BERNARD LEFAUCONNIER and JON OVE HAGEN

SURGING AND CALVING GLACIERS IN EASTERN SVALBARD

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Foreword

The increased activity in the Barenst sea associated with to exploration and potential future oil/gas drilling activity has given a growing interest in the variable iceberg occurrence in this area. It was with this background that the Ice Data Acquisition Program (IDAP) Committee of the OKN (Operatørkomite Nord) asked the Norwegian Polar Research Institute to carry out a program to review past calving and surging glaciers in the eastern part of Svalbard that could affect the Barents Sea. OKN is a committee consisting of members from eleven different oil companies with interests in oil exploration.

Many glaciers located on the eastern area of the Svalbard Archipelago have the potential to produce icebergs that could affect offshore opearations in the Barents Sea. The main task of this work was therefore to review a list of potential future surging glaciers that could be considered as sources of icebergs in the Barents Sea. This should be done through a mapping of former front positions of the glaciers. The mapping was performed through analysis of all available aerial photos as well as satellite images and through literature search. Unfortunately the new aerial photos from 1990 were not available until late spring 1991 when this work was finished. However, satellite images have given a fairly good estimate of the front positions that exist today. The historic literature available at NP has provided many valuable discriptions and map positions from the end of the last century, up to fifty years before the first aerial photos became available.

Because this information provides knowledge about past surges and surge cycles on many different glaciers we decided to extend the work to cover all calving glaciers in the eastern area of Svalbard, not just the limited number of large glaciers requested from the IDAP-committee. In addition to the front variations, we decided to study the change of glacial and proglacial morphology. A review such as this is of general interest in the study of surging glaciers. The triggering process of surges is not yet fully understood. We need more field information about surging glaciers. These periodic fast flowing glaciers are of great importance for the understanding of the discharge of ice from the interior of the great ice caps in Greenland and Antarctica. Knowledge about surging glaciers will therefore have implications when modelling the response of great ice sheets to predicted climatic change. Thge review also gives information about the short time respons of the glaciers to the current climate.

We are grateful for the support from the IDAP-committee under OKN that financed most of this study. The result is reported to them in an internal report "IDAP 89 - Analysis of NP photography - Surging and calving glaciers". We are grateful to Olav Liestøl who was engaged as a glaciologist at NP for forty years. He has contributed information about historic references and allowed us to use his unpublished front position sketches. We also thank Mona Bendixen who draw the maps and Howard Parker who corrected the English text.

What is a glacier surge ?

Generalities.

Glacier surge is a dramatic increase of glacier motion up to a hundred times the normal flow rate. The surge results in the transportation of a great volume of ice from the higher to the lower part of the glacier, usually accompanied by a rapid advance of the glacier front. The phenomenon repeats itself in roughtly constant periods characteristic for each glacier. The periods may vary from 30 to more than 100 years, and the typical duration of a surge is from 1 to 3 years (Meier & Post 1969). The phenomenon seems to be most common in subpolare glaciers (with temperate and cold parts), but temperate glaciers (T at 0^0 C throughout), polare or cold glaciers (T $<0^0$ C throughout) can also surge.

Glacier surges occur independentely of climatic variations, only the surge period is affected by climatic forcing.

In a normal non-surging glacier there is balance between accumulation in the upper part of the glacier and the ice transport/ice flux down to the ablation area. Hence the glacier maintains a constant (steady state) longitudinal profile. In a surging glacier, however, the flow rate and hence the ice flux, is too low to maintain the steady state profile. When the ice flux is significantly less than the accumulation the possibility of a surge exists. The surface gradient gradually increases, causing the basal shear stress to also increase. When the shear stress reaches a critical, but unknown, value the surge commences and the sliding velocity increases rapidely (Meier & Post, 1969).

The ice velocity in a surge varies with different glaciers; 2-5 m/d is common, but up to 100 m/d has been recorded at Bruarjøkulen, Iceland (Thorarinson 1969). Due to the great sliding velocities, the basal ice must be at melting point during the surge (Paterson 1983). Increased heat due to friction results in a corresponding increase in production of water which in turn functions as a lubricant to control the sliding velocity, maintening and lowering the gradient even more effectively than a non surging glacier in a steady state profile. The upper part of the glacier is usually lowered by 50-100 meters while the lower part is thickened by the same amount or even slightly more. After the surge the lower part stagnates and is thinned by melting while the upper part is thickening by accumulation.

Glacier registration indicates that 90% of Svalbard's glaciers are surging. Surges have been dated on more than 80 glaciers, but several must have surged in unknown years. For some of these glaciers the change of longitudinal profiles and front positions have been recorded.

Surges occur on all types of glaciers, from small inland glaciers to large calving, tide-water glaciers. Typical longitudinal changes are shown in Fig. 1, where A is an example of a calving glacier and B a valley glacier terminating on land. The largest surges in Svalbard took place at approximately the same time, the Negribreen in 1935-36 and the Bråsvellbreen in 1937-38. The Negribreen advanced almost 12 km into the fjord in one year along a 15 km wide section of the front. The Bråsvellbreen advanced 20 km into the sea with a 30 km wide front. These glaciers are both described in this report.

When a glacier surges into the sea, a large number of icebergs are produced during the active advancing period. The icebergs are numerous and of various scale. During the period after the advance, the activity is less and the number of icebergs decreases, although the iceberg size may remain very large.

Characteristic features, both on the glacier and on the landscape, are formed by surging glaciers, and when preserved these formations provide evidence of earlier surge. Folded median moraines and frontal change as shown in Fig. 1 C are typical post-surge features. Folded frontal moraines after a strong push may occur on glaciers ending on a sandur plain close to sea level as on Usherbreen (Fig. 2 B). Figs. 1, 2, 3, 4 and 5 show some typical surging glaciers and features.

Criterions used to determine a surge:

1) Sudden variation in the front position with an important advance of the glacier (Figs. 1 and 3).

2) Presence of numerous long and parallel crevasses on a very large part of the basin (Figs. 1, 2, 3 and 5).

An active glacier may display such crevasses on the tongue. To be defined as a surge, these crevasses have to be present continuously higher up in the basin. Some of the glaciers studied here show such crevasses on the air photos from 1936 until 1970-71, such as Vasilievbreen, Buldrebreen, and other ice-streams on the eastern part of Valhalfonna. In each case the information available was insufficient to determine whether these crevasses had subsisted from past surges during more than 50 years , or had been reactivated. In the case of Vasilievbreen they probably were reactivated by the surge of a small tributary, but not in the case of Valhallfonna.

3) Presence of crescentic crevasses in the upper basin, especially close to the mountain slopes and often associated with a visible depression of the ice surface (Figs. 1 and 3).

Adjacent to mountain slopes, in Svalbard and in temperate regions as well, a very long crevasse called "rimaye" or "bergschrund" is usually located. This consists of one, two or three cracks only and the presence of more crevasses usually indicates the occurence of a recent surge. These cracks usually occur together, with a depression of the ice surface visible along the mountain slope. Sometimes the different elevations between one basin after a recent surge and one where no surge occurred is well visible.

4) Front and lateral surface with a well marked convexity, if possible associated to one or two other criterions or visible at a date following observation without such features (Figs. 1 and 2).

When a glacier is in a growing phase related to positive climatic conditions, its front and sides close to the front are convex. However, the sudden appearence of such convexity is due to a surge. In this study the occurence of a surge is based upon convexity together with other criterions or convexity alone if preceeded by an observation without visible convexity, (e.g. during a period of glacial decay).

5) Change in the width of ice-streams (Figs. 1 C and 3).

The tributaries of a glacial ice stream usually reached an equilibrium between them and have regular ice flows. In the lower basin the contact between two ice streams may be easily observed, especially when they are carrying a median moraine. A displacement of this boundary along the glacier width means a change in the relative value of the ice streams. A surging glacier will spread out its own ice mass and thus extend the width of its ice stream. Some years later the adjacent glaciers will regain their previous level of flow some times more as the surging glacier may weaken following the surge. This criterion is of the same type as the following.

6) Presence of median moraines with a folded shape (Figs. 1 C and 4).

When non-surging tributaries are of small or medium size, their flows may be completely stopped during the period of surge and the lateral moraine between them and the surging glacier may become laminated and pined against the glacier side. When the surge stops, the tributary will again flow. The front of this flow will form a lobe inside the ice mass of the previously surging glacier, and the mediane moraine will take a folded form. This phenomenon was previously described on Svalbard glacier by Gripp as early as 1929.

7) Presence of frontal moraines of the Usherbreen type (Figs. 2 B and § 21).

Usherbreen has been well studied by Hagen (1987). This glacier posseses the peculiarity of having several concentric morainic crests at the front which portray an aspect of waves. Some of these have a core of ice. According to Hagen they are formed from older moraines removed during an advance of the glacier under the following specific conditions: a) permafrost is present in front of the glacier, b) there were morainic deposits before, c) proglacial deposits will not be removed in such concentric crests, d) the push from the glacier has to be sudden, as from a surge. A usual climatic advance will rebuild the frontal morainic sediment as one main huge moraine associated with rounded and slipped deposits along its own external slope.

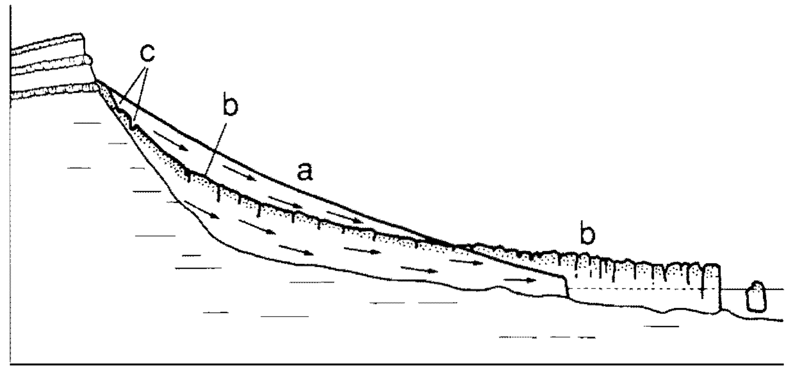
Criterions used to define the maximum extension

1) The extension of the observed front may correspond to the furthest morainic submarine vallum (end moraine) on maps.

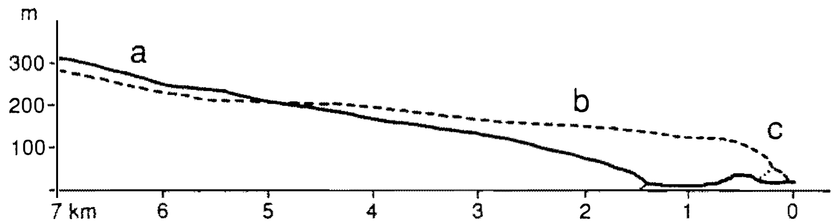
2) Lateral moraines and part of frontal moraines may or may not be situated in an outermost position in the moraine deposit. That is not always easy to determine. In fact, it is necessary to analyse the morphology of the moraines in order to determine whether the last moraine deposited has, or has not touched previously deposited moraines. A better determination is obtained with identical results along the mountain slopes, on the piedmont and if possible in the sea.

Freemanbreen is a good exemple. On the shore it is possible to identify two different and concentric morainic deposits, and on the marine map two submarine vallums at distances

A



B



C

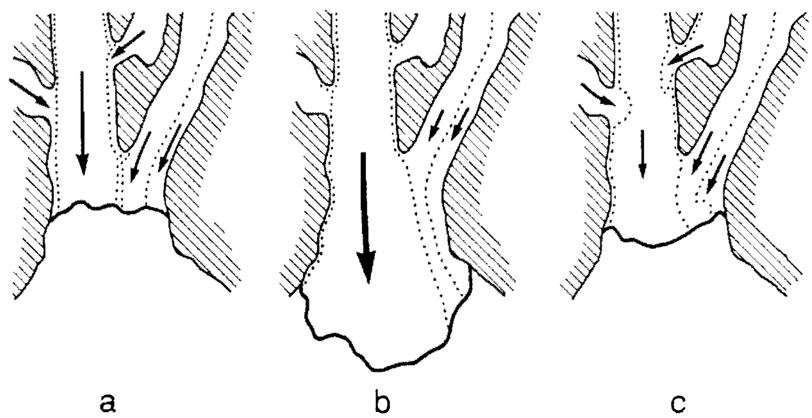


Fig. 1 Illustration of change in glaciers due to surges.

A. Longitudinal profile change during a surge on a calving glacier: **a**) pre-surge surface; **b**) post-surge surface associated with numerous crevasses along the entire glacier, the upper basin is depressed and the lower basin is thickened and moved forward; **c**) concentric crevasses in the upper basin close to the rock wall (after Liestøl 1989).

B. Longitudinal profile of the Usherbreen (non-calving glacier). **a**) pre-surge surface; **b**) post surge surface; **c**) well-marked frontal convexity (from Hagen 1987).

C. Schematic representation of folded moraines due to surges. **a**) Pre-surge situtation, the different ice-streams find an equilibrium position between them; **b**) during the surge, the ice streams from small tributaries are stopped and median moraines are pinned against the glacier sides; **c**) after the surge, the ice flow from the surging glacier decreases, and tributaries flow again, and the median moraines take a folded form.

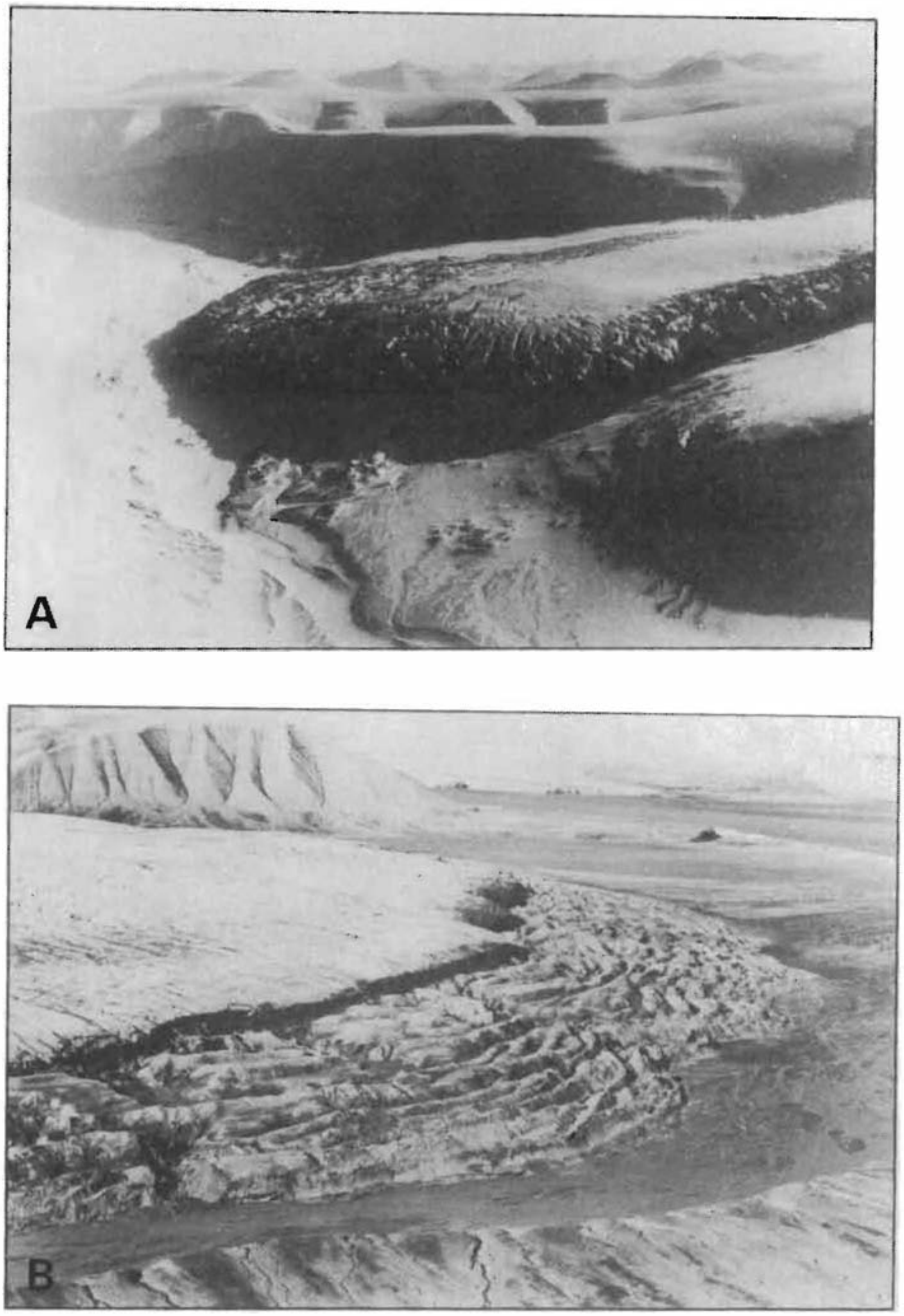


Fig. 2 **A:** The Marmorbreen just after its surge in 1965-70 with a well marked convexity of the frontal zone.
B: The Usherbreen in 1985 after a surge in 1978. Note the persistence of frontal convexity and the folded, pushed morainic ridges. (see § 21, p.41).

Fig. 3 A. Aerial photograph (1970, N 4626) showing the Jemelianovbreen starting to surge. Note the appearance of crevasses in the upper basin and the small fold on the median moraine at the confluence with the Spælbreen (right). The Anna Margrethebreen (left) surged some years before (see also the Fig. 3 B, next page).

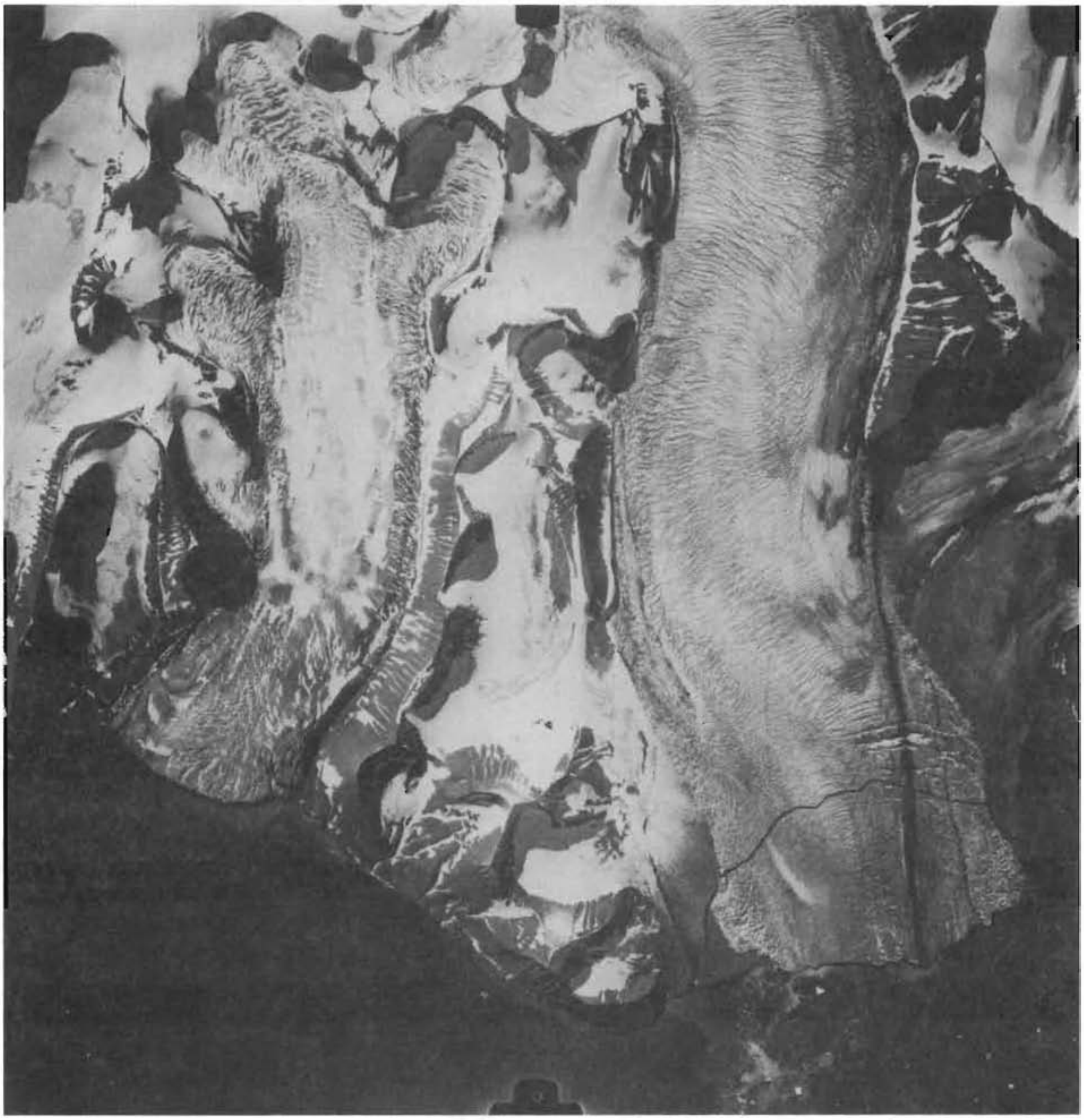


Fig. 3 B. Aerial photograph (1971, N 6035) showing the Jemelianovbreen during its surge and the Anna Margrethebreen some years after a surge. Note the presence of crevasses along the entire basin of both glaciers. In the upper cirques of tributaries, crevasses are concentric and basins depressed. Note also the contact between the Jemelianovbreen and the Spælbreen, the median moraine is pushed to the North (on the right side of the photo), but the surge pass over and affects also a part of the Spælbreen. The line indicates the front position in 1970. The advance of the front will continue for more than two kilometers (see also § 14 and Fig. 12, p. 33).

Fig. 4. Aerial photograph (1961 N 1248) showing folded moraines on the Battyebreen (Dickson valley) long after a surge of this glacier. This photo illustrates well Fig. 1 C.

Fig. 5. Oblique aerial photograph (1938, N 2133) during the surge of the Etonbreen, Nordaustlandet (see § N 8, p. 97), showing numerous crevasses of a surging glacier in opposition with glaciers in a quiescent phase as seen in the background. Note also the presence during the surge of numerous icebergs, some of wich are 100 m long

of 500 and 800 m. In this case, it is possible to say that the last extension of the Freemannbre deposited the inner moraines and didn't reach the maximum extension which previously formed the outer moraines.

Presentation

First, a list of present and past calving glaciers from the area defined in the project is presented. Included are glaciers which are able to produce icebergs capable of penetrating the Barents Sea. Such glaciers are located in Storfjorden, Hinlopenstretet and north of the Eric Ericsenstretet.

The glaciers are located in 4 regions:

S) Storfjord, eastern coast of Spitsbergen.

B) Barentsøya, and E) Edgeøya.

H) Hinlopenstretet, north-eastern coast of Spitsbergen.

N) Nordaustlandet, from Hinlopenstretet to the north-eastern coast, including Storøya and Kvitøya.

List of air photos

A list of air photos covering the front of each glacier is presented. Photos of the whole glacier are sometimes presented when a study of the basin was necessary to determine if the glacier surged or not.

Aerial photographs from 1936 and 1956 are oblique photos, from other years they are vertical.

Information from the Atlas of Svalbard Glaciers

Information from the Atlas of Svalbard Glaciers (not yet published) is also included. For each glacier: the area in square kilometers, the length in kilometers, the maximum and median elevations and the estimated Equilibrium Line Altitude (ELA) given in meters above sea level are presented.

Particular notice should be taken of the following points:

a) The maximum altitude corresponds to the highest point of ice accumulation within the basin and may be situated high up on a mountain slope, far above the top of the main accumulation area. For instance, Vasilievbreen is noted as having a maximum elevation of 750 m, while the top of its main accumulation area is only about 250 m. The best information is therefore the median elevation of the glacier.

b) The ELA across Svalbard is shown in Fig. 6. This map adequately illustrates the distribution pattern of the variations in ELA throughout Svalbard. However, the actual ELA is probably higher than that given in the figure as the glaciers are not in balance with the existing climate, i.e. the net mass balance is mainly negative. For instance, an ELA of about 300 m is given for Lovénbreen and Brøggerbreen , situated in the Kongsfjord area, but determination of this altitude using field measurements gives 399 m and 417 respectively for the period 1966-88. Discrepancies of this kind must be kept in mind when comparing the median altitude with the ELA. Nevertheless this type of information is interesting because glaciologists consider that, for a temperate glacier, an area accumulation ratio of 0.7 corresponds to a glacier with a net balance of zero (Paterson, 1983). In Svalbard, glaciers can be considered to have a potential net balance which is either positive or zero when the median altitude is at least 50 or 100 meters higher than the actual ELA.

Figures.

The fig. 7 (at the end of the present document) shows the location of all glaciers.
For each glacier a sketch showing front positions has been drawn, using all available information: air photos, satellite imagery, past mapping and information from the literature. References to noted years on front positions came from:

1858 - 1873 front positions were provided by different maps plus one map showing a summary of previous front information. Sources are from Swedish expeditions (e.g. Nordenskjold), then from Franklin, Koldewey, Heuglin, Smith and Ulve expeditions.

1896-1897 from Conway and Garwood, which carried out two expeditions across central Spitsbergen.

1898-1901 from Vasiliev or De Geer, during their missions to measure one arc of a terrestrian meridian in Spitsbergen. Front positions were recorded from 1898 to 1901. Pinpointing of the precise dates would often require important bibliographic work and is not necessary for this report. Only data from 1900 and 1901 are used, in the absence of specific reference to other years.

In certain instances other maps have been used, but only for one or two glaciers. In such cases the source references are cited directly in the text. The accuracy of these maps is often questionable, in which case positions have been cross-checked with other sources before beeing used. Front positions were accepted without question when the distance to the front from the shore line is such that no mistakes could have been made by the observers. Generally, front positions from Vasiliev from Sørkapp to Ginevrabotten are believed to be fairly correct. In the North, De Geer made special note of the front position of the Hochstetterbreen.

1936-1938 from oblique aerial photos and NP maps at a scale of 1/100000.

1947 mainly from NP maps.

1956 from oblique aerial photos.

1961,1969,1970 and 197171 from aerial photos and some NP maps.

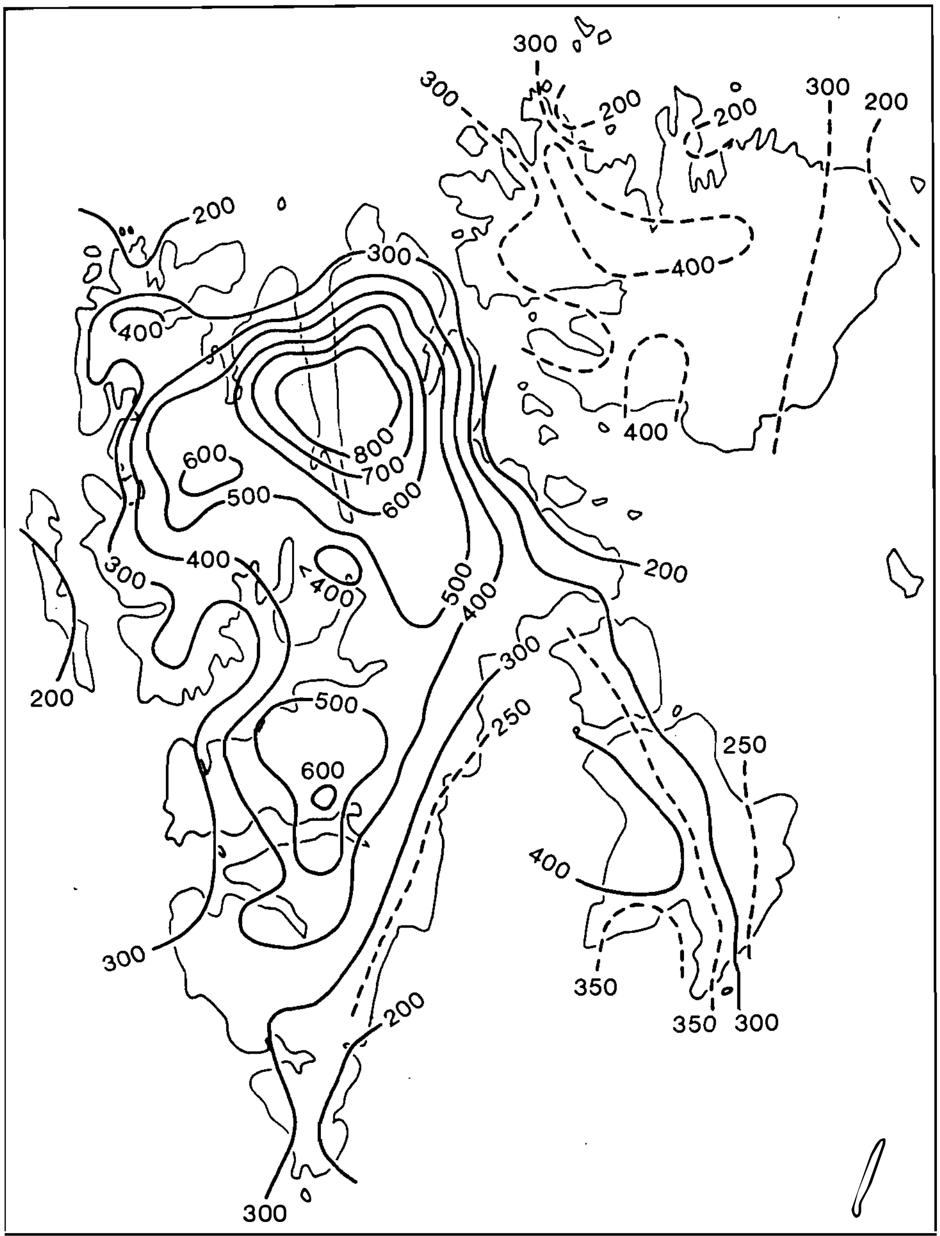


Fig. 6 Distribution pattern of the estimated Equilibrium Line Altitude across Svalbard (after Liestøl and Roland). Values are only indicative (see comments above in : Information from the Atlas of Svalbard glaciers)

1985 and 86 from Landsat images and some NP maps at a scale of 1/200000.

Scale and orientation of figures.

Usually, figures are shown at a scale of 1/100 000 with north at the top of the page, in this case orientation is not indicated. In some cases, e.g. for glaciers of very large area or with large fronts, the scale used is different (mainly at 1/200 000) and the orientation could be with the North at the left side of the page, in which case the orientation is shown in the figure.

Definition of some expressions used in the texte.

"Little Ice Age". This expression refers to the last period with a general advance of glaciers. This Little Ice Age is well-studied in the northern hemisphere. It started during the 13th century. The extension of glaciers was stopped during the 14th and 15th centuries. Then, the last period of glacial advance started around 1580-1600, and culminated around 1750. The final decrease started after 1850. In Svalbard the Little Ice Age is believed to agree roughly with these dates, there is no precise information on its beginning while the end occurred between 1880 and 1915.

"Recorded surge" A surge actually recorded as an historical note, map or aerial photo.

"Probable surge" A surge whose existence seems likely, based on direct or indirect evidence, but in the absence of one conclusive criterion.

"Potential surge" a surge whose existence is based on only one positive criterion which however is not considered sufficient evidence for a classification as a recorded surge.

These definitions may be expressed in terms of probability:

"Recorded surge": probability of surge = 1.
"Probable surge": probability of a surge close to 1.
"potential surge": probability of surge weak but not zero.

Additional information.

Historic sources are listed in the references at the end of the report
Only the 1936 aerial photos cover the entire of Svalbard.

S: SPITSBERGEN, STORFJORDEN FROM SØRKAPP TO STRAUMSANDET:

S 1 Mathiasbreen

A.P:	1936:	2414-23.
	1961:	3026-28
	1961:	3727-28

		/ Elevation(masl) \		
Area(km2)	Length(km)	Max.	Med.	ELA.
12.80	5.0	450	300	200

Mathiasbreen is a non-calving glacier. At its maximum extension its front was at 1 km from the sea. It is mentioned here because a future important surge could potentially reach the sea (but would not give any important calving).

S 2 Keilhaubreen

A.P:	1936:	2420-26
	1961:	3026-27, 3246-48

		/ Elevation(masl) \		
Area(km2)	Length(km)	Max.	Med.	ELA.
15.4	5.2	550	250	130

The front positions in 1900 and 1919 are from the Vasiliev and a Norsk Svalbard expeditions. The map from Nordenskjold (1874) shows Keilhaubreen with a small lobe into the sea.Since then the glacier has shown continuous retreat. In 1900 and 1919 the front was calving and grounded a few years before 1936. At the present it is about 2 km from the sea. The bathymetry at the front is not known. Lateral moraines, studied by aerial photograph analysis, show that at the maximun position (before 1900) this glacier had probably developed a very large lobe into the sea. This maximum might have been a surge which occurred before 1874. On aerial photos from 1961 could be seen some small frontal morainic ridges, probably deposited in shear stress cracks during the retreat of the front.

The maximum extension of Keilhaubreen occurred long before 1900 and the glacier developed a very important lobe into the sea. This maximum could have corresponded with a surge. A new surge could occur and again reach the sea, but predicting potential calving is almost impossible.

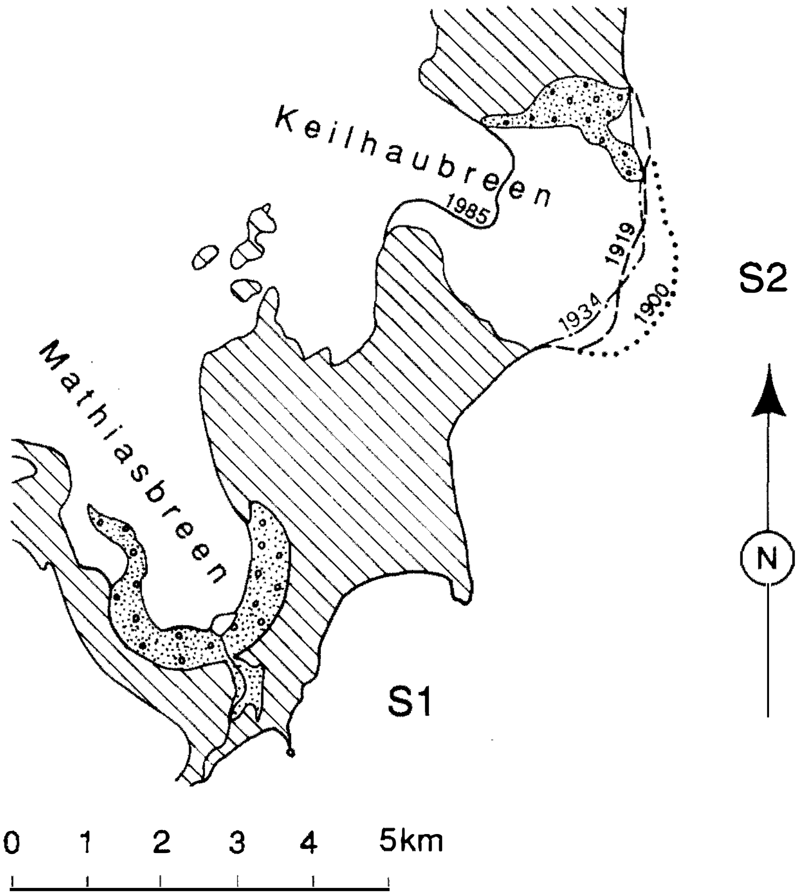

Keilhaubreen
1985
1919
1934
1900
S2
Mathiasbreen
S1
N
0 1 2 3 4 5km

Fig. 8

S 3 Svartkuvbreen (Area: 4.7 km^2)

A.P:	1936: 2423-29

Svartkuvbreen is a non-calving glacier, and despite its proximity to the coast is unlikely to reach the sea even during an important surge.

S 4 Randbreen

A.P.	1936: 2427-34 , 2441-44
	1961: 3024-25

		/ Elevation(masl) \		
Area(km2)	Length(km)	Max.	Med.	ELA.
9.60	4.7	450	180	150

Randbreen was calving in 1900 and has been retreating since then. Surges prior to this time are unknown.It had a partly tide-water front in 1936 but with little calving. At its maximum extension the ice extended around 500 m farther south. Most likely the 1900 map is fairly reliable. Likewise, the small tongue to the north just reached the sea. A potential future surge will probably not produce significant calving.

S 5 Vasilievbreen

A.P.	1936: 2430-58
	1961: 2900-04, 3019-24
	and: 3240-46
	1970: 4640-43
	1971: 6021-23

		/ Elevation(masl) \		
Area(km2)	Length(km)	Max.	Med.	ELA.
211.0	13.5	750	210	160

The Nordenskiold Karte of 1874 which is not really precise, shows Keilhaubreen with a small lobe into the sea and Vasilievbreen with a linear front from south to north. The position of the front on this map seems to be generally correct. That means that the maximum advance of this glacier occurred before 1874. Since then, the glacier has been in constant retreat. On aerial photographs, some important residual moraines at the front and on the northern side prove that at its maximum the glacier front was fairly far into the sea.

