(or the opposite) by local hunters is needed. However, both maps by Kleinschmidt (1860) and Jensen (1889) give the impression that the glacier front in 1885 was still close to its Little Ice Age maximum extent. According to the information presented above, the glacier must have advanced in the first part of the 1800s, after which thinning and development of superficial moraines have occurred throughout the 1900s (Fig. 20).

It is deemed likely, therefore, that J.A.D. Jensen's reference to the advancing glacier passing a bird cliff around 1840 refers to the steep southern mountain slope, today situated 1–2 km behind the Little Ice Age maximum as determined from terminal moraines and a narrow trimline zone. It is suggested that the glacier front passed the bird cliff in the first part of the 1800s during an advance that reached the Little Ice Age maximum extent sometime at or after the middle of that century. The magnitude of the advance may have been between 1 and 2 km (the distance between the cliff and the Little Ice Age maximum extent; Fig. 19).

The first accurate evidence of the position of the glacier front was provided by Gripp after his visit to the glacier in 1930. From his description (Gripp 1932, 1975), the glacier seems to have been surrounded by Little Ice Age moraines and a trimline zone, and it must be concluded that the glacier front was in a stage of initial thinning. The distance from the glacier front to ruin group 8 in 1934 was estimated by Roussell to be 2 km, which is close to the present distance. The Puilassoq ruin site and Kangilinnguata Sermia are shown on a photograph from 1934 by Roussell (Roussell 1941, fig. 52, p. 76).

Aerial photographs from 1936, 1968 (Fig. 20A) and 1985 give the impression that the glacier front was thinning and becoming increasingly covered with surface moraine. The front was probably receding slightly. A Landsat image from 2009 indicates continuous thinning of the front with further development of the trimline zone, but development of dead ice makes it difficult to determine the exact recession of the glacier front. The same is seen on an ASTER image from 2007 (Fig. 20B).

Comparisons with regional glacier fluctuations

The description of the five outlets from the Inland Ice that are found in the Kangersuneq area shows the great diversity in response to past climate changes. In order to discern a possible pattern in the geographical distribution of these responses, it was necessary to look at changes of the outlets from a larger geographical region of the western slope of the Inland Ice. Preliminary investigations of calving glaciers in south-western Greenland were made by Weidick (1994a, b) and of the south-western slope of the ice sheet in general, based on aerial photographs from around 1950 and 1985 (Weidick 1991a, b). It appears that thinning and recession since the Little Ice Age are connected with piedmont-like outlets spreading over extensive lowland areas such as the Qassimiut lobe (Podlech 2004) and Frederikshåb Isblink (described here) in South-West Greenland with relatively small frontal changes, or with large ice streams such as Kangiata Nunaata Sermia and Jakobshavn Isbræ (Sermeq Kujalleq) in West Greenland that show large frontal changes (Fig. 21). Fluctuations of the ice margin are also recorded in other parts of the ice sheet, but the amplitudes are small, and hence it is difficult to identify and date the former changes. However, it appears that a small but widespread advance was characteristic for outlets and marginal parts from around 1950 to 1985. At most localities, the margin only advanced up to a maximum of a few hundred metres during this period. The other outlets from the ice-sheet margin in the Godthåbsfjord region are described below, beginning from the south.

South of Kangersuneq to Frederikshåb Isblink

The outlets in this region are Frederikshåb Isblink, Nakkaasorsuaq in Allumersat fjord (Bjørnesund), Sermeq glacier, Isortuarsuup Sermia, 1CG14004 and Kangaasarsuup Sermia (Fig. 2). Un-named outlets are described using their inventory code numbers according to Weidick *et al.* (1992).

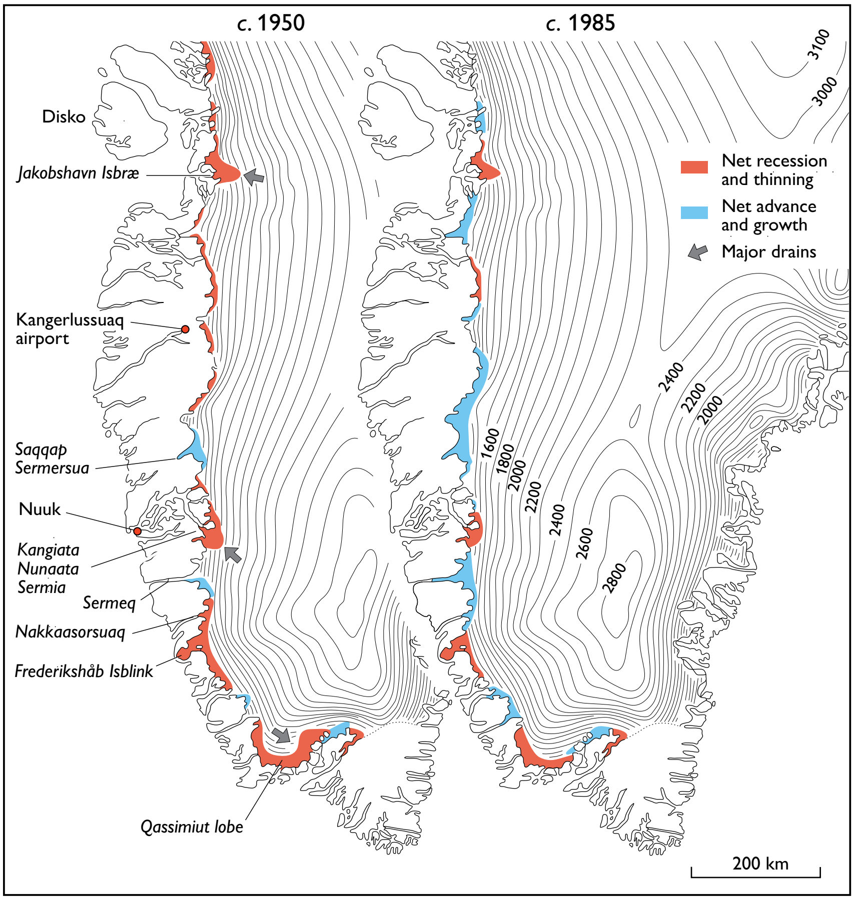

Fig. 21. Maps of south-western Greenland with ice-sheet contours from Bindschadler *et al.* (1989). The coloured zones show recession or growth in *c.* 1950 and *c.* 1985 (Weidick 1991a, fig. 1, p. 40). The grey arrows show the major calf-ice producing outlets (Jakobshavn Isbræ, Kangiata Nunaata Sermia and Eqalorutsit Killiit Sermiat). The latter is an outlet from the eastern flank of the Qassimiut lobe.

Frederikshåb Isblink

Frederikshåb Isblink is a large, land-based outlet from the Inland Ice, with a circular piedmont lobe (definition by Armstrong *et al.* 1973). It has a frontal diameter of *c.* 25 km and is separated from Davis Strait by a 5–10 km wide alluvial plain (Fig. 22).

This large outlet attracted early attention, and was described by several travellers.

It was described in the 1700s by Hans Egede (1741, 1925), Erich Larssøn (1942), Poul Jochumsen Moltzou (1935), Lars Dalager (1915) and Egil Thorhallesen (1914). However, these descriptions are often vague, and it is difficult to identify the described localities.

This is also the case for descriptions by O. Fabricius (1788). Fabricius was a Danish priest, zoologist and linguist who lived in Paamiut just south of Frederikshåb Isblink from 1768 to 1773. He gave the first detailed description of the margin of the Inland Ice and discussed the origin of icebergs (Fabricius 1788, pp. 69–70): *The ice sheet is a most peculiar natural phenomenon, greatly exceeding the glaciers known in other countries, since it reaches from one end of the country to the other and conceals the entire interior part of the land with permanent ice, so that only some mountaintops protrude here and there, black and without ice cover. When ascending one of the highest mountains on the ice-free land near the coast but at the same time close to the ice sheet, one is faced with a frightful sight; however, one becomes eager to learn more about it.*

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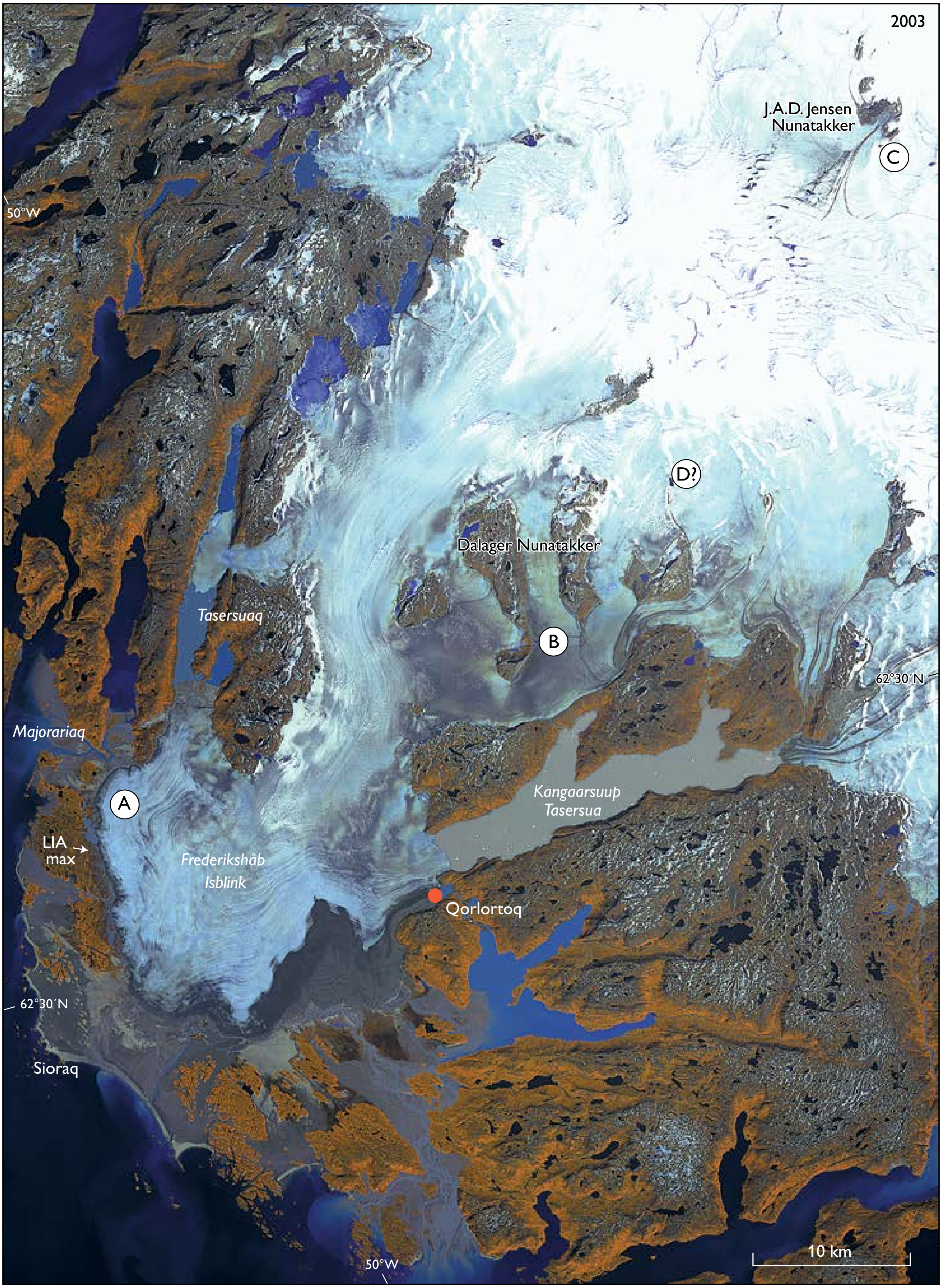
Fig. 22. Satellite image of Frederikshåb Isblink, ASTER pseudocolour mosaic from 1 July 2003. The altitude of the glacier north of Dalager Nunatakker is *c.* 1000 m a.s.l. The entire outlet is surrounded by a clear trimline zone indicating a general thinning of the glacier since the Little Ice Age maximum (**LIA max**), but the frontal recession, even near sea level, is only a few kilometres. A marked cover of superficial moraines has formed around the southern margin. The red dot shows the location of the studies conducted at Qorlortoq by Pitman (1973). **A**, **B**, **C** and **D?** refer to areas mapped by A. Kornerup in 1878 (see Fig. 23).


2003
J.A.D. Jensen Nunatakker
C
50°W
D?
Dalager Nunatakker
Tasersuaq
B
62°30´N
Majorariaq
A
Kangaarsuup Tasersua
LIA max
Frederikshåb Isblink
Qorlortoq
62°30´N
Sioraq
50°W
10 km

I believe even a superficial person will here be put into a state of profound reflection. As far as the eye can see, to the north, south or east, nothing but a sparkling plain of ice is seen. It deserves the name of an ice sea, because the ice-covered areas are situated lower than the nearest mountains in the ice-free land. This ice expands year by year more and more, growing both in height, and in extent, and hence has covered most of the land.

