the life of the molluscs. However, numerous radiocarbon dates of molluscs that lived in sea water suggest that recycling of old carbonate within these animals is negligible. Therefore, the radiocarbon dates of marine shells from different parts of the world are generally good (Hubbs et al. 1965, p. 71; Crane et al. 1963, p. 229).

2) The apparent radiocarbon ages of some modern animals from McMurdo Sound in Aantarctica are as great as 1,200 years B.P. According to Broecker et al. (1961, p. 179) these animals lived in old deep-sea water that outcrops in McMurdo Sound. However, the C-14 consentration in the sea water in the northern North Atlantic was found to be considerably higher, mainly because of good water circulation. The effect of the Gulf Stream is very strong along the coast of Norway. The chances are, therefore, negligible that the radiocarbon dated shells lived in old deep sea water. The consistency between the obtained radiocarbon dates of shells from different parts of this coast supports this conclusion.

3) A post-depositional contamination of the shells by carbon exchange with ground water and air is possible. This kind of exchange generally causes an apparent radiocarbon age that is too low. The degree of contamination depends to some extent on the sealing quality of the host sediments. In general, fresh-looking shells with hard crusts are suitable for radiocarbon datings. The effect of the contamination increases with increasing age of the shells. The chances for a considerable contamination by ionic exchange are relatively small for fresh-looking shells that are no older than the dated shells in Troms. This is indicated, too, by the good correspondence in radiocarbon age between inner and outer fractions of most of the dated shells from Troms, and from Spitsbergen also (Feyling-Hanssen and Olsson 1959—60, p. 126; Olsson 1960, p. 119). However, two of the dated samples from Troms,

and two of the samples from Spitsbergen, which were between 9,000 and 12,000 years old, were considerably contaminated. The differences in apparent ages between inner and outer fractions of these samples were approximately 1600 years (T-436 A, B), 800 years (T-437 A, B), 700 years (U-131, U-132), and 400 years (U-165, U-166). Therefore, a contamination of the shells by ionic exchange of carbon cannot always be excluded.

The crust of the shells is of course the part that is most exposed to contamination by carbon exchange. Therefore, the crusts (outer 10 % to 20 %) of the shells were removed before the dating was done. However, the samples T-173, T-174, and T-175 were so small that the entire samples were used for the datings. All shells for these samples had hard crusts and the host sediments for two of them (T-173, T-74) were blue clay with a high sealing quality. Still, the shells were thin, and a contamination of the crusts could have had some effect on the radiocarbon dates; this is reflected in the comparatively large indicated errors. Fortunately, the apparent ages of the three samples correspond very well with expected ages, although slightly higher apparent ages could also be accepted.

Sammendrag.

De beskrevne undersøkelsene har pågått i en årrekke etter 1951. De begynte med et studium av Tromsø—Lyngen-trinnet, men ble etter hvert utvidet til å omfatte hele glaciasjonshistorien for vestlige Troms. Hovedvekten ble allikevel lagt på undersøkelsene av Tromsø—Lyngen-trinnet, og de yngste glacialavsetningene ble bare studert på korte rekognoseringsturer.

Økonomisk støtte til undersøkelsene ble gitt av Norges Almenvitenskapelige Forskningsråd, Norges Geologiske Undersøkelse og Arctic Institute of North America.

De eldste dannelsene på kontinentalhyllen: Det er ikke påvist avsetninger som med sikkerhet er eldre enn siste istid på kontinentalhyllen i Troms. Men det er sannsynlig at slike avsetninger finns i betydelige mengder, spesielt langs Egga. Store bueformete fremspring ved munningene av de undersjøiske «fjordene» Andfjorden og Malangsdjupet må være enorme brefront-dannelser, en slags brefront-vifter. Overflaten på viftene heller jevnt 12°—16° ned mot det store havdyp (Pl. 1 og fig. 2). Glacialformene dominerer på kontinentalhyllen i Troms, og mange av disse formene ble tolket som glacialdannelser av f. eks. O. Holtedahl (1940) og en rekke andre forskere. U-formete tverrprofil, hengende undersjøiske «daler», traudannelser og rygger med karakteristisk randmorene-form finns over hele kontinentalhyllen (Pl. 1, fig. 2 og 3). Det kan derfor ikke være tvil om at kontinentalhyllen var dekket av innlandsisen. Under siste istids maksimum var det kanskje isfrie partier ytterst på kontinentalhyllen mellom de fremskutte hovedbrestrømmene i de store undersjøiske «fjordene». Men det er mulig at hele hyllen var totalt dekket av innlandsisen både under siste istid og de foregående store istidene. Selv om kontinentalhyllen var totalt dekket av innlandsisen så er det mulig at det har vært delvis isfrie nunatakker på f. eks. de høyeste toppene på Senja (fig. 4).