On aerial photographs from 1936 there are no crevasses while from 1961 numerous cracks are visible on almost the entire surface of the glacier. Nevertheless, the general aspect of the glacier is one of the typical ablation surface, smooth and dusty. On the top of a small

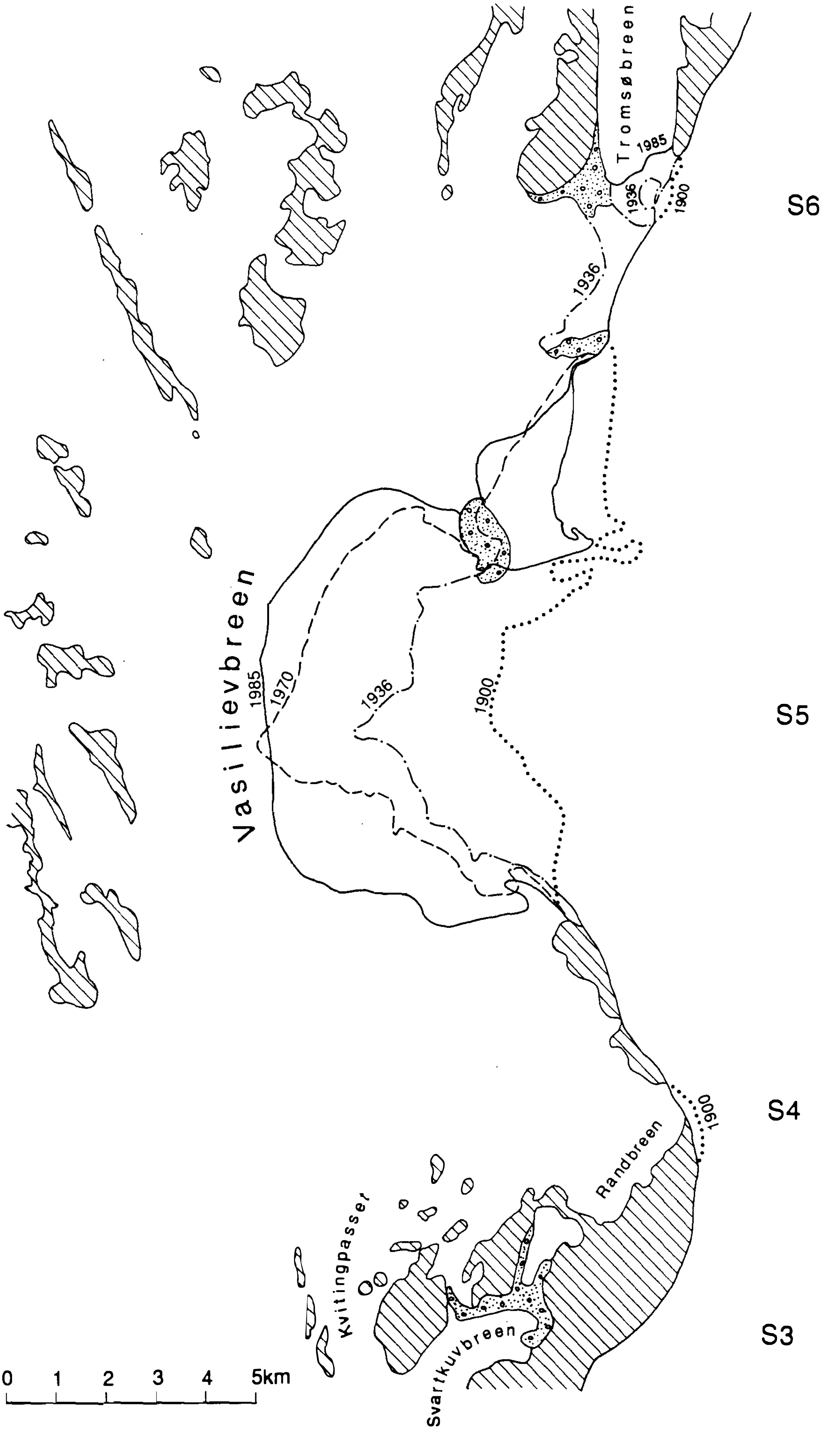

Tromsøbreen
1985
1936
1900
S6
1936
Vasillievbreen
1985
1970
1936
1900
S5
1900
S4
Randbreen
Kvitingpasset
Svartkuvbreen
S3
0 1 2 3 4 5km

Fig. 9

southern tributary situated in Kvitingpasset, characteristic concentric and deep crevasses are visibles. Also, numerous small icebergs can be seen at the front . Therefore, we believe that this small southern tributary (in Kvitingpasset) had a surge in the years 1959-61 and reactivated the main area of Vasilievbreen. It is possible that similar surges occurred but were not recorded.

In 1970 and 1971, despite numerous cracks, the general aspect of the glacier was that of an inactive glacier, and few iceberegs were calving.

Vassilievbreen is feeded by one main fonna* and several small tributaries. About 90% of its surface is situated below 250 m above sea level, and thus it is largely in ablation area. Moreover it may be seen from aerial photographs that the bedrock comprises an important geologic north-south threshold close to the main concavity of the front. These characteristics, along with the length of the front (about 20 km) make Vasilievbreen an unusual glacier. A major surge is improbable, but several small ones could occur and calve a lot of small icebergs, as in 1961.

The maximum extension of Vasilievbreen occurred before 1874. Around 1961, a surge from one small tributary affected almost the entire glacier and reactivated the front. No following surges have been recorded. Future surges from tributaries may produce numerous small icebergs again.

S 6 Tromsøbreen

A.P.	1936: 2446-51, 2457-62
	1961: 3239-40
	1970: 4638-42
	1971: 6023-24

		/ Elevation(masl) \		
Area(km2)	Length(km)	Max.	Med.	ELA.
15.10	8.5	500	200	150

In 1900 (Vasiliev's map), Tromsøbreen was a tide-water glacier front. Analysis of aerial photographs shows that at its maximum extension the front joined the northern lobe of Vasilievbreen. In 1936 the front was terrestrial for several years. The retreat has continued to the present and because a lagoon has been formed in front of the glacier, significant amount of sediments have been deposited in the proglacial area and the Svalbard marine map indicates a depth of less than 17 m at 4 km from the front.

No surge has been recorded since 1900 for Tromsøbreen. A surge could occur but because of a relatively small basin and shallow water in front of the glacier, this surge will probably be of the Duckwitzbreen type (see § B1).

* *fonna* is the usual term wich indicates an accumulation plateau in Svalbard.

S 7 Barbarabreen (Area: 1.5 km²)

Kanbreen (Area: 1.4 km²)

Coryellbreen

Bevanbreen and Unnamed

A.P.	1936: 2462-71 1970: 4637-39 1971: 6023-26

These glaciers are small. Only Barbarabreen has an independent basin. A small part of this basin is facing toward the East and thus the sea. It is possible that one small tongue of this glacier reached the sea at its maximum extension. No traces of past surges are visible. The small size of this partial basin suggests that a future surge is improbable, and will not result in any important calving.

The rest of Barbarabreen basin is a tributary of Sykorabreen, itself a tributary of Hambergbreen. Kanebreen, Coryellbreen and Bevanbreen have three small tongues facing eastwards and two of these tongues reached the sea in 1936 (and before). At the present, they are very reduced and the moderate size of these tongues should not produce surges capable of calving. Because of the presence of a crest, the main parts of these glaciers are facing westward and are also tributaries of Sykorabreen. These tributaries were activated by the surge of Hambergbreen (see § 8) just prior 1970.

The small unnamed glacier in the North is independent and was calving a few years before 1936. Its basin is in low altitude and has a little area. A surge is unlikely and will not be important.

The eastward basin of these glaciers partly reached the sea at their maximum extension but only little calving occurred. Future surges and calving are improbable.

S 8 Hambergbreen

A.P.	1936: 2469-73 1961: 2911-14, 3010-16 1970: 4634-38, 44-46 and 4649-52 1971: 6025-28

		/ Elevation(masl) \		
Area(km2)	Length(km)	Max.	Med.	ELA.
144.0	16.2	600	220	210

The Vasiliev map indicates that a very strong surge of Hambergbreen occurred few years before 1900. The morainic deposits on the northern shore show that the glacier extended further into the sea at its maximum extension. This maximum position probably

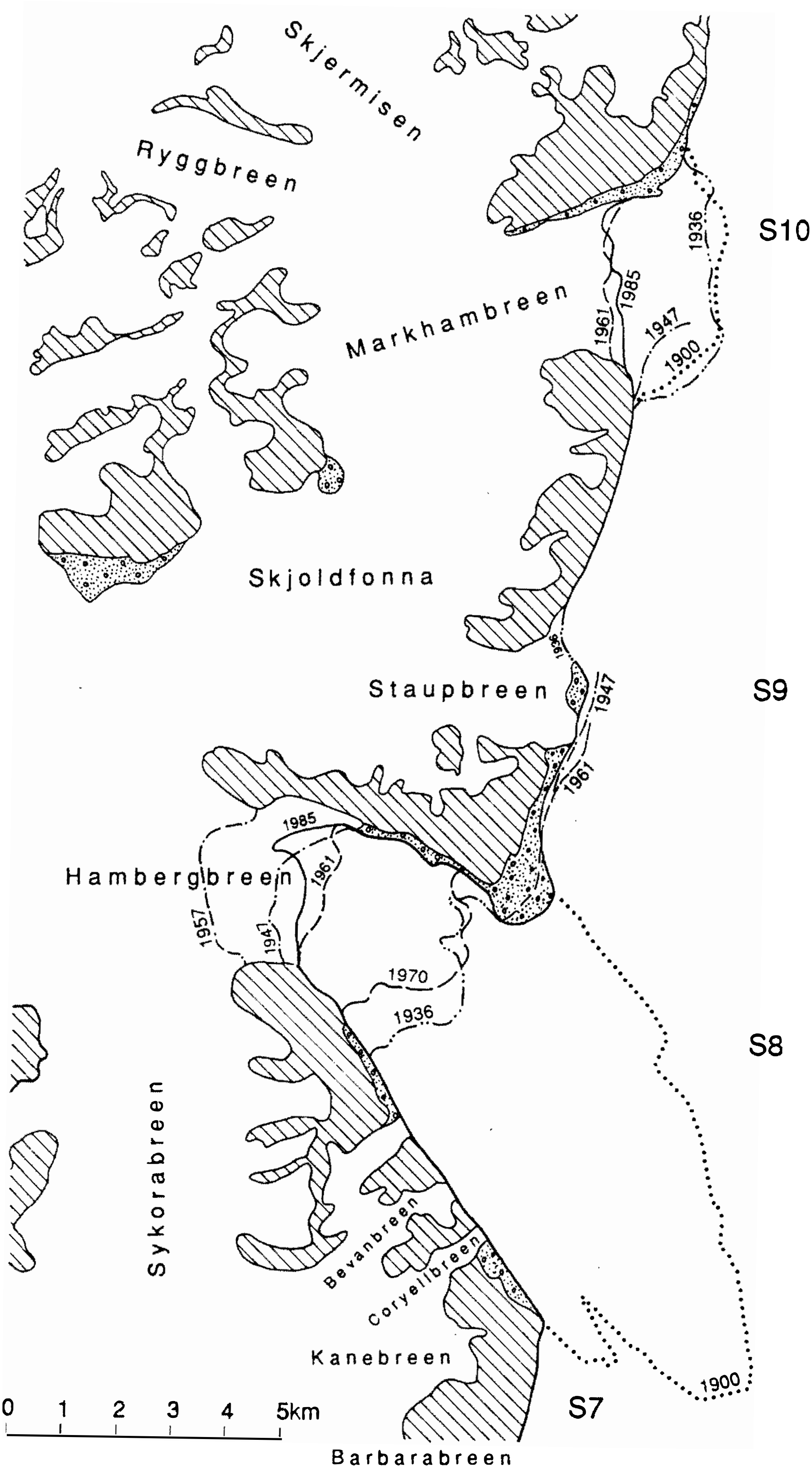

Skjermisen
Ryggbreen
Markhambreen
Skjoldfonna
Staupbreen
Hambergbreen
Sykorabreen
Bevanbreen
Coryellbreen
Kanebreen
Barbarabreen
S10
S9
S8
S7
1936
1985
1961
1947
1900
1957
1970
0 1 2 3 4 5km

Fig. 10

corresponds with the submarine morainic ridge on the marine map 505. That means that the front was about 15 km from the present position. In the medium axis of the glacier, the highest point of this moraine is at 41 m below sea level, whereas inside the ridge the depth of the sea is 96 m. That means that the glacier was able to remove sediments and build a crest 55 m hight. Between 1900 and 1936 the retreat was 9 km, comparable to the retreat of 5 km between 1936 and 1957, i.e. respectively about 250 and 240 m per year. This rate is very regular and comparable to that of Kongsbreen, a well known calving glacier on the West coast of Spitsbergen. The area of Hambergbreen as it is defined on the map, is small relative to the size of the surge, so it is likely that the entire basin contributed to the surge.

In 1936 remnants of ice were visible on both sides, far from the front. Aerial photographs show that the small glaciers mentioned in § A 7 were locked by Hambergbreen during its advance. There were no important crevasses visible in the basin.

Photographs from 1961 and 1970 show numerous crevasses on a large part of the basin. The glacier started a surge around 1961 (see also the positions in 1961 and 1970 compared with 1957). In 1961 some icebergs were visible close to the front. Crevasses are visible mainly in the central part of the glacier. The lower part of Skjoldfonna is slightly more active than Sykorabreen. Inversely, in 1970 no icebergs were visible and Skjolfonna seems unactive, whereas Sykorabreen is entirely affected by the surge. A median moraine indicates that the flow coming from Sykorabreen, occupied half of the front in 1970, compare to a third in 1961. In its accumulation area, small tributaries have typical crescentic heavy crevasses, such as were the case with Barbarabreen, Kanebreen and Coryellbreen, as it is mentioned above (§ A.7).

A surge likely started in 1961 initiated by the small fonna which is the accumulation area of Hambergbreen itself, as defined on the map. This initiated a surge from Sykorabreen. Analysis of aerial photographs shows that in 1970 the glacier was very close to the maximum position reached during this surge and that the lower part of the Hambergbreen basin was less active. On the left side (north) it may be seen that the glacier surface in 1970 was lower than some of the ice deposited lateraly during the surge. The maximum occurred probably 2-4 years before 1970. This surge probably lasted 4-6 years. The total advance during this surge was more than 5 km.

In addition it is interesting to note that at about the same time (several times before 1961) at the same latitude but facing westward, most of the glacial area probably surged from Hornbreen, Svalisbreen, Mendelejevbreen, Flatbreen and all the tributaries including Isbroadbreen, Samarinbreen and Storbreen. This was also the case for Staupbreen (see § S 9).

Hambergbreen had a very important surge which affected the entire basin, a few years before 1900, at which time it reached its maximum extension with a lobe into the sea about 15 km from the present (1985) front position. A second surge occurred in 1961-70, initiated by Hambergbreen itself and then activating Sykorabreen. During this surge the front advanced 5 km.

S 9 Staupbreen

A.P.	1936: 2472-74
	1961: 3234-35
	1970: 4633-35, 44-49
	1971: 6027-28

		/ Elevation(masl) \		
Area(km2)	Length(km)	Max.	Med.	ELA.
12.4	6.0	400	260	200

On the aerial photographs from 1936 the Staupbreen was retreating from a previous extension. In spite of the presence of snow at higher altitude, it is possible to see on these photos numerous, long, concentric cracks over most of the entire basin. Nevertheless, the lower part of the glacier and the front were not really active. It is difficult to say if one surge occurred several years before 1936 or if a surge was about to start. In the central part of the front a deposit, free of ice, shows aerial erosion of slope. This proves that this deposit has been uninfluenced by ice for a long time and supports the hypothesis of a pre-surge situation.

In 1961, the glacier was in a post-surge position. The front was active, but crevasses still visible in great number in the basin, did not appear to be largely opened. The morphology of lateral moraines shows that the maximum extension during this surge was the maximum for the entire Little Ice Age. This glacier with a fairly small basin had the typical surge of terrestrial glacier: a big concave lobe which just reached the sea. It did some calving but only parts of its front could be considered as a tide-water front. This calving consisted of numerous, very small icebergs. Aerial photographs from 1961 show dark morainic dust at the foot of the front,indicating that only a small part of the glacier was situated below sea level. This contention is confirmed by bathymetry. From the front and out to 3 km, sea depth is less than 17 meters. Because this surge corresponded with the maximum extension of the glacier during the entire Little Ice Age, and because the basin is fairly small, a new surge is unlikely to occur within several years. Additionally if this surge should extend beyond the previuos maximum recorded position, it will most likely be of Duckwitzbreen type (see § B 1).

The Staupbreen surged between 1936 and 1961. The maximum recorded position is a result of this surge. No further surges have been recorded here.

S 10 Markhambreen

A.P.	1936: 2475-79
	1961: 3232-34
	1970: 4632-33
	1971: 6028-30

		/ Elevation(masl) \		
Area(km2)	Length(km)	Max.	Med.	ELA.
60.6	10.7	650	260	210

According to the Vasiliev map, in 1900 the Markhambreen had a lobe into the sea. In 1936 (air photos) the glacier displayed characteristic signs of having surged very recently. It was heavily crevassed on almost 80% of its basin. It is obvious that the surge mainly affected the central basin and northern tributaries (Skjermisen and Ryggbreen) and lesser the southern tributaries. A part of the front has always had a characteristic lobe form. The 1936 position is very close to the 1900 position (from the Vasiliev map). Nevertheless, remnants of lateral moraines were not touched by this surge, so the maximum extension of the glacier occurred before 1900 with a very large lobe extending into the sea. This 1936 surge affected the central and northern basin (Rykkebreen and Skjermisen).

In 1961 the Markhambreen was in a retreating position. In 1970 and 71, as well as in 1985, the front was almost at the same position as in 1961. Aerial photographs from 1970 and 1971 show the presence of crevasses on a large part of the glacier surface. They are parallel close to the front and concentric higher up in the basin, and calving is always present. Such phenomena of constant activity can be observed on other glaciers as on Fortjendejulibreen on the west coast of Spitsbergen (B. Lefauconnier, personal observation).

The Markhambreen had its maximum extension some years before 1900 and developed a large lobe into the sea. It reached a second maximum during a surge just before 1936 which affected both Rykkebreen and Kjermisen. The extension during this surge is not known.

S 11 Crollbreen

Stepanovbreen

A.P.	1936: 2479-83
	1961: 3231-32
	1970: 4630-32
	1971: 6030-32

		/ Elevation(masl) \		
Area(km2)	Length(km)	Max.	Med.	ELA
25.7 *	8.5	600	300	220

Note: The area of Stepanovbreen and of the tributaries to Crollbreen are included here.

According to the Vasiliev map, the Crollbreen, in 1900 had a lobe into the sea. Morphology of lateral moraines analysed from air photos indicates that the glacier has developed a very large tide water lobe during its maximum extension.

In 1936 (air photos), the northern part of the glacier (Crollbreen itself, excluding Stepanovbreen and Matrosbreen - see the map in Fig. 11) shows frequent cracks in the lower part of the ablation area. These cracks could be due to calving at the front, or to the start of a little fluctuation initiated by a small tributary. The partial mapping from 1947 indicates a front further into the sea. Aerial photos from 1961 show the glacier in a retreating position. The retreat is more pronounced on the Crollbreen itself (the only part where the glacier is always tide water, the Stepanovbreen having a terrestrial front).

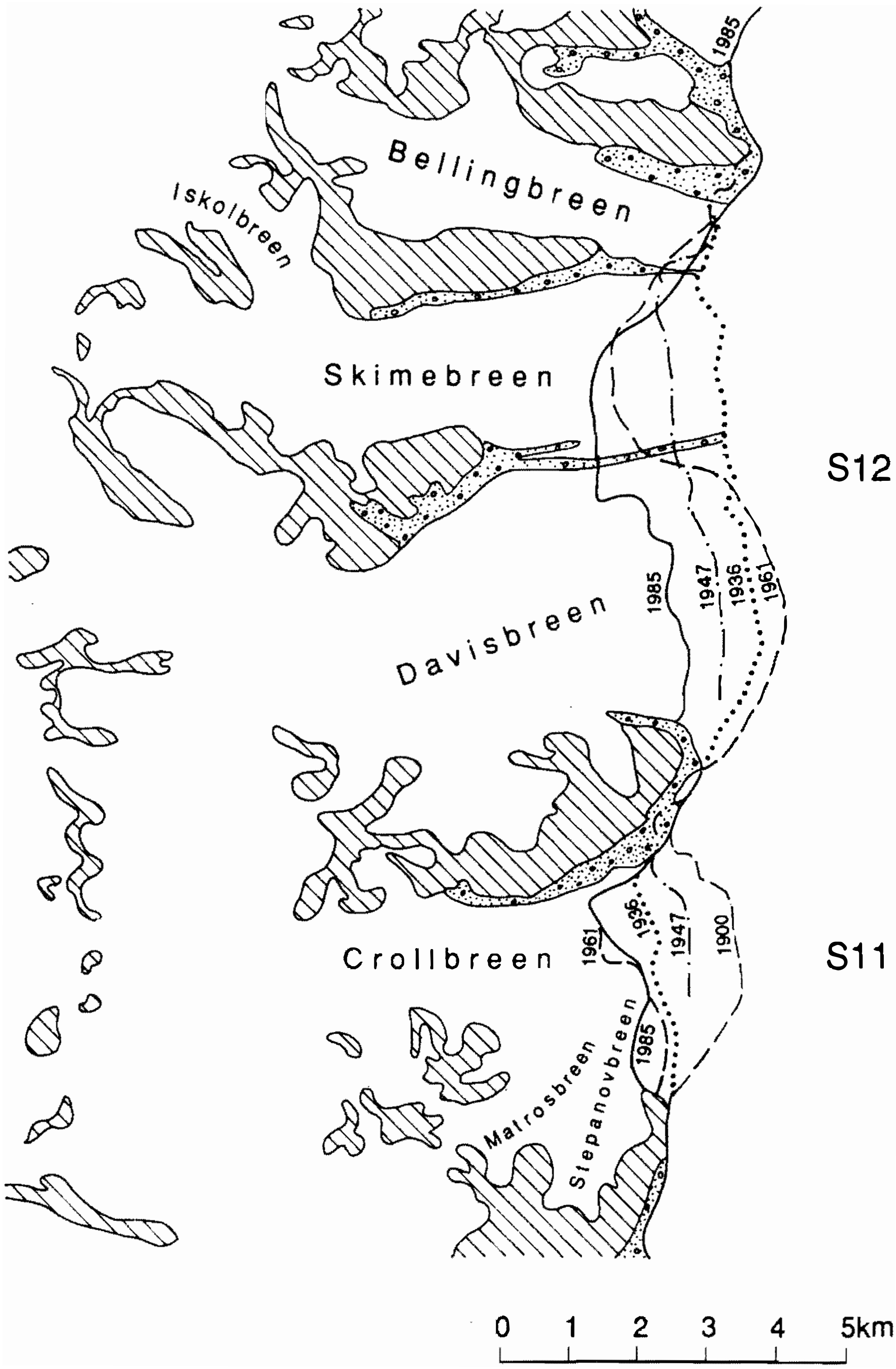

Bellingbreen
Iskolbreen
Skimebreen
Davisbreen
Crollbreen
Matrosbreen
Stepanovbreen
1985
1947
1936
1961
1900
S12
S11
0 1 2 3 4 5km

Fig. 11

Analysis of aerial photographs, confirms that, in contrast to the retreat, a pulsation occurred between 1936 and 1961. On the left side (northern side) the ice seems to be in a slightly upper position and a valley splits the white ice from the lateral moraine. Moreover, the median moraine between Stepanovbreen and Crollbreen is pushed to the south by the latter. It is not possible to determine which part of the basin initiated this small advance, even when assuming that this advance really started in 1936. Nevertheless such small pulsations are known from other places in Spitsbergen, as for the Blomstrandbreen (in the Kongsfjord area) in 1968-69 (Lefauconnier 1987).

Analysis of aerial photographs from 1970 and 1971 indicates a continuous retreat after this advance.

The Crollbreen probably reached its maximum position several years before 1900 Since then, its retreat has been interrupted by a small advance between 1936 and 1961, due likely to an unobserved surge of a small tributary. From this date until the present, this retreat has been continuous.

S 12 Davisbreen

Skimebreen

Bellingbreen

A.P.	1936: 2482-89
	1961: 3229-31
	1970: 4628-30
	1971: 6031-34

		/ Elevation(masl) \		
Area(km2)	Length(km)	Max.	Med.	ELA.
56.6	13.2	650	260	260
21.3	8.7	650	240	250
10.4	6.4	650	250	250

The front position of the three-glaciers complex on the Vasiliev map (1900) is unchanged in 1936 (air photos). Lateral moraines in 1936 indicate a previous large frontal lobe into the sea. Therefore, the maximum extension of the whole front occurred before 1900. In 1936 only a few cracks parallel to the front were visible on the Davisbreen.

Partial mapping from 1947 indicates a retreating front. In 1961 aerial photographs show numerous cracks on the glacier surfaces and many very small icebergs into the sea. All tributaries in the accumulation area were affected. Southern lateral moraine and smoothed crevasses indicate that a surge occurred several years before 1961.

In 1970 and 1971 (air photos) the front, as a whole, was in a quiescent phase. The 1985 (Landsat image) position indicates that a small retreat had occurred since 1971. The Iskollbreen, started a surge in 1970, and in 1971 a bulge, in the form of several waves was visible in the lower part of this glacier before its confluence with the Skimebreen. This surge could have been the cause of the relatively small advance of the front in the northern part of the Skimebreen noted from the Landsat image in 1985.

*Notes:*a) The front of the Bellingbreen became terrestrial in 1961, b) all tributaries of the Davisbreen and Skimebreen except Iskollbreen, showed an important deflation of the upper accumulation area between 1936 and 1970. The Iskollbreen itself has a part of its basin fed by a small fonna. the Iskollen, while all other tributaries are delimited by mountain crests.

The maximum general extension of the frontal complex formed by the Davisbreen, Skimebreen and Bellingsbreen was reached before 1900 (10-20 years?). The Davisbreen surged several years before 1961. The Iskollbreen, a small tributary of the Skimebreen, began to surge in 1970. No more surges have been recorded here.

S 13 Anna Margrethbreen

A.P.	1936: 2487-91
	1961: 3227-28
	1970: 4627-28
	1971: 6033-35

		/ Elevation(masl) \		
Area(km2)	Length(km)	Max.	Med.	ELA.
18.4	8.0	550	300	240

At its maximum extension, the Anna-Margrethebreen developed a very large lobe into the sea. The date can not be approximated because the Vasiliev map does not give any accurate information.

The morphology of lateral moraines in 1936 indicates that a retreat of the glacier occurred since the maximum, without any readvance between this maximum and 1936. The front emptied into a lagoon which had connection with the sea. In 1961 the glacier was still in a quiescent phase. In 1970 the entire surface was crevassed including all tributaries. The front was not heavy crevassed, and probably close to being terrestrial but it presented a vertical ice cliff and was likely calving during the surging phase itself. This surge occurred one or two years prior to 1970. Aerial photos indicate that the situation was the same in 1971.

The Anna Margrethebreen reached its maximum position probably before 1900 and at this time developed an important lobe into the sea. Its decreasing phase lasted to until 1-2 years before 1970 when a new but much less important surge occurred, in spite of the fact that the complete basin was affected.

S 14 Jemelianovbreen

Spælbreen

A.p.	1936: 2492-96, 1724-27
	1961: 3226-27
	1970: 4624-28
	1971: 6034-37

		/Elevation(masl)\		
Area(km^2)	length(km)	Max.	Med.	ELA
95.0 *	16.9	650	250	240

**Note*: the area of Spælbreen is included in the area of Jemelianovbreen.

The Vasiliev map shows a front largely extended into the sea and very close to the maximum reached by the glacier. An important retreat of more than 9 km followed this period. In 1936 the glacier was still retreating. No readvance occurred between the maximum and 1936 when the front was nearly close to be terrestrial. In the north, the tongue of Spælbreen was mostly dead ice. In 1961 the retreat was still underway and in 1970 some cracks appeared in the upper part of the basin together with an longitudinal bulge along the left side (northern mountain: Volkovicsjfjellet) as well as a fold in the median moraine between the Jemelianovbreen and the Spælbreen, close to the confluence. The surge occurred in 1971 and the entire basin was heavily crevassed. All tributaries in the upper basin were activated, the front advanced into the sea and the surge passed over the median moraine to reactivate an important part of the tongue of the Spælbreen and its entire front. The position in 1976 was established from Landsat imagery and as the surge ended before this, the maximum extension pushed the front a little bit further into the sea.

The maximum extension of the complex formed by Jemelianovbreen and Spælbreen occurred some years before 1900 with a major lobe extending into the sea more than 5 km off shore. The Jemelianovbreen surged a second time in 1970-71 and its front advanced about 4-5 km into the sea.

It is interesting to note that the main basin is the basin of the Jemelianovbreen and in 1970-71 the surge affected this main basin, but was very small compared to the probable previous surge before 1900. These two maxima of extension are of two different scales. Moreover, air photos at the present allow a fairly good delimitation of basins, the mountain crests clearly divide all tributaries. It may easily be seen on aerial photographs from 1970 or 1971 that numerous accumulation areas in the upper tributaries are depressed and will need to have their masses rebuilt before a new surge can occurred. One of these tributaries, the Kvatsbreen (see Fig. 12) has for some time had a stable ice mass in the accumulation area which could easily surge in a few years.

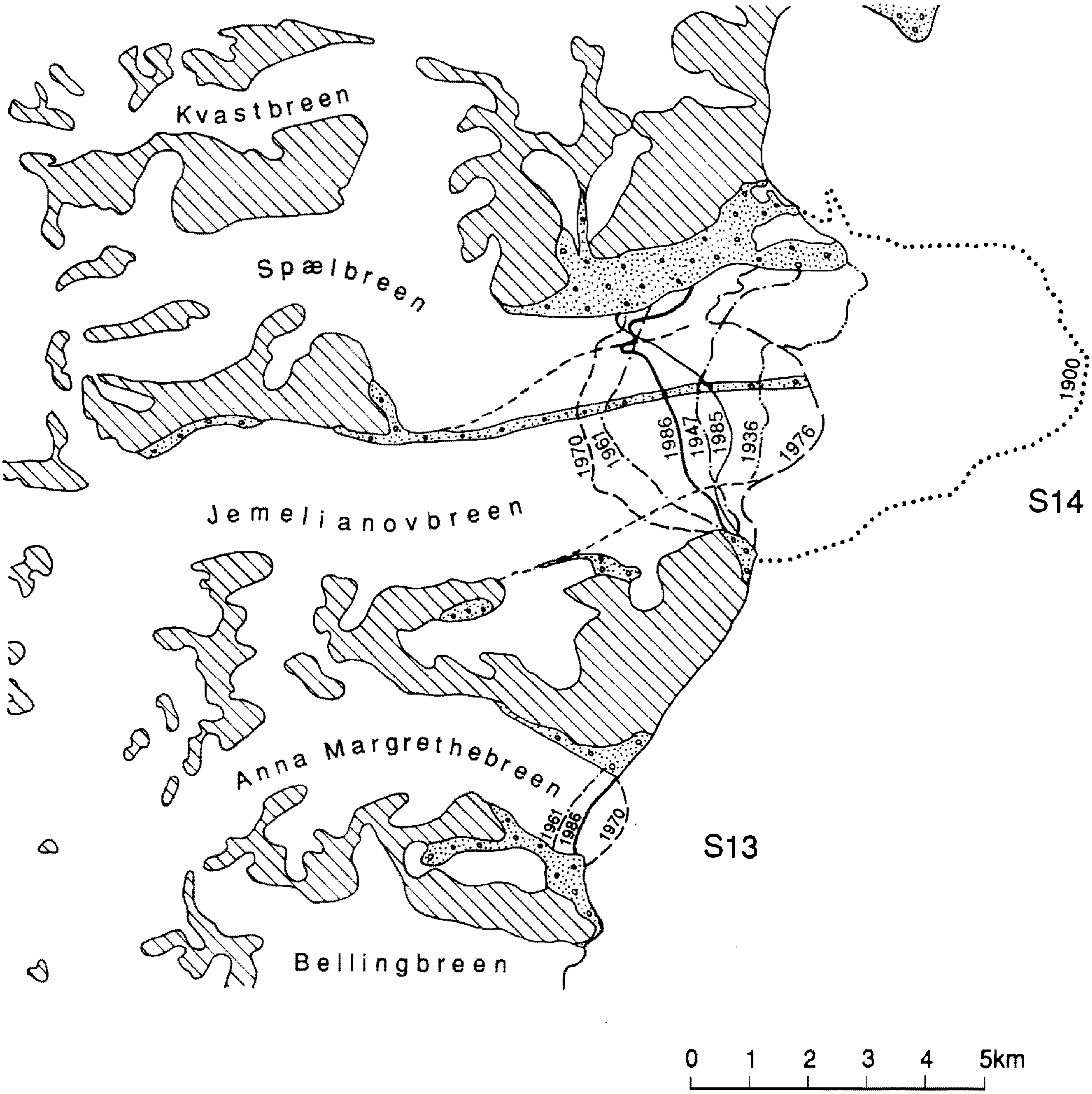

Kvastbreen
Spælbreen
Jemelianovbreen
Anna Margrethebreen
Bellingbreen
1970
1961
1986
1947
1985
1936
1976
1900
S14
1961
1986
1970
S13
0 1 2 3 4 5km

Fig. 12

S 15 Strongbreen

Perseibreen

Kvalbreen

A.P.	1936: 1724-4 0
	1948: 946-69
	1961: 3220-24
	1970: 4666-69

		/Elevation(masl)\		
Area(km^2)	length(km)	Max.	Med.	ELA
283.0	25.3	750	300	280
59.0	11.5	650	320	290
82.0	16.2	800	230	240

The Heuglin map from 1870 does not show a very precise position of the glacier front, but Kvålvagen is shown free of glacier ice far into the bay. The Kvalbreen has its own front separated from Strongbreen. The front of the later is shown with two lobes which seem to correspond to the two glacial flows from Morsjnovbreen to the North and Nuddbreen to the South. Thus, in spite of the rough nature of this map, the front in 1870 was apparently far into the bay.

Inversely the Vasiliev map indicated that the front layed close to the mouth of the fjord. This map is believed to be relatively exact because it shows two pointed caps on both sides which already were in existence, and represent the extremity of lateral moraines. In 1900 these caps were likely covered by the ice, meaning that the glacier was retreating after an important surge which occurred between 1870 and 1900. This is also confirmed by Rabot (1900) who recounts observations from whalers who reported that the anchorage into this bay was filled up by a glacier in the years just before 1876.

The retreat of the glacier has lasted until today. In 1936, the front position was of course in retreat but the moraine lobes also confirm that a surge occurred before. This is particularly true of the well formed lobe of the lateral moraine between Strongbreen and Kvalbreen as well as between Nuddbreen and Srongbreen (these moraine positions are shown on the Norsk Polarinstitutt map C11, with the 1936 position). These lobes prove that the Strongbreen itself as well as the Morsjnevbreen surged and then started their quiescent phase. The Nuddbreen and Kvalbreen were first stopped for a while by the important flow of the Strongbreen, and then began to flow again. It is also possible that Nuddbreen was affected by the surge.

Aerial photograhs from 1970 confirm a continous retreat. Nevertheless, it may be seen from these photos that the Perseibreen (which has a tide-water front) has an ice mass preserved in the upper part of its accumulation area, and thus may surge in the near future.

The Strongbreen reached its maximum position during a very important surge between 1870 and 1876. Since then, the retreat has been continuous to this day. The surge was activated by the Strongbreen itself along with one important tributary, the Morsjevbreen (and possibly the Nuddebreen). No further surges have been recorded since then.

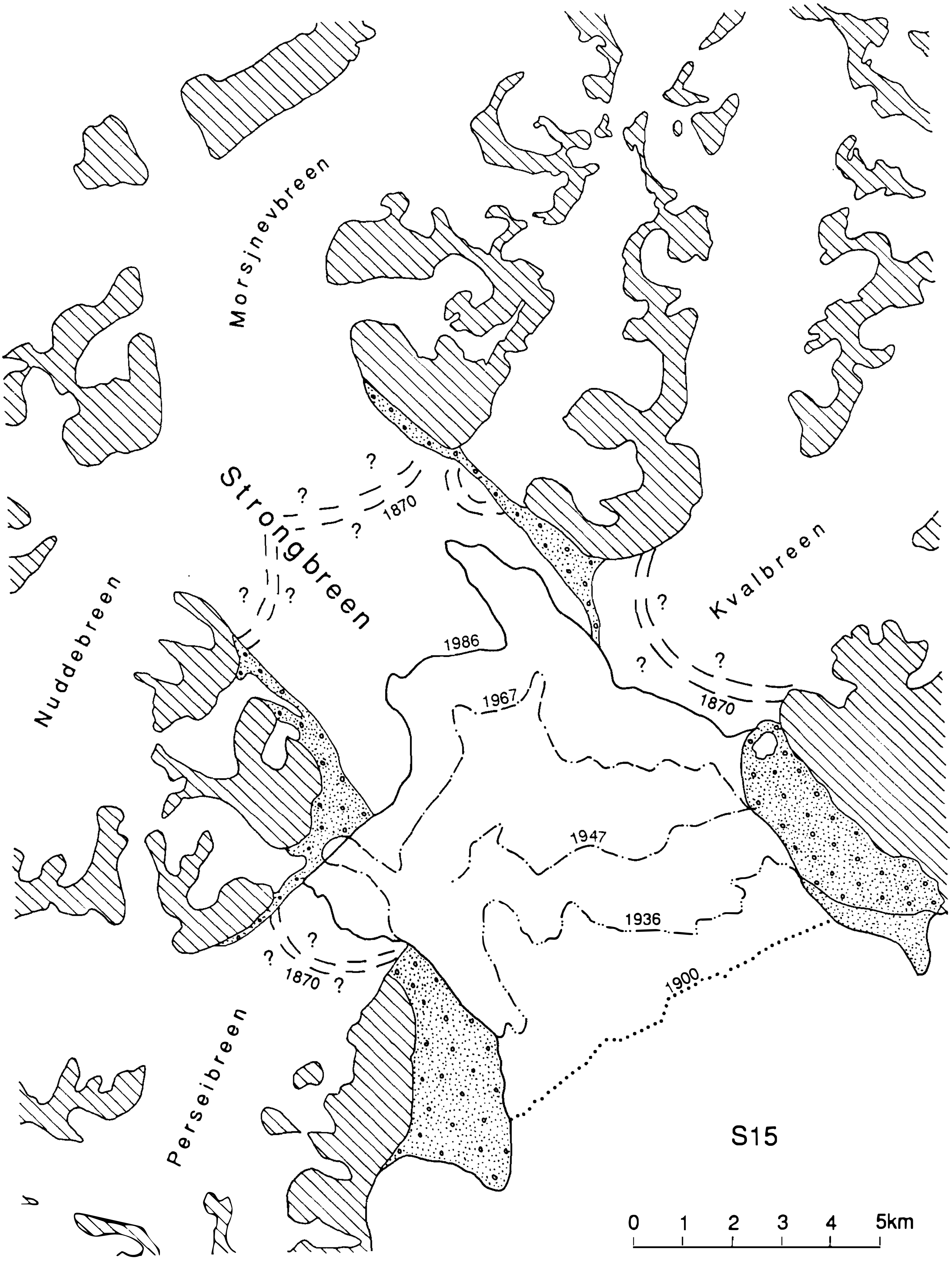

Morsjnevbreen
Strongbreen
Nuddebreen
Kvalbreen
Perseibreen
1870
1986
1967
1947
1936
1900
S15
0 1 2 3 4 5km

Fig. 13

S 16 Thomsonbreen

A.P.	1936:	1748-53
	1948:	930-32
	1969:	2073-75

		/Elevation(masl)\		
Area(km^2)	length(km)	Max.	Med.	ELA
61.0	11.0	500	270	260

The Vasiliev map indicates a small lobe in the sea. Aerial photographs from 1936 indicate a retreat and a quiescent phase with few cracks close to the front. Morphology of lateral moraines indicates that at its maximum, the front was further into the sea and adjacent to the front of the Richardsbreen.

