MEDDELELSER OM GRØNLAND
UDGIVNE AF
KOMMISSIONEN FOR VIDENSKABELIGE UNDERSØGELSER I GRØNLAND
Bd. 188 · Nr. 5

SOME GLACIERS OF THE STAUNING ALPER, NORTHEAST GREENLAND

BY

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WITH 12 FIGURES, 7 MAPS AND 9 TABLES IN THE TEXT

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1971

Abstract

A Study of the glaciers of the northern Stauning Alper is presented. The moraine structure of the glaciers is discussed with reference to the recent glacial recession in the area.

A mass balance of the lower regions of a typical glacier is presented and shows a considerable deficit at the snout.

The overall picture of glacier recession in the region is compared with that shown by neighboring parts of the North Atlantic Coast line, and shows very similar effects.

ISBN 87 421 0040 2

CONTENTS

1. Introduction

The Stauning Alper of Northeast Greenland, lat. 72°N. are an isolated mountain complex south of Kong Oscar Fjord. The glaciers of the northern part of the complex are in general small and well defined. The area is also relatively accessible from the airfield at Mesters Vig. The glaciers thus offer a good opportunity for studying the glacial recession in this part of Greenland. This work reported in this paper represents the first stage of such a programme.

During the summer of 1963 the snouts and ice bodies of several typical glaciers ranging from cirque to valley glaciers were surveyed and photographed from fixed cairns which will be revisited and photographs compared at a future date. Three different regions were selected for study (map 1), Deltadal, Skeldal and Kap Peterséns, so that a representative group of glaciers were observed, under different conditions. A more detailed investigation was carried out on the Bersærkerbræ. Three transverse and one longitudinal height profiles were measured so that in future it will be possible to directly estimate the ice loss at the snout of this glacier. In addition by measurement of flow and ablation an estimate of the mass loss at the snout of this glacier was made.

In this paper the snout features of the glaciers in the area are discussed and compared with aerial photographs taken in 1949 and 1950.[1] An overall picture of the glacial recession was built up and shown to be very similar to that from other parts of the North Atlantic Coast Regions.

The glaciers of the Stauning Alper appear to be sub-polar on AHLMANN's classification (AHLMANN, 1948). Precipitation is small (373 mm) and mostly occurs during the winter (October-February). Summer weather is usually warm and dry, though during the "night" thick mists develop on the coast of Kong Oscar Fjord. The mean annual temperature at Mesters Vig is −9.7°C. A more detailed summary of the climate will be found in WASHBURN (1965).

The paper is divided into five sections. The first three describe and discuss the glaciers in the three different regions of study. The fourth

[1] Aerial surveys of the Danish Geodetic Survey, Copenhagen.

Map 1. Map of the North Stauning Alper showing the glaciers studied. The map is based on the survey of the Geodetic Institute, 1933.

considers the ice loss of the Bersærkerbræ during the summer of 1963. In the last sections the detailed picture of ice recession in the area is brought together and considered in relation to the glacial changes in other parts of the North Atlantic Region.

A detailed introduction to the area is given by Washburn (1965) in the first of a series of reports from his research programme in the Mesters Vig district and should be consulted for more information on the background to this paper.

2. The Glaciers of the Deltadal District

The Østre Gletscher, Mellemgletscher, Vestre Gletscher and Retrætegletscher were originally all confluent and flowed into Kong Oscar Fjord through Mesters Vig. Traces of earlier glaciation can be observed high on the valley sides, probably relics of the last ice-age (PESSL, 1962). The valley now holds a large braided stream and is filled with outwash from the glacier complex.

About 2 km from the present ice edge is a large ice-cored push moraine system, which is associated with lateral moraines on both sides of the valley. The system is of recent origin and its double structure indicates two major advances, after which the glaciers then retreated and separated. These glaciers will be dealt with individually in the following sections.

Østre Gletscher

The Østre Gletscher is a valley glacier of type I on AHLMANN's classification (AHLMANN, 1948), about 12 km long flowing North. About half way along its length it makes a sharp 90° bend to the Northwest. A little lower, about 4 km from the ice edge, is a further sharp bend to the Northeast of about 60°. Associated with the first bend are a series of well formed small crevasses of about 10 m separation and at 20° to the line of flow. At the lower bend the ice on the inside becomes steeper and the crevasse separation decreases to about 5 m. At this latter bend there is a large gap between the rock wall and the glacier, due to the glacier pulling away from the wall on the inside of the bend. A large melt-water stream now occupies and maintains the gap, but this appears too large to have been formed by water erosion. Below this the ice becomes very uneven. Towards the snout the surface appears as a series of waves about 6 m in height and 100 m in separation. This wave appearance is also preserved in the dirt band structure, suggesting that folding has taken place; although it is thought that such an origin is unlikely and that the feature is probably the result of surface ablation. Lower down the waves become irregular and finally the surface becomes completely broken up with ice cliffs and gorges. In this region is a section of glacier bounded by a medial moraine starting from the Kolossen ridge (map 2). When the glacier was visited in July, 1963 the snow line was already

Map 2. Map of the moraine complex of the Østre Gletscher and Mellemgletscher in Deltadal. Map taken from Geodetic Institute survey 1957.

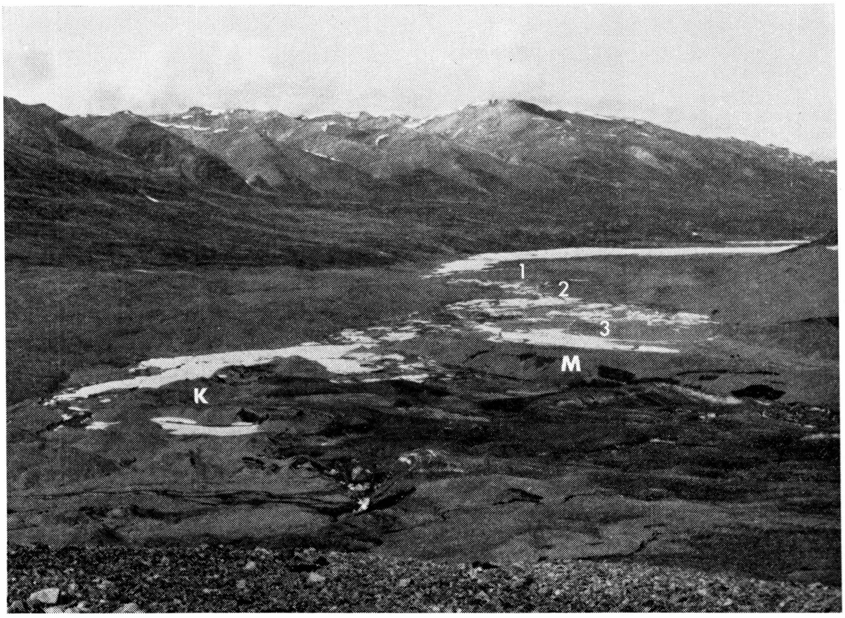


Fig. 1. Looking north from the foot of the Kolossen ridge over the snout of the Østre Gletscher and Deltadal. The outermost double moraine structure, labelled 1 and 2 and the inner push moraine 3 can be clearly seen. The fine debris "kames" K are shown. In the centre the large red moraine M can be seen extending down the valley. Notice also the ice exposure in the lateral moraine on the extreme right of the picture.

above the steep section at the lower bend (300 m). This elevation is higher than the maximum height of this section of ice, which must therefore be decaying and, as there is no bergschrund, almost stagnant.

The lateral moraine on the east side of the glacier is about 80–100 m above present ice surface. At its upper end it is based on a bedrock spur, but is ice-cored at its lower end. It is suggested that this is a relic of the previous confluent advance formed by the Retrætegletscher (a small glacier to the East) becoming superposed on the ice of the Østre Gletscher. Since 1949 a patch of exposed ice has appeared in this moraine (Fig. 1); H. R. Thompson (1957) has suggested that such ice exposures are due to a general climatic improvement, but only an increase in air-temperature (or sunshine) in the summer period when melting can occur is needed. The patch may also be due to slumping of material off the moraine thus exposing the ice. This process is self-degenerating resulting in the gradual disintegration of the moraine. The true lateral moraine from the east of the Østre Gletscher is the large red moraine in the centre of the glacier. The ice to the east of this comes from the two small tributaries which are now almost separate from the major flow. This ice is debris-covered in the lower regions and appears dead.

Fig. 2. One of the collapsed sub-glacial caverns on the Østre Gletscher.

Against the rock on the west side of the valley is a large moraine built by the confluent system. Several earlier positions of the ice-edge probably are marked by disused river beds in this moraine. Just to the west of the present river bed is a former bed, part of which was occupied in 1949 (map 2). Behind this is a small ridge which appears to be a terminal moraine. Further evidence of recent activity is provided by observation of thrust planes near the present outflow river of the Østre Gletscher. 'Kames' formed by fine debris on ice are found at the present ice edge, now being destroyed in places by the river from Vestre Gletscher and Mellemgletscher. The fine debris of these resembles fluvial deposit and it is suggested that it was raised to the ice surface by the action of former thrust planes, which are now either ablated or covered by debris. The glacier is, however, at present retreating. The present major outflow river has caused a significant recession of the ice edge (map 2) on the east side of the glacier. The river from Vestre Gletscher and Mellemgletscher has also caused significant changes in the snout of the Østre Gletscher modifying and excavating the ice edge on the west. It is thought that there will be significant changes in this part in the near future.

A further indication of the recession is provided by the appearance of a small fluted moraine on the west of the major medial moraine. Schytt (1963) has shown that such deposits only appear from beneath the ice as the ice edge recedes. These stripes were in a region of small streams and standing water in which they would be unlikely to survive for long. However, their appearance indicates that the melting of the ice was not due simply to the action of the nearby, formerly sub-glacial river, but was in fact a result of ice becoming stagnant and melting. The smooth, gently sloping ice surface at this point would also appear to confirm this. Evidence of glacial thinning was provided by the discovery of two collapsed sub-glacial caverns (LLIBOUTRY, 1958; DE BOER, 1949) (map 2, Fig. 2) farther up the glacier. These caverns are formed underneath stagnant ice by mining action of the sub-glacial river. If the ice above the cavern becomes too thin it can no longer support the roof and the cavern collapses, giving rise to the characteristic series of radial crevasses, as seen in Fig. 2. The limiting ice thickness at which this occurs is about 10 m. They are thus indicative of a thinning of the ice, and as they do not appear on the 1949 air-photo, indicate that thinning is still taking place.