Egga-trinnene: Brede undersjøiske rygger på kontinentalhyllen har klart karakter av randmorener. Både sedimentene, formen og beliggenheten av ryggene passer med en slik tolkning, og det er ikke mulig å finne noen annen rimelig tolkning. Det er påvist opptil tre parallelle rygger som sannsynligvis representerer tre forskjellige trinn. Disse trinnene er alle sammenfattet under betegnelsen Egga-trinnene. O. Holtedahl (1940) beskrev flere av de nevnte undersjøiske ryggene, og han antok at de kunne være morenerygger. Evers (1941) kalte dannelsene på Malangsgrunnen for «Delta-Moräne».

Alle forhold tyder på at Egga-morenene er siste istids morener. F. eks. var store deler av kysten i Troms sterkt nediset så sent som i Yngre Dryas tid, og Yngre Dryas (Tromsø—Lyngen) morenene ligger meget nær Egga morenene (s. 25). Videre finns det bare relativt unge, lavtliggende strandlinjer på de ytterste øyene, hvilket viser at øyene var dekket av is i tidligere faser av siste istid (s. 137). Dimensjonene på Egga morenene svarer også ganske godt til dimensjonene på kjente Dani-glaciale randmorener i f. eks. Danmark og Nord-Tyskland. Faktisk ligger Egga-morenene så nær de unge Tromsø—Lyngen morenene at det er fristende å slutte at de kan representere en ung del av Dani-glacial tid. Men hvis Egga-tidens strandlinje lå 80 m til 110 m lavere enn i dag er det mer sannsynlig at de representerer en tidlig del av Dani-glacial tid, kanskje også siste istids maksimum.

Egga-trinnenes strandnivå lå sannsynligvis 80 m—110 m lavere enn vår tids strandnivå. Vitnesbyrdene om dette er mange. F. eks. ligger det på Malangsgrunnen en stor flate som ligner en sandurflate, 80 m til 120 m under havflaten (fig. 2 og 5). I forbindelse med denne flaten og moreneryggene finns det lange, smale horisontale rygger som sannsynligvis er strandvoller (fig. 5). Videre blir mange av moreneryggene påfallende brede på dyp mellom 80 m og 110 m, og en horisontal terrasse (linje) langs sydsiden av Malangsgrunnen er svært lik en strand-terrasse. Også O. Holtedahl (1940) pekte på en rekke forhold som tydet på at havflaten engang hadde stått meget lavere enn i dag på bankene i Troms. Han antok at voller på Malangsgrunnen helt ned til 160 m's dyp kunne være strandvoller.

De høyeste marine dannelser på Andøya, ytterst på kontinentalhyllen, ligger ca. 50 m o.h. Kysten av Andøya ble deglaciert like etter Egga-trinnene, og de nevnte stranddannelsene skriver seg sannsynligvis fra en tidlig deglaciasjonsfase. Meget tyder derfor på at havflaten ytterst på kontinentalhyllen steg fra minus 80—110 m under Egga-trinnene til pluss 50 m like etter Egga-trinnene. For å illustrere hvordan en slik sterk havstigning kan ha foregått ble strandforskyvningskurven på fig. 6 konstruert. Den bygger på grovt beregnede kurver for den isostatiske landstigningen og den eustatiske havstigningen. Strandforskyvningskurven er derfor tegnet som et bredt belte, og den gir bare uttrykk for hvordan strandforskyvningen i hovedtrekkene må ha foregått. Av kurven går det frem at havnivået sto meget lavt dengang brefronten rykket frem over kontinentalhyllen. Sannsynligvis var store deler av kontinentalhyllen tørt land på den tid. Innlandsisen støtte derfor neppe på uoverstigelige hindringer før den nådde frem til dyphavet utenfor Egga. I avsmeltningstiden steg havflaten raskt, og dermed ble sannsynligvis innlandsisen tvunget raskt tilbake fra kontinentalhyllen.

Eldste lokalbre-trinn (Island I-trinnet): I områdene mellom Egga-morenene og Skarpnes-morenene er det få betydelige randmorener bortsett fra relativt unge lokalmorener. På yttersidene av enkelte av de ytterste øyene finns det noen få brede morenerygger avsatt av eldre lokalbreer. Det tilsvarende bre-trinnet er kalt Island I-trinnet. Submarine terskler ved innerkanten av kontinentalhyllen, f. eks. ved Hekkingen er muligens randmorener avsatt av innlandsisen på omlag Island I-trinnets tid. For øvrig finns det spredte morener i enkelte av sundene mellom øyene, og de representerer kanskje randmorener.