In 1969 the Thomsonbreen was in a post surge quiescent phase. The positions of the moraines, as well as a small lobe in the northern part of the front and the depressed upper basins of its small tributaries show that the surge was due to the Innifonna, and that the tributary from the Gråkallen cirque was affected. It is difficult to know the scale of this surge but the depressions in the upper basins are important. It should also be pointed out that a dammed lake may be seen at almost each glacial confluence. One surge occurred probably 10-20 years before 1969. Air photos from 1948 did not show any signs of a surge. So the surge probably occurred just a few years after 1948.

The Thomsonbreen reached its maximum extension several years before 1900. A surge occurred between 1948 and 1969, probably only a few years after 1948. The southern basin has shown no signs of a surge.

S 17 Richardsbreen

A.P.	1936:	1750-60
	1948:	926-28
	1969:	271-73

		/Elevation(masl)\		
Area(km^2)	length(km)	Max.	Med.	ELA
70.60	13.0	600	280	270

The Vasiliev map does not mention the Richardsbreen which suggests that this glacier probably had no lobe extending into the sea. Nevertheless the photographs from 1936 show that the glacier was retreating with many crevasses parallel to the front (and only in the vicinity of this front). On the south side the glacier was adjacent to the Thomsonbreen. Lateral moraines on both sides do not provide usable information.

In 1969 the retreat was still under way and a large part of the basin (Richarsbreen and Virgolbreen but not Ingerbreen) was in the ablation area. Nevertheless, one mediane moraine had a characteristic fold, so a previous surge is possible but uncertain. A Landsat image from 1985 indicates that the retreat is still in process.

The Richardsbreen had a fairly important maximum extension but over an unknown period. No surge has been recorded since 1900.

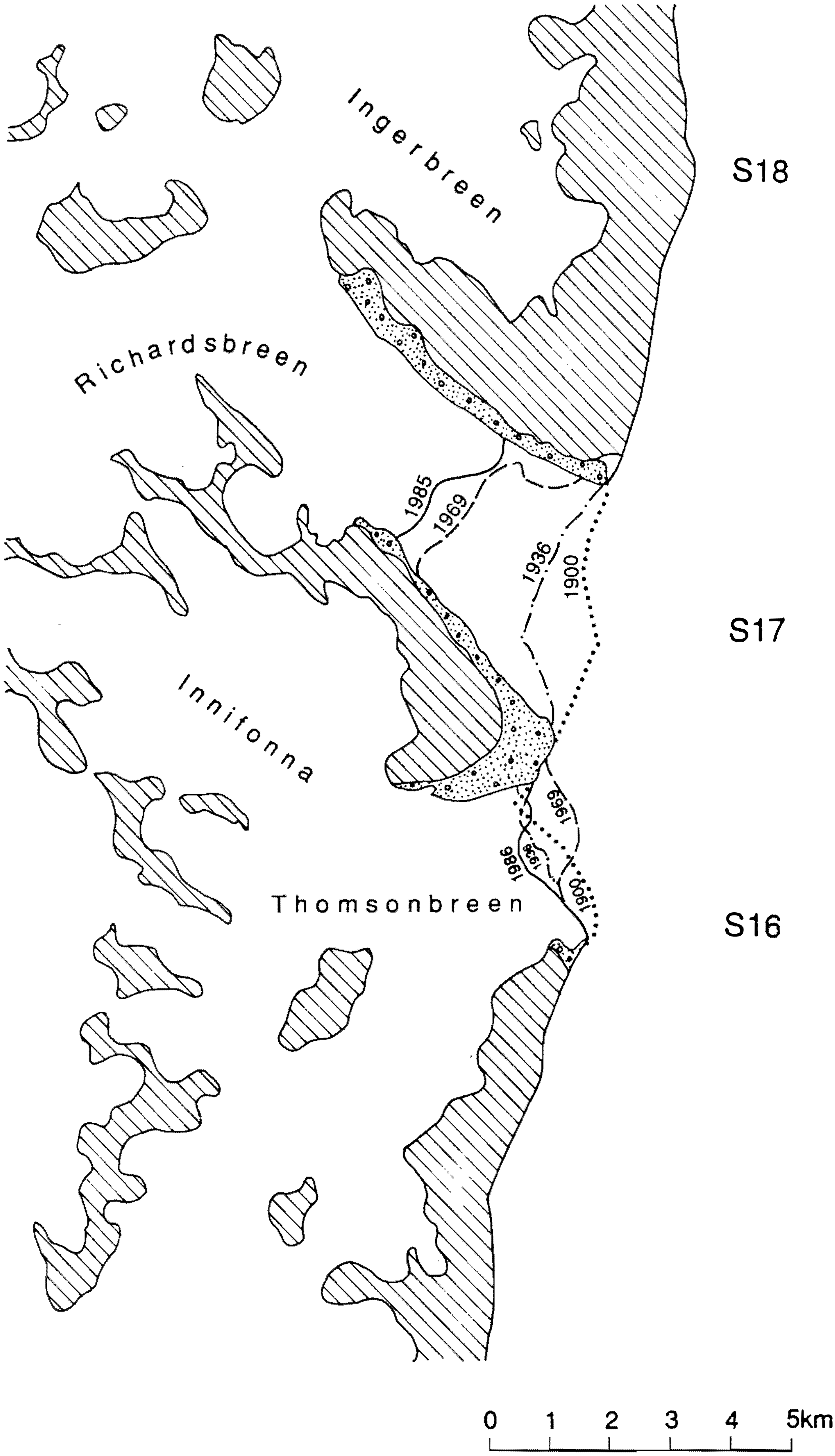

Ingerbreen
S18
Richardsbreen
1985
1969
1936
1900
S17
Innifonna
1969
1986
1936
1900
Thomsonbreen
S16
0 1 2 3 4 5km

Fig. 14

S 18 Ingerbreen

Kaptainsbreen

Bratthengbreen

A.P. 1936: 1760-65

These glaciers are mentioned here because at maximum extension they had small tongues which reached (or were very close to) the sea, but without any calving. They are tributaries of the Beresnikovbreen, even if the Ingerbreen partly feeds the Richardsbreen. In 1936 a large part of this complex was in the accumulation area.

S 19 Beresnikovbreen

Arnesenbreen

Inglefieldbreen

Nordsysselbreen

A.P.	
	1936: 1766-75
	1948: 917-25
	1956: 0555-68, 1397-1409
	1969: 2966-69
	1970: 3857-60

		/Elevation (masl)\		
Area (km^2)	Length (km)	Max.	Med.	ELA
31.4	8.9	550	220	200
30.0	14.0	550	250	230
84.0	21.5	650	300	240
66.7	19.4	700	330	270

On the Vasiliev map these four glaciers had a common front. The Beresnikovbreen showed a lobe protuding into the sea, and probably had surged some years before.

In 1936 (air photos) the Beresnikovbreen, Inglefieldbreen and Nordsysselbreen had very smoothed surfaces. Some moraines had lobes or folded shapes. Thus, likely the Inglefieldbreen surged long before this date (may be before 1900). The Arnesenbreen showed numerous crevasses and characteristic crescentic cracks in the upper part of its basin. Some parts of its frontal moraine were of the same type as that of the Usherbreen moraines (see § 21). Thus, the Arnesenbreen surged before 1936, but without its front actually reaching the sea. One small tributary of the Beresnikovbreen, close to the front, on the southern side also showed characteristic aspect of an old, past surge. This glacier has its basin situated at low altitude.

The retreat of the Beresnikovbreen in 1969 made the Arnesenbreen partly tide-water.

The complex of the Beresnikovbeen, Arnesenbreen, Inglefieldbreen and Nordsysselbreen reached its maximum extension long before 1900. The Beresnikovbreen surged several years before 1900, the Inglefieldbreen surged long before 1936 and the Arnesenbreen some years before 1936 . A very small tributary of the Beresnikovbreen surged also before 1936.

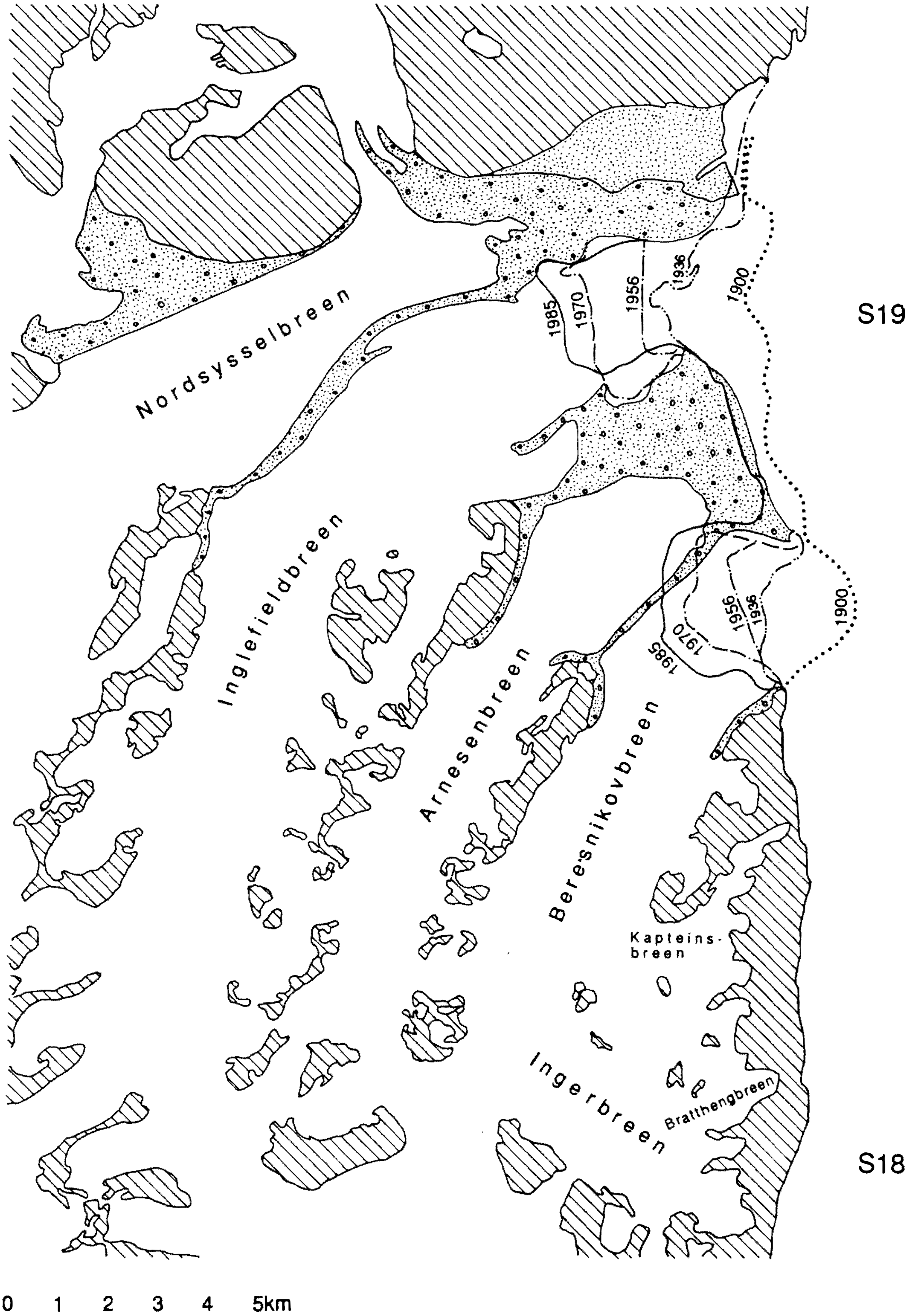

Nordsysselbreen
Inglefieldbreen
Arnesenbreen
Beresnikovbreen
Kapteins-
breen
Ingerbreen
Bratthengbreen
1985
1970
1956
1936
1900
S19
S18
0 1 2 3 4 5km

Fig. 15

S 20 Ulvebreen

A.P.	1936: 1790-95
	1969: 1838-41, 86-88
	1970: 2097-2110
	1971: 6073-75

		/Elevation(masl)\		
Area(km^2)	length(km)	Max.	Med.	ELA
88.0	15.5	700	350	290

Heuglin (mentioned by Rabot in: "Variation de la longueur des glaciers dans les régions arctiques et boréales, 1900) visited the glacier in the years 1870-1871 and believed that the glacier previously had a greater extension, based on the presence of enormous moraines to the north-east, and the presence of an island. Conway's and Vasiliev's maps show a difference in front positions between 1896 and 1900 (or 1899) which seems reasonable. Apparently the Ulvebreen was wider in 1900.

Aerial photographs from 1936 show that the Ulvelbreen completely hindered the flow coming from the Buckfallet, and was also in a quiescent phase for a long time.So a surge likely occurred around 1896 -1900, at which time the maximum extension was probably reached. A retreat has continued to the present and aerial photographs from 1969, 1970 and 1971 do not provide further information.

The Ulvebreen had a very large extension before 1870 and surged likely around1896-1900. Since then the glacier has retreated without any further surges.

Note: This glacier has a tidewater front in shallow water. It is interesting to note also that its area is fairly large, about half of which lies above 350 m and probably mainly above the ELA.

S 21 Usherbreen

A. P:	1936: 1795-97

The Usherbreen is not a calving glacier. It is mentioned here because it shows remarkable and characteristic pushed frontal moraines similar to those reported for some other glaciers studied in this report. In this respect the Usherbreen is used as a reference. Heuglin noticed in 1870 that it was in a retreating position, and since then has surge previous to 1936. Another surge started in 1978 and lasted until 1984 (Hagen 1987).

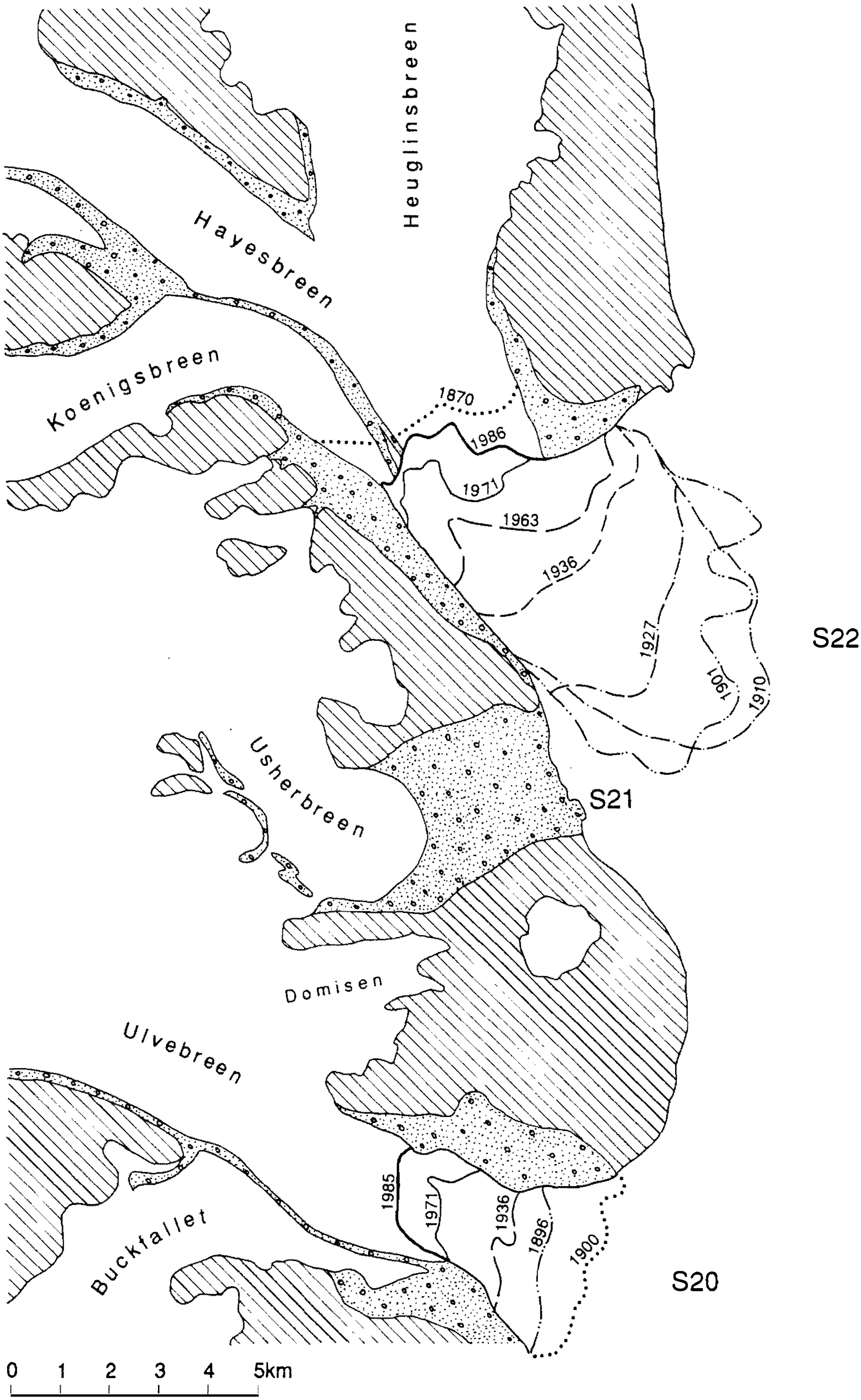

Heuglinsbreen
Hayesbreen
Koenigsbreen
1870
1986
1971
1963
1936
1927
1901
1910
S22
Usherbreen
S21
Domisen
Ulvebreen
Buckfallet
1985
1971
1936
1896
1900
S20
0 1 2 3 4 5km

Fig. 16

S 22 Hayesbreen

Koenigsbreen

Heuglinbreen

A. P. 1936:	1796-98, 0920-33, 0937-39
1948:	909-14
1969:	1942-46, 83-84
1970:	2095-96, 2112-15
1971:	6077-79

		/Elevation(masl)\		
Area(km2)	Length(km)	Max.	Med.	ELA
243.0	25.3	750	300	280
59.0	11.5	650	320	290
82.0	16.2	800	230	240

The old maps from 1870 (Heuglin) and 1896 (Conway), despite their lack of precision, show clearly that the glacier front was positioned a long way into the bay. Heuglin noticed that the glacier had a grounded front covered with moraine and that it was difficult to distinguish the glacier itself (Rabot op. cit.).

Vasiliev map (1901) indicates that the Hayesbreen developed at this time a very large lobe into the sea. Philipp from Filchner's expedition has drawn a fairly accurate front position for 1910. This expedition carried out triangulation work in this area and used a base very close to the glacier front at the foot of the hill known as "Teistberget". On this map the mediane moraine position indicates clearly that the surge was caused by the Hayesbreen and that the Heuglinbreen was not affected. Comparing the positions from 1901 and 1910, we may conclude that the glacier was retreating in 1910 and was not at its maximum extension in 1901. Thus the surge was active in 1901 and lasted at least one year more. The front reached a position almost 9 kilometers ahead of the present position. From an analysis of aerial photographs it is not possible to say if this surge result in the maximum extension, but the marine map 505 shows an important submarine morainic lobe with a crest between 20 and 50 meters height at about 14 kilometers from the present position. There is no more morainic lobe further upstream. Thus it is likely that, during the surge which started in 1901, the glacier was at its maximum extension for the Little Ice Age.

The 1927 position is from Gripp who remarked that the glacier was 3 kilometers in retreat of the 1910 position reported by Philipp. In 1936 (air photos) the median moraine between the Hayesbreen and Koenigsbreen had a characteristic lobe form, indicating the resumption of the flow from the Koenigsbreen after the surge. The convexity of the flow from the Heuglinbreen is also visible. Four icebergs are visible close to the front, they are small but tabular, meaning that a part of the front is floating, or close to floating. Aerial photographs from 1948, 69, 70 and 71, and a Landsat image from 1986, confirm a permanent retreat.

In the longitudinal axis, where the retreat is the most important, it amounted annually to about 120 m for the period 1910-27, 310 m for 1927-1936, 81 m for 1936-63, 175 m for 1963-71, and 40 m for 1971-85. Thus, we believe that the bathymetry at the front of the Hayesbreen may prove of interest relative to the depth of the sea.

The Hayesbreen, was surging in 1901, and advanced about 15 kilometers into the sea. No more surges have been since recorded from the Hayesbreen nor from the Heuglinbreen and the Koenigsbreen.

S 23 Negribreen

A.P.1936:	0900-23, 34-43
	1006-13, 1800-12...,
1948:	881-958
1956:	0290-0319, 1473-89
1969:	1947-54, 72-81, 91-95
1970:	2092-94, 2116-19

		/Elevation(masl)\		
Area(km^2)	length(km)	Max.	Med.	ELA
1180.0	41.0	1200	420	360

Note: a) The air photos from 1936 with numbers from 1813 include the upper basin. b) The sketches of front positions were mainly done by Liestøl (unpublished).

Charles Rabot (op. cit.) studied the Spitsbergen map from the Van Keulen's Atlas, and mentioned that in 1695 the Whichebukta was shown as a real fjord. Also that the island Kvalrossøya, along with a second island unknown at the present was visible as well. On Heuglin's map (1870) Kvalrossøya was not visible. There is some agreement between other mapped front positions as from 1884 (Nathorst), 1896 and 1897 (Conway), 1899 (Vasiliev) and 1910 (Philipp). They show quite similar front positions despite the obvious lack of accuracy involved with these observations. In 1899 several expeditions walked on the northern side of the glacier. The Negribreeen had at that time a lobe fairly well advanced into the sea. Vasiliev conducted some triangulation in this area. He visited the glacier and walked at the confluence between the Negribreen and the Gardebreen. Moreover he shows on his map, on the northern side of the Negribreen, a very large morainic lobe from the Gardebreen, which exists at the present, as well as a small morainic island in front of the Negribre which obviously is the island Kvalrossøya. Photographs from this Russian expedition show some moraines which indicate that the glacier was in recession. All this information suggests that a surge occurred before 1870 and that the glacier was retreating in 1899.

The 1927 position is from Gripp. His map is not very precise but he noticed that the glacier had retreated about three kilometers since the construction of the Filchner's map. He also observed more than 80 tabular icebergs close to the front, many of them more than 100 m long. That means that the tongue was probably floating, possibly after having left a grounded treshold position.

Aerial photos from 1936 indicate a sudden change in the glacier front position. The front was now far into the sea with an aspect of broken line, and Kvalrossøya was not visible. In 1935 and 1936 the glacier was surging. The 1935 front position on the map included here is produced by a German expedition (Liestøl, pers. comm.) Photographs from the upper part of the glacier show that the entire accumulation area was surging. The two lower tributaries, the Petermannbreen and the Gardbreen, were not affected by the surge, but all the others glaciers in the area had characteristic parallel crevasses and characteristic crescentic heavy cracks in the upper parts of their basins. This was the case for the Ordonnansbreen, Akademikbreen, the eastwards flow from the Transparentbreen

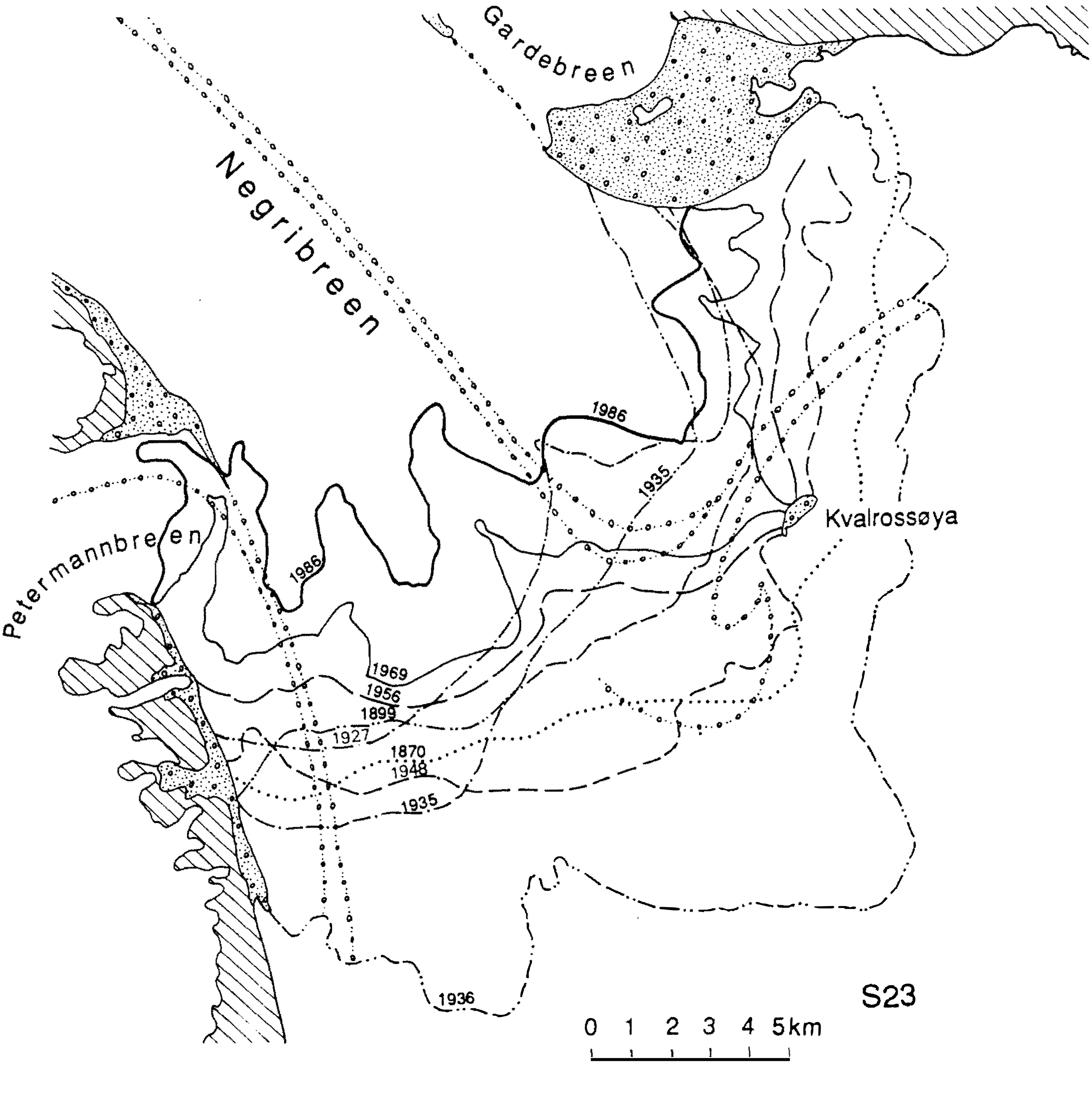

Gardebreen
Negribreen
Petermannbreen
Kvalrossøya
1986
1986
1935
1969
1956
1899
1927
1870
1948
1935
1936
S23
0 1 2 3 4 5km

Fig. 17

and for most of their tributaries, as well as the unnamed glacier situated between Maltebrunfjellet and Sillhogda (see figure 18 at the front). This glacier was calving along its whole front, and the very large morainic lobe presented on the map is likely due to the relief of the bedrock (a partial threshold at the level of Kvalrossøya). Between Kvalrossøya and the left side (South) the front was partly floating.

Liestøl(1969) estimated that the front advanced with an average about 35 m per day.

In 1956 (aerial photographs), the front was in a very quiescent phase and the glacier surface was flat and smooth. Some crevasses were visible close to the central part of the front. The 1956 position shows an important retreat from 1936, but Kvalrossøya was not visible yet, being still covered by a small ice cap.

Aerial photographs from 1969 and 1970 indicate the following pattern of retreat . Analysis of lateral moraines on the left side (south) indicate, firstly that the maximum extension during this surge was a little further than that of 1936 surge, (so 1936 is actually the main year of the surge), and secondly that this maximum is the maximum for the entire Little Ice Age. On the north side, photographs from 1936 show a lateral moraine not yet reach by the surge at the date of the photo. This moraine is completely removed by the later surge which means that the maximum extension before the surge in 1936 was very close to the maximum observed in 1936.

The Landsat image from 1986 (and not 1988, error on the N.P. map) confirmes a permanent retreat.

It is difficult to estimate precisely the rate of the retreat because we do not have the real maximum position of the front. Nevertheless, it is obvious that at the beginning of this retreat the annual rate was higher than today. For the period 1936-56 , between Kvalrossøya and the southern side, the retreat was approximately 400-500 m a year, while from 1956 until the present the retreating rate has been about 110-130 m a year.The Negribreen is not floating at its front. However the main volume of the ice is below sea level, so the buoyancy force is considerable. Recent observations has revealed (as it is also possible to see in the photographs from 1969 and 1970) relatively large icebergs in this area, as well as some large cracks in the frontal area.

According to the NP map C 8, the glacier has a very weak slope (0.1%) from the 1969 front position to the confluence (i.e at about 15 km). This means that if the retreat continues we will probably have tabular iceberg production from this glacier for a long period.

Surprisingly, both in 1969 and 1970 some cracks were visible in the upper parts of the Petrovsbreen, i.e. the eastward flow from the Transparentbreen and the Opalbreen. Due to insufficient informations it is not possible to explain this phenomena. It could have been due to a continuing and slightly stronger flow from these glaciers, or by an unrecorded surge from a small tributary. Nevertheless, characteristic moraines are

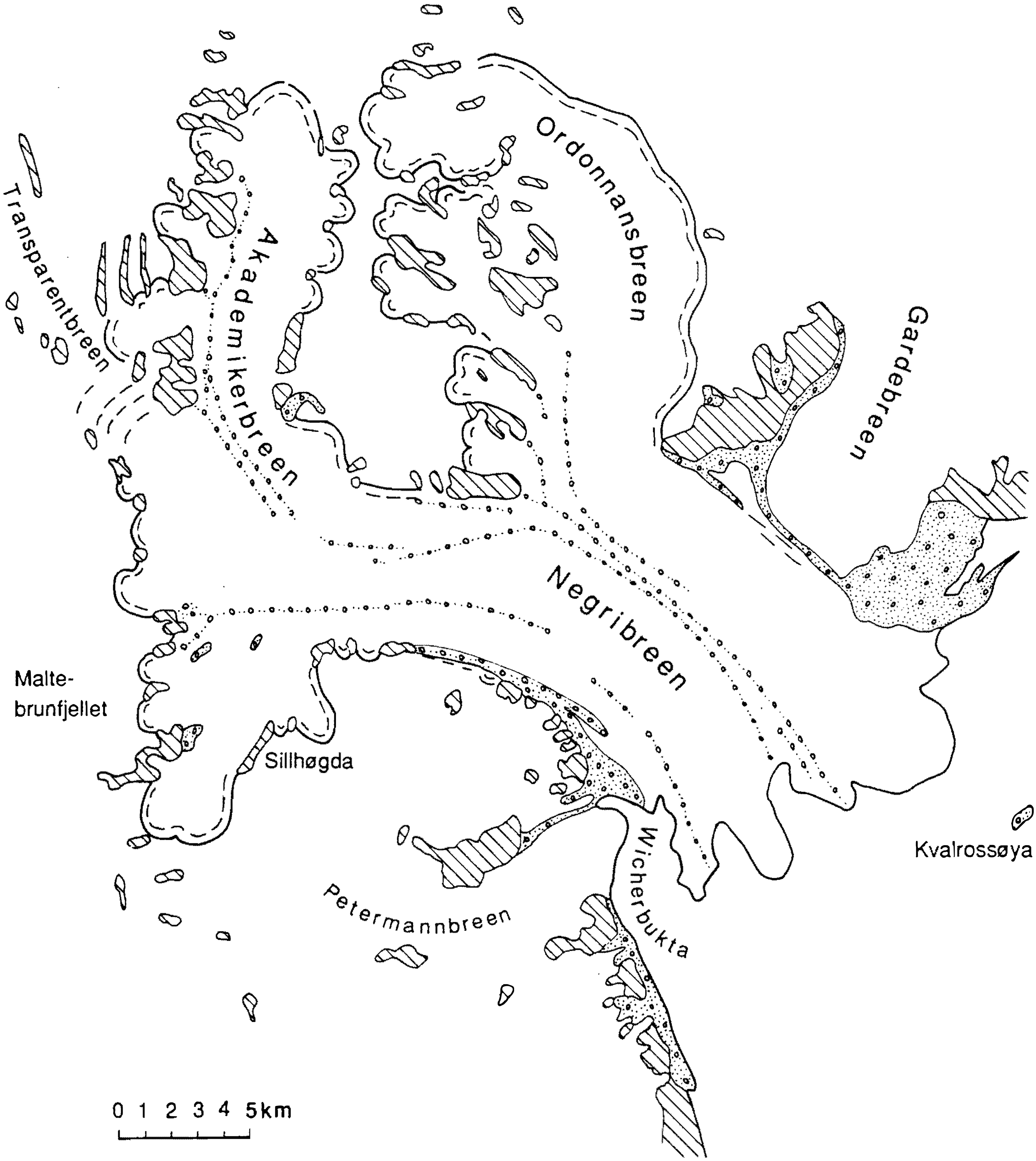


Fig. 18 Area affected by the surge of the Negribreen in 1935-36.

visible. Thus it will be possible to confirm this point later by the aerial photographs from 1990 when they will be available.

The present front position is already more retreated than the previous pre-surge position. The Petermanbreen is no longer confluent with the Negribreen, and has its own tide-water front.

The Negribreen had an important extension (at an undetermined time) during the 18th or early 19th centuries. A large surge occurred in 1935-36 which affected its entire basin exept the Petermanbreen and Gardenbreen, both of which have their confluence with the Negribreen very close to sea level. The maximum extension was slightly greater than that visible on aerial photographs from 1936 and was also the maximum for the Little Ice Age. Since then the retreat has been continuous with calving of some large (around 100 m) and tabular icebergs.

S 24 Helge Backlundbreen

A.P.	1936: 0945-49
	1969: 2016-17

		/Elevation(masl)\		
Area(km^2)	length(km)	Max.	Med.	ELA
27.1	9.0	400	270	250

The glacier was retreating in 1936 but had a front position near the maximum position as indicated by the lateral moraines. The lower part of the basin is separated from the rest by a small depressed arc of geologic origin. Above this arc, to the north, numerous cracks may be seen. The maximum extension, reached some years before 1936 was therefore probably due to a surge.
The air photos from 1969 show that the basin is divided in one low and one high basin with a dammed lake situated between them, in the south. On the other hand, a lateral moraine on the northern side shows a fold, characteristic of a past surge.

The maximum extension of the Helge Backlundbreen occurred several years before 1936 during a probable surge. Since then, a continuous retreat has taken place.

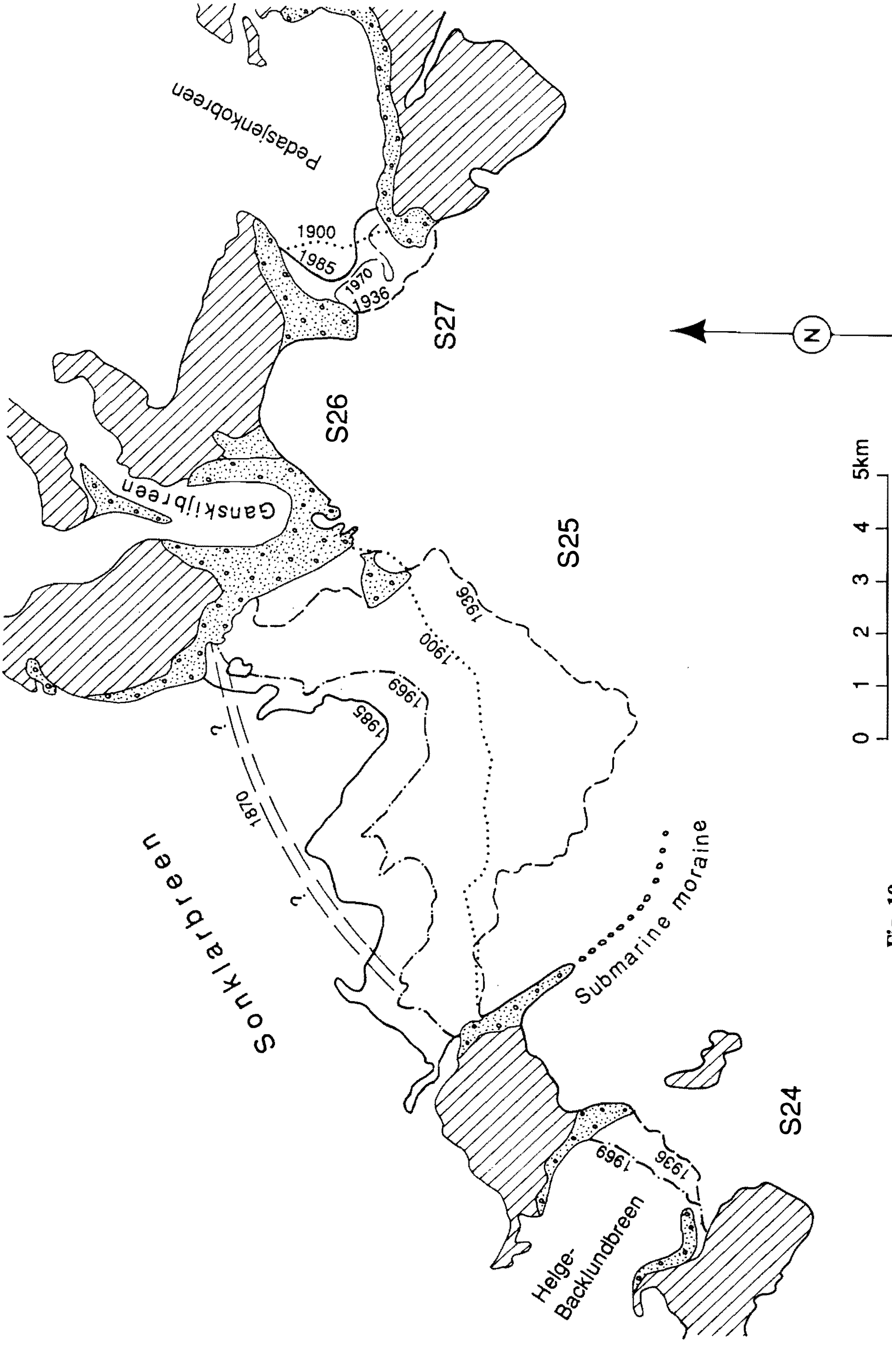

Pedasjenkobreen
Ganskijbreen
Sonklarbreen
Helge-
Backlundbreen
Submarine moraine
S24
S25
S26
S27
N
1900
1985
1970
1936
1969
1870
0 1 2 3 4 5km

Fig. 19

S 25 Sonklarbreen

A. P.	
	1936:0945-59
	1969: 1997-99, 2020-24

		/Elevation(masl)\		
Area(km^2)	length(km)	Max.	Med.	ELA
272.0	17.0	530	340	280

On Heuglin's map, in 1870, the front of the Sonklarbreen is shown at shoreline level, i.e. without a lobe into the sea. It has a morainic edge which is also marked on the Vasiliev map (1900), which is visible on all air photos and which is still present today. Lamont, who sailed in this area before 1870, mentions nothing about the Sonklarbreen, so the glacier was likely in a quiescent phase then. According to the lateral moraines morphology the maximum extension was probably reached before 1870, and at this time a very large lobe probably extended into the sea. Its position can be followed a little bit further along the southern morainic ridge, because on aerial photos from 1969 a string of small icebergs was grounded there. In 1898 the glacier was visited by Prince Albert of Monaco (in Rabot op.cit.) and was in a quiescent phase. The prince was quite possibility able to walk directly onto the ice directly from a rowboat, as on a quai, along the southern side of the front.

On the photographs from 1936 the glacier front is positioned into the sea. The glacier surface shows typical characteristics of a glacier in a quiescent retreating phase. This glacier could have had two pulsations, one between 1870 and 1900 and a second between 1900 and 1936. The first one could have been caused by the surge of a small tributary, though the imprecision of Heuglin's map does not allow any final conclusion on this. It is also possible that the 1900 position was mapped during a surge. Evidence in the form of the slow retreat of the Negribreen as well as the general opinion of Dowdeswell (1989) suggests that the 1936 position is concevable assuming a surge around 1900. Moreover in 1936 the glacier was also almost completely an ablation area.

The air photos from 1969 show a characteristic lobe in one mediane moraine, close to the northern side, which confirms that the advance before 1936 was a surge. Photographs from 1936 and 1969 indicate that the small glacial flow on the left side of the front was not affected by the last pulsation. From then up to the present the retreat has been continuous.

The Sonklarbreen reached an important maximum extension long before 1870. Since then a possible but uncertain pulsation took place before 1900 and a surge occurred between 1900 and 1936, probably nearer 1900.

S 26 Ganskijbreen

A.P.	1936: 0957-59
	1969: 1797-99

		/Elevation(masl)\		
Area(km^2)	length(km)	Max.	Med.	ELA
21.4	10.0	580	310	320

According to Vasiliev's map the Ganskijbreen had a small calving front around 1900 and was in a retreating position at this time. This glacier surged a few years before 1936. In 1936 lateral and frontal moraines showned the same characteristics as those of the Usherbreen (see § 21). The sediments pushed by the front built a sort of rampart between this front and the sea. This small glacier also has a low and a high basin separated by a geologic step.

The Ganskijbreen was retreating in 1900. It surged few years before 1936 and since then has retreated. At the present it is not a real calving glacier.

S 27 Pedasjenkobreen

A. P.	1936: 0958-62
	1969: 1798, 1847-49

		/Elevation(masl)\		
Area(km^2)	length(km	Max.	Med.	ELA
39.0	8.7	600	320	300

The Vasiliev map indicates that the glacier was in retreat and clearly shows its lateral moraines. In 1936 the glacier was retreating after a recent surge. This surge did not reach the previous maximum extension. Analysis of the lateral left moraine morphology indicates the possibility of three different successive pulsations.

The glacier has a small calving front only, but its piedmont lobe extends further east. This glacier also has a geologic step which separates a low basin from an upper one.

The Pedasjenkobreen probably had three advances at the end of the Little Ice Age, but it is not an important calving glacier because its front is only partly a tide-water front.

B BARENTSØYA
and
E EDGEØYA

B 1 Duckwitzbreen

A. P.	1936:	3329-38, 3635-41
		3663-67, 3670
		3703-04, 3715-17,
		3846-61
	1969:	1747-50, 69-70
		1805-07, 37-39
	1970:	3540-41

		/Elevation (masl)\		
Area (km2)	Length (km)	Max.	Med.	ELA
98.10	19.6	660	420	360

In 1870 Heuglin noticed (cit. in Gripp 1929) the presence of a moraine along the entire front. Vasiliev's map (1901) showed the front at the same position. In 1919 Tyrell indicated that the glacier had moved about 5,5 km forward and had partly recovered the Anderson Islands. That means that the glacier was surging at that time, or had been surging only one or two years previous.

In the 1936 air photos the glacier was quite close to its maximum extension. Numerous crevasses were still visible on the surface, and the frontal moraine deposed in the sea was a characteristic pushed moraine of the type associated with notable waves, such as the moraines of the Usherbreen (see § S 21). The upper basin was depressed, and about 5-6 kilometers from the shore line an important step of geological origin was visible across the glacial valley. The front was very low and the slope of the tongue very weak. The calving may have produced a few small icebergs, but they were probably stopped by the end moraine. The retreat of the front has been very slow, and the ablation by melting more important than ice mass lost by calving. On other air photos, as well as at the present, a large part of the frontal moraine has disappeared having been washed away by the sea, but the submarine ridge is still present.

The Duckwitzbreen probably reached its maximum extension during this surge. However due to the shallow sea, the presence of thick sediments and of the frontal pushed moraine there was no important calving. At present the glacier is no longer tide-water, and it is rebuilding an important and new frontal moraine above sea level.

The Dukckwitzbreen surged in 1919 or a few years before. No more surges have been recorded. This surge was associated with some characteristic features, in particular a marine frontal moraine deposited in shallow water.

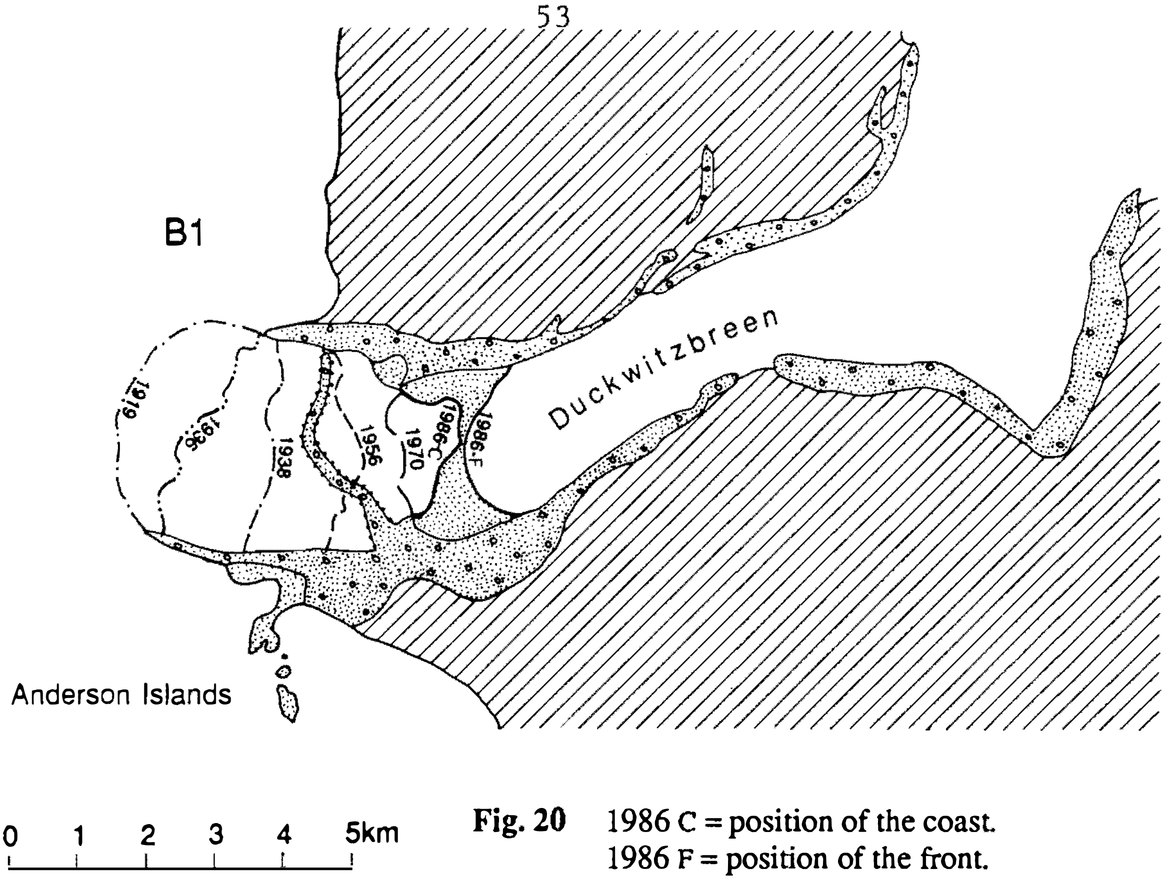


Fig. 20 1986 C = position of the coast.
1986 F = position of the front.

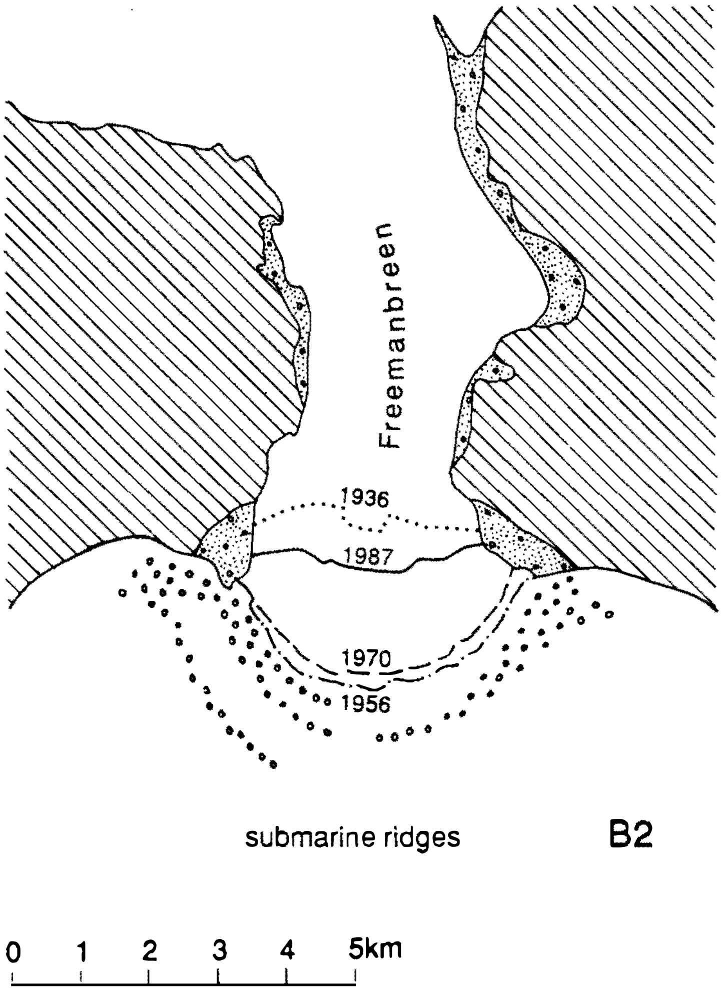


Fig. 21 Dots in the sea in front of the Fremanbreen indicate position of submarine morainic ranges.

B 2 Freemanbreen

A.P.	1936:	3292-97, 3705-12, 20-26, 3839-43
	1956:	1390-96
	1969:	1760-61
	1970:	4565-69
	1971:	7154-56

		/Elevation	(masl)\	
Area (km2)	Length (km)	Max.	Med.	ELA
96.o	19.0	640	300	300

In 1936 the Freemanbreen was retreating from an important maximum extension reached many years before. The morphology of lateral shore moraines indicates that during this previous maximum the glacier had developed a very large lobe into the sea. This point can be corroborated by the bathymetry plotted in 1987 (marine map N° 533). In 1956 the Freemanbreen was surging. During this surge the glacier was very close but did not reached the previous maximum position. On the marine map, downstream from the 1956 front position, the bathymetry reveals two morainic ridges about two hundred meters apart. These two ridges may have been built by the 1956 surge. A third ridge lies about 800-1000 meters futher downstream. This ridge corresponds to the previous maximum which is also the maximum for the Little Ice Age. The retreat after the 1956 surge was very slow. Front positions in 1970 and 1971 were very close to the 1956 position. The rate of the retreat was less than 10 meters per year. From 1971 until the present the rate has been about 90 meters per year.

The maximum extension of the Freemanbreen occurred long before 1936, probably at the end of the previous century or at the beginning of the present. A surge occurred in 1955-56 and the glacier developed an important lobe into the sea, but did not reached the previous maximum.

B 3 Hübnerbreen

Reymonbreen

A. P.	1936: 3295-3304
	3701-06, 22-26,
	3823-43
	1956: 1394-96
	1970: 4550-53, 64-66

		/Elevation (masl)\		
Area (km2)	Length (km)	Max.	Med.	ELA
53.2	15.0	640	320	270
33.0	9.0	600	270	270

The first information about these glaciers is found in the aerial photographs from 1936. Analysis of the morphology of lateral moraines and grounded till indicates that, at its maximum, the glacier reached the sea. It developed a fairly large lobe here and some calving occurred. In 1936, the front was about two kilometers from the shore line. Taking into account the distance between the estimated tide-water front and the 1936 position, it may be concluded that the maximum occurred a long time previous. During the retreating phase the Hübnerbreen was nearly split into a lower and an upper glacier. The boundary between these two zones was well marked by a depressed area caused by an important sub-glacial drainage system across the width of the glacier. Sub-glacial channels have put two large lateral lakes in connection. In 1936 the upper glacier showed an important number of crevasses, and its lateral sides were very convex. The boundary between the two parts of the glacier was marked by an important step. The sub-glacial drainage between the two sides was closed. From these observations it may be concluded that only the upper part surged, surprisingly, the lower part was only slightly disturbed. The lower front was not affected by the surge which occurred before 1936, and was ended at this time.

Aerial photographs from 1956 show that the Reymondbreen was surging. The contact line with the non-surging Hübnerbreen as well as a vertical cliff at the front lobe were readily visible. Analysis of air photos from 1970 confirm that a large part of the Hübnerbreen was affected by the surge. Due to the position of the Reymondbreen, the pressure ran diagonally towards the Hübnerbreen. The surging front was continually vertical. In the proglacial area where the thickness of the deposited sediments is thin, several very small morainic ridges were visible. These moraines may be annual moraines, or more likely, small ridges deposited in the glacier shear faults parallel to the front . The glacier did not remove these sediments and no pushed frontal moraine exists. Probably the permafrost here lies very close to the ground surface. A hydrolaccolith with a typical pingo shape and a diameter of about 150 m was visible in 1970, while it didn't exist in 1936.

These two surges seemed to have had an important part of their energy dispersed into the lower part of the Hübnerbreen, thus the fronts did not advance as far down stream as expected, and did not reach the sea.

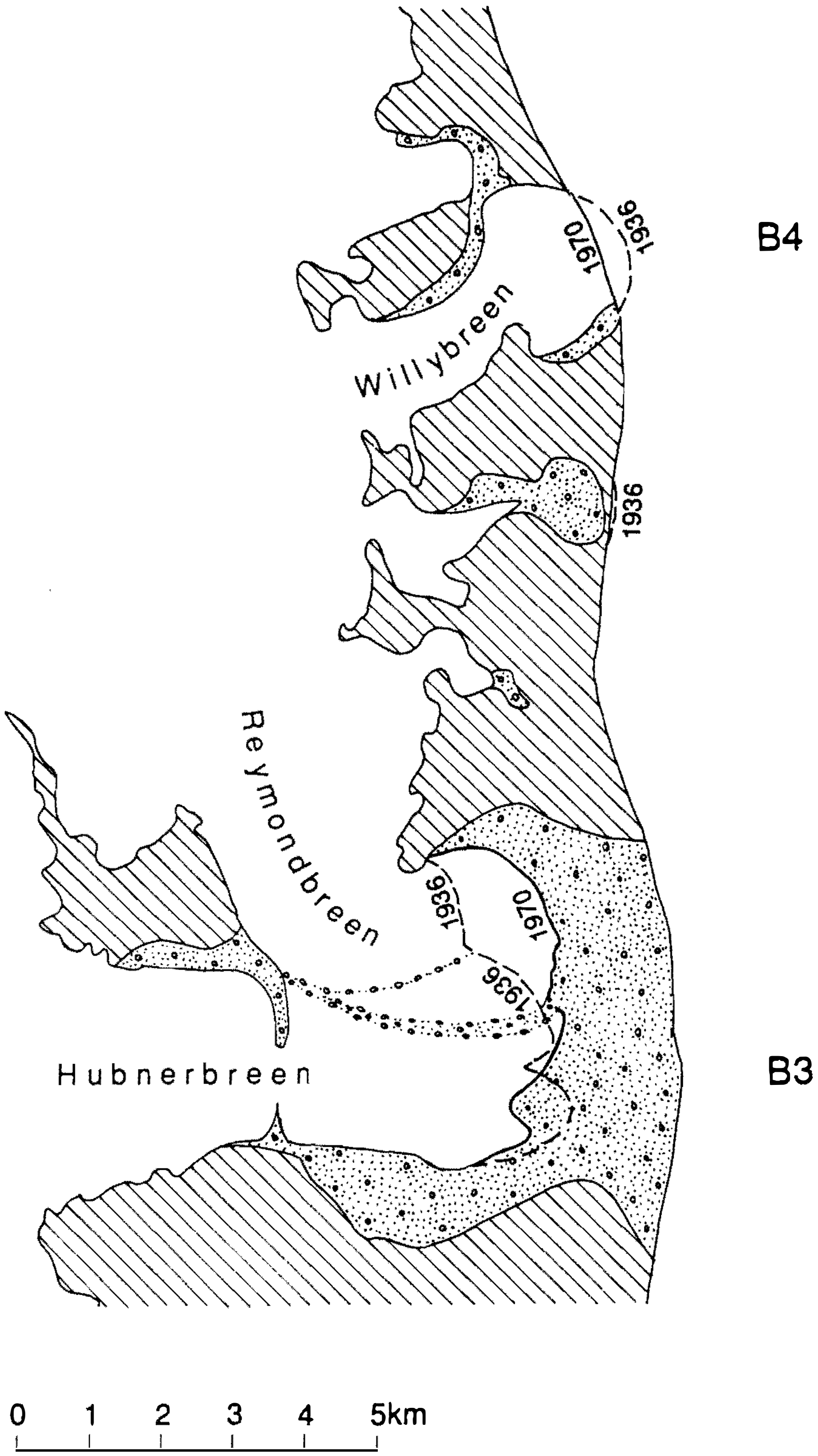

1970
1936
B4
Willybreen
1936
Reymondbreen
1936
1970
1936
B3
Hubnerbreen
0 1 2 3 4 5km

Fig. 22

The maximum extension of the Hübnerbreen and the Reymondbreen occurred long before 1936, and both glaciers had tide-water fronts. The degree of calving which occurred at this time is difficult to estimate. The upper part of the Hübnerbreen surged just a few years before 1936. The Reymondbreen surged in 1956. Surprisingly, these two surges did not result in significant changes in the position of the front, which since then has not reached the sea again.

B 4 Willybreen

A P.	1936: 3303-08, 3822-23
	1070: 4552-54

		/Elevation (masl)\		
Area (km2)	Length (km)	Max.	Med.	ELA
11.4	6.0	500	250	300

To the north of the above mentioned glaciers are two small outlets. During their maximum extension the first outlet was very close to the sea but did not calve. The second glacier, the Willybreen, developed a lobe into the sea but significant calving hardly occurred. In 1936 the front of the Willybreen was still tide-water. In 1970 however, this front became situated at the shore line.

B 5 Besselbreen

Augnebreen

A. P.	1936: 3305-11, 3640-47
	3676-84, 90-99
	1969: 1840-44 ?? ??
	1970: 4554-63

		/Elevation (masl)\		
Area (km2)	Length (km)	Max.	Med.	ELA
146.8	22.5	630	330	230
90.6	14.0	600	320	200

The first information about these glaciers was provided by the 1936 air photos. Morphology of lateral moraines indicates that the last maximum extension reached before 1936 was the maximum for the Little Ice Age. At this time the Besselbreen developed a very large lobe into the sea and the northern lobe of the Agnebreen nearly reached the shore line, but did not calve.

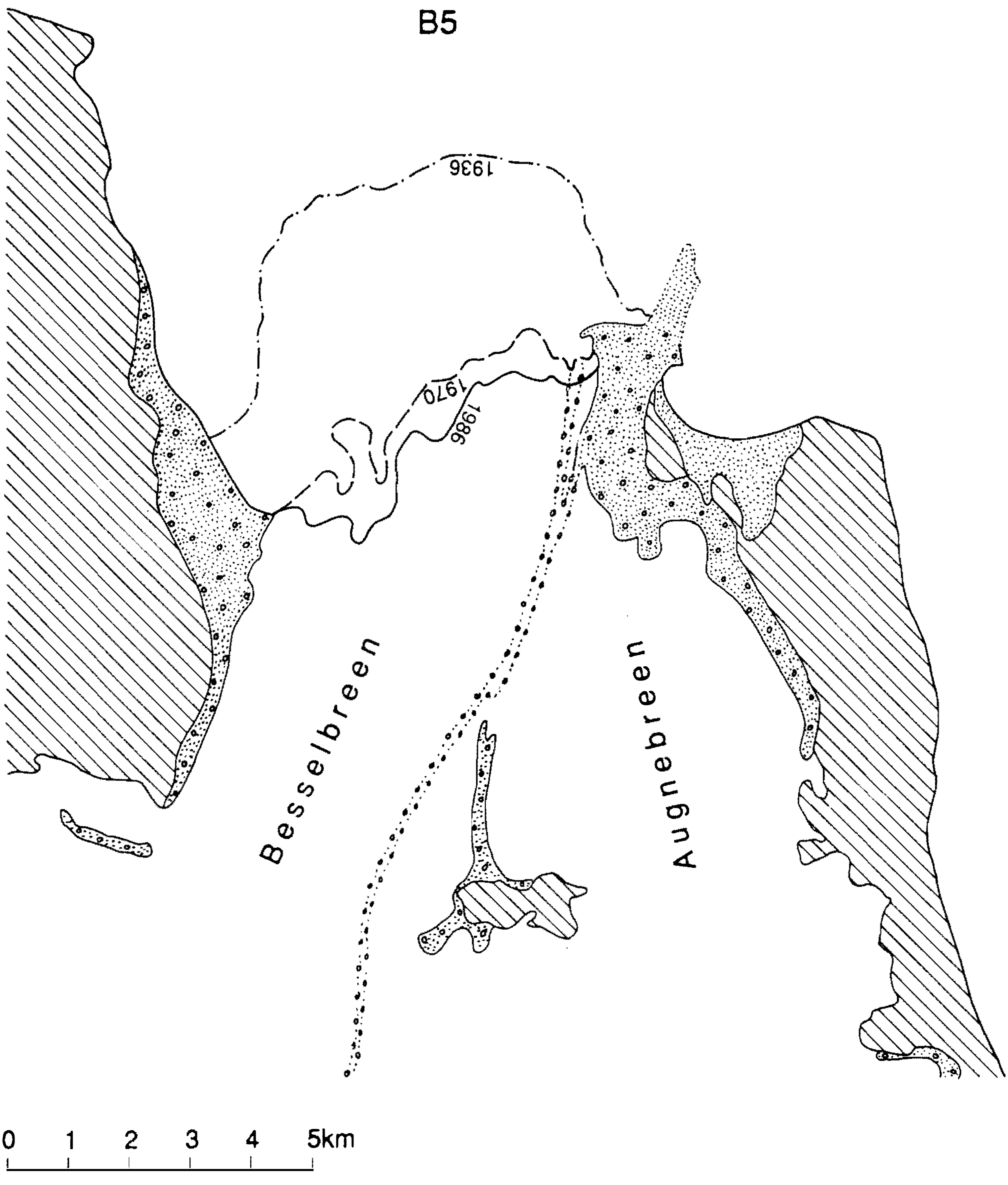


Fig. 23

In 1936 these glaciers were retreating into a quiescent phase, and apparently have been doing so for some time after having reached the maximum extension. The surface of the Besselbreen was very smooth and the edge of the tide-water front was only a few meters above sea level. The tongue was very flat and probably nearly floating. The sea depth at the front was about 60 m (marine map 507). The retreat is also well marked above water level at the boundary of this glacier. In 1936 nearly the entire basin was below the firn line.

After 1936 the glacier continued to retreat. On the eastern side of the front a long lateral moraine extended in the sea, disappeared, and was washed away by the sea (see Fig. 23). The retreat rate of the front was about 100 m per year between 1936 and 1970, and has been about 30 m per year from 1970 until today. That means that the front is probably lying on a shallow sea.

The Besselbreen and Augnebreen reached their maximum positions at the end of the last century or at the beginning of the present. Since then, they have been retreating continuously until the present. The front of the Besselbreen has continuously been tide-water and calving. No surges have been recorded for these glaciers.

E 1 Skrentbreen

E 2 Kuhrbreen

Note: The Skentbreen and Kuhrbreen are only located on the map of the Fig. 7, there is no independent map for these two glaciers.

A. P.	1936: 3415-25
	1969: 1821-24
	1971: 7133-35, 73-80

		/Elevation (masl)\		
Area (km2)	Length (km)	Max.	Med.	ELA
28.6	7.2	570	320	300
94.6	17.5	560	320	350

The fronts of the Skrentbreen and the Kuhrbreen lie in close proximity, but the glaciers drain two different accumulation areas.

At present, they are non-calving glaciers, but during their last maximum advance before 1936 they nearly reached the sea. Only its own frontal moraine prevents the Kuhrbreen from being a tide-water glacier. It is conceivable that this glacier was in fact calving before 1936, but analysis of all available aerial photographs indicates that it is unlikely. Nevertheless, these glaciers show characteristic folded mediane moraines as well as frontal moraines of the Usherbreen type that means that the Skrentbreen and the Kuhrbreen reached their maximum extensions during a surge.

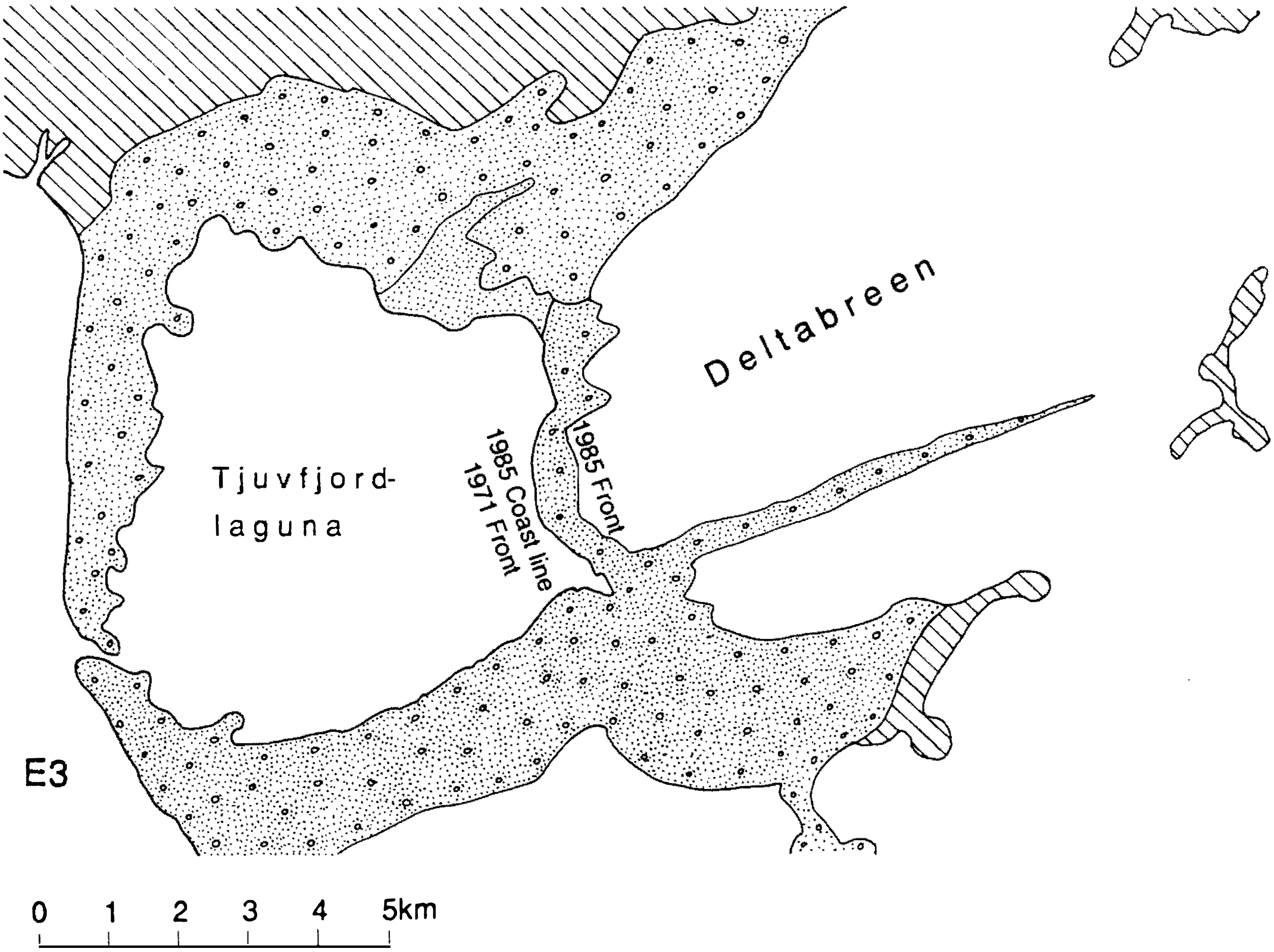

Deltabreen
Tjuvfjord-
laguna
1985 Coast line
1971 Front
1985 Front
E3
0 1 2 3 4 5km

Fig. 24

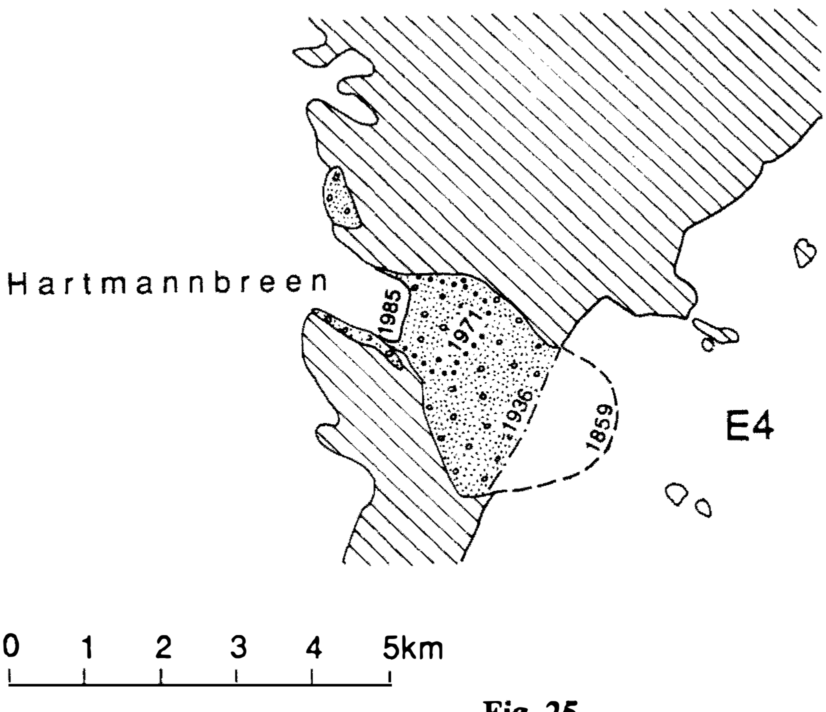

Hartmannbreen
1985
1971
1936
1859
E4
0 1 2 3 4 5km

Fig. 25

The Skrentbreen and the Kuhrbreen surged before 1936. They are non-calving glaciers, and in spite of their proximity to the sea they have no real chance to becoming calving glaciers.

E 3 Deltabreen

A. P.	1936:	3476-78, 84-86 3751, 79-82, 3791-3806
	1956:	3489-94
	1971;	7215-23, 7628-40, 65-70, 81-84

		/Elevation (masl)\		
Area (km2)	Length (km)	Max.	Med.	ELA
186.70	17.6	420	210	300

James Lamont (1861) visited the Deltabreen area in 1859. He found the glacier detached of its frontal moraine and ending in a lagoon. He noticed on the inner part of the moraine the presence of saxifrages and mosses, indicating that the retreat of the glacier from this moraine had occurred a long time ago. Air photos from 1936, 56, 71 as well as a Landsat image from 1985 show the same situation that described by Lamont.

The name of the Deltabreen comes from the large delta located at its front. As for the Duckwitzbreen, the frontal moraine was formed by the proglacial sediments emitted by the glacier itself. This moraine separates the glacier from the sea, and there is little calving in the proglacial lagoon. Analysis of the morainic complex shows similarities to the Usherbreen moraines. This means that the maximum extension occurred during a surge. Moreover, it is possible that the last extension was not the maximum reached by the glacier. It seems that a previous surge occurred and made the Deltabreen tide-water for some years. It is not possible to know if the last surge occurred before or after the visit of Lamont. Presentely, only a field observation could give the right information. Nevertheless, the outermost part of the moraine has an extremely smooth surface indicating that its maximum extension occurred a long time ago. In any case, any calving which might have occurred in the past is likely to have been insignificant due to the shallow sea and the accumulation of glacio-marine sediments. Future surges are not likely to produce any significant calving. Moreover, at the present the glacier has a second frontal moraine lying directly at its front.

The Deltabreen may have been a tide-water glacier during some years in the distant past. It surged once or twice before Lamont's visit in 1859. No surges have been recorded since then. Due to large amounts of proglacial sediments any future surges are not likely to produce any important calving.

E 4 Hartmannbreen

A. P.	1936: 3488-95
	1971: 7657-60, 7739-42

		/Elevation (masl)\		
Area (km2)	Length (km)	Max.	Med.	ELA
11.35	4.6	500	330	300

Lamont noticed two glaciers in this area with tide-water and semi-circular fronts about 5 km length and protruding about 2.5 km into the sea. These glaciers are the Hartmannbreen and the Pettersenbreen. Dimensions seem to be a little exaggerated for the Hartmannbreen. In 1936 this glacier was no longer tide-water. It is not possible to know if the last advance of the Hartmannbreen was due to a surge, nor if this advance was the maximum extension of the glacier. Nevertheless, any new surge of the Hartmannbreen woulød have small chance of reaching the sea.

The Hartmannbreen likely reached its maximum extension around 1860. Since then its retreat has made it a non-calving glacier. There is no recorded surge for this glacier.

E 5 Pettersenbreen

A P.	1936: 3475-81
	1971: 7746-49, 81-84

		/Elevation (masl)\		
Area (km2)	Length (km)	Max.	Med.	ELA
11.35	4.6	500	330	300

According to Lamont, in 1859 the Pettersenbreen had a lobe of about 2.5 km protuding into the sea. In 1936 the glacier had still a semi-circular front jutting into the sea of about the same length. Moreover, the glacier surface had a lot of parallel and concentric cracks, particularly in the upper basin. A surge occurred several years before, likely around 1925 or slightly later. Observation of lateral moraines from aerial photographs seems to indicate that this surge did not reach the maximum extension of the glacier. In this case this maximum appears to coincide with the observation of Lamont. Nevertheless, it is not possible to say if the maximum extension at the time of Lamont's visit was due to a surge or not. Today, the Pettersenbreen is withdrawing and does not calve, but the glacier could reach the sea and start calving again during a new surge..

The Pettersenbreen reached its maximum extension during the last century which may indicate a surge. A recent surge occurred before 1936, likely around 1925.

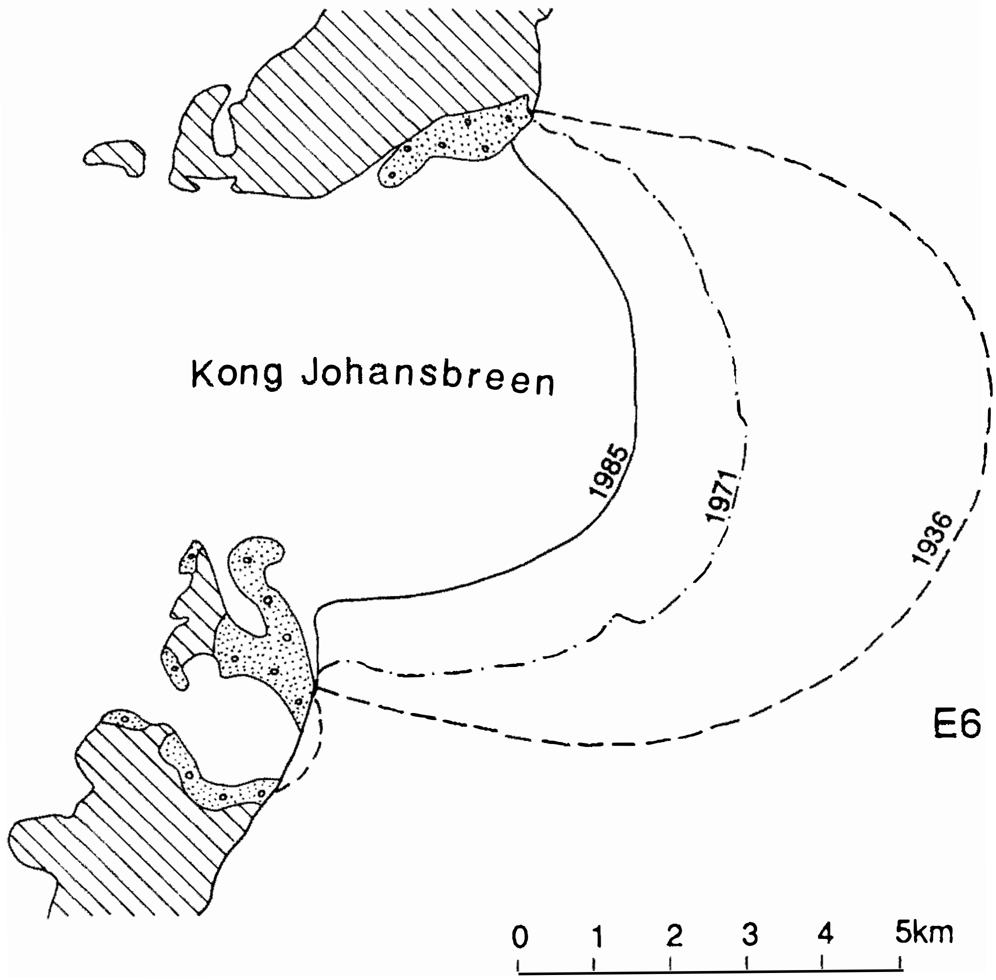

Kong Johansbreen
1985
1971
1936
E6
0
1
2
3
4
5km

Fig. 26

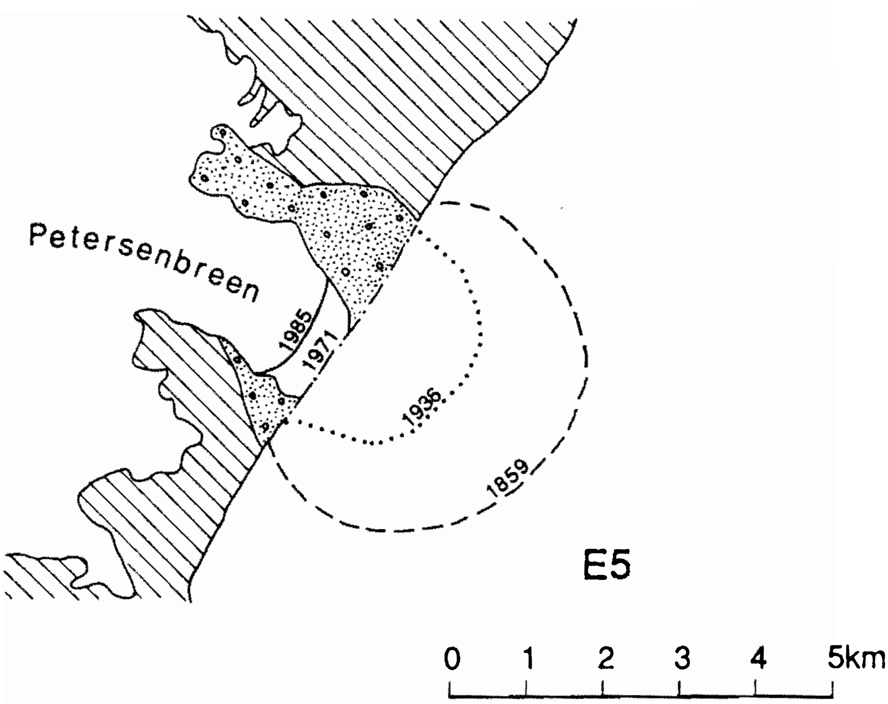

Petersenbreen
1985
1971
1936
1859
E5
0
1
2
3
4
5km

Fig. 27

E 6 Kong Johansbreen

A.P.	1936: 3460-71
	3779-81
	1971: 7820-24, 60-67

		/Elevation (masl)\		
Area (km2)	Length (km)	Max.	Med.	ELA
106.8	16.0	460	180	200

Lamont, in 1859, observed that the complex of fronts from the Kong Johansbreen and the Stonebreen, had three semi-circular divisions protuding into the sea for 5-6.5 km. Information from Lamont unfortunately are not more precise. Apparently the three lobes correspond to one from the Kong Johansbreen and two from the Stonebreen. There was no land visible from the sea between these glaciers. A five kilometers extension into the sea corresponds very roughly to the front position of the Kong Johansbreen in 1936. In this year aerial photographs show the front as a vertical cliff, and heavily crevassed. Other crevasses, long and parallel are visible on the glacier surface particularly in the upper part of the basin. There is no doubt that this glacier surged a few years before 1936. Depressed areas of ice show fairly well which part of the surface was affected by this surge. A small independent front to the south was also calving at that time. During the maximum extension of these glaciers, the two fronts were contiguous. It is not possible to say if the glacier reached its maximum extension during this surge or not. Positions in 1971 and 1985 indicate a normal retreat.

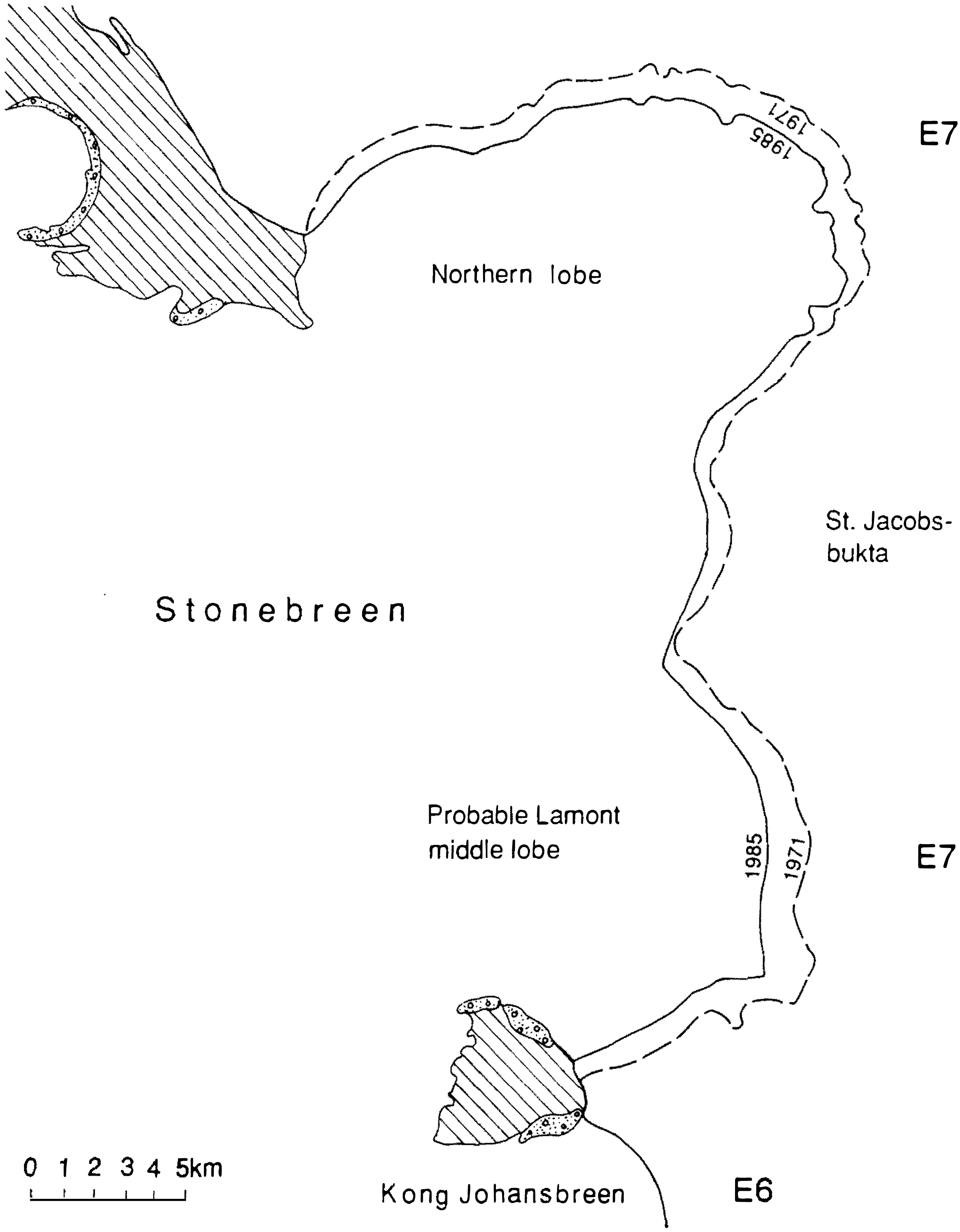
The Kong Johansbreen had two period of maximum extension. The first was during the last century, and the second when it surged around 1925-1930. No further surges have been recorded for this glacier.

E 7 Stonebreen

A.P.	1936: 3254-70, 3443-65
	3746-50, 3808-21
	1971: 7785-7802, 7806-09
	37-60, 68-81

		/Elevation (masl)\		
Area (km2)	Length (km)	Max.	Med.	ELA
711.75	33.5	510	250	250

James Lamont mentioned a complex of glacier fronts of about 50 km. That is the length of the front of the Kong Johansbreen plus the Stonebreen. Also, the middle division of the glacier, in Lamont's description corresponds to the southern lobe of the Stonebreen. In 1859 the northern lobe of the Stonebreen and the southern lobe (Kong Johansbreen) were smooth and showed small activity, while the middle lobe was very active and appeared as "a forest of pine-tree covered with snow". From the front to about 10-12 km inland, the glacier was " indescribly rough and jagged". This part of the glacier was lower than the two "smoothed parts" and booming, very frequentely as well as calving.



1971
1985
E7
Northern lobe
St. Jacobs-
bukta
Stonebreen
Probable Lamont
middle lobe
1985
1971
E7
0 1 2 3 4 5km
Kong Johansbreen
E6

Fig. 28

The description corresponds to a very active glacier, and in accordance with our knowledge of Svalbard glaciers it seems likely that the glacier was surging or had been surging during the past few years. Lamont's crew who had made several previous visits to this area, claimed to have seen the glacier behaving similarly meaning that the surge probably had lasted for some years.

The aerial photographs from 1936 show a very smooth glacier surface with a great quantity of dust in the ablation area, and with an important zone with a well marked melting aureole especially in the northern part. At the front, only a low cliff above water level was seen. The Stonebreen was in a quiescent phase.

In 1971 the complete surface was smooth exept for the northern side where it was possible to see numerous old cracks filled with snow. Close to the front these cracks were more visible, and some small lakes persisted in the crevasses. It is obvious that a surge had occurred a long time before. Unfortunately we do not have sufficient information to determine precisely the date of this surge.

Different parts of the Stonebreen surged at different times. During the last century, between 1850 and 1860, the southern basin surged. The active front was then between the Kong Johansbre and the St Jacobsbukta. The northern part surged between 1936 and 1971. We have no more information on surging activities for this glacier.

H SPITSBERGEN, HINLOPENSTRETET

H 1 Hannebreen

A. P.	1936: 0963-74
	1969: 1847-49
	1970: 3498-3500

		/Elevation (masl)\		
Area (km^2)	Length (km)	Max.	Med.	ELA
41.0	12.8	550	320	250

No accurate information on Hannebreen is available from old maps. Vasiliev did not mention this glacier. So, the first known front position is from the 1936 air photos. At this time the Hannbreen had developed a fairly large lobe into the sea but its surface was smooth and crevasses were visible only in the middle part of the basin. As for some other glaciers, an important step of geological origin marked the boundary between the lower and upper basin. The surge occurred several years before 1936. Based on the morphology of lateral moraines it seems that the pre-1936 surge did not reach the maximum extension of the glacier.

In the years 1969 and 1970 (air photos) as well as in 1985 (Landsat image) the Hannbreen was in a retreating position.

The maximum extension of the Hannbreen occurred long before the first observation of its position in 1936. The glacier surged several years before 1936. Since then it has been retreating continuously.

H 2 Koriskabreen

A. P.	1936: 0974-77,
	1620-27, 30-35
	1938: 1747
	1969: 1849-50
	1970: 3495-96

		/Elevation (masl)\		
Area (km^2)	Length (km)	Max.	Med.	ELA
50.0	13.0	550	300	300

There is no information from old maps about this glacier. Aerial photographs from 1936 show that the front of the Koriskabreen extended about one kilometer from the shore line into the sea. Its surface was smooth and the ice cliff at the front was only of few meters above sea level. The glacier was in a quiescent retreating position. Lateral moraines indicate that the maximum extension reached some years before was also the maximum for the Little Ice Age. It is not possible to determine if this maximum was due to a surge or not. Since then the glacier has been continuously retreating. In 1970 (air photos) its front was situated at the shore line.

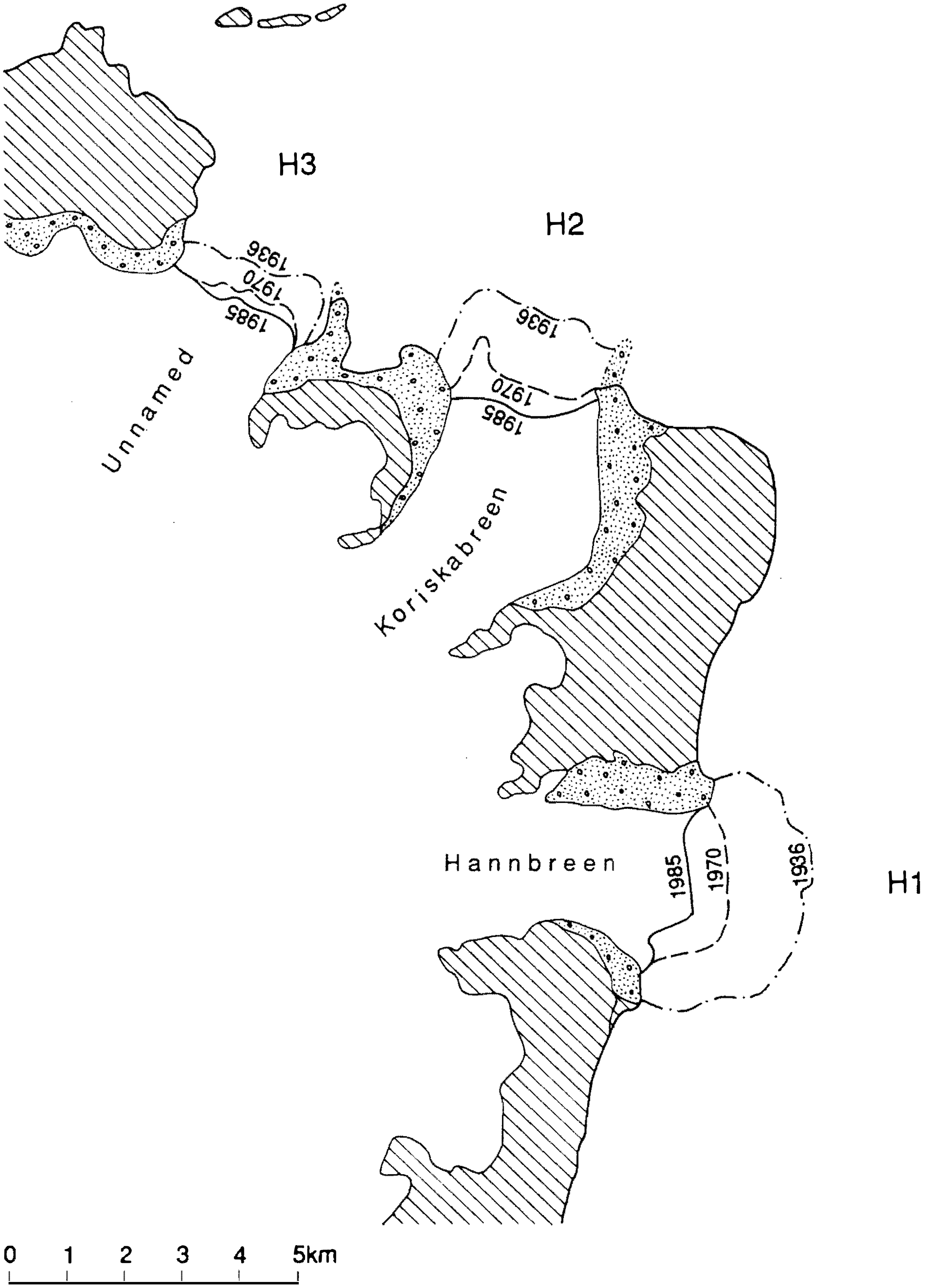

H3
H2
H1
1936
1970
1985
1936
1970
1985
1985
1970
1936
Unnamed
Koriskabreen
Hannbreen
0 1 2 3 4 5km

Fig. 29

The Koriskabreen reached its maximum extension for the Little Ice Age before 1936 (20-30 years?) at which time there developed an important lobe protuding into the sea. Since then it has been retreating. No known surge has been recorded for the Koriskabreen.

H 3 Unnamed

A. P.	1936: 0974-77
	1620-27, 32-39
	1938: 1747
	1969: 1774-51
	1970: 3494-95, 3500-01

		/Elevation (masl)\		
Area (km²)	Length (km)	Max.	Med.	ELA
68.0	10.7	620	350	300

This unnamed glacier is situated between the Koriskabreen and Hochstetterbreen. In 1936, as well as in 1938 (air photos), the surface was smooth. The front had an altitude extending from sea level to some meters above. The glacier was retreating from a previous more extended position . In 1970 the retreat induced more calving at the western part of the front with the result that numerous crevasses appeared on the surface. The morphology of lateral moraines shows that the maximum extension reached before 1936 was probably the maximum for the Little Ice Age, and that the frontal lobe had made a moderate extension into the sea. Since then, this glacier has been retreating continuously.

This unnamed glacier reached its maximum extension for the Little Ice Age several years before 1936. Since then, it has been retreating. No surge has been recorded for this glacier.

H 4 Hochstetterbreen

A. P.	1936: 0974-77
	1938: 1626-27, 40-53
	1969: 2026-28
	1070: 3492-93, 3502-05

		/Elevation (masl)\		
Area (km²)	Length (km)	Max.	Med.	ELA
580.0	37.5	620	350	300

Gerard de Geer (Missions scientifiques pour la mesure d'un arc de méridien au Spitsberg, mission suédoise, tome II, IX ième section) observed the Hochstetterbreen from Thumb point (now, called Wilhelmøya) and, in spite of the distance, produced a rough cartography of the front. This front at that time protuded about 5-7 km into the sea. De Geer presents in his report a map showing this front position (see Fig. 30). He mentioned also a map from 1868 by Koldewey which shows a front almost at the shore line. That means that in 1901 the Hochstetterbreen was observed during a surge, or possibly a few years after.

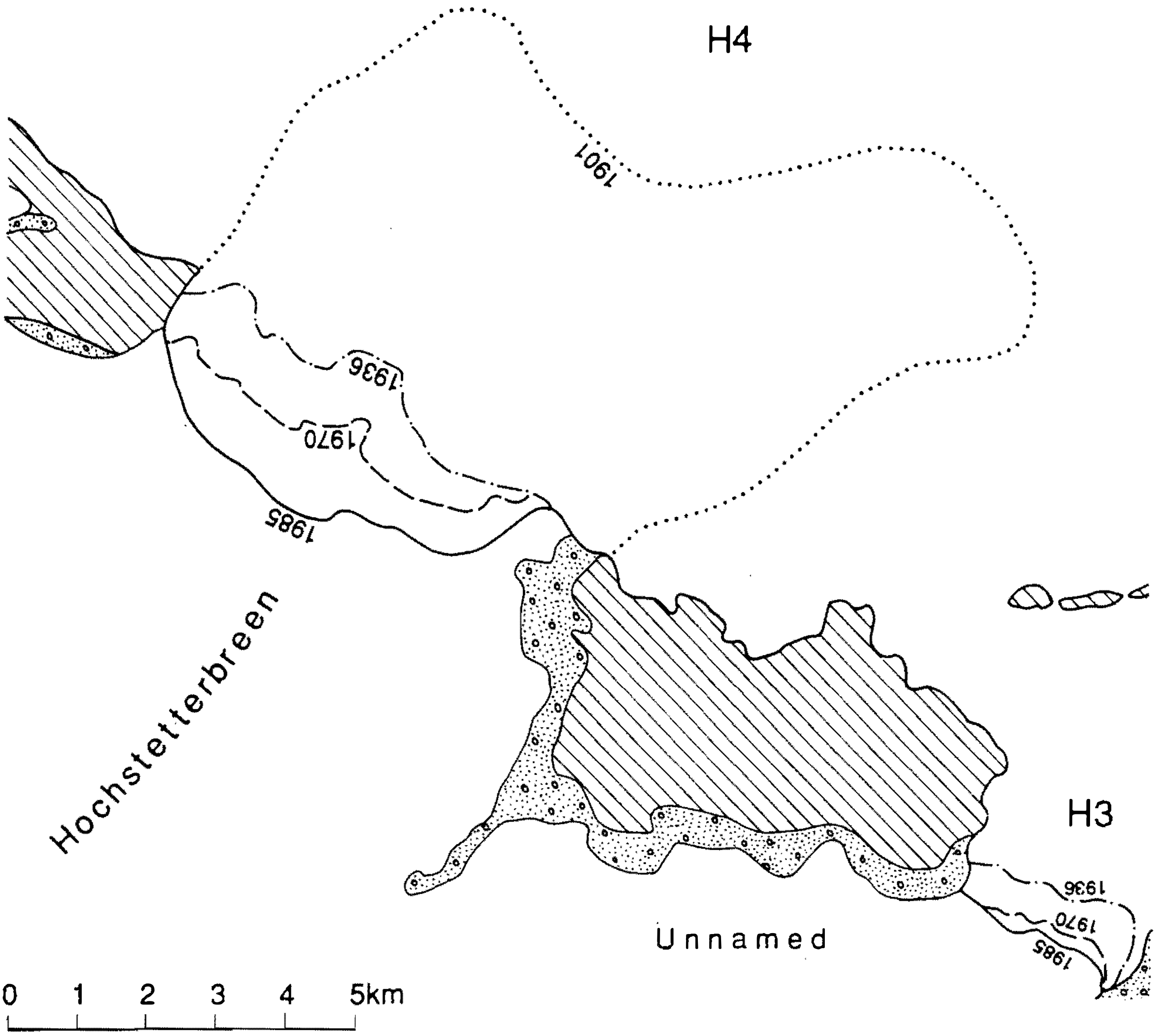

H4
1901
1936
1970
1985
Hochstetterbreen
H3
1936
1970
1985
Unnamed
0 1 2 3 4 5km

Fig. 30

Air photos from 1936, 38, 69 and 70 as well as Landsat image from 1985 show a permanent retreat of the front which is now situated inland from the shore line. In 1936-38, even though its surface was smooth and undulating, the glacier possessed numerous cracks showing that a very large part of the basin had been affected by the surge.

In 1969 and 1970 the crevasses were still visible but almost closed, except in the vicinity of the western part of the front where all the crevasses were still open and where the largest calving occurred. The morphology of lateral moraines indicates that this surge corresponds to the maximum extension of this glacier during the Little Ice Age.

The Hochstetterbreen surged in 1900-1901, or few years before, and developed a 5-7 km lobe into the sea. Since then it has been retreating. No more surges have since been recorded for the Hochstetterbreen.

H 5 Unnamed

A. P.	1936: 0983-87
	1938: 1651-55
	1969: 2029-30
	1970: 3491

		/Elevation (masl)\		
Area (km^2)	Length (km)	Max.	Med.	ELA
14.9	3.0	380	230	200

This glacier is a small unnamed glacier situated between the Hochstetterbreen and the Molktebreen. The air photos from 1936 and 1938 show this glacier with a small lobe extending into the sea. A part of its upper basin had characteristic cracks due to a fairly recent surge but the front had a smooth surface. So, most likely the surge occurred several years before and did not affect the entire basin. The front was only partly tide-water, and because the area is small, the glacier did not really calve and is unlikely to produce important calving in any future surge.

This small unnamed glacier surged some years before 1936 and reached the sea, but is not an important calving glacier.

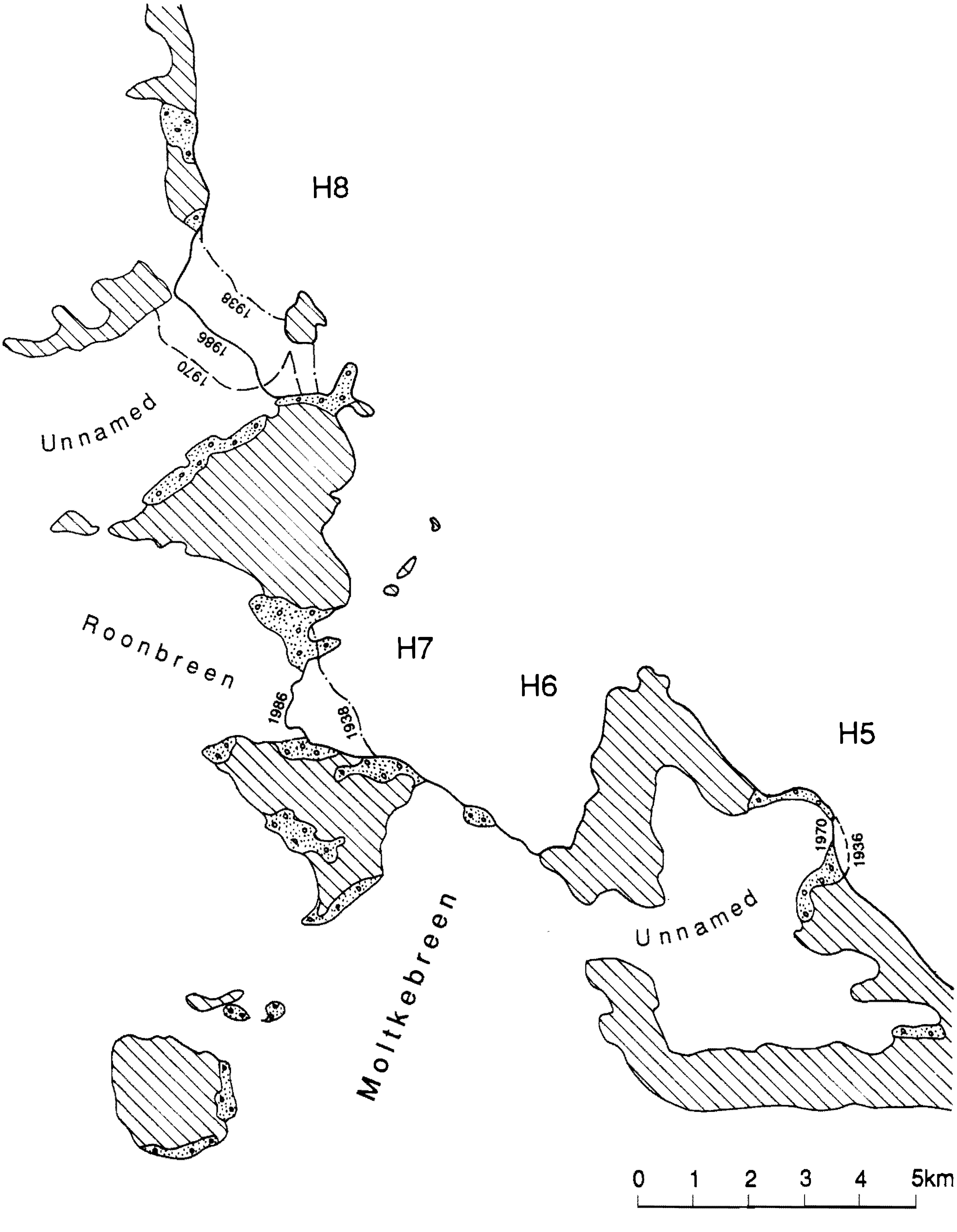

H8
1938
1986
1970
Unnamed
Roonbreen
H7
1986
1938
H6
H5
1970
1936
Unnamed
Moltkebreen
0 1 2 3 4 5km

Fig. 31

H 6 Molktebreen

A. P.	1936: 0986-91
	1938: 1621-28, 54-57
	1969: 2007-10
	1970: 35, 3489-90

		/Elevation (masl)\		
Area (km^2)	Length (km)	Max.	Med.	ELA
60.5	10.0	550	250	210

The basin of this glacier seems to be very small because in the 1936 air photos, at less than 6 kilometers from the front, the ice was affected by the surge of the Hochstetterbreen. Actually, it is fed by a larger area located mainly above the 1970 equilibrium line, judging from the Atlas of Svalbard glaciers.

On all air photos from 1936 to 1970 the Molktebreen shows a surface with numerous cracks and an activly calving front, especially on its western part. From 1936 to the present its front has been situated at almost the same position. It may have surged at the same time as the Hochstetterbreen, or at least before 1936, and since remained active as it has a large accumulation area and a fairly abrupt slope close to the front.

No surge has been recorded for the Molktebreen, but one may have occurred before 1936. From 1936 to 1970 the front was active and continually producing icebergs 20-30 meters in size.

H 7 Roonbreen

A. P.	1936: 0986-91, 1655-60
	1969: 2007
	1970: 3488-89, 3508-09

		/Elevation (masl)\		
Area (km^2)	Length (km)	Max.	Med.	ELA
37.0	7.5	550	350	180

From 1936 till today, the Roonbreen has been retreating in a quiescent phase. The morphology of lateral moraines indicates that the Roonbreen had at least two different periods of extension during the Little Ice Age. Nevertheless, no certain surge has been recorded for this glacier.

H 8 Unnamed

A.P.	1936: 0986-91
	1938: 1658-65
	1969: 2005-06
	1970: 3487-88

		/Elevation	(masl)\	
Area (km^2)	Length (km)	Max.	Med.	ELA
73.0	12.0	630	350	200

In 1936 this unnamed glacier was in a quiescent retreating phase which lasted at least until 1970. It is difficult to determine from the morphology of lateral moraines if in fact the maximum extension which was reached before 1936, was the maximum for the Little Ice Age. On air photos, particularly from 1970, an important step of geological origin marked the boundary between a lower and upper basin on one third of the glacier's width. The upper basin possessed several long crevasses.

On the Landsat image from 1986 the front was situated a little further in the sea. A small advance of the glacier had recently occurred. A mediane moraine has been moved closer to the northern side, and the above mentioned step has been more accentuated. A part of the basin likely surged between 1970 and 1986. Analysis of 1990 air photos will confirm this point and allow estimation of the terminal extension.

From 1936 to 1970 this unnamed glacier was retreating in a quiescent phase. Between 1970 and 1986 a small surge occurred, likely from the southern basin, followed by a further advance of the front into the sea.

H 9 Vaigatbreen

A. P.	1936: 0987 and ...
	1938: 1662-77
	1969: 1964-65, 2004-06
	1970: 3451-53, 84-86

		/Elevation	(masl)\	
Area (km^2)	Length (km)	Max.	Med.	ELA
74.0	10.8	630	280	200

Note: In 1936, between the above mentioned unnamed glacier and the Vaigatbreen three glacier tongues, emitted from the small fonna that covers the Vaigatfjellet, were visible. The southern one joined the unnamed glacier and had a common calving front with it. The two others did not reach the sea, but deposited a terminal morainic lobe on the shore.

On De Geer's map (1901) the front of the Vaigatbreen is situated almost at its present position. The poor accuracy of this map allows few conclusions to be made except that in 1901 the glacier had not extended a large lobe into the sea, nor was it undergoing a drastic retreat.

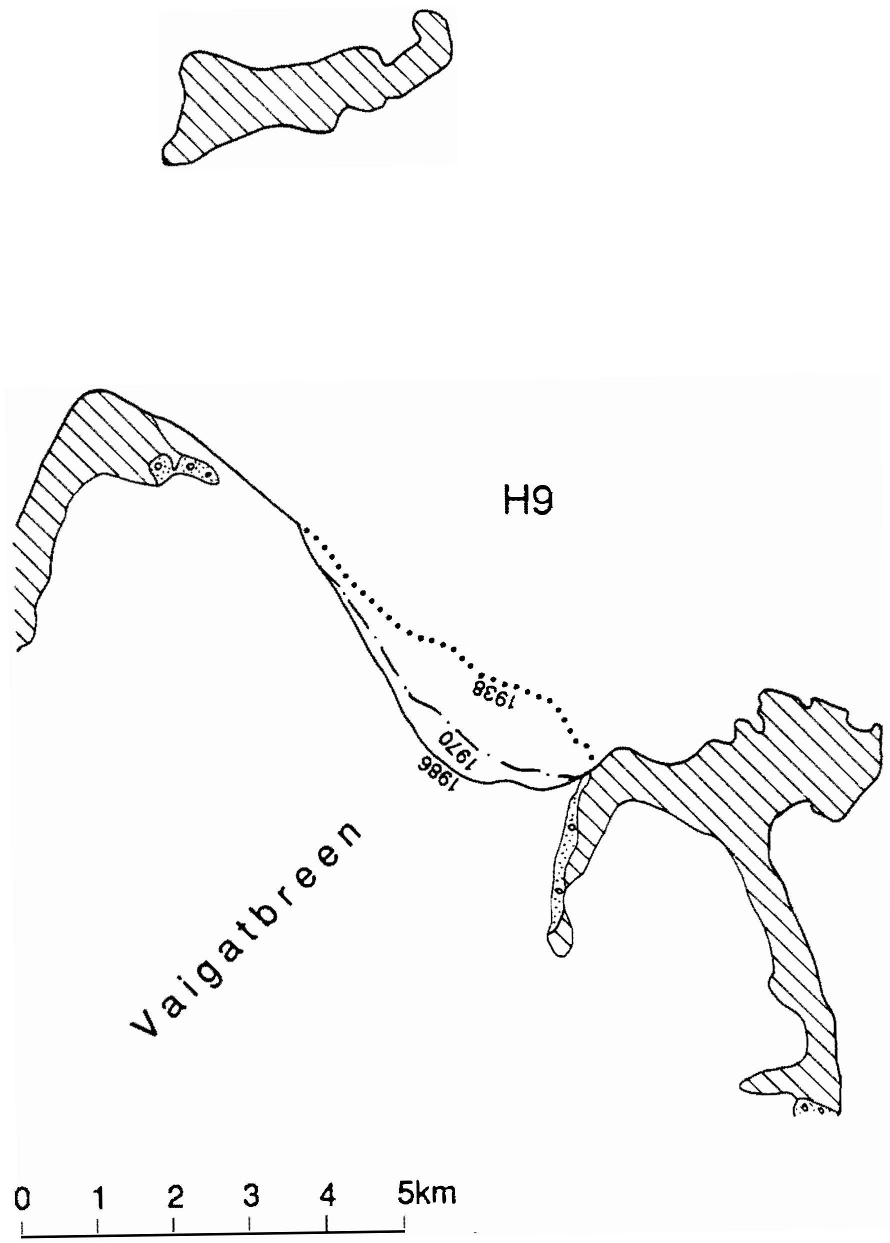


Fig. 32

The front can be considered as a complex of two different fronts. A western front emitted by a glacial stream from the south-west which is a termination of the Sløttsjøkulen, and an eastern front which is the front of the Vaigatbreen glacier and the only front producing calving. The retreat since 1936 has been general and slow, and more marked at the front of the Vaigatbreen itself.

There is no lateral moraine available for study in the north-western corner. At the eastern side a very small lateral moraine still existed in 1970. It was more prominent in 1938 and indicated that, at its maximum extension, the glacier protuded further into the sea.

De Geer's map indicated a small cape on land at the right side of the front. Thus it may be argued that the above mentioned maximum probably occurred before 1901.

The Vaigatbreen reached its maximum extension before 1936, and likely before 1901. Since then it has been retreating. No surge has been recorded for this glacier.

H 10 Hinlopenbreen, (La Vallée Blanche)

A. P.	1936:	0989-99
	1938:	1666-89, 1770-93
	1956:	0340-47
	1961:	3178-80
	1969:	1955-72, 2037-43, 3170-74,
	1970:	2063-69, 2125-36, 50-56 3448-51, 82-86, 3510-14
	1971:	7545-56

		/Elevation	(masl)\	
Area (km^2)	Length (km)	Max.	Med.	ELA
1250.0	68.5	1600	700	390

The Hinlopenbreen ("La Vallée Blanche" on the Vasiliev's map) is the first glacier in this area for which we also have a fairly accurate map from De Geer. Vasiliev's map is rough, but the front position nearly agrees with that on De Geer's map. On the latter the glacier front is almost linear, and on the eastern side, very close to the cape at the foot-hill of the Eremitten. On the western side, the Hinlopenbreen just joined the front of the Loderbreen, a smaller tide-water glacier.

Because of the presence of this Loderbreen on the western side, it is difficult on air photos to determine if the maximum extension reached before 1901 resulted in a front reaching far into the sea or not. Nevertheless, a small remnant of moraine suggests that the Hinlopenbreen extended further North into the sea than the Loderbreen front. On the right side the lateral moraine is deposited as part of the cape itself. That means that on this side the glacier protruded at least partly into the sea. Therefore, it is likely that during its maximum extension the Hinlopenbreen developed a large lobe extending into the sea.

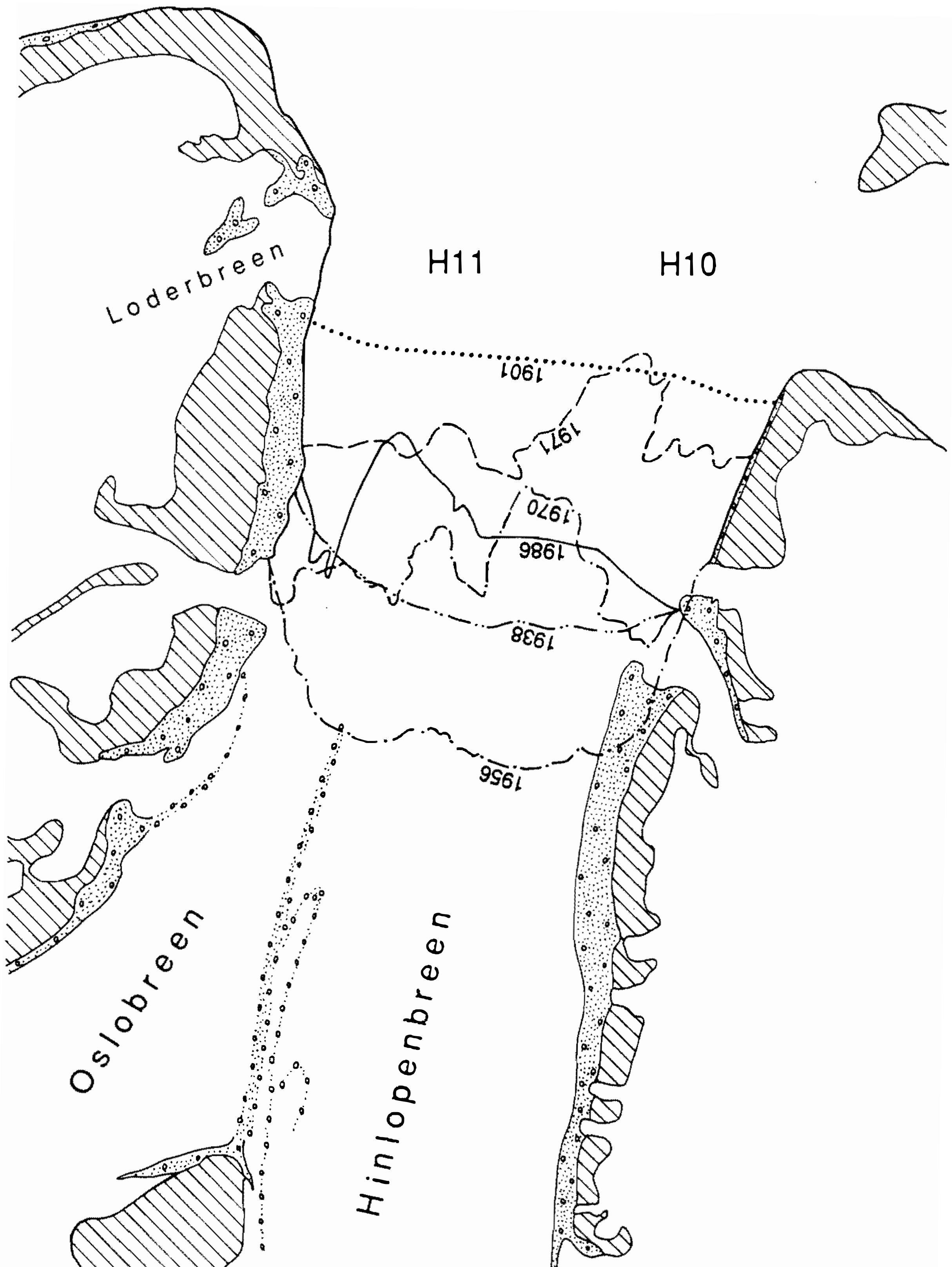

H11
H10
Loderbreen
1901
1971
1970
1986
1938
1956
Oslobreen
Hinlopenbreen
0 1 2 3 4 5km

Fig. 33

The glacier was probably retreating in 1901. Air photos from 1936, 1938 and 1956 indicate a permanent retreat. On air photos from 1938 may be seen folded moraines on the Oslobreen, an important tributary of the Hinlopenbreen, which are witness of a very old surge of this glacier. The precise date and extension of course are not known. In 1956 the general retreat of the Hinlopenbreen created two smaller tributaries (one on each side) with independent calving fronts. Both in 1938 and 1956 the front was active and calving icebergs, particularly in 1956 when the tongue of the glacier was notably crevassed. At this time the Hinlopenbreen was a characteristic "active, crevassed tide-water valley glacier" as defined by Dowdeswell (1989).

Available air photos from 1961 show just a small part of the upper basin of the glacier. They indicate no cracks and no beginning of surge.

Air photos from 1969 show numerous cracks over most of the entire basin (the front was unfortunately covered by clouds). The lower part of the glacier, from the front to twenty kilometers upstream, was apparently more crevassed than in 1961, while the upper basin showed little sign of activity. In 1970 air photos were taken at 15 days interval, the 6 and 16 August. The surface showed many cracks. On the 6th of August, the front was covered by clouds, but on the 16th more than 100 icebergs 20-150 meters long were visible.

From 1970 to 1971, in 370 days, the front advanced about 2.5 km into the sea. Some icebergs of up to 100 m were also visible on the 21 of August 1971. Using some characteristic points from moraines or crevasses rough estimates of speed were done. The most characteristic point consists of a morainic lobe plotted on the new NP map D6. This lobe is easily visible on the left side of the glacier, and between the 13/08/1969 and 16/08/1970 this lobe moved 3000 m, or a mean speed of 8.2 m a day. Another point in the same area moved with a speed of about 10 m a day between 1969 and 1970 and 8.5 m a day between 1970 and 1971. In the central part of the glacier as well as on the right side, several speeds of about 12 m a day were recorded between 1970 and 1971.

From the Norsk Polarinstitutt map D6, it may be seen that the ice cliff has a height of 25-50 m. Likely the ice thickness was more than 100 m. Assuming this ice thickness and a front width of 6 km, the ice flow between 1970 and 71 was approximatly 4000 m, i.e. 24 km^2 and about 2.4 km^3, which must be considered a minimum.

The surge started in 1969 or just before. In 1970 and 1971 the front was very active, and continually fast-moving in 1971, while in the upper part of the basin the crevasses seemed more opened in 1970 and 1971 than in 1969. Nevertheless some parts higher up in the basin had a smooth surface in 1971. Because there are no air photos after 1971 it is difficult to say if the surge affected the upper part of tributaries or not. Likewise it is not possible to determine precisely when the surge ended.

In 1986 the front was retreating according to Landsat image observations.

The Hinlopenbreen likely had an important extension before 1901. Thereafter it retreated until 1969 or slightly before when a surge occurred. This surge affected the main basin, but apparently had less effect on the upper part of the tributaries. During this surge the front was very active with important calving. The Oslobreen a main tributary of the lower basin, surged at an unknown date, long before 1938.

It will be interesting to study this glacier more. Firstly, it has an important accumulation area, and secondly it is a characteristic glacier activated by a surge for several years during which the front was very active and calving. Lastly air photos are available for three years with two exposures in 1970. In spite of the cloud cover in 1969, and on the 6th of August 1970, several of the same points are visible at different times and precise topographic mapping should reveal more information about the flow speed and the calving rate.

H 11 Loderbreen

A. P.	1938: 1682-89, 1790-95
	1956: 0341-52, 1618-22
	1970: 2135-37, 46-47
	1971: 7555-56

		/Elevation (masl)\		
Area (km^2)	Length (km)	Max.	Med.	ELA
25.4	6.5	620	350	200

In 1901, on De Geer's map, the Loderbreen had a common front with a small unnamed glacier located further north. The resulting lobe protuded moderately far into the sea, but only the Loderbreen calved. The position of one terminal morainic lobe, partly visible on air photos, indicates that this lobe likely correspond to the maximum extension for the Little Ice Age.

Aerial photographs from 1938 and 1956 indicate that a permanent retreat has occured since 1970. On the air photos from 1956, in the northern portion of the Loderbreen, the end moraine from the unnamed glacier is partly visible. However a remnant of moraine out of this vallum is also visible which is believed to have been deposed by the Hinlopenbreen as mentioned above (§ C 10).

Unfortunately, in air photos from 1970 and 1971, the fronts were covered by clouds and therefore front positions are not available for these years. On the Landsat image from 1986, the front of the Loderbreen is situated at the shore line. Thus the Loderbreen has likely been quiescent from 1901 until today.

The Loderbreen and one small unnamed glacier situated to its north, had their maximum extension around 1900, at which time they developed a small lobe extending into the sea. Since then these two glaciers have retreated slowly until the present. No surge has been recorded for these glaciers.

H 12 Polarisbreen

Chydeniusbreen

A. P.	1938:	1689-97, 99-1701
		1793-1801
	1056:	0347-56
	1961:	3170-73
	1969:	3178-80
	1970:	2050-60, 2145-46
		3424-27
	1971:	7117-19

		/Elevation (masl)\		
Area (km^2)	Length (km)	Max.	Med.	ELA
125.0	21.0	1050	650	350
340.0	39.5	1500	850	480

De Geer's map (1901) shows a slightly convex lobe for the common front of the Chydeniusbreen and the Polarisbreen, a lobe slightly convex but not protuding out of the shore line. According the position of lateral moraines on air photos from 1938 and 1956, the 1901 position doesn't correspond to the maximum extension of these glaciers. Due to the 1938 position, the front in 1901 was likely retreating from a previous larger extension.

Air photos from 1961, 1969 and 1971 give only little information about the basin. Either the front is not present on these photos or covered by clouds. The basin shown at these different times indicates a decrepit surface, smoothed and slightly undulating, characteristic of glaciers experiencing a long and non-active phase.

The photos showing the front from 1938 indicate that the glacier was calving. In 1956 the front was partly grounded in the northern side, at a place where now may be seen a morainic deposit.. The photos from 1970 and the Landsat image from 1986 confirm a permanent retreat.

The maximum extension of a common front of the Chydeniusbreen and the Polarisbreen occurred before 1901. At this time the glaciers developed a fairly important lobe extending into the sea. Since then they have been retreating continuously. There is no recorded surge for these glaciers.

These two glaciers are of special interest due to the lack of recorded surge, at least for the past century, and because they possess a top far above sea level and a very large part of their basins above the ELA. Future surges are therefore likely.

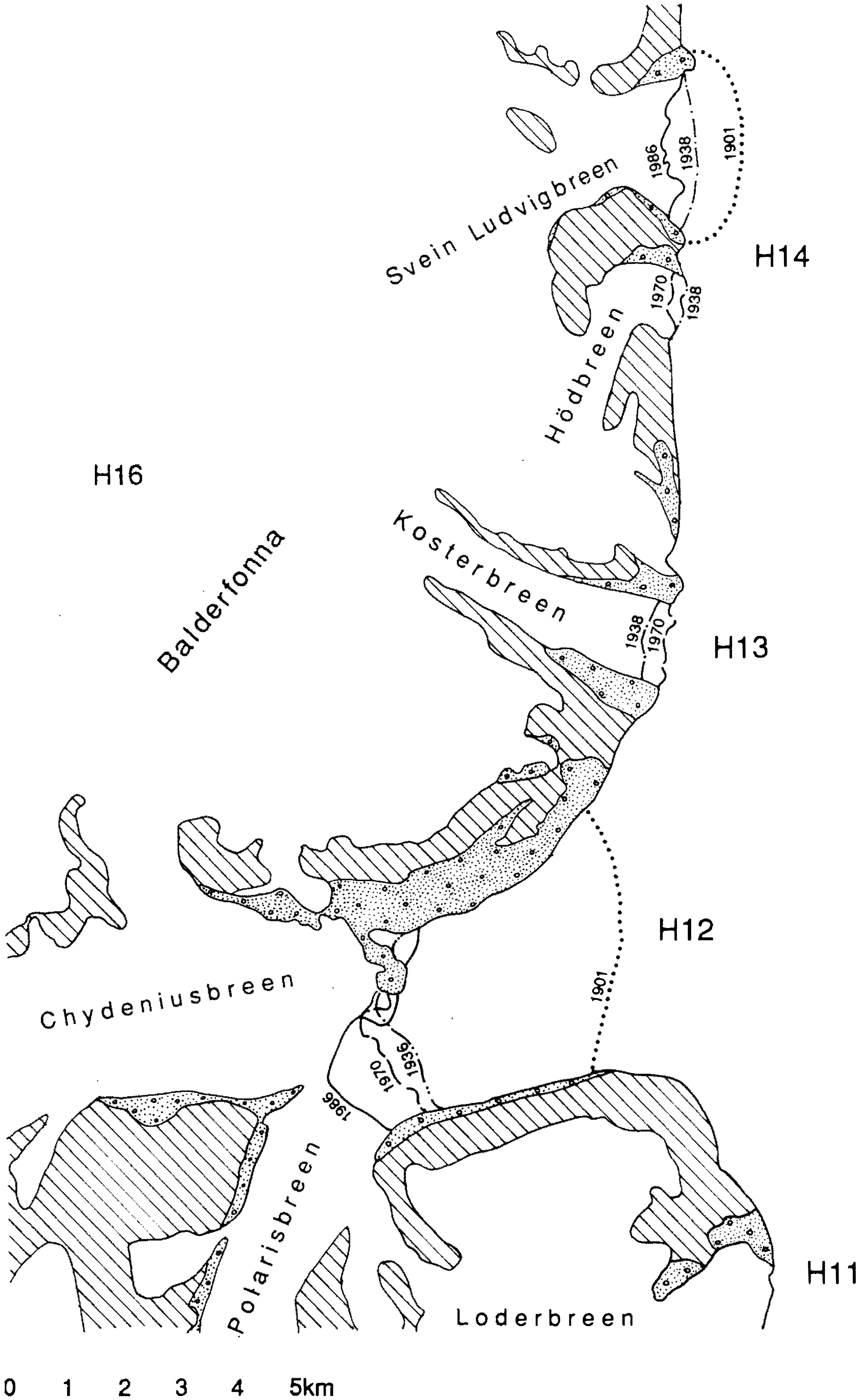

Svein Ludvigbreen
1986
1938
1901
H14
1970
1938
Hödbreen
H16
Kosterbreen
Balderfonna
1938
1970
H13
H12
1901
Chydeniusbreen
1970
1936
1986
Polarisbreen
H11
Loderbreen
0 1 2 3 4 5km

Fig. 34

H 13 Kosterbreen

A. P.	
1938:	1694-98, 1798-1806
1956:	0352-56
1970:	2139, 2143-44
	3423-25

		/Elevation (masl)\		
Area (km^2)	Length (km)	Max.	Med.	ELA
47.0	11.5	700	480	230

Note: In the southern part of the Kosterbreen, a small glacial lobe covered by morainic debris nearly reached the sea. Its size and its perfectly circular frontal lobe made it a curiosity. Nevertheless in case of a future surge, it is not likely to calve.

Fluctuations of the Kosterbreen itself are difficult to analyse. The glacier front on De Geer's map (1901) was almost at the shore line. According to the morphology of lateral moraines, this front does not correspond to the maximum extension of the glacier. Every known front positions is close to this 1901 posititon, only very small advance and retreat can be seen on air photos. The glacier has been slowly retreating until 1936, and the 1986 position according to a Landsat image is very close to the 1970 position.

In 1936 the surface was smooth but showed numerous cracks on the main part of the basin. It was probably about the same in 1956 and 1970, when the surface appeared as a typical post surge surface. It is difficult to link this information with the above mentioned front positions. On the other hand, a renewal of activity due to an increase in calving is unlikely to have resulted in so many crevasses in the basin, as only a small part of the front is below sea level. It is possible that two small parts of the basin surged at different times. Between 1956 and 1970 at least, it is unlikely that front advances were related to changes in climate. The largest extensions must have been due to small surges, one starting around 1936 and a second one between 1956 and 1970.

Past fluctuations of the Kosterbreen are uncertain. No large surges have been recorded. Nevertheless, reactivation of the glacier by one or two small surges from minor parts of the basin likely occurred in 1936 and between 1956 and 1970.

H 14 Hödbreen

Svein Ludvigbreen

A. P.	1938: 1804-14
	1970: 3421-23, 3442

		/Elevation (masl)\		
Area (km^2)	Length (km)	Max.	Med.	ELA
10.0	5.0	470	350	180
46.3	10.5	630	440	200

These two glaciers have adjacent fronts, but even at their maximum extension they were not jointed.

The Hödbreen is a very small glacier which never really calved and which at present is retreating from a maximum which occurred around 1901.

The Svein Ludvigbreen, according to De Geer's map (1901) and the morphology of lateral moraines on air photos, reached its maximum extension around 1901 at which time a small lobe protruded into the sea. Since then the glacier has been continuously retreating .

The Hödbreen and Svein Ludvigbreen reached their maximum extensions around 1901, probably slightly before. Since then they have continually been retreating. No surge has been recorded for these glaciers.

H 15 Reliktebreen

A. P.	1938: 1813-18
	1970: 3420-22,
	3409-11, 21-41

		/Elevation (masl)\		
Area (km^2)	Length (km)	Max.	Med.	ELA
19.0	7.0	450	370	220

On De Geer's map (1901) the Reliktebreen had a very small lobe protruding into the sea. Morphology of moraines from air photos indicate that the maximum extension occurred slightly further out to sea, and that this was the maximum for the Little Ice Age. Thus, the maximum most likely occurred before 1901. Since then the glacier has been retreating. Front positions from 1936 and 1970 (air photos), as well as 1986 (Landsat image), indicate a permanent and slow retreat.

The Reliktebreen reached its maximum of extension before 1901. Since then it has been continuously retreating. No surge has been recorded for this glacier.

H 16 Balderfonna *

Kantbreen *

Glintbreen *

A. P.	1938: 1669-1712
	1961: 3164-66
	1969: 3180-85
	1970: 2052-56, 2141-42

		/Elevation (masl)\		
Area (km^2)	Length (km)	Max.	Med.	ELA
64.6	*	700	630	430 *
153.0	21.0	1100	700	350

* *Note:* The information from the Atlas must be employed with care. The Balderfonna refers to the eastern and northern parts of the glacier. The rest including the Glintbreen are a part of the Kantbreen area. On the other hand, the length of any one fonna, as well as the ELA, have no significance for this study, especially the ELA , which varies with each versant of the fonna. Lastly, a large part of the upper basin of the Kantbreen is also a part of the Balderfonna.

These glaciers are mentioned here because their total area is large and comprises the upper accumulation area of several previously mentioned glaciers, from the Polarisbreen to the Reliktebreen. Nevertheless, the two outlets Kantbreen and Glintbreen rarely calve. Only the Kantbreen is likely to produce a large surge in the future, and in spite of its location may calve some icebergs into the Hinlopenstretet.

H 17 Tommelbreen

A. P.	1938: 1820-30
	1970: 2140-41
	3410-13, 17-20

		/Elevation (masl)\		
Area (km^2)	Length (km)	Max.	Med.	ELA
63.0	9.0	650	250	250

The Tommelbreen (which is called "glacier Duim" on De Geer's map) had, in 1901, a front nearly reaching the shore line. Due to the lack of significant lateral moraines it is not possible to know if, during its maximum extension, the Tommelbreen developed a larger lobe into the sea, nor to say if the maximum occurred before or after 1901.

In 1938 (air photos) the glacier was in a characteristic quiescent phase and the retreating front was very close to the shore line. Upstream, the presence of a folded median moraine indicates a past surge from one tributary. In 1970 (air photos), the front had retreated somewhat more. In 1986 (Landsat image) the Tommelbreen was in retreat, but also still calving.

The maximum extension of the Tommelbreen occurred around 1901, though the precise year is uncertain. Since then, it has been retreating. There has been no surge recorded for the Tommelbreen.

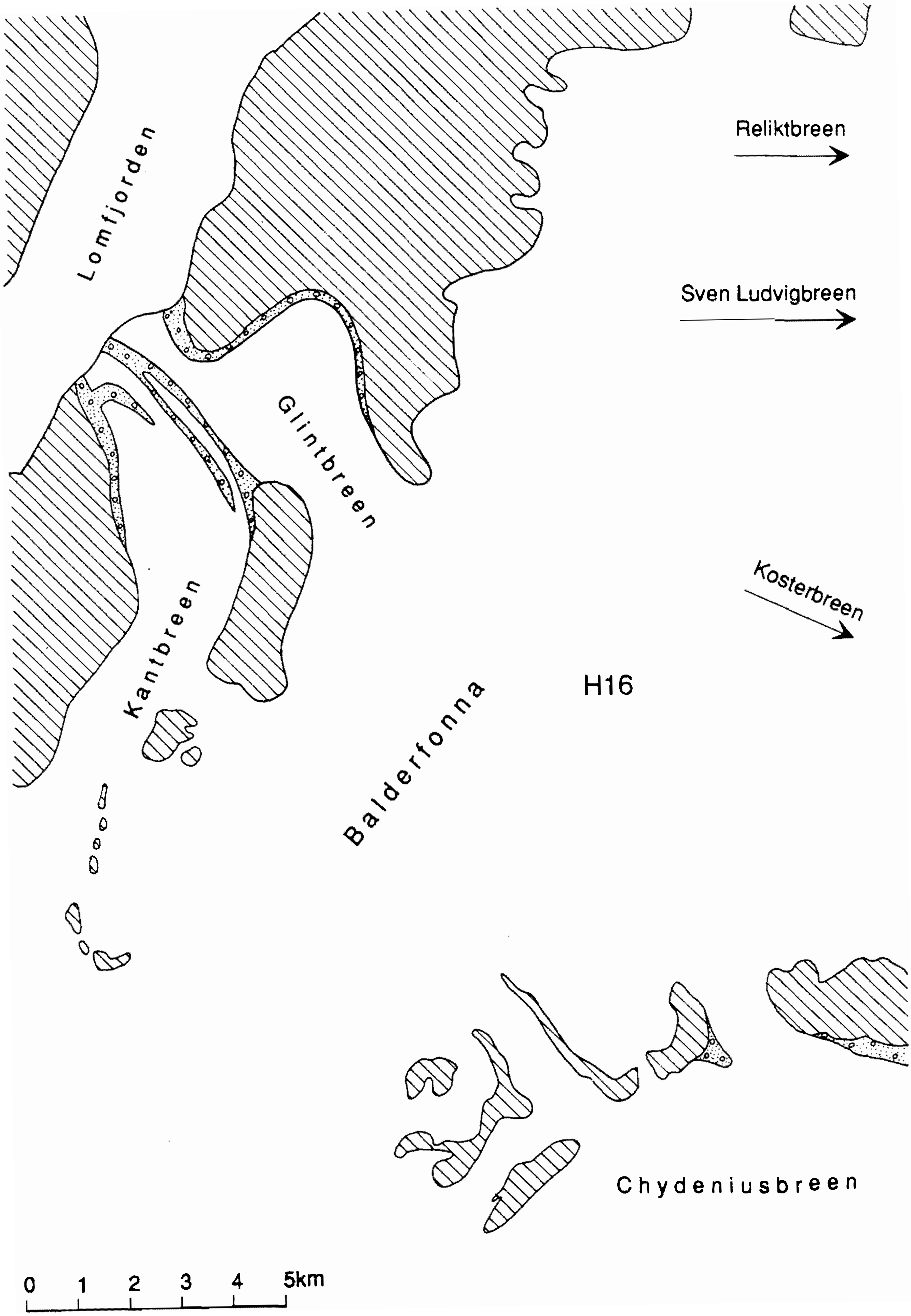

Lomfjorden
Reliktbreen
Sven Ludvigbreen
Glintbreen
Kosterbreen
Kantbreen
H16
Balderfonna
Chydeniusbreen
0 1 2 3 4 5km

Fig. 35

H 18 Odinjøkulen

Frøyabreen

A. P.	1936: 1242-54, 60-64
	1938: 1824-48
	1969: 3186-89
	1970: 2047-51, 3411-13

		/Elevation (masl)\		
Area (km^2)	Length (km)	Max.	Med.	ELA
46.6	6.0 *	650	400	250
23.2	8.0	650	450	300

The Odinjøkulen is a glacier which feeds the Tommelbreen. It has three small westward outlets. Only the Frøyabreen reached the sea, but did not really calve. Eastward, the Odinjøkulen reaches the sea at three points for a total length of 2-3 kilometers. In the Fig. 36, these fronts are plotted with the 1970 positions. On a large part of the front width the ice covers a rock wall. Therefore the glacier is tide-water at only a few points. De Geer's map does not provide accurate information concerning a larger extension. It may be seen that this map just shows the Frøyabreen, a westward outlet partly fed by the Torsfonna, in retreat from a previous maximum.

The main difference between 1936-38 and 1970 consists of one small advance of a northern outlet indicated by an arrow on the figure 36, a small surge occurred some years before 1970. The basin affected by this surge can be seen on the air photos as indicated by characteristic crevasses. The surging basin covered an area of about 15 km^2 with a length of 5 km.

This small surge did not result in any large calving, but nevertheless provided important information as it proved that the Odinjøkulen consists of several independent glacial basins, and therefore that a general surge of this fonna is unlikely.

In 1901 the Odinjøkul was probably in quiescent phase and likely experiencing a very slow retreat. From this date until today, only one surge from a small outlet has been recorded. This suggests that a surge of the entire Odinjøkulen is unlikely.

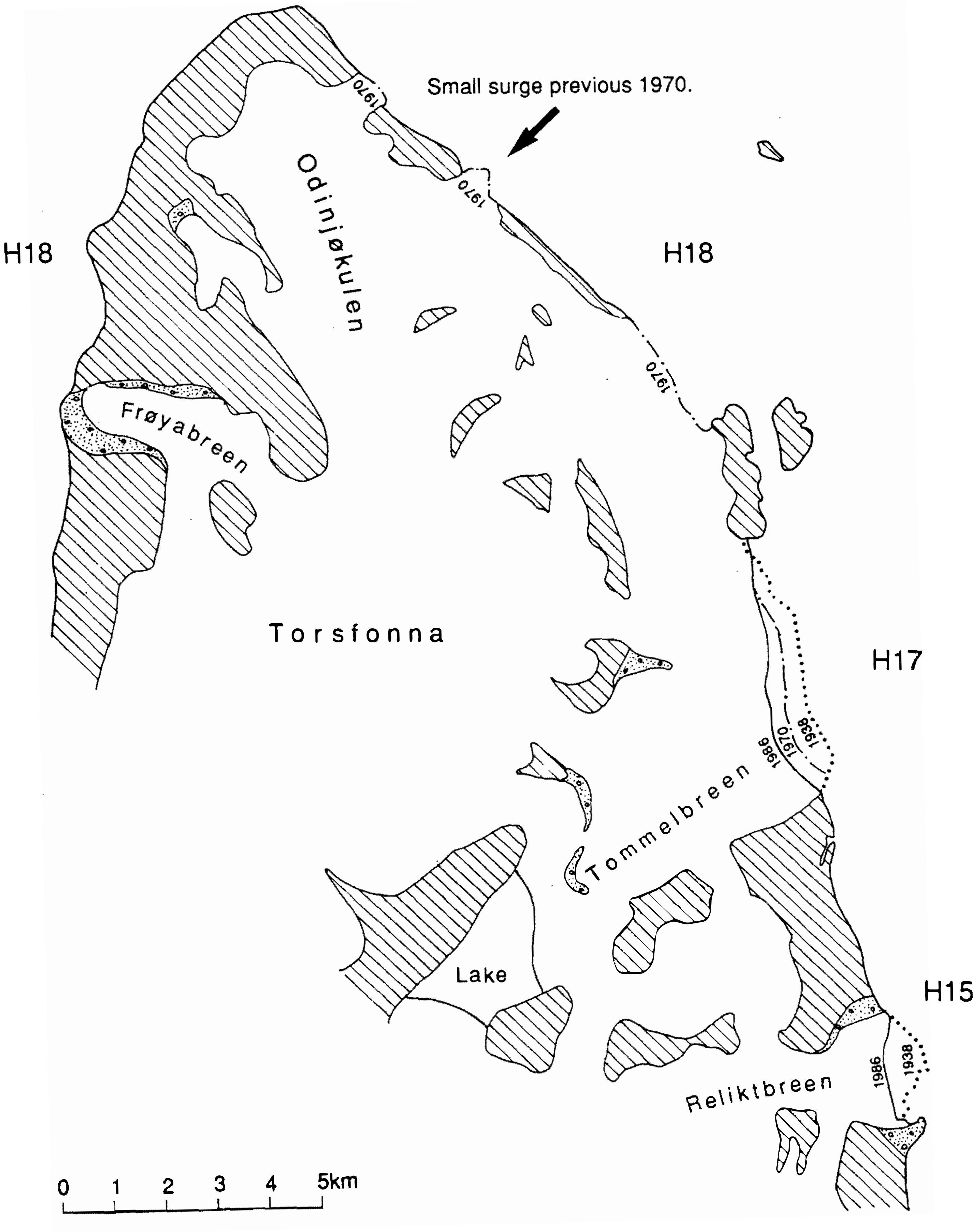

Small surge previous 1970.
H18
H18
1970
1970
1970
Odinjøkulen
Frøyabreen
Torsfonna
H17
1986
1970
1938
Tommelbreen
Lake
H15
1986
1938
Reliktbreen
0 1 2 3 4 5km

Fig. 36

H 19 Valhallfonna

Buldrebreen

A. P.	1936: 1222-29
	1938: 1729-43, 1848-50, 1900-09
	1961: 3150-59
	1966: 4701-07
	1971: 6007-6110, 6114-16

Area (km^2)	Length (km)	/Elevation (masl)\ Max.	Med.	ELA
310.0	17.5	850	350	350

The map from De Geer, as well as the 1938 front position from the Norsk Polarinstitutt map DE4, do not provide sufficient accuracy. It is not possible to compare exactly the different front positions. It may just be seen that except for the Buldrebreen in the north, the position of the front did not change really. Air photos from 1936, 38, 61, 66 and 1971 allow the determination of different flows from the eastern part of the glacier as indicated roughly on the map of the figure 37. The grounded ice fronts in the north and the south (marked 2 and 4, imply a very slow and small retreat since the maximum extension. The ice streams marked 1 (Buldrebreen), 3 and 5 show some signs of activity and numerous crevasses parallel to the front. In addition, the ice surfaces are smooth and undulating which is characteristic of a long period of decay. In front of these ice streams 1, 3 and 5 the bathymetry noted on the marine map 507 indicates a greater sea deepth than in front of the ice streams 2 and 4. Thus, the activity may have been due to the calving associated with a faster ice speed. However, such surfaces may sometimes be observed on glaciers long after a surge. The lack of further informations does not allow prediction of future surges.

The front of the Buldrebreen has been retreating since 1901. On the 1936 air photos the glacier showed numerous important crevasses on its tongue. On air photos from 1961, 1966 and 1971, in spite of presence of snow, long crevasses are visible in the central and upper basins. A surge might have occurred before 1936 but this remains uncertain due to a lack of information.

There has been no surge recorded with certainty for the Valhallfonna or Buldrebreen despite the fact that the characteristics of some ice-streams may be due to old surges. Nevertheless analysis of aerial photographs show that, on its eastward side, the fonna is divided into several different basins. Therefore a large and combined surge is unlikely.

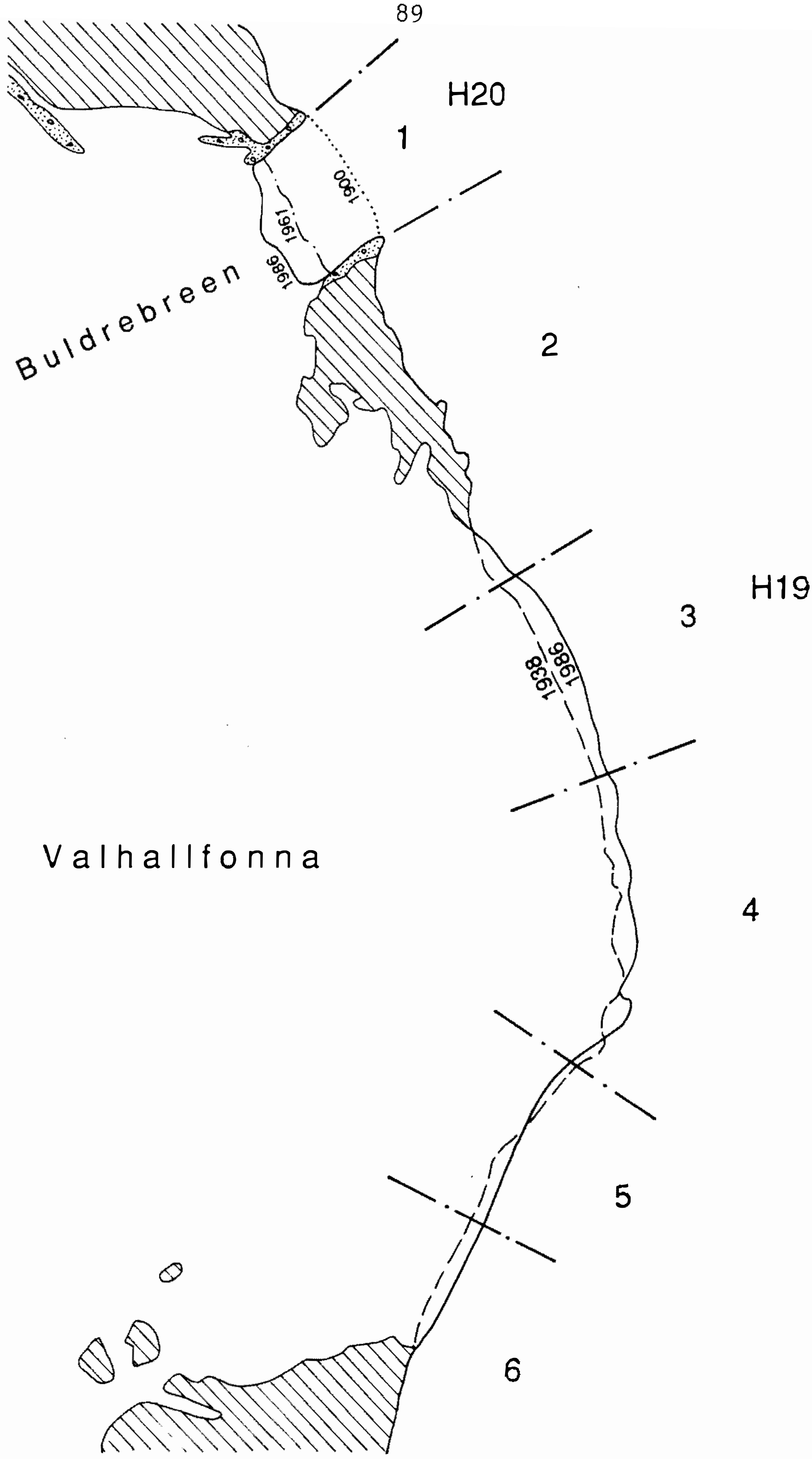


Fig. 37 Numbers delimitate independent outlets flows (see text).

N NORDAUSTLANDET, STORØYA, KVITØYA

Notes:

1) Little historic information is available from this area. De Geer visited only the eastern extremity of the island of Nordaustlandet. The first observations providing front positions are from sketches during the Oxford University Expeditions in 1924 and 1935-36. When Nordenskjöld passed Austfonna in 1873 he made observations which allowed the determination of an extremely important past surge of the main basin of the Austfonna (see below § N 19).

2) In the present study two important scientific works are used: 1) a study of the submarine surging zone of the Bråsvellbreen and of the outlet here named "Austfonna 8" by Solheim (1988), and 2) a remote sensing study of the main part of Nordaustlandet by Dowdeswell (1984 and 1986).

3) An important point is discussed by Dowdeswell concerning the meaning of the roughness of a glacier surface along longitudinal profiles (flow line). The described roughness corresponds to the undulating surface that was described above for some basins of the Valhallfonna (see § H 19). According to Dowdeswell more studies are needed, but such features might be characteristic of glaciers in a quiescent phase between surges. They may also be related to ice streams with calving fronts, flowing on a relatively lower elevation of the bedrock, compared to neighbouring ice.

4) More readily interpreted are the elevations of these longitudinal profiles against theoretical profiles. Dowdeswell plotted such comparative profiles for several glaciers in Nordaustlandet. After a surge, the observed profile is always below the theoretical one, especially in the lower part of the basin. Such determination is not completely clear on valley-like outlets as in the Walhenbergfjorden, but when made for ice-streams from the ice-cap of Austfonna, they provide important information for the determination of past surges. Contrarily, the presence of an observed profile above the theoretical one is believed to indicate a potential future surge.

5) For numerous glaciers, the front positions have changed very little from the first observation until today. Even for those glaciers where slightly different front positions have been mapped, we only present a general map with the locations of these glaciers as little other information of interest exists.

6) Numerous glaciers are unnamed. For these glaciers we have used the name of the "fonna" that feeds the glacier, and which refers to a code number from the Svalbard Glacier Atlas.

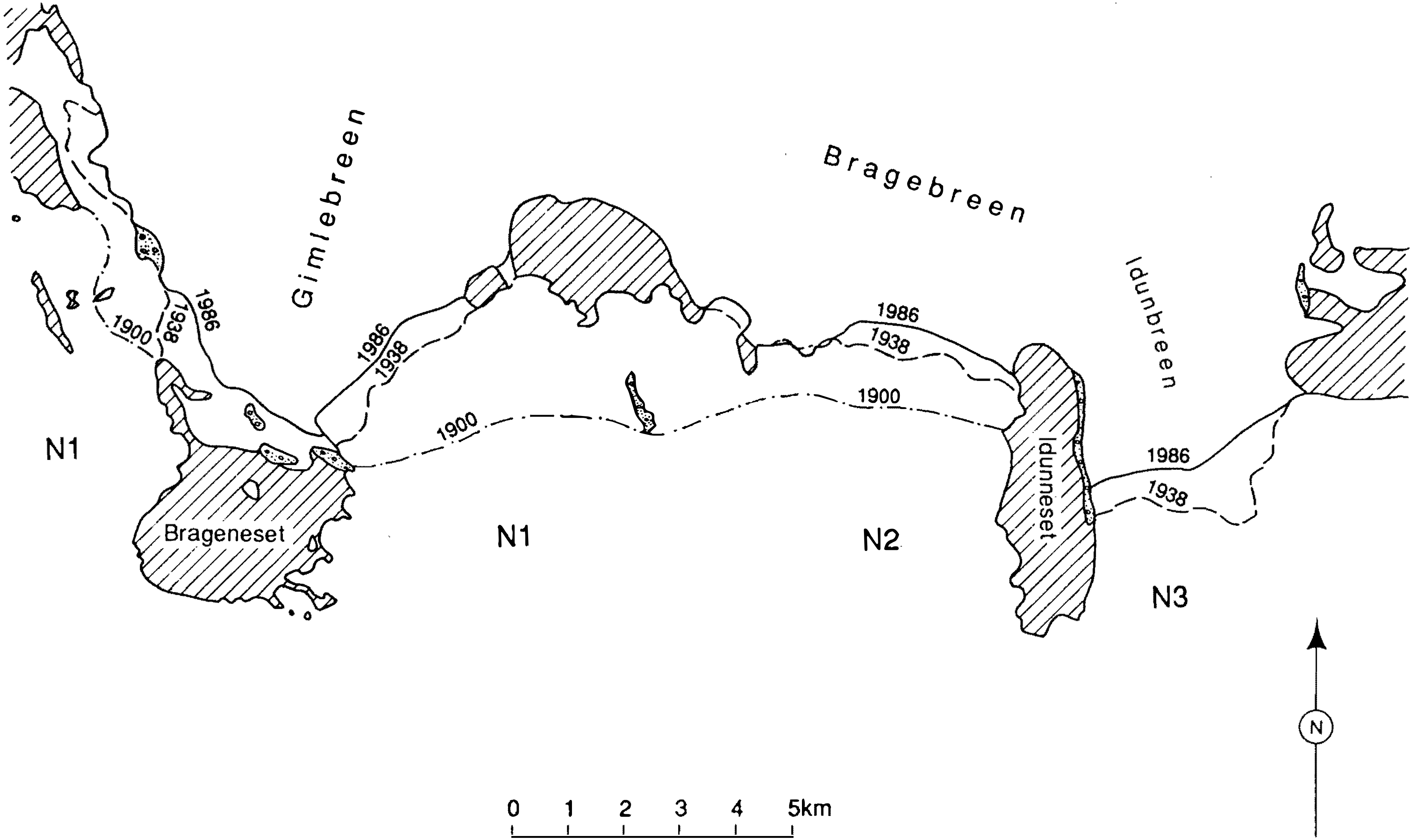

Gimlebreen
Bragebreen
Idunbreen
Brageneset
Idunneset
N1
N1
N2
N3
1986
1938
1900
N
0 1 2 3 4 5km

Fig. 38

N 1 Gimlebreen

A.P.	1938: 1535-49, 1910-12
	2095-99
	1969: 3217-18
	1970: 3669-72
	1971: 7562-69
	1977: 1147-49

		/Elevation(masl)\		
Area(km2)	Length(km)	Max.	Med.	ELA.
70.8	10.5	350	170	250

The Gimlebreen has two fronts divided by the Brageneset. It is one of the glaciers for which De Geer's map provides a good information. In 1901 the Gimlebreen and Bragebreen had a common front, and both glaciers were very close to their maximum extension. The limit of this extension is well visible as morainic deposits on the Brageneset and Idunneset. On the Idunneset, raised beaches are visible beyond the point of this maximum extension. The small island between the Brageneset and the Iduneset is covered with a moraine, and thus was reached by the glacier at its maximum.

On all air photos from 1938, 69,70,71,77 the ablation area of the eastern ice-stream of the Gimlebreen which produced calving, showed a smooth and undulating surface, as well as numerous, almost closed crevasses. These crevasses were long and concentric in the vicinity of the ELA.

In spite of the long time span between the maximum extension (before 1900) and the present, the aspect of the surface of the Gimlebreen may be due to an old past surge. Since then the retreat has been continuous until today.

The maximum extension of the Gimlebreen occurred before 1900. Since then it has been retreating continuously.There is no surge recorded here.

N 2 Bragebreen

A.P.	1938: 1544-49, 1912-13
	2089-98
	1970:3717-19
	1971: 7505-08, 14
	1977: 1149-51

		/Elevation(masl)\		
Area(km2)	Length(km)	Max.	Med.	ELA.
106.7	14.5	450	310	300

The oldest known front position is from the De Geer's map. As mentioned above, in 1901 the Bragebreen had a common front with the Gimlebreen and its maximum extension is well visible on the Indunneset. Since then, the glacier has been continously retreating until today. The glacier surface shows the same characteristics as the surface of the Gimlebreen. Thus it is possible that the maximum position before 1900 was due to a surge. Three kilometers upstream from Idunneset, at the boundary between Bragebreen and Idunbreen, the 1938 air photos show two small supraglacial lakes which were still visible at almost the same place in 1977 .

The maximum extension of the Bragerbreen occurred before 1900 (and may have been due to a surge). Since then, the glacier has been retreating until today. There is no recorded surge for this glacier.

N 3 Idunbreen

A.P.	1938: 1549, 1913-14, 2084-92 1970: 3759-61 1971: 7510-13, 15-19 1977:1150-55

		/Elevation(masl)\		
Area(km2)	Length(km)	Max.	Med.	ELA.
323.2	25.4	610	360	300

For the Idunbreen, as well as for all other glaciers in Nordaustlandet no precise information on front positions is available before 1938.

In 1938 the front was retreating and this slow retreat is still going on today. The glacier surface showed the same characteristics as those of the above described glaciers: smooth and undulating with numerous old crevasses. Today, the front is still active and calving.

The maximum extension of the Idunbreen occurred before 1938. Since then the glacier has been retreating. No surge has been recorded for this glacier.

N 4 Frazerbreen

A.P.	1938: 1915, 2071-78 1970: 3762-67 1971: 7525-28 1977: 1153-56

		/Elevation(masl)\		
Area(km2)	Length(km)	Max.	Med.	ELA.
220.9	22.5	620	330	350

The maximum extension of the Frazerbreen occurred before 1938. Since then it has been retreating. On all air photos the glacier showed the same characteristics as those of the above studied glaciers: a smooth and undulating surface. Numerous crevasses, more or less perpendicular to the flow of ice, are visible in the ablation area. These crevasses are parallel to the ice flow just below the ELA. Higher up in the basin are numerous long and concentric crevasses, again perpendicular to the flow of ice. It can be seen that at about 5-6 kilometers from the front, where the crevasses are parallel to the ice flow, the glacier

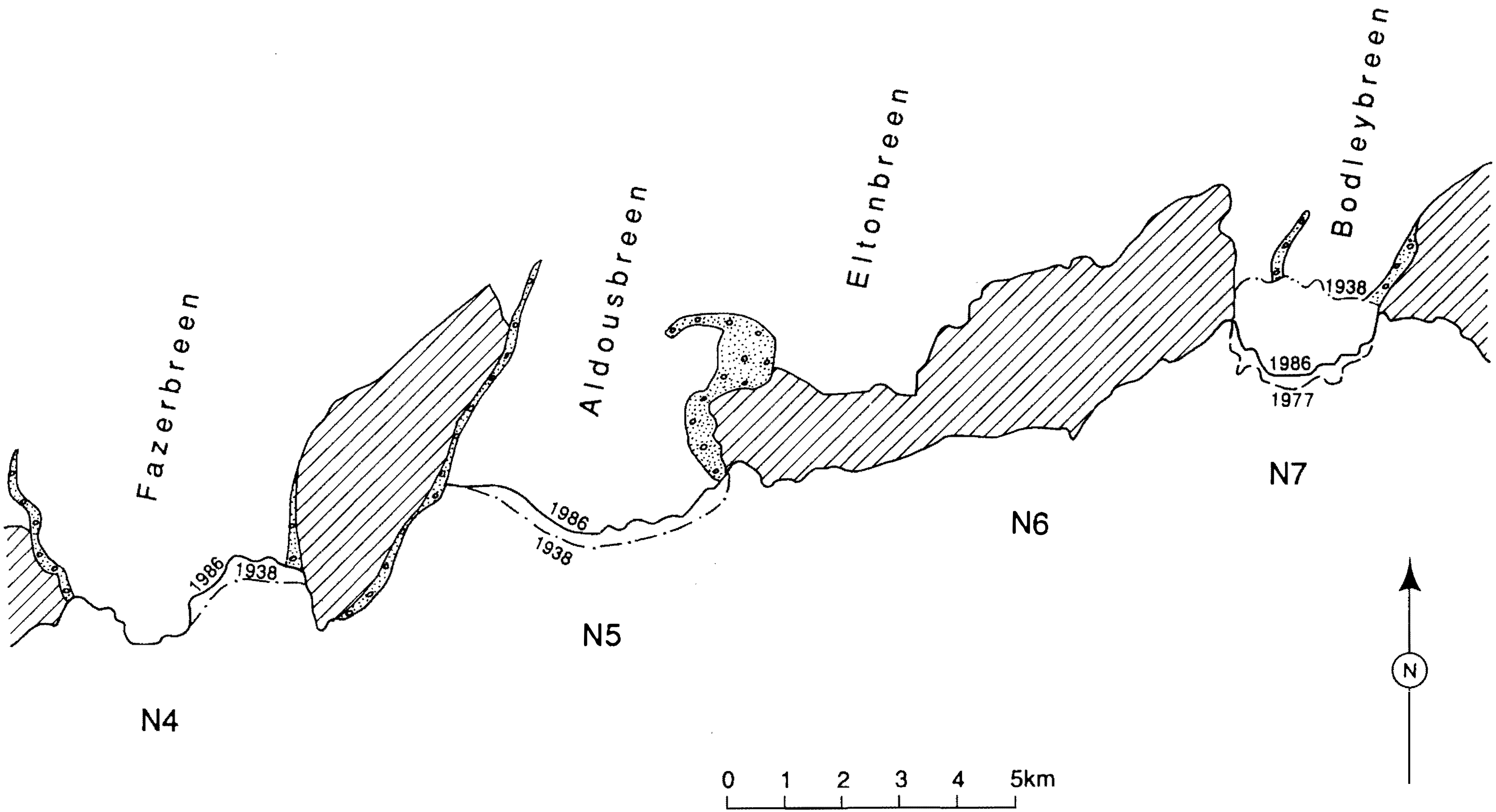

Fazerbreen
Aldousbreen
Eltonbreen
Bodleybreen
N4
N5
N6
N7
1986
1938
1986
1938
1938
1986
1977
N
0
1
2
3
4
5km

Fig. 39

width is only 2 kilometers. Upstream and downstream from this point the glacier is much wider. Thus it is likely that crevasses parallel to the ice flow are linked to the narrowing of the ice stream. In 1977 the front was still calving, but not very active.

The maximum extension of the Frazerbreen occurred before 1938. Since then, it has been continuously retreating until today. No surge has been recorded for this glacier.

N 5 Aldousbreen

A.P.	1938: 1915, 2062-72
	1970: 3800-02
	1971: 7530-36
	1977: 1155-56

		/Elevation(masl)\		
Area(km2)	Length(km)	Max.	Med.	ELA.
126	21	620	375	400

In 1938 the Aldousbreen was retreating from a previous maximum extension. Some features on its western side, which may be interpreted as fluted moraines, seem to indicate that during this maximum the glacier at least reached the cape located between itself and the Frazerbreen (see the map in fig. 39).

On all air photos the surface of the Aldousbreen shows features similar to those of the Frazerbreen. As for the Frazerbreen, at about six kilometers from the front the width of the ice stream is only 2 kilometers. At 1.5 kilometers from the front Dowdeswell (1990) obtained a maximum surface velocity of 205 m a year on the median axis of the glacier, and 40-60 m a year on the eastern side.

The maximum extension of the Aldousbreen occurred long time before 1938. Since then the retreat has been continuous. There is no recorded surge for this glacier.

N 6 Eltonbreen

A.P.	1938: 1915, 2059-66
	1969: 1783
	1970: 3803-05
	1971: 7437-41
	1977: 1171-72

		/Elevation(masl)\		
Area(km2)	Length(km)	Max.	Med.	ELA.
82.7	16.8	620	420	450

Even though the front of the Eltonbreen is not far from the sea, any future surge is unlikely to reach the sea, and if so it will probably not result in important calving.

N 7 Bodleybreen

A.P.	1938:	1190-97, 1915, 2026-39, 2050-52 2119-20, 2117
	1969:	1783
	1970:	1932-36, 3803-06
	1971:	7540-43
	1977:	1172-74

Area(km2)	Length(km)	/Elevation(masl)\ Max.	Med.	ELA.
92	15.5	610	360	450

There are numerous air photos from 1938 available for the Bodleybreen. Unfortunately, every one was taken a long way from the glacier. Thus, no accurate information is available about the glacier from 1938. On aerial photographs from 1969, 70 and 71, the surface showed the same features as the above studied glaciers. But crevasses were somewhat less visible close to the front, which was nearly grounded. There was very little calving.

Dowdeswell and Lindsay Collin (1990) determined a maximum annual velocity of 197 m between 1970 and 1971 along the median axis, declining to 20-50 m on the glacier sides. During the same period they also found an increase in ice thickness of approximately 5 m at about 1.5 kilometers from the glacier front. Then the Bodleybreen surged. Few changes were visible on one 1973 Landsat image, but a Landsat image from 1977 as well as NP air photos from the same year, indicate a front position more than 1.5 km further out to sea than in 1971. This surge was associated with a reduction in ice thickness of about 10-15 m in the upper basin.

On the air photos from 1971, icebergs lying close to the glacier front indicated shallow water, and remnants of previous lateral moraines indicated that the glacier front during the surge did not reach the previous maximum extension.

The maximum extension of the Bodleybreen occurred before 1938 (probably long before this date). The glacier then retreated until 1973 when a surge occurred and the front advanced 1.5 km, but giving just few small icebergs.

N 8 Etonbreen

A.P.	1938:	1193-98, 1915
		2022-34, 2044-58
		2104-13, 2121-39,
		2171
	1969:	3338-45
	1970:	3581-84, 3611-14
		3729-32, 3729-32
	1971:	7429-34
	1977:	0690-95

		/Elevation(masl)\		
Area(km2)	Length(km)	Max.	Med.	ELA.
664.2	42	680	420	350

The first known front position of the Etonbreen is provided by the 1935-36 Oxford expedition (Glen 1937). On the 1938 air photos the glacier was surging. This surge affected the main ice-stream along the basin but not the total area. At the front, numerous icebergs were visible, some of them were about 100 m long. As for the Jemelianovbreen, the surge activated a part of a lower tributary (here the Palanderisen 2), passing over the median moraine between the two glaciers. The terminus in the north may have reached the previous maximum extension of the glacier, but remnants of lateral moraines along the lake Brånevatnet, as well as on the southern side downstream of the Palenderisen 2, indicate that this surge did not reach the previous maximum extension.

On 1969 air photos, the glacier on some lower parts showed a characteristic smooth and undulating surface. The front was mainly in retreat, especially on the northern side, but Brånevatnet was almost filled up by the ice and on the southern side the ice from the Palanderisen 2 had extended a little further into the sea. That means that the maximum extension resulting from the surge in 1938 occurred following the day on which the photos were taken. In 1969 ten icebergs about 100 m long and two icebergs about 200 m long were visible.

On the 1970 air photos, the surface of the middle and upper basins was smooth and undulating as indicated above for all outlets from the Vestfonna in the Wahlenbergfjord. The few air photos from 1977 cover the upper part of the basin where the surface was still smooth and undulating with a distance between the undulation crests from 500 m to 2 km. Several supra-glacial lakes were also visible.

According to the 1986 Landsat image the glacier front was retreating.

Note 1. On the shore of the Brånevatnet are features believed to be raised beaches. This means that the glacier never completely filled up this lake during the Holocene. However, more precise analysis would be required to confirm this point.

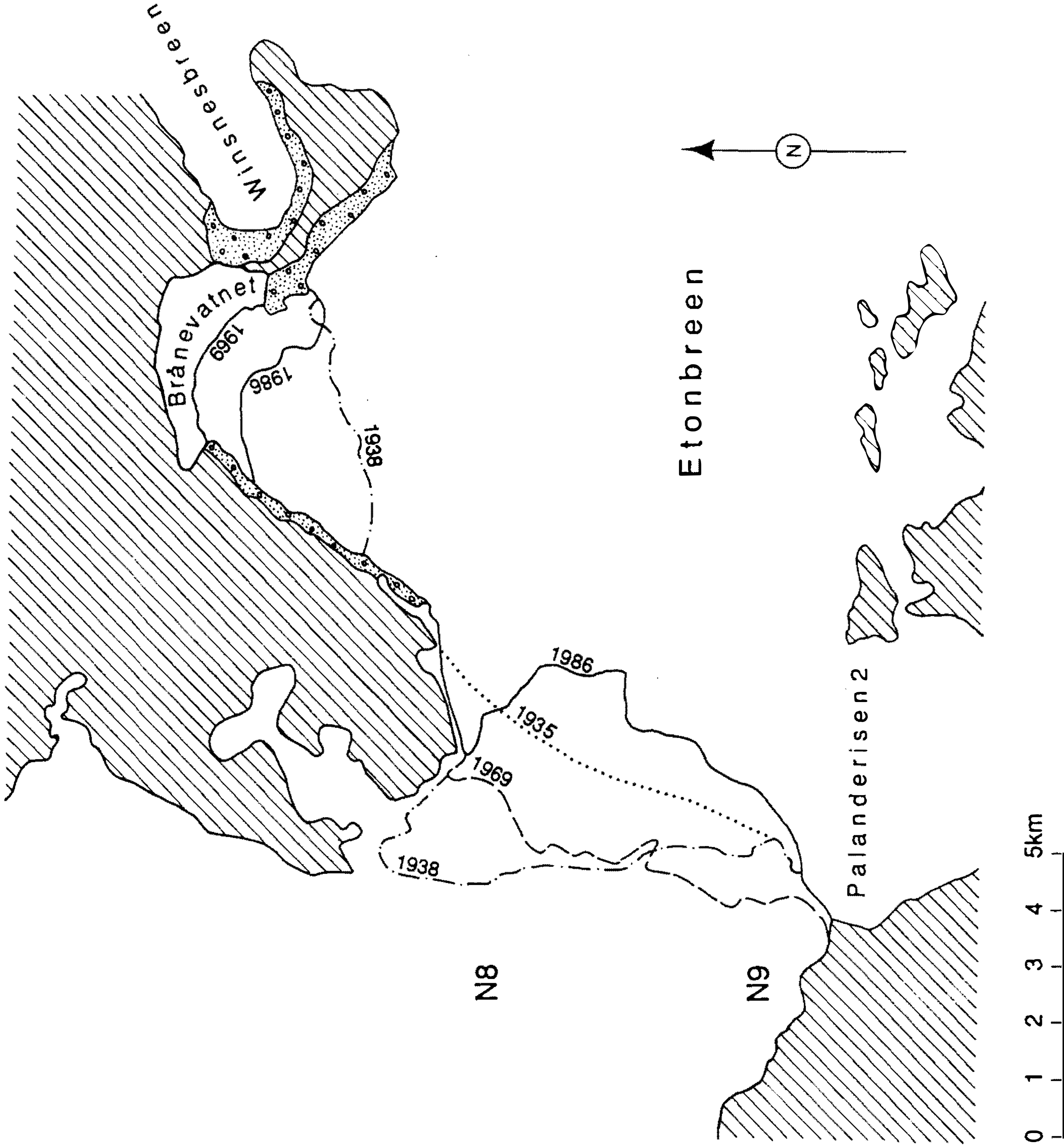

Winsnesbreen
Brånevatnet
1969
1986
1938
N
Etonbreen
1986
1935
1969
1938
Palanderisen 2
N8
N9
0
1
2
3
4
5km

Fig. 40

Note 2. On air photos from 1971, aerial rhombohedral morainic patterns such as submarine patterns described by Solheim and Pfirman (1985) and Solheim (1988) are visible in the vicinity of the glacial lobe, which was still filling up a part of the Brånevatnet.

The maximum extension of the Etonbreen for the Little Ice Age occurred before 1938 (probably long time before) . It is possible that this maximum was also the maximum for the Holocene. A surge occurred in 1938 and the glacier reached a new maximum extension. Icebergs up to 100 m long have been calved during the surge. Since then the Etonbreen has been retreating.

N 9 Palenderisen 2

A.P.	1938: 2104-07, 26-40
	1969: 3338-41
	1970: 3630-32

		/Elevation(masl)\		
Area(km2)	Length(km)	Max.	Med.	ELA.
142.88	14.5	560	325	350

In 1938 a large part of the basin of the Palenderisen 2 was depressed with a characteristic smooth and undulating surface. Old crevasses were also visible, and in its western part the glacier had a small calving front. The above mentioned (see § N 8) remnant of moraine on the southern shore of the Wahlenbergfjorden was not deposited by the Palenderisen, but during a previous maximum extension of the Etonbreen. The front of Palenderisen partly recovered this moraine. On the other hand, Dowdeswell (1984) determined the theoretical surface profile in steady glacial state and compared the result with the observed surface profile. The comparison indicates that the lower part of the basin of Palenderisen 2 is depressed but very close to the theoretical profile, while the upper basin has a surface elevation higher than the theoretical profile. There is agreement between this information and the morphological analysis, and it may be concluded that the glacier most likely surged long before 1938 and at the present is rebuilding an ice mass in its upper basin which may give a new surge in the future.

Due to the pressure from the Etonbreen during the surge, the front of the Palenderisen appeared in 1969 a little further into the sea than in 1938. The 1969 and 1970 air photos do not indicate any significant changes on the glacier.

The Palenderisen 2 likely surged long before 1938. In 1938-39 its small calving front advanced a little into the sea due to the pressure from the surging Etonbreen. Since then it has not advanced.

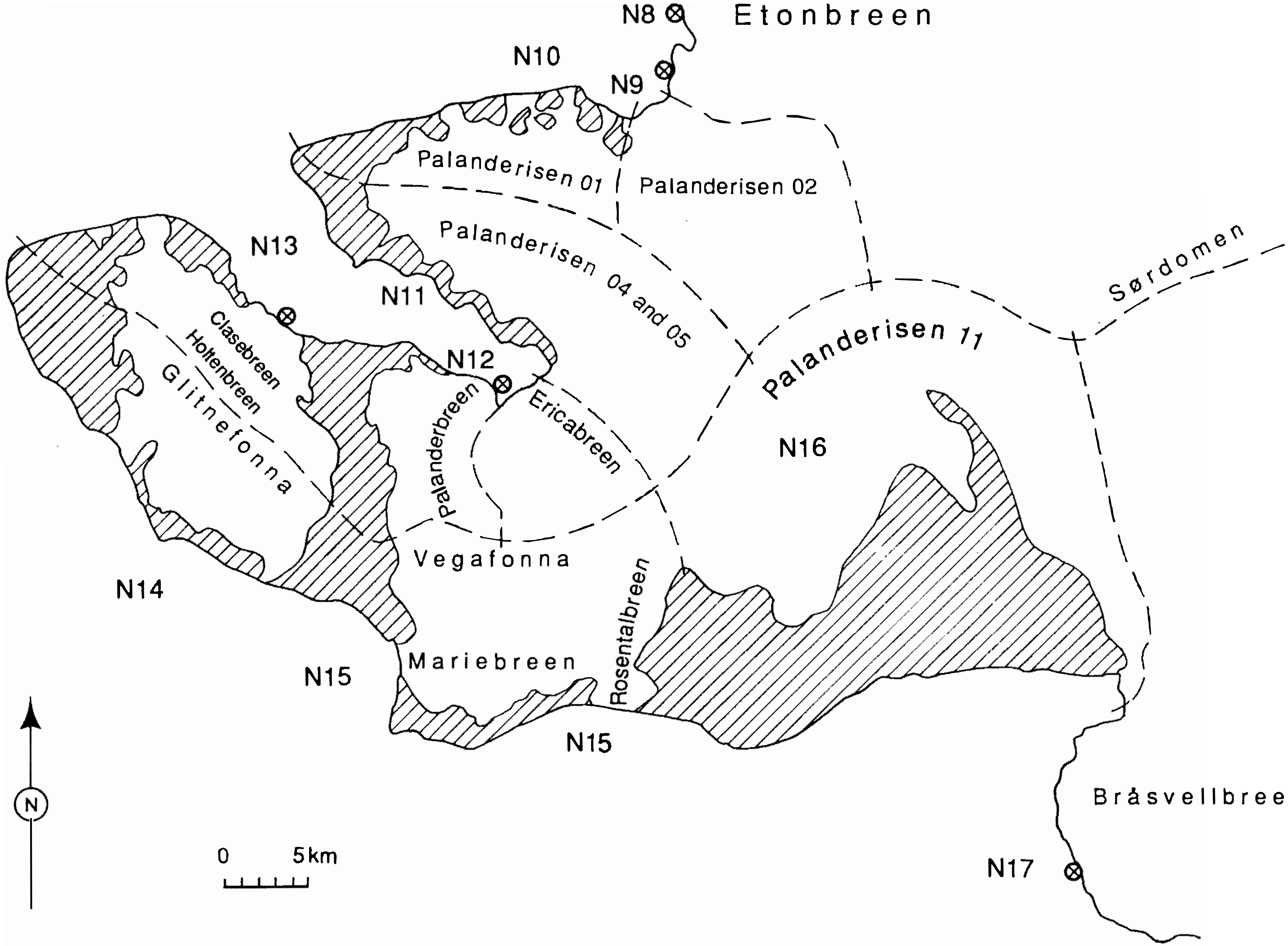


Fig. 41 Recorded surges are indicated by circles with a small cross.

N 10 Palenderisen 1

A.P.	1938: 2140-59, 2171
	1969: 1782, 84
	1970: 3630-35, 49-50

		/Elevation(masl)\		
Area(km2)	Length(km)	Max.	Med.	ELA.
65.7	8	500	300	300

From the Palenderisen 1, five glacial tongues flow down to the sea. In 1938, from east to west, the first three tongues had reached the sea and produced some calving. The fourth had just reached the sea but did not calve and the last one did not reach the sea. Lack of raised beaches on the lateral sides of the glacial lobes of the first four glaciers indicated that these glaciers might have been more extended previously. Presence of raised beaches in front of the last tongue indicates that this glacier did not reach the sea during the Little Ice Age. No sign of past surges were visible.

In 1970 each glacier was in a retreat phase, especially the two western tongues, and the total calving activity was reduced to almost zero. Due to the fact that the Palenderisen 1 has a small area and that the outlet is divided into five tongues, future surges will not give any important calving.

There is no sign of past surges from the five small outlets from the Palenderisen 1. Any potential future surges are not likely to be important.

N 11 Palenderisen 4

A.P.	1938. 2169-70, 72-92
	1969: 1780-81, 85
	1970: 3636-38, 46-48

		/Elevation(masl)\		
Area(km2)	Length(km)	Max.	Med.	ELA.
169.65	12	570	350	400

The Palenderisen 4 is the part of the Palenderisen facing westward and flows to the Palenderbukta. There are three small distinctive outlets. Only the southern one on the right side of Ericadalen has a small ice cliff at the shore line. This front is almost 400 m wide. There were no signs of past surges on air photos from 1938, 1969 and 1970. The flow speed is probably very slow. Nevertheless small surges may occur, as happened on Palenderbreen (see § N12), but probably it will not result in important calving.

N 12 Ericabreen

Palenderbreen

A.P.	
	1938: 2160-70, 80-94
	1969: 1780, 885-86
	1970: 3636-39, 46-47

		/Elevation(masl)\		
Area(km2)	Length(km)	Max.	Med.	ELA.
54.08	8.5	470	320	300
60.30	9.5	470	320	300

The Ericabreen and Palenderbreen are two tide-water outlets from the northern part of Vegafonna. A third, small lobe lying in the west of the Palenderbreen had a part of its front joining this glacier and was partly tide-water in 1938, but did not give any significant calving. At this time there were no signs of past surges for the three tongues.

In 1969 and 1970 the Palenderbreen showed characteristic signs of a recent past surge in the form of depressed upper basin with long, concentric crevasses, and with heavy crevasses in the ablation area. The front had extended further into the sea and some icebergs were visible. In 1969 two icebergs were more than 50 m long. Since this date the three tongues have been retreating.

There is no sign of old past surges for these glaciers. The Palenderbreen surged just prior 1969 and produced icebergs up to 50 m long..

N 13 Glitnefonna north-east

A.P.	
	1938: 2198-2219
	1969: 3120-28
	1970: 3646-48

		/Elevation(masl)\		
Area(km2)	Length(km)	Max.	Med.	ELA.
79.75	5.6	450	300	250

From the northern Glitnefonna four outlets reach the sea in Palenderbukta. The two in the east, the Holtenbreen and Clasebreen, have a common calving front. The third just reached the shore line and probably produced only a few small icebergs in 1938. The fourth is still tide-water, but with no real calving activity.

In 1938 there were no signs of past surges. However analysis of the 1969 air photos indicates that a small part of the Holtenbreen may have surged some time before, probably long before 1938. In 1938 the Clasebreen was surging, the front was extended slightly into the sea with characteristic broken line and numerous crevasses visible in the lower basin. In 1969 the front had advanced slightly further and characteristic crevasses were visible over the entire basin. The surge probably started in 1938 with the maximum extension occurring just after the photo had been taken.

It is possible that the Holtenbreen had a small surge before 1938. The Clasebreen surged in 1938-39, but did not give important calving..

N 14 Glitnefonna south-west

A.P	1938:	1278-87, 2227-33
	1969:	3118-20, 28-32

		/Elevation(masl)\		
Area(km2)	Length(km)	Max.	Med.	ELA.
93.6	8.0	450	320	300

Three lobes face the Hinlopenstretet from the western and southern part of the Glitnefonna. On De Geer's map, as well as on the 1938 air photos, the northern lobe, located just to the south of the Angelinberget, just reached the sea. In 1938 the lobe located just north of the Svarberget did not reach the sea. The last one, located south of the Myrkberget reached the sea, but only as a small, thin and flat expanse.

The 1969 air photos as well as the 1986 Landsat image, indicate a slow retreat. The northern lobe is retreating from the shore line and the stagnant ice of the southern lobe has melted.

There is no sign of old or recent past surge for the Glitnefonna.

N 15 Mariebreen

Rosenthalbreen

A.P.	1938:	1289-97
	1969:	1778-79, 88-91, 3134-39
	1970:	3624-29, 41-43

		/Elevation(masl)\		
Area(km2)	Length(km)	Max.	Med.	ELA.
81.38	9.5	470	330	350
95.85	11.0	470	330	350

Actually, the Mariebreen and the Rosenthalbreen are more or less separated from the Vegafonna. They are directly fed by two small icecaps and are separated from the Vegafonna by valleys. In the event of surge from the Vegafonna these two glaciers may be reactivated. However if they surge themselves, the surges are not likely to be very important. Just to the west of the Rosentahlbreen a small lobe issued directly from the Vegafonna lies very close to the sea. A future surge from this glacier would probably be more significant than from the Rosenthalbreen.

In 1938 the Mariebreen and Rosenthalbreen reached the sea. Today they are still tide-water, but not calving significantly.

There is no sign of old or recent past surges for the Mariebreen and the Rosenthalbreen.

N 16 Palenderisen 11.

A.P.	1938:	1296-98, 1917-19, 1983-89
	1956:	1170-77
	1969:	3139-48
	1970:	3587-90, 95-96 3617-20,
	1977:	0699-0702

		/Elevation(masl)\		
Area(km2)	Length(km)	Max.	Med.	ELA.
369.15	*12.5*	630	*380*	400

Note: The length and median elevation are only roughly estimated.

The Palenderisen 11 is a glacier complex located north of Svartknausflya and has two parts, one is fed by the Palenderisen itself and one by an ice mass issued from the Sørdome. These glaciers are separated from the sea by the Svartknausflya which has a mean width of 3-6 kilometers. Along the Bråsvellbreen this glacier reaches the sea, but under the form of almost stagnant ice covered with moraine. In the event of a future surge, only this small tongue is likely to produce calving.

There is no sign of old or recent past surges on air photos, nor on the 1986 Landsat image of the Palenderisen 11.

N 17 Bråsvellbreen

A.P.	1938:	1917-27, 1946-89
	1956:	1172-1209
	1969:	3146-48, 3322-37
	1970:	3553-61, 92-98 5200-13
	1977:	0695-0702

		/Elevation(masl)\		
Area(km2)	Length(km)	Max.	Med.	ELA.
1111.39	45.0	670	325	350

The first front position for the Bråsvellbreen is not a mapped position but an approximation after observations by the 1923-24 Oxford University Arctic Expedition and the 1931 Swedish-Norwegian Expedition (in Glen 1937 and 1939). In 1935 and 1936 (Glen 1937 op. cit.) the glacier front was almost at the same position. The glacier surged some years later. On air photos from 1938, the glacier had advanced about 20 km into the sea with a width of more than 30 km, and heavy crevasses were visible from the front to many kilometers into the upper basin. Vinje (1985) reported that in 1937, about one hundred icebergs were observed by sealers in this area. Thus the surge likely started in 1937. In 1938 numerous icebergs were visible close to the front on the air photos. After the surge, the Bråsvellbreen started a quiescent retreating phase, probably with a mean flow speed of around 10 m a year.

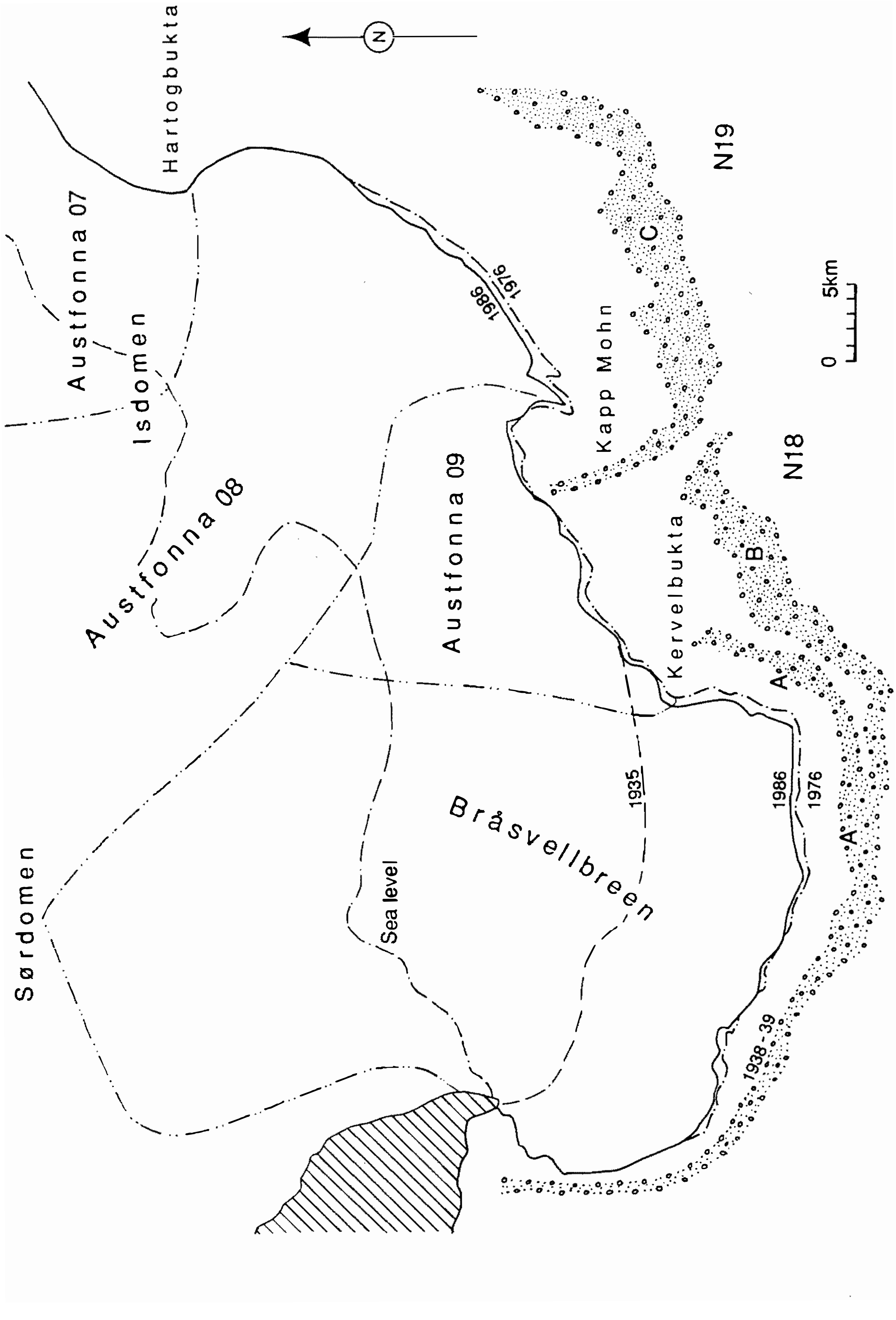

N
Hartogbukta
Austfonna 07
Isdomen
Austfonna 08
Austfonna 09
Kapp Mohn
N19
N18
C
B
A
A
Kervelbukta
1976
1986
1935
1938 - 39
Bråsvellbreen
Sea level
Sørdomen
0
5km

Fig. 42

This surge is of historic significance as it is the greatest surge ever observed. At the time, scientists knew very little of this glacial phenomena. Glen noticed (Glen 1937, p. 207): "The cause is still unknown except that it certainly was not a developing glaciation, and can only have been either a tectonic disturbance, or some internal glacial cataclysm, perhaps of the kind describe by professor Mason in his "Study of threatening glaciers" ".

The total area covered by ice during the surge was approximately 500 km^2 while the total basin area is 1111 km^2. Solheim (1988) estimated a total surged amount of ice of 96 km3.

Figure 42 shows the position of submarine terminal moraines from Solheim and Pfirman (1985) which correspond to the maximum extension. The 1936 position is based on Solheim after Glen (1939 and 1941) who himself interpreted previous observations. The limit of the bedrock at sea level is from Dowdeswell (1984). Delimitations of glacial basins are from the Glacier Atlas of Svalbard. The limits of the Bråsvellbreen basin were easy to define, due to the well delimited area affected by the surge. In front of the Bråsvellbreen the submarine moraine noted "A" corresponds to the maximum extension reached during the 1937-38 surge. An interesting feature is noted in "B". It is analysed by Solheim as another submarine moraine. The basin noted "Austfonna 9" in this report has a small area, and the morainic ridge "B" in its southwestern part is parallel to the ridge "A". For these reasons, Solheim interprets this morainic ridge as the mark of a possible previous extension of the two basins of Bråsvellbreen and Austfonna 8. This extension might have been due to a near simultaneous surge of these glaciers. This interpretation is plausible, it brings up the important following question: Schytt (1969) estimated the surge cycle of the Bråsvellbreen to be "considerably more than 200 years", and Solheim (1988) estimated this cycle to be between 370 and 500 years. If this morphology "B" is really due to such previous surges, is it possible for these glaciers to have had two very important surges during the Little Ice Age, and particularly to have reached their maximum extension 150 or 200 years before the maximum of the Little Ice Age ?

On air photos from 1956, the tongue of the glacier was smooth. Crevasses due to the surge had disappeared and only few crevasses parrallel to the front were visible. Other air photos provide little information. In 1977 only a small part of the glacier was photographed along the glacier noted Palenderisen 11. On these photos the surface appeared smooth and undulating. The relief was readily visible due to the fact that tops of crests and small bumps were naked ice, while small depressions were filled with snow.

From 1938 to 1986 the mean retreat was 3-3.5 km, or 60-70 m a year. The length of the front is about 50 km . Assuming a flow speed of 10 m a year and a mean ice thickness of 100 m this gives a total calving of about 3.5 km^2 and 0.35 km^3 of ice. This is almost 50% more than from the Kronebreen, an active calving valley glacier on the west coast of Spitsbergen (Lefauconnier in prep.).

It is possible that the Bråsvellbreen had two periods of maximum extension due to two different surges. The first one may have occurred a long time ago,possibly at the beginning of the Little Ice Age. Dating of this event is difficult. The Bråsvellbreen surged in 1937-38 and reached its maximum extension with an advance of about 20 km into the sea. Since then it has been in a quiescent retreating phase.

N 18 Austfonna 9

A.P.	1938: 1937-59
	1956: 1210-24
	1970: 5212-13

		/Elevation(masl)\		
Area(km2)	Length(km)	Max.	Med.	ELA.
232.8	18.5	410	250	400

The front of this glacier is located between Kervelbukta and Kapp Mohn.

The basin designated 9 from the Austfonna has a relatively small area, and its surface has a low elevation compared to the two neighbouring glaciers. There has been no surge recorded for this basin. The maximum extension was probably reached a long time ago, possibly at a time when the Bråsvellbreen and the "Austfonna 8" surged simultaneously or successively, (see comments in § N17). Based on the present knowledge on surging of Svalbard glaciers and the lack of evidence (especially on air photos) of recent past surges for this glacier, a future surge may occur. If so, it should be of a smaller scale than the surge in 1938 on Bråsvellbreen, or the pre-1973 surge of the "Ausfonna 8".

There has been no surge recorded for this glacier. According to an analysis of Solheim (1988), it is possible that it reached its maximum extension at the beginning of the Little Ice Age, when its flow was subject to the pressure from neighbouring glaciers.

N 19 Austfonna 8

1938: 1921-24, 28-39
1956: 1210-24
1977: 1216-18

		/Elevation(masl)\		
Area(km2)	Length(km)	Max.	Med.	ELA.
1271.14	60.0	770	440	400

The front of this glacier is located between Kapp Mohn and Hartogbukta.

According to Solheim's analysis of submarine frontal moraines (Solheim 1988, see also § N 17) it is possible that this glacier first reached its maximum extension during a surge a long time ago, possibly at the beginning of the Little Ice Age. The moraine noted "C" in the figure 42 was analysed by the same author as a moraine deposed by a surge. This event must be related to the observation of extremely large crevasses made by Nordenskjold in 1873. In that year Nordendenskjöld led an expedition across Nordaustlandet. When this expedition walked on the south side of the Nordomen, on the upper basin of the glacier noted here as Austfonna 8, members had to pass over large and long crevasses. A description and some sketches by one of the crew, show crevasses with a depth of 15 meters and a width of 10-30 meters. They were parallel and about 100 meters apart. They were real channels cutting the ice surface. This suggest that Nordenskjöld and his companions most probably travelled across this region some years after an exeptionaly large surge.

The retreat of the front until the present has been about 3 kilometers,which corresponds to a mean retreat of around 25 meters a year. If such glaciers are close to being stagnant, it is obvious that during the first few years after the surge they were both calving and flowing somewhat more than during the following long quiescent phase. On the other hand, recent front positions shown in figure 42, as well as front positions between 1970 and 1985 (or 86), on the NP maps F5 and G5, indicate a similar rate of retreat for the Bråsvellbreen and the two previous mentioned glaciers, Austfonna 9 and Austfonna 8.

The three air photos from 1977 show an important contrast between the surfaces of this glacier and the Austfonna 7. Close to the front the surface of the Austfonna 8 is fairly smooth with a gentle slope, while the surface of the Austfonna 6 show a characteristic undulation (see below, § N 20).

It is possible that Austfonna 8 had two periods of maximum extension. The first maximum may have been reached a long time ago, possibly at the beginning of the Little Ice Age. As for the Bråsvellbreen, the dermination of this surge remains a problem. The Ausfonna 8 surged during the second half of the last century, probably some years before 1873. This was a major surge, probably somewhat more significant than the 1937-38 Bråsvellbreen surge.

N 20 Austfonna 7 and 6

A.P.	
	1938: 1928-32
	1956: 1223-36
	1970: 1982-86
	1977: 1211-16

		/Elevation(masl)\		
Area(km2)	Length(km)	Max.	Med.	ELA.
242.93	25.0	650	380	400
670 73	33.0	740	490	*350*

The fronts of these glaciers are located between Hartogbukta and Isispynten.

On air photos from 1956, 70 and 71 the surfaces were smooth and undulating. In the ablation area, from the front to 3-6 kilometers inland, the tops of these undulations are quite close together as described for the Valhallfonna (see § H 19). In the upper basin they are more distant as described for the upper basin of the Etonbreen (see § N 8). Nevertheless there have been no important changes in the front position since the Oxford University observations.

Isispynten is a group of small islands partly covered by moraine. On the 1956 and 77 air photos, some raised beaches are visible facing the sea on the outer part of the main island. At this place the island marks the maximum glacial extension for the Little Ice Age.

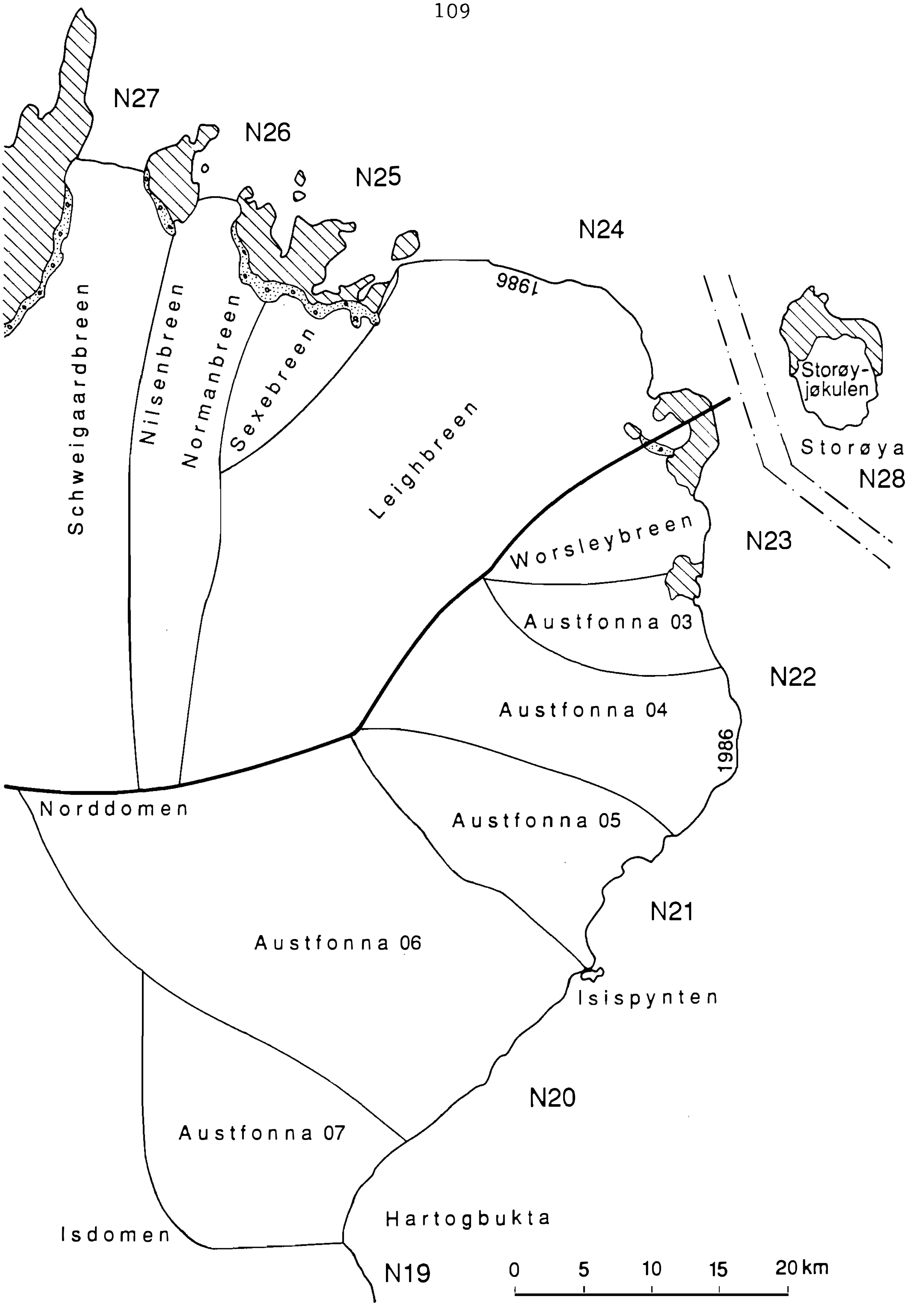

N27
N26
N25
N24
1986
Schweigaardbreen
Nilsenbreen
Normanbreen
Sexebreen
Leighbreen
Storøy-
jøkulen
Storøya
N28
N23
Worsleybreen
Austfonna 03
N22
Austfonna 04
1986
Norddomen
Austfonna 05
N21
Austfonna 06
Isispynten
N20
Austfonna 07
Hartogbukta
Isdomen
N19
0 5 10 15 20 km

Fig. 43

According to Dowdeswell (1984) the bedrock is at sea level at about 10 kilometers from the present front. The same author determined the present and a theoretical longitudinal profile for this glacier. The present profile corresponds to the theoretical one in the lower 10 kilometers, and is more elevated in the upper basin. This means that if the last surge of this glacier occurred a long time ago, then a new surge may be not to far in the future.

The glacier has been retreating since the first visit in 1935-36 established an approximate front position. No surge has been recorded here. A surge in the relatively close future is possible.

N 21 Austfonna 5

A.P.	1956: 1234-44
	1977: 1208-11

		/Elevation(masl)\		
Area(km2)	Length(km)	Max.	Med.	ELA.
176.74	22.0	600	375	300

From 1956, and most likely since the Oxford Expedition this glacier has been retreating. In 1935-36 the glacier front was a sligthly convex lobe into the sea. This lobe was still visible on the 1956 air photos. Today it has almost disappeared. The surface was smooth on the air photos without undulation, and crevasses were visible only in the vicinity of the front. As for the Valhallfonna, the different characterisitcs between this and the neighbouring glaciers is difficult to interpret. Comparison between theoretical and observed longitudinal profiles by Dowdeswell (1984) shows that in the lower 5 kilometers observed and theoretical profiles are similar, while in the upper basin the observed profile has a higher elevation than the theoretical one.

This glacier has been retreating since 1935-36. No surge has been recorded for this glacier. A surge in the future is possible.

N 22 Austfonna 4

Austfonna 3

A.P.	1956: 1241-47
	1977: 0615, 1208

		/Elevation(masl)\		
Area(km2)	Length(km)	Max.	Med.	ELA.
248.55	23.0	600	330	300
71.0	15.2	500	330	300

The sketch of the front from the Oxford Expedition of 1935-36 (Glen 1937) shows a glacial lobe protuding slitghly into the sea, as on the air photos from 1956, the NP maps, and the 1986 Landsat image. Thus, since 1935 the glacier has been in a quiescent phase and the front has retreated very slowly. On the 1956 air photos the lower part of these glaciers had a smooth and undulating surface, and numerous crevasses were visible.

No surge has been recorded for these glaciers. Though little information is available, it seems likely, though uncertain that these glaciers, like their neighbours, could surge in the future.

N 23 Worsleybreen

A.P.	1970: 2026-31
	1977: 0613-15

		/Elevation(masl)\		
Area(km2)	Length(km)	Max.	Med.	ELA.
101.14	16.3	500	280	300

Glen's map (1937) using sketches from the Oxford Expeditions showed a small frontal lobe protuding sligthly into the sea, as do the 1970 and 1977 air photos and the NP map with a 1976 front position from a satellite image. On the1970 air photos the front had two distinct parts. The southern part was almost straight, and upstream the surface showed large, weak undulations. The northern part was the part with a lobe, and upstream the surface was smooth and without undulation. In 1986 (Landsat image) this lobe was reduced, but still present.

The Worsleybreen has most likely been in a slow quiescent retreating phase for long time. No surge has been recorded here.

N 24 Leigthbreen

A.P.	1938: 2625-36, 40-44
	1956: 0913-39
	1970: 2023-28
	1971: 6681-84, 87-88
	1977: 0609-13, 58-63

		/Elevation(masl)\		
Area(km2)	Length(km)	Max.	Med.	ELA.
715.4	47.0	680	440	250

From 1935 (Oxford University Expedition) and 1938 (NP air photos) until today the front of the Leigthbreen remained almost at the same place. Analysis of air photos indicates a smooth and undulating surface with a distance between undulation peaks of 0.5-2 km in the upper bassin and less than 500 meters in the lower kilometers close to the front. In this lower area numerous crevasses were visible, while some supra-glacial lakes were present in the upper basin.

Thus from 1935 until today, the Leigthbreen has been in a quiescent retreating phase, which probably started a long time ago.

Dowdeswell (1986) determined that the observed profile was below, but close to the theoretical profile all along the longitudinal median axis of the glacier. This suggests that the Leigthbreen may have surged a long time ago.

Topographic curves in the upper basin are concave on the right side but convex on the left side. It would be interesting to further survey this basin, particularly with respect to the difference in the accumulation areas.

The date of the maximum extension of the Leigthbreen is not known. Since the first observation around 1935-36 the glacier has been in a quiescent retreating phase, probably following a surge which may have occurred a long time ago. No surge has been recorded for this glacier.

N 25 Sexebreen

Nordmanbreen

A.P.	1938: 2621-29, 42-49
	1956: 0934-48
	1971: 6655-61
	1977: 0602-09, 63-66

		/Elevation(masl)\		
Area(km2)	Length(km)	Max.	Med.	ELA.
79.80	15.0	520	350	350

Note: In the Glacier Atlas, information on the Nordmanbreen is included along with the datas of the Nielsenbreen.

These glaciers are difficult to delimit precisely on maps. Between the Leigthbreen and Nielsenbreen they consist of mostly dead ice. At the present, they are still very close to their maximum extension. The left side (Sexebre) on the 1977 air photos shows a very smooth surface without undulations, while the Nordmanbreen had an undulating surface. The Sexebreen most likely was not affected by the movements of the Leigthbreen, while the Normandbreen undergone the movements of the Nielsenbreen. The two glaciers are not calving and were not calving previously.

No surge has been recorded for these glaciers.

N 26 Nielsenbreen

A.P.	1938: 2615-24
	1956: 0945-55
	1971: 6663-66
	1977: 0605-06, 66-68

		/Elevation(masl)\		
Area(km2)	Length(km)	Max.	Med.	ELA.
263.6	43.0	690	500	350

From the 1935-36 Oxford University Expedition and the 1938 air photos, it appears that the front of the Nielsenbreen has been retreating very slowly. On the air photos a remnant of lateral moraine on the northern side indicates that, at its maximum extension, the glacier extended slightly into the sea. As for other glaciers in the area, their surfaces appeared smooth and undulating, with highly visible crevasses in the vicinity of the front due to a small but continual calving activity. There have been no surges recorded here. Lack of information does not allow further conclusions concerning future surge activity.

From the first visit in 1935-36 until today, the Nielsenbreen has been in a retreating, quiescent phase. No surge has been recorded here.

N 27 Schweigaarbreen

A.P.	1938: 2614-19
	1956: 0951-58
	1971: 6667-70
	1977: 0604-05, 67-69

		/Elevation(masl)\		
Area(km2)	Length(km)	Max.	Med.	ELA.
473.3	45.0	740	500	350

The Sweigaarbreen shows features similar to those of the Nielsenbreen: a smooth and undulating surface with a distance between undulation peaks of about 500 meters or less in the lower basin, 0.5-2 km in the upper basin. From the first observations by the 1935-36 Oxford University Expedition until today the glacier front has been retreating. There are no important morainic deposit on either side of the glacier. The maximum extension was most likely not very far from the present front position.

From its maximum extension before 1935 until today the Sweigaarbreen has been retreating. No surges have been recorded here.

N 28 Storøyjøkulen

A.P.	1938: 2638-39
	1977: 0646-48, 53-55

		/Elevation(masl)\		
Area(km2)	Length(km)	Max.	Med.	ELA.
29.1	3.2	240	140	100

Storøyjøkulen is an ice-cap which covers around 50% of the small island Storøya, situated northeast of Nordaustlandet. This ice-cap was still calving in 1977 on all sides except the north. On the entire ice-cap the surface is smooth with a gentle slope. There are no signs of past surges. On land the ice boundary cuts lines of raised beaches and analysis of air photos does not allowed any conclusion about the maximum extension for the Little Ice Age. On the other hand, the general aspect of the glacier surface provide good evidence to suggest that this ice-cap probably never surged.

Storøyjøkulen has likely never surged.

N 29 Kvitøyjøkulen

A.P.	1956: 1019-54, 1632-65
	1977: 0620-29, 34-43

		/Elevation(masl)\		
Area(km2)	Length(km)	Max.	Med.	ELA.
705.0	13.0	379	200	100

Kvitøya is almost completely recovered by an ice-cap which consists of two domes. The 1956 air photos were taken from a very low altitude due to the presence of clouds. Nevertheless, the ice cliff is tide-water almost continuously around 95% of the island, but consists of different elevations. On the 1977 air photos the ice surface showed characteristics typical of the Valhallfonna: close to the front the surface is alternatively smooth with a gentle slope and no sign of activity or undulating and crevassed with some activity at the front (but with little calving). These different areas are noted on the map in the fig 44. It is possible that Andréeneset was an an ice-free area along the Little Ice Age.

No past surges has been recorded for the Kvitøyøkulen. Some areas may be experiencing a quiescent phase between surges. Future surges are possible, but because the ice mass is divided in two domes, and due to the diverse outflows, a major surge is unlikely.

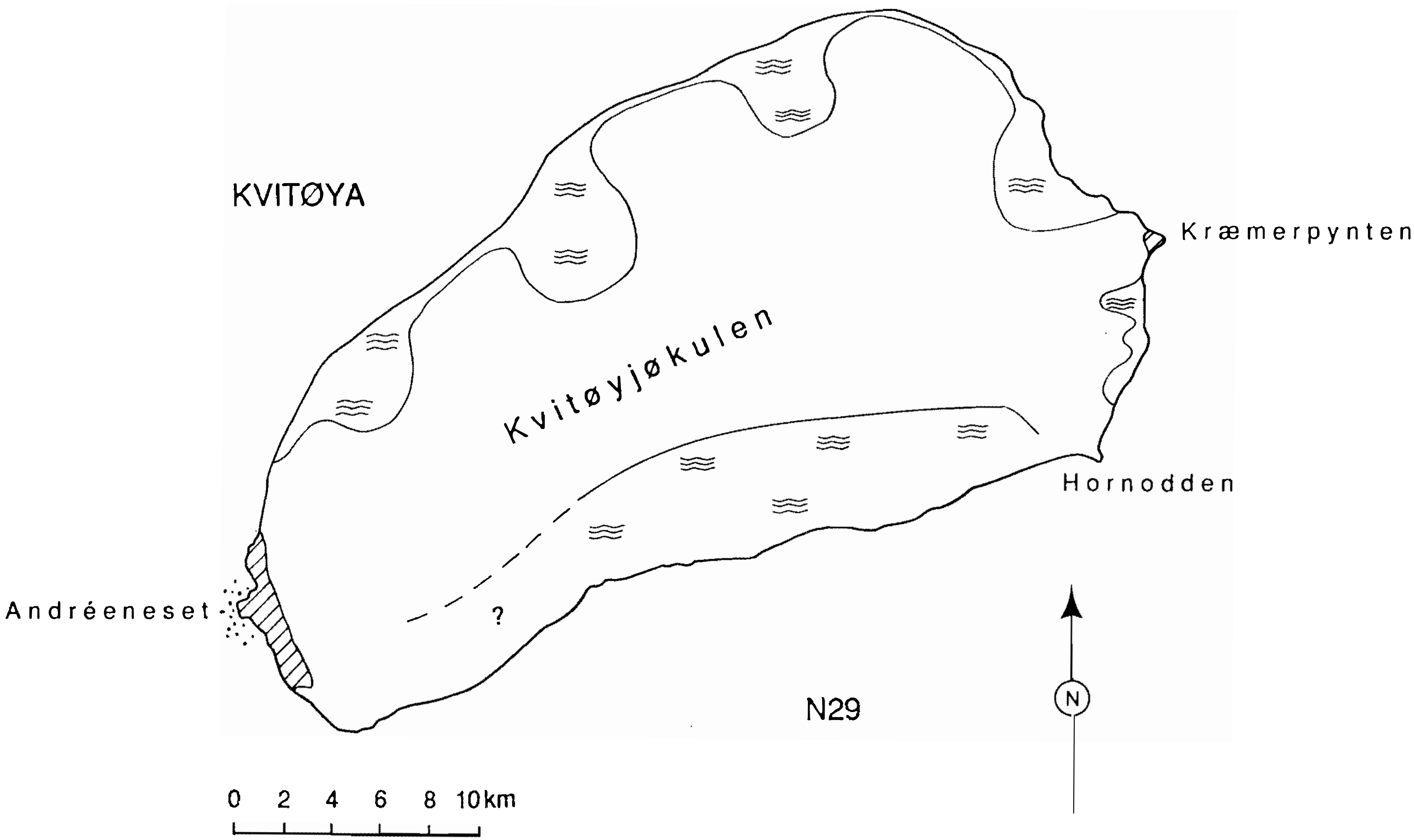


Fig. 44 Small waves indicate undulating and crevassed surfaces. Out of these areas, the surface is smooth with a gentle slope.

Glacier list with recorded surges

Glacier	maximum extension	surge main ... ¤ tributary ... *	potential future surge with calving
Storfjord (Spitsbergen East coast)			
S 1 Mathiasbreen			
S 2 Keilhaubreen	b.1900		
S 3 Svartkuvbreen			
S 4 Randbreen			
S 5 Vasilievbreen	b.1874	a .1961 *	++
S 6 Tromsøbreen	b.1900		
S 7 Barbarabreen			
Kanebreen			
Coryellbreen			
Bevanbreen			
Unnameden			
S 8 Hambergbreen	j.b.1900	j.b.1900 ¤	++
		bt.1961-70 ¤	
A 9 Staupbreen	bt.1936-61	bt.1936-61 ¤	
S 10 Markhambreen	b.1900	b.1936 ¤	
S 11 Crollbreen	b.1900	bt.1936-61 *	
Stepanovbreen			
S 12 Davisbreen	1900	b.1961 ¤*	
Skimebreen		1970 *	
Bellingbreen			
S 13 Anna Margrethbre.	b.1900	j.b.1870 ¤	
S 14 Jemelianovbreen	b.1900	1970-71 ¤	+
Spælbreen			
S 15 Strongbreen	bt.1870-76	bt.1870-76 ¤	++
Perseibreen			++
Kvalbreen			++
S 16 Thomsonbreen	b.1900	bt.1948-69 ¤	
S 17 Richardsbreen	b.1936		

S 18 Ingerbreen				
Kapteinsbreen				
Bratthenbergbreen				
S 19 Beresnikovbreen	b.1900	b.1900	¤	++
Arnessenbreen		b.1936	¤	
Inglefieldbreen		l.b.1936	¤	++
Nordsysselbreen				
S 20 Ulvebreen	b.1870	a.1896-1900	¤	+
S 21 Usherbreen	b.1936	b.1936	¤	
	1984	1978-84	¤	
S 22 Hayesbreen	1901-1910	1901-1910	¤	++
Koenigsbreen				++
Heuglinbreen				++
S 23 Negribreen		b.1870	¤	+
	1936-37	1935-37	¤	
S 24 Helge backlundbre.	b.1900	b.1900	*	
S 25 Sonklarbreen	b.1870	bt.1900-1936	*	+
S 26 Ganskijbreen	b.1936	b.1936	¤	
S 27 Pedasjenkobreen	b.1900	b.1936	¤	

Barentsøya - Edgeøya

B 1 Duckwitzbreen	a.1919	a.1919	¤	
B 2 Freemanbreen	b.1936	1955-56	¤	
B 3 Hübnerbreen	b.1936	a.1930-36	¤	
Reymondbreen		1956	¤	
B 4 Willybreen				
B 5 Besselbreen	a.1900			+
Augnebreen				
E 1 Skentbreen	b.1936	b.1936	¤	
E 2 Kuhrbreen	b.1936	b.1936	¤	
E 3 Deltabreen	b.1858	b.1859	¤	
E 4 Hartmannbreen	a.1860			
E 5 Pettersenbreen	b.1900	a.1925	¤	
E 6 Kong Johansbreen	b.1900			
	a.1925-30	a.1925-30	¤	
E 7 Stonebreen		bt.1850-60	*	+
		bt.1936-71	*	

Hinlopenstretet (Spitsbergen North-East coast)

H 1	Hannebreen	l.b.1936	j.b.1936	¤	
H 2	Koriskabreen	b.1836			
H 3	Unnamed	b.1936			
H 4	Hoschetetterbreen	a.1900	a.1900	¤	+
H 5	Unnamed		b.1936	*	
H 6	Molktebreen	b.1936			
H 7	Roonbreen	b.1936			
H 8	Unnamedbreen		bt.1970-86	*	
H 9	Vaigatbreen	b.1900			
H.10	Hinlopenbreen	b.1901	l.b.1938 1969-71	* ¤	+
H 11	Loderbreen	a.1900			
H 12	Polarisbreen Chydeniusbreen	b.1901			++ ++
H 13	Kosterbreen	b.1936	b.1936 bt.1956-70	* *	
H 14	Hödbreen Svein Ludvigbreen	a.1900			
H 15	Reliktebreen	b.1901			
H 16	Balderfonna Kantbreen Glintbreen				
H 17	Tommelbreen	a.1900			
H 18	Odinjøkul Frøyabreen	b.1901	b.1970	*	
H 19	Valhallfonna Buldrebreen				

Nordaustlandet, Storøya, Kvitøya

N 1	Gimlebreen	b.1900		
N 2	Bragerbreen	b.1900		
N 3	Idunbreen	b.1938		
N 4	Frazerbreen	b.1938		
N 5	Aldousbreen	l.b.1938		

N 6 Eltonbreen				
N 7 Bodleybreen	l.b.1938	1973	¤	
N 8 Etonbreen	l.b.1938	1938-39	¤	
N 9 Palenderisen 2	l.b.1938	l.b.1938	¤	
N 10 Palenderisen 1	b.1938			
N 11 Palenderisen 4	b.1938			
N 12 Ericabreen	b.1938			
Palenderbreen	b.1938	j.b.1969	¤	
N 13 Glitnefonna N.E				
(Holtenbreen)		l.b.1938	*	
(Clasebreen)		1938-39	¤	
N 14 Glitnefonna S.W	b.1938			
N 15 Mariebreen	b.1938			
Rosenthalbreen	b.1938			
N 16 Palenderisen 11	b.1938			
N 17 Bråsvellbreen	l.b.1938 and	l.b.1938	¤	
	1937-38	1937-38	¤	
N 18 Austfonna 9	l.b.1938			
N 19 Austfonna 8	l.b.1873 and	l.b.1873	¤	
	b.1873	b.1873	¤	
N 20 Austfonna 7, 6	b.1935			+
N 21 Austfonna 5	b.1935			+
N 22 Austfonna 4,3	b.1935			+
N 23 Worsleybreen	b.1935			+
N 24 Leigthbreen	b.1935			+
N 25 Sexebreen				
Nordmanbreen				
N 26 Nielsenbreen	b.1935			
N 27 Schweigaarbreen	b.1935			
N 28 Storøyjøkul				
N 29 Kvitøyøkul				+

Symbols and abbreviations used in the table:

Letters and numbers before the glacier name refer to the comment in the text:
S = Storfjord, glaciers situated on the East coast of the Spitsbergen, **B** = Barentsøya,
E = Edgeøya, **H** = Hinlopenstretet, glaciers located on the North East coast of Spitsbergen, **N** = Nordaustlandet, Storyøya, Kvitøya.

l.b = Long before. Ex:" l.b.1900". That means that the maximum extension for the mentioned glacier occurred at an undertermined date but not in the 10 or 20 years before 1900. This symbol is used to mark the difference with the following:

b. = Before. Ex: "b.1936" means that a surge occured during the 10 or 20 years before 1936, but not during the 5 years before 1936.

j.b. = Just before, Ex: j.b.1936 means that a surge occured during the few years before 1936

bt. = Between. Ex:"bt.1936-61" means that the maximum extension for the glacier occurred between these two dates.

Two years without symbol, Ex: 1969-71 means that the surge started in 1969 and lasted until 1971.

a. = Around Ex: a.1900 means that a surge occured in 1900 or few years around this date.

*Note:*When symbol noted for the maximum extension and a surge are exactly identical the maximum extension is due to the surge. If these symbol are not exactly identical the maximum extension and the noted surged are two independent events, even if the table gives the same date for both, which is possible when missing information about the precise date of the maximum extension.

¤ The surge affected the main basin.

* The surge is due to a tributary.

¤* The surge is due to the main outlet but didn't affected the entire basin.

Future surges with calving : It is obvious that to predict surges is not really possible. Nevertheless, in this column is proposed a list of two categories of glaciers which are able to surge in the near future. Glaciers in the list A, are thought to have a greatest probability of surge, and/or to give more calving than those in liste B. Glaciers were placed in the list by taking into account the estimate surge cycle, the lack of recent recorded surge and the lack of surge from important tributaries. For some glaciers in Nordaustlandet, the existence of an observed longitudinal profile at a higher altitude than a theoretic profile as define by Dowdeswell and Drewry (1989), is also used. Active valley glaciers with calving for which a small surge initiated by any small tributary may increase the calving rate, are also noted. In addition are mentioned three glacier fronts (the Jemelianovbreen and Spælbreen, the Negribreen and the Hinlopenbreen) which have surged recently but are always active and for which the survey may provide important information about glacier surges.

List A

S 6 Vasilievbreen. The glacier has a very large front and is continuously calving, in spite of a slow and permanent retreat for maybe more than one century. This glacier may calve numerous small icebergs in some years due to the surge of tributaries.

S 8 Hambergbreen. The two recorded surges both affected the main basin and indicate a probable surge cycle of about 70 years. This is very short for such a large glacier. This suggests that the Hambergbreen is a very active glacier. It is continuously calving, while the Skjoldfonna to the north has no recorded surge.

S 19 Beresnikovbreen, Arnesenbreen, Inglefieldbreen, Nordsysselbreen. The last surge from the Beresnikovbreen (and probably from the Inglefieldbreen) occurred before 1900. No surges have been recorded for the Nordsysselbreen.

S 22 Hayesbreen, Koenigsbreen, Heuglinsbreen. The Hayesbreen has a large area. Its last surge occurred 90 years ago and at the present its front is nearly grounded. There have been no surges recorded from the Koenigsbreen and the Heuglinbreen.

E 7 Stonebreen. The southern basin of the Stonebreen had its last surge around 1850, almost 150 years ago. The Stonebreen has a large area and during surges developed very large lobes into the sea.

H 12 Polarisbreen,Chydeniusbreen. The last surge from these glaciers occurred long ago, probably long before 1900. They are long valley glaciers with a common front and nearly grounded. They have fairly large areas, and an important part of these areas are situated at high altitude.

List B

S 14 Jemelianovbreen,Spælbreen. The Jemelianovbreen surged twice during 80 years. These surges affected the main basin. No surges have been recorded for the Spælbreen, which suggests that a surge could occurred in a near future. These glaciers are of major interest mainly because of good coverage by air photos, and because interesting information was gathered during the latest surging period. Further study of the flow and the ice mass in the upper basins of these glaciers will provide important information about surging behaviour.

S 15 Strongbreen, Perseibreen, Kvalbreen. The last recorded surge occurred here about 120 years ago and was due to the Strongbreen itself. At present, the retreat is of the same scale as that which occurred before the last surge. No surges have been recorded for the Perseibreen and Kvalbreen. But it is important also to keep in view that these glaciers have their accumulation area in very low altitudes.

S 20 Ulvebreen. This glacier has an important accumulation area. Its last surge occurred almost a century ago and no surge has been recorded for its southern tributary.

S 23 Negribreen. The last surge from this glacier (1935-36) can be considered as a recent surge and the Negribreen is still active and calving. Its tongue has a very weak slope which is one of the reasons why it is permanently calving. On other hand, no surges have been recorded for the lower tributaries, the Petermannbreen and the Gardebreen.

S 25 Sonklarbreen. Precise information is lacking on the date of the last surge of this glacier, though one may have occurred long before 1936, probably around 1900. The Sonklarbreen has a large area and is an active glacier which has been calving continually during its very slow retreat.

B 11 Besselbreen,Augnebreen. The maximum extension for these glaciers occurred around 1900. Since then the Besselbreen has been a tide-water glacier with a calving front.

H 4 Hochstetterbreen. The last surge of this glacier occurred around 1900. Presently the front position is retreating from the shore line.

H 10 Hinlopenbreen. The last surge is recent (1969-71), and one surge is recorded for the main low tributary (Oslobreen). Nevertheless, this glacier is still particularly interesting to survey because it is an active and continually calving valley glacier. There is good coverage by NP air photos. Firstly, measurement of the flow speed and of the calving rate during a surge can be conducted. Secondly, we believe that with these results and further study of the 1990 air photos and potential satellite images, the Hinlopenbreen should be one of the glaciers, best suited to improve the understanding of surging behaviour.

Note concerning glaciers from Nordaustlandet:

In this area past information is lacking, and it is difficult to estimate the real probability of future surges. Determination of possible future surges is mainly due to the characteristics of the present surfaces and comparison between observed and theorical longitudinal profile by Dowdeswell and Drewry (1989). Of course, a doubt may exist for glaciers which have not being surveyed by these authors. Nevertheless, the main point is that the glaciers mentioned here are all located on the eastern part of the island. An unknown element exist, the surge cycle which is probably very long.

N 20 Austfonna 7 and 6, and
N 21 Austfonna 5. For these glaciers, previous surges are estimated to have occurred very long ago, and observed profiles are characteristically above theorical profiles in the accumulation area.

N 22 Austfonna 4 and 3,
N 23 Worsleybreen,
N 24 Leigthbreen. These glaciers appear less candidates for a surge than the three mentioned above, but their last surges occurred long ago. The Leigthbreen apparently is formed of two different ice-streams. Comparison between theoretic and observed profiles indicate that for one ice-stream a surge is unlikeley. However the second ice-stream may surge in the near future.

N 29 Kvitøyøkul. Because the ice mass of the Kvitøyøkul is divided in two domes and in several ice-streams, a major surge is unlikely, but minor surges from one of these ice-streams are possible.

General comments

Are maximum extensions due to surges ?

This question is difficult to answer due to the lack of adequate information. However, all large glacial lobes such as the extensions of Bråsvellbreen, Negribreen, Hochstetterbreen, Hayesbreen and Hambergbreen correspond to surges. Based on the present knowledge of Svalbard glacial behaviour it seems reasonable to assume that all major lobe extensions into the sea are due to surges. Some surges could have occurred a long time ago, after which glaciers might have rebuilt a major ice mass due to climatic forcing and then reached a large extension before decreasing and possibly surging again. Theoretically if such late surges are due to tributaries, they might have reached their maximum extensions due to surges at a shorter distance into the sea than during their extensions caused by favourable climatic conditions. On the other hand, Lefauconnier and Hagen (1989), have shown that in West Spitsbergen, the maximum extension reached by alpine glaciers (potentialy without surges) during the Little Ice Age occurred at the end of the last and begining of the present centuries. The above mentioned list of surges from important outlets provides evidence for the contention that few tide-water glaciers could have reached their maximum extension without surges. Thus we conclude that the maximum extension of most if not all glaciers in East Svalbard, most likely has been due to surges.

In the Storfjord, all maximum extension mentioned in this report are probably related to surges, though some doubt exists concerning Stonebreen and Kong Johansbreen on Edgeøya. The positions of two wide lobes observed by Lamont which are believed to be similar to the present lobes may correspond to a large extension reached at the maximum of the Little Ice Age or due to a past surge. If these positions do, in fact, correspond to surges then this would indicate a surge rhythm of 100-150 years.

In the Hinlopenstretet, all outlets are believed to have reached their maximum due to surges, though some doubt exists for the calving fronts emitting from the three small fonna Vaigat, Valhall and Odinjøkul.

In Nordaustlandet, it has not be possible to determine which factors have been responsible for the maximum extensions of each small outlets in the Whalenbergfjord. However, all other outlets thus far studied emitting from the Austfonna are believed to have reached their maximum extension during a surge.

In conclusion, the interpretation of maximum extension as a surge extension in the present study of surge rythms of Svalbard glaciers is believed to provide accurate information.

What will be the scale of future surges ?

For most of the above glaciers, the maximum extension occurred during the last century or around 1900. More recent surge have resulted in lesser extensions. Such was the case for surges of e.g. Hambergbreen (maximum just before 1900, lesser surge between 1961 and 1970), Crollbreen, Davisbreen, Jemelianovbreen and Sonklarbreen.

Important exeption may exist for some of the largest glaciers whose maximum extensions, due to surges, occurred sixty years ago or less. Such is the case for Negribreen (surge and maximum extension in 1935-36), Bråsvellbreen (1936-38), Kong Johansbreen (around 1925-30) and the northern part of the Stonebreen (after 1938).

For other large glaciers, the maximum extension occurred around 1900 or before with no further surge. Such is the case for the Vasilievbreen (before 1874), Strongbreen (between 1870-76), The Hochstetterbreen (around 1900) and the stream denoted N 19 or Austfonna 8, in Nordaustlandet (before 1873). No information is available for other large outlets in Nordaustlandet.

The problem of the scale and the date of the last surge is related to surge rhythm. After a surge, glaciers with large area require a long time to rebuild an ice mass in the accumulation area of sufficient critical profile to trigger new surging behaviour. Due to climatic change, ice accumulation on these glaciers is less now than at the end of the last century. Summer ablation has increase mainly due to an increase in temperature during the period 1915-1920. The result has been a general retreat of glaciers fronts and decreasing ice mass during the last sixty years. The critical point at which time the glacier surges will then occur will be reached at a lower profile and with less ice mass than previously. Therefore large recent surges have to be followed by surges of smaller scale. Exceptions exist for large glaciers for which maximum extension due to surges have not yet occurred. This may be the case for some outlets of the Austfonna with the exceptions of the Bråsvellbreen and the Austfonna 8 (N19).

This phenomenon was taken in account when comprising the above list of glaciers able to surge and/or calve in the near future..

Complementary note on icebergs in the Hinlopenstretet.

The marine map 507 "Nordsvalbard", indicates that there is a threshold between Torellneset in Nordaustlandet and the Olav V land (see the map of the fig. 7). From Torellneset to Von Otterøyane, the sea depth is comprised between 10 and 30 m. Along the coast of the Olav V land, the map is not complete, but numerous islands exist, indicating a probable shallow water until Kapp Payer. The greatest icebergs calved to the west of this line, will be grounded there. Then they will be of smaller size when reaching Sørporten and then Erik Erksenstretet or Olgastretet. That means that large icebergs calved by possible surges of almost all glaciers noted here under the reference **H**, will be of reduced size when reaching Sørporten. Only the Hannebreen (H 1), Koriskabreen (H 2) and the unnamed (H 3) are not concerned by such limitation in the iceberg size. A doubt may subsist for the unnamed (H 8) and its following neighbouring glaciers, but this doubt is only due to the lack of precise information about the sea depth to the east and south of Vaigatøyane.

All the glaciers in Nordaustlandet from the Bragebreen (N 1) to the Mariebreen (N 15) are concerned by this limitation in the size of icebergs when reaching Sørporten.

Conclusion

In this study we have listed 87 glacier fronts which are calving or have been calving in the close past. But there are more than 118 independant ice-streams (except ice-streams from the Valhallfonna and Kvitøyøkulen). 55 surges have been recorded, 42 from main ice-streams and 13 from tributaries. Information about glacier surges started in the middle of the last century i.e. about 150 years ago. The information is not complete from the beginning of this period until the first aerial photographs in 1936. Since 1930 until today 23 surges occurred. A few glaciers had two surges during the observed period, as the Hambergbreen, Jemelianovbreen and Negribreen. The submarine moraines indicated two advances due to surges for other glaciers as Freemanbreen, Bråsvellbreen and Austfonna 8. Moreover, numerous glaciers might have had two surges during the period when considering that the maximum extension is due to a surge.

From these remarks, it may be concluded that, in the studied area surge cycles are difficult to determine, but also that a surge from any glacier might occur every 3, 4 or 5 years. Some of these surges, when due to a small tributary as for the tributary of the the Skimebreen which surged in 1970 (see in § S 12), will not give any significant calving. Some surge from tributaries will be followed by increasing activity at the front as for the surge of the Kvitingpasset which activated the front of the Vassilievbreen (see § S 5). At last, surges from main ice-streams of valley glaciers will give numerous icebergs with some of them of a large scale as for the Hinlopenbreen in 1969-71 (see § H 10).

Precise prediction of surge can not be done. Nevertheless, the above study allows to give a list of glaciers which are able to surge in the close future and/or to give calving. This list thus has to ve considered as a guide for more survey.

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Note Available informations in Backlund H. "Observation geologique du Spitsberg Central". Photo of the Negribreen, map from Billefjord to Negribreen and map across the West Spitsbergen. Map of the lateral moraine of the Strongbreen.
Maps of the East Spitsbergen:
I Feuille du nord
II Feuille du milieu
III Feuille du sud

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Fig. 2 Location of calving glaciers in East Svalbard.
Letters and numbers refer to the paragraphs in the text. Stars indicate recorded surges.