

Neoglacial and historical glacier changes around Kangersuneq fjord in southern West Greenland

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Greenland, Godthåbsfjord, Kangersuneq, Kangiata Nunaata Sermia, glaciology, tidewater glaciers, Quaternary, Holocene, Neoglacial, Little Ice Age.

Cover

The calving front of Kangiata Nunaata Sermia seen from the south-west. The trimline zone on Nunataarsuk semi-nunatak in the background reaches almost to the top of the mountains. The calving front is 4.5 km long. Photograph: Dirk van As, 22 August 2011.

Frontispiece: facing page

Qamanaarsuup Sermia is separated into an upper and a lower part by a bedrock high. The area in the foreground was covered by an ice-dammed lake during the Little Ice Age maximum. The lower part of the glacier is c. 2 km wide. Photograph: Dirk van As, 28 August 2012.

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Abstract

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The Nuup Kangerlua region in southern West Greenland became deglaciated in the early Holocene and by the mid-Holocene, the margin of the Inland Ice was located east of its present position. Discussion of late Holocene changes in the frontal positions of outlets relies on descriptions, paintings, photographs, maps, data from investigations of Norse ruins, aerial photographs and satellite images.

The Kangiata Nunaata Sermia glacier system has receded over 20 km during the last two centuries, indicating a marked response to climatic fluctuations during and since the Little Ice Age (LIA). A large advance between 1700 and 1800 was followed by rapid recession in the first half of the 1800s. Limited data from *c.* 1850–1920 indicate that although the long-term position of the glacier front remained *c.* 10–12 km behind the LIA maximum, the late 1800s and the early 1900s may have seen a recession followed by an advance that resulted in a pronounced moraine system. The ice-dammed lake Isvand formed during the LIA maximum when meltwater from the western side of Kangiata Nunaata Sermia drained to the Ameralla fjord in the west. This is in contrast to the drainage pattern before the 1700s, when water probably drained to Kangersuneq in the north. Thinning of Kangiata Nunaata Sermia resulted in total drainage of Isvand between 2000 and 2010 and the discharge of water through Austmannadalen has now returned to the same level as that in medieval times.

Other outlets in the region, such as Akullersuup Sermia and Qamanaarsuup Sermia have varied in phase with Kangiata Nunaata Sermia, but with amplitudes of only a few kilometres. In contrast, Narsap Sermia has been nearly stationary and Kangilinguata Sermia may have advanced until the middle of the 1900s.

Lowland marine outlets in south-western Greenland were characterised by large amplitude changes during the Neoglacial. Extreme examples, in addition to Kangiata Nunaata Sermia, are Eqlorutsit Killiit Sermiat at the head of Nordre Sermilik fjord in southern Greenland and Jakobshavn Isbræ in Disko Bugt, central West Greenland. The Neoglacial advances appear to have occurred at different times, although this may in part reflect the limited information about fluctuations prior to the 1930s. The differences could also reflect variations in mass balance of different sectors of the ice sheet, different subglacial dynamics or topographical factors. The lowland areas are separated by uplands and highlands that extend below the marginal part of the Inland Ice; in such areas, the outlets have been advancing almost up to the present, so that the position of the glacier front around AD 2000 broadly coincides with the LIA maximum. Charting the fluctuations of the outlets thus illustrates the large variability of the glaciers' response to changing climate but it is notable that the number of advancing outlets has decreased markedly in recent years.

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Introduction

In recent years, the Greenland ice sheet (the Inland Ice) has become a symbol of climate change. The ice sheet is losing mass at an accelerating rate (Dahl-Jensen *et al.* 2009; Rignot *et al.* 2011; van As *et al.* 2011), and it is becoming increasingly clear that we need a better understanding of the past behaviour of the ice sheet and in particular its sensitivity to climatic change. Here we present a review of our current knowledge about late Holocene changes of the Inland Ice margin in the Nuup Kangerlua region in southern West Greenland (Figs 1, 2).

Recent climate change has resulted in thinning of marginal parts of the Inland Ice (Dahl-Jensen *et al.* 2009). Politicians as well as ordinary citizens are concerned that the melting of the Inland Ice and the consequent rise in sea level will lead to world-wide environmental and sociological problems. Over the next century, the sea level may rise by about 1 m; a large part of this predicted rise is attributed to melting of the Inland Ice.

However, during the past centuries different sectors of the margin of the Inland Ice have responded to climate change in various ways. Some sectors have been stable, others have receded and others have advanced. This implies that predicting glacier hazards such as changes in calf-ice production from the large tide-water outlets or ice-margin changes at hydropower plants can be difficult.

It must be remembered that the Inland Ice is an immense body of ice. At the margin, the ice sheet is often confluent with minor ice caps or other local glaciers that have their own mass budget. The Inland Ice has extensive accumulation areas, and it is difficult to delimit the catchment areas for the individual sectors or outlets from the ice sheet. In addition, the catchment areas may change over time. The aim of this work is to compile information about marginal changes of the Inland Ice in the Nuup Kangerlua region to give an impression of former variations. The work focuses on the last centuries, but includes data concerning the last 6000 years.

Nuup Kangerlua (Godthåbsfjord) is the largest fjord complex in southern West Greenland and the longest fjord extends *c.* 160 km. The fjord branches are often surrounded by steep mountains, but lowlands are also represented. The inner parts of Nuup Kangerlua were colonised by Norse people about 1000 years ago. The Norse established the Western Settlement (Vesterbygd) with *c.* 95 farms and two churches, but they abandoned the region after 350–400 years (Arneborg 2004; Dugmore

et al. 2012). The only written information about the Greenland ice sheet from the Norse period is found in *The King's mirror* from *c.* 1260 where it is briefly stated that most of the land is icebound (Larson 1917; Weidick & Bennike 2007). Some legends from the later Eskimo people (Thule culture) refer to their relationships with the Norse people (e.g. accounts by Aron from Kangeq and Jens Rosing presented in Birket-Smith 1961), but provide no information on glacier extent or glacier changes. The European exploration of the Baffin Bay and Davis Strait



Fig. 1. Map of Greenland showing the location of the studied region and the location of selected ice cores.

region from *c.* 1500–1700 did not increase our knowledge of the Greenland ice sheet or glaciers in Greenland. The region was again colonised by Europeans in 1721, and from this time onward a fairly rich body of historical information exists about the outlet glaciers from the Inland Ice in the region.

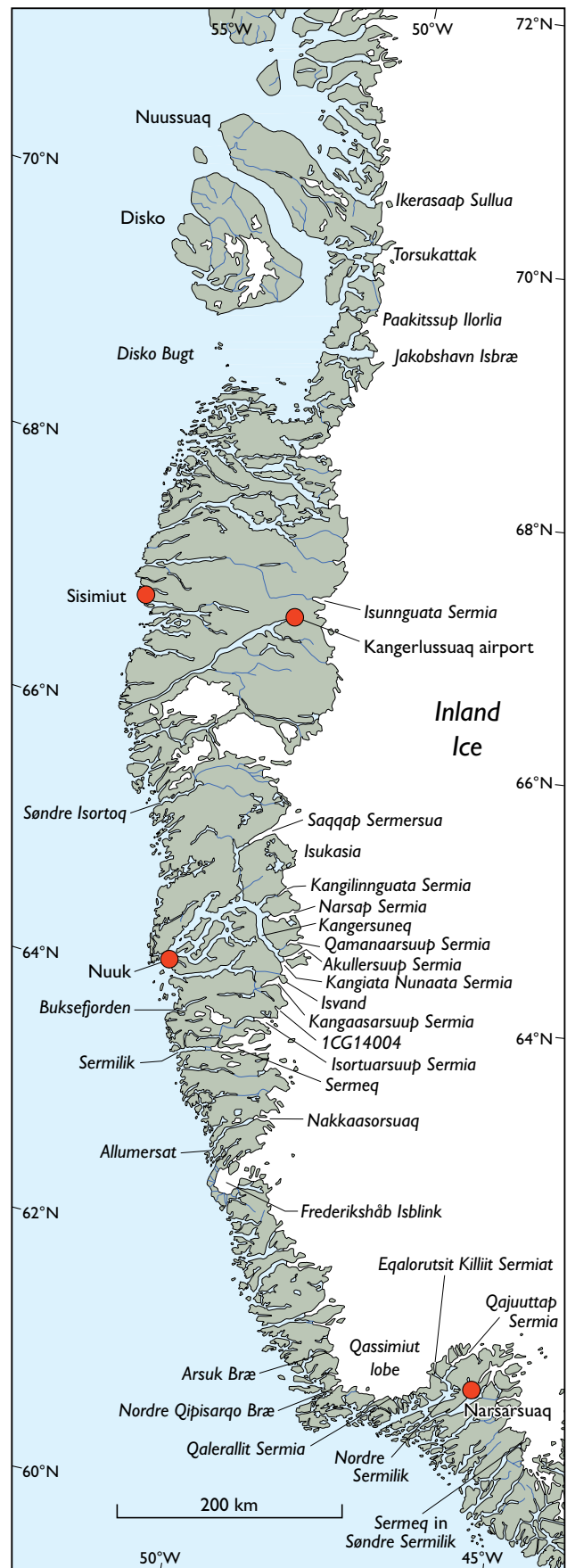
This presentation summarises information about glacier changes from geological observations, archaeological evidence, historical sources, as well as more recent evidence from aerial photographs and satellite images. An index of relevant place names is included to aid understanding of older data sources. The emphasis is on the scattered historical information on glaciers, which dates back to the early part of the exploration history in the beginning of the 1700s, and up to the first half of the 1900s. Work on the fluctuations of the glaciers in this area was initiated 52 years ago (Weidick 1959); more recent work and the recognition or re-evaluation of historical sources have necessitated an updating and revision of the record.

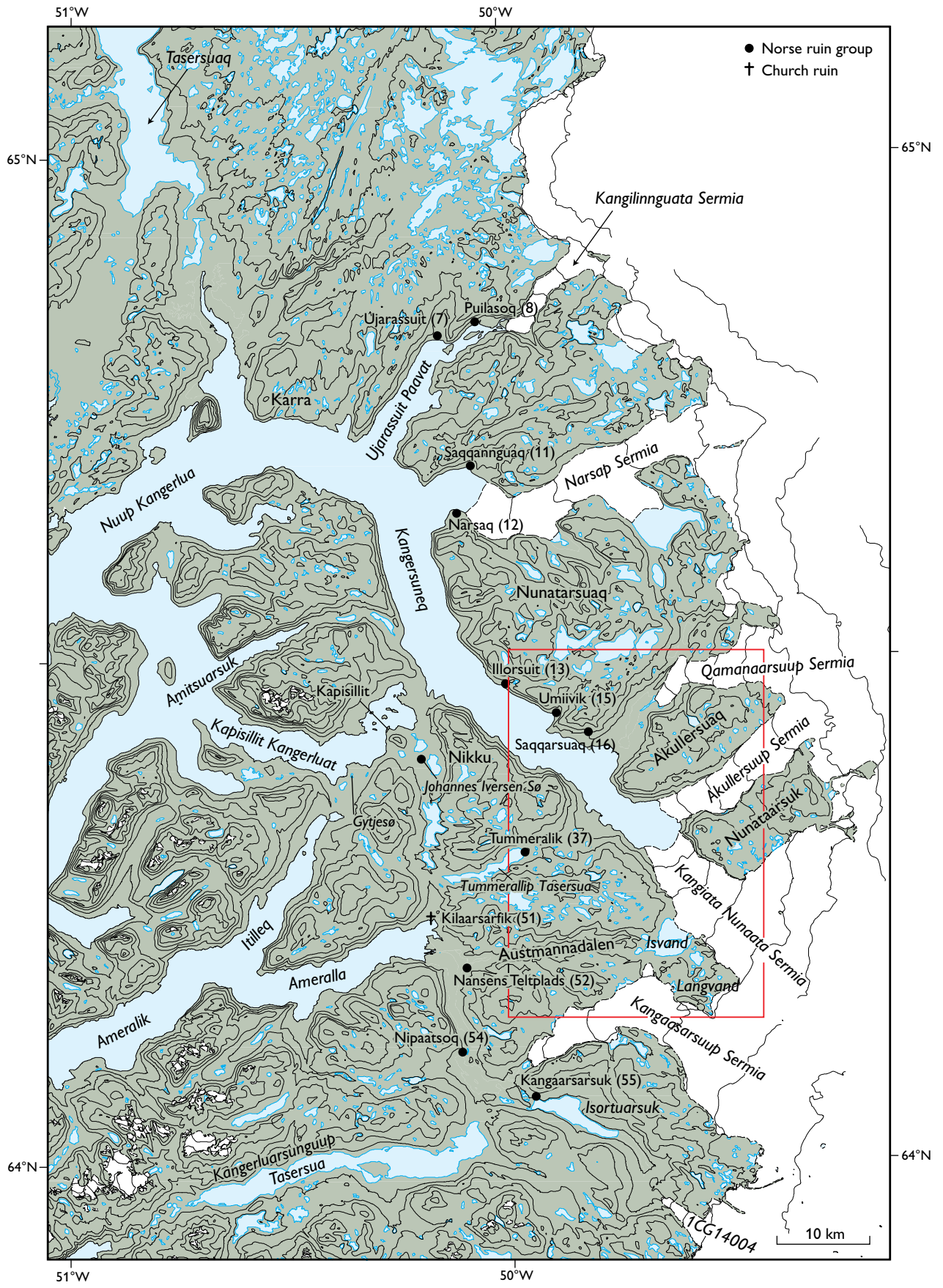
Since the advent of aerial photography in the 1930s and particularly with the recent influx of satellite information, data on ice-sheet history have become both more accurate and more readily available. These data are dealt with in more general terms, tracing the major trends of the glacier fluctuations up to the first decade of this century.

Setting

This study is centred on the area at the head of Nuup Kangerlua (Godthåbsfjord), *c.* 80 km east of the town of Nuuk (Fig. 3). The ice-free land in this part of Greenland is 100–125 km wide, with lowlands and uplands with elevations up to 1000–1500 m above sea level (a.s.l.). The landscape is dissected by numerous straits and fjords, of which the longest, Nuup Kangerlua, reaches from the outer coast to the Inland Ice. In its inner part, in the Kangarsuneq area, the ice-sheet margin reaches sea level, or close to sea level, in five outlets. From south to north, these are Kangiata Nunaata Sermia, Akullersuup Sermia, Qamanaarsuup Sermia, Narsap Sermia and Kangilinnuata Sermia (Figs 2, 3).

Fig. 2. Map of south-western Greenland showing outlet glaciers, the marginal areas of the Inland Ice and major fjords mentioned in the text.





Kangiata Nunaata Sermia and Akullersuup Sermia are both calving tidewater glaciers with appreciable calf-ice production. The flux of Kangiata Nunaata Sermia was *c.* 6 km³ per year in 1996, but by 2005 it had increased by 33% (Rignot & Kanagaratnam 2006). According to Mortensen *et al.* (2011), the glacial ice discharge is 8 km³ per year. At their maximum extent, the two glaciers Kangiata Nunaata Sermia and Akullersuup Sermia were coalescent, and the calving front of the glacier system was located more than 20 km farther to the north than today. The term ‘Kangiata Nunaata Sermia glacier system’ is used here to describe the two confluent glaciers.

The third glacier, Qamanaarsuup Sermia ends on land today, but previously ended in a proglacial lake that was dammed by the advanced, confluent glacier system consisting of the present-day Kangiata Nunaata Sermia and Akullersuup Sermia.

The fourth glacier, Narsap Sermia, is also a tidewater glacier, but calf-ice production is small, and it is sometimes possible to sail along the glacier front by boat. The fifth outlet glacier, Kangilinnuata Sermia, is situated at the head of Ujarassuit Paavat, which is a northern branch of Kangersuneq fjord at the head of Nuup Kangerlua. Kangilinnuata Sermia is presently a minor land-based outlet.

Whereas Kangiata Nunaata Sermia, Akullersuup Sermia and Qamanaarsuup Sermia were surrounded by broad, fresh trimline zones in the last century, such a zone is only found to a very restricted degree around Narsap Sermia. The trimline zone around Kangilinnuata Sermia is narrow, which indicates a slight recession of the glacier in recent times. Kangaarsuup Sermia, south of Kangiata Nunaata Sermia, has experienced a somewhat larger glacier recession (Fig. 4).

Mass-balance measurements have been carried out on Qamanaarsuup Sermia between 1979 and 1989 and on a small local nameless glacier (ICG14033) situated at the junction between Ameralik fjord and Kangerluarsunnguag (Buksefjorden), *c.* 75 km south-west of Qamanaarsuup Sermia, during the period 1982–1989 (Braithwaite 1989, 1990; Braithwaite & Olesen 1989). At both places, the investigations were carried out to evaluate the

hydropower potential in the region. On Qamanaarsuup Sermia, volume changes were also measured from 1968 to 1980 (Knudsen 1983) and again from 1988 to 1993 (Taurisano 2004). North of the Kangersuneq area (at Isukasia), glaciological investigations were conducted in connection with evaluations of the hydropower potential at the Inland Ice margin in the years 1974–1980 by the Arctic Consultant Group (ACG) and Vattenbyggnadsbyrå (Colbeck 1974; Kryolitselskabet Øresund 1980).

Notes on the Holocene history of the area

The Holocene history of the area is not known in detail. A Quaternary map of the region on a scale of 1:500 000 was published by the Geological Survey of Greenland (Beschel *et al.* 1978), but without explanatory notes or a map description. Notes on the Quaternary history have been published by Weidick (1975a, b) and Long *et al.* (2006).

During the last glacial maximum, *c.* 21 cal. ka BP (cal. ka BP = calibrated to calendar ka before present, where present = AD 1950), the margin of the Inland Ice extended to the edge of the continental shelf according to Vinther *et al.* (2009). The outer coast of the region became ice free during the early Holocene (Bennike & Björck 2002). During the following millennia, net recession continued, but ice-margin deposits mark some halts or minor readvances of the ice margin. The correlation of these ice-margin deposits in western Greenland is uncertain (Weidick 1968, 1984a, b; Kelly 1980, 1985; Long *et al.* 2006). The recession of the ice margin over the present ice-free land followed after the abrupt warming at the Younger Dryas – Holocene transition, which is dated to 11.7 ka before AD 2000 (Rasmussen *et al.* 2006), and which was followed by increasing temperatures during the earliest Holocene.

A characteristic feature of the Kangersuneq area is the wide belt of ice-margin deposits, which can be followed at the heads of Nuup Kangerlua and Ameralik fjords at a distance of 10–30 km outside the present margin of the ice sheet. The deposits indicate a halt or readvance. These Holocene ice-margin features have been variously termed the Fjord stage by Weidick (1968), the Younger Fjord moraine system by Ten Brink & Weidick (1974) and the Kapisigdlit moraine system by Kelly (1985). The term ‘the Kapisigdlit stade’ is used here to stress the local character of these ice-margin deposits. Near the settlement of Kapisillit, the marine limit drops abruptly from

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Fig. 3. Map of the inner Nuup Kangerlua and Kangersuneq fjord region, showing the locations of named features and Norse ruins mentioned in the text. The map is based on aerial photographs from 1985; outlined area shown in Fig. 16.

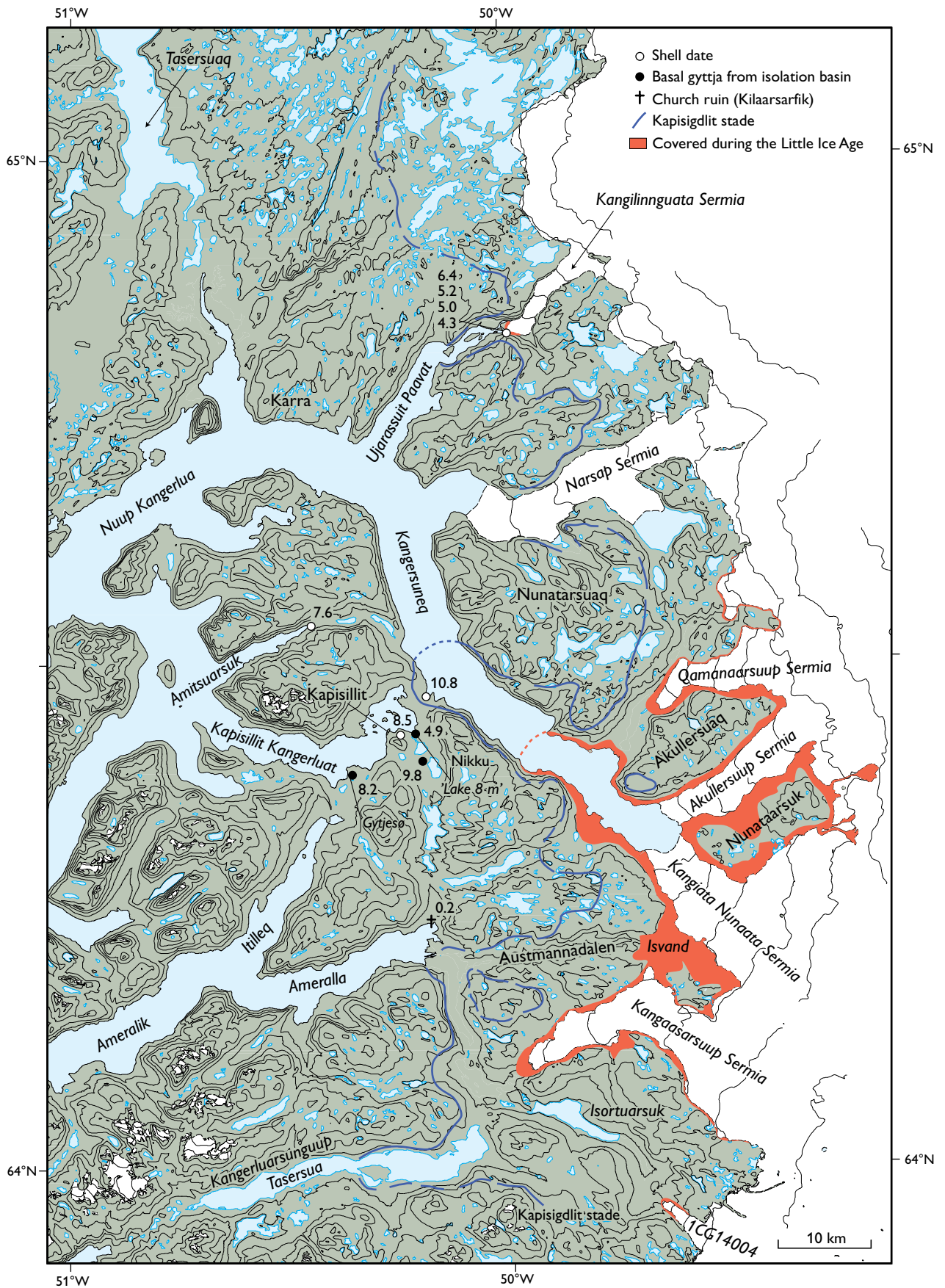


Table 1. Selected radiocarbon age determinations from the Kangarsuneq region

Locality	Lat. (north)	Long. (west)	Elevation m	Laboratory no.	Age 14C yrs BP *	Calibrated age ±1 stdv., BP †	Material	Reference
Johs. Iversen Sø	64°24′	50°12′	100	K-2294	8640 ± 130	9432–10153	Gyttja	Fredskild 1983
Gytjesø	64°23.5′	50°21.5′	57.3	K-2295	7430 ± 100	8031–8402	Gyttja	Fredskild 1983
Kapisillit	64°26′	50°10′	40	K-1036	7560 ± 150	8106–8861	Shells	Weidick 1968, 1972
Amitsuarsuk	64°32′	50°28′	16	I-8596	6670 ± 110	7365–7776	Shells	Weidick 1976
Kapisillit	64°28′	50°11′	5	Ua-3476	9490 ± 105	10570–11109	<i>Macoma calcarea</i>	This study
Lake 8 m	64°26′	50°12′	8	K-802	4340 ± 120	4583–5305	Gyttja	Fredskild 1973
Kilaarsarfik	64°15′	50°13′	–2	Archaeol.		c. 800		Roussell 1936, 1941

* Ages were not normalised for isotopic fractionation, except for Ua-3476 that was normalised to a $\delta^{13}\text{C}$ value of 0‰ on the PDB scale.

† Calibrated according to the CALIB09 dataset (gyttja) and the MARINE09 dataset (marine shells); stdv: standard deviation.

over 100 m a.s.l. west of the moraine system to less than 80 m a.s.l. east of the moraines. On the basis of the radiocarbon ages from the area (Fig. 4) and archaeological information on increasing relative sea level at the church ruin at Kilaarsarfik ('Sandnes') after medieval times (Fig. 3; ruin group no. 51; Roussell 1936), an uplift curve has been proposed (Fig. 5). In the Disko Bugt region, the correlative of this c. 9–8 ka old stade was called the 'Fjord stage' by Weidick & Bennike (2007, p. 37).

According to the uplift curve, the Kapisigdlit stade can be dated to 8.1–8.3 ka BP, and it may reflect a readvance as a result of the 8.2 ka BP cold event (Alley *et al.* 1997). The age of the Kapisigdlit stade may correspond to the age of the Tasiussaq moraine system in Disko Bugt (Weidick & Bennike 2007, Young *et al.* 2011). However, a shell of the marine bivalve *Macoma calcarea*, found at Kangarsuneq near the settlement of Kapisillit (Figs 4, 6) was dated to 9490 ± 105 ^{14}C years BP (Ua-3476; Fig. 6B), or 10.6–11.1 cal. ka BP (Table 1). The shell was found in a 5–10 m high coastal cliff section with a surface that gradually rises to 13 m a.s.l. at the foot of the proximal side of a Kapisigdlit stade moraine, in a silty boulder diamicton containing concretions with shells (Fig. 6B).

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Fig. 4. Map of the inner Nuup Kangerlua and Kangarsuneq fjord region, showing locations of radiocarbon-dated samples (ages in calibrated ka BP, Tables 1, 2), the approximate position of the Kapisigdlit stade (Weidick 1975a) and the maximum extent of the ice margin during the Little Ice Age (LIA max). The red areas around the present ice margins show the extent of the trimline zone. This zone is broadest around the Kangiata Nunaata Sermia glacier system. The map is based on aerial photographs from 1985.

The shell fauna included rare but well-preserved shells of *Mya truncata* and *Balanus* sp. The shells probably come from invertebrates that lived at the bottom of Kangarsuneq icefjord at a time when the ice margin was located near its present position or farther to the south and east than today. During the Kapisigdlit stade, the shells were dredged from the fjord bottom by the advancing glacier, and deposited in a diamict accumulation, which is now exposed in a coastal cliff section.