Skarpnes-trinnet er representert ved betydelige endemorener og tildels markerte sidemorener. Endemorenene ligger oftest nær munningene av fjorden, 3—8 km utenfor Tromsø—Lyngen-trinnets endemorener. De høyeste øyene og fjordhalvøyene var sterkt lokalnediset, og deler av store lokalmorenekompleks (Island II) ble avsatt på denne tid. Lokalbreene var omlag like store som Tromsø—Lyngen-trinnets lokalbreer. De klimatiske forholdene var derfor meget like under de to trinnene (se følgende avsnitt). Skarpnes-trinnets strandlinjer lå omlag 7 m—10 m høyere enn Hovedstrandlinjen (the Main shore line) i områdene nær morenene.

Skjellavsetninger ved morenen på Langneset (lokalitet 13, pl. 1) er sannsynligvis av samme alder som Skarpnes-trinnet. De ble C-14 datert til ca. 12 000—12 500 år før nåtid (fig. 8).

Tromsø—Lyngen-trinnet: De største og mest dominerende randmorenene i Troms svarer til Tromsø—Lyngen-trinnet. Noen av disse ble beskrevet meget tidlig, f. eks. morenen på Tromsø (Helland 1889) og andre morener i Balsfjordområdet (Grønlie 1931). Holmes og Andersen (1964) undersøkte morenene i Ullsfjord-området, og noen Tromsø—Lyngen morener ble også beskrevet av Lind (1955) og Undås (1939). Men de fleste morenene som er inntegnet på pl. 1 har tidligere bare vært kort omtalt i en foreløpig meddelelse (Andersen 1965b).

Lange fjordbreutløpere fylte de trange fjordene i Troms på Tromsø—Lyngen-trinnets tid. De avsatte markerte sidemorener (fig. 15) og endemorener (fig. 9). Mange steder ble to parallelle morenerygger avsatt. Overflatene på fjordbreene hellet meget svakt (12—14 m/km) bortsett fra nær frontene hvor gradienter på ca. 60 m/km var vanlig (fig. 10). De høyeste øyene og fjordhalvøyene var sterkt lokalnediset på denne tid. Lokalbreene avsatte de yngste og mest dominerende morenene innen morenekompleksene som representerer Island II-trinnene. Ved studier av høydene på fjellene som var nediset og høydene på sidemorenene ble Tromsø—Lyngen-trinnets glaciasjonsgrenser og firngrenser beregnet til å ha ligget ca. 475 ± 50 m lavere enn vår tids glaciasjonsgrenser og firngrenser (fig. 23 og Pl. 2). Dette passer ganske godt med den beregnede senkning på 525 ± 50 m av snegrensen under Lysefjordtrinnet i Ryfylke (s. 127). Da de to trinnene begge er av Yngre Dryas alder lå snegrensene og glaciasjonsgrensene på den tid omlag 525 + 50 m og 475 ± 50 m lavere enn i dag langs kysten av henholdsvis Vest- og Nord-Norge.

En rekke brefront-delta avsatt av Tromsø—Lyngen-trinnets breelver svarer i høyde til Hoved-strandlinjen (Main shore line) og til litt høyere strandnivåer. Hovedstrandlinjen er også som regel meget tydelig like utenfor Tromsø—Lyngen-trinnets endemorener, mens de mangler i fjordene et stykke innenfor morenene. Hovedstrandlinjen og litt høyereliggende strandnivåer må derfor svare til Tromsø—Lyngen-trinnet. Det er imidlertid mulig at en yngste del av Hovedstrandlinje-sonen kan svare til avsmeltningsfasen ved slutten av Tromsø—Lyngen-trinnet. Også Marthinussen og Holmes og Andersen (s. 134) fant at Hovedstrandlinjen svarer til Tromsø—Lyngen-trinnet.

Tilsammen 18 prøver av organisk materiale fra Tromsø—Lyngen morenene og avsetninger nær knyttet til disse morenene ble C-14 datert (Tabell 3). Dateringene viser at alderen på Tromsø—Lyngen-trinnet må ligge et sted mellom 10 100 og 12 000 år før nåtid. De viser også at en hovedfase av (kanskje hele) Tromsø—Lyngen-trinnet er av Yngre Dryas alder, 10 350 ± 150 til 10 950 ± 150 år før nåtid (Tabell 4). Men brefrontene lå ved eller innenfor områdene ved Tromsø—Lyngen-morenene allerede i tidlig Allerød tid. Noen dateringer tyder også på at de eldste Tromsø—Lyngen moreneryggene kan være avsatt i tidlig Allerød eller Eldre Dryas tid.