Where it meets high mountains it must stop until it grows over them, so it without hindrance can continue. It has been attempted to erect a stake on the bare land, some distance from the ice, and next year the stake was taken by the ice. So fast is its growth that Greenlanders speak about localities where their parents hunted reindeer, and which are now completely ice covered. Personally, I have seen trails that lead up to the inner part of the land; trails that have been made earlier but which now end in the ice, confirming the account of the Greenlanders. The ice sheet advances in particular in the valleys and where these reach the sea or the heads of fjords; here it advances so much that it forms large sheets of ice on the water. (Authors' translation.)

Fabricius continued with a detailed description of glacier surfaces, crevasses and meltwater draining into crevasses. He also described glacier erosion, deposition of till and calving. From his detailed description it is clear that he had a thorough knowledge of the glaciers and the margin of the ice sheet in the area south of Frederikshåb Isblink, but it is difficult to position his described localities. It is clear from his description, however, that the ice margin was generally advancing in the latter part of the 1700s in this region.

K.L. Giesecke visited the area in 1809 (Giesecke 1910), A. Kornerup in 1878 (Kornerup 1879), N.O. Holst in 1880 (Holst 1886) and J.C.D. Bloch in 1890 (Bloch 1892). From this period, the descriptions by Kornerup and Bloch are particularly interesting for the many details they provide about the ice and the landscape.

An example of the results of the detailed investigations in 1878 is shown here (Fig. 23). The map is based on surveys of selected areas of Frederikshåb Isblink by Kornerup (Kornerup 1879, pp. 132–133). It can be compared with the satellite image from 2003 (Fig. 22), and with an aerial photograph of J.A.D. Jensen Nunatakker from 1985 (Fig. 24). The rate of recession of the margin of Frederikshåb Isblink during this 125 year period has varied. In 1878, in the western parts of Frederikshåb Isblink, the glacier front was located just behind the moraines that mark the Little Ice Age maximum (Fig. 23; Kornerup 1878); by 2003 the margin had receded 1–2 km. At Dalager Nunatakker, a thinning is seen at the lower parts of the nunataks alongside some deformation of the median moraines, shown on Kornerup's map. Little change is seen on J.A.D. Jensen Nunatakker although some development of trimline zones is apparent. On the 1985 aerial photograph, grey snow-free areas of exposed glacier ice are seen at *c.* 1300 m a.s.l., south-west of the nunataks, indicating that the nunataks are situated close to the snow line.

Based on his visit in 1890, Bloch described the western frontal, alluvial plain as a clay plain. Furthermore Bloch (1892, pp. 150–151) reported the presence of wide river beds testifying to high summer discharge from the ice (the expedition visited the locality at the end of May) and thick vegetation cover with large willow bushes that extended up to the moraine in front of the ice margin proper, indicating that it had not receded for a long time period.

Bloch (1892) reported a single main end-moraine, which was situated close to the margin of the ice. At a single locality, two moraines were recognised, spaced about 60 feet (*c.* 19 m) apart; the outer moraine was old, however, and already partly overgrown. Locally, the ice margin was located *c.* 30 feet (9 m) behind the main moraine, the dimensions of which varied a great deal. At many localities, the rivers had breached the moraine. The largest moraine was 20 feet (6 m) high and 10 feet (3 m) wide; it consisted of clayey gravel with large and small rounded clasts.

The margin of the Inland Ice was described by Bloch (1892) as a *smooth, descending plain*; these notes are followed by a short description of the ice. Both Kornerup's and Bloch's descriptions of the frontal parts of Frederikshåb Isblink, based on visits in 1878 and 1890, indicate a position close to the maximum for the Little Ice Age. The oldest moraine described by Bloch may have formed in the 1700s.

In the following century, a map was drawn by K. Gripp and S. Hansen using terrestrial photogrammetry based

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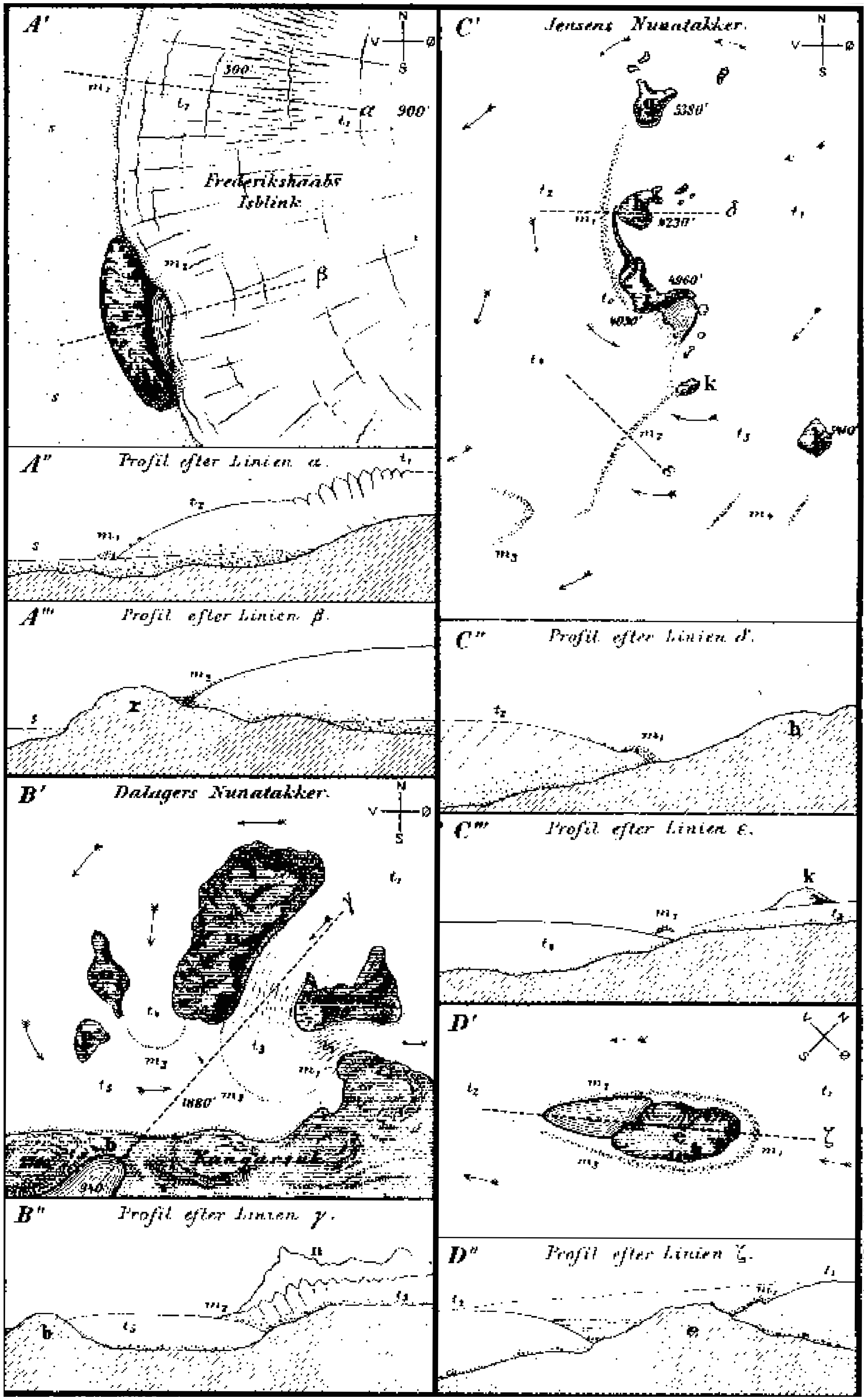
Fig. 23. Detailed maps of areas in the Frederikshåb Isblink area (see Fig. 22), surveyed by A. Kornerup in 1878 (Kornerup 1879). **A**: front of Frederikshåb Isblink. **B**: Dalager Nunatakker. **C**: J.A.D. Jensen Nunatakker. **D**: probably a small nunatak situated about 8 km east of the easternmost of Dalager Nunatakker, located as **e** on Kornerup's original map (Kornerup 1879, map sheet C).



A'
Frederikshaabs Isblink
A"
Profil efter Linien α.
A'''
Profil efter Linien β.
B'
Dalagers Nunatakker.
1880'
Kangarsuk
B"
Profil efter Linien γ.
C'
Jensens Nunatakker.
5380'
4230'
4960'
4030'
C"
Profil efter Linien δ.
C'''
Profil efter Linien ε.
D'
D"
Profil efter Linien ζ.

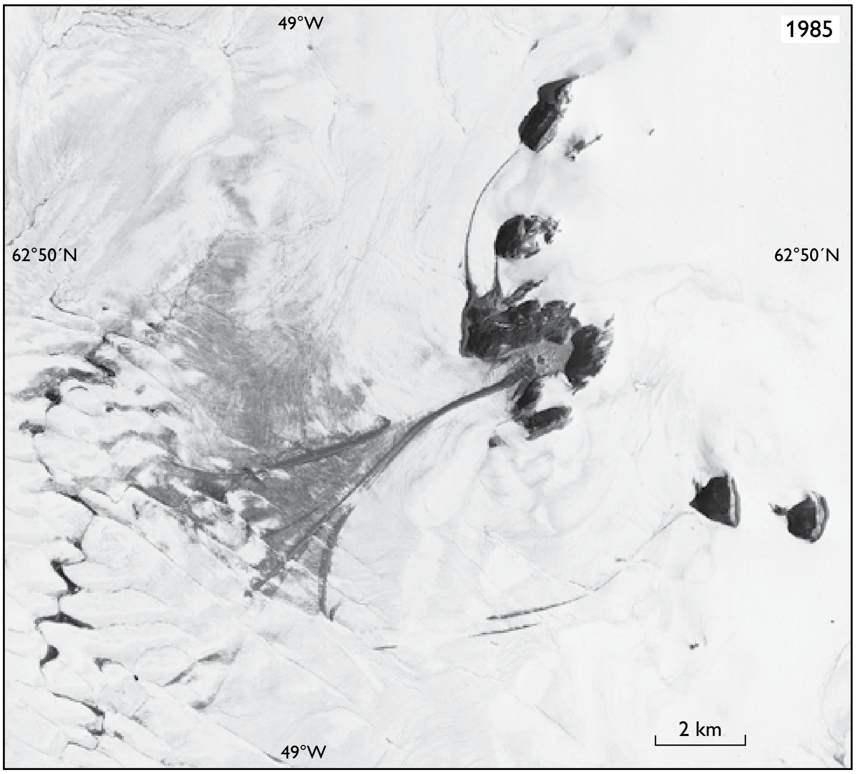


Fig. 24. J.A.D. Jensen Nunatakker, 19 July 1985, Geodetic Institute, route 886N, no. 1672. When compared to Fig. 23C it is seen that only minor changes have occurred since 1878, although a narrow trimline zone seen locally indicates a lowering of the Inland Ice surface in the region. Dark areas on the Inland Ice surface south-west of the nunataks indicate sporadic areas of snow-free glacier ice and the proximity of the snow line at this altitude on the Inland Ice surface (*c.* 1300 m a.s.l.). The elevation of the peaks of the nunataks in this area varies from 1440 to 1680 m a.s.l. according to Geodetic Institute (1974).

on photographs taken in 1930. The unpublished map covers part of the glacier front to the Davis Strait on a scale of 1:10 000 and with a 10 m contour interval. Aerial photographs taken between the 1930s and 1985 show a gradual thinning of the large lobe and photographs from 1985 show the trimline zone to be *c.* 1 km wide.

At the northern part of the front of Frederikshåb Isblink, near the Majorariaq river, the total recession from the outer moraines of the trimline zone (the Little Ice Age maximum) to the position in 2010 can be estimated to be *c.* 3 km whereas the total recession of the western part of the front near Sioraq is scarcely 1–2 km for the same time period. Farther south at Qorlortoq, at a profile of Pitman (1973), the ice front shows a total recession of *c.* 500 m from the Little Ice Age maximum to 2010.

Frederikshåb Isblink is a large glacier, and it will be necessary to conduct new field investigations in order to locate and re-measure the localities described, before

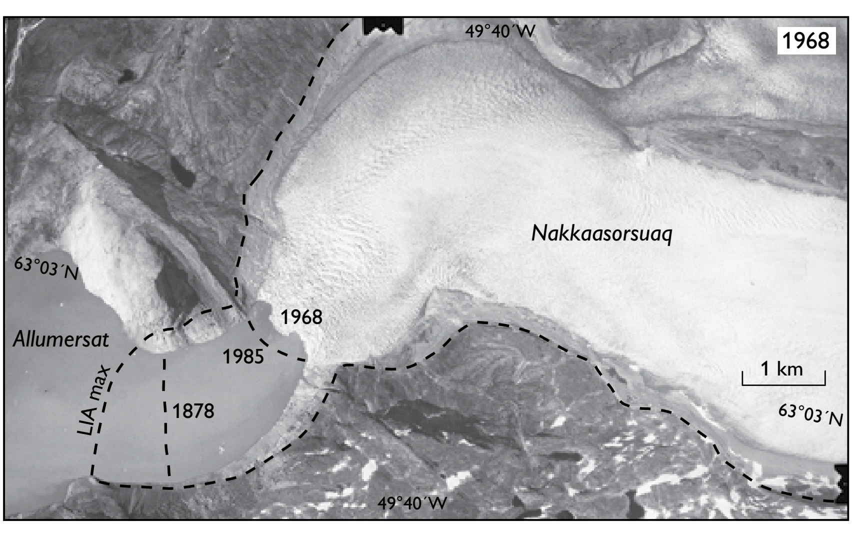


Fig. 25. Nakkaasorsuaq outlet in Allumersat (Bjørnesund). The approximate frontal positions during the Little Ice Age maximum (**LIA max**), in 1878 and in 1985 are shown (Geodetic Institute, route 281M, no. 434, 13 August 1968). The position in 2010 was the same as in 1968.

a comprehensive evaluation of the changes of the entire glacier can be made. Pitman (1973) carried out work on the glacial history of Frederikshåb Isblink near the Qorlortoq locality, at 62°29.5′N, 49°47′W, south-west of the large ice-dammed lake Kangaarsuup Tasersua. Ages were determined using lichenometry, and the Little Ice Age maximum was dated to 1832. Between the Little Ice Age maximum and *c.* 1950, the glacier has receded *c.* 400 m. Later aerial photographs from 1964 (Geodetic Institute, route 272V, no. 100, 2 July) and 1985 (Geodetic Institute, route 886L, no. 665, 9 July) and satellite images from the first decade of the 2000s show little change in the frontal position of the glacier. This is presumably due to the strong development of surface moraine cover over the southern part of Frederikshåb Isblink, which has led to large areas of dead ice.

Nakkaasorsuaq

The Nakkaasorsuaq glacier in Allumersat fjord at 63° 03′N, 49°42′W is a tidal, calving glacier, but with limited calf-ice production. The front is *c.* 800 m wide and is surrounded by a trimline zone that extends *c.* 2.5 km out beyond the present front (Fig. 25).

Early descriptions of the area date back to 1801 (Mørch 1942), but give no details of the geography of the fjord, and only state that it is closed by ice (Weidick 1959). Giesecke visited the fjord in 1809, but he did not reach the head.

Mapping of the interior of Allumersat started with the collection of map sketches made by local hunters (Rink's map collection in the Royal Library, Copenhagen), but it is not possible to locate the glacier front from this source (the best example is 'Peter's map', mentioned by Weidick (1959)).

The first description and more detailed mapping of the glacier and the surrounding area took place in 1878 (Jensen 1879, pp. 35–38 and his enclosed map). During the expedition, Jensen visited the mountain of Qaqqatsiaq *c.* 10 km north of the glacier on 12–14 June. After the descent, the expedition made soundings in the fjord at a distance of 0.25 mile from the glacier front and found a maximum depth of 212 fathoms. Assuming Danish units were used, it means that the depth was *c.* 400 m at *c.* 2 km from the glacier front (1 Danish fathom = 1.8331 m, 1 Danish mile = 7.5 km). The position of the glacier front in 1878 was *c.* 800 m behind the Little Ice Age maximum (Fig. 25). This estimate is supported by a water colour made by A. Kornerup (Fig. 26A) during the expedition, published by Weidick (1975a) together with a later photograph from the same site, taken in 1936 by J. Helk (Fig. 26B). The latter photograph is the only information for the period following Jensen's expedition in 1878. It shows the front of the Nakkaasorsuaq glacier in a retracted position, *c.* 2 km from the Little Ice Age maximum.

Aerial photographs from the early 1940s, 17 June 1948, 13 August 1968 and 20 July 1985 all show that the glacier front was located at a narrow part of the fjord. During this period, the glacier front had a surface falling steeply over a distance of *c.* 3 km from 500 m down to sea level. A Landsat image from 2010 shows the position of the glacier front close to the position in 1968 (Fig. 25).

Sermeq in Sermilik icefjord

The Sermeq glacier is 65–70 km long and 3.5–5 km wide. On its way to Sermilik icefjord the glacier receives several tributaries from local ice caps in the surrounding alpine highland (Fig. 27). A river plain and tidal flat, *c.* 5 km long, separate the glacier front from the fjord (Fig. 28). The present position of the glacier front is 63°32′N, 50°45′W. The middle and upper part of the outlet is seen in Fig. 29.

The glacier is surrounded by very fresh moraines around its front, so the Little Ice Age maximum is close to the present front position. About 6 km east of the present front, the glacier sends a branch northwards towards Alanngorlia fjord. This branch is also separated from the fjord by a 1–2 km long river plain/tidal flat.

The sources from before the middle of the 1800s provide little information about the position of the front of the Sermeq glacier. After investigations of the fjord Sermilik and its northern branch Alanngorlia in 1878, Jensen wrote (1879, pp. 31–32): *The margin of the Inland Ice has lately advanced in these fjords and according to information by training college teacher Kleinschmidt, boats could, as late as at the beginning of this century, pass through the valley that is found east of the mountain Iviangiusat, but this strait is now completely filled with the Inland Ice.* (Authors' translation.) If this is true, the front may have advanced at least 7 km since the beginning of the 1800s, supposing that the mentioned passage through Alanngorlia first was blocked by proglacial sedimentation before the glacier passed and blocked this

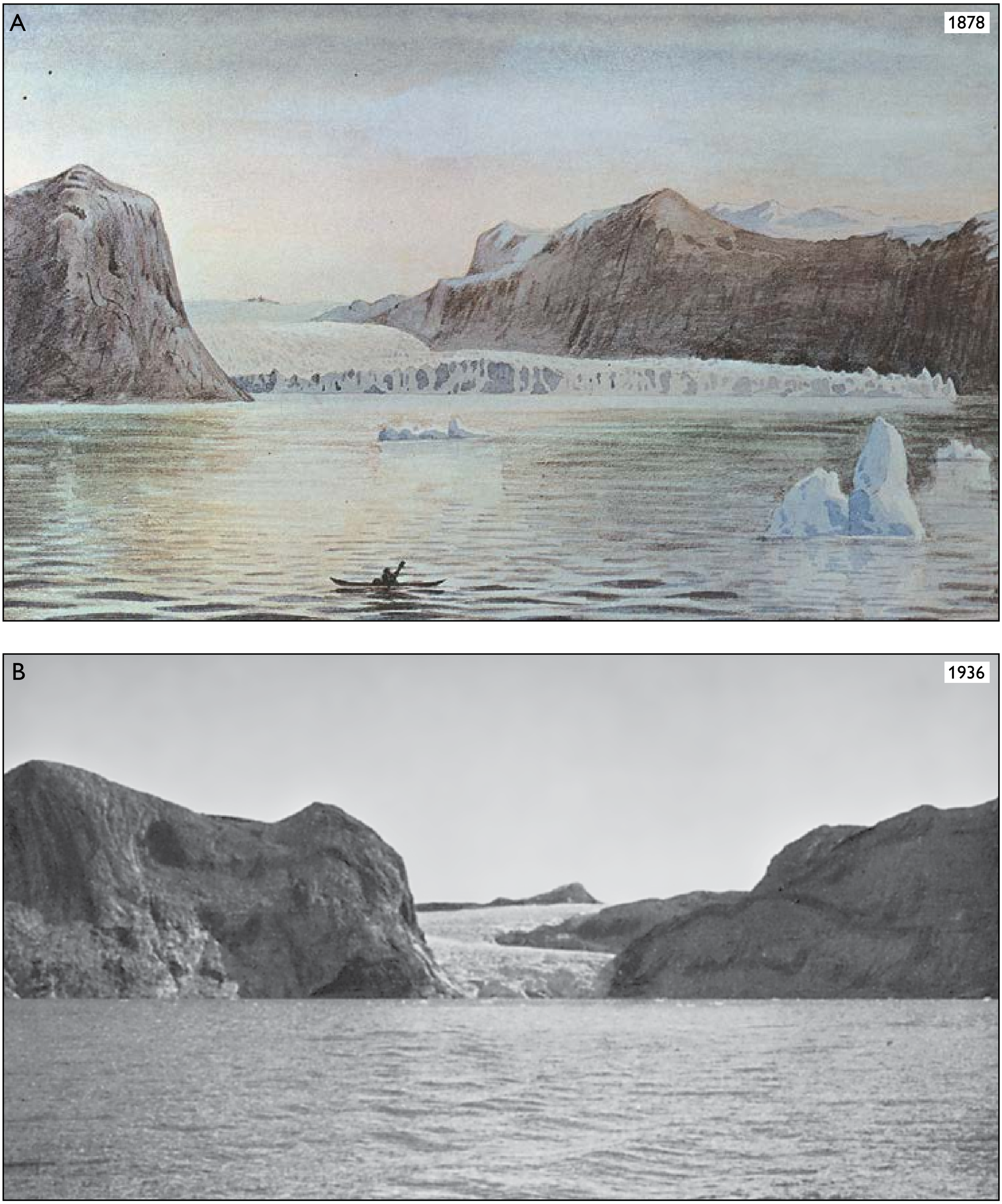


Fig. 26. Nakkaasorsuaq in Bjørnesund. **A**: The watercolour of the glacier front was painted by A. Kornerup on 15 June 1878 (Kornerup 1879, 1978). **B**: The glacier front photographed by J. Helk on 26 July 1936. Copyright Arktisk Institut, Copenhagen. J. Helk was head of the photogrammetrical section at the Geodetic Institute in Copenhagen and subsequently director of Arktisk Institut in Copenhagen.

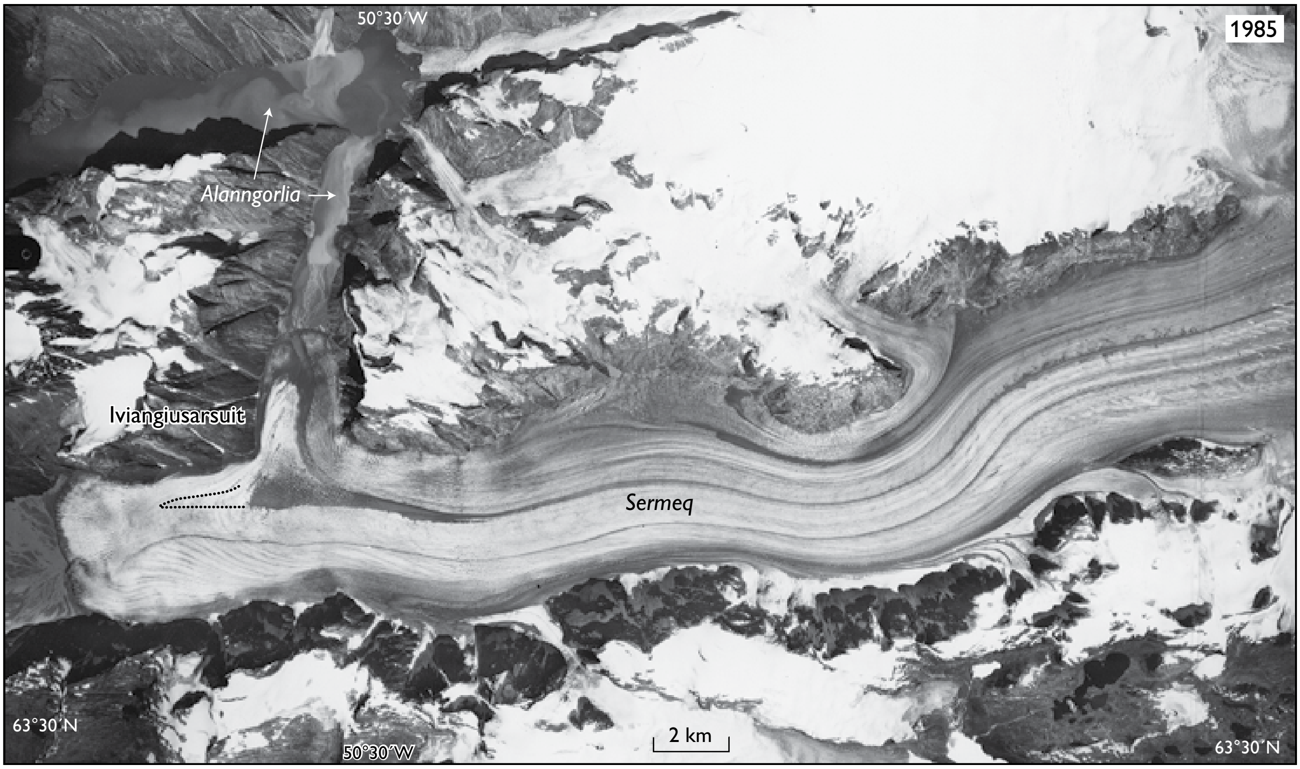


Fig. 27. Sermeq glacier, aerial photograph from 20 July 1985, Geodetic Institute, route 886K no. 1843. Dotted line: deformation of the median moraine according to a satellite image from 2010. Meltwater from the glacier drains west (left) to the Sermilik fjord.

passage. Today, the place name 'Iviangiusat' is changed to Iviangiusarsuit.

With respect to early maps of the area, we note that the Alanngorlia–Sermilik connection was blocked by ice on maps by Kleinschmidt from 1855 and by B. Peters from 1859 (B. Peters in the Kleinschmidt map collection at the Royal Library in Copenhagen (Weidick 1959, fig. 42)). The first map by Jensen (1889) was corrected in later versions (presumably after data acquired during later expeditions to West Greenland) so that the glacier front of Sermeq is shown in a position closer to the present one and with a distance to the Alanngorlia branch of *c.* 6–8 km. The northern part of the front of Sermeq is located at a 'bay' just south of a large local glacier coming from Iviangiusarsuit (Fig. 28).

The following information on the position of the glacier front was given by K. Gripp (1975) from investigations in 1930. Gripp noted that moraines were formed at the active ice margin. A photograph of the glacier front shows the entire front and its surroundings, seen from the north at an elevation of 385 m a.s.l. The estimated position of the front in 1930 is shown on an aerial photograph from 1968 (Fig. 28B). If it is correct that the position of the glacier front at the beginning of the 1800s allowed boats to pass from Alanngorlia to Sermilik fjord south-west around Iviangiusarsuit, the front of the Sermeq glacier may have had a position at least 5.5 km behind the position in 1930 and *c.* 6 km behind that in 1968 (Figs 27, 28). The following advance, given by the estimated positions of the glacier front in 1985 and 2010, is shown in Fig. 28.

The estimated advance from *c.* 1800 to 1930 was *c.* 6 km (?), corresponding to 46 m per year. From 1930 to 1968 it advanced 18 m per year (700 m in 38 years) and from 1968 to 1985 (Figs 27, 28B), it advanced 12 m per year (200 m in 17 years). Finally, from 1985 to 2010 (Landsat image) the northern flank of the glacier front may have advanced *c.* 100 m, corresponding to *c.* 4 m per year.

Isortuarsuup Sermia

Isortuarsuup Sermia at 63°50´N, 50°00´W, is an over 20 km long, *c.* 5 km wide outlet that calves in the Isortuarsuup Tasia lake at *c.* 450 m a.s.l. (Fig. 29). The calf-ice

Fig. 28. **A**: The front of Sermeq glacier seen from the north-west from an altitude of 385 m a.s.l. Photograph by K. Gripp, 11 September 1930, published by Gripp (1975, plate 1, fig. 2). According to Gripp, most of the drainage from the ice front appeared to occur via a subglacial tunnel located below the large median moraine at the centre line of the glacier front. The median moraine can also be seen on the aerial photograph of the front from 1968, shown in Fig. 28B. **B**: Sermeq glacier. Aerial photograph from 14 August 1968, Geodetic Institute, route 281H, no. 263. The estimated positions of the glacier front in 1930 (see Fig. 28A), 1985 and 2010 are shown on the photograph. **LIA max**: Little Ice Age maximum.

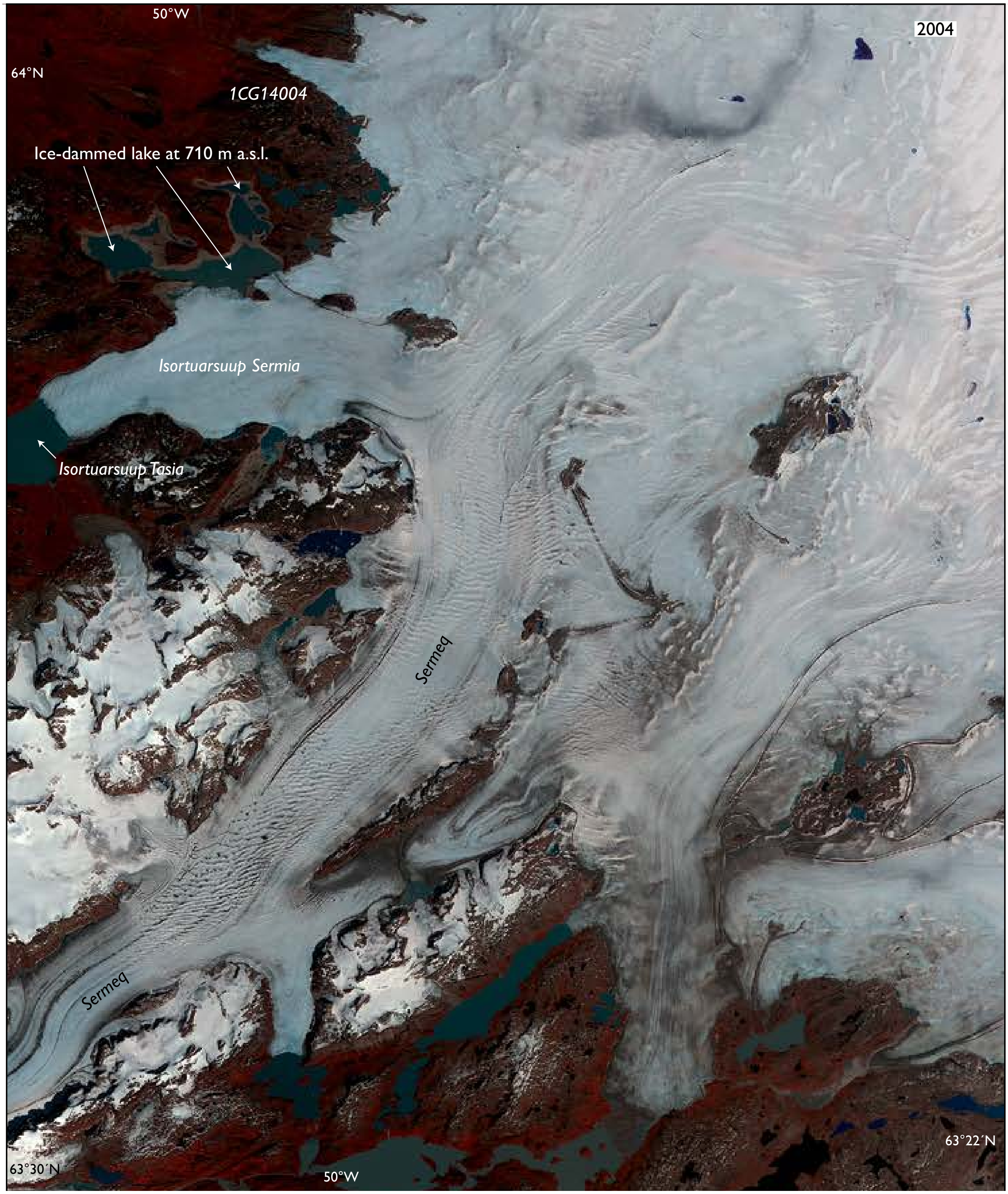


Fig. 29. ASTER image of Isortuarsuup Sermia from 4 August, 2004 covering a large part of Sermeq (Fig. 27) and the un-named glacier 1CG14004 (Fig. 31). The area adjacent to the margin of the Inland Ice is barren, partly alpine with local glaciers confluent with the marginal part of the Inland Ice, which might influence the response character of the ice-sheet margin. The position of the glacier front is close to the positions in 1985 and 2010. Between 1938 and 1987 the ice-dammed lake at 710 m a.s.l. has drained at regular intervals (every 8th or 9th year) via Isortuarsuup Sermia. This periodicity is thought to have also prevailed since 1987 with inferred draining events in 1993 and 2002 (see Fig. 30).

production appears to be small and the maximum height of the glacier front is about 40 m above the lake level.

Details of the glacier and its surrounding area are best seen on an aerial photograph from 1968 (Geodetic Institute, route 281O, no. 317, 13 August). The glacier front was surrounded by a 100–300 m wide trimline zone indicating recent thinning of about 50 m near the front. The trimline zone pinches out at elevations above 750 m a.s.l. The trimline zone indicates a Little Ice Age maximum about 400 m more westerly than seen in 1968. Comparisons with aerial photographs from 1937(?) and 1985 reveal only a slight change in the position of the front and the same is seen on a Landsat image from 2010.

'Lake 710 m' is a large ice-dammed lake situated on the north side of Isortuarsuup Sermia, 5–10 km behind (east of) the front. The glacier and the ice-dammed lake are situated in a region that received little attention before the 1930s. Due to the need for hydropower for Nuuk (Kangerluarsunnguaq or Buksefjorden hydropower plant), hydrological and glaciological investigations have been carried out in order to calculate the future hydropower potential (Braithwaite 1989).

As illustrated by Fig. 29, the margin of the Inland Ice around Isortuarsuup Sermia is surrounded by alpine uplands and highlands covered with large local glaciers. The determination of the position of the main glacier front must therefore to some degree be controlled by the mass balance and dynamics of the contributing local glaciers. The position of the front of Isortuarsuup Sermia varied little from 1950 to 2004. The stability of the frontal position and the thickness of the glacier are also reflected in the regularity of the draining periods of the ice-dammed lake at 710 m. Between 1938 and 1987, draining occurred at intervals of 8–9 years (Thomsen *et al.* 1992; Fig. 30). The ASTER image from 2004 (Fig. 29) shows a lake in the process of being filled up and it is possible that the lake drained in 1992 and 2001. In 2011, the lake level was again at a maximum (Fig. 30).

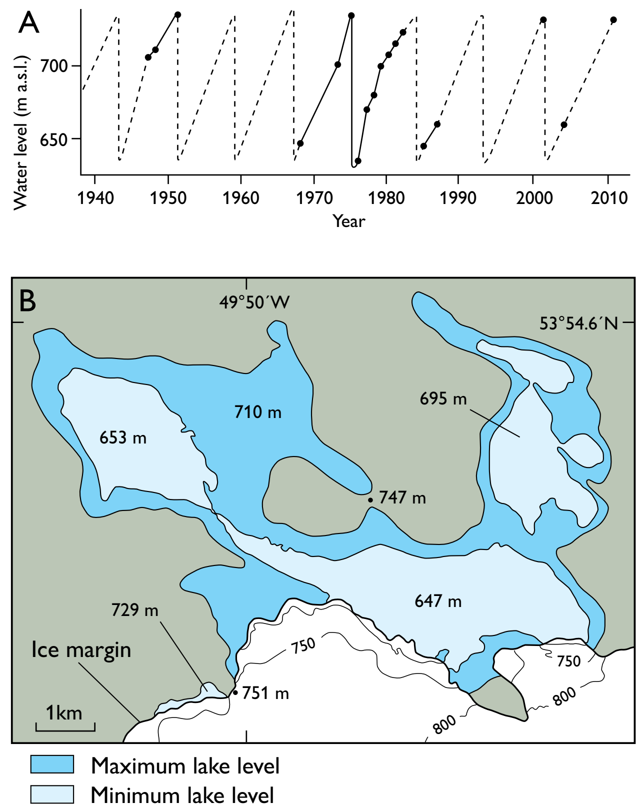


Fig. 30. Ice-dammed lake at 710 m a.s.l. (see Fig. 29) that is periodically drained via Isortuarsuup Sermia. The data for the period 1937–1987 are from Thomsen *et al.* (1992), and the continuation is based on satellite images. **A**: Estimated lake levels and draining events. **B**: Map of the ice-dammed lake at 710 m a.s.l. Redrawn from Thomsen *et al.* (1992, figs 5.3 and 5.4, pp. 27 and 29).