Mellemgletscher

The Mellemgletscher is a valley glacier of type III in AHLMANN's classification (1948). It is about 7 km long with a large bend occupying most of the upper section. It is separated from the Østre on the east in its lower part by the Kolossen ridge; however at the higher end of the ridge there is an area of common ice.

The terminus is much better defined than that of the Østre Gletscher, particularly on the western side where there is a large marginal river. The east side of the terminus where the ice is debris-covered and decaying, is partly associated with the similar ice on the west of the Østre Gletscher and is a relic of the former confluent glacier. The Mellemgletscher has no terminal moraines of its own as they would be destroyed by the outflow river. The lateral moraine on the west side crosses the snout of the Vestre Gletscher and must formerly have been a medial moraine of the confluent system, though today there is not any ice-contact. The present run-off river from the Vestre Gletscher runs beneath the Mellemgletscher west lateral moraine and then along the front of the snout. The two earlier river beds shown in map 2 probably also indicate former stationary positions of the snout though unfortunately when these occurred is not known. The outer terrace was probably formed by a marginal stream from the Vestre Gletscher, when it was a tributary of the Mellemgletscher. It may also be associated with a terrace lower down the moraine on the west side of the valley indicating that it dates from the time of the major confluence.

The present junction of the Mellemgletscher with the Østre Gletscher at the southern (upper) end of the Kolossen ridge incorporates an unexplained feature, which is shown diagrammatically in Fig. 3. On the west side there is a distinct drop of about 10 m with a small ice-cliff.

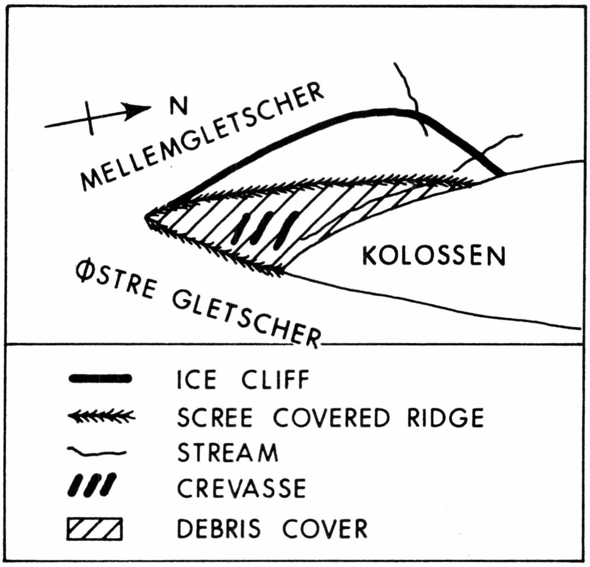


Fig. 3. Sketch map of the region of confluence of the Østre Gletscher and Mellemgletscher at the southern end of the Kolossen ridge.

Streams run into this depression and disappear, presumably becoming sub-glacial. On the east side the region is bounded by a scree ridge, which appears morainic, not apparently due to the presence of bed-rock. On the east of this ridge and depression are a small region of crevasses, moraine and a second scree ridge – apparently a continuation of the Kolossen, which bounds the Østre Gletscher. The only suggestion as to a possible origin is that the feature is a small snout of the Mellemgletscher formed by a fairly flat extension of the Kolossen ridge. The Mellemgletscher has now retreated away from this leaving the debris-covered ice in the centre. The formation of the second ridge is not satisfactorily explained by this suggestion. The depression is due to further 'recession' leaving a stagnant piece of white ice which is steadily ablating away.

There is no apparent change in ice-limit of the Mellemgletscher from the air-photos taken in 1949 though some thinning may have taken place over this period.

Vestre Gletscher

The Vestre Gletscher is a valley glacier of type I (Ahlmann, 1948), about 5 km long. The glacier is almost straight from its collection area to its snout. It is joined by one tributary from the south.

The glacier has prominent lateral moraines. The northern-most is the larger, and in the lower part of the valley is forced south to sweep round a rock ridge (map 2), which is covered with drift, and was at one time submerged beneath the ice. A small, tongue of the glacier between this bed-rock and the northern hillside has long since vanished leaving a partially stream-eroded valley. As the ice thinned to the level of the ridge the moraine was formed, running into the major lateral moraine of the confluent system. At a lower level, about half the height above the ice of this ridge, is a second ridge, which is also forced to the south, but this time by an obstruction farther up the glacier (see map 2). This appears to be a true moraine formed due to this second obstruction separating the ice from the first moraine ridge.

There is no terminal moraine due to the rapid retreat from confluence with the Mellemgletscher, and any deposit further down the valley would have been destroyed by the run-off river.

Comparison with the air-photo of 1949 indicates considerable retreat. In 1949 there was an exposed ice tongue bounded by two medial moraines which actually appeared to be in ice-contact with the Mellemgletscher. The ice is now $^1/_2$ km from the Mellemgletscher (map 2) and only relics of the medial moraines remain, probably no longer even ice-cored.

Retrætegletscher

The Retrætegletscher is a small valley glacier of type II (Ahlmann, 1948) about 1 km wide and 3 km long. There is one tributary from the south. The glacier occupies a hanging valley 100 m above the level of the Østre Gletscher. Behind this initial rise is a further steep rise of 100 m over which the glacier must have flowed. As suggested earlier the glacier is thought to have been superimposed on the Østre Gletscher at the time of confluence.

At the base of the snout is a series of lakes lying in a hollow behind the second rise. The rivers drain through a small ice ridge but do not yet empty the fairly shallow lakes. We can thus infer that the retreat of the glacier to its present position was fairly recent. Despite this the snout is steep (about 10°) and 'apparently active', but this may be due to the general steepness of the glacier, as many overall steep mountain glaciers appeared to have steep snouts.

Glacier in Oksedal

One glacier in Oksedal was also visited (see map 1). The glacier is of type II (Ahlmann, 1948) about 4 km long. As the terminal part lies in a narrow valley it was thought that it would be a good indicator of glacial change. In fact it proved otherwise as the outflow river is also confined within this valley and has removed most traces of previous advances.

The glacier has large lateral moraines which extend about 1 km down the valley beyond the ice edge. The moraines have two or (possibly) three different levels. These do not seem to be the result of recent slumping as suggested by Flint (1948) but appear to be due to slumping on to an ice surface existing at that level, which later retreated, leaving the terrace protected by its debris covering. These terraces thus probably mark a period of comparative stability. All but the upper (and possibly that also) are ice-cored. There is evidence, particularly on the 1950 air-photos, of a discontinuity in the lateral moraine, both in height and in texture, which resembles a surge, about level with the present ice-edge. About 200 m below the emergence of the run-off stream is a narrow gully through which the stream flows. The small ridge is the remains of a small former terminal moraine.

The river emerges sub-glacially from a tongue of moraine about 200 m long, formed by a debris train from a submerged (in ice) rock boss (Flint, 1948). The ice terminus is funnel-shaped due to a combination of the presence of the rock boss and the action of the surface run-off streams.

Comparison with the 1950 air-photos indicates no change in the position of the snout.

3. The Glaciers of the Skeldal District

Skeldal is dominated by Skelbræ and Bersærkerbræ and its southern half is filled with morainic and outwash debris from these two glaciers. However as this valley is the subject of an extensive geomorphological study carried out by Lasca (1969) we shall not discuss it in great detail but just consider the evidence of the recent glaciation.

Between the Bersærkerbræ and Skelbræ the outflow from the Skelbræ flows in a braided stream in the valley base. The floor is of fluvial material and a pair of strand lines show that the area was once a lake[1] dammed by the Bersærkerbræ glacier which blocked the Skeldalriver. The northern half of the valley is divided by a bed-rock ridge which runs parallel to the valley sides.

Bersærkerbræ

The Bersærkerbræ is a valley glacier of type II (Ahlmann, 1948) about 22 km long. The glacier has one major tributary from the Dunottar Gletscher (map 1), the Harlech Gletscher being nearly dead and the Tårnfjeld Gletscher now entirely separated (from the parent). Below the

[1] When first visited in early July, 1963, the valley was filled with lake ice indicating that after the river has frozen in winter the lake still forms.