En Boreo-arktisk type skjellfauna er mest vanlig i Allerød-avsetningene (Tabell 1). Arter som *Mya truncata, Macoma calcarea, Hiathella arctica* og *Astarte elliptica* dominerte på den tid. Men i det kalde svakt brakke vannet like ved flere av brefrontene levde sannsynligvis en *Yoldia* fauna karakterisert ved *Portlandia arctica. Yoldia* faunaer er vanligst i Yngre Dryas avsetningene, men selv på den tid levde sannsynligvis en mer Boreo-arktisk preget fauna på større avstander fra brefrontene. Ved overgangen fra Yngre Dryas til Pre-Boreal tid ble *Yoldia* faunaene avløst av *Arca* faunaer og videre av Boreo-arctiske faunaer med *Mya truncata, Macoma calcarea, Hiathella arctica* osv.

Stordal-trinnene: De første markerte endemorenene innenfor Tromsø—Lyngen morenene ligger stort sett nær bunnen av fjordene. Opptil tre suksessive endemorener finns i enkelte av fjordene. De representerer små glacialfaser kalt Stordal-trinnene. Bare de høyeste fjellene var lokalnediset på Stordal-trinnenes tid, og lokalbreene avsatte små morener kalt Island III morenene. De tilsvarende snegrenser og glaciasjonsgrenser lå omlag 200 ± 50 m lavere enn vår tids snegrenser og glaciasjonsgrenser. Brefront-delta av Stordal alder ligger 5 m—10 m lavere enn den forlengete Hovedstrandlinjen. En rekke C-14 dateringer av skjell fra sedimenter av Stordal alder ga resultater mellom 9 000 og 10 000 år før nåtid.

Områdene innenfor Stordaltrinnene er karakterisert i det vesentlige ved avsmeltnings-dannelser. Spredte randtrinn i disse områdene består hovedsakelig av lite markerte morener og randterrasser. Det er vanskelig å avgjøre om slike trinn representerer klimaforverringer eller ei. De fleste av dem skyldes sannsynligvis lokale topografiske forhold, som terskler og innsnevringer av dalene. Grønlie avmerket en serie morenetrinn på et oversiktskart (Pl. 1). Men flere av disse trinnene består av fremspringende partier på sandurterrasser eller uklare morener, og det var vanskelig å avgjøre med sikkerhet om de representerer brerand-trinn.

I de nordlige (nordvestlige) delene av de store dalførene innenfor Stordal-morenene ligger det mektige dalfyllinger av glacifluviale og glacifluvio-marine sedimenter. Elvene har skåret seg dypt ned i de opprinnelige vide sandur-terrassene, som er representert ved vanligvis smale terrasselister langs dalsidene (Pl. 1). Mot syd (sydøst) blir hoveddalene trange og fører bratt opp mot høyfjellsviddene ved svenskegrensen. I disse trange, bratte delene dominerer ofte glacifluviale erosjonsformer, canyons og lateral-renner. På høyfjellsviddene nær svenskegrensen er det vide daler med lange esker-rygger (Pl. 1 og fig. 21). Alle de nevnte glacial-dannelsene vitner om en sterk avsmeltning i tiden etter Stordal-trinnene. Denne avsmeltningen foregikk sannsynligvis i tidlig Boreal tid da klimaet stort sett var ubetydelig kaldere enn i dag.

Recente morener ligger nær frontene på de fleste breene. Det er som regel små skarpe rygger. Ved noen breer ligger det 2 til 3 parallelle rygger. De eldste ryggene svarer sannsynligvis til brefremstøt i første halvdel av 18. århundre, mens de yngste ryggene kan svare til brefremstøt i det 19. og 20. århundre.

Lokal-morener på øyene og fjordhalvøyene ble avsatt under en rekke forskjellige bretrinn som ble kalt Island I... IV trinnene. De ble korrelert med innlandsisens trinn som angitt i foregående avsnitt.

Snegrenser og glaciasjonsgrenser: Glaciasjonsgrensen angir en nedre høydegrense for fjell hvor breer kan dannes. Toppene på glacierte fjell ligger over denne grensen, mens toppene på ikke glacierte fjell ligger under grensen. På grunn av lokale topografiske forhold varierer høyden på glaciasjonsgrensen ofte ganske sterkt fra fjell til fjell. Av praktiske grunner ble derfor denne glaciasjonsgrensen kalt den lokale glaciasjonsgrensen. Gjennomsnittshøyden på de lokale glaciasjonsgrensene innen et område ble kalt den regionale glaciasjonsgrensen. Høydene på vår tids regionale glaciasjonsgrenser ble beregnet først og fremst ved hjelp av «topp-metoden» (fig. 23). De funne verdier ble plottet på kartet (Pl. 2) hvor også de tilsvarende høydekurver, isoglacihypser er trukket.