Moraines related to the Kapisigdlit stade were first described from Nansens Teltplads (Nansenip Tupeqafia) at the entrance to Austmannadalen from Ameralla (near Norse ruin group 52c; Figs 3, 7). They were called

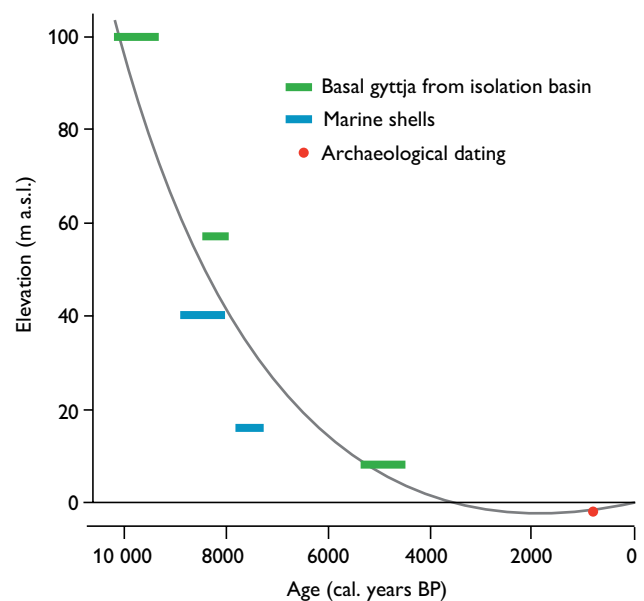


Fig. 5. Model of Holocene relative sea-level changes in the Kangarsuneq icefjord area, based on data presented in Table 1; a.s.l.: above sea level.

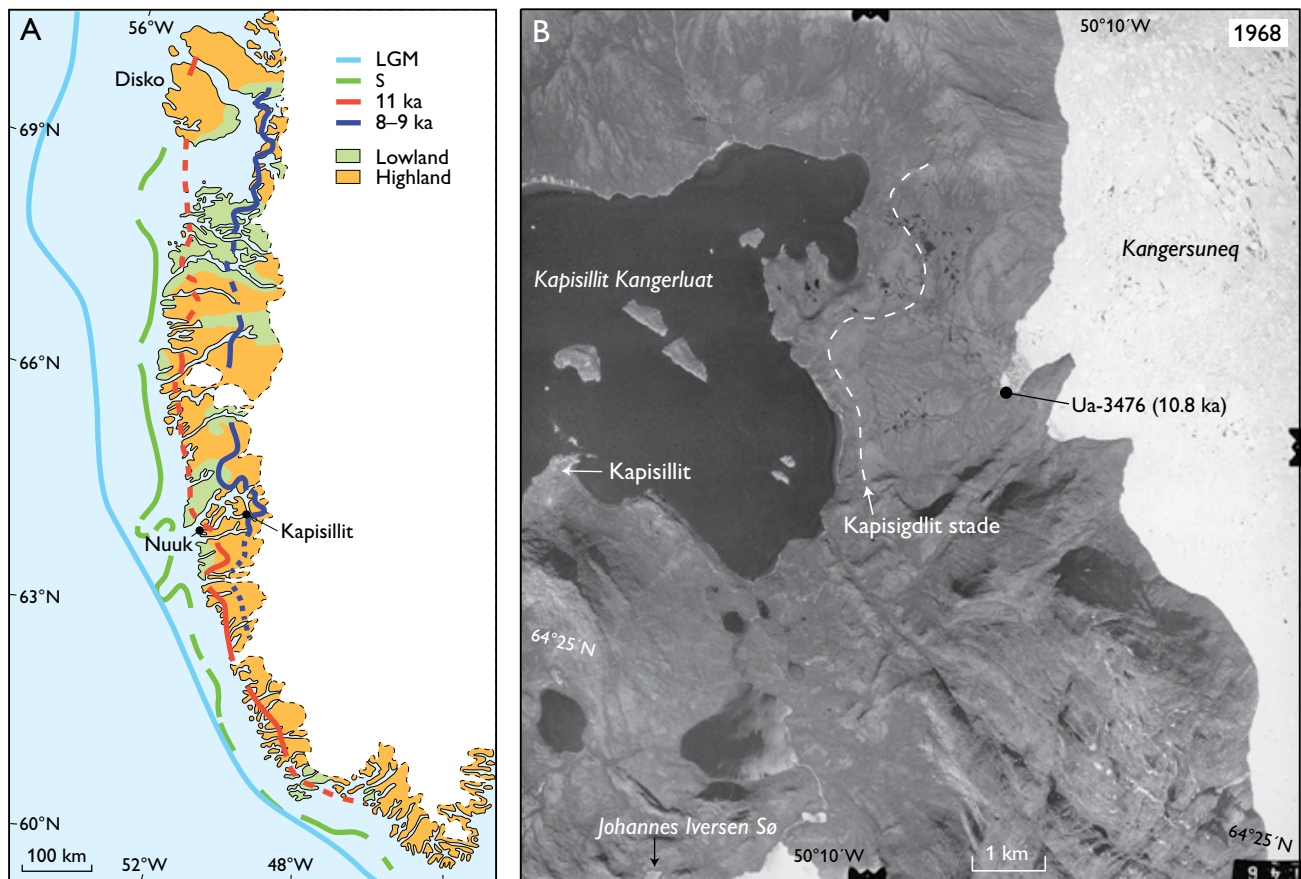
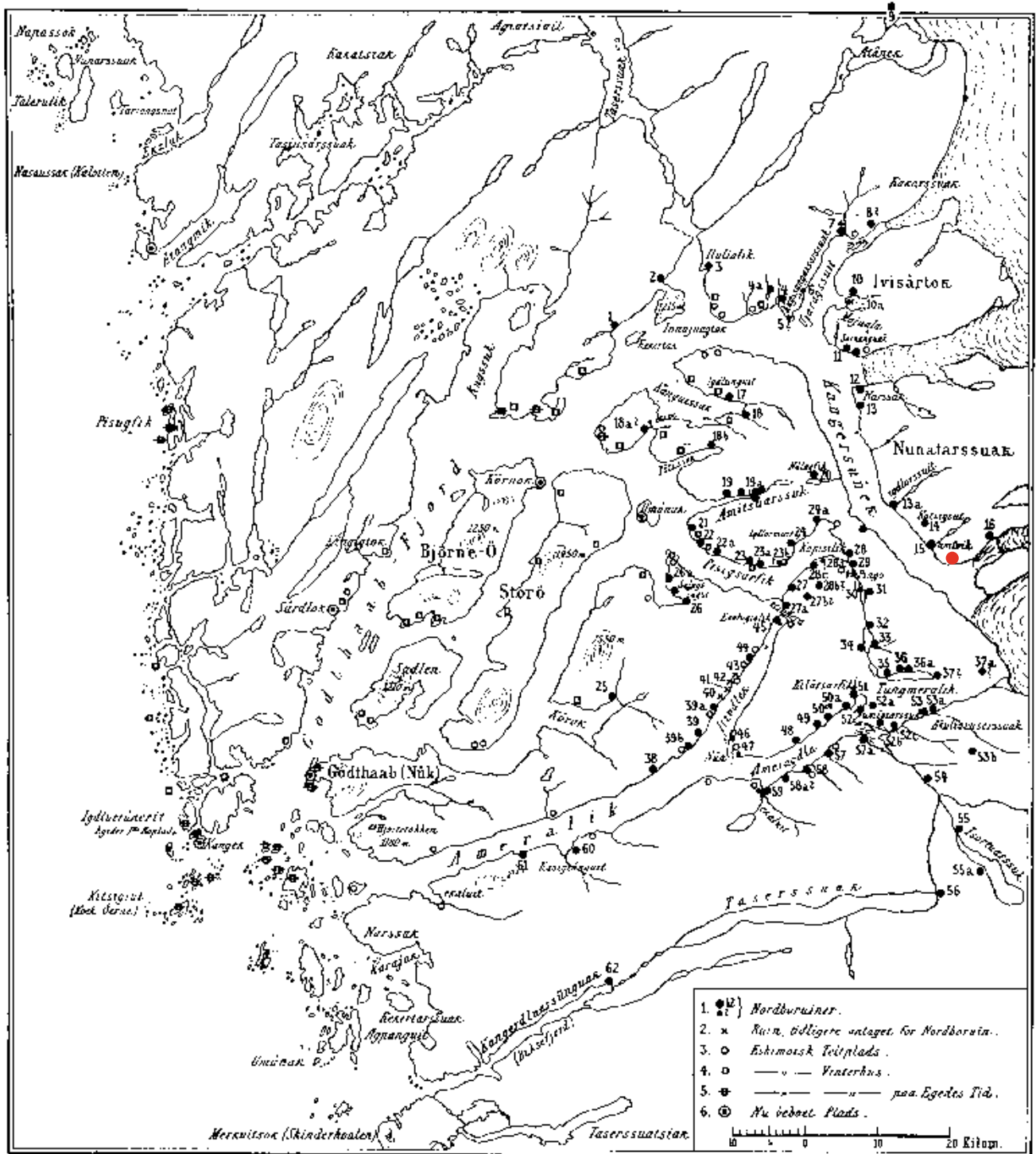


Fig. 6. **A:** Ice-margin positions during the recession of the of the Inland Ice margin in western Greenland (simplified). The numbers indicate approximate mean ages in ka BP. **LGM:** Last Glacial Maximum, dated to *c.* 22 ka BP, the position is according to Vinther *et al.* (2009). **S:** the Sisimiut glacial event. The latter stade was dated to 11–14 radiocarbon ka BP, corresponding to *c.* 12.9–17 cal. ka BP according to Kelly (1985). However, it is possible that the Sisimiut glacial event may correlate with the Younger Dryas cooling (11.7–12.9 cal. ka BP; Rasmussen *et al.* 2006). The stade marked **8–9 ka** shows the approximate position of the ‘Fjord stade’, including the local Kapisigdlit stade in the Kangersuneq – Nuup Kangerlua area and the Marrait and Tasiussaqa moraine systems in Disko Bugt. Lowlands are areas below 300 m a.s.l. **B:** Aerial photograph showing the area around the isthmus at Kapisillit between the fjords Kangersuneq and Kapisillit Kangerluat. Ice-margin features belonging to the Kapisigdlit stade, the location of the shell sample dated to 10.6–11.1 cal. ka BP (Ua-3476) and Johannes Iversen Sø, investigated by Iversen (1953) and Fredskild (1973, 1983) are shown. Aerial photograph from 13 August 1968, Geodetic Institute, route 281R, no. 146.

‘jøkelgjærde’ (moraine ridge) by Nansen (1890, map) and Bruun (1917, p. 102). This moraine may be cut by a marine terrace at *c.* 50 m a.s.l. Another early observation of ice-margin deposits come from Kangersuneq fjord, near ruin group 15 (Umiivik), where Roussel mentioned that about 700 m up from the ruin site is a large moraine bank running across the valley (Figs 3, 7; Roussel 1941, pp. 60–61).

The recession presumably continued after the Kapisigdlit stade, up to the peak of the Holocene thermal maximum at *c.* 7–6.5 ka. At around this time the ice margin was generally located inland of the present position. It is not known how far east the ice margin retreated. However, a minimum estimate can be given for the time interval during which the ice margin was behind the

present margin, based on ages of marine shells in concretions sampled from Little Ice Age moraines and from the alluvial plains in front of the outlet of Kangilinnuata Sermia, and dredged by the glacier from the bottom of the fjord. Age determinations of four samples gave ages of 6.4 to 4.2 cal. ka BP (Table 2). It is presumed that the net readvance was characterised by separate readvances of increasing magnitude, which generally culminated towards the end of the Little Ice Age at AD 1700–1900. The geomorphology of moraine localities and the content of fossils in the deposits were described by the German geologist K. Gripp (1932, 1975), who also described marine fossils from Alanngorlia at Sermeq glacier and Frederikshåb Isblink.



● Ruin group 16

Fig. 7. Norse and Eskimo ruin groups in the area between Nuup Kangerlua (Godthåbsfjord) and Ameralik fjord (Bruun 1917); Bruun's numbers for ruin groups are still being used today. D. Bruun used a map by J.A.D. Jensen (drawn after field work in 1884 and 1885) as a basis for plotting archaeological sites after collecting information in Greenland in 1903 and using additional information from O. Bendixen after his travels in 1916. The map shows that the Norse farms and churches are found in the interior part of the ice-free land. Jensen's map was in general use up to the 1930s. Legend: 1. Norse ruins. 2. Ruins previously believed to be Norse. 3. Eskimo tent sites. 4. Eskimo winter houses. 5. Eskimo winter houses from the time of Hans Egede (younger than 1721). 6. Inhabited sites (i.e. from 1884 to the 1930s). The red dot marks the location of ruin group 16 according to Roussel (1941).

Table 2. Neoglacial radiocarbon ages of shells from the bottom of Ujarassuit Paavat (64°50' N, 50°0' W)

Laboratory no.	Age ¹⁴ C yrs BP *	Calibrated age ±1 stdv., BP †	Reference
Ua-3473	5590 ± 90	6240–6628	This study
Ua-1089	4535 ± 110	4951–5544	Weidick 1993
Ua-3475	4280 ± 95	4683–5244	This study
Ua-3474	3780 ± 70	4057–4448	This study

*The radiocarbon ages were normalised for isotopic fractionation to a $\delta^{13}\text{C}$ value of -0‰ on the PDB scale.

†Calibrated according to the MARINE09 dataset; stdv: standard deviation.

Moraine systems (partly with ice-cored moraines) are especially well developed around the Kangiata Nunaata Sermia glacier system. Relicts of shear moraines can be seen in Kangersuneq *c.* 11–12 km behind the Little Ice Age maximum extent as defined by the extension of the trimline zone. In the following, this advance is called the '1920 stade'.

The first overview of the bathymetry of the Nuup Kangerlua region was compiled by Beschel *et al.* (1978), although data were lacking from major parts of the interior fjords. Mortensen *et al.* (2011) presented a depth profile of Nuup Kangerlua and Kangersuneq. The depth of the inner part of Nuup Kangerlua is about 600 m, whereas the depth in Kangersuneq icefjord is around 300–400 m (Fig. 8). A major threshold is found at the Little Ice Age maximum, where the depth is *c.* 150 m. Another smaller threshold is found *c.* 8 km inside this,

with a depth of *c.* 300 m. The latter is found 1–2 km in front of the 1920 stade. A third threshold may occur at the 2010 frontal position of Kangiata Nunaata Sermia, where the water depth is 210–240 m. The thresholds are separated by depressions with depths of 350 and 400 m (Fig. 8). The depressions may have been eroded during time periods when Qamanaarsuup Sermia (during the Kapisigdlit stade) and Akullersuup Sermia (during the Little Ice Age maximum) were tributaries to the Kangiata Nunaata Sermia glacier system. The present frontal height of Kangiata Nunaata Sermia is <50 m; the glacier front is probably mainly resting on the fjord bottom.

Geological, archaeological and historical information on glacier fluctuations and sea-level changes

The uplift curve (Fig. 5) shows a rapid emergence of land in the early Holocene, which was a consequence of the decrease of the ice load over the region. Uplift was followed by submergence in the late Holocene. Indications of relative submergence were already noted by Arctander (1793) and Pingel (1841, 1845) based on observations of archaeological sites situated at or below the present sea level. Their observations were confirmed by Matthiassen (in: Gabel-Jørgensen & Egedal 1940, pp. 8–10), Roussell (1936, 1941) and Larsen & Meldgaard (1958) based on

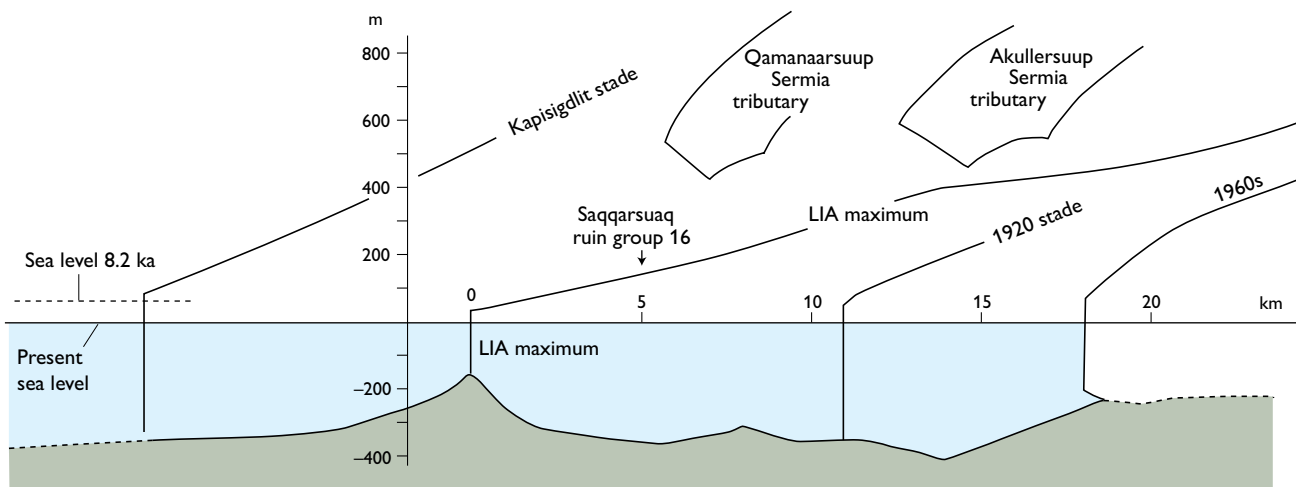


Fig. 8. Depth profile of Kangersuneq icefjord showing profiles of Kangiata Nunaata Sermia during the Kapisigdlit stade (8.2 cal. ka BP?), during the Little Ice Age (LIA) maximum (1700s), during the 1920 stade (*c.* 1920) and during the 1960s. The minor depression of the fjord bottom 4–6 km off Qamanaarsuup Sermia and *c.* 14 km off Akullersuup Sermia may be due to the erosive effect of the frontal part of Kangiata Nunaata Sermia glacier system when the two tributary outlets joined the main glacier Kangiata Nunaata Sermia.

archaeological investigations, as well as by Saxov (1958, 1961) based on geophysical work. A review of these investigations was published by Weidick (1996).

Investigations have been carried out at a few localities in southern West Greenland by dating the timing of isolation of lakes from the sea using pollen analysis and radiocarbon age determination. The pioneers of such investigations in the area were Iversen (1953) and Fredskild (1973, 1983). More recent investigations have been made by Long *et al.* (2009) at a locality on the outer coast south of Sisimiut, and by Bennike *et al.* (2011) at a locality near Sisimiut. The relative sea-level history in the inner part of the Nuuk region was undoubtedly different from that of the Sisimiut region 300 km to the north-west, but the fact that the church ruin at Kilaarsarfik ('Sandnes') is now covered by the sea at high tide shows that this region has been transgressed.

Dietrich *et al.* (2005) suggested a recent uplift of about 1 mm per year near Sisimiut and a subsidence of 2.2 mm per year at Kapisillit in the inner region of Nuup Kangerlua based on GPS measurements at a number of stations in western Greenland. Long *et al.* (2009) suggested that the difference reported by Dietrich *et al.* (2005) could be a consequence of the behaviour of the ice margin in the two areas. More recently, Bevis *et al.* (2012) reported an uplift rate of 7.5 mm per year at Kapisillit. Although this figure may be uncertain due to problems with uplift processing, it is likely that the uplift rate has accelerated.

Roussell (1936, p. 8–10; 1941, p. 14–18) in his treatise on the Norse farms and churches in the inner parts of Nuup Kangerlua and Ameralik made two important observations on the environmental situation of the Norse settlements:

1. The relative sea level was some metres lower at the Kilaarsarfik church (ruin group 51, Figs 3, 7) at the head of Ameralik fjord in early medieval time than today. We suggest that the following relative sinking of the land is primarily related to the increasing glacier load during the Neoglacial.
2. The many farms along the head of Ameralik, in Austmannadalen west of Kangiata Nunaata Sermia, at the head of Ujarassuit Paavat north of Kangersuneq and in Kangersuneq icefjord must have been more accessible from the sea in medieval times than at present, where kilometre-long tidal flats or calf-ice accumulations are found at the heads of the fjords. The tidal flats reflect a large increase in sediment supply, probably due to a marked glacier advance af-

ter the Norse disappeared from the area, presumably around 1345 when the Norwegian priest Ivar Bardarsson visited the area (Gad 1967; Arneborg 2004).

As mentioned in the introduction, data on glaciers and glacier changes are sparse up to the first half of the 1800s. However, in the mid-1800s there was a growing international interest in the Arctic regions. The first systematic investigations of western Greenland were undertaken between the 1870s and 1900 by the Commission for the Direction of the Geological and Geographical Investigations in Greenland. In addition to geological and geographical studies, archaeological, botanical and other scientific investigations were carried out. The results were published in *Meddelelser om Grønland*, which was issued by the commission.

Data from aerial photographs and satellite images

The use of aerial photography in Greenland began in the 1930s, in connection with a new systematic mapping programme (Wenzel-Petersen 1970; Nielsen 2000). The oldest photographs were oblique ones. During the Second World War, the US Air Force covered parts of Greenland with a combination of oblique and vertical photographs (trimetrogon). Oblique aerial photographs were also used by the Geodetic Institute in following years. These photographs cover large areas, but distant objects show little detail and more recent series are thus all vertical.

Aerial photographs from Greenland have been acquired and collected since the 1930s by the former Geodetic Institute which was established in 1928 and was originally an institution under the War Ministry (Krigsministeriet; Helk 1954; Wenzel-Petersen 1970, p. 31). The Geodetic Institute produced and sold maps and copies of aerial photographs. The total collection of aerial photographs was available without restrictions, even during the cold war. On 1 January 1989, the Geodetic Institute became part of the National Survey and Cadastre (Kort & Matrikelstyrelsen), currently in the Ministry of the Environment (Nielsen 2000, p. 77).

In addition to topographical mapping, the West Greenland photographs from the 1930s were also used in connection with archaeological investigations of the Norse ruins. The many details seen on the photographs made them suitable for archaeological and other scien-

tific investigations. However, the old series did not cover all the ice-free land, and it was not until 1985 that a total coverage of vertical aerial photographs was achieved.

Since the 1970s, satellite images have been used to map glacier changes. These images cover large regions

and are available at short intervals. Data from satellites can be used in mass-balance calculations of specific sectors (Dahl-Jensen *et al.* 2009). However, in this work we have only used data from satellites to update information from historical sources and aerial photographs.

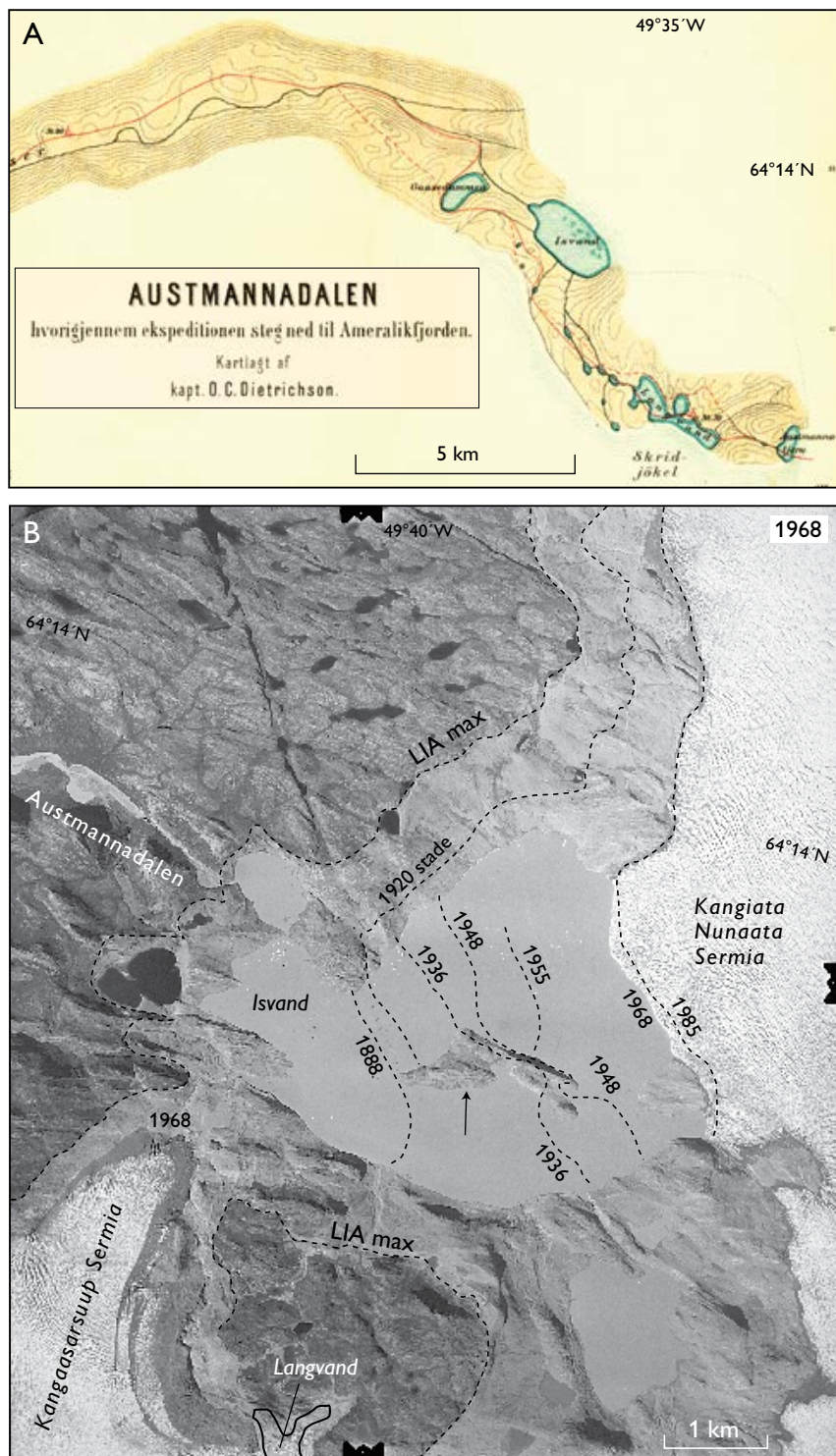


Fig. 9. **A:** Isvand and the eastern part of Austmannadalen in 1888. Eastern part of a map by O.C. Dietrichson (Nansen 1890). Skridjököl: glacier, here part of a southern outlet of the Inland Ice (Kangaarsuup Sermia). Isvand is drawn fairly schematically, but at its east side one can see the damming glacier marked by icebergs in the lake. **B:** Isvand and its discharge into the river through Austmannadalen. Vertical aerial photograph from 16 August 1968, Geodetic Institute, route 281T, no. 85. The arrow indicates the island discussed in the text. The recession of the damming ice margin is given by approximate positions of the ice margins with years of observations from 1888 to 1985. The recession was probably interrupted by minor advances, with the most pronounced culminating just before 1920 (marked 1920 stade). The most impressive change occurs in the area between the present glacier margin and the limit of the maximum ice coverage during the Little Ice Age. This limit is marked **LIA max**, and the area behind is still relatively barren even though major parts of this trimline zone have been free of ice for around 200 years. The position of the front of Kangiata Nunaata Sermia was stable between 1985 and 2010. After Weidick & Citterio (2011).

Glacier changes in the Kangersuneq area

The description and evaluation of glacier changes primarily concern the fronts of the glaciers Kangiata Nunaata Sermia, Akullersuup Sermia, Qamanaarsuup Sermia and Kangilinnuata Sermia although the record from Kangiata Nunaata Sermia is supplemented by data from the locality of Isvand, a former ice-dammed lake situated on the western flank of the glacier (Figs 3, 9). The individual glaciers or localities are treated separately, the presentation of the historical and modern data being followed by an evaluation of these datasets in terms of the glacial history.