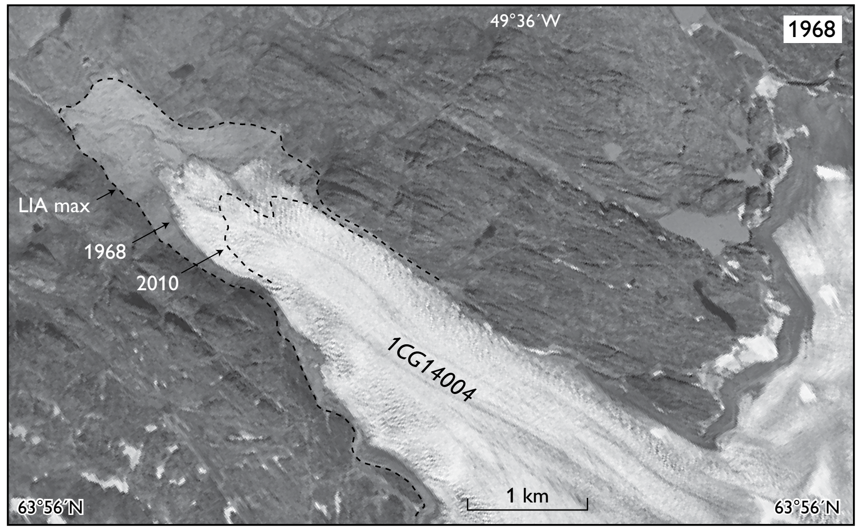
1CG14004

1CG14004 is a small, *c*.6 km long and *c.* 1 km wide, unnamed land-based outlet from the Inland Ice, situated at 63°58′N, 49°42′W (Figs 29, 31). The present glacier front is situated *c.* 1500 m behind moraines that mark the Little Ice Age maximum. The age of the moraines is unknown, but we suggest that they formed in the mid- or late part of the 1800s, based on dating of the Little Ice Age maximum of other smaller land-based glaciers in the region. The first information about the frontal position of 1CG14004 comes from aerial photographs from the 1930s (not very detailed) and from 1968 and 1985. It appears that in 1968 the front was situated *c.* 900 m behind the Little Ice Age maximum. The recession continued up to 2010 when the glacier front was situated about 1500 m behind the Little Ice Age maximum.

Kangaasarsuup Sermia

Kangaasarsuup Sermia is a land-based outlet with a length over 20 km from its beginning at the Inland Ice to the front at 64°06′N, 49°59′W. At the front and along its flanks, the glacier is surrounded by a wide trimline zone, with a length of 2–3 km at the front (Fig. 32).

Fig. 31. Aerial photograph from 1968 of outlet glacier 1CG14004 from the Inland Ice (Geodetic Institute, route 281S, no. 79, 13 August). The glacier code number is according to Weidick *et al.* (1992). The approximate glacier extent during the Little Ice Age maximum (**LIA max**) and the estimated position of the glacier front in 2010 (from a satellite image) are shown.



Historical knowledge about this outlet is sparse. The glacier is not shown on the first map of the area by J.A.D. Jensen. Subsequent investigations by the end of the 1800s formed the foundation for the map by Amdrup *et al.* (1921; 1:1 000 000). Descriptions of Norse ruin groups no. 54 (Nipaatsoq, *c.* 6 km west of the present glacier front) and no. 55 (Kangaarsarsuk, at the north-western end of lake Isortuarsuk, 3.5 km south of the glacier front) do not include any information concerning the glacier (Jensen 1889, p. 117; Bruun 1917, p. 102).

The first sketch map showing details of the glacier is probably that published by Roussell (1941, p. 14, fig. 6). A set of aerial photographs from 1936 (which formed the basis for Roussell's sketch map) shows the glacier front surrounded by a trimline zone (e.g. Geodetic Institute, route 768C, no. 25297) and on the aerial photographs the glacier front is situated *c.* 1.3 km behind the Little Ice Age maximum as defined by the outer limit of the trimline zone. A later aerial photograph from 13 August 1968 (Fig. 32) shows the front situated *c.* 3 km from the Little Ice Age maximum.

Roussell (1941, p. 16) mentioned that according to Thorhallesen, the eastern arm of Ameralik (possibly Naajat Kuuat, Fig. 10, loc. 9) reached a lake that was covered by an advancing glacier. It is unlikely that this lake was Isortuarsuk (Fig. 32), and it is also unlikely that the glacier was Kangaasarsuup Sermia. We consider it more likely that the lake was Isvand, which was covered by the western flank of Kangiata Nunaata Sermia in the 1700s (Fig. 9, see earlier description).

E. Knuth (1944, pp. 94–109) provided a review of the knowledge of the topography of the interior parts of the Nuup Kangerlua region, based on his own and Roussell's archaeological investigations in the early 1930s, as well as on aerial photographs from 1936. Knuth's discussion included the ruin group 'Kangârssârssuk'. According to Knuth, local people told him that the latter place name should be 'Kangârssârssuaq' (Knuth 1944, pp. 104–109). Knuth included an aerial photograph of Kangaasarsuup Sermia (p. 99) and provided a short description of the frontal parts of the glacier, which he called a 'dead glacier' (p. 104) after crossing it.

Landsat and ASTER images from 2009 and 2010 record a continuation of the recession, with the front of the glacier situated *c.* 3.4 km behind the Little Ice Age maximum in 2010. The trimline zone looks fresh and sterile, but possible correlation with the development around Isvand north of the Kangaasarsuup Sermia may imply a greater age (1700?) for the formation of the outermost part of the trimline zone.

North of Kangersuneq to Saqqap Sermersua

A wide coastal area with lowlands and uplands and numerous lakes is found between Kangilinnguata Sermia in the south and Saqqap Sermersua in the north (Fig. 2). The ice-free coastland reaches elevations of around 1200 m a.s.l. near the margin of the Inland Ice. The *c.* 50 km long margin of the Inland Ice is undulating, with a number of lobes, but without proper outlets from the ice sheet. Some parts of the ice margin terminate in ice-

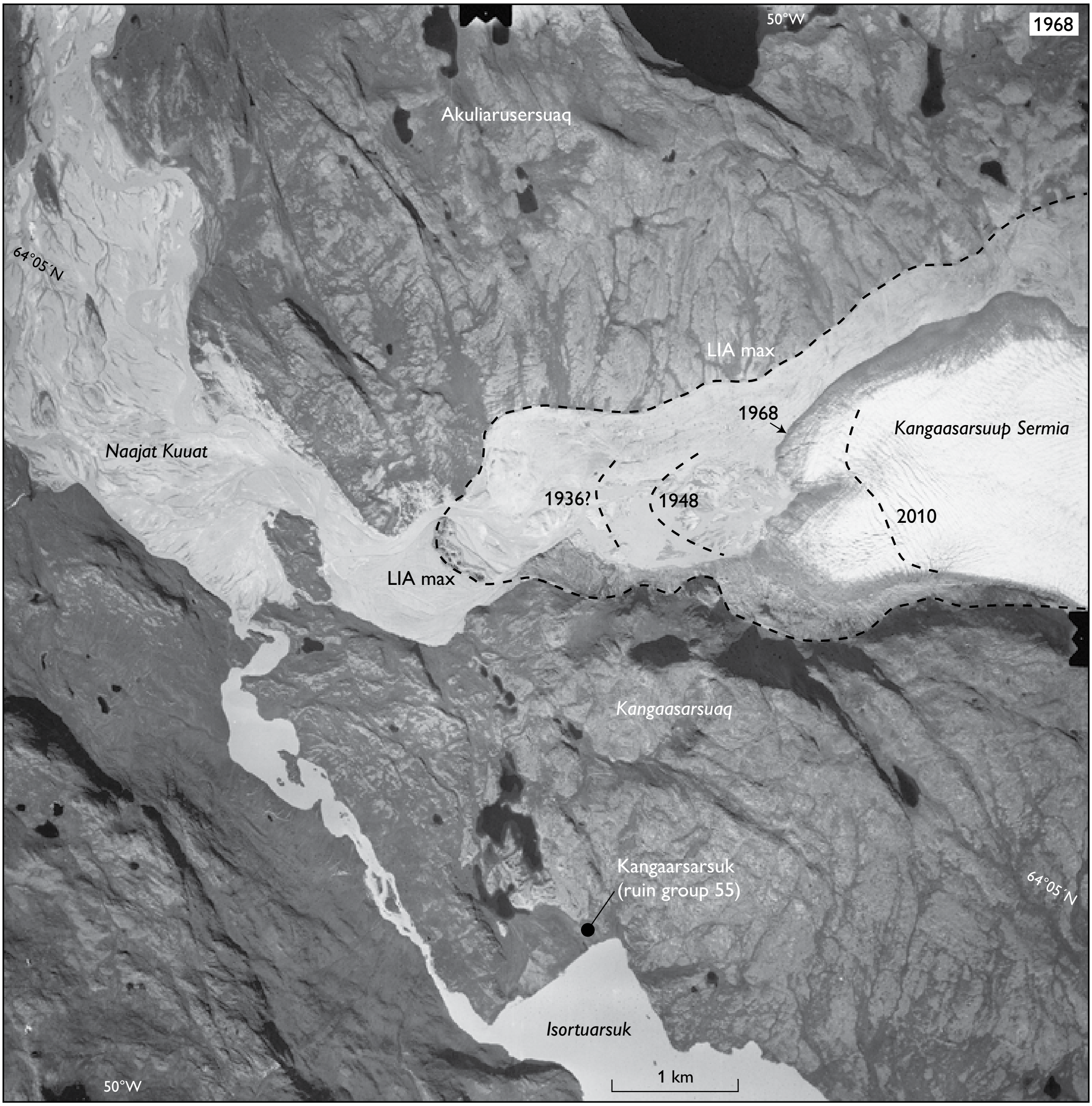
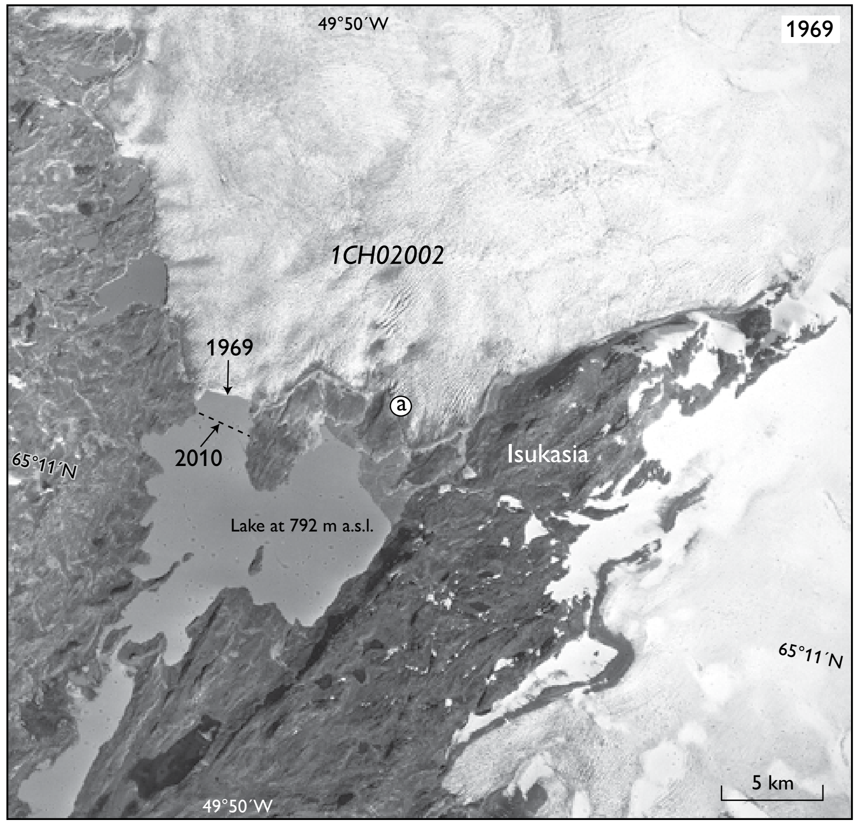


Fig. 32. Aerial photograph from 13 August 1968 (Geodetic Institute, route 281Q, no. 178) of Kangaasarsuup Sermia. The approximate positions of the glacier front during the Little Ice Age maximum (**LIA max**), in 1936 (Geodetic Institute, route 768C, no. 25297), in 1948 (Geodetic Institute, route 505 D1-Ø, no. 9774, 4 September) and in 2010 (from a satellite image) are shown. The total recession is *c.* 3.4 km.

dammed lakes that drain to the south to the Ujarassuit Paavat and Nuup Kangerlua fjords. North of Saqqap Sermersua, ice-dammed lakes drain towards the Søndre Isortoq fjord (Fig. 2).

The ice-sheet margin around 65°N (Fig. 2) is described below, an area for which some data are available from early visitors. Specific descriptions focus on the Isukasia area (sector 1CH02002; Weidick *et al.* 1992), located in the central part of the region where the local hydropower potential has been investigated, and on the large outlet Saqqap Sermersua in the north.

Fig. 33. Part of the Inland Ice margin at Isukasia. Estimated advances of the ice margin near the lake at 792 m a.s.l. are shown on the aerial photograph from 1969 (Geodetic Institute, route 281Y, no. 88, 10 August). The locality marked **a**, in the eastern inlet, is the site of annual measurements of frontal positions from 1974 to 1980 made by ACG (Kryolitselskabet Øresund 1980). The approximate position of the glacier front position in 2010 is indicated.



The ice-sheet margin at Isukasia

The southern areas of the ice-sheet margin at Isukasia (65°11′N, 49°50′W; Fig. 33) were first mapped by J.A.D. Jensen during 1884–1885 (Jensen 1889). Jensen's map may be partly based on information from older sources. It is not possible on the basis of the outline of the lakes around Isua and Ataneq (Fig. 34) to make comparisons with modern maps of the area, or to map changes in the position of the ice margin. The locality Isua on Jensen's map is named Isukasia on later maps (Fig. 34).

The area has been visited and described in connection with investigations of basement rocks and iron-ore deposits at Isukasia (Henriksen *et al.* 2009). Glaciological investigations have been conducted as part of an evaluation of the hydropower potential of the locality in connection with possible future mining (Colbeck 1974; Kryolitselskabet Øresund 1980). The glaciological investigations included determination of ice-margin fluctuations, going back to the 1930s, based on aerial photographs. During the period of glacial and hydrological investigations, direct measurements of annual fluctuations of the ice margin were carried out from August 1974 to August 1980. The data showed a continuous advance of the ice margin of 50–80 m, i.e. a few metres per year (Kryolitselskabet Øresund 1980). On the basis of aerial photographs and Landsat images from 1969, 1985 and 2010 (Fig. 33), the total advance between 1969 and 2009 is estimated to *c.* 300 m, or *c.* 7 m per year. The rate of advance seems to have been fairly constant during the last four decades, following the annual measurements from 1974 to 1980 by Kryolitselskabet Øresund (1980).

Saqqap Sermersua

Saqqap Sermersua at 65°12.5′N, 50°39′W is a *c.* 28 km long, land-based outlet from the ice sheet. The frontal width is *c.* 3 km and at present a *c.* 2 km long alluvial plain separates the glacier front from the large Tasersuaq lake (Fig. 34).

Although remote, the Saqqap Sermersua area has attracted reindeer hunters. Kleinschmidt's map of the Nuuk area (Fig. 11) gives a good impression of the general knowledge of this area in the 1850s. The first published information on changes of Saqqap Sermersua appeared in the Greenlandic newspaper Atuagagdliutit (Barselaj

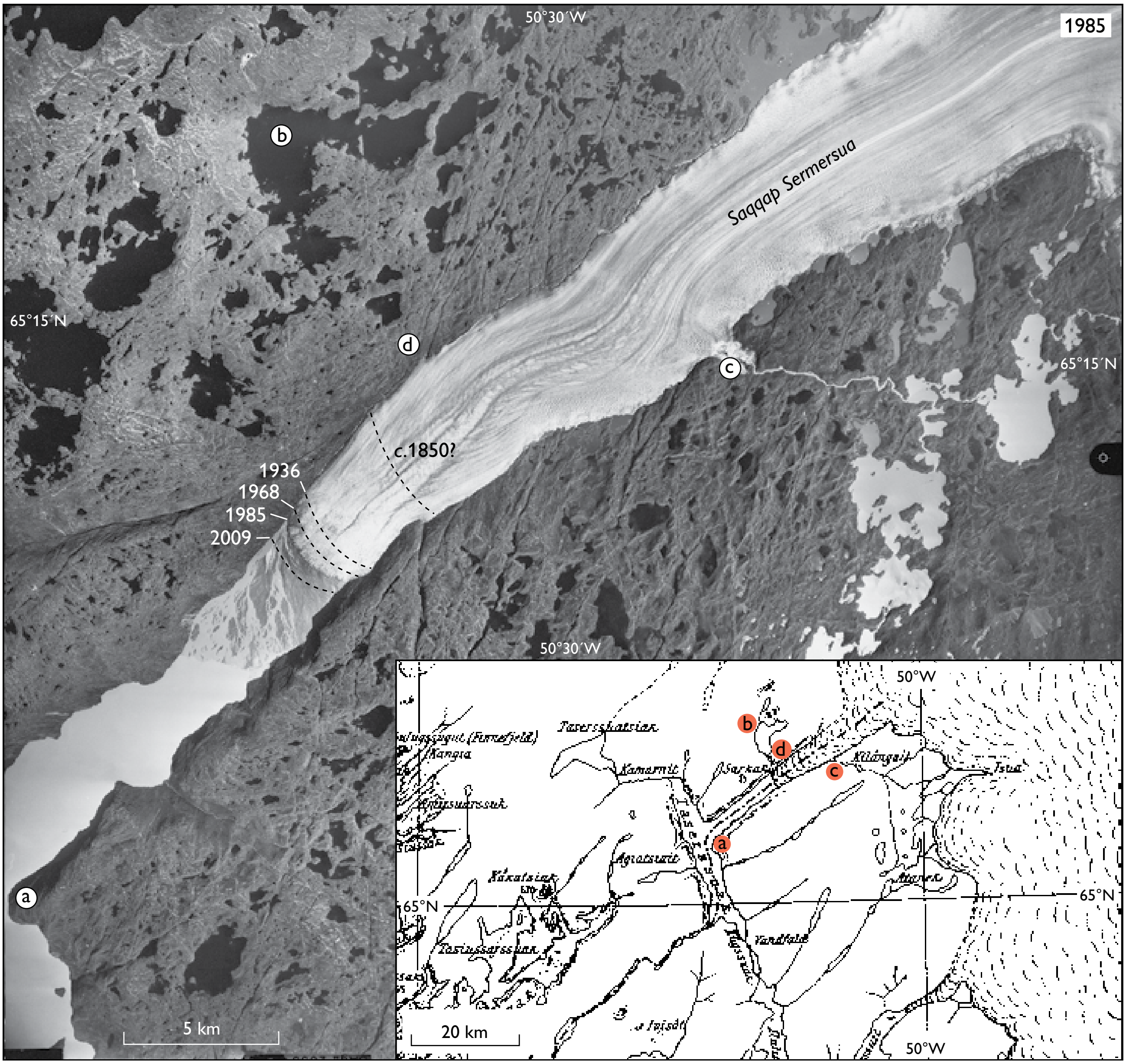


Fig. 34. Aerial photograph of Saqqap Sermersua. Estimated advance of the ice margin between the 1850s and 2009 is shown on the photograph from 11 July 1985 (Geodetic Institute, route 886K, no. 1456). The inset map was presumably made on the basis of the map by J.A.D. Jensen after his survey work in the area in 1885 (Amdrup *et al.* 1921). The locations of features **a** to **d** can be found on modern maps and the distances between these points on old and modern maps fit within ± 1 km; the date of this version of the map is unknown. The ice-front position around 1850–1860 is taken from Fig. 11 (Kleinschmidt's map), and is located *c.* 2–3 km downstream of point **d**.

1866). Barselaj was a parish clerk and a member of the local council in Nuuk. His family name was probably Ezekiassen, but only his first name was used as the author of the article. Barselaj visited the Saqqap Sermersua area in 1862 and 1865. On his first visit he was told that the glacier was advancing. This was confirmed during his second visit to the glacier in July 1865, when he saw an old trail that was partly buried under the ice. The advance of the glacier appeared to be faster during the summer than in winter (H.C. Petersen, personal communication, 1996). Barselaj also noted that there was calf ice in lake Tasersuaq, but the location of the front was not given, which is strange because at present the glacier front is separated from Tasersuaq by an extensive alluvial plain. This plain is not shown on J.A.D. Jensen's map, made after surveys in 1884–1885.

Jensen's map provides a relatively detailed picture of the area surrounding the glacier front (Jensen 1889). However, there is no map scale and the coastlines and other landscape features are somewhat distorted. It appears that the front of Saqqap Sermersua was located close to the modern position. The map was used for decades as a base map of the area, and it was used by Bruun to map Norse settlements (Fig. 7). A modified version of the map was included in the description of Greenland, published 200 years after Hans Egede's arrival in Greenland (Amdrup *et al.* 1921). Part of this map with Saqqap Sermersua and the surrounding area (still without the alluvial plain in front of Saqqap Sermersua) is reproduced here and compared to an aerial photograph from 1985 (Fig. 34). The suggested position of the glacier front shown on the aerial photograph in Fig. 34 shows the probable situation in the 1850s, based on Kleinschmidt's map (Fig. 11). North of the glacier, several large lakes are found (b). The lakes drain via a river (d) to Saqqap Sermersua at a place that was located 1–2 km behind the front on Kleinschmidt's map. On aerial photographs (Fig. 34) and modern maps, the glacier front is seen with the same river located 5–6 km behind the glacier front. This implies that the glacier front advanced *c.* 4 km from the middle of the 1800s to 1968 (*c.* 34 m per year). During the following period from 1968 to l985 it advanced *c.* 500 m (*c.* 29 m per year) and finally during the period from 1985 to 2009 it advanced *c.* 500 m (*c.* 21 m per year). We suggest that the front experienced a steady advance of *c.* 30 m per year throughout the period from the 1850s to the present time. The variations may reflect uncertainties in the determination of the frontal positions.

Discussion

Temperature changes

Considering the temperature history since the end of the 1700s in western Greenland (Vinther *et al.* 2006), the sparse information up to the mid-1800s may indicate a cold period; for the subsequent years (Cappelen 2005), there is a parallel trend for all stations on the west coast with relatively cold periods around 1900 and a less extreme cold period *c.* 1990, interspersed with warmer spells *c.* 1940. The present marked increase in temperatures began *c.* 1995.

The definition of geological periods in the Quaternary is basically related to temperatures inferred from proxy data obtained from investigations of plant or animal remains or stable isotopes of material from sediment or ice cores. With respect to the term Neoglacial, this period is defined by the cooling following the Holocene thermal maximum that may have peaked in the inland areas of southern West Greenland between 7000 and 6500 cal. years BP (Bennike *et al.* 2010). The Neoglacial can be subdivided in various ways (e.g. Dahl-Jensen *et al.* 1998; Kaplan *et al.* 2002; Seidenkrantz *et al.* 2007; Kuijpers *et al.* 2009). It is subdivided here into an older (6500–2000 cal. years BP) and younger part (2000 cal. years BP to the present).

Older Neoglacial (6500–2000 years BP)

We can only provide a fragmentary picture of the fluctuations of the ice margin during older periods. The ice margin receded rapidly in the early Holocene until the peak of the Holocene thermal maximum at *c.* 7.0–6.5 cal. ka BP (Fig. 35). At several localities reworked marine fossils have been found in Neoglacial deposits or in glacier ice near the ice margin:

1. Southern flank of the Qassimiut lobe at around 61°N, 47°W. Eight samples gave ages of 8.4 to 2.9 cal. ka BP (Weidick *et al.* 2004).

2. Søndre Qoornoq Bræ (61°09′N, 47°50′W. A few shells were found during reconnaissance work in 1955 (Weidick 1959). No samples have been dated.

3. Frederikshåb Isblink (*c.* 62°37′N, 50°08′W). Marine shells from the moraine and alluvial plain in front of the glacier were collected by D. Heling (Heling 1974) and a sample dated to 21 740 ± 400 ^{14}C years BP (Weidick 1975a; I-7622). The sample is a bulk sample and may consist of a mixture of Holocene and pre-Holocene shells.

4. Kangilinnguata Sermia (*c.* 64°50′N, 50°00′W). Four age determinations of shells gave ages from 6.4 to 4.3 cal. ka BP (Table 2).

5. The Jakobshavn Isbræ area (around 68°58′–69°45′N, 50°14′–50°20′W). Fifteen radiocarbon dates of marine shells and a walrus tusk collected at the present margin of the ice sheet around Jakobshavn Isbræ ranged from 6.1 to 2.2 cal. ka BP (Weidick & Bennike 2007).

In the area around Jakobshavn Isbræ, Briner *et al.* (2010) have investigated numerous lakes close to the recent ice margin. They presented 18 radiocarbon ages ranging from 7.4 to 0.8 cal. ka BP. Deglaciation continued after 7.3 cal. ka BP beyond the present ice margin until *c.* 2.3 cal. ka BP south of Jakobshavn Isbræ and until 0.4 cal. ka BP north of the ice stream. Marine sediments at the mouth of Jakobshavn Isfjord (Kangia) indicate 'extensive ice phases' at *c.* 2 and 0.5 cal. ka BP relating to a buried 'Narssarssuaq stade' and a 1700–1800 culmination of Little Ice Age advances in this region. The problem here is whether 'extensive ice phases' imply glacier advances or conversely extensive calf-ice production due to ice-front disintegration accompanying recession of a calving glacier.

The general decrease in temperatures caused initial glacier expansions. Beschel (1961) in his research on gla-

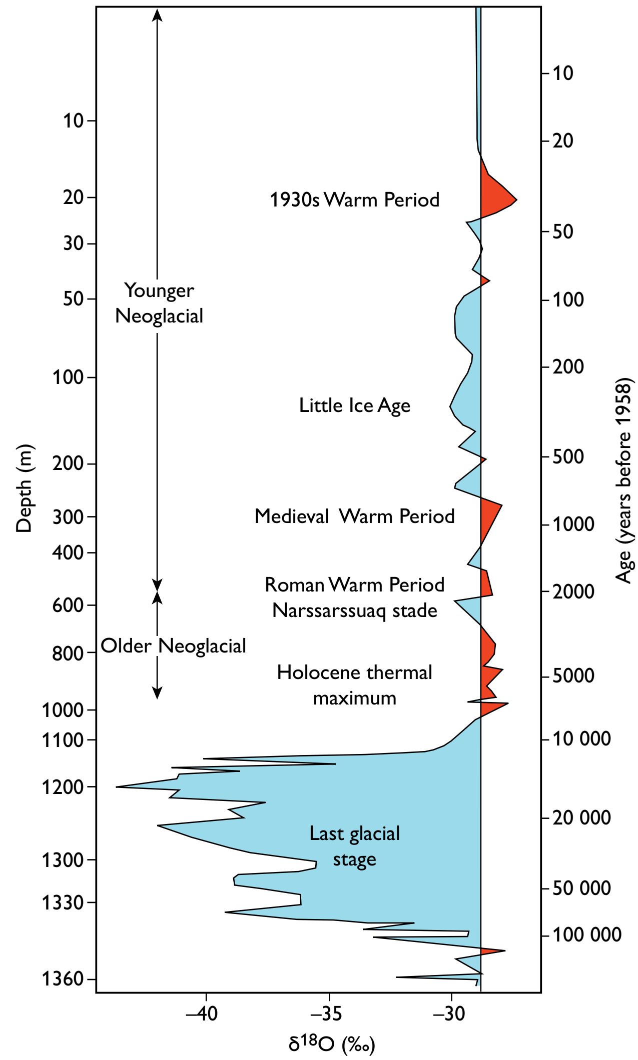


Fig. 35. Late Quaternary temperature history according to the Camp Century ice-core record. Redrawn from Dansgaard (2004). Blue areas: colder than present; red areas: warmer than present. The age-depth model is tentative.

cier fluctuations in West Greenland discerned the general glacier advances in this period: the 'Hochmoos' advance of an uncertain age, although indicated at *c.* 4000 years BP on his fig. 2, and the 'Larstig' advance, estimated at between 2800 and 2500 years BP. Both stades were defined in the Alps from moraines found in front of Little Ice Age moraines associated with minor local glaciers. The Narssarssuaq stade in South Greenland (61°10′N, 45°25′W; Weidick 1963; plate 1) is referred to the Older Neoglacial. The moraines of the Narssarssuaq stade in the area around Narsarsuaq in South Greenland follow the present ice margin at a distance of 5–10 km along an ice-margin length of *c.* 60 km. A northern continuation of this moraine system may have existed around the Qajuuttap Sermia ice stream, *c.* 30 km north-west of the Narsarsuaq airport. Moraines in this area were described by Moltke & Jessen (1896, p. 100). Qajuuttap Sermia started to advance and expand in the first half of the 1900s, an advance that probably ended towards the end of the last century. The moraines recorded by Moltke and Jessen were thus presumably removed or covered by Qajuuttap Sermia during this most recent advance (Weidick 2009). The Narssarssuaq moraines have been dated by lichenometry and radiocarbon dating to *c.* 2000 cal. years BP (Dawson 1983; Bennike & Sparrenbom 2007).

Farther north at the head of Kangerlussuaq (Søndre Strømfjord, 67°11′N, 50°10′W, Fig. 2), the age of a Neoglacial advance of Isunnguata Sermia of the same magnitude as the following Little Ice Age maximum was determined by optically stimulated luminescence (OSL) dating to *c.* 2000 cal. years BP (Forman *et al.* 2007). This advance may thus have taken place at the same time as the Narssarssuaq stade.

Finally, a series of moraines on the Nuussuaq peninsula north of Disko Bugt crosses the inner part of Nuussuaq. The moraines can be followed from Torsukattak icefjord in Disko Bugt in the south to Ikerasaap Sullua (Qarajaq Isfjord) in the north and continue on the peninsulas north of Ikerasaap Sullua. These moraines were first described by E. von Drygalski (1897, vol. 1, p. 121) and later by Weidick (1968, p. 92). The length of the moraine system across Nuussuaq peninsula is 32 km and the system follows the present ice margin at a distance of 0.5–1 km. This glacial stade was called the Drygalski stage by Weidick (1968, p. 136). The moraines were possibly formed during a period when the relative sea level was not higher than at present, and the moraines are older than the Little Ice Age moraines that are found between the Drygalski moraines and the present ice margin. The moraine system is tentatively correlated to the Narssarssuaq stade in South Greenland. During reconnaissance work in August 1961, the system was followed all the way from Torsukattak to Ikerasaap Sullua (Beschel & Weidick 1973, p. 313).

Younger Neoglacial (2000 years BP – present)

The Medieval Warm Period (MWP) extended from AD 850 to 1200. It can be divided into several phases separated by one or more cold spells, as seen in records from Ameralik fjord (Kuijpers *et al.* 2009). Farther south, Kaplan *et al.* (2002) investigated a sediment core from 'Qipisarqo Lake', located 2 km from Nordre Qipisarqo Bræ which is an outlet from the Qassimiut lobe (Fig. 2) at *c.* 61°03′N, 47°42′W. Between *c.* 9.1 and 0.4 cal. ka BP and again from AD 1850 onwards, the margin of Nordre Qipisarqo Bræ was at or behind its present position. The Qassimiut lobe had in general a reduced extent during the period 8.4–2.9 cal. ka BP, as shown by dating of reworked marine shells near its present margin (Weidick *et al.* 2004).

During the Little Ice Age, Nordre Qipisarqo Bræ was larger than at present, and it advanced into the catchment of 'Qipisarqo Lake', which led to deposition of minerogenic sediment in the lake during the period from AD *c.* 1550 to 1850 (Kaplan *et al.* 2002). With respect to the advance during the Little Ice Age, Holst visited the margin of Nordre Qipisarqo Bræ in 1880 (Holst 1886; Weidick 1959) and reported that the glacier front was situated only *c.* 100 feet behind the Little Ice Age maximum. We suggest that the ice-margin position reached its maximum during the middle of the 1800s.

A relatively cold period at around AD 600–900 is seen in the Greenland ice-core records, such as the Camp Century ice core from 77°10′N, 61°08′W (Dansgaard 2004; Fig. 35). The record from the DYE-3 ice core has been used for modelling the response of the Inland Ice margin north of Jakobshavn Isbræ, at Paakitsup Ilorlia (Fig. 2; Reeh 1983; Weidick & Bennike 2007). According to this model, a glacier advance occurred around AD 800; the magnitude of the advance was nearly as marked as later advances occurring around 1700 and 1900. There were possibly several cold spells, of which the most extreme may have been the so-called Fimbul winter, described in Nordic mythology, and dated to AD *c.* 536 (Gräslund 2007).

The initial onset of the Little Ice Age is often placed at AD 1100, but the real start of the Little Ice Age probably did not take place until after 1200–1400. In addition, there were warm spells between 1570 and 1600. These relatively warm periods subdivide the Little Ice Age into several parts. No documented glacier advances took place during the oldest part of the Little Ice Age although it is possible that traces of such advances were covered by younger advances in the 1700s and 1800s. According to the modelling by Reeh (1983) of ice-margin fluctuations at Paakitsup Ilorlia near Jakobshavn Isbræ for the period AD 600–2000, an advance occurred around AD 1200, but the expansion of the ice margin was extremely modest. The trimline zone was mainly

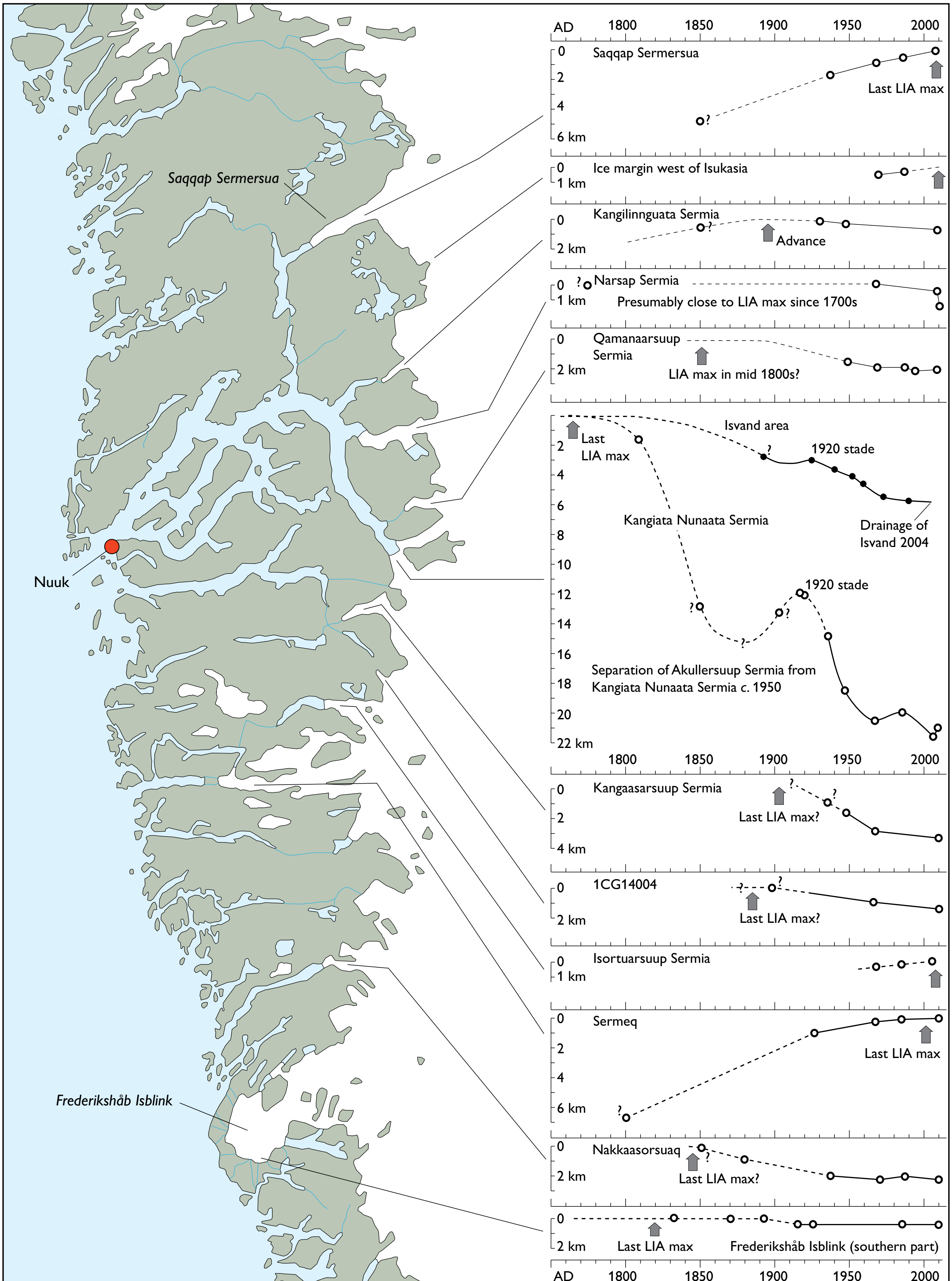

Saqqap Sermersua
Nuuk
Frederikshåb Isblink
AD
1800
1850
1900
1950
2000
Saqqap Sermersua
Last LIA max
Ice margin west of Isukasia
Kangilinnguata Sermia
Advance
Narsap Sermia
Presumably close to LIA max since 1700s
Qamanaarsuup Sermia
LIA max in mid 1800s?
Isvand area
Last LIA max
1920 stade
Kangiata Nunaata Sermia
Drainage of Isvand 2004
1920 stade
Separation of Akullersuup Sermia from Kangiata Nunaata Sermia c. 1950
Kangaasarsuup Sermia
Last LIA max?
1CG14004
Last LIA max?
Isortuarsuup Sermia
Sermeq
Last LIA max
Nakkaasorsuaq
Last LIA max?
Last LIA max
Frederikshåb Isblink (southern part)

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Fig. 36. Estimated fluctuations of 12 major outlets and sectors of the Inland Ice margin discussed in the text. The curves illustrate the large variation in glacier response to climate change. Three outlets show late Little Ice Age maxima (**LIA max**), in the 20th century, and other outlets have maintained an extent close to earlier Little Ice Age maxima. Only Kangiata Nunaata Sermia shows large variations during the last two centuries.

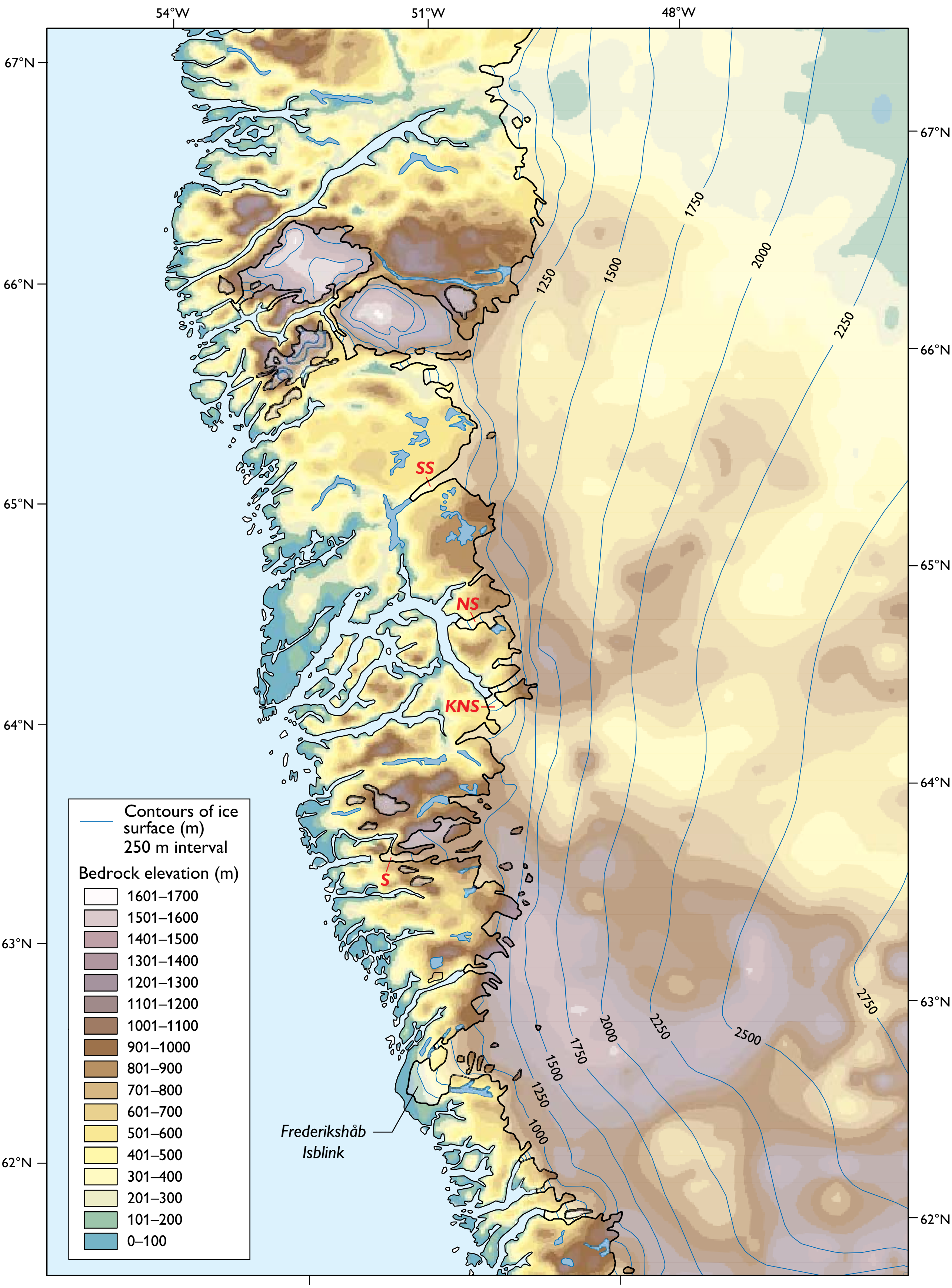
formed during the Little Ice Age maximum from the 1700s or at the end of the 1800s. These two maximum advances are often marked by differences in vegetation cover and soil formation on the moraines, the older moraines being darker because they have a denser cover of lichens than the younger moraines. This was described for the Qassimiut lobe, at Qalerallit Sermia in South Greenland (Weidick 1963, pp. 91–93; Fig. 2). In some places, the old moraines (1700s?) are located distal to the younger moraines, whereas in other areas, the older moraines disappear under the younger ones. This contradicts the general idea, taken from local glaciers, that the oldest moraines are nearly always situated distal to the younger moraines. For small, local glaciers in West Greenland, Beschel (1961, pp. 1058–1059) followed this concept when dating moraines by lichenometry. An advance occurred at *c.* 1600 followed by another advance at 1770–1780. Larger advances occurred in the second half of the 1800s, around 1870–1880 and 1890–1895, followed by a minor advance in 1920–1925.

For the Inland Ice margin, the trimline zone often indicates the maximum advance from the 1700s, and the middle or late part of 1800s. However, in some sectors of the ice-sheet margin, the trimline zone is poorly developed, and in other places, a trimline zone is missing. Information about fluctuations of the Inland Ice margin is sporadic. Sometimes it is only based on lichenometric ages, which can be questionable (Jochimsen 1973; Webber & Andrews 1973). However, lichenometric ages may be used to estimate the relative age of moraines, which are difficult to date using other methods. Historical information can also be uncertain. An example discussed here is the uncertain determination of the position of the front of Kangiata Nunaata Sermia, which in the middle of the 1800s, 1903 and in the l930s was at the approximately same position. This would lead to the conclusion that this glacier was relatively stable, with approximately the same position of the front for more than a century. However, the photograph by Nissen from 1921 and the recognition of the '1920 stade' show that the glacier front receded in the early 1800s, advanced *c.* 1903 and retreated in the 1930s (Fig. 36).

Concluding remarks

Radiocarbon ages of marine material, transported from the subsurface of the West Greenland ice sheet to its margin, demonstrate a widespread recession of the ice margin during the Holocene. Dated shells from the Qassimiut lobe show that the ice margin was located behind the present margin as late as 2.9 ka BP (Weidick *et al.* 2004) and at Kangilinnguata Sermia at 4.3 ka BP (this study). At the southern part of Jakobshavn Isbræ, the ice margin was behind the present margin at 2.2 ka BP (Weidick & Bennike 2007) and at the northern part of this ice stream at 0.4 ka BP (Briner *et al.* 2010). These investigations focused on ice-free areas adjacent to the largest calf-ice-producing outlets from the ice sheet, and the behaviour of other parts of the ice-sheet margin may have been different.

The fluctuations of the ice-sheet margin are still poorly documented, especially before the 1900s. However, from the sparse data available we can conclude that the Inland Ice margin had a retracted position, not only at the peak of the Holocene thermal maximum, but also in the following millennia, at least in some lowland areas. Local deviations may have occurred, such as the advance during the Narssarssuaq stade (around 2000 years ago). This advance may have been related to the first large cold spell after the Holocene thermal maximum, as shown in the temperature history inferred from the ice core from Camp Century (Fig. 35; Dansgaard 2004). A cold period


54°W
51°W
48°W
67°N
66°N
65°N
64°N
63°N
62°N
1250
1500
1750
2000
2250
2500
2750
1000
SS
NS
KNS
S
Frederikshåb
Isblink
Contours of ice surface (m)
250 m interval
Bedrock elevation (m)
1601–1700
1501–1600
1401–1500
1301–1400
1201–1300
1101–1200
1001–1100
901–1000
801–900
701–800
601–700
501–600
401–500
301–400
201–300
101–200
0–100

is recognised at 2000 years BP, which could have initiated the Narssarssuaq stade that only locally went beyond the present extent of the ice margin. The subsequent cold period of the Little Ice Age seems to have two minima at about AD 1550 and AD 1850 (Dahl-Jensen *et al.* 1998). Traces of the early advances of the ice margin have been obliterated by later advances.

With respect to the response of the individual sectors of the Inland Ice margin to climatic changes it must first be stressed that the current information about amplitude and exact dating of culmination is often uncertain, and that the trend of the fluctuations, even for the relatively well-documented last century shows a high degree of variability (Fig. 36). It is clear that if the trimline zones around outlets indicate the maximum Little Ice Age extent of the glacier, then localities without trimline zones must delineate areas where the present-day position coincides with the Little Ice Age maximum. It is concluded that the Little Ice Age maxima show a spread of ages, although for minor lowland outlets, the majority are related to the youngest Little Ice Age maximum from the mid- or end of the 1800s.

With respect to outlets without a trimline zone, it should be mentioned that some of these (Narsap Sermia, Sermeq), at the end of the 1900s and the beginning of this millennium, seem to show an initial recession. In Fig. 36 the fluctuations of the outlets and ice margin are shown. If this picture is compared with a map showing the topography of the ice-free coastland and the subglacial topography of the adjoining parts of the ice sheet, it can be suggested that the large fluctuations of Kangiata Nunaata Sermia may be related to the presence of a large valley system that is evident under this ice stream (Fig. 37), and therefore to the mass balance and the dynamics of this ice stream.

Otherwise outlets without trimline zones, such as Saqqap Sermersua in the north and Isortuarsuup Sermia in the south, seem to be related to nearby uplands and highlands although this can scarcely explain the steady advance of a local outlet. As regards the role of glaciers and their fluctuations as a 'climatoscope' for climate change in general, this seems to have been most successful for minor local glaciers where a well-defined delineation of the glacier form favours a more direct expression of the ruling local climatic and mass-balance conditions (Leclercq 2012; Leclercq *et al.* 2012). In contrast, the accumulation (catchment) area and ablation area within specific sectors of the Inland Ice may not be constant since the boundaries of these areas may shift position as a result of changing climatic conditions in combination with a series of factors that influence the dynamics and response time of the outlet. Such factors include surface elevation, bed elevation, local and temporal variations in snow fall, mass balance, basal ice temperature, depth of the transition between Weichselian and Holocene age ice, curvature of the surface contours and slope aspect of the surface terrain (listed for modelling of the Inland Ice dynamics by Ahlstrøm *et al.* 2008, p. 24). The specific gaps in understanding and modelling of the ice-margin response to climatic change are also dealt with by Dahl-Jensen *et al.* (2009); the observations and information discussed here can serve as examples of the strong variability in the response of the individual segments of the ice-sheet margin. This does not, however, weaken the credibility of estimates of the total mass balance of the entire Inland Ice. It is more related to the problem of prognoses of the response time of the individual sectors, where detailed short-term predictions are required to evaluate glacier hazards with respect to future exploration for minerals or hydropower.

Facing page:
Fig. 37. Map of southern West Greenland showing the landscape in the coastal region and its continuation (subglacial topography) below the adjacent part of the Inland Ice. The marked fluctuations of Kangiata Nunaata Sermia (**KNS**) may be related to its role as the only lowland area that connects the marginal part of the ice sheet with the sea. The 'quasi-stable' behaviour of Narsap Sermia (**NS**) or the advance of Sermeq (**S**) and Saqqap Sermersua (**SS**) may be related to interplays of mass balance, dynamics and the bedrock topography. Data are from the ETOPO1 global relief model, provided by the National Geophysical Data Center in the USA (Amante & Eakins 2009); suppressed colour tones are utilised to differentiate the subglacial topography from the surficial topography west of the Inland Ice.

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Index to place names

This is an index to place names used in the text, together with the former spelling used in the original texts. Many place names have been spelled in different ways over the years, in particular before 1851. After the Greenlandic grammar was published by S. Kleinschmidt (1851), the spelling of the Greenlandic language was standardised, and Kleinschmidt's spelling was commonly used until 1973, when the present spelling was introduced. In this index, the place names show the 1973 spelling, followed by the Kleinschmidt spelling, if different (in brackets). Pre-Kleinschmidt spellings and un-official names are in quotation marks. In addition, the feature relating to the names is given (mountain, glacier etc.). The exact location of old place names is often difficult to determine from old maps.

The original spelling for stratigraphical and other geological terms is retained. Thus the current spelling of a settlement is 'Kapisillit', but the name for the local moraine stade is the Kapisigdlit stade. Similarly, the place name Narsarsuaq is spelled so today, but we retain the spelling for the Narssarssuaq stade. The location of ruin groups is seen in Figs 3 and 7.

The list does not show all the versions of spellings used by various authors.

Page numbers in **bold** refer to figures and tables.