De regionale glaciasjonsgrensene for Island II og III-trinnene, Tromsø—Lyngen- og Stordal-trinnene ble også beregnet ved hjelp av «topp-metoden» fig. 23. De funne verdiene sammen med isoglacihypsene for Island II (Tromsø—Lyngen) trinnene er avsatt på kartet Pl. 2. Glaciasjonsgrensene for Island II (Tromsø—Lyngen) trinnene og Island III (Stordal) trinnene lå henholdsvis 475 ± 50 m og 200 ± 50 m lavere enn vår tids (1945—1960) glaciasjonsgrenser.

De regionale snegrensene for Island II og III trinnene, Tromsø — Lyngen — Stordal-trinnene.

Gjennomsnittshøyden for firngrensene på breer som ligger i vest, øst- og nord-vendte skråninger i et område ble kalt den regionale snegrensen. Høydene på de regionale snegrensene ble beregnet i flere områder (Pl. 2). I de sydlige områdene ved Ullsfjord hvor nedbøren er relativt liten ligger de regionale snegrensene 250—350 m lavere enn de regionale glaciasjonsgrensene. Lenger ute på kysten hvor klimaet er fuktigere er høydeforskjellene mellom de to slags grenser bare omlag 150 m.

Sidemorener blir avsatt nedenfor firngrensene, men på gunstige steder kan de øvre endene på sidemorenene bli avsatt like ved firngrensene. Ved å plotte de øvre endene på sidemorenene til et morenetrinn

inn på en høydeskala er det derfor mulig å beregne den omtrentlige høyde på trinnets regionale snegrense (fig. 25). Tromsø—Lyngen (Island II) trinnets og Stordal (Island III) trinnenes regionale snegrenser ble på denne måte beregnet til å ha ligget henholdsvis 375—500 m og 100—250 m lavere enn vår tids (1945—1960) regionale snegrenser.

Strandlinjer: Det finns to dominerende strandlinjer i Troms, Tapes-strandlinjen og Hoved-strandlinjen. Begge linjene er ofte skåret inn i fast fjell, og de kan følges sammenhengende over store områder (Pl. 1). Andre strandlinjer og terrasser er som regel bare tydelige rent lokalt, og i mange områder er det bare Tapes- og Hovedstrandlinjene man lett får øye på.

En rekke forskere har undersøkt strandlinjene i Troms. Hellands undersøkelser var mest bemerkelsesverdige idet han så tidlig som i 1899 påviste at Tapes-linjen og Hovedlinjen stiger fra kysten innover i fjordene (Pl. 3). For øvrig har spesielt Pettersen og Grønlie utført en mengde strandlinjemålinger. Grønlie konstruerte et strandlinje-diagram og isobasene for Tapes-linjen og Hoved-linjen (Pl. 3). Også Marthinussen konstruerte isobasene for Hoved-linjen.

Forfatterens strandlinjeundersøkelser ble konsentrert om å påvise hvilke strandlinjer det er som svarer til de forskjellige brerand-trinnene. Resultatene av disse undersøkelsene er omtalt i de foregående avsnittene. Basert på egne observasjoner og på observasjoner utført av andre forskere ble ekvidistante strandlinjediagrammer konstruert for Ullsfjord, Balsfjord og Malangen (fig. 27, 28, 29). Bare observasjoner av Tapes-linjen, Hoved-linjen og den marine grense ble avsatt på diagrammene. Det fremgår at de observerte høydene på Hoved-strandlinjen ligger innen belter langs de rekonstruerte linjene. Det ville derfor være mer korrekt å angi Hoved-linjen som et belte enn en skarp linje. Isobaser for Hoved-linjen ble også konstruert (Pl. 3). De faller meget nær sammen med Grønlie's og Marthinussen's isobaser for samme linje.