The former ice-dammed lake Isvand

The description below concentrates on the area east of Austmannadalen, in particular the area including the former ice-dammed lakes Isvand and Langvand, located south-west of Kangiata Nunaata Sermia and north of Kangaasarsuup Sermia (Figs 3, 9). The earliest information about the ice margin in this area was given by Hans Egede (1925, p. 104) in 1723. He refers to observations by reindeer hunters, who from Ameralik fjord presumably travelled up Austmannadalen, and observed the large ‘ice mountain’ which expanded over the mountains and undoubtedly was connected with the ice cover and mountains that Egede had seen farther south. The hunters saw a large lake under the ‘ice mountain’, into which large ice lumps had fallen from the ‘ice mountain’, and Egede compared it with an earlier mentioned ‘Ujarachsuach’ (now: Kangersuneq), which also was full of icebergs that had fallen from the ice. It is uncertain whether this description refers to Isvand, but Isvand was the largest of the ice-dammed lakes in this area at the head of Austmannadalen. This ice-dammed lake formed after the Little Ice Age maximum extent of the ice, when the whole area of the later Isvand was ice covered. The comparison to the ice conditions in ‘Ujarachsuach’ fjord is also open to question. It appears that this name was sometimes used for the present Kangersuneq, but usually it was only used for the fjord Ujarassuit Paavat (Figs 3, 10).

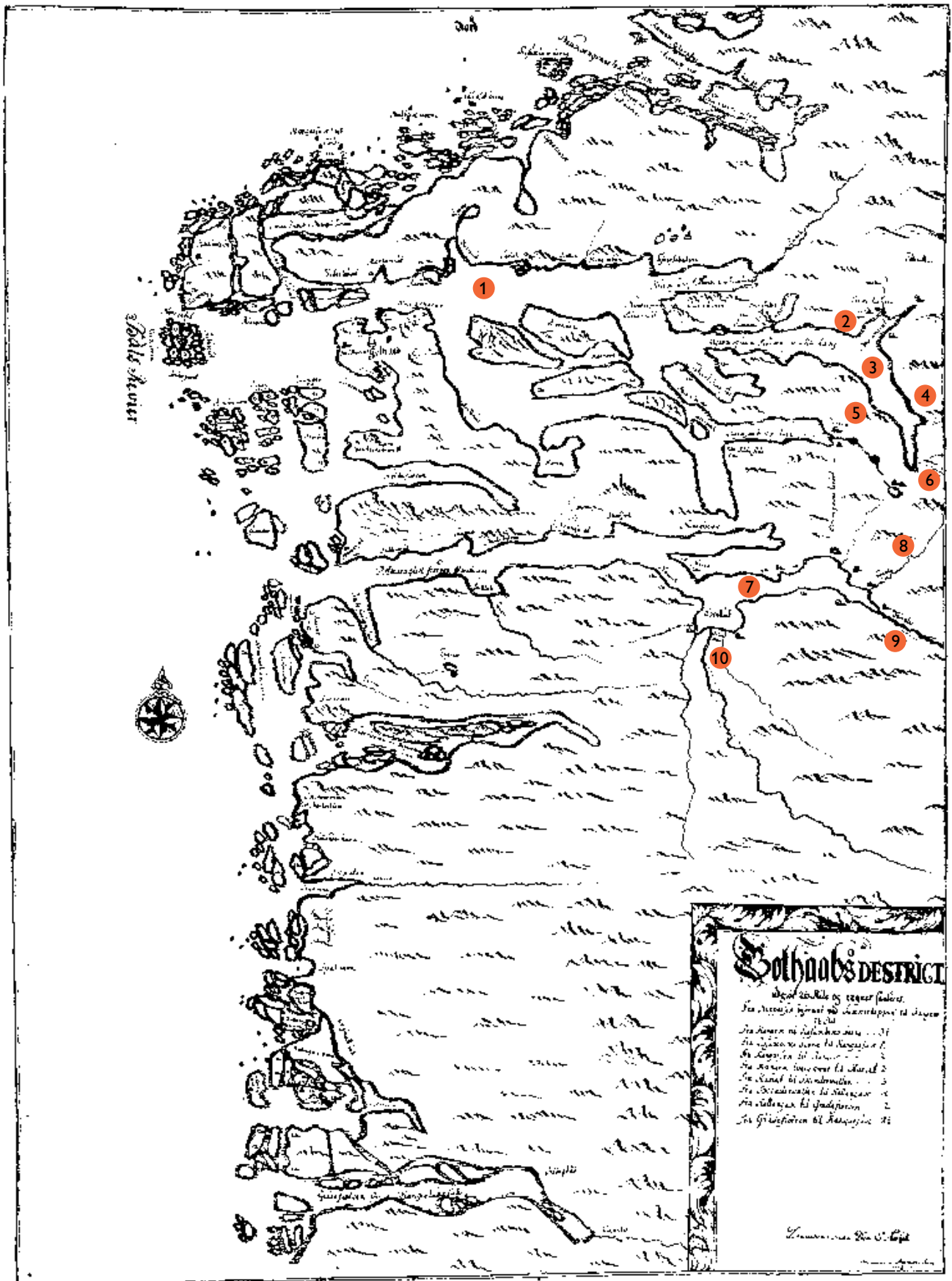
It may also have been via Austmannadalen that governor Claus Enevold Paars in April 1729 visited the ice margin, sailing from Nuuk to the head of Ameralik and

then walking through Austmannadalen with a party of Danes, guided by two Greenlanders to reach the Inland Ice. From his observations near the ice margin, he described glacier crevasses, the crystalline structure of the glacier ice, and erratic boulders on the ice surface (Bobé 1936a, p. 26, 1936b, pp. 186–189). On the trip he also found ruins, but he does not mention the ice-dammed lakes at all. If large ice-dammed lakes existed, they must have formed an obstacle for approaching the Inland Ice margin and would probably have been recorded.

Egil Thorhallesen, a missionary who lived in Greenland between 1765 and 1775, toured the central parts of western Greenland, especially in 1774 and 1775. He published an account of the Norse ruins (Thorhallesen 1776), but his original description of the country, its people and nature was not published until 1914 by Bobé (Thorhallesen 1914, including maps of the area). Thorhallesen mentioned several Norse ruins, amongst others at a locality called Kangia, presumably at the head of Ameralla: *In the eastern end of the bay several ruins from the old Europeans are also found; some may also be situated on high ground and some may have been covered by the glacier-ice in recent time. This is described in more detail in the “Efterretning om Rudera i Baals Revier [Treatise on rudera in Baals Revier]”.* (Thorhallesen 1914, pp. 51–52; authors’ translation.)

It is difficult to locate Thorhallesen’s place names from his map (Fig. 10). ‘Baals Revier’ is Nuup Kangerlua (Godthåbsfjord). The river named ‘Laxelv’ is probably the river running through Austmannadalen. ‘Storelv’ is probably the Naajat Kuuat river, which drains the glacier Kangaasarsuup Sermia (not shown on Thorhallesen’s map, Fig. 10) and also drains the large lake Isortuarsuk.

The head of Ameralik and Ameralla fjords was called ‘Kangia’ by Thorhallesen, but in a note by Bobé (Thorhallesen 1914, p. 51) it was changed to ‘Umiviarsuit’, which is a locality close to the Kilaarsarfik church ruin (Bruun’s map 1917, Fig. 7). Thorhallesen noted that the length of Ameralla fjord from Equaluit to its head at Kangia (or Umiviarsuit) is 2 Danish miles (15 km), which is close to the distance on modern maps. On Thorhallesen’s map, the lengths of the fjords are generally close to distances on modern maps whereas the orientations of the individual parts are distorted. Roussell (1941) noticed that the route to the Norse ruins behind the present extensive tidal flats may have been easier in the 18th centu-



Bothnia's DISTRICT

1. *Anders Eriksson*
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Anders Eriksson

ry than today. It is possible that much of the sedimentation took place after Thorhallesen's visit. Sedimentation rates may have increased due to the increased ablation that accompanied glacier recession in the 1800s.

The ruins at Tummernalik were also mentioned by the early explorers of the region, and from a visit to the area around Tummernalik on 1 June, 1810 (Giesecke 1910, 254–259). Giesecke described the ruins at Tummernalik as well as the ice margin of the 'Eisblink', which may be the ice margin situated *c.* 5 km east of Tummernalik (Tummerallip Tasersua). Ruin group 37a shown on Bruun's map (Fig. 7) is not mentioned or plotted on newer maps of Norse ruins in the area (Gad 1967; Kort & Matrikelstyrelsen 1993) and may therefore not exist, at least not as Norse ruins. From a camp at 'Auaitirsar-bik' (3–4 km from the ice margin of the glacier?) in 1810, Giesecke (1910, pp. 257–258) described the ice margin: *This evening I went to the incredibly beautiful glacier (Sermer-soak in Greenlandic), which is surrounded by a lake. The glacier is up to 80 feet high. Its margin is split into pointed cone-shaped prisms that are separated by deep crevasses, and some of the cones are almost pyramid-shaped. The surface of the glacier has large, often undulating peaks and depressions. The first impression is ghostlike; and the surrounding, completely barren area put me in a melancholy mood; it seemed to me that I was in another world. It was midnight – I was resting alone in this depressing area, which had presumably never before been visited by any European. However, soon I enjoyed an uplifting drama in this desert when the sun rose behind this colossal mirror of ice...* (authors' translation).

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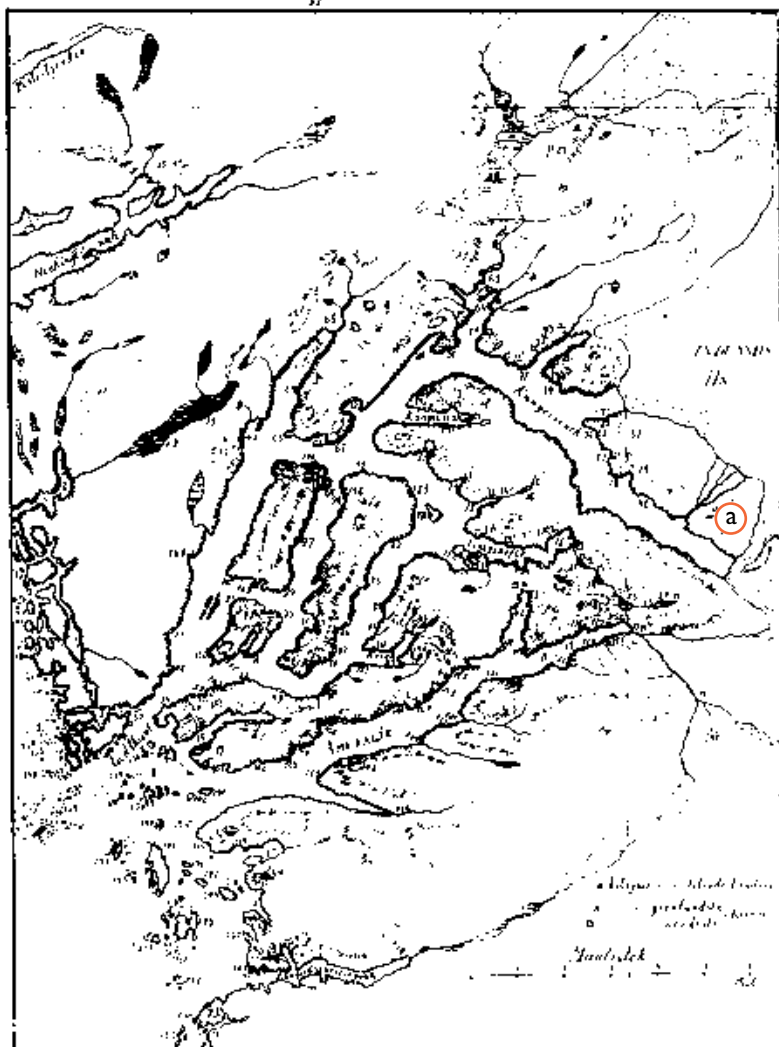
Fig. 10. Map of the 'Gothaabs Destrict' compiled by E. Thorhallesen in 1776, accompanying the report on his voyage to central West Greenland (Thorhallesen 1914). The map gives an impression of the geographical knowledge gained by the end of the 1700s of the area of Greenland that was best known at that time. The numbers show the location of some of the place names used in this study: **1:** Nuup Kangerlua (Godthåbsfjord). **2:** Ujarassuit. **3:** Kangersuneq. **4:** Narsap Sermia. **5:** Isthmus between Kapisillit Kangerluat (on the map: 'Pisigsarfik fjorden') and Kangersuneq. **6:** Kangiata Nunaata Sermia. **7:** Ameralla. **8:** Austmannadalen. **9:** Naajat Kuuat. **10:** Eqluit. The map published in 1914 measures 32 × 23 cm. E. Thorhallesen (1734–1789) was born in Iceland and was a priest in Greenland (1765–1775). He made a description of West Greenland in connection with mapping of Norse ruins.

Further observations by Giesecke may refer to the development of a trimline zone and ice-marginal lakes, but his description is unclear.

Several old maps of the area, drawn by local Greenlandic hunters, are housed in a collection at the Royal Library in Copenhagen. This collection was established on the initiative of Hinrich Rink, the inspector and later director of the Royal Greenland Trade. He encouraged local hunters to collect information and draw maps of their hunting areas. The linguist and missionary, Samuel Kleinschmidt, also participated in this collection of information; his map of the region (Fig. 11) provides the best overview of the area from this time. The map was presumably drawn in the years before 1859, based on various sources and printed in 1860 (Kleinschmidt 1860). On this map, a lake is apparently indicated at the site where Austmannadalen ends at the glacier margin, although it is possible that this lake is just two converging rivers. On newer versions of the map from the last half of the 1800s, this feature was sometimes coloured to indicate a lake.

Kleinschmidt's map was based on maps prepared by local hunters and their information, as well as on his own sketches, bearings and data from surveyors. His map is recognised as being of a high standard for the time. A comparison of Thorhallesen's map from 1776 (Fig. 10) with Kleinschmidt's map from 1860 (Fig. 11) shows major improvements. The importance of Kleinschmidt with regard to the geographic knowledge of the Nuuk region is emphasised by Wilhelm (2001, pp. 144–152).

J.A.D. Jensen reported from his visit to the area in 1885 (Jensen 1889, p. 88) that he could not enter the interior of Kangersuneq due to dense calf ice in the fjord. Furthermore he noted: *In later years the calf-ice concentration [in Kangersuneq] has increased considerably, and the Greenlanders are now rarely able to travel there, which was quite common earlier.* (Authors' translation.) This could mean that the glacier had receded. However, compared with the earlier maps of the 1800s, J.A.D. Jensen's map from his expedition is more accurate and a later version of this map was used as the base map for Bruun's systematic mapping of the Norse ruins in the area (Bruun 1917). The map of the interior parts of Kangersuneq (Fig. 7) may well have been drawn from the mountain 'Nivko' (Jensen 1889, pp. 88–89). According to Jensen's travel report, this mountain is 3130 feet high (970 m), and he noted that he had a good view of the interior landscape around the southern part of Kangersuneq. It must be the same mountain, named Nivko, which on the map published by Kort & Matrikelstyrelsen (1993) is shown with



Kort over det Indre af Godthåbs Distrikt.

Især med Hensyn til den ældre skandinaviske Bebyggelse sammenstillet efter forskellige Jagttogelser samt efter Tegninger og Beretninger af Grønlandere, navnlig Aron og Abraham paa Kangeq.

af

S. Kleinschmidt.

GODTHAAB 1860.

TAVLE 3. INSPEKTORATETS BOKTRYKKERI.

Sunde og Fjorde. 1. natallik. 2. sarfep på. 3. wauk. 4. nigtarfik. 5. hua. 6. sarfermetok. 7. kangerdluarsooruck. 8. saagmissorsup ilua. 9. narajap ilua. 10. kangerdluarsook. 11. kangerdlua. 12. tasiussan. 13. ilua. 14. påtussox. 15. amitsarsuk. 16. kapiagdlit. 17. amiragda.

Indsøer. 18. taserossuk. 19. ipitakip tasia. 20. taserossuk. 21. nagtoralinguit tasia. 22. igdlorsuit tasia. 23. apulitup tasia. 24. tungmeragdlup tasia.

Fjelde m: m. 25. kaksatsik. 26. kuaggek. 27. kingigtok. 28. irial. 29. nagsasit kál. 30. isvajuagtok. 31. sigtorit. 32. kangerdluitok. 33. tarsaartok. 34. ujaragtok. 35. kerdloatsiat. 36. itiaartok. 37. natarassuk. 38. suluresugut. 39. piagpacfuta. 40. uorassasok. 41. kingak. 42. nákaigugtok. 43. sermitsiak [Sæden]. 44. narajap. 45. akagdluk. 46. apulitok. 47. pingorabak. 48. inagsugsuus. 49. oviartorfik. 50. arnilok. 51. isnarssungup kull (Store Malene). 52. sungsugsuus (Lille Malene). 53. kingigtorsua. (Hjortetakken). 54. narajap kingigtorsua. 55. saagmissorsuk. 56. merkuitsok.

Forskjellige benævnte Egne. 57. nívarssualtan. 58. kasigánguit. 59. kasitoguit. 60. pågtorfik. 61. kanásut. 62. ipitake. 63. nógarsnugsua. 64. norssarsuk. 65. kugasuk. 66. itioqa. 67. nuualugtok. 68. nógarsungua. 69. higssup ohua. 70. igdlorsuit. 71. kugssogassorsua. 72. soppalætok. 73. ujaragsuit. 74. sarkogua. 75. narsak. 76. mánik. 77. igdlorsuit. 78. katiqok. 79. iviangiussánguit. 80. umívit. 81. nívarsiat. 82. naujarsuit (kukik). 83. abúerka. 84. sgdliak. 85. talorsuit. 86. itivarsnagugtok. 87. topaguit. 88. sigsarigugua. 89. kingimánguit. 90. ikátok. 91. pungtorfik. 92. serfarsuit náat. 93. séreiook. 94. ianguit náat. 95. avolgsarnerjok. 96. aorait náat. 97. okerdluk kangerdluk. 98. unalioguit. 99. nívarnok. 100. híverpagsuit náat. 101. uppi. 102. arnilok. 103. nógarsungua. 104. itivara. 105. itivara kangerdluk. 106. tuapagsuit. 107. akullissassak. 108. nípinga. 109. unangit. 110. sarsulik. 111. nonagigook. 112. sarsjamenek. 113. itivlek. 114. náa. 115. nívarsiat (?). 116. igdlorduit. 117. niakóssat. 118. serfat. 119. tuperdluit. 120. ovaluit kangerdlit. 121. náluk. 122. iterdlak. 123. kangerdluk saagmissok. 124. kasigánguit. 125. narssarsuk. 126. ovaluit párdit. 127. appánguit. 128. amitsorsua. 129. kerdloat. 130. natluglek.

Øer. 131. kangerssuk. 132. ineriguit (Ilaaheta Ø). 133. narajugtok. 134. kitiguit (Rokberne). 135. igssingassungua (Jacobsholm). 136. amáan. 137. kaksat. 138. ikássat. 139. angissungua. 140. kingigtok. 141. stóntá. 142. nisugtút. 143. naujardlugtút. 144. nagssagdlit. 145. nagsorsua. 146. akilla (Hjortetallik). 147. kigtorká. 148. ukerfarsua. 149. nilangarsuit. 150. amáat. 151. tuperssuáttit. 152. stóntá. 153. siglut.

Nyere Hustomter. 154. igdlucinerit (Egedes første Koloni). 155. igdlurpait. 156. sermitsiap igdluc. 157. erasup igdluc. 158. igllinguss. 159. ikátsiat. 160. hássungsup igdlua. 161. hássup igdlua. 162. kerdluak. 163. itivlíngua. 164. narajap.

Pladser beboede 1859-60. 165. kangek. 166. narsak. 167. ukerfarsuit. 168. sárdlok. 169. sarsuk. 170. nóraok. 171. amáan.

Fig. 11. Map of the Nuuk area (title in Greenlandic). The Danish text below the map translates: *Map of the inner part of Godthåb District, with special regard to the former Scandinavian settlements. Compiled from various observations, as well as from drawings and accounts by Greenlanders, especially Aron and Abraham from Kangeq. By S. Kleinschmidt, Godthåb 1860. Printed in the printing office of the Inspectorate.* (Authors' translation.) The Danish headings to the right of the map translate as follows: **Sunde og Fjorde**: straits and fjords. **Indsøer**: lakes. **Fjelde m:m::** mountains etc. **Forskjellige benævnte Egne**: various mentioned areas. **Øer**: islands. **Nyere Hustomter**: newer house ruins. **Pladser beboede 1859-60**: Inhabited settlements 1859-1860. The legend translates as follows: **betegner ... beboede Pladser**: designates ... inhabited settlements. **... grønlandske Ruiner**: Eskimo ruins. **... nordiske Ruiner**: Norse ruins. The scale (**Maalestok**) is in Danish miles (1 Danish mile = 7.5 km); a: Akullersuaq. The map is reproduced from Gulløv (1983). A printed version of the original map is in the Royal Library in Copenhagen; the map in this version measures 26 × 19 cm. S. Kleinschmidt (1814-1886) was a teacher at the Teacher's College in Nuuk (Godthåb Seminarium); he published a famous Greenland grammar and added many details to the geographical knowledge of West Greenland.

an altitude of 924 m a.s.l., and which is located on the south-western side of Kangersuneq near the settlement Kapisillit. Jensen also described ice-dammed lakes along the south side of Narsap Sermia on the semi-nunatak Nunatarsuaq and their draining through Narsap Sermia and he mentioned the innermost semi-nunatak Nuna-taarsuk. In view of the details provided, the approximate position of the front of Kangiata Nunaata Sermia south of the semi-nunatak Akullersuaq may be realistic (Figs 3, 4), but the front may also have been copied from Kleinschmidt's or other early maps from the middle of the 1800s.

The following information about the area between Kangiata Nunaata Sermia and Ameralik fjord in 1888 is taken from F. Nansen's description (Nansen 1890). Nansen crossed the Inland Ice from South-East Greenland to Ameralik fjord in West Greenland. He described the descent from the Inland Ice and compiled a map over parts of the ice margin, the ice-dammed lakes Isvand and Langvand and the valley (Austmannadalen) leading down to Ameralla fjord (Fig. 9). All three names were given by Nansen's expedition. The area was mapped by O.C. Dietrichson; only the western part of it concerning Isvand is shown here (Fig. 9A). This map from 1888 shows that the marginal lakes are situated inside the trimline zone, which must have formed before this year. If Kleinschmidt's map from 1860 shows a lake at this site, Isvand must have existed around or before the middle of the 1800s. Initial thinning of the glacier implies that recession from the maximum extent of Kangiata Nunaata Sermia began before the visit by Nansen's expedition. The following recession can be seen on aerial photographs from 1936 to 1985 (Fig. 9B).

The Norse ruins in Austmannadalen were located in 1934 and excavated in 1937 (Roussell 1941, p. 14). In connection with these activities, the area was covered by aerial photographs in 1936. The photograph in Fig. 9B from 1968 shows the eastern part of Austmannadalen with the ice-dammed lakes Isvand and Langvand. The glacial extent in 1936 can be compared with the situation in 1888 (Nansen 1890, map; Fig. 9A), as well as with an aerial photograph from 1985 and an ASTER image from 2010 (Fig. 12).

The photograph from 1968 shows the Inland Ice margin surrounded by a wide trimline zone. It is difficult to differentiate between the ice-dammed lakes Isvand and Langvand (Fig. 9B) and the surrounding trimline zone as the lakes were filled with the same silt that covers the vegetation-poor trimline zone; this is in marked contrast to other lakes in the area that appear black on the

photographs. The extent of the trimline zones indicates that the maximum coverage of the margin of the Inland Ice occurred before 1888, but also that the ice margin at this locality in 1888 had already receded 2–3 km from the Little Ice Age maximum. On the aerial photographs from 1936 and subsequent years, a series of ice-margin features, which must have formed during an advance before the 1930s, can also be seen. They can be followed down to the former semi-stable front of the Kangiata Nunaata Sermia glacier system situated *c.* 12 km behind the Little Ice Age maximum. The stade marked by these moraines is the 1920 stade mentioned earlier.

On the aerial photographs from 1936, an ice-free headland, peeping out from the ice margin in the lake, is seen. Following recession until 1985 (Fig. 9B), this headland became an island (see arrow on Fig. 9B) and the recession of the ice margin during this period must be *c.* 2 km. The shape of the Isvand lake in the period 1936–85 remained unchanged, indicating a nearly permanent lake level at *c.* 360 m a.s.l. (Kort & Matrikelstyrelsen 1993), with no periodic sudden drainage of Isvand under or through Kangiata Nunaata Sermia to Kangersuneq and with a permanent discharge through Austmannadalen.

Comparison of the 1985 photograph with a Landsat image from 2009 shows a dramatic change in the area. Satellite images from between 1987 and 2010 indicate that the shrunken Isvand lake underwent sudden drainage events via Kangiata Nunaata Sermia in 2004 and 2009. It appears that the continuous thinning of Kangiata Nunaata Sermia resulted in drainage of Isvand. The fluvial discharge through Austmannadalen to Ameralla and Ameralik fjords must now be just as modest as it was during the Norse period. However, the area formerly covered by Isvand is now covered by a layer of silt and the head of Ameralla is filled up with extensive tidal-flat silt accumulations; these features testify to the former influence of Isvand and its drainage through Austmannadalen.

Photographs taken by Dirk van As on 26 August 2010 apparently show a renewed filling up of the ponds of the former Isvand. This is also seen on ASTER images from earlier in 2010 (Fig. 12). Presumably the lake remnants are now partly emptied by periodic drainage via Kangiata Nunaata Sermia.