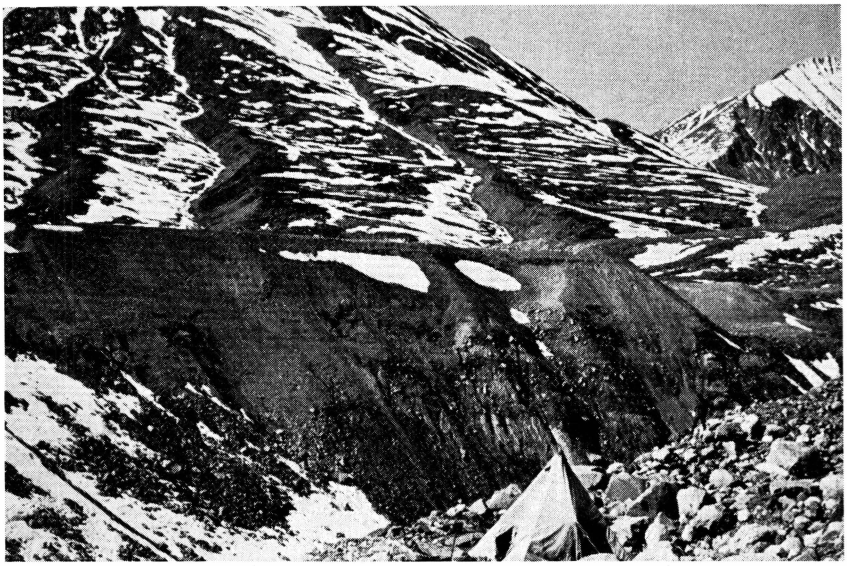
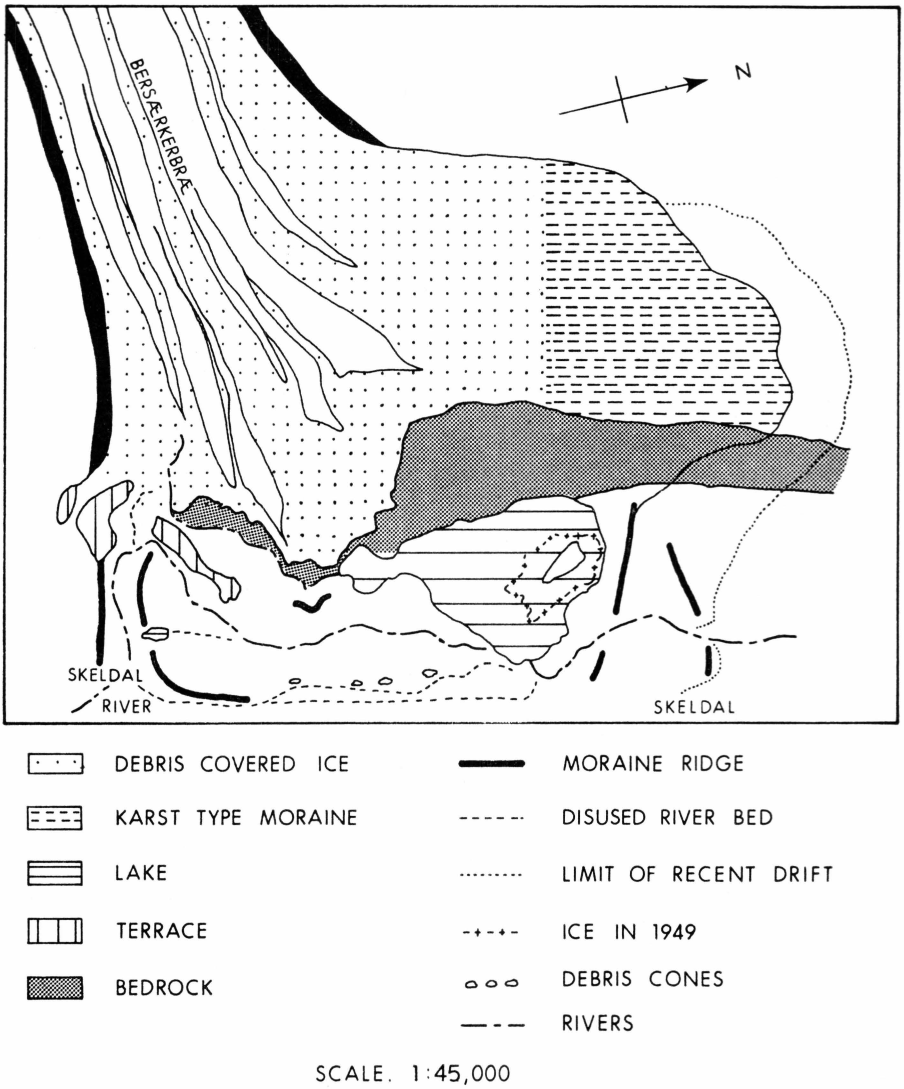


Fig. 4. Photograph showing the large terrace built on to the lateral moraine of the Bersærkerbræ. The gorge cut by the Skeldal river in the moraine can be seen in front of the terrace.

Tårnfjeld cwm the glacier turns to the east through about 30°. On the south side of the corner is a small ice-fall. The results of flow and ablation measurements made on this glacier will be discussed later.

The moraine of the Bersærkerbræ is complex and confused by much dead ice. The northern section of the glacier terminus is turned through 90° (to flow north) by the bed-rock ridge (map 3). This is now a mass of debriscovered dead ice which is decaying as a result of sub-glacial stream action. Beyond this is a section of recent moraine beneath which most of the ice appears to have melted. This latter region is marked by a number of lakes, presumably filling kettle holes. The southern section is more interesting and revealing. The glacier here was also turned north, but now only reaches about half way across the valley. Fresh moraine can be traced northwards as far as the moraine limit on the west side.

The evolution of the present Bersærkerbræ moraine system has involved three phases. A large scale advance of the glacier across the valley and northward obliterated traces of the earlier moraine and formed the outer push moraine near the limit of fresh debris. At this time the glacier dammed the Skeldal river forming a lake between the Skelbræ and the Bersærkerbræ. At the west side of the valley are two large terraces (Fig. 4) built on to the south lateral moraine, resulting from the discharge from the Bersærkerbræ over the lateral moraine and into the



Map 3. Map of the moraine of the Bersærkerbræ. Map based on aerial photographs flown by Geodætisk Institut in 1949.

main Skeldal lake. On the smaller terrace a number of strand lines are preserved in the loose material marking former heights of the lake (Fig. 5). The presence of these latter lines on the friable material indicates that the lake was fairly recent. As the terraces are built on top of the lateral moraine but do not reach much above it they would not require too great a time for construction. The whole system could thus date from a comparatively recent time. The outflow from the Skeldal

Fig. 5. A second terrace in the lateral moraine of the Bersærkerbræ. Notice the strand lines in the wall of the mound immediately behind the camp.

lake flowed marginally along the east side of the glacier forming the highest terrace (map 3).

Subsequently the glacier retreated and then advanced again to the second push moraine inside the earlier moraine. At this time the Skeldal river occupied the second terrace on the east side of the valley. Along this bed are a series of "kames" formed by debris slumping down ice-cliffs.

The glacier has since retreated with possibly one small recent advance or stationary state, forming the small mound of debris in front of the present ice-edge. As the glacier retreated the Skeldal river broke through the southern lateral moraine. The present river path which splits the moraine was originally an outflow river from the glacier into the lake flowing in the opposite direction. The large block of debris-covered ice in front of the snout was left by the retreating glacier near its last terminal moraine. If the block is assumed to have melted at a fairly uniform rate, we get a time of recession of about 100 years.

Comparison with the 1949 air-photos indicates little change in position of the ice-edge.

Skelbræ

The Skelbræ is not really one glacier but two which have ice-contact. The ice from the upper reaches near the Skelpas (denoted the "Southern"

Fig. 6. Air photo of Skeldal from the North West, taken in 1950. The moraine of the Bersærkerbræ (B) can be seen in the centre of the photograph. The Skelbræ (S) is on the right, with its twisted moraine structure clearly visible. Glacier B (G.B.) and Deltadal (D) can be clearly seen. Copyright Geodetic Institute (A44/68).

Fig. 7. Composite photograph of the snout of the Skelbræ. The distorted moraines can be clearly seen. On the right of the photograph is the edge of the silt push moraine. The second small ridge and the adjacent platform can be seen in the right hand half of the picture.

section) has its own terminus on the east side of the valley near the junction with the western ice which crosses and fills the lower part of the valley completely. A large medial moraine stretches across the valley marking the limit of the southern ice (Fig. 6). Behind this moraine the slope of the ice surface decreases and perhaps even becomes negative.

The northern section is fed from the two "tributary" cwms on the west. The ice sweeps round from these in a gentle curve to the snout (Fig. 6). At the snout is a long tongue of the medial moraine formed from the ridge separating the two cwms. At the snout the glacier apparently bends back on itself (Fig. 7); LLIBOUTRY (1958) has observed a similar feature on a retreating glacier in Chile but the phenomenon is not well understood. Despite the heavy debris cover of the present terminus there is little morainic deposit at the snout, as two large branches of the Skeldal river remove the debris as it is deposited. A prominent mound primarily of silt about 1 km below the present snout, presumably an old push-moraine (the surface being fluvial muds similar to those lower down Skeldal) marks the limit of fresh morainic drift. About $^{1}/_{2}$ km from the ice-edge a second smaller ridge (Fig. 7) is probably the result of slumping into the Skeldal lake; the adjacent platform indicates the presence of the lake at this period, when the Skelbræ was apparently stationary. As no further platforms are found behind this one, the lake drained soon after this time.

The lateral moraine on the west side is large and ice-cored. It runs alongside the ice but was pushed out from the valley walls by a former tributary, which in 1950 had ice contact with the Skelbræ but is now separated. One of the glacier outflow rivers emerges from beneath this moraine which consequently terminates level with the ice-edge. The eastern lateral moraine lacks an ice-core and in places the bed-rock is exposed through the debris; as the tongue of the "southern section" which lay between the present glacier and the valley wall was inactive and retreated rapidly leaving very little deposit. The eastern side of the glacier has been much eroded by the marginal river from the southern section which has removed much of the true lateral moraine of the glacier, (the medial moraine between the north and south sections) (Fig. 6).

Since 1950 the ice-edge has undergone slight modification, but the greatest change has been the retreat of the former tributary from confluence referred to earlier.

Glacier A

Glacier A is a valley glacier of type II about 3 km long and about 200 m wide.

The glacier lies between two large lateral moraines. The entrance to the valley is much covered with debris, but the glacier does not appear to have extended into Skeldal. The terminal moraine is not ice-cored. Behind the terminal moraine lies a flat platform about 400 m long, apparently underlain by ice as the run-off stream appears from a hole at its end. The lateral moraines rise about 100 m from this platform on either side. The southern moraine has an ice exposure near the end and the other also appears ice-cored.[1] The end of this platform is marked by a former stream bed and is followed by a section of moraine, initially steeply but progressively more gently sloping up to the ice edge about

[1] There are a number of benches on the lateral moraines, particularly on the southern, which are thought to be landslip benches as described by Flint, (1948).

Fig. 8. The snout of glacier A seen from the entrance to its valley.

100 m above the platform. The ice edge is marked by a marginal stream. The ice slopes steeply up at an angle of 17° for about 200 m before settling down to a general rise of about 12° at 200 m above the platform (Fig. 8). At this height the lateral moraines are only about 10 m above the ice. The glacier is split by a prominent medial moraine, relics of which could be traced in the platform.

The glacier gave the impression of having simply melted back to its present position. It is thought that the position of the former stream may mark a position of equilibrium during the retreat. There is no trace of a recent stationary period. Although the actual snout is steep, the glacier does not seem to be active, *c.f.* Retrætegletscher. The steep snout is probably a result of differential snow cover. When the glacier was visited the steep section was almost clear of snow (Fig. 8) while on the ice above there was a layer of old snow. At these altitudes (about 600 m) the overall snow cover only ablates slowly, however on the steep section there is little snow which is soon lost and ablation proceeds more rapidly.

Comparison with the 1950 air-photo indicates that a slight retreat has taken place, but it is difficult to estimate as the glacier is in partial shadow on the photograph.

Fig. 9. The snout of glacier B showing the prominent ice and dirt banding.

Glacier B

Glacier B is a cirque glacier about 1 km long and 0.5 km wide. The glacier has a steep snout (27°) rising 20 m in height. Two prominent debris bands (Fig. 9) have appeared across the snout since 1950. The quantity of debris contained in these bands is too great for them to be accumulation layers (Grove, 1960) in a region where there is little dust and the cirque has no head wall. It is more probable that the layers are active thrust planes. Morainic deposits stretch 100 m down the valley from the snout.

Fig. 9 taken at the end of August, shows that the region above the steep snout was still covered in snow, the ice exposure being almost unchanged since July, which probably accounts for the steep terminus. Unless ablation took place at a very rapid rate the glacier must still have had a considerable snow cover at the end of the season, which must be due to its north-facing aspect, for its snout altitude is only 700 m and the snow line on the Bersærkerbræ had reached that altitude by the end of July. This positive mass budget is probably the cause of the present activity of the glacier.

Glaciers C and D

These two complex valley glaciers will be discussed together as they were formerly confluent but have now separated. The glaciers have retreated from an old terminal moraine 2 km down the valley leaving prominent lateral moraines, particularly on the south side. There are no further moraines between this old terminus and the present snout, and the valley floor is filled with outwash.

Glacier C still extends into the valley leaving a complex mass of decaying debris-covered ice-relics of the medial and lateral moraines. Glacier D has retreated about 1 km up its own valley. Comparison with the 1950 air-photo indicates that glacier D may have retreated slightly over that time and glacier C now appears to have less white ice visible so that more ice has become debris-covered and thus dead.

4. The Glaciers of the Kap Peterséns District

This area comprises the glaciers of the Stauning Alper which face Kong Oscar Fjord. The glaciers are mainly north-facing and surprisingly, no cirques are to be found in the area. The area is primarily composed of metamorphic rocks which are being heavily weathered and result in large ablation moraines.

Skjoldungebræ

The Skjoldungebræ is the largest glacier in the North Stauning Alper. It is a valley glacier of type III about 28 km long. About 8 km from the snout there is a 90° bend to the east. At this point there is a subsidiary outlet leading to a small secondary snout.

The large push moraine at the primary snout faces an old outwash plain (Fig. 10). The stony surface of the outwash is not recent since it is covered with vegetation and present streams have cut their own beds to depths of 10–20 cm in it. The outwash continues down to the sea. The push moraine has several gullies cut into it by former streams but most are now dead and covered in vegetation. At the northern end of the plain is the present outwash delta. Cut 50 cm into the old outwash, the present major outflow river runs down to the sea. The river has cut a path through the terminal moraine and emerges at bed-rock about $1^1/_2$ km from the present terminus of the glacier. The exit of this river from the moraine is marked by several terraces (Fig. 10) at heights varying from 10–50 m, relics of previous sealevels. It is probable that the outwash plain was also once covered by the sea since near the lowest of these terraces whale bones and shells were found. However the vegetation cover shows that these terraces considerably predate the recent push moraine. Behind the push moraine is a region of decaying debris-covered ice extending back about 1 km, the debris cover gradually decreasing as the ice becomes more active. The region of dead ice is most extensive on the southern side of the snout. About $1^1/_2$ km from the

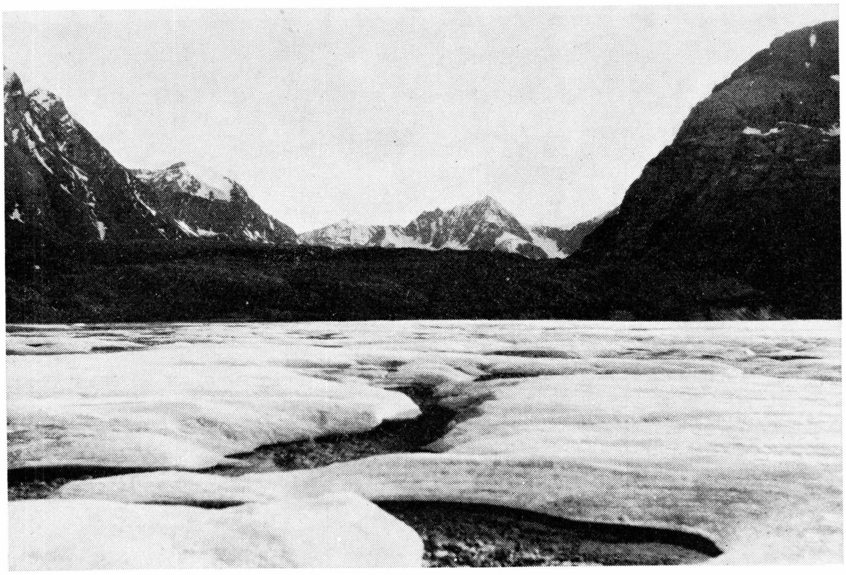


Fig. 10. The push moraine of the Skjoldungebræ near the exit of the outflow river. Notice the outwash plain in foreground, which is covered with snow. Photograph taken in 1930 – by courtesy of Norsk Polar Institutt.

terminus a small ice-fall is caused by a prominent outcropping ridge. Below the ice-fall, a small moraine running transversely across the glacier indicates the considerable slowing effect of the ridge.

The main run-off from the glacier is by the large river running between the lateral moraine and the northern valley wall. It now emerges from the ice at bed-rock, but immediately above its present exit is a former englacial river passage. The cavern is not very long for after a distance of 200 m a moulin opens out to the surface. However no trace of large scale surface drainage remains. The northern lateral moraine above the river exit is in three levels. The highest layer next to the rock wall is primarily of rounded stones, particularly near its termination. The middle layer is of mixed rounded and angular stones and the lowest of angular stones only. As the composition of the three layers is so different it is unlikely that they are solely a result of slumping, though it probably did take place. Below the river exit the lateral moraine is composed of rounded stones, similar to those in the higher regions. The origin of this rounded material was probably in a run-off river, which ran down the lateral moraine. The moraine is still ice-cored and is composed of large cones 30 m high, formed as a result of differential debris-cover which has caused the ice with smaller cover to melt. Near to these in a patch of exposed ice are a series of large dirt cones 10 m in height, the result of crevasse filling and differential ablation (fig. 11).

The southern edge of the snout of the glacier is much cut up by sub-glacial streams. The ice is heavily covered by ablation moraine and is decaying due to the action of the sub-surface water only. The lateral moraine has been largely destroyed by a marginal stream.

Further up the glacier the ice is very hummocky, presumably cut up by surface melt water.

The subsidiary snout to the north at the bend is very heavily covered by ablation moraine. The ice is decaying slowly by the action of sub-surface streams, but there is little surface melting on account of the thick cover of debris. There is a small terminal moraine about 200 m down the valley, but it does not appear to be of recent origin and there is no fresh moraine on the valley walls. It must therefore be concluded that the glacier has remained in a stationary position in recent years, though it has thinned considerably in this period.

Glacier E

This glacier is a small valley glacier of type III about 2 km long. The glacier is situated about 400 m above sea-level in the Syltoppene mountains. Two old vegetation-covered moraines line the valley reaching about half way down to the fjord. 1 km from the present snout is an old terminal moraine across the valley. Lateral moraines associated with this are thin but can be traced up to the present snout. The terminus of the glacier is very heavily covered with ablation moraine which does not permit much melting of the ice (Fig. 12). This has caused the snout to be very steep (35° slope compared with a general slope of the glacier of 11°) so that an exposed face of ice is presented. A small terminal moraine is being built up (Fig. 12) at the foot of the terminal cliff. This probably represents a slow advance of the glacier, though it could be due to deposition of the surface moraine at the base of the cliff by slumping. However as the height of the ice cliff is 10 m and the slope is 11° it is unlikely that the ablation of the steep northeast-facing cliff is sufficient to balance the flow.

The glacier thus appears to have reached a stationary position after a period of retreat from a previous maximum extent and may now possibly be slowly advancing.

Glacier F

This glacier is a small transection glacier about 11 km in maximum extent. Two prominent lateral moraines extend out of the valley about 2 km from the snout. At the end of the lateral moraines a system of morainic mounds resembling a small kame moraine is the remnant of a former push moraine after the ice core had melted out. The end moraine system appears to have a double structure similar to those of the

Fig. 11. Large dirt cone on Skjoldungebræ. Its scale may be gauged by comparison with the figure standing by it. The cone is probably the result of crevasse filling and differential ablation.

Fig. 12. The debris covered snout of glacier E. Notice the small ridge which has formed at the base of the steep exposed ice cliff.

Østre Gletscher and Bersærkerbræ, but unfortunately it is very difficult to separate one series from the other. Between this moraine and the present snout is a long outwash plain through which run two large streams. Large medial moraines are found on the glacier and relics of them may be observed in the debris in front of the snout. There is a small terminal moraine about 50 m in front of the present snout, but it does not extend across the glacier. On the north side, the lateral moraine is in two layers. The upper layer is old and dead and is cut by an old stream bed about 1 km from the snout. The lower, which is fresh and new, terminates at the break due to the old stream bed. The south side lateral moraine is made up of several layers, but is difficult to distinguish the medial moraines from it.

We believe that the glacier first retreated from its maximum and then probably re-advanced to a position just short of its previous (maximum) position. This was followed by a retreat almost to the present position where the snout became stationary for a short period. At present the glacier appears to be retreating again. Comparison with an air-photo indicates a slight retreat since 1950.

Linné Gletscher

The Linné Gletscher is a valley glacier of type III, about 15 km long. The glacier has a large terminal moraine built on bed-rock near the fjord edge, about $1^1/_2$ km from the present ice edge. As distinct from many of the terminals this is a single structure. A very prominent lateral moraine leads to the ice on the west side. On the east side the moraine cover is more sparse and probably not completely ice-cored. The east lateral moraine lies in two definite platforms. The lower platform is approximately level with the present surface of the glacier and leads down to a small group of mounds of drift about 400 m from the ice-edge. Further mounds are found spasmodically as the snout is reached. They are believed to be formed by slumping over an ice cliff at the snout and the first numerous group indicates a more active phase in the history of the glacier.

The glacier snout is partially debris-covered and initially rises slowly. The slope increases after 100 m to about 14° compared with a general slope of 7°, and the glacier appears more active. However the glacier seems to be retreating with a decaying snout. The lower platform of the lateral moraine indicates that thinning has accompanied the retreat.

5. An Estimate of the Mass Balance of the Snout of the Bersærkerbræ

In the previous sections we have considered the record of ice change as seen in the glacial relics left by the retreating ice fronts. In this section we will attempt to infer the current position from observations of ice flow activities and ablation rates made on a single glacier, the Bersærkerbræ.

It is shown in Appendix 1 that the total volume of ice φ flowing through a section of the glacier of width ω(m) is given approximately by:

$$\varphi = 42.5\, \omega V_s^{5/4} \Big/ \sin^{3/4} \alpha \text{ cu m/year}$$

where V_s is the surface speed in cm/day and α is the angle of slope of the glacier surface.

The accuracy of this calculation is limited to about 20 % due to the unknown importance of the bed-slip sliding process on the surface speed.

The calaculation also assumed a section of the glacier well away from the walls where the depth may be taken to be constant over the width of a section. Such a "tube of flow" may be defined by considering the region of glacier lying between two medial moraines, which can be expected to closely follow the surface flow profile.

In this case if the transverse surface flow profile is measured at a number of locations in the tube of flow, we may compare the ice flow through the profiles with the ice-melt due to ablation in the area between them. Thus if ω_1 and ω_2 are the distances between the moraines at the two flow profile locations and l the longitudinal distance up the glacier between them, the ice-loss ablation in one year is given by:

$$A = \frac{1}{2} l (\omega_1 + \omega_2)\, \bar{a}$$

$\bar{a}$ is the mean net ablation in the zone.

The techniques and results of the surface flow measurements on the Bersærkerbræ are given in Appendix 2. Ablation was also measured during the months of July and August at the stakes used for the surface flow measurements (Appendix 2). The stakes were drilled into position at the beginning of July when the summer thaw had just started and only the winter snow had melted off the glacier. Unfortunately the expedition had to leave the field at the end of August so that the ablation measurements must be extrapolated to the end of summer to obtain the total net ablation. This is almost impossible to achieve but an approximate value was obtained by multiplying the ablation for July and August by 5/4 to take into account September. The probable error in this procedure is about 10 % and certainly less than 20 %.

Results

In table 1 are shown the values of the minimum speed, moraine separation and slope at each transverse stake line. The quantities enable one to estimate a mass balance in the zones between the bottom line and snout. Probable errors are about 10 % in the ablation A and 20 % in the flux φ.

It should be noted that the mean annual velocity is assumed to be the minimum velocity measured. Values were measured over a two month summer period during which basal "lubrication" occurred. While it is not possible to estimate the extent to which this took place in winter, it is thought that on the upper two stake lines it only represented a perturbation to the shear flow. The minimum observed flow then is a reasonable approximation to the mean annual value. For the bottom stake line this does not seem to be a reasonable assumption and it is assumed that the flow is almost entirely due to basal slip. The formula given for the flux is not then a good approximation and the value of the flux for this line is probably greatly in error.

Table 1

1 (m.)	ω (m.)	S (sq.m.)	$\bar{a}_m$ (cm.)	A (cu.m.)	$\sin\alpha$	V_{min} (cm./day)	Ø (cu.m./yr/)
Top	400				.050	11.0	3.1×10^6
2432..		8.8×10^5	118	1.3×10^6			
Middle....	321				.052	9.8	2.1×10^6
1687..		7.1×10^5	185	1.6×10^6			
Bottom ...	517				.085	7.3	1.4×10^6
1950..		11.5×10^5	180	2.5×10^6			
Snout	660						

The flux difference in the zone between the upper two lines balance within the limits of error the total ablation occurring in the area. However this is not the case in the region below the middle line. Even if the flux through the middle line were taken at its maximum value there is still a deficit of 1.6×10^6 cu.m/year of ice which would represent a surface lowering of about 1 m./year, and cannot be accounted for in the errors inherent in the measurements and techniques.

Thus we see that on the avidence of the summer of 1963 there is a serious deficit in the mass balance of the snout of the Bersærkerbræ, though not of the upper regions. The difference between the two regions may well be due to the magnified effects of climatic change at the snout of a glacier as discussed by Nye (1960).

6. Discussion of the Glacial Variations

Before discussing the sequence of events which appear to have taken place in the North Stauning Alper we must analyse the overall picture described in the previous section. The following table (2) analyzes the present state of the glaciers and the structure of their moraines.

Table 2. *Number of Glaciers showing Terminal Changes.*

Present Position	*Definite*	*Probable*	*Total*
Retreating	4 (27 %)	3 (20 %)	7 (47 %)
Stationary	6 (40 %)		6 (40 %)
Advancing		2 (13 %)	3 (13 %)
Recent Glacial Change			
Outer terminal moraine shows double structure	6 (40 %)	2 (13 %)	8 (53 %)
Small terminal near to present ice edge	1 (7 %)	4 (27 %)	5 (34 %)

Thus the present position is in general one of a gradual retreat. The mass balance measurements on the Bersærkerbræ also indicate this recession. Although this glacier shows no ice retreat at its snout, there is no doubt that it has an overall ice balance deficit, so that it is in fact receding and thinning by about 1 m/year near its snout. The retreat is not as fast as it was but is still continuing. Many of the stationary glaciers have their ice-edge formed by river action and would not necessarily show retreat over a short period even if thinning of the ice is occurring further up the glacier.

The glaciers which may be advancing are both exceptional. Both are north-facing and have the ice in the ablation region covered for most of the year.

The presence of ice exposures in the old lateral moraines of several glaciers may be interpreted as evidence of a general climatic improvement. As mentioned earlier it is difficult to interpret this fact specifically. It could be a result of several factors:

(a) Increase of mean temperature (Thompson, 1957) raising the mean temperature below the debris above freezing.

(b) Increase of summer temperature, permitting greater melting to take place in the ice, sufficient to dislodge the debris.

(c) Increase in sunshine. Due to the dark nature of the debris, the heat from the sun will be highly absorbed, so an increase of sunshine due to a decrease of cloud cover will raise the temperature of the debris.

The first possibility may be excluded as the mean air temperature is too low and the sunlight insufficient to raise the mean temperature of the debris above freezing. The third possibility is also unlikely to be the cause of these ice exposures as East Greenland generally has good weather with little cloud cover. The second possibility requires an increase of the summer temperature. As the penetration of a diurnal variation is about 1 m in debris, 1 day is the shortest period of a temperature fluctuation which will reach the ice. The total melting per year is thus proportional to the product of the total number of days for which the mean daily air temperature is above freezing and the mean air temperature during this period. An increase in either of these quantities will increase the melting beneath the debris and the chances of forming an ice exposure. A further possibility is slumping due to the dislodgement of debris by melt water from the winter snows. It is thought that although this might account for one or two exposures it is unlikely to be the cause of all those observed. It is interesting that whereas four or five exposures in the old major moraines were found in 1963, none could be found in the air-photos of 1950.

The general picture of the recession is shown by the recent moraine structure. All the glaciers have large fresh lateral moraines which are much higher than the present ice-level, indicating that a large amount of thinning has taken place. In many cases a large push moraine can be associated with these laterals. Most of these moraines are ice-cored which, unless the debris layer is at least 10 m thick,[1] must be slowly decaying. As few of the moraines approach this thickness we must suppose they are fairly recent, *i.e.*, their life may be measured in hundreds rather than thousands of years. Thus all the glaciers have a similar outer moraine structure, which was caused by a large scale advance which obliterated most traces of earlier glaciation, subsequent to Pleistocene times.

This outer moraine is a double structure in a number of cases (Table 2) indicating that a second advance or a stationary period followed the major extension of the glacier after a period of retreat. In general a large scale retreat then followed which in some cases was recently interrupted for a short period.

[1] This figure is estimated from the thermal diffusivity of soil and a period of about 100 days in which the air temperature is above 0° C.

Ahlmann (1953) has shown that this pattern is typical of many regions throughout the world, and in particular the glaciers of the North Atlantic Coast. About 1750 there was a major advance of all the glaciers in this region which was followed by further advances during the years 1820–1850 and 1920–1930. It is suggested that this pattern was followed in the Stauning Alper.

We shall now consider the evidence for dating the various advances in this part of East Greenland. There is little evidence on which to base the dates of the fluctuations in the area studied and we must therefore investigate the neighbouring region.

There is a good deal of evidence of an advance about 1930. In the "Fiord Region of East Greenland", (Boyd, 1935), there are photographs of several glaciers to the immediate north of the Stauning Alper. Many of these appear more active than glaciers today (in particular one which has been compared with a 1950 air-photo) and although it was not explicitly stated it is suggested that three glaciers thoroughly investigated (Louise, Trident and Moraine-less glaciers) were actually advancing. Several other glaciers also appear to have been advancing in 1933 though few of the photographs are sufficiently detailed for a definite opinion to be made.

If we measure the rate of retreat of the Østre Gletscher since 1949 and assume the glacier retreated at the same rate prior to this date, we find that the glacier reached the most recent terminal about 1930. A similar result is found by extrapolating the retreat of the Frejagletscher (lat. 74° N) (Ahlmann, 1953). Prior to this the evidence becomes more scanty. Gribbon (1964) working in Schweizerland (lat. 66° N), where the general moraine structure is similar to that described here, (Bøgvad, 1931) found by lichen dating that the retreat away from the large lateral moraines began about 130 ± 20 years B.P., *i.e.* about 1830. As already mentioned the melting of the ice block at the snout of the Bersærkerbræ would give a rough estimate for this retreat of about 100 years. This indicates that the retreat from the major push moraine began about 1830–1850 and the inner ridge, if it exists, probably dates from this time.

There is no evidence to date the major advance and we can only compare it with the sequence shown in the remainder of the North Atlantic Coast area, which gives a date of about 1750 for the advance.

As will be realized these dates are extremely uncertain. It is unlikely that all the glaciers would show an exact time correlation so the dates where applicable, could differ by 20 years from glacier to glacier.

The general picture of recent glacial change in the Stauning Alper may be pictured as shown below.

1750		1830–50		1925–30	
Advance	Slow Retreat	Minor Advance	Retreat	Minor Advance or Stationary Period	Retreat Slowing to Present Day

which is very similar to the other areas of the North Atlantic Coast Line. (FITCH, *et al.* 1962).

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Acknowledgements

This work was carried out during the 1963 Imperial College East Greenland Expedition. The author owes a great debt to the other members of the expedition for their help in making the field trips which yielded these results.

The expedition was generously supported by numberous bodies of whom the Mount Everest Foundation and the Imperial College Exploration Board deserve special mention. Equipment was loaned by the Royal Geographical Society. Thanks are also due to all those nameless individuals who helped and contributed to the success of the expedition.

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Appendix 1

Calculation of the Mass Flow of a Glacier

The flow of a glacier down its bed is due to two different types of motion. At the base of the glacier a slipping motion due to a combination of ice creep, and pressure melting and re-freezing results in a flow of the glacier past obstacles on the bed (WEERTMAN, 1957; LLIBOUTRY, 1967). In addition, creep flow in the ice bulk takes place and causes a further mass transport; the creep flow of ice has been found to be described by the relation (GLEN, 1955):

$$\gamma = KT^n \tag{1}$$

where γ is the rate of shear, T the shear stress and K and n are constants. In the case where the ice is homogeneous throughout the glacier, NYE, (1965) has calculated the creep velocity distribution for a variety of bed profiles. If the width of the glacier is much greater than its depth, the velocity relation takes a simple algebraic form provided the surface compression rate is small (NYE, 1952). The velocity, v, at depth, h, being given by:

$$v = v_s - \frac{K(\varrho g \sin \alpha)^n h^{(n+1)}}{(n+1)} \tag{2}$$

in terms of the surface velocity v_s, the ice density ϱ, the surface slope α, gravitational acceleration g, and the constants K and n of equation (1).

The ice flux φ, through a section of glacier of unit width and depth h_0 is then given by:

$$\varphi = \int_0^{h_0} v \, dh = v_b h_0 + \frac{K(\varrho g \sin \alpha)^n}{(n+2)} h_0^{(n+2)} \tag{3}$$

where v_b is the basal slip speed given by:

$$v_s = v_b + \frac{K(\varrho g \sin \alpha)^n}{(n+1)} h_0^{(n+1)} \tag{4}$$

Eliminating h_0 from (3) and (4) and rearranging gives:

$$\varphi = \varphi_0 \left[n + 1 + \frac{v_b}{v_s} \right] \left(1 - \frac{v_b}{v_s} \right)^{1/(n+1)} \tag{5}$$

where

$$\varphi_0 = \frac{1}{(n+2)} \left[\frac{(n+1)}{K(\varrho g \sin \alpha)^n} \right]^{1/(n+1)} v_s^{(n+2)/(n+1)} \tag{6}$$

In experiments with ice crystals at temperatures from 0 to $-13°$C., GLEN (1955) found that $n = 3.17$ and that K varied with temperature. BUTKOVICH and LANDAUER (1958) found $n = 2.96$ from measurements on natural ice from North Greenland at $-5°$C. The dependence of the flux through the section on the basal flow velocity is shown in Table 3 where the ratio φ/φ_0 is shown as a function of v_b/v_s, the ratio of basal slip to the total surface flow of the glacier, for the value $n = 3$. It can be seen that except for exceptional cases, the flux is given with an error of less than 14 % by:

$$\begin{aligned} \varphi &= 3.5\,\varphi_0 \\ &= 42.5\, v_s^{5/4} / \sin^{3/4}\alpha \qquad \text{sq.m/year} \end{aligned} \tag{7}$$

where v_s is in cm/day and K ($= 0.863 \times 10^{-8}$, T in kg/cm^2 and γ sec^{-1}) is taken from the results of BUTKOVICH and LANDAUER, (1958).

Table 3

$\frac{v_b}{v_s}$ . . .	0	.05	.1	.15	.2	.25	.3	.35	.4	.45	.5
$\frac{\varphi}{\varphi_0}$ . . .	4	3.998	3.994	3.987	3.972	3.956	3.938	3.905	3.874	3.832	3.784
$\frac{v_b}{v_s}$ . . .	.55	.6	.65	.7	.75	.8	.85	.9	. 95	1.0	
$\frac{\varphi}{\varphi_0}$ . . .	3.725	3.659	3.574	3.478	3.359	3.210	3.019	2.885	2.341	–	

This result has been used to calculate the volume of ice flowing in a cross-section near the centre of the Bersærkerbræ. As the depth of the glacier is less than 200 m at all observation points and the width greater than 4500 m, the depth is always much less than the width and the surface speed near the centre of the glacier should be given by equation (2). The constants for ice deformation were taken from BUTKOVICH and LANDAUER as their experiments were carried out on naturally occurring ice, similar to that of the Bersærkerbræ. However, as the stresses involved are of the order of 1 bar, variations of the value of n from 2.96 to 3.17 make little difference to the final result. Similarly, little error is incurred by inaccuracy in the value of K as it only appears in (6) to the 1/4 power.

Appendix 2

Surface Flow Speeds and Ablation of the Bersærkerbræ

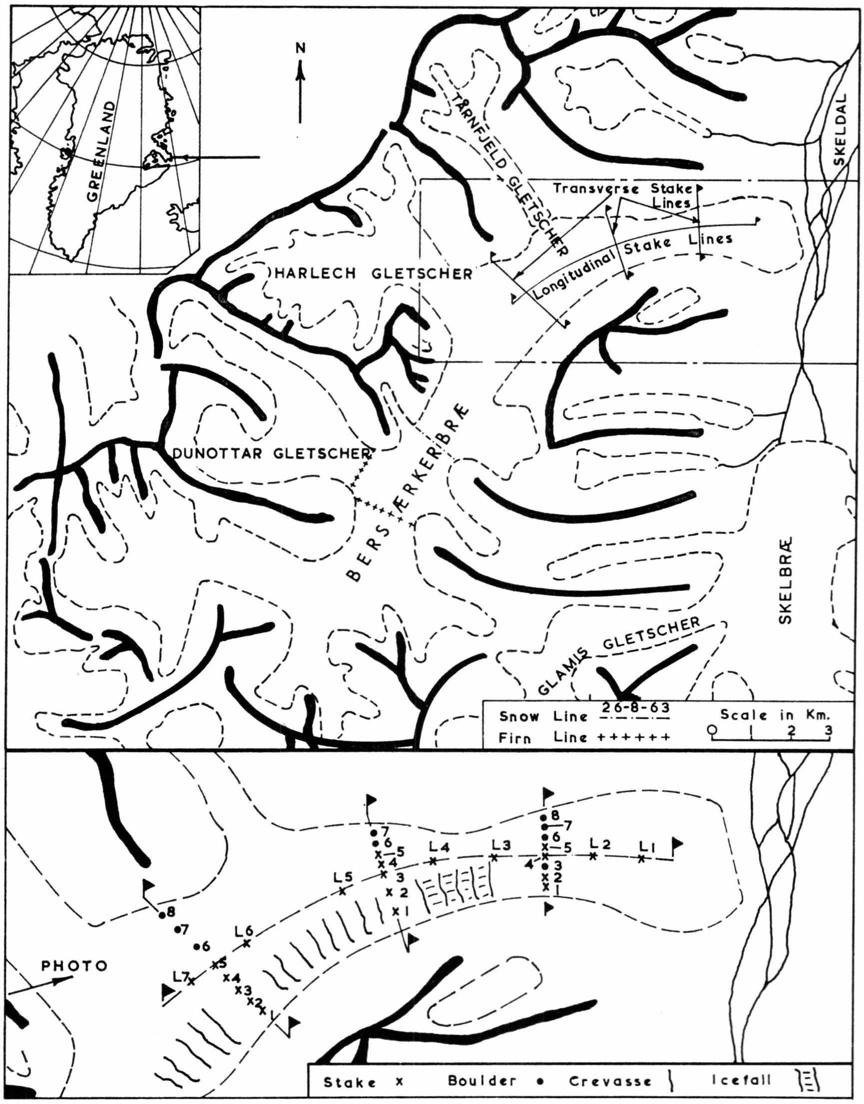
Three transverse and one longitudinal stake lines were established for surface flow measurements in the lower 7 km of the Bersærkerbræ. In this region the glacier flows round a bend as the valley turns east to join Skeldal. Map 4 indicates the positions of the lines. Two types of marker were used. On bare ice, 11 ft. pine stakes were drilled 8 ft. into the ice using a hand auger. This depth proved sufficient to avoid the necessity of re-drilling, only one stake (in the lower line) becoming loose in the last period of observation. On medial moraines small stones were used as markers in the transverse lines. These were painted with a cross, put in a small hollow and covered with a large stone. These markers proved very satisfactory and no disturbance was observed.

The movements of the transverse lines were measured by the offset technique. The displacements were directly measured along the direction of flow by taping from the line between two cairns, one on each side of the glacier. The stakes on the longitudinal line were surveyed from the two nearest cairns used for the offsets. The distances between the cairns were obtained from surveying a measured base line. Measurements of stake positions were made once during an eight-day period providing six sets of readings.

For practical reasons offsets were taken to the point where the stake entered the ice causing a systematic error due to ablation and non-vertical alignment of the stakes. The error of measurement in the transverse stake line was found to be 1 inch. Measurements of the longitudinal stakes were made to the top of the stakes with an error of less than 1 inch.

Ablation measurements were made at each stake and are shown in Table 5. The measurements were made by taping the distance from the top of the stake to the neighbouring ice surface.

The correlation between surface flow and ablation rate has been discussed elsewhere (Friese-Greene & Pert, 1965) and indicates that although bed-slip occurred, its effects were small (and thus the analysis of Appendix 1 is valid) for the upper and middle stake lines.



Map 4. Map of the Bersærkerbræ showing the positions of the cairns and stakes used in the surface flow, ablation and surface profile measurements.

The strain rates measured from the longitudinal line displacements were:

Upper stake line	0
Middle stake line	< .01
Bottom stake line	.025/year

and were small.

Table 4

Date	Bottom Stake Line								Middle Stake Line							Top Stake Line							
	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	1	2	3	4	5	6	7	8
July 7	..	..	..	0	0	0	0	0	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
8	0	0	0	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
9	..	..	..	..	..	..	..	..	..	..	..	0	..	..	0	..	..	..	..	..	..	..	..
10	..	..	..	..	..	..	..	..	..	0	0	..	..	..	..	..	..	..	..	..	..	..	..
11	..	..	..	..	..	..	..	..	0	..	..	..	..	..	..	..	..	..	..	..	..	..	..
13	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	0	0	0
15	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	0	0	0	0	0	..	..	..
16	12	20	27	31	29	35	28	20	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
19	..	..	..	..	..	..	..	..	46	60	63	65	0	0	20	..	..	..	..	..	..	..	..
21	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	24	38	42	43	50	60	32	7
24	23	44	50	66	59	66	53	37	66	84	87	85	19	11	26	..	..	..	..	..	..	..	..
28	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	43	66	72	74	77	88	47	8
Aug. 2	35	67	78	92	99	97	79	57	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
3	..	..	..	..	..	..	..	..	110	133	140	140	165	40	40	64	100	110	114	128	127	69	12
14	46	97	120	132	130	137	110	81	158	192	198	190	116	70	58	..	..	..	..	..	..	..	..
15	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	98	156	169	174	185	188	94	12
22	62	126	142	155	157	159	130	92	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
23	..	..	..	..	..	..	..	..	186	228	232	226	146	90	64	..	..	..	..	..	..	..	..
24	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	120	195	209	216	236	234	118	16

Displacements of the markers in inches

(continued)

Table 4 (cont.)

Date	Longitudinal Stake Line						
	L_1	L_2	L_3	L_4	L_5	L_6	L_7
July 8	..	0	0	..	..	..	..
11	..	..	..	0	0	..	..
15	..	..	..	..	..	0	0
16	..	..	..	..	..	..	..
19	0	35	87	..	..	..	..
20	..	..	..	66	55	..	..
22	..	..	..	..	..	49	57
24	5	46	112	90	74	..	..
28	..	..	..	..	..	74	85
August 2	25	71	157	..	..	..	..
3	..	..	..	148	125	109	124
14	51	102	199	217	177	..	..
15	..	..	..	..	..	169	183
22	66	122	237	..	..	..	..
23	..	..	..	262	215	..	..
24	..	..	..	..	..	207	226

Table 5. *Ablation readings*

Date	Stake Line Bottom				Middle Stake Line				Top Stake Line					Longitudinal State Line						
	1	2	4	5	1	2	3	5	1	2	3	4	5	L_1	L_2	L_3	L_4	L_5	L_6	L_7
July 7	0	0	0	0	..	..	..	..	..	..	..	..	..	0	0	0	..	..	..	..
9	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	0	..	..	..
10	..	..	..	..	..	0	0	..	..	..	..	..	..	..	..	..	..	..	..	..
11	..	..	..	..	0	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
13	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	0	0
15	15	14	13	13	..	..	..	..	0	0	0	0	0	..	..	..	..	..	..	..
19	..	..	..	..	16	15	17	0	..	..	..	..	..	..	..	..	..	..	..	..
21	..	..	..	..	..	..	..	..	12	12	12	13	16	..	..	..	..	..	..	..
24	32	31	30	30	22	21	23	7	..	..	..	..	..	..	..	..	..	..	..	..
26	..	..	..	..	..	..	..	..	..	..	..	..	..	28	24	45	..	0	16	18
28	..	..	..	..	..	..	..	..	19	18	18	20	24	..	..	..	..	..	..	..
Aug. 2	50	48	46	43	..	..	..	..	..	..	..	..	..	38	36	57	..	..	..	..
3	..	..	..	..	37	36	33	22	30	34	32	32	36	..	..	..	42	9	26	28
14	72	68	66	65	57	51	46	40	..	..	..	..	..	..	..	..	..	..	..	..
15	..	..	..	..	..	..	..	..	45	43	48	48	52	..	..	80	..	..	..	..
22	80	74	73	72	..	..	..	..	..	..	..	..	..	70	66	86	..	..	..	..
23	..	..	..	..	64	66	50	46	..	..	..	..	..	..	..	..	66	25	..	..
24	..	..	..	..	..	..	..	..	50	48	56	62	58	..	..	..	..	..	42	49

Measurements in inches.

Appendix 3

Surface Height Profiles of the Bersærkerbræ

To provide a datum for future study of the ice loss of the Bersærkerbræ, the surface height profiles were measured along each of the stake lines. Three profiles were measured tacheometrically across the glacier between the base of the cairns at each end of the stake line. The results of these measurements are shown in Tables 6, 7 and 8 where the height and distance are measured from the base of the cairn on the southern bank of the glacier. Distances to significant surface features on the glacier are also given. The accuracy of these profiles is estimated at greater than 0.5 $^0/_0$.

A longitudinal profile was also measured along the line of the longitudinal stakes using a chain and aneroid. The traverse was started near the ice-cliff terminating the glacier and marked by a cairn. Heights and distances are given relative to the cairn; however, fixed datum points for the profile are provided by the appropriate stakes in the transverse lines, which can be related to the height of the fixed cairns. Accuracy of this profile is estimated at better than 1 $^0/_0$. The results of the survey are shown in Table 9 where the bearing of the profile is also given. Comparison between the measured profile and one taken from the aerial survey map of 1933[1] shows substantial surface lowering in this period. However it is thought that accuracy of the map is insufficient to allow any conclusions to be drawn on the degree of lowering.

[1] Sheet 72Ø2 published by Geodetic Institute, Copenhagen, 1938.

Table 6

Bottom Stake Line		
Remarks	Cumulative Dist. (Feet)	Ht. Above Datum (Feet)
Cairn C_1	0	1000.0
Moraine...........	38	994.5
Edge of red moraine	194	918.3
Top of red moraine	349	928.5
Moraine...........	492	869.1
Moraine...........	640	826.2
Sidestream	846	797.8
	935	807.0
(1) Flag	988	809.3
	1178	820.9
	1290	832.9
Thin moraine	1449	837.1
	1603	837.6
(2) Flag	1818	852.3
	1989	861.3
Edge of moraine ..	2202	863.0
(3) Boulder	2352	905.2
Edge of moraine ..	2511	855.1
	2771	876.5
	3026	894.3
	3124	889.5
(4) Flag	3305	890.8
	3451	895.4
(5) Flag	3556	899.2
Edge of moraine ..	3771	895.6
(6) Boulder	4038	945.8
Edge of moraine ...	4115	914.5
Edge of moraine ...	4258	896.8
Moraine...........	4418	913.0
Moraine...........	4496	896.4
(7) Boulder	4687	919.5
Moraine...........	4784	922.9
(8) Boulder	4949	890.6
Moraine...........	5160	884.1
Moraine...........	5379	932.2
Top of lateral moraine	5620	1065.2
Cairn C_2	5750	1109.2

Table 7

Middle Stake Line		
Remarks	Cumulative Dist. (Feet)	Ht. Above Datum (Feet)
Cairn C_3	0	1000.0
Moraine...........	177	977.1
Moraine...........	320	928.0
Moraine...........	474	920.2
Moraine...........	584	900.6
Moraine edge	774	886.7
	1008	913.8
(1) Flag	1208	917.5
	1424	922.4
	1646	921.4
	1796	922.4
(2) Flag	1954	924.4
	2092	914.7
Very thin moraine .	2246	908.8
(3) Flag	2553	894.9
	2737	881.2
	2937	884.3
Edge of moraine ..	3091	877.1
(4) Boulder	3300	896.7
Edge of moraine ...	3416	879.1
	3568	891.9
	3769	848.8
(5) Flag	3892	885.1
Edge of moraine ...	3997	885.6
(6) Boulder	4172	898.8
(7) Boulder	4347	882.2
	4506	890.4
Cairn C_4	4670	925.5

Table 8

(cont.)

Top Stake Line			Top Stake Line		
Remarks	Cumulative Dist. (Feet)	Ht. Above Datum (Feet)	Remarks	Cumulative Dist. (Feet)	Ht. Above Datum (Feet)
Cairn C_5	0	1000.0		3278	965.7
Base of buttress...	7	986.9		3374	955.5
Edge of scree	163	942.3		3479	961.1
Top of moraine ...	354	956.5	Edge of moraine ...	3626	964.4
Edge of moraine ...	539	939.3	(6) Boulder	3672	977.3
(1) Flag	648	949.1	Edge of moraine ...	3706	970.3
	806	942.0		3872	971.0
Stream	955	935.3		4080	970.0
	1029	939.8		4173	972.6
(2) Flag	1167	951.9		4382	963.6
	1272	953.4	Edge of moraine and		
	1385	959.5	big stream	4512	954.5
	1647	966.1		4753	1005.1
(3) Flag	1847	966.6	(7) Boulder	4801	976.8
	1942	968.2		4893	951.1
	2280	959.3		5057	916.1
Small flat moraine.	2359	961.1		5118	923.7
(4) Flag	2410	959.7	Edge of red moraine	5239	910.4
	2578	961.5	(8) Boulder	5340	929.1
	2761	965.3	Edge of red moraine	5411	903.5
	2862	963.0		5552	962.1
(5) Flag	2950	965.0		5690	938.1
	3146	969.7	Cairn C_6	5944	1093.3

(continued)

Table 9

Longitudinal Stake Line Height Traverse

Remarks	Cum. Dist. (Yards)	Height (Feet)	Bearing (°Magnetic)
Bottom cairn . .	0	0	300°
	100	48	
	200	84	
	300	109	
	400	133	
	500	166	
	600	198	
	700	223	300°
	800	240	
	900	266	
	1000	284	
L_1	1100	311	305°
	1200	332	
	1300	356	
	1400	385	
	1500	400	
L_2	1550	–	
	1600	423	
	1700	447	
	1800	471	
	1900	497	
(4)	1970	–	305°
	2000	518	
	2100	564	
	2200	586	
	2300	612	
	2400	641	
	2500	669	
L_3	2600	705	310°
	2700	740	
	2800	773	
	2900	801	
Crevassed region starts . . .	3000	827	
	3100	844	
	3200	901	
L_4	3300	922	
	3400	949	

(cont.)

Longitudinal Stake Line Height Traverse

Remarks	Cum. Dist. (Yards)	Height (Feet)	Bearing (°Magnetic)
	3499	972	
	3598	1000	
End of crevassed region .	3697	1012	
	3796	1037	
(3)	3816	–	275°
	3895	1018	
	3994	1054	
	4093	1080	
	4192	1097	
	4291	1113	
L_5	4340	–	280°
	4390	1132	
	4489	1130	
	4588	1155	
	4687	1169	
	4786	1188	
	4885	1199	
	4984	1213	
	5083	1228	280°
	5182	1249	
	5281	1262	
	5380	1281	
	5479	1297	
	5578	1312	
	5677	1326	
	5776	1331	
L_6	5865	–	270°
	5875	1358	
	5974	1367	
	6073	1385	
	6172	1395	
	6271	1404	
	6370	1438	
	6469	1448	
(5)	6476	–	270°
	6568	1465	
	6667	1470	
L_7	6766	1483	

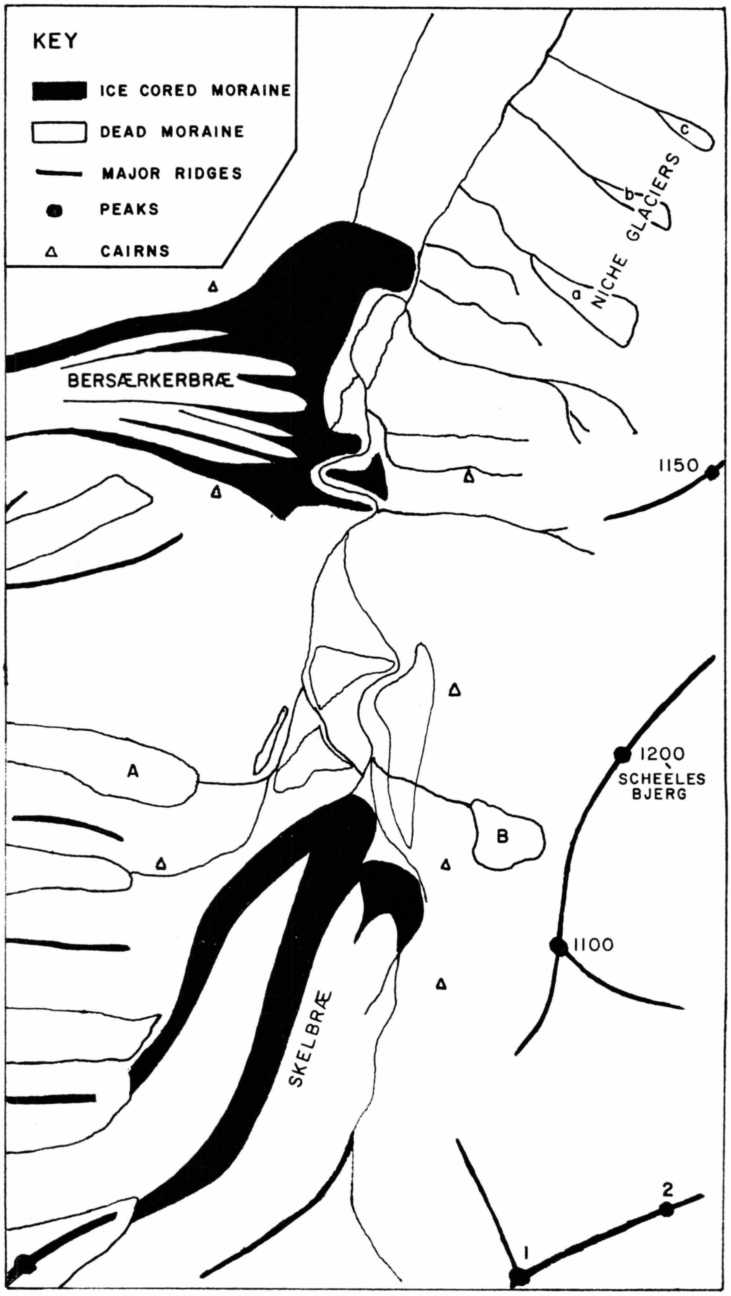
(continued)

Appendix 4

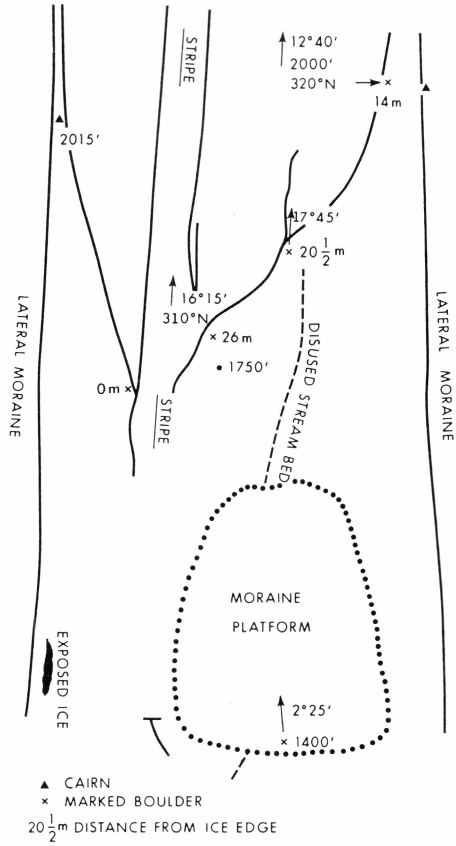
Measurements of the Snout Positions of Glaciers in the Stauning Alper

In order to provide a record on the position of the snout of the glaciers in 1963 the glaciers were photographed from fixed cairn positions. For selected glaciers distances were taped off from the ice-edge to marked boulders and the slope angle, azimuth (magnetic) and altitude of the snout measured. Details of these measurements are given below.

Østre Gletscher	Photograph from prominent terrace below Kollossen ridge.
Mellemgletscher	Photographs from ridge leading to bedrock spur on west of glacier.
Vestre Gletscher	Photographs from summit of moraine mound on north of glacier.
Glacier in Oksedal	Photographs from cairn above west lateral moraine at side of prominent gulley.
Bersærkerbræ	Photographs from three cairns, positions shown on map 5. East cairn was about half way up the hill on the south of a gulley. South cairn was on a prominent platform above the moraine. North cairn was on the extreme eastern rock outcrop above the glacier.
Skelbræ	Photographs from three cairns shown on Map 5. West side on a small rock ourcrop level with ice-edge. East side (north) prominent cairn on valley side in line with old terminal moraine. East side (south) at top of moraine debris in line with ice-edge.

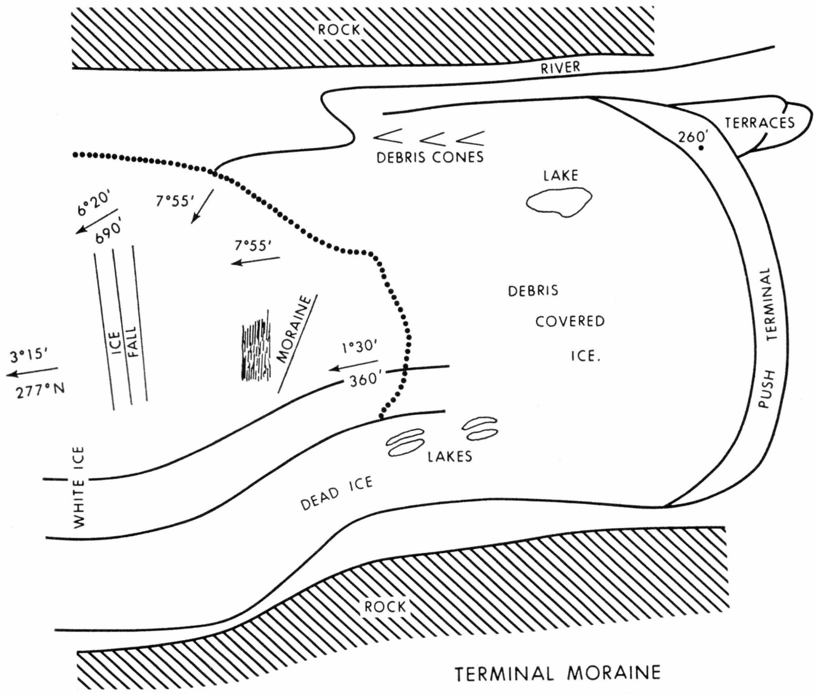


Map 5. Sketch map of Skeldal showing the location of the photographic cairns in the valley. The moraine structure of the Skelbræ is also shown.



Map 6. Sketch map of the snout of Glacier A showing the position, altitudes above sea level (in feet), slope and azimuth (°N. magnetic) of the significant features. The distances (in metres) from the ice-edge to fixed markers (boulders) is shown.

Glacier A	Measurements of slope angle, altitude, bearing and position of marked boulders are shown on sketch map 6. Altitude of lowest point of ice-edge 1750 feet above sea level.
Glacier B	Photographs from cairn on top of level buttress below glacier snout on morth. Altitude of ice-edge 2200 feet above sea level. Angle of snout $27^1/_2$°; of glacier 15° Azimuth 163° N. Position of ice-edge from marked boulders: South boulder (3) .... 8 metres Centre boulder (1) .... 13 metres North boulder (2) .... 6.30 metres.



Map 7. Sketch map of the principal snout of the Skjoldungebræ showing slope, altitude (in feet above sea level) and azimuth (in °N. magnetic) of significant features.

Glacier C	Photographs from two cairns. South on top of old moraine just below buttress of conglomerate. North on large boulder above red-coloured moraine level with snout. Angle of snout: 23°; of glacier: 4°; of bedrock: $3^1/_2$° Altitude of ice-edge 1330 feet above sea level Azimuth 290° N.
Skjoldungebræ	Major branch: Photographs from two cairns. South on a rock spur above snout. North on a sandstone outcrop (yellow) below gulley separating yellow rock from dominant grey buttress. Altitudes and surface slopes of dominant features are shown in map 7. West branch: Photographs from cairn on prominent black outcrop below yellow cliff. Altitude of ice-edge: 740 feet above sea level.

Glacier E	Photographs from two cairns. West on prominent conglomerate outcrop in red scree gulley below white cliff. East on moraine ridge near top. Angle of snout: 37°50′; of glacier: 10°35′; of bedrock 14°25′. Altitude of lowest point of ice-edge: 1150 feet above sea level. Azimuth 270° N. Distance from ice-edge to marked boulders: From east: Boulder 1: 8 metres Boulder 2: 19.90 metres Boulder 3: 13.40 metres Boulder 4: 8.20 metres.
Glacier F	Photographs from two cairns. North: on a small ledge about 20 yards from edge of clean rock at 900 ft. altitude – (difficult to find). South: on lateral moraine in front of and slightly behind two prominent mounds.
Linné Gletscher	Photographed from cairn on top of the east lateral moraine above ice-edge. Angle of snout: 13°55′; of glacier: 7°; of bedrock: 1°35′. Altitude of ice-edge: 470 feet above sea level. Azimuth 192° N.

Niche Glaciers in Skeldal (Map 5)

Visited 18th July, 1963.

a. Snout altitude 540 feet above sea level.
Distance from snow/ice-edge to marker: 14 m.

b. Snout altitude 570 feet above sea level.

c. Snout altitude 600 feet above sea level.
Distance from snow/ice-edge to marker: 34 m.

Færdig fra trykkeriet den 10. maj 1971.