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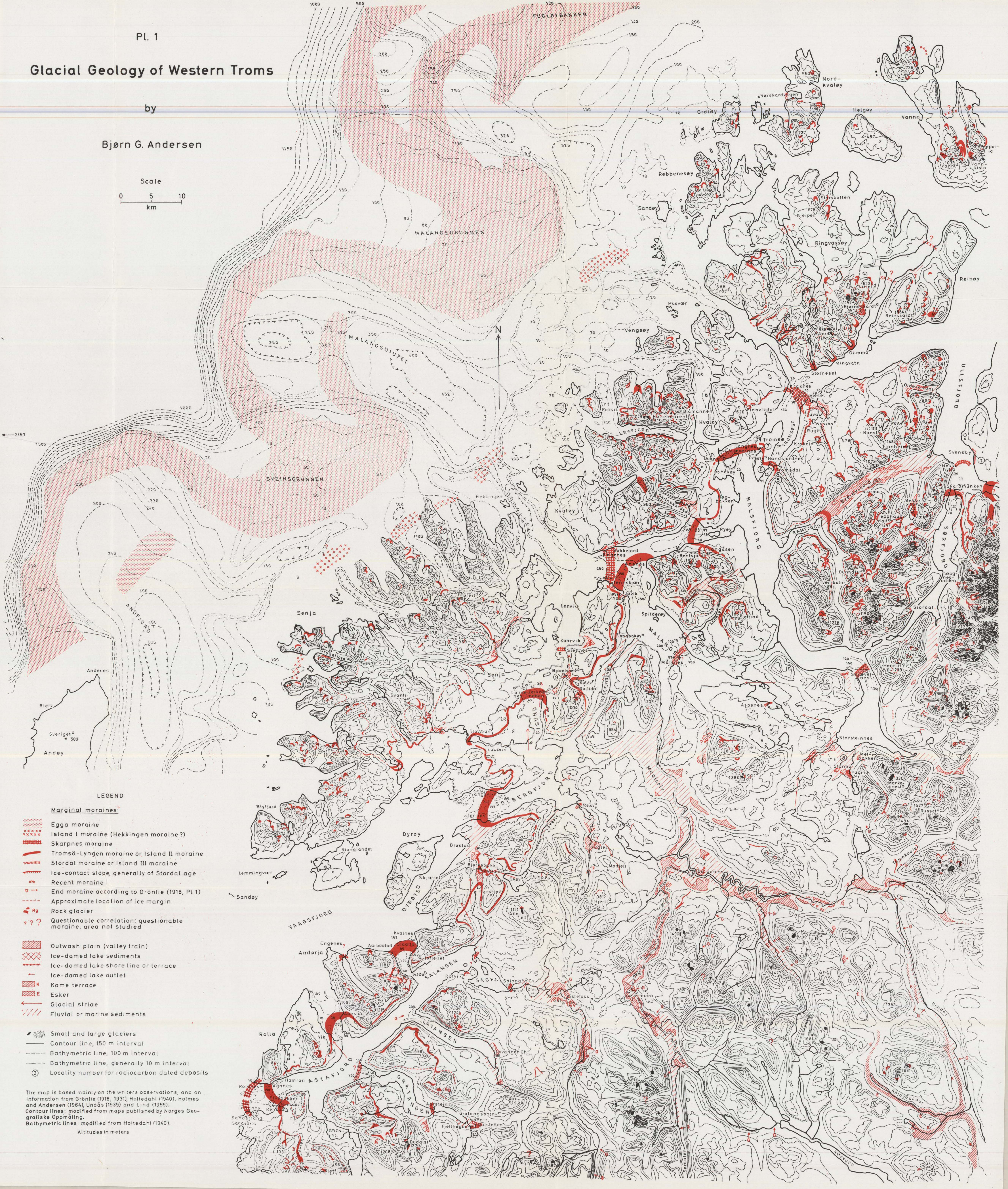
Pl. 1

Glacial Geology of Western Troms

by

Bjørn G. Andersen



LEGEND

Marginal moraines:

- ▨ Egga moraine
- ××× Island I moraine (Hekkingen moraine?)
- Skarpnes moraine
- Tromsö-Lyngen moraine or Island II moraine
- Stordal moraine or Island III moraine
- Ice-contact slope, generally of Stordal age
- Recent moraine
- G → End moraine according to Grönlie (1918, Pl. 1)
- ---- Approximate location of ice margin
- Rg Rock glacier
- ? ? ? Questionable correlation; questionable moraine; area not studied

- ▨ Outwash plain (valley train)
- ××× Ice-damed lake sediments
- Ice-damed lake shore line or terrace
- ← Ice-damed lake outlet
- ▨ K Kame terrace
- ▨ E Esker
- ← Glacial striae
- //// Fluvial or marine sediments

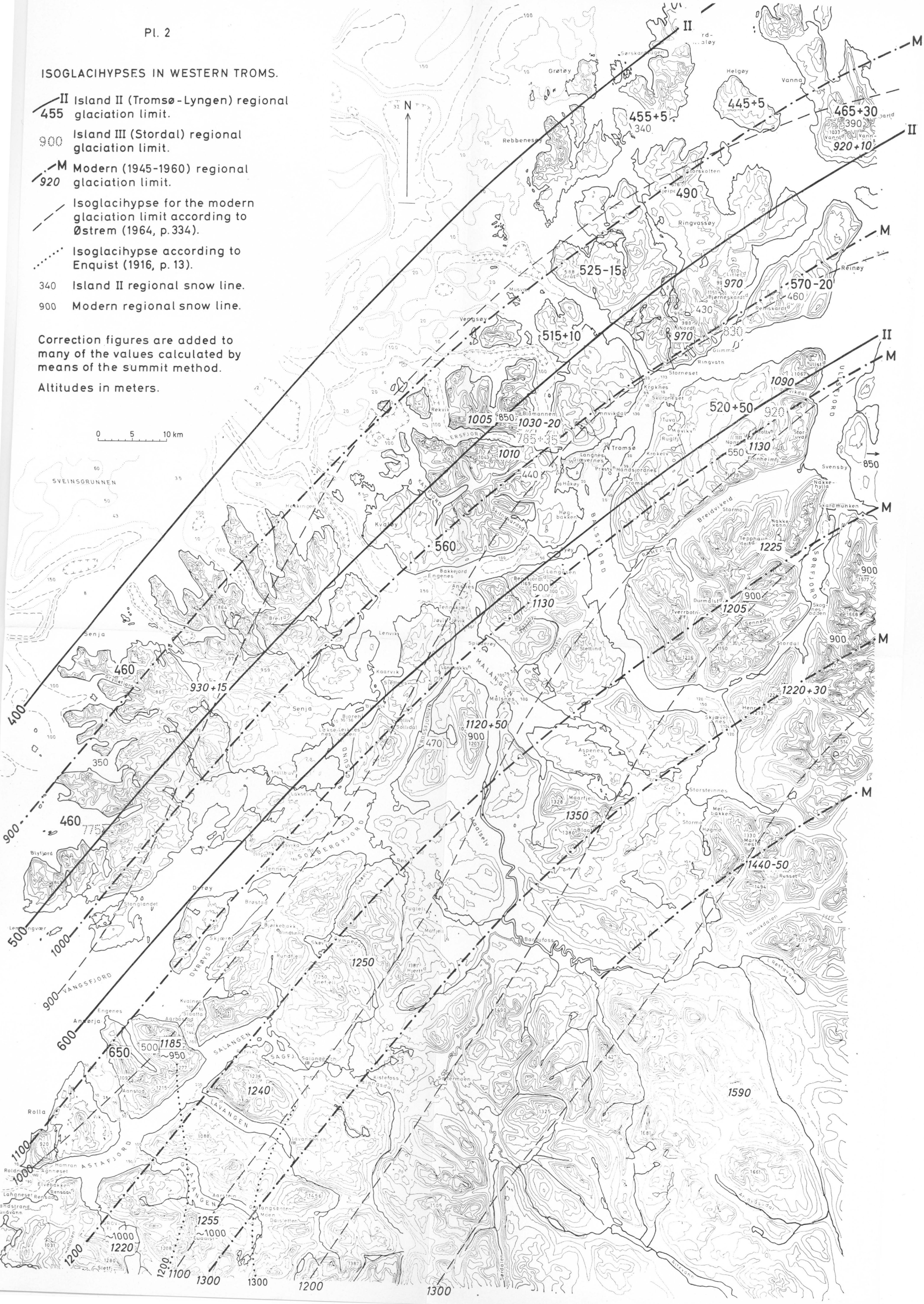
- Small and large glaciers
- —— Contour line, 150 m interval
- ---- Bathymetric line, 100 m interval
- ········ Bathymetric line, generally 10 m interval
- ② Locality number for radiocarbon dated deposits

The map is based mainly on the writers observations, and on information from Grönlie (1918, 1931), Holtedahl (1940), Holmes and Andersen (1964), Undås (1939) and Lind (1955).
Contour lines: modified from maps published by Norges Geografiske Oppmåling.
Bathymetric lines: modified from Holtedahl (1940).

Altitudes in meters

Pl. 2

ISOGLACIHYPSES IN WESTERN TROMS.

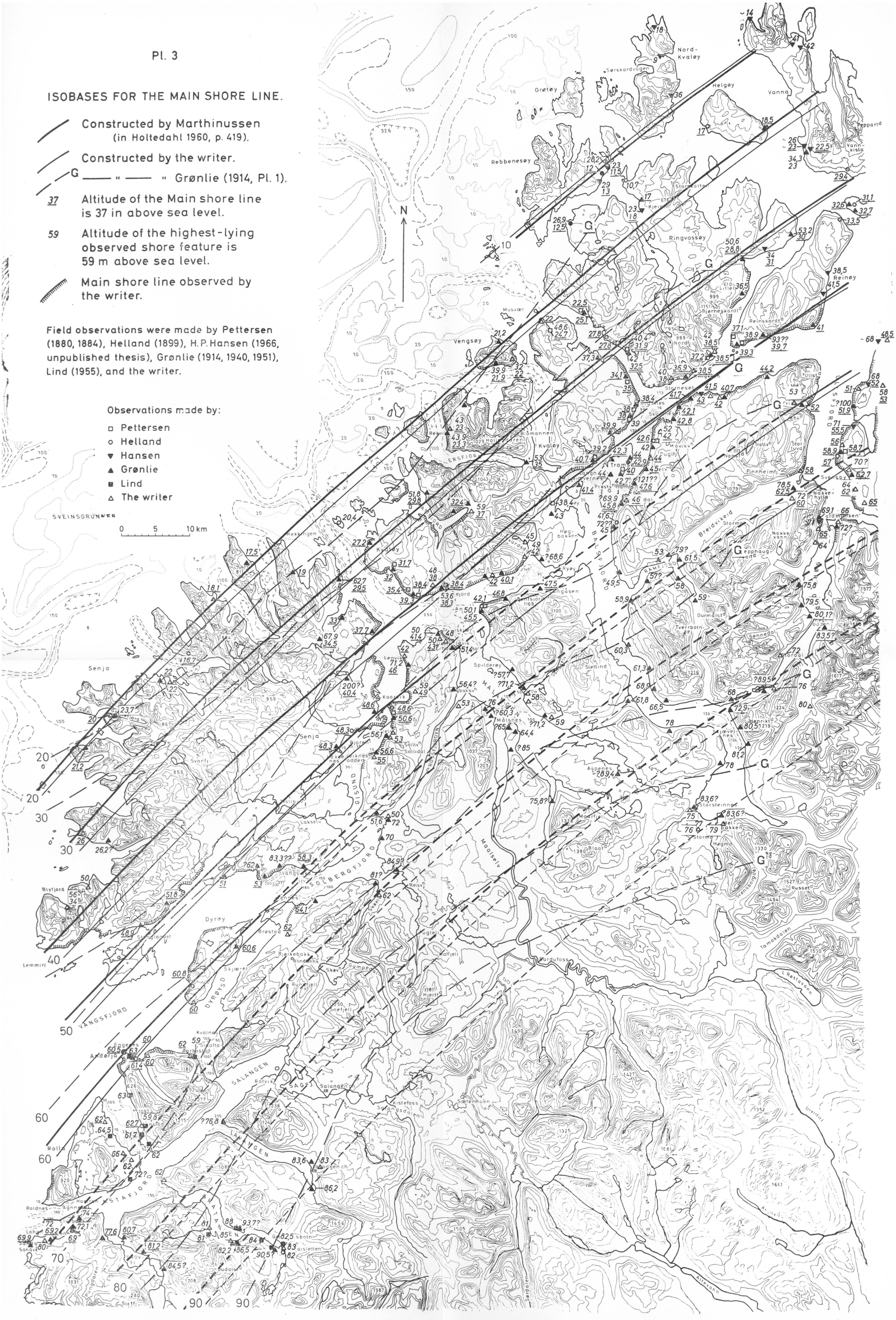


- II / 455 Island II (Tromsø-Lyngen) regional glaciation limit.
- 900 Island III (Stordal) regional glaciation limit.
- M / 920 Modern (1945-1960) regional glaciation limit.
- Isoglacihypse for the modern glaciation limit according to Østrem (1964, p. 334).
- Isoglacihypse according to Enquist (1916, p. 13).
- 340 Island II regional snow line.
- 900 Modern regional snow line.

Correction figures are added to many of the values calculated by means of the summit method.

Altitudes in meters.

Pl. 3



ISOBASES FOR THE MAIN SHORE LINE.

Constructed by Marthinussen (in Holtedahl 1960, p. 419).

Constructed by the writer.

G —— " —— " Grønlie (1914, Pl. 1).

37 Altitude of the Main shore line is 37 m above sea level.

59 Altitude of the highest-lying observed shore feature is 59 m above sea level.

Main shore line observed by the writer.

Field observations were made by Pettersen (1880, 1884), Helland (1899), H.P.Hansen (1966, unpublished thesis), Grønlie (1914, 1940, 1951), Lind (1955), and the writer.

Observations made by:
- □ Pettersen
- ○ Helland
- ▼ Hansen
- ▲ Grønlie
- ■ Lind
- △ The writer

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