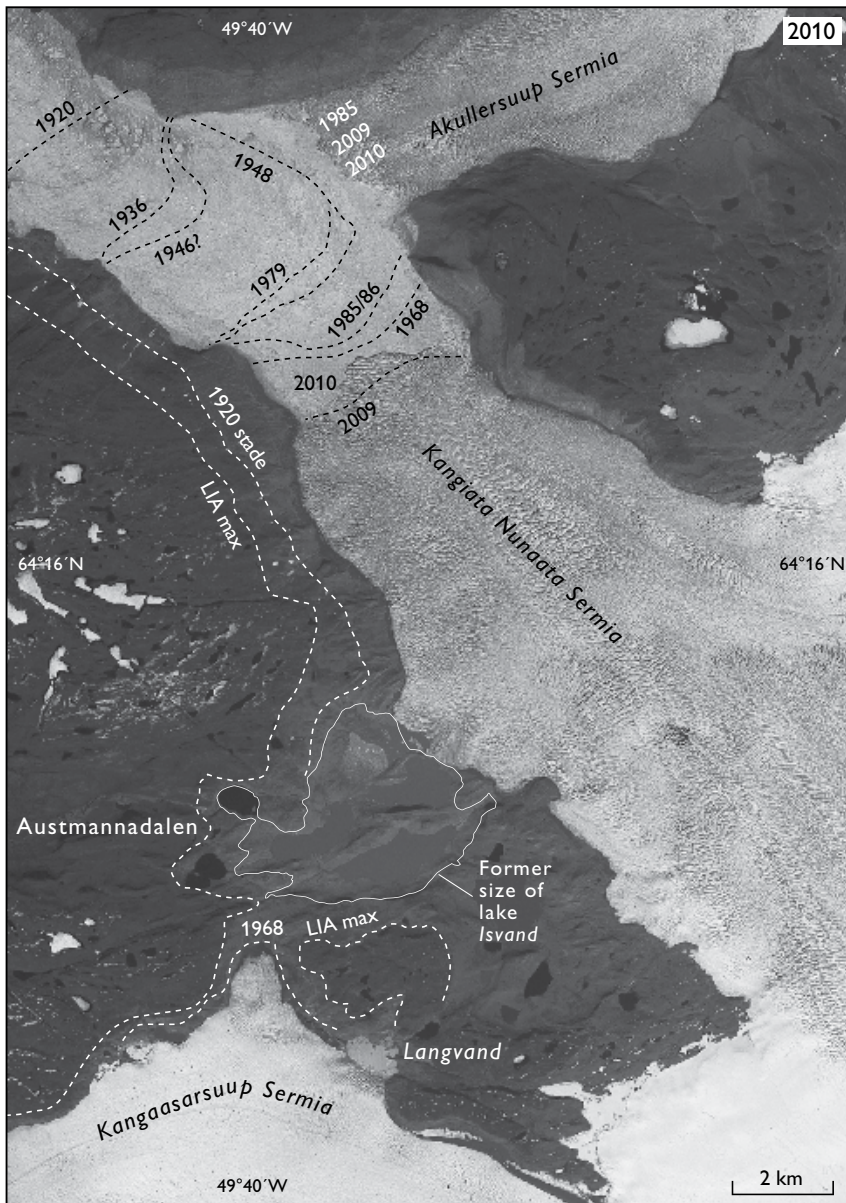


Fig. 12. Advanced spaceborne thermal emission reflection radiometer (ASTER) satellite image of the area in front of Kangiata Nunaata Sermia and former size of lake Isvand showing the situation in 2010. The outline of the former lake Isvand in 1968 is shown with white lines (see Fig. 9B). The approximate positions of the front of Kangiata Nunaata Sermia are shown for the period c. 1920–2010; the Akullersuup Sermia ice front remained nearly stationary between 1985 and 2010. **LIA max**: Little Ice Age maximum. After Weidick & Citterio (2011).

Evaluation

During the time of the Norse settlers, the river running through Austmannadalen only received water from the restricted hydrological basin of Austmannadalen and therefore had a very modest discharge. The following culmination of the Little Ice Age is uncertain, but the ice margin was probably situated at the pass point between Austmannadalen and the valley around Isvand. H. Egede visited the region in 1723 and mentioned an expanding ‘ice mountain’ and water ‘under’ (and around?) the ice (Egede 1925, p. 104). In 1729, C.E. Paars traversed the area, but he does not mention an ice-dammed lake (Bobé 1936b, pp. 186–187). It is therefore possible that Isvand

did not exist and the ice margin may have been located at the pass point between Isvand and Austmannadalen (at c. 360 m a.s.l.).

During the period when Isvand existed in the 1700s, 1800s and the 1900s, the pass between Isvand and Austmannadalen received meltwater from large parts of the western ablation areas of Kangiata Nunaata Sermia that drained via Austmannadalen to Ameralla. The lake may have had the same level at c. 360 m a.s.l. throughout the period of its existence, and the development of the lake reflects the recession of the ice margin, which led to a growth of the lake area, but without any essential change of its outline. After the rapid drainage of the

lake through Kangiata Nunaata Sermia in 2004 and 2009, the ice margin became more stable, and the fluvial regime in Austmannadalen became similar to that in medieval times. The only change compared with the medieval conditions is the blanket of silt and mud that now covers the trimline zone including the earlier lake floor of Isvand. In addition, an extensive tidal flat has formed at the head of Ameralla fjord.

The glacial events in the Austmannadalen and Isvand area can be summarised as follows:

c. 1700 – c. 1750: The advance leading to the Little Ice Age maximum presumably occurred c. 1729 and led to the formation of Isvand, the ice-dammed lake, in perhaps 1723. This implies that significant drainage of meltwater through Austmannadalen from Kangiata Nunaata Sermia took place. Subsequent minor recessions and readvances of the ice margin may have occurred during this period.

c. 1750 – c. 1800: Initial thinning of the western flank of Kangiata Nunaata Sermia. The size of Isvand depended on the minor fluctuations of the glacier. Over this time period, the area drained via Austmannadalen to Ameralla. The size of Isvand was restricted.

c. 1800–1888: The ice margin at Isvand receded c. 2.5 km, presumably with large variations. The rate of recession was reduced towards the end of the period.

1888 – c. 1920: The decreasing recession rate during this period shifted to a marked advance of the glacier margin at some time well before 1920, and ended with the culmination of the advance c. 1920. This may have been due to low average annual temperatures in West Greenland. Hence at Nuuk, a period with average annual temperatures below -2°C occurred during the period from 1873 to 1920 (Cappelen 2005). Other factors could also have influenced the mass balance of the glacier, but it is possible that the glacier did not respond until around 20 years after the onset of cooling.

Pronounced moraines referred to the 1920 stade can be followed for 16 km from Isvand to the glacier front, which at that time was located in Kangersuneq fjord, c. 12 km behind the Little Ice Age maximum position (Fig. 12). The location of the glacier margin in Isvand between the positions in 1888 and 1936 also implies an approximate culmination of this event c. 1920.

1920–1985: This period shows an increasing rate of recession beginning in 1920 and culminating c. 1955–1968 with a rate of c. 70 m per year. The recession rate fell to 12 m per year between 1968 and 1985. This pattern may reflect the temperature history in the region (Cappelen 2005). The temperature record at Nuuk shows that there was a broad maximum in mean annual temperatures around 1930, followed by slowly decreasing temperatures until c. 1960. The time period from 1960 to 1990 was characterised by fluctuating low temperatures.

1985–2010: The distance between the outer part of the trimline zone and the ice margin is rather stable at c. 5.5 km from the Little Ice Age maximum extent (Fig. 9B). Satellite images indicate that the shrunken Isvand lake in the first decade of the 2000s have drained through Kangiata Nunaata Sermia. This happened on two occasions, around 2004 and 2009. Thus after at least c. 250 years, the drainage of lake Isvand to Ameralla has changed back to the medieval conditions of the area with a very modest water discharge through Austmannadalen (Weidick & Citterio 2011).

The Kangiata Nunaata Sermia glacier system

Conditions around the head of Kangersuneq fjord after the time of the Norse settlers cannot be described better than by Roussell (1941, p. 16–18), who after a description of Ameralik and Austmannadalen writes about Kangersuneq: *This is the great fjord, now called Kangersuneq, which from the innermost part of the settlement cuts its way southeast towards the Inland Ice and embraces three glaciers, one of which is dead whereas the other two are very active, even if their calves are only small in comparison with those of North Greenland. All the same, their production is large enough to prevent the fjord from being navigable even to small craft. It is said that the chances of getting through are best in the month of August; one year at this time we succeeded with great difficulty in forcing a boat half way up the fjord, where we had to go ashore and continue on foot. Another year we arrived a little earlier, but the fairway was closed. Considering that along the east shore there are several farms, and not the smallest either, it must be assumed that conditions in the Middle Ages were different. On the other hand one cannot be too careful when summing up natural conditions in Greenland. In the same fjord it is clearly to be seen that the principal glacier once*

extended much farther out (fig. 8); the lower part of the rock sides is as if were divided into two parts along a line which slants evenly down from the present upper edge of the ice to the water about 10 km down the fjord. Above this line the fells have the usual brownish-green vegetation, but below it they are bare and barren, as if the ice had left them only recently. Now, there are ruins inland behind the place which would then have been the front margin of the glacier, which seems somewhat incredible; can it be, then, that in the time between 1360 and now the glacier advanced and then retreated? A photograph taken by Rink (National Museum archives) in the 1850s shows that the conditions were exactly as they are today. And one is tempted to say that if eighty years cannot spread the vegetation, the situation may just as well be eight hundred years old.

The fjords then as now were the main lines of communication for the settlements, and no one left the waterside of his own free will. Nevertheless, in both the Vatnahverfi of the East Settlement and to some extent in the West Settlement there are farms lying several hours' journey from the landing place (fig. 9), and accordingly this must be taken as evidence of the extraordinary intensity of the settlement. In the West Settlement there is the possibility that these inland farms were those of the last remnants of the tribe, who in these remote regions tried to find peace from the Eskimos. This, however, has been disproved with complete certainty by the excavations in the Austmannadal. The fairly rich finds of artefacts were of exactly the same types as those unearthed in the main farms by the fjord, and the bones in the refuse heaps show that even inland the large marine mammals were an important economic factor, which means that the farmers in the valley cannot have concealed themselves, but must often have gone whaling and sealing out through the fjord to the open sea.

The photograph mentioned as fig. 8 in this quotation shows ruin group 16 and the trimline zone on Akullersuaq semi-nunatak, seen from the north. The photograph by Rink mentioned in the text is also shown here (Fig. 13A). Roussell's fig. 9 shows an inland Norse farm in the innermost part of Austmannadalen. The Eastern Settlement refers to the Norse settlements in South Greenland and the Western Settlement to the Norse settlement in the Godthåbsfjord region. Little is known about the innermost parts around Kangiata Nunaata Sermia from the 18th century. On Thorhallesen's map from 1776 (Fig. 10; Thorhallesen 1914) two large outlets are seen coming from the Inland Ice and calving in Kangersuneq. The northern of these outlets must be Narsap Sermia and the southern is the Kangiata Nunaata Sermia gla-

cier system, consisting of Kangiata Nunaata Sermia and Akullersuaq Sermia.

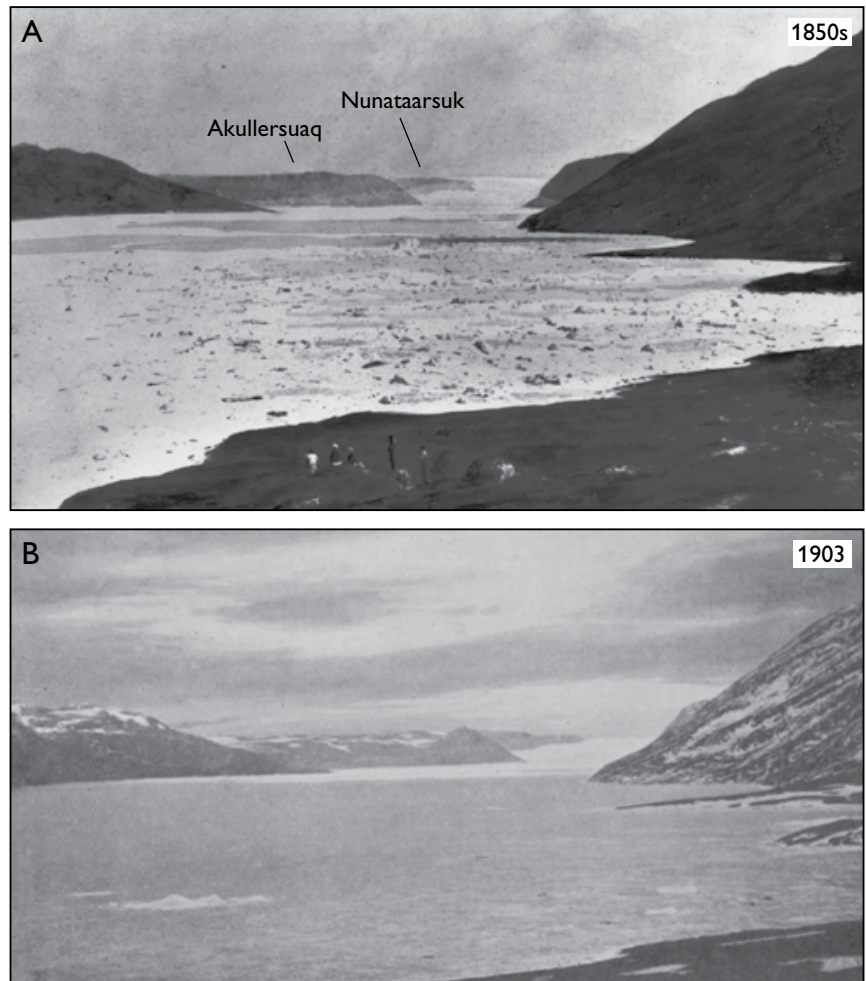
K.L. Giesecke described the area around the head of Kangersuneq, which he visited in August 1808, mentioning the place names Nunatarsuaq and Illorsuit. He may have camped between Illorsuit (ruin group 13a; Fig. 7) and ruin group 15 (at Umiivik). Giesecke (1910, p. 150) described the ruins as stone heaps, traces of stone walls and single buildings, covered with soil, grass and bushes.

The following description of the Norse ruins at Saqqarsuaq is more detailed (ruin group 16, Figs 3, 7). On older maps, ruin group 16 is located on the north-western slope of the valley between Qamanaarsuup Sermia and the inner part of Kangersuneq, c. 5 km from the icefjord (Figs 3, 7). Roussell (1941, p. 78, fig. 54) and Kort & Matrikelstyrelsen (1993), however, placed ruin group 16 near the southern tip of the semi-nunatak Nunatarsuaq, near the coast of Kangersuneq. According to his diary for 7–12 August 1808, Giesecke (1910, pp. 147–151) passed Narsap Sermia and Narsaq on his way to the head of Kangersuneq and then camped close to Narsaq due to bad weather. The following attempt to reach the front of Kangiata Nunaata Sermia glacier system took place on 12 August, when Giesecke and his companions arrived at the Illorsuit site (ruin group 13a, Figs 3, 7), described as being located at the end of Kangersuneq. They reached ruin group 16 (Saqqarsuaq) in the valley between Qamanaarsuup Sermia and the frontal parts of Kangiata Nunaata Sermia. Giesecke wrote (pp. 150–151) the following about the valley, the glaciers and the ruin group: *This valley runs to the opposite side back down to the sea, and has as the former in its centre a large raging mountain river. Part of it runs straight to the sea, and part of it runs via another curvature around a small mountain towards the glacier to the east.*

This glacier is larger, steeper and more dangerous than the one to the north-east, and there are no nunataks, one sees only the immense masses of towering ice. Here, very close to the ice, I found a well-preserved Norse ruin that protruded above the small shrubs. It formed a square and measured close to 50 × 50 feet, and in some places the walls reached c. 1 yard [1 m] above the moss, grass and shrubs. The inner walls were difficult to discern, but the shrubs indicated three main rooms. Several other buildings in this rocky valley were probably buried below the glacier long ago.

I ascended both mountains located between the described valleys in the area. These mountains are extremely fissured; the fissures are sometimes 1 fathom [2 m] or more wide and very long. The surface of the mountains is covered by enormous rock fragments, which indicates a fairly recent

Fig. 13. **A:** The front of Kangiata Nunaata Sermia, seen from the north. The photograph was taken in the 1850s by H. Rink; it is housed in the archives of The National Museum in Copenhagen. **B:** Same as above, taken by John Möller in 1903. Reproduced from Bruun (1917, fig. 11, p. 76). The location of the photographer was not exactly the same as for **A**. H. Rink (1819–1893) was a royal inspector of South Greenland and later a director of the Royal Greenland Trade. In addition to his administrative duties, he is known for his pioneering studies of the geology, glaciology and anthropology of Greenland. J. Möller (1867–1935) was born in Greenland and educated in Denmark as a printer, photographer and interpreter.



earthquake, because the rock fragments, which here and there fit together are still very sharp. On the other side of the valley, towards the glacier, a large lake is found, which drains over a bedrock threshold to the glacier and on to the sea. In the valley near the lake some reindeer grazed quietly until I was around fifty paces away...

Giesecke described the view from the mountain (c. 1000 m above sea line): *From the higher of the aforementioned mountains I could see Pisissarfik, a part of Ameraglikfjord with its small islands, as well as both glaciers in this region. The glaciers actually belong to the great ice cover that is found on all land from north-west to south-east. The sight of this ice cover is incredibly beautiful, and well worth the difficult ascent.* (Authors' translation.) 'Pisigsarfik' was the fjord that is now called Kapisillit Kangerluat; the name Pisissarfik is now used for a 1220 m high mountain peak on the northern shore of this fjord.

Following the descriptions above and a later description by Roussell, the location of ruin group 16 near

Kangersuneq can be determined. The presence of a large ice-dammed lake filling the valley in front of Qamanaarsuup Sermia must imply an advanced position of the Kangiata Nunaata Sermia system. The general description also indicates that the front was close to ruin group 16, and that the glacier dammed the meltwater from Qamanaarsuup Sermia to form an ice-dammed lake (called 'Saqqarsuaq lake' in the following). Knuth (1944, p. 100) doubted that Giesecke had visited ruin group 16, which he suggested should be located farther to the east in accordance with D. Bruun's map (Fig. 7). However, Roussell's description of ruin group 16, and Roussell's localisation of ruin group 16 to a position close to the eastern margin of Kangiata Nunaata Sermia based on the description of Giesecke, fits with Roussell's own measurements of the ruin group.

Kleinschmidt's map from 1860 (Fig. 11) shows the front of Kangiata Nunaata Sermia in a more retracted position than described by Giesecke in 1808, when Kangia-

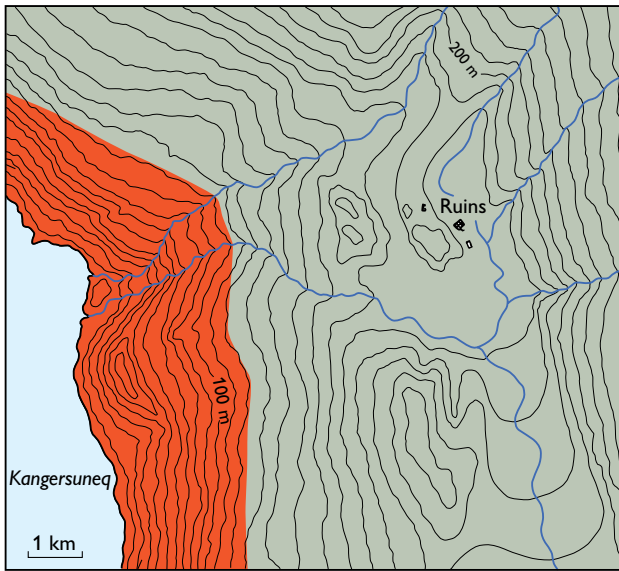


Fig. 14. Ruin group 16 and the surrounding terrain at Saqqarsuaq, Kangersuneq icefjord. Redrawn from Roussell (1941, fig. 54). The red part of the terrain indicates the estimated extent of the ice cover of Kangiata Nunaata Sermia at its maximum during the Little Ice Age. The slope of the trimline zone maximum is c. 20 m/km, decreasing towards the north. According to Roussell (1941), the altitude of the trimline zone is 123 m a.s.l., and the ruins are at 208 m a.s.l., although the latter figure is not in accord with the contours on the map. Note that this is a reproduction of the original map.

ta Nunaata Sermia blocked the valley to Qamanaarsuup Sermia leading to the formation of an ice-dammed lake. On Kleinschmidt's map the glacier front is placed south of the Akullersuaq semi-nunatak, 10–12 km from the Little Ice Age maximum position as shown by the trimline zone. The same position is shown on J.A.D. Jensen's map from 1885.

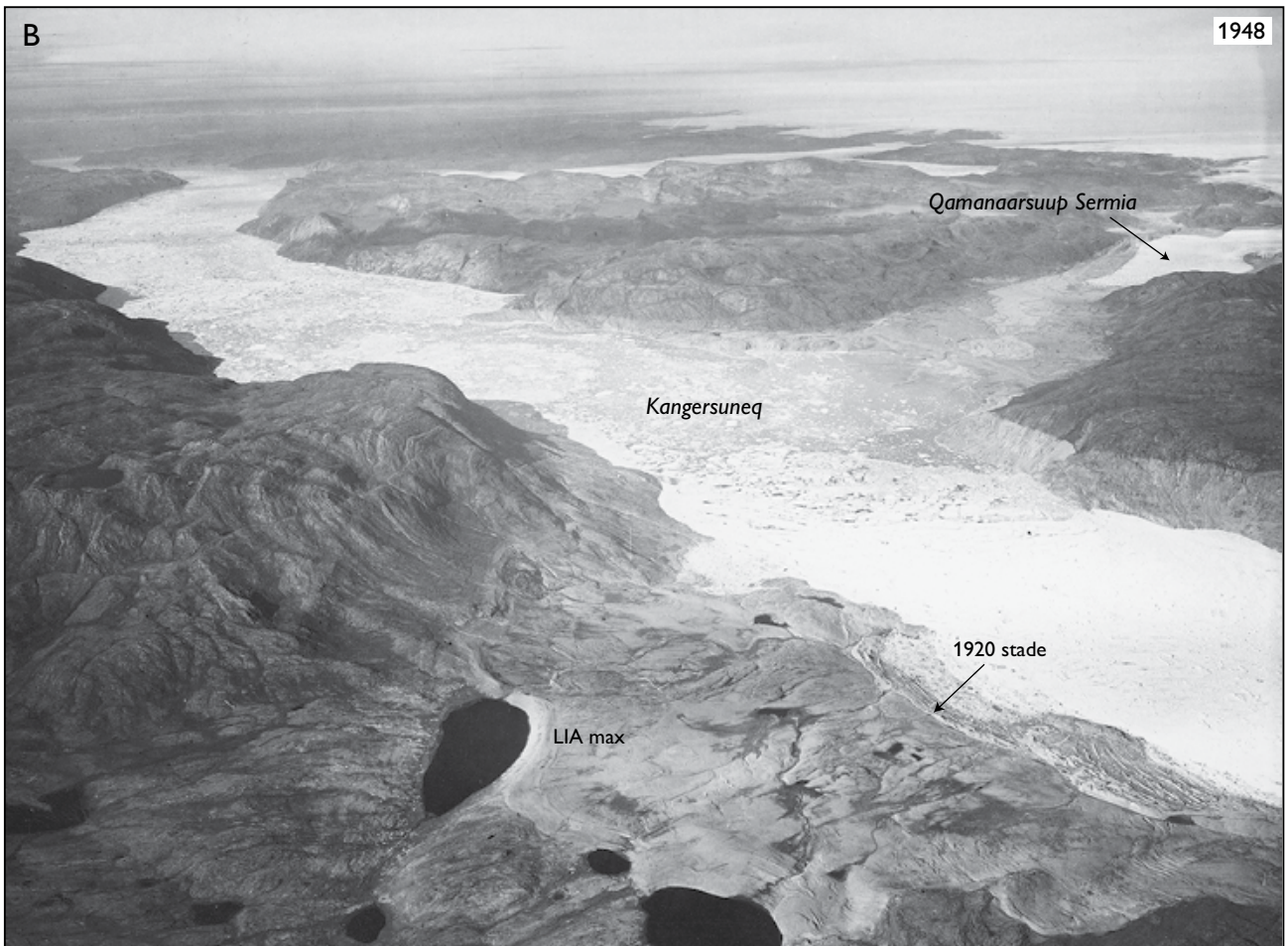
The earliest photograph of a glacier in Greenland may be that taken by Rink in the 1850s. Rink's photograph shows the front of Kangiata Nunaata Sermia, seen from the west side of Kangersuneq at the isthmus between Kapisillit Kangerluat and Kangersuneq, north-east of the Kapisillit settlement (Fig 6B). Rink's photograph, which is also mentioned by Roussell (1941, p. 17), is reproduced here (Fig. 13A). A later photograph taken from approximately the same position by John Møller in 1903 and published by Bruun (1917, fig. 10, p. 76) is shown here as Fig. 13B. The trimline zone on the mountain walls of the semi-nunataks Nunataarsuk and Akullersuaq can be seen and the position of the glacier front on both photographs can be estimated to 10–12 km south of the Little Ice Age maximum extension of the glacier. Following a

visit in 1909, Nordenskiöld (1914, p. 638–639) wrote that Kangiata Nunaata Sermia had been retreating, in contrast to Narsap Sermia which was advancing during the first years of the 1900s. Concerning ruin group 16 at Saqqarsuaq, Bruun (1917, p. 78) wrote that he was told by Greenlanders during his visit in 1903 that there was a rather small ruin, but earlier there could have been more ruins, which may have been flushed away by a river or destroyed by the ice. Both Bruun's and Nordenskiöld's evidence for recession of Kangiata Nunaata Sermia could refer to the middle or the last decades of the 1800s, and the advance leading to the 1920 stade may have started in the last decades of the 1800s or the beginning of the 1900s.

The older Little Ice Age maximum advance seems therefore to have occurred in the 1700s and Giesecke's description of a lake in the valley between Qamanaarsuup Sermia and the Kangiata Nunaata Sermia glacier system implies a situation with the front of the Kangiata Nunaata Sermia glacier system close to the Little Ice Age maximum extent. Bruun's record of other ruins at the site of ruin group 16 being removed by the nearby glacier or flushed away by its marginal drainage is easy to understand if it occurred during the maximum extent of the Kangiata Nunaata Sermia glacier system. According to the trimline zones, the glacier in this area at its Little Ice Age maximum reached an elevation of 123 m a.s.l. (Roussell 1941, p. 79). The present ruins are located at 208 m a.s.l., according to Roussell's description of the ruin site (Roussell 1941, fig. 54, p. 78), which is indeed close to the trimline zone (Fig. 14). The apparently fairly stationary

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Fig. 15. **A:** Front of Kangiata Nunaata Sermia in 1921 seen from the west. Photograph by Aa. Nissen in GEUS' glaciological archive (filed under glacier 1CH23003); Aage Nissen (1889–?) was a teacher at and later a leader of the Teacher's College in Nuuk in the period from 1920 to 1927. **B:** Oblique aerial photograph of the interior part of Kangersuneq looking from the south-west over Kangersuneq to the north-east, where the front of Qamanaarsuup Sermia can be seen, surrounded by a broad trimline zone. In the foreground a double set of marginal moraines can be seen. The outer set (labelled **LIA max**) marks the extension of the Kangiata Nunaata Sermia glacier system in the 1700s. The younger set (labelled 1920 stade) marks the maximum of a large readvance, presumably initiated during the beginning of the 1900s and culminating shortly before 1920. Geodetic Institute, route 506B-N, no. 6270, 21 August 1948.



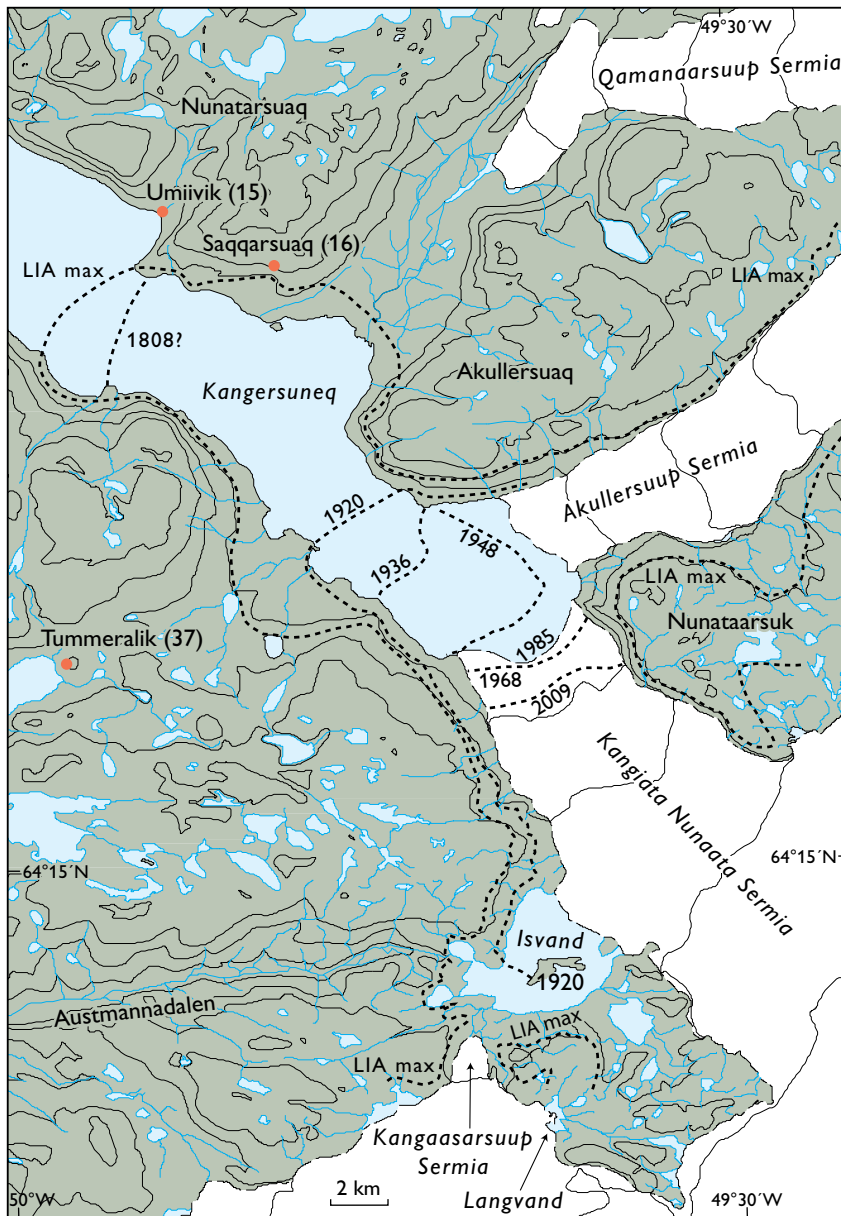


Fig. 16. Recession of Kangiata Nunaata Sermia since the Little Ice Age maximum (LIA max) in the 1700s. The oldest ice margin known after the LIA max is the presumed position of the glacier front in 1808, when the glacier prevented water from draining from the Qamanaarsuaq Sermia glacier to the Kangersuneq fjord. During later positions from c. 1850 to the 1930s, the front was located somewhere between the southern tip of the Akullersuaq semi-nunatak in the north-east and the area east-north-east of Tummeralik (ruin group 37) in the south-west. Umiivik: ruin group 15, Saqqarsuaq: ruin group 16. The map is based on aerial photographs from 1985 when the ice-dammed lake Isvand was at its maximum extent.

glacier front at the end of 1800s and beginning of the 1900s astonished Roussell (see quotation on pages 23–24). He estimated the front of Kangiata Nunaata Sermia to be c. 10 km from its Little Ice Age maximum position, indicating a century of ‘stability’ of the position of the glacier front. However, the large fluctuation during the 1920 stade must have taken place during this period.

With respect to ruin group 15 (Umiivik), Bruun (1917, p. 78) referred to the statement of the Greenlanders, viz. that it is a locality with many, partly overgrown ruins, which is in accordance with information from a visit to the place by O. Bendixen in 1916 (mentioned in

Bruun 1917, p. 72). As mentioned above, J.A.D. Jensen’s map was widely used up to the 1930s. A photograph from 1921 shows the front of Kangiata Nunaata Sermia seen from the north-west (Fig. 15A). The glacier front is located close to the moraines that formed during the 1920 stade.

During the first decades of the 1900s, ice-margin features formed in the central parts of the trimline zone (Fig. 15B). These ice-margin features are widespread and dark in several places, which imply dead ice or ice-cored moraines. Traces of this advance (the 1920 stade) are also seen at Isvand.

A more general recession began in the 1920s, but on aerial photographs from 1948 Kangiata Nunaata Sermia and Akullersuup Sermia are still confluent, forming a 'Kangiata Nunaata Sermia glacier system' where the glacier tongues have a common front in Kangersuneq. Not until the end of the 1940s was the recession so pronounced that the glaciers were split up into two separate outlets. According to a satellite image from 22 June 2009 (Figs 12, 16), continued recession has brought the front of Kangiata Nunaata Sermia to a position 21–22 km behind the position of the Little Ice Age maximum in the 1700s. During the period from 1985 to 2010, the front of Akullersuup Sermia has only retreated 1–2 km.

Evaluation

The sources from the 18th century all describe an advancing glacier. The front of calving tidal glaciers may show both annual fluctuations of up to a kilometre, with advance during the winter and retreat during the summer, and larger decadal fluctuations. The historical record can provide information about the latter, but usually only give general trends, and only rarely contribute with accurate data.

The Little Ice Age maximum extent was presumably reached for the first time in the beginning of the 1700s, but as some sources also speak about advance later in that century, it is possible that the ice margin was close to the Little Ice Age maximum throughout the century, although with minor fluctuations:

c. 1775–1810: The frontal advance of the Kangiata Nunaata Sermia glacier system may have culminated near a headland in Kangersuneq, located just south of the ruin group at Umiivik (Qassertup Nuua). Thorhallesens map from 1776 gives little information but the glacier at the head of what is called 'Ujaraksoak fjorden' on the map must be the Kangiata Nunaata Sermia glacier system. This map shows the length of Kangersuneq fjord from the mouth at Karra (Fig. 3) to the head of the fjord at the Little Ice Age maximum of the Kangiata Nunaata Sermia glacier system to be about 6 miles; since 1 Danish mile is 7.5 km (Norsk Forlishistorisk Forening 2012; Marcussen 2011), this equates to c. 45 km, a distance that is compatible with modern maps (e.g. see Fig. 3).

The overall advance ended in the 18th century, and was followed by a slow recession that may have continued to the beginning of the 19th century, when the Kangiata

Nunaata Sermia glacier system still blocked the valley to Qamanaarsuup Sermia. The 'Saqqarsuaq ice-dammed lake' existed in the beginning of the 1800s, implying that c. 1808 the glacier front was still close to the maximum extent of the Little Ice Age, which can be mapped from the well-defined trimline zone (Fig. 14).

1810–1860: During the following decades, fast recession took place, so that the front at the latest around 1860 had retreated c. 10–13 km from the Little Ice Age maximum extent. During this c. 50 year period of recession, the average recession rate was 200–260 m per year.

The information from Giesecke about an ice-dammed lake (the 'Saqqarsuaq lake') between Kangiata Nunaata Sermia and Qamanaarsuup Sermia in 1808 and the short distance (c. 5 km) from the Little Ice Age maximum of the frontal parts of Kangiata Nunaata Sermia to the 'Saqqarsuaq lake' must imply a glacier dam by a large ice body (Fig. 17A). Roussell (1941, p. 79) measured the maximum height of the trimline zone at ruin group 16 (Saqqarsuaq) to have been 123 m a.s.l., i.e. close to the lake. The exact lake level is unknown, but it was presumably c. 48 m a.s.l. (Fig. 17A). The damming ice body can scarcely have had a much smaller thickness than at the Little Ice Age maximum, and we therefore suggest that the glacier front in 1808 still had a position close to the maximum of the glacier system.

As mentioned in the introduction, depths over 600 m are found in the inner part of Nuup Kangerlua. Off Kapisillit, the bottom of Kangersuneq is flat at c. 340 m, and no indication of a submarine threshold or moraine is observed that may have been formed during the Kapisigdlit stade. In contrast, ice-margin deposits from the Little Ice Age maximum form a threshold at 150 m below sea level (b.s.l.). The 1920 stade is only marked by a small rise of the sea bottom to a depth of c. 300 m. It is possible that both thresholds were anchoring points for the front for longer periods, but it is not known if the thresholds consist of bedrock or ice-margin deposits (Fig. 8).

The increase of ice in Kangersuneq before 1885 (J.A.D. Jensen 1889, p. 88) could have been connected to a large breakup during the thinning of the outermost part of the Kangiata Nunaata Sermia glacier system. As large calf-ice production may be a sign of a retreating glacier rather than an advancing glacier, the increased calf-ice production could indicate a period with fast recession in the first half of 1800s.

1860–1903: Information from 1850 and the following decades are based on the map of Kleinschmidt, and

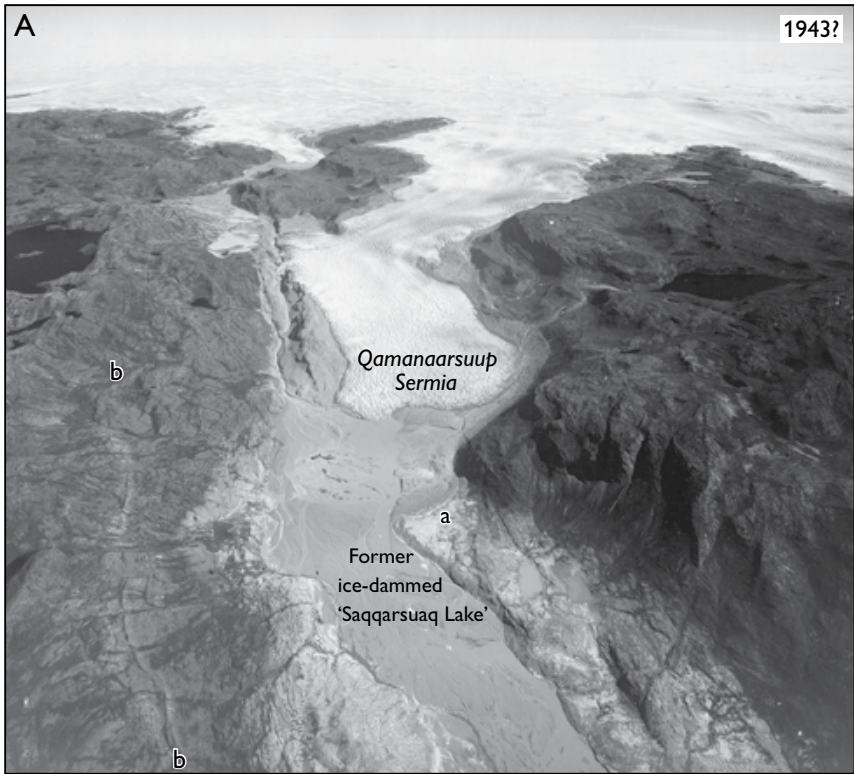
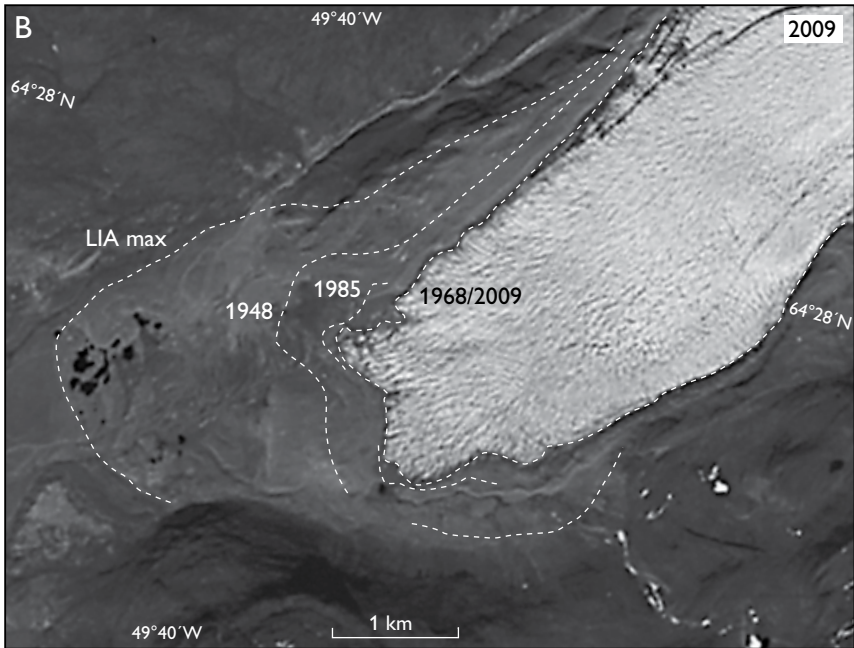


Fig. 17. **A:** Qamanaarsuup Sermia, seen from the west. In the foreground near the front of the glacier a proglacial lake terrace (**a**) is seen. It is presumably related to the ice-dammed ‘Saqqarsuaq Lake’, that occupied the valley between Qamanaarsuup Sermia and Kangersuneq until the beginning of the 1800s, as observed by K.L. Giesecke in 1808 (Giesecke 1910). **b–b** marks a moraine ridge that may be referred to the Kapisigdlit stade (tentatively dated to 8.2 ka BP). Aerial photograph, Geodetic Institute, route 505 E-Ø, no. 7418 (probably from 1943). **B:** Qamanaarsuup Sermia with frontal positions at the Little Ice Age maximum, in 1948, 1968 and 1985 according to Taurisano (2004, fig. 3.5), plotted on an ASTER image from 2009.



Rink’s and Møller’s photographs from the 1850s and 1903. They indicate that the glacier front, at least at these specific times, was located at a position 10–12 km from the Little Ice Age maximum, as also suggested by Aa. Roussell.

1903–1920: Only little information is available from the first two decades of the 1900s. Although it could seem that the front was essentially stable from *c.* 1850 to *c.* 1920, however, significant changes in the frontal position must have occurred during this period. A pho-

tograph by Aa. Nissen from 1921 (Fig. 15A) shows the front of the Kangiata Nunaata Sermia glacier system. The glacier front was close to, but behind the moraines of the 1920 stade, and the 1921 glacier front was closely surrounded by fresh moraines deposited just prior to 1921. The moraines are the result of a marked advance, presumably initiated one or two decades before. The ice-margin features can be seen in the trimline zone on the west side of Kangiata Nunaata Sermia, extending from an altitude of around 400–450 m a.s.l. in the Isvand area (*c.* 15 km from the front) and down to the calving front in Kangersuneq fjord. A large initial recession must have taken place before *c.* 1900, but how far up the Kangersuneq fjord is not known. The following advance probably occurred during the first two decades of the 1900s.

A clear colour difference is seen between the trimline zone below and above the line of the 1920 stade on photographs and satellite images (Fig. 9B). The upper and older part of the trimline zone, which is from the 1700s, is characterised by widespread lichen and vegetation cover, as well as some soil development. The lower and younger part of the trimline zone was not left finally by the glacier until after *c.* 1920, and this part is therefore more barren than the older part. However, both parts can be characterised as ‘barren ground’ that is clearly different from the surrounding areas with older vegetation.

1920–1985: A period of fast recession of the front took place after *c.* 1920. Around 1950–1960, this led to a separation of the Kangiata Nunaata Sermia glacier system into the Kangiata Nunaata Sermia proper and Akullersuup Sermia, which is now a separate outlet from the ice sheet. The later development of the frontal position of Kangiata Nunaata Sermia is shown by the following estimated positions of the front behind the Little Ice Age maximum: 1920: 11.5 km, 1921: 11.8 km, 1936: 14.5 km, 1948: 18 km and 1968: 20.5 km (Fig. 16). An advance took place in the following years and in 1985 the front had advanced to a position *c.* 20 km behind the Little Ice Age maximum, as also pointed out by Timm (2010).

1985–2010: By 2009, the front of Kangiata Nunaata Sermia reached a position 22 km behind the Little Ice Age maximum. According to a 2010 ASTER image, however, it had advanced to a position *c.* 20.5 km from the Little Ice Age maximum. These secondary fluctuations of the frontal position during the last decades presumably reflect minor annual fluctuations of the glacier, the frontal position of which is determined by anchor

points such as submarine thresholds or other features of the fjord topography (e.g. Mercer 1961).

Regarding the recession of Akullersuup Sermia, we note that the height of the trimline zone above this glacier also indicates a marked thinning, as recorded for Kangiata Nunaata Sermia. After the split of the glacier system, the front of Akullersuup Sermia has receded only *c.* 2 km between 1985 and 2010.

Qamanaarsuup Sermia

This glacier has already been mentioned above in connection with the formation of the ice-dammed ‘Saqqarsuaq lake’ in front of the glacier (Fig. 17A). Its more recent development is described below. The glacier and its surroundings are located in the most remote part of the Kangersuneq region. Although its name refers to reindeer hunting (*qamavoq* = wait for it), it must have been difficult to access during the Little Ice Age maximum in the 1700s when the valley in front of it was closed by the ‘Saqqarsuaq lake’ and the Kangiata Nunaata Sermia glacier system. Hence the first information about this glacier and the valley in front of it was published following the mapping by J.A.D. Jensen in 1885 (Jensen 1889). The glacier is now surrounded by a trimline zone, the outermost parts of which appear to be related to the proglacial, ice-dammed lake that may have existed in the 1700s.

Morphological evidence of a former ice-dammed lake was also reported by Andsbjerg (1985). This lake may have drained in the first half of the 1800s, but a more complete understanding of the history of this lake must be left to future investigations of the lacustrine deposits in the valley.

The oldest aerial photograph that covers Qamanaarsuup Sermia dates from 27 August 1936 (Geodetic Institute route 61A, no. 25283, not shown). Unfortunately, this oblique photograph was taken from a distance and the glacier lobe can only be faintly seen surrounded by a trimline zone.

Taurisano (2004) puts the last advance to the Little Ice Age maximum at 1880–1890 on the basis of the lichenometrical dates of Beschel (1961). However, Beschel’s data do not preclude that the maximum position was reached earlier, in the 1700s. Beschel’s data on growth rates of lichens are from central West Greenland, far from the Kangersuneq region, and are mainly based on fluctuations of local, small glaciers. Subsequent frontal positions

of Qamanaarsuup Sermia between 1948 and 1993 were mapped by Taurisano (Fig 17B; Taurisano 2004, fig. 3.5).

From the Little Ice Age maximum to 1948 the glacier receded 1.5 km, corresponding to an average value of 24 m per year, if recession began in 1885 as suggested by Taurisano. From 1948 to 1968, the glacier receded 0.5 km, corresponding to 25 m per year. Between 1968 and 1985, recession was very limited. From 1985 to 1993, the glacier front receded *c.* 100 m, corresponding to 13 m per year. Finally, on a Landsat image from 2009 the front was at approximately the same position as in 1993.

On the basis of aerial photographs from 1968 and 1980, detailed maps (1:10 000, contour interval 10 m) were made by Knudsen (1983). From a comparison of the two maps, Knudsen concluded that the glacier had receded 25–50 m and he recorded a thinning near the snout of the glacier to less than 10 m. The contour lines at higher elevations were nearly identical in the two years.

Evaluation

Little is known about the fluctuations of this glacier before the 1900s. Its frontal deposits at the former ice-dammed lake may indicate that the maximum extent of the glacier and the formation of the ice-margin deposits took place at the same time as the possible formation of the lake, so that the history of this glacier may be similar to that of Kangiata Nunaata Sermia. However, the later recession of this land-based glacier so far only amounts to around 2 km. During the more detailed measurements of the changes of this glacier between 1968 and 1985, the recession was only 25–50 m, i.e. 1–3 m per year. The presumed ice-dammed lake ('Saqqarsuaq lake') must have been emptied during the recession between 1810 and 1850. The terrace in Fig. 17A marked 'a' may be a remnant of the alluvial plain that formed during the Little Ice Age maximum; the surface of the terrace would thus mark the level of the former 'Saqqarsuaq lake' at its maximum extent. The elevation of the terrace was measured by GPS in the summer 2011 to be 48 m a.s.l. (Dirk van As, personal communication, 2011), which must indicate the maximum elevation of the lake level. Because the elevation of the former lake bottom is 0–30 m a.s.l., the lake must have been shallow even though it had an extent of *c.* 10 km².

Observations of the frontal positions of Qamanaarsuup Sermia in 1948, 1968 and 1993 (Taurisano 2004) show positions of 1.5, 2.0 and 2.1 km behind the Little

Ice Age maximum, respectively, and indicate that the recession rate began to decrease in the 1960s, possibly induced by a minor cooling of the climate. According to a Landsat image, in 2009 the frontal position was close to that of 1993, as mapped by Taurisano (Fig. 17B).

According to Taurisano (2004, pp. 36–39), the lower and upper parts of Qamanaarsuup Sermia showed marked differences in surface elevation changes from 1968 to 1985. The upper part thickened by 1 m per year whereas the lower part thinned by 0.3 m and is gradually being transformed into dead ice (see frontispiece).

Narsap Sermia

The surroundings of Narsap Sermia have been described several times due to the occurrence of Norse ruins (groups 11 and 12; Figs 3, 7) near the front of Narsap Sermia (Figs 3, 7, 18). Early records of these ruins are from Bruun (1917, pp. 75–77), who included information from O. Bendixen from a journey in 1916 and from Greenlanders who noticed these ruins close to the front of the glacier.

Narsap Sermia was plotted on the early map by Thorhallsen (Fig. 10). Although his map is sketchy and does not depict ruin sites in this area, the glacier front is, as today, shown at some distance from Kangersuneq. This is in contrast to the more northern fjord, on his map called 'Naviangoæt', where the Norse ruin groups 7 and 8 are located (Figs 3, 7).

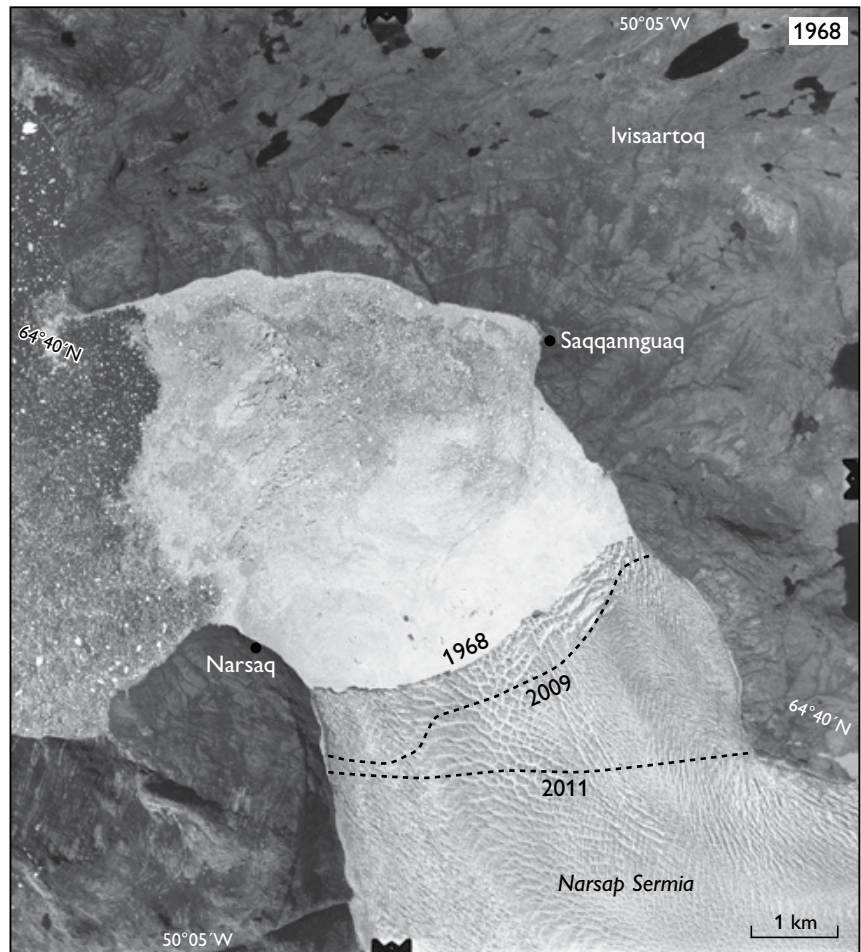
The proximity of the front of Narsap Sermia to Kangersuneq and to Narsaq was also recorded by Giesecke (1910, p. 147–148). On 7 August 1808, he passed its front on the way from Ujarassuit Paavat to Narsaq (ruin group 12, Figs 3, 7), and continued to a place called 'Narkseeitsiaq', where he camped. The camp site must have been relatively close to Narsaq since he described calving noise from the front of Narsap Sermia.

J.A.D. Jensen's map, based on observations in 1884 and 1885, shows a position of the front closer to Kangersuneq. In his description of ruin groups 11 and 12, Jensen does not mention the nearby front of Narsap Sermia (Jensen 1889, p. 110).

From a visit in 1909, Nordenskiöld (1914) reported that Narsap Sermia had advanced during the first years of the 20th century; the advancing glacier had buried several hunting camp sites.

D. Bruun (1917, p. 75) noted, when describing ruin group 11 (Saqqannguaq), that ruins are found at the

Fig. 18. Narsap Sermia. The frontal position of the glacier is taken from a Landsat image from 2009 and drawn on an aerial photograph from 16 August 1968, Geodetic Institute, route 281T, no. 70. In 1968, the Norse ruins at Narsaq and Saqqannguaq were located around 1 and 2.5 km from the glacier front, which is the local Little Ice Age maximum of the glacier. Marked recession of the centre line of the glacier (*c.* 1 km) occurred between 2009 and 2011.



shores of rivulets. This is based on observations by O. Bendixen from his voyage in 1916. For ruin group 12 (Narsaq), D. Bruun (1917, p. 77) reported that at Narsaq, between a steep headland and the end of the glacier, there is a small ruin on the slope immediately above the fjord. Some of the ruins had slipped into the water.

The descriptions of Roussell, after visiting the area in the 1930s, give no new information about Narsap Sermia. Aerial photographs and satellite images from 1936 onwards show that the front of Narsap Sermia has been located at about the same place. It appears that the front of this glacier may have been relatively stable for around 250 years, although this conclusion is based on scattered information. General recession of the glacier front seems to have started in the first decade of this century.

Evaluation

It appears from the map of Thorhallesen (1914; Fig. 10) that the front of Narsap Sermia was situated in a small fjord branch, a short distance from Kangarsuneq. The same is seen on aerial photographs from 1936, 1948 and 1985, as well as on satellite images from 2009 and 2011. The glacier is only surrounded by a narrow trimline zone, which supports the proposal that it has not fluctuated much during the past centuries.

Based on studies of aerial photographs and satellite images, Timm (2010) considered the glacier stationary or advancing between 1936 and 1985, but it was suggested that the central parts of the glacier front receded *c.* 700 m between 2002 and 2009. This is in accordance with a narrow trimline zone developed at the lower flanks of the glacier. It appears to be the first signs of the following frontal recession of around 1 km that occurred in the period 2009–2011 (Landsat image, 14 July, 2011), as measured along the centre line of the glacier (Fig. 18).

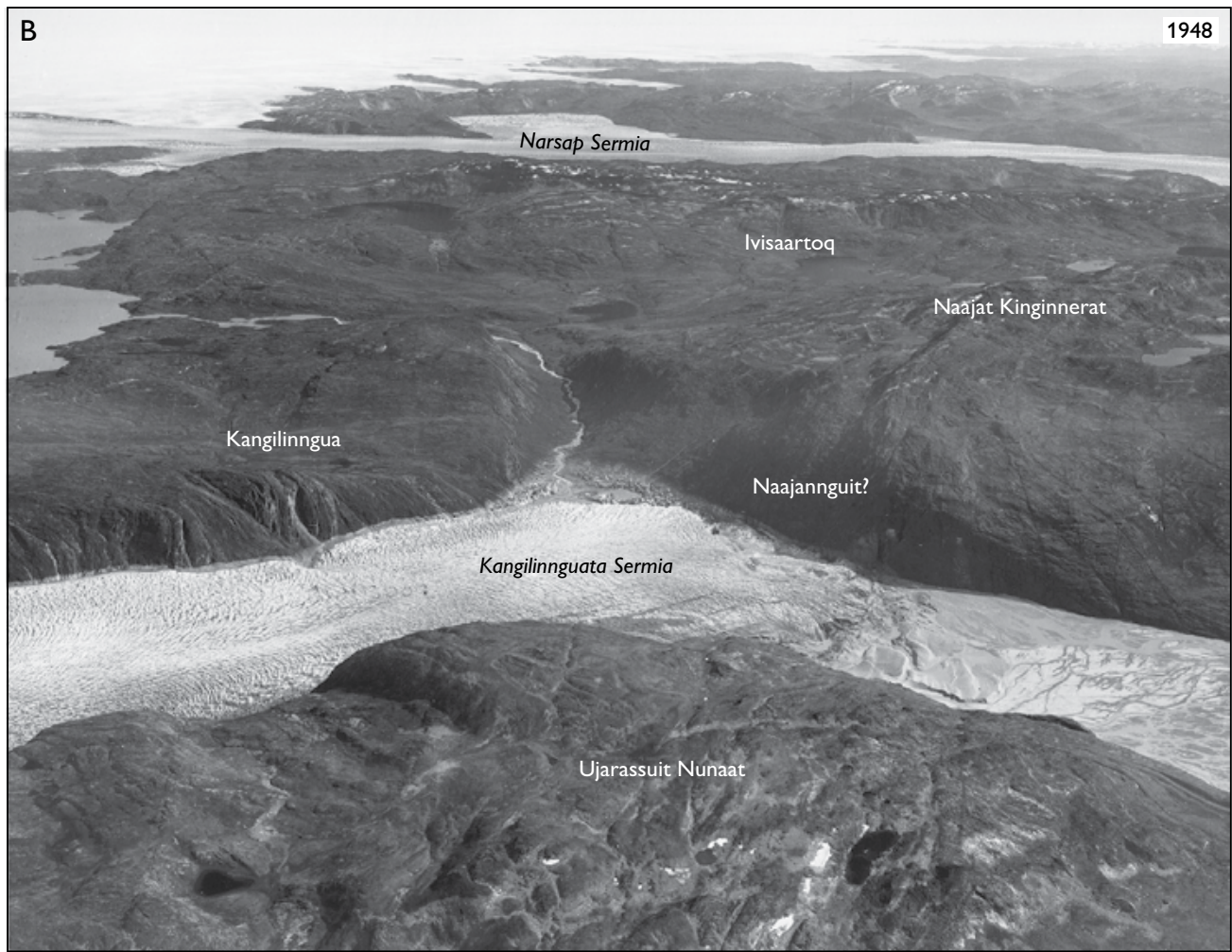


Fig. 19. **A:** Kangilnguata Sermia on 25 August 1930, seen from a height of 630 m a.s.l. (Gripp 1975, plate 2, fig. 2). The arrow indicates the location of Norse ruin group 8 (Figs 3, 7), which was mapped, described and photographed with the glacier in the background by Roussell in 1934 (Roussell 1941, pp. 76–78). **B:** Kangilnguata Sermia seen from the north in 1948 (Geodetic Institute, route 505-ES, no. 1948). The lake south of the glacier front (top left) receives large amounts of meltwater from the Inland Ice margin south of Kangilnguata Sermia. This meltwater drains to the Ujarassuit Paavat fjord, to the right (see Fig. 3) via the outermost part of the front of Kangilnguata Sermia.

Kangilnguata Sermia

In contrast to the other outlets around Kangersuneq described above, the interior of Ujarassuit Paavat was described by Hans Egede, who lived in Greenland from 1721 to 1736. His descriptions of the Ujarassuit Paavat fjord region concentrated on a large group of ruins 8 km from the glacier (Ujarassuit; ruin group 7, Figs 3, 7), whereas only few persons have described the more modest ruin group at Puilasoq (group 8, Figs 3, 7), situated only c. 2 km from the glacier front. This is because a c. 7 km long tidal flat separates the navigable outer part of Ujarassuit Paavat from the inner part of the fjord with the Puilasoq ruin group 8 and the Kangilnguata Sermia glacier.

E. Thorhallesen seems to have visited the inner parts of Ujarassuit Paavat. On his map from 1776 (Fig. 10), he calls this fjord 'Naviangoæt' and the Ujarassuit site is designated 'Europ. Rudera'. The un-named ruin group at Puilasoq is marked by a single building. The ice-sheet margin north-east of Puilasoq is marked 'Jökull'. In his description of the locality, Thorhallesen (1914, pp. 46–47) wrote: *At high tide this bay is twice as long, and from a high mountain I saw three or four more rudera [ruins] in the area. The ruins can be seen from a great distance, because the grass, where the field has been fertilised, dies and becomes red in late summer, since it starts growing earlier in the spring. The glacier ice, which covers the uplands from north to south, as far as can be seen, and which covers the highest mountains, falls towards the south-east from Naviangoæt down to the sea, which is perhaps the head of Ujaraksoak fjord, unless it continues farther below the ice. Sometimes large pieces of ice fall down and float around until a strong eastern wind drives them out of the fjord.* (Authors' translation.)

Although the frontal position of Kangilnguata Sermia is not well defined, it seems that the front during the last half of the 18th century was advancing and that the glacier calved into the fjord, at least at high tide. Hence it is possible that the tidal flat in the inner part of the fjord formed after Thorhallesen's visit.

K.L. Giesecke also visited Ujarassuit Paavat. In his diary, he mentioned on 5–6 August 1808 (Giesecke 1910, pp. 145–147) the earlier visits by H. Egede and E. Thorhallesen, but he only briefly mentions the glacier. Kleinschmidt's map from 1860 (Fig. 11) depicts Ujarassuit Paavat, the bay at Ujarassuit and the head of an outlet from the Inland Ice that almost reaches the inner part of Ujarassuit Paavat. The latter outlet must be Kangilnguata Sermia. The sketchy contours of the map do

not allow us to determine the exact position of the glacier front, but it appears that the glacier did not reach the sea. After a later visit in 1885, by J.A.D. Jensen (Jensen 1889, p. 109), ruin group 8 and its surrounding area were described thus: *Should be located on the north side of Ujaragsuit's north-eastern branch, into which the Inland Ice now protrudes, transporting large amounts of clay that are deposited in the fjord, so that it becomes dry at low tide. Living Greenlanders remember that until around 1840 they could sail up this fjord branch by umiaq to a bird cliff on the south side, but the ice has advanced far beyond this place.* (Authors' translation.)

Based on the statements by Thorhallesen from the middle of the 1700s and those by J.A.D. Jensen from the middle of the 1800s, we suggest that Kangilnguata Sermia was advancing at this time and that sedimentation in Ujarassuit Paavat was increasing.

Although visited subsequently by D. Bruun in 1903 (Bruun 1917) and by O. Bendixen in 1916 (both mentioned in Bruun 1917, p. 72), no further information was provided about the glacier. Aa. Roussell, after work in 1934, provided detailed descriptions of ruin group 7 (Anavik, now Ujarassuit; Roussell 1941, pp. 32–34) and group 8 (Puilasoq, pp. 75–77, 167–171). Roussell stated that the distance from ruin group 8 to the front of Kangilnguata Sermia was around 2 km (Roussell 1941, p. 76). He published a photograph showing the glacier at approximately the same position as at present (Roussell 1941, fig. 52, p. 76).

The glacier was also described by Gripp, who investigated the glacier in 1930 and described marine faunas found in concretions in the moraine and in the alluvial plain in front of the glacier (Gripp 1932). Gripp also described the geomorphology of deposits in front of the glacier and within the glacier, where push and shear moraines occurred (Gripp 1975). Gripp (1932, 1975) published photographs of Kangilnguata Sermia (Fig. 19A). It appears that the glacier still had no pronounced trimline zone around 1930, but the glacier front was heavily crevassed and partly dominated by shear moraines and about 10 m high push moraines close to the active glacier ice. Gripp's photographs can be compared with aerial photographs of the glacier from 1948, 1968 and 1985 as well as a satellite image from 2007 (Figs 19, 20). Apart from a slight increase in the size of the superficial moraine area in 1948, only small changes are seen in the frontal appearance, in addition to a little thinning.

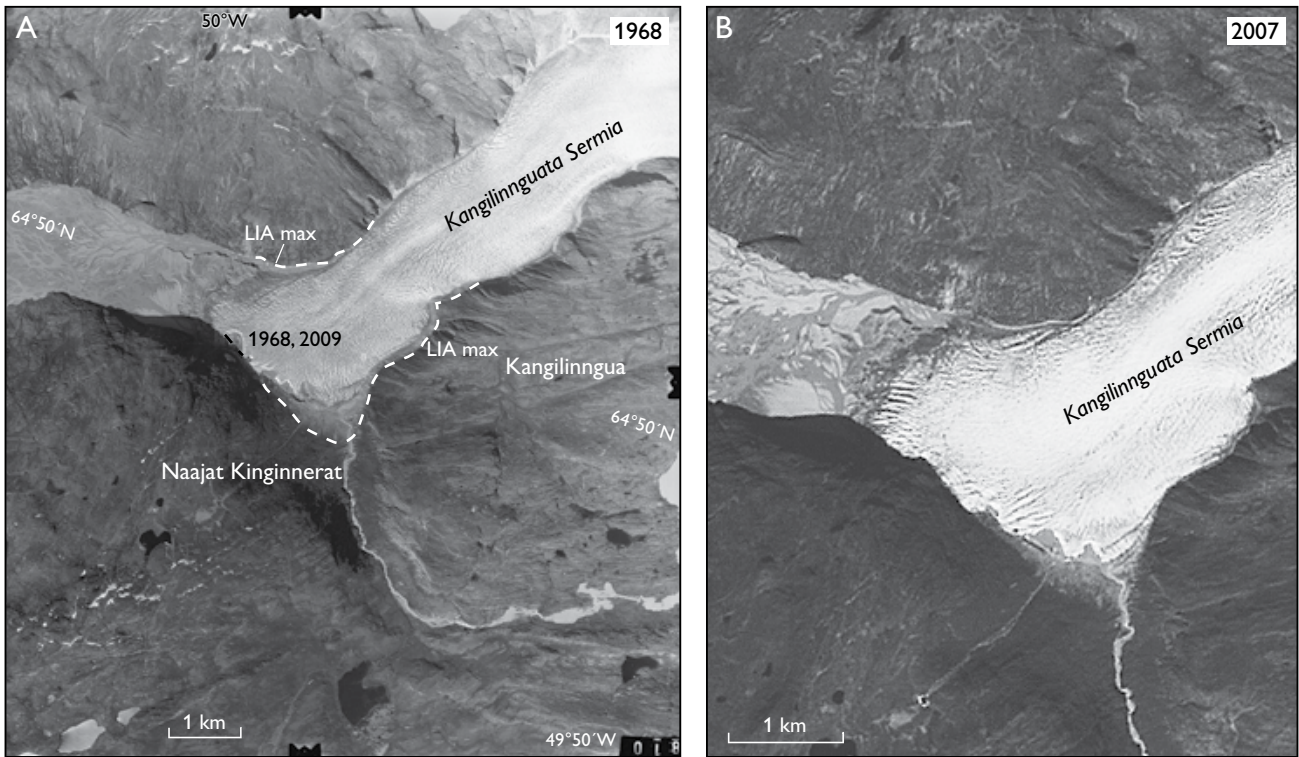


Fig. 20. **A:** Kangilnguata Sermia on 25 August 1968 (Geodetic Institute, route 281V no. 810). **B:** Kangilnguata Sermia front on 4 August 2007 (ASTER image). Comparisons between the photographs from 1930 and 1948 (Figs 19A, B), the aerial photograph from 1968 and satellite images from 2007 and 2009 indicate a slight thinning. In addition, a thin trimline zone developed around the glacier front during this 77 year period. **LIA max** (Little Ice Age maximum).

Evaluation

Thorhallesen's description from the 1700s indicates that Kangilnguata Sermia was calving in the fjord now named Ujarassuit Paavat, but called 'Naviangoæt' by Thorhallesen. It is possible that the interior part of Ujarassuit Paavat was not filled with sediments to such a high degree as at present; if so, Kangilnguata Sermia may have been a calving glacier even if the front was located at the same place as today. However, it is also possible that calf ice drifted into Ujarassuit Paavat from the Kangersuneq icefjord. From the descriptions from the 1700s and most of the 1800s, it is difficult to determine the position of the glacier front. The records state that the glacier was advancing and possibly at the same time filled the interior parts of the fjord with sediments.

Since only a narrow trimline has developed around the glacier front, its position cannot have been farther west than today during the Little Ice Age (including the narrow belt of shear moraines at the present glacier front). The formation of the proglacial tidal flat can only be explained by increased sedimentation. This is in ac-

cordance with the record by J.A.D. Jensen that the head of the fjord could be reached by boat as late as around 1840, but not at the time of his visit in 1885, due to the development of a tidal flat. The formation of this tidal flat can hardly be taken as evidence of a glacier advance, but the notes in J.A.D. Jensen's report on the glacier front passing a bird cliff may provide information about the timing and extent of the advance. Thorhallesen used the name 'Naviangoæt' for the inner part of Ujarassuit Paavat. According to L. Bobé's footnote to Thorhallesen's text (Thorhallesen 1914, p. 46), this place name can be translated as 'Naujanguit', which is used by the Greenlanders for the glaucous gull (*Larus hyperboreus*) and the Iceland gull (*L. glaucooides*); 'Naviangoæt' is thus probably a name for a bird cliff with breeding gulls. The southern side of the frontal parts of Kangilnguata Sermia borders on a 500–700 m high steep mountain slope, and the mountain is called Naajat Kinginnerat, but no bird cliff is known from the site (D. Boertmann and L.M. Rasmussen, personal communication 2011). However, this could be caused by the present inaccessibility to the place because of the advancing glacier. Confirmation

(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 Kangilinguata 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, ICG14004 and Kangaasarsuup Sermia (Fig. 2). Un-named outlets are described using their inventory code numbers according to Weidick *et al.* (1992).

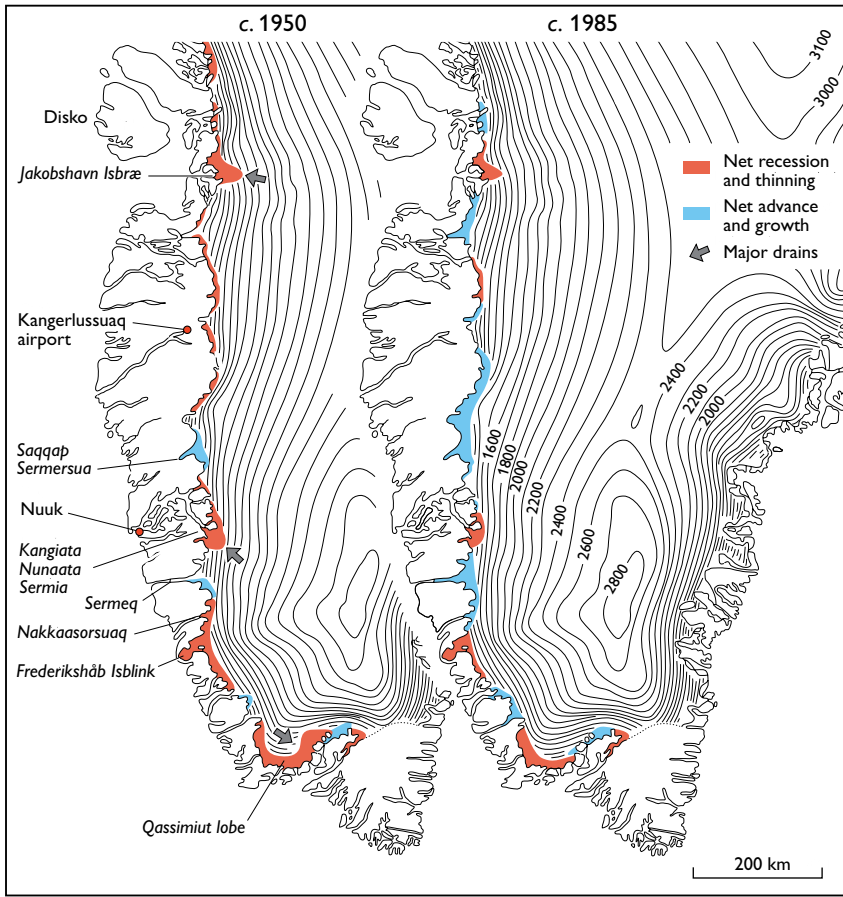


Fig. 21. Maps of south-western Greenland with ice-sheet contours from Bindschadler *et al.* (1989). The coloured zones show recession or growth in c. 1950 and c. 1985 (Weidick 1991a, fig. 1, p. 40). The grey arrows show the major calf-ice producing outlets (Jakobshavn Isbræ, Kangiata Nunaata Sermia and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

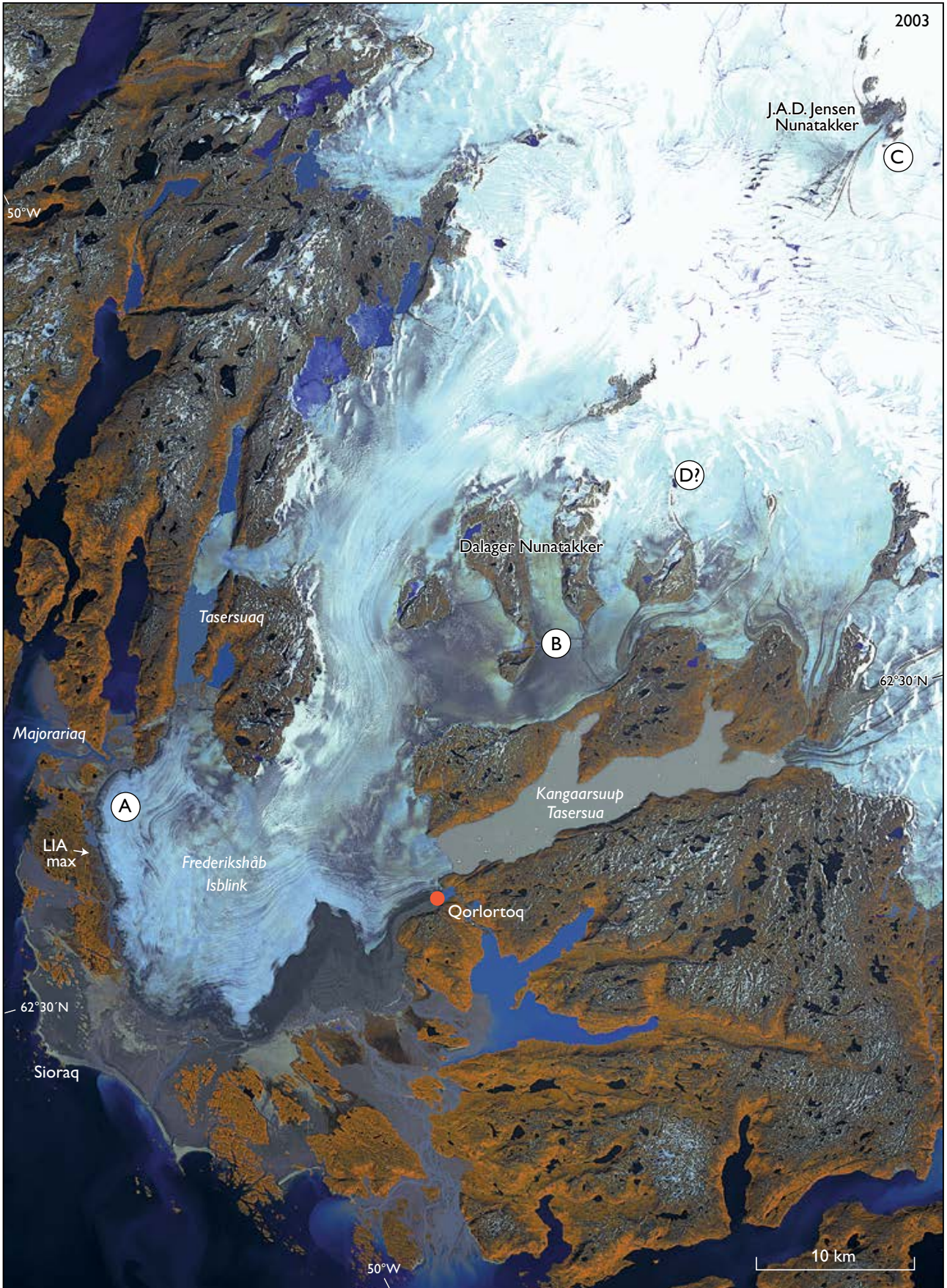
It was described in the 1700s by Hans Egede (1741, 1925), Erich Larsson (1942), Poul Jochumsen Moltzou (1935), Lars Dalager (1915) and Egil Thorhallesen (1914). However, these descriptions are often vague, and it is difficult to identify the described localities.

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 pseudo-colour mosaic from 1 July 2003. The altitude of the glacier north of Dalager Nunatak 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).



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.

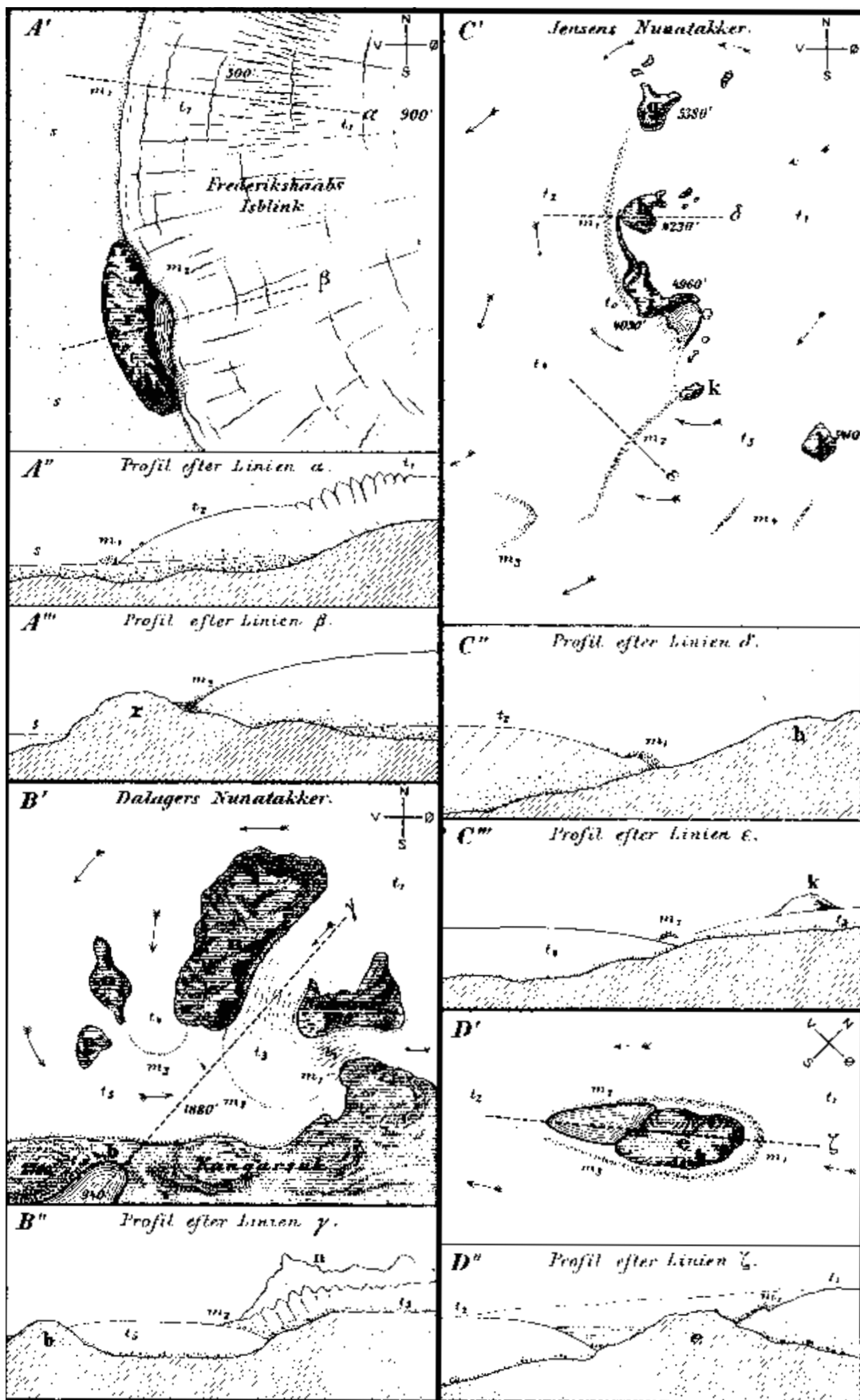
Bloch (1892) reported a single main end-moraine, which was situated close to the margin of the ice. At a single locality, two moraines were recognised, spaced about 60 feet (c. 19 m) apart; the outer moraine was old, however, and already partly overgrown. Locally, the ice margin was located c. 30 feet (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).



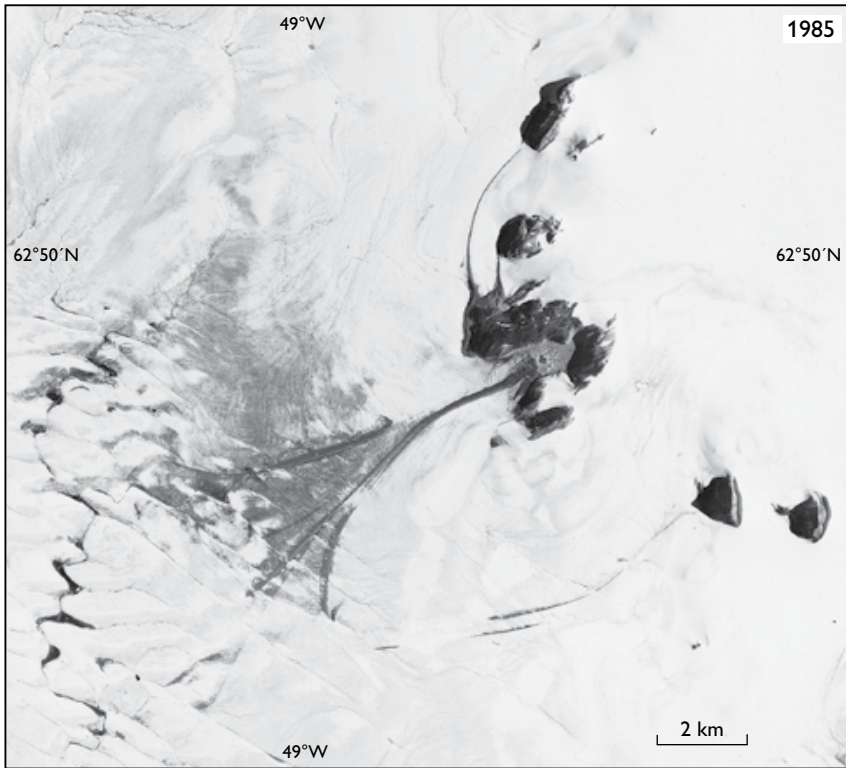


Fig. 24. J.A.D. Jensen Nunatak, 19 July 1985, Geodetic Institute, route 886N, no. 1672. When compared to Fig. 23C it is seen that only minor changes have occurred since 1878, although a narrow trimline zone seen locally indicates a lowering of the Inland Ice surface in the region. Dark areas on the Inland 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

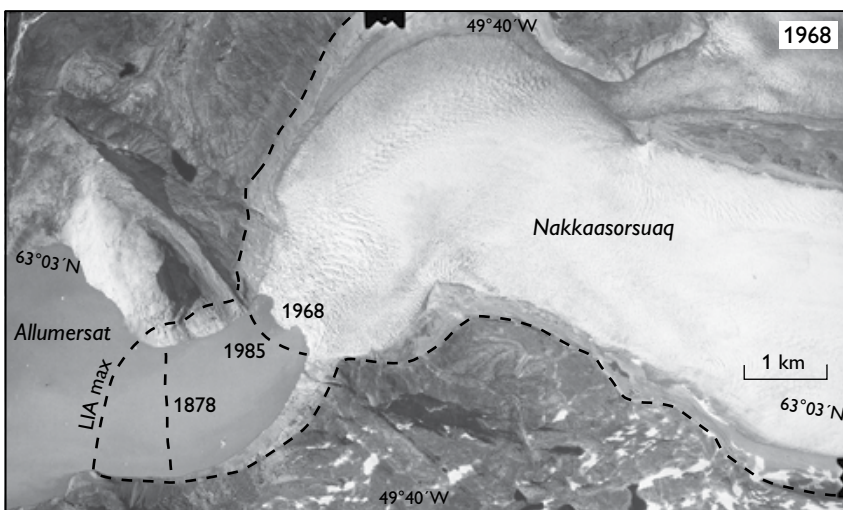


Fig. 25. Nakkaasorsuaq outlet in Allumersat (Bjørnesund). The approximate frontal positions during the Little Ice Age maximum (LIA max), in 1878 and in 1985 are shown (Geodetic Institute, route 281M, no. 434, 13 August 1968). The position in 2010 was the same as in 1968.

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.

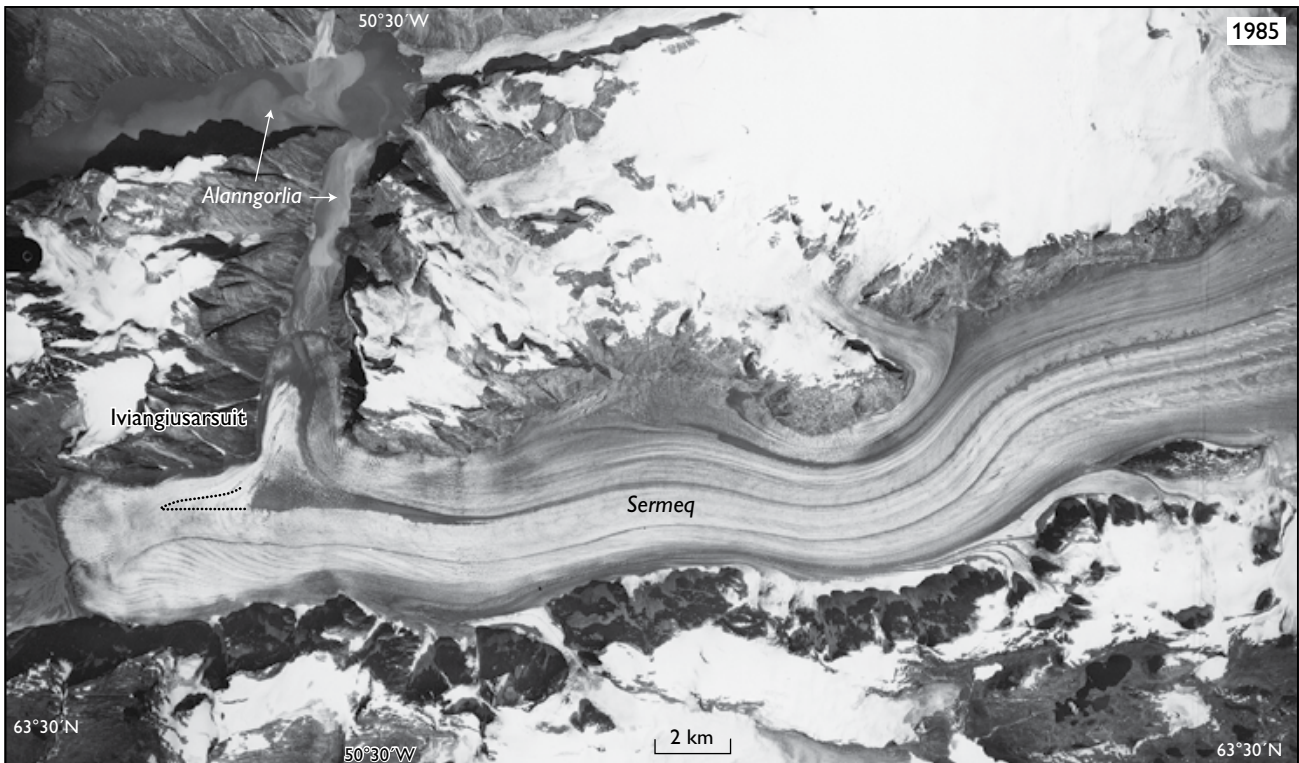


Fig. 27. Sermeq glacier, aerial photograph from 20 July 1985, Geodetic Institute, route 886K no. 1843. Dotted line: deformation of the median moraine according to a satellite image from 2010. Meltwater from the glacier drains west (left) to the Sermilik fjord.

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 po-

sition 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

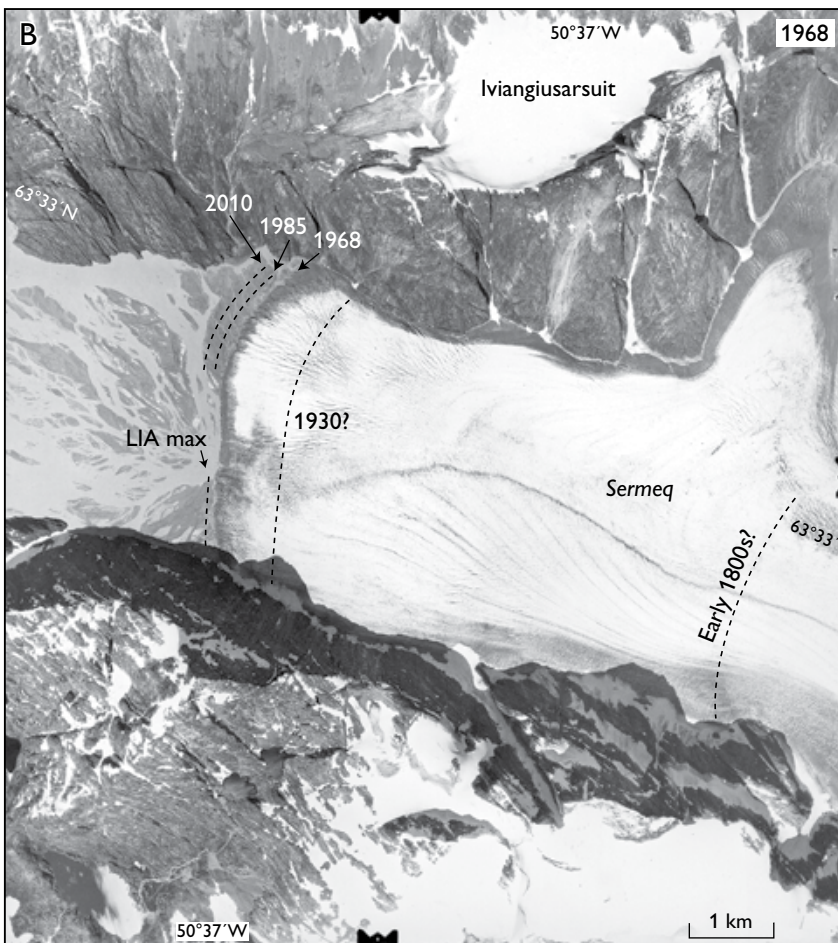


Fig. 28. **A:** The front of Sermeq glacier seen from the north-west from an altitude of 385 m a.s.l. Photograph by K. Gripp, 11 September 1930, published by Gripp (1975, plate 1, fig. 2). According to Gripp, most of the drainage from the ice front appeared to occur via a subglacial tunnel located below 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.

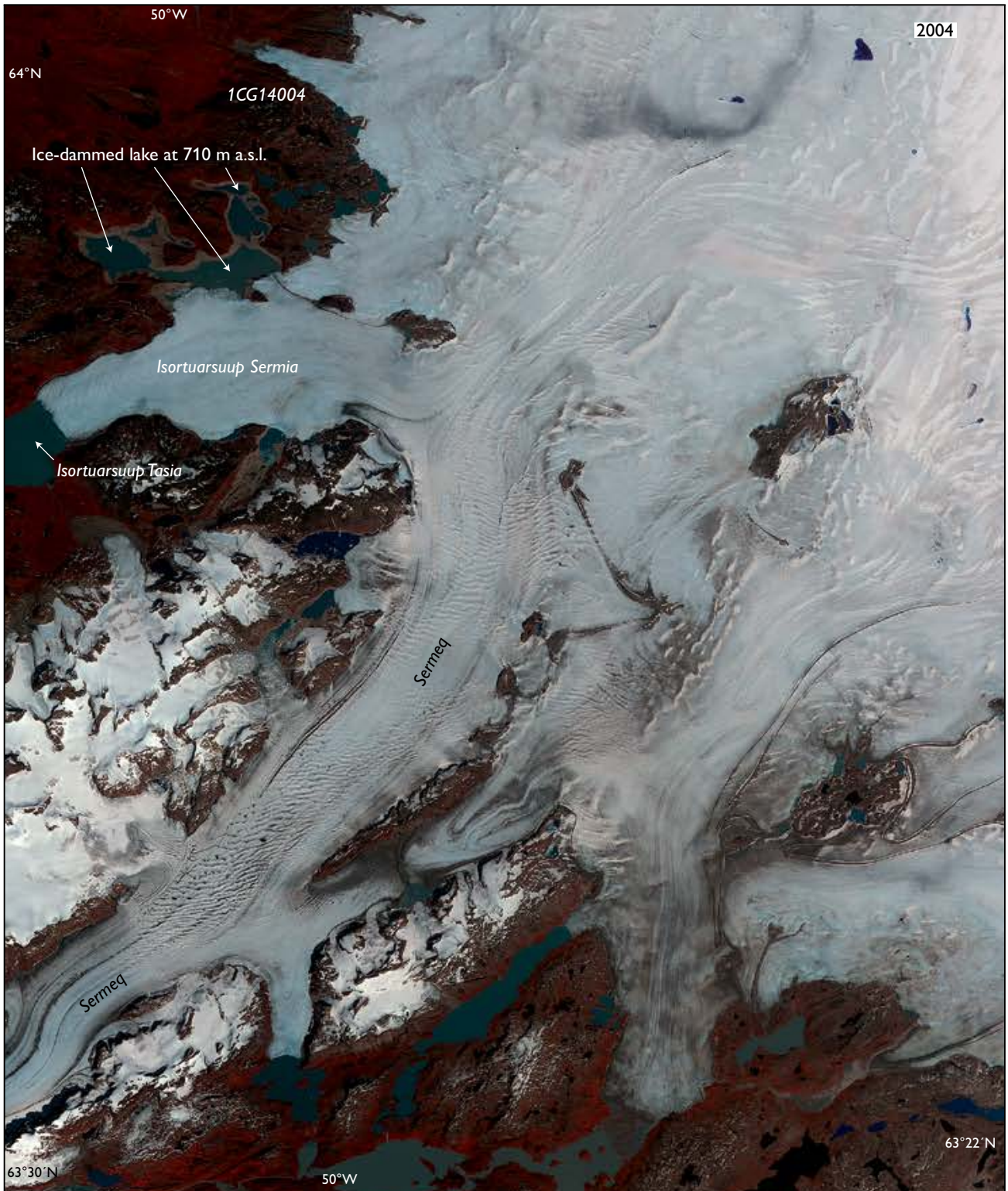


Fig. 29. ASTER image of Isortuarsuup Sermia from 4 August, 2004 covering a large part of Sermeq (Fig. 27) and the un-named glacier 1CG14004 (Fig. 31). The area adjacent to the margin of the Inland Ice is barren, partly alpine with local glaciers confluent with the marginal part of the Inland Ice, which 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 (Kangerluarsunguaq or Buksefjorden hydropower plant), hydrological and glaciological investigations have been carried out in order to calculate the future hydro-power 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).

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

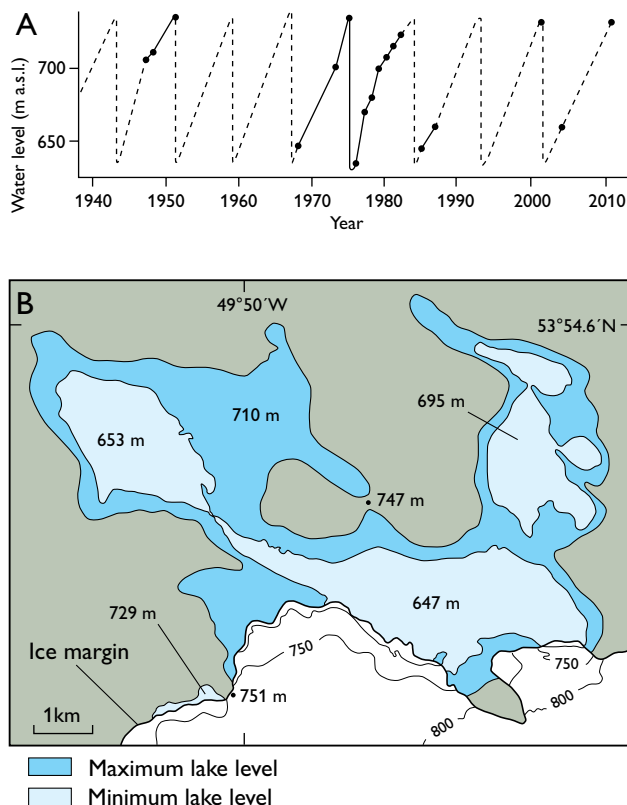


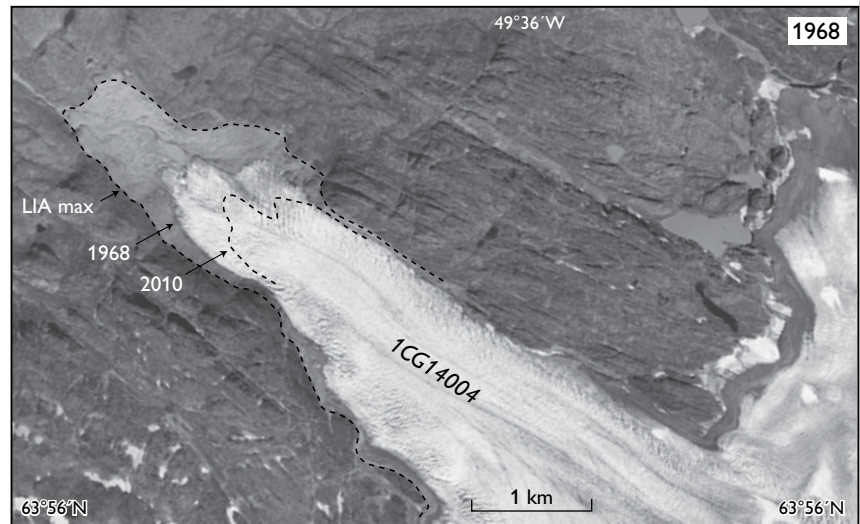
Fig. 30. Ice-dammed lake at 710 m a.s.l. (see Fig. 29) that is periodically drained via Isortuarsuup Sermia. The data for the period 1937–1987 are from Thomsen *et al.* (1992), and the continuation is based on satellite images. **A:** Estimated lake levels and draining events. **B:** Map of the ice-dammed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

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 ICG14004 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 (Nipaatsok, *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 Roussel (1941, p. 14, fig. 6). A set of aerial photographs from 1936 (which formed the basis for Roussel'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.

Roussel (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 Kangaarsarsuk 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 Roussel's archaeological investigations in the early 1930s, as well as on aerial photographs from 1936. Knuth's discussion included the ruin group 'Kangårssårssuk'. According to Knuth, local people told him that the latter place name should be 'Kangårssårssuaq' (Knuth 1944, pp. 104–109). Knuth included an aerial photograph of Kangaarsarsuk 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 Kangaarsarsuk Sermia may imply a greater age (1700?) for the formation of the outermost part of the trimline zone.

North of Kangarsuneq 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-

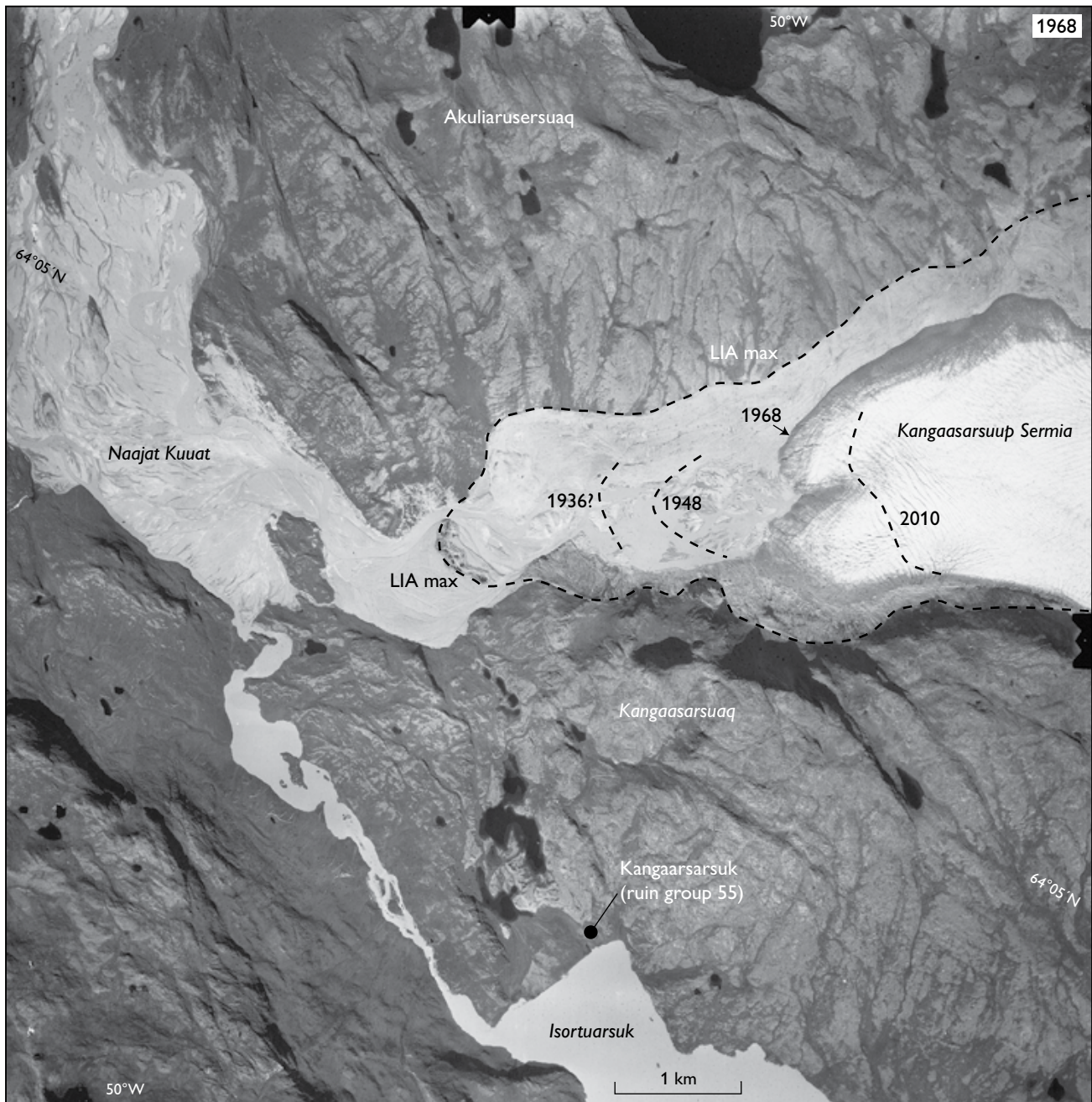


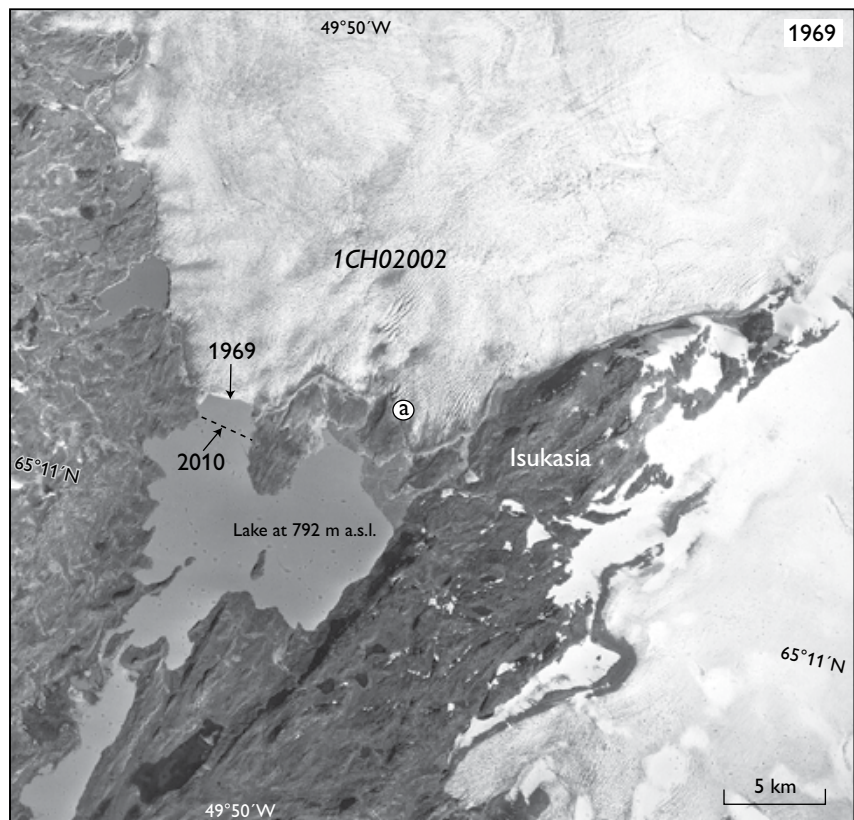
Fig. 32. Aerial photograph from 13 August 1968 (Geodetic Institute, route 281Q, no. 178) of Kangaasarsuup Sermia. The approximate positions of the glacier front during the Little Ice Age maximum (**LIA max**), in 1936 (Geodetic Institute, route 768C, no. 25297), in 1948 (Geodetic Institute, route 505 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 ad-

vance 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

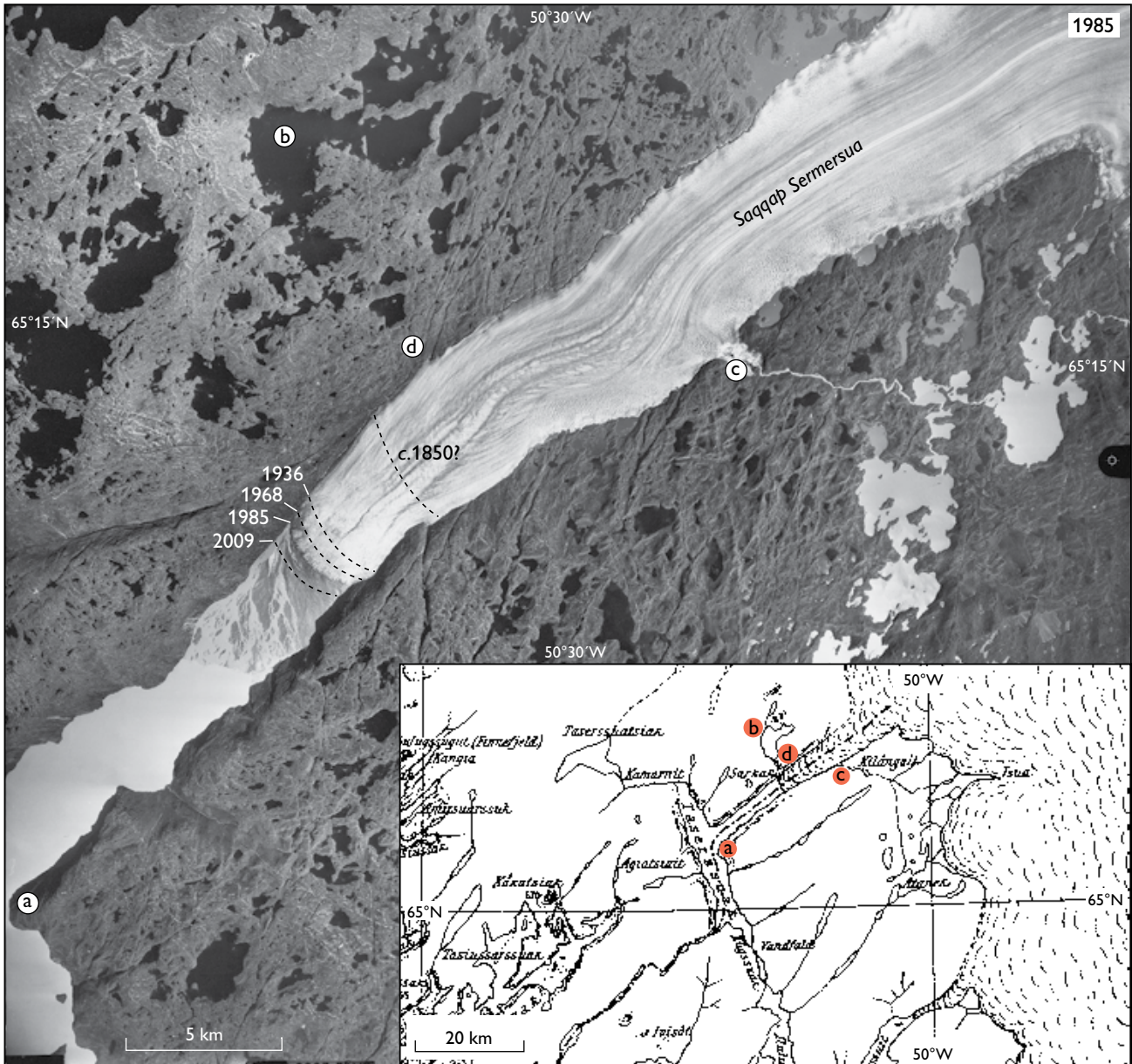


Fig. 34. Aerial photograph of Saqqap Sermersua. Estimated advance of the ice margin between the 1850s and 2009 is shown on the photograph from 11 July 1985 (Geodetic Institute, route 886K, no. 1456). The inset map was presumably made on the basis of the map by J.A.D. Jensen after his survey work in the 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 Eze-kiassen, 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 1985 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 $21\,740 \pm 400$ ¹⁴C 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. Kangilinnuata 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 'Narsarssuaq 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-

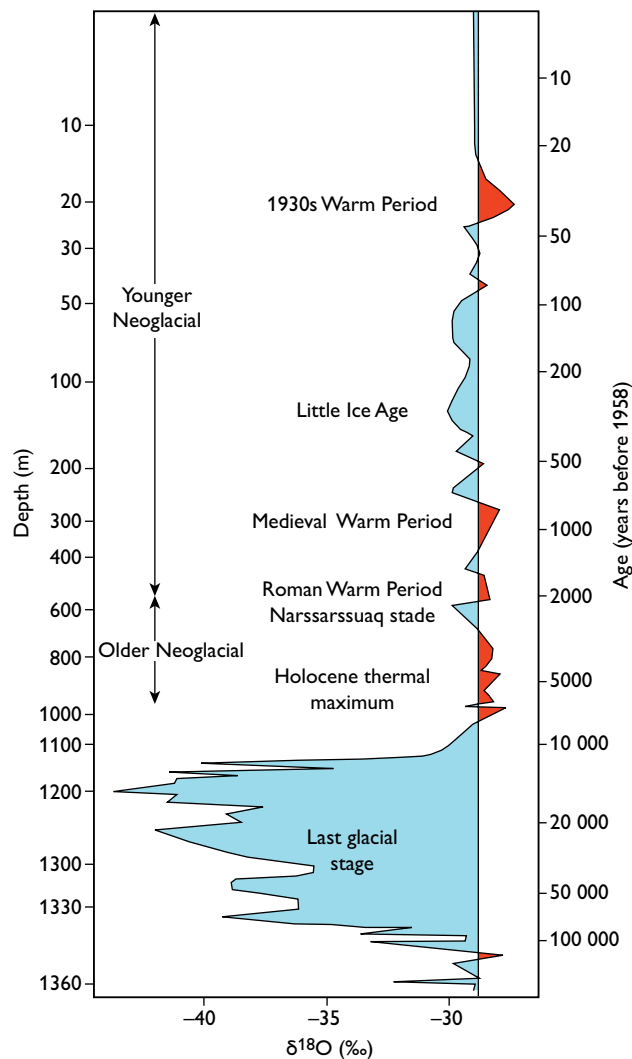


Fig. 35. Late Quaternary temperature history according to the Camp Century ice-core record. Redrawn from Dansgaard (2004). Blue areas: colder than present; red areas: warmer than present. The age-depth model is tentative.

acier 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 Narsarssuaq stade in South Greenland (61°10'N, 45°25'W; Weidick 1963; plate 1) is referred to the Older Neoglacial. The moraines of the Narsarssuaq 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 continu-

ation 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 Narssarsuaq 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 Narssarsuaq 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 Narssarsuaq 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)

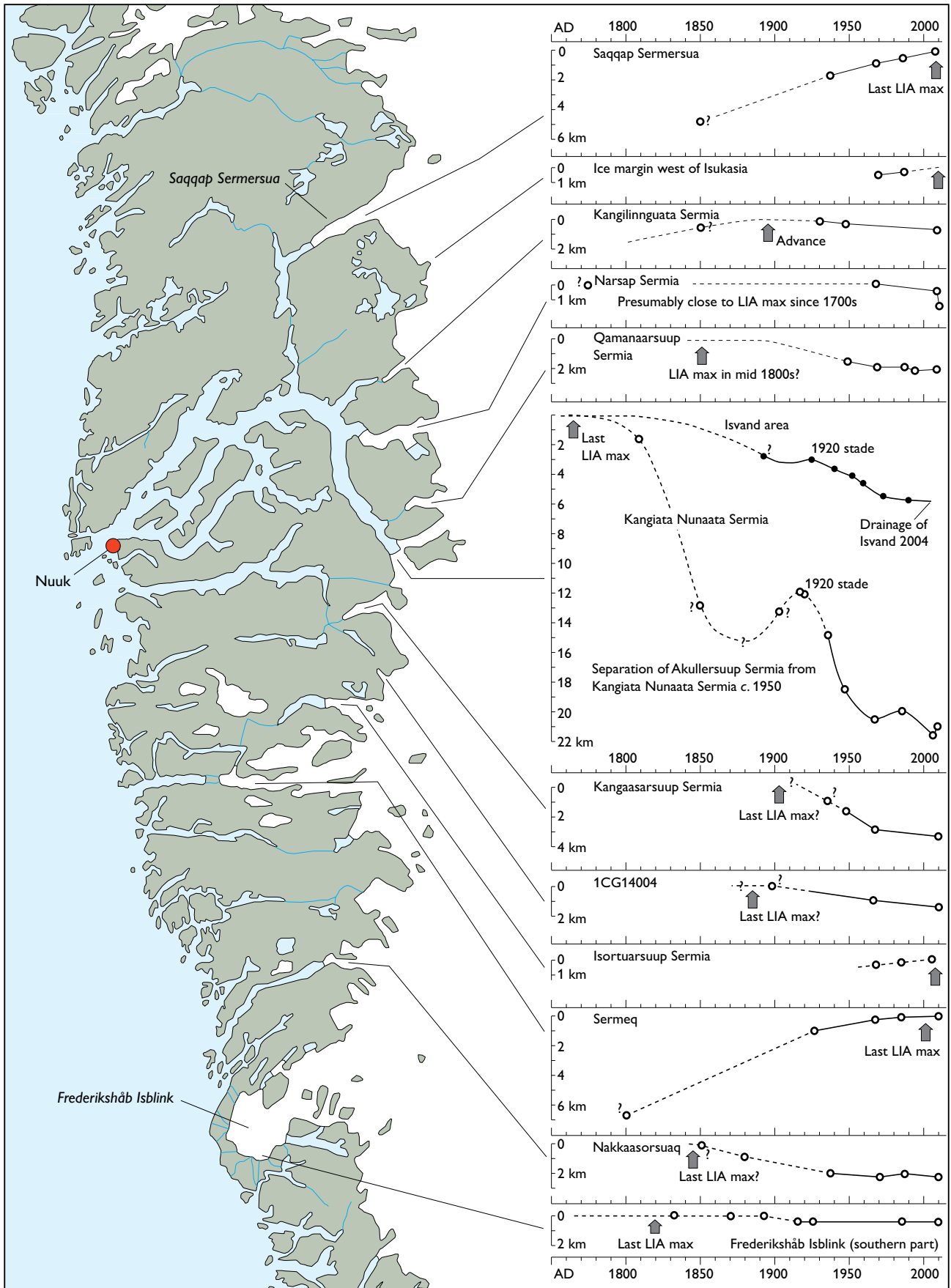
The Medieval Warm Period (MWP) extended from AD 850 to 1200. It can be divided into several phases separated by one or more cold spells, as seen in records from

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 re-worked 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



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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 ad-

vance 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 1930s 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 Kangilinnuata 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 calving-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 Narsarsuaq 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

is recognised at 2000 years BP, which could have initiated the Narssarsuaq 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.

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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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References

- Ahlstrøm, A.P., Mottram, R., Nielsen, C., Reeh, N. & Andersen, S.B. 2008: Evaluation of the future hydropower potential at Paakitsoq, Ilulissat, West Greenland. Danmarks og Grønlands Geologiske Undersøgelse Rapport **2008/37**, 50 pp.
- Alley, R.B., Mayewski, P.A., Sowers, T., Stuiver, M., Taylor, K.C. & Clark, P.U. 1997: Holocene climatic instability – a prominent widespread event 8200 yr ago. *Geology* **25**, 483–486.
- Amante, C. & Eakins, B.W. 2009: ETOPO1 1 arc-minute global relief model: procedures, data sources and analysis. NOAA Technical Memorandum NESDIS NGDC-24, 19 pp. Boulder, Colorado: National Geophysical Data Center.
- Amdrup, G.C., Bobé, L., Jensen, A.S. & Steensby, H.P. (eds) 1921: Grønland i Tohundredaaret for Hans Egedes Landing. Meddelelser om Grønland **60**, **61**, 567 pp., 795 pp. + atlas.
- Andsbjerg, J. 1985: **1:** Barretyper på en recent, proximal sandur; Qamanarssup Sermia, Godthåbsfjorden, Vestgrønland. **2:** Proximale smeltvandsaflejring, Bjergsted Hedeslette, Vestsjælland: aflejningsgeometri og sandurudbygning. Unpublished M.Sc. thesis (two parts), Københavns Universitet, Danmark.
- Arctander, A. 1793: Udkrift af en Dagbog, holden i Grønland paa en Recognosceringsrejse i Julianehaabs District i Aarene 1777–79. Samleren, et Ugeskrift **6**, 1103–1242.
- Armstrong, T., Roberts, B. & Swithinbank, C. 1973: Illustrated glossary of snow and ice. Scott Polar Research Institute, Special Publication **4**, 58 pp.
- Arneborg, J. 2004: Det europæiske landnam – Nordboerne i Grønland 985–1450 e.v.t. In: Gulløv, H.C. (ed.): Grønlands forhistorie, 220–278. København: Gyldendal.
- Barselej [Ezekiassen?] 1866: Taserssualiarnermik kingornalo angalanermik tusagassiat (Account from a voyage to the Taserssuaq area). The newspaper Atuagagdliutit, 30 November, columns 1238–1240 and 8 December, columns 1246–1251.
- Bennike, O. & Björck, S. 2002: Chronology of the last recession of the Greenland ice sheet. *Journal of Quaternary Science* **17**, 211–219.
- Bennike O. & Sparrenbom, C.J. 2007: Dating of the Nassarsuaq stade in southern Greenland. *The Holocene* **17**, 279–282.
- Bennike, O., Anderson, N.J. & McGowan, S. 2010: Holocene palaeoecology of southwest Greenland inferred from macrofossils in sediments of an oligosaline lake. *Journal of Paleolimnology* **43**, 787–798.
- Bennike, O., Wagner, B. & Richter, A. 2011: Relative sea level changes during the Holocene in the Sisimiut area, south-western Greenland. *Journal of Quaternary Science* **26**, 353–361.
- Beschel, R.E. 1961: Dating rock surfaces by lichen growth and its application to glaciology and physiography (lichenometry). In: Raasch, G. (ed.): *Geology of the Arctic*, 1044–1062. Toronto: University of Toronto Press.
- Beschel, R.E. & Weidick, A. 1973: Geobotanical and geomorphological reconnaissance in West Greenland, 1961. *Arctic and Alpine Research* **5**, 311–319.
- Beschel, R.E., Kelly, M., TenBrink, N. & Weidick, A. 1978: Quaternary map of Greenland 1:500 000, Frederikshåbs Isblink – Søndre Strømfjord, Sheet 2. Copenhagen: Geological Survey of Greenland.
- Bevis, M. *et al.* 2012: Bedrock displacements in Greenland manifest ice mass variations, climate cycles and climate change. *Proceedings of the National Academy of Sciences* **109**, 11944–11948, <http://dx.doi.org/10.1073/pnas.1204664109>
- Bindschadler, R.A., Zwally, H.J., Meyer, J.A. & Brenner, A.C. 1989: Surface topography of the Greenland ice sheet from satellite radar altimetry. National Aeronautical Space Administration Special Publications **503**, 105 pp.
- Birket-Smith, K. 1961: Eskimoerne, 304 pp. København: Rhodos.
- Bloch, J.C.D. 1892: Bemærkninger til Kaartet fra Tiningnertok til Julianehaab fra 62°18' til 60°30' N. B. paa Grønlands Vestkyst. Meddelelser om Grønland **7**(5), 145–162.
- Bobé, L. 1936a: Indledning Nr. 1 til Diplomatarium Groenlandicum 1492–1814. Meddelelser om Grønland **55**(1), 54 pp.
- Bobé 1936b: Diplomatarium Groenlandicum 1492–1814. Aktstykker og Breve til Oplysning om Grønlands Besejling, Kolonisation og Missionering. Meddelelser om Grønland **55**(3), 431 pp.
- Braithwaite, R.J. 1989: Glaciers and hydropower for Nuuk/Godthåb, West Greenland. Open file Series Grønlands Geologiske Undersøgelse **89/2**, 49 pp.
- Braithwaite, R.J. 1990: Effects of glaciers and annual run-off of east of Nuuk. Rapport Grønlands Geologiske Undersøgelse **148**, 87–91.
- Braithwaite, R.J. & Olesen, O.B. 1989: Calculation of glacier ablation from air temperatures, West Greenland. In: Oerlemans, J. (ed.): *Glacier fluctuations and climatic change*, 219–233. Dordrecht: Kluwer Academic Publications.
- Briner, J.P., Stewart, H.A.M., Young, N.E., Philipps, W. & Losee, S. 2010: Using proglacial-threshold lakes to constrain fluctuations of the Jakobshavn Isbræ ice margin, western Greenland, during the Holocene. *Quaternary Science Reviews* **29**, 3861–3874.
- Bruun, D. 1917: Oversigt over Nordboruiner i Godthaab- og Frederikshaab-Distrikter. Meddelelser om Grønland **56**(3), 55–147.
- Cappelen, J. 2005: DMI annual climate data collection 1873–2004, Denmark, the Faroe Islands and Greenland – with graphics and Danish abstracts. Danish Meteorological Institute, Technical Report **05–06**, 21 pp.
- Colbeck, S.C. 1974: A study of glacier flow for an open-pit mine: an exercise in applied glaciology. *Journal of Glaciology* **13**(69), 401–414.
- Dahl-Jensen, D., Mosegaard, K., Gundestrup, N., Clow, G.D., Johnsen, S.J., Hansen, A.W. & Balling, N. 1998: Past temperatures directly from the Greenland ice sheet. *Science* **282**, 268–271.
- Dahl-Jensen, D. *et al.* 2009: The Greenland ice sheet in a changing climate: snow, water, ice and permafrost in the Arctic (SWIPA), 115 pp. Oslo: Arctic Monitoring and Assessment Programme (AMAP).
- Dalager, L. 1915: Grønlandske Relationer indeholdende Grønlandernes Liv og Levned, tilligemed nogle korte Reflectioner

- over Missionen, sammenskrevet ved Frederichshaabs Colonie i Grønland Anno 1752. Introduction by L. Bobé. Det Grønlandske Selskabs Skrifter **2**, 94 pp.
- Dansgaard, W. 2004: Frozen annals. Greenland ice sheet research, 122 pp. Odder: Narayana Press.
- Dawson, A.G. 1983: Glacier dammed lake investigations in the Hullet lake area, South Greenland. Meddelelser om Grønland, Geoscience **11**, 24 pp.
- Dietrich, R., Rülke, A. & Scheinert, M. 2005: Present-day vertical crustal deformations in West Greenland from repeated GPS observations. Geophysical Journal International **163**, 865–874.
- Dugmore, A.J., McGovern, T.H., Vésteinsson, O., Arneborg, J., Streeter, R. & Keller, C. 2012: Cultural adaptation, compounding vulnerabilities and conjunctures in Norse Greenland. Proceedings of the National Academy of Sciences **109**, 3658–3663, <http://dx.doi.org/10.1073/pnas.1115292109>
- Egede, H. 1741: Det gamle Grønlands ny Perustration, 131 pp. København: Johan Christoph Groth.
- Egede, H. 1925: Relationer fra Grønland 1721–36 og Det gamle Grønlands ny Perustration 1741. Edited by L. Bobé. Meddelelser om Grønland **54**, 458 pp.
- Fabricius, O. 1788: Om Driv-Iisen i de Nordlige Vande og fornemmelig i Davids-Strædet. Nye Samling af det Kongelige Danske Videnskabers Selskabs Skrifter, Tredje Deel, 65–84.
- Forman, S.L., Marin, L., van der Veen, C., Tremper, C. & Csatho, B. 2007: Little Ice Age and neoglacial landforms at the Inland Ice margin, Isunguata Sermia, Kangerlussuaq, West Greenland. Boreas **36**, 341–351.
- Fredskild, B. 1973: Studies in the vegetational history of Greenland. Palaeobotanical investigations of some Holocene lake and bog deposits. Meddelelser om Grønland **198**(4), 245 pp.
- Fredskild, B. 1983: Holocene vegetational development of the Godthåbsfjord area, West Greenland. Meddelelser om Grønland Geoscience **10**, 28 pp.
- Gabel-Jørgensen, C.C.A. & Egedal, J. 1940: Tidal observations made in Nanortalik and Julianehaab in 1932–34. Meddelelser om Grønland **107**(2), 47 pp.
- Gad, F. 1967: Grønlands historie I, indtil 1700, 461 pp. København: Nyt Nordisk Forlag.
- Geodætisk Institut 1974: 62 V.1. Frederikshåbs Isblink. Topographical map, 1:250 000. København: Geodætisk Institut.
- Giesecke, K.L. 1910: Karl Ludwig Gieseckes mineralogisches Reisejournal über Grönland 1806–13. Meddelelser om Grønland **35**, 532 pp.
- Gräslund, B. 2007: Fimbulvintern, Ragnarök och klimatkrisen 536–537 e. Kr. Saga och Sed. Kungl. Gustav Adolfs Akademiens Årsbok **2007**, 93–123.
- Gripp, K. 1932: Einige besondere Fossilien in Geschieben aus der Inland Eis Grönlands. Meddelelser om Grønland **91**(5), 11 pp.
- Gripp, K. 1975: Eisrandstudien ausgehend von Sermeq, SW-Grønland. Meddelelser om Grønland **195**(8), 118 pp.
- Gullov, H.C. 1983: Nuup kommuneani qangarnitsanik eqqaassutit inuit-kulturip nunaqarfii. Fortidsminder i Nuuk kommune – inuitkulturens bopladser, 240 pp. Nuuk: Kalallit Nunaata Katersugaasivia & Nationalmuseet.
- Heling, D. 1974: Investigations on recent sediments in the Fiskeneset region, southern West Greenland. Rapport Grønlands Geologiske Undersøgelse **65**, 66–68.
- Helk, J.V. 1954: Flyvefotografering over Grønland. Grønland **1954**, 47–52, 177–181, 302–305.
- Henriksen, N., Higgins, A.K., Kalsbeek, F. & Pulvertaft, T.C.R. 2009: Greenland from Archaean to Quaternary. Descriptive text to the 1995 Geological map of Greenland 1:2 500 000, 2nd edition. Geological Survey of Denmark and Greenland Bulletin **18**, 126 pp.
- Holst, N.O. 1886: Berättelse om en år 1880 i geologiskt syfte företagen resa till Grönland. Sveriges Geologiska Undersökning **C81**, 68 pp.
- Iversen, J. 1953: Origin of the flora of western Greenland in the light of pollen analysis. Oikos **4**, 85–103.
- Jensen, J.A.D. 1879: Premierleutenant J.A.D. Jensens Indberetning om den af ham ledede Ekspedition i 1878. Meddelelser om Grønland **1**(2), 19–76.
- Jensen, J.A.D. 1889: Undersøgelse af Grønlands Vestkyst fra 64° til 67° N.B. 1884 og 1885. Meddelelser om Grønland **8**(2), 33–121.
- Jochimsen, M. 1973: Does the size of lichen thalli really constitute a valid measure for dating glacial deposits? Arctic and Alpine Research **5**, 417–424.
- Kaplan, M.R., Wolfe, A.P. & Miller, G.H. 2002: Holocene environmental variability in southern Greenland. Quaternary Research **58**, 149–159.
- Kelly, M. 1980: The status of the Neoglacial in western Greenland. Rapport Grønlands Geologiske Undersøgelse **96**, 24 pp.
- Kelly, M. 1985: A review of the Quaternary geology of western Greenland. In: Andrews, J.T. (ed.): Quaternary environments eastern Canadian Arctic, Baffin Bay and western Greenland, 461–501. Boston: Allen & Unwin.
- Kleinschmidt, S. 1851: Grammatik der grönländischen Sprache mit teilweisen Einschluss des Labrador dialects, 182 pp. Hamburg: Druck und Verlag G. Reimer.
- Kleinschmidt, S. 1860: Kaart over det Indre af Godthaabs Distrikt (Map). Godthaab: Inspektoratets Bogtrykkeri.
- Knudsen, N.T. 1982: Glaciological investigations at Qamanârussup Sermia, West Greenland. Rapport Grønlands Geologiske Undersøgelse **110**, 88–90.
- Knudsen, N.T. 1983: Photogrammetric investigations at glaciers in West Greenland. Rapport Grønlands Geologiske Undersøgelse **115**, 115–117.
- Knuth, E. 1944: Bidrag til Vesterbygdens Topografi. De afsidesliggende Bebyggelser. Det Grønlandske Selskabs Aarsskrift **1944**, 81–124.
- Kornerup, A. 1879: Geologiske Iagttagelser fra Vestkysten af Grønland (62°15'–64°15' N.B.). Meddelelser om Grønland **1**(3), 77–139.
- [Kornerup, A.] 1978: Kornerups Grønland. Sketches from Greenland 1876–79, 138 pp. København: Kommissionen for Videnskabelige Undersøgelser i Grønland.
- Kort- og Matrikelstyrelsen 1993: 64 V.2. Kapisigdlit. Topographical map, 1:250 000. Copenhagen: Kort- og Matrikelstyrelsen.
- Kryolitselskabet Øresund 1980: Prospecting Isukasia. Ore mine field investigations. Report on movement of glaciers and surface eleva-

- tions (Arctic Consultant Group), 5 pp. + 8 appendices (maps).
- Kuijpers, A., Malmgren, B.A. & Seidenkrantz, M.-S. 2009: Termination of the Medieval Warm Period: linking subpolar and tropical N Atlantic circulation changes to ENSO. *Pages News* **17**, 76 only.
- Larsen H. & Meldgaard, J. 1958: Palaeo-Eskimo cultures in Disko Bugt, West Greenland. *Meddelelser om Grønland* **161**(2), 75 pp.
- Larson, L.M. 1917: *The King's mirror*, 388 pp. New York: Twayne Publishers and The American-Scandinavian Foundation.
- Larsson, E. 1942: Reckognosceringsekspeditionen efter Østerbygden 1723. In: Ostermann, H. (ed.): *Diary of Erich Larsson. Det Grønlandske Selskabs Aarskrift* **1942**, 93–114.
- Leclercq, P.W. 2012: Glacier fluctuations, global temperature and sea-level changes, 170 pp. PhD. thesis, Utrecht University, the Netherlands.
- Leclercq, P.W., Weidick, A., Paul, F., Bolch, T., Citterio, M. & Oerlemans, J. 2012: Brief communication: historical glacier length changes in West Greenland. *The Cryosphere* **6**, 3491–3501, <http://dx.doi.org/10.5194/tcd-6-3491-2012>
- Long, A.J., Roberts, D.H. & Dawson, S. 2006: Early Holocene history of the West Greenland ice sheet and the GH 8.2 event. *Quaternary Science Reviews* **25**, 904–922.
- Long, A.J., Woodroffe, S.A., Dawson, S. Roberts, D.H. & Bryan, C.L. 2009: Late Holocene relative sea level rise and the neoglaciation history of the Greenland ice sheet. *Journal of Quaternary Science* **24**, 345–359.
- Marcussen, J. 2011: Distancer, skalaer og gradnet i søkort. Nogle om-sætningstal og bemærkninger til distancer på søkort. <http://www.jmarcussen.dk/maritim/mart/distancer.html>
- Mercer, J.H. 1961: The response of fjord glaciers to changes in the firn limit. *Journal of Glaciology* **3**(29), 850–858.
- Moltke, C. & Jessen, A. 1896: Undersøgelser af Nordre Sermilik Bræ. *Meddelelser om Grønland* **16**(2), 93–107.
- Moltzou, P.J. 1935: Journal holden paa Godthaabs Colonie fra d. 28. juli 1743 indtil d. 10. august 1744 (Moltzou's diary). *Norges Svalbard- og Ishavs-undersøkelser, Meddelelser* **33**, 47–71.
- Mortensen, J., Lennert, K., Bendtsen, J. & Rysgaard, S. 2011: Heat sources for glacial melt in a sub-Arctic fjord (Godthåbsfjord) in contact with the Greenland ice sheet. *Journal of Geophysical Research* **116** (C01013), <http://dx.doi.org/10.1029/2010JC006528>
- Mørch, J.C. 1942: Tanker om Grønlands Østerbygd i Anledning af Herr Cencellie Raad v. Egger's Afhandling [1792] i Landhuusholdnings Selskabets Skrifter 4de Deel [1794]. Julianehaab d. 8. Januarii 1799. In: Ostermann, H. (ed.): *Johan Christian Mørch, Avhandlinger om Grønland 1799–1801. Norges Svalbard- og Ishavs-undersøkelser, Meddelelser* **52**, 17–69.
- Nansen, F. 1890: Paa Ski over Grønland. En Skildring af den norske Grønlandsekspedition 1888–89, 704 pp. Kristiania: Aschehoug.
- Nielsen, A. 2000: Grønlands nyere kortlægning. In: Jakobsen, B.H. *et al.* (eds): *Topografisk atlas Grønland*, 76–81. København: Det Kongelige Geografiske Selskab and Kort & Matrikelstyrelsen.
- Nordenskiöld, O. 1914: Einige Züge der physischen Geographie und Entwicklungsgeschichte Süd-Grønlands. *Geographische Zeitschrift* **20**, 425–441, 505–524, 628–641.
- Norsk Forlishistorisk Forening 2003: Gamle danske måleenheter, <http://www.maritimt.net/arkforsk/danskem.htm>
- Pingel, C. 1841: Om Sænkningen af Grønlands Vestkyst. *Forhandlinger fra det 2. skandinaviske Naturforsker-møde i København i 1840*, 353–363.
- Pingel, C. 1845: Meddelelse om et Par nye Kjendsgeninger vedrørende Sænkningen af Grønlands Vestkyst. *Oversigt over det Kongelige Danske Videnskabernes Selskabs Forhandlinger* **1845**, 122–123.
- Pitman, G.I.K. 1973: A lichenometrical study of snow patch variation in the Frederikshåb district, South-West Greenland, and its implication for studies of climatic and glacial fluctuations. *Meddelelser om Grønland* **192**(7), 31 pp.
- Podlech, S. 2004: The Qagssimiut ice lobe, South Greenland. An assessment of significant ice margin thinning. PhD thesis, University of Copenhagen, Denmark. Danmarks og Grønlands Geologiske Undersøgelse Rapport **2004/67**, 137 pp.
- Rasmussen, S.O. *et al.* 2006: A new Greenland ice core chronology for the last glacial termination. *Journal of Geophysical Research* **111**, D06102, <http://dx.doi.org/10.1029/2005JD006079>
- Reeh, N. 1983: Ikke-stationær beregningsmodel for Indlandsisens randzone. *Gletscher-hydrologiske Meddelelser Grønlands Geologiske Undersøgelse* **83/7**, 81 pp.
- Rignot, E. & Kanagaratnam, P. 2006: Changes in the velocity structure of the Greenland ice sheet. *Science* **311**(5763), 986–990.
- Rignot, E., Velicogna, I., van den Broeke, M.R., Monaghan, A. & Lenaerts, J. 2011: Acceleration of the contribution of the Greenland and Antarctic ice sheets to sea level rise. *Geophysical Research Letters* **38**, L05503, <http://dx.doi.org/10.1029/2011GL046583>
- Roussell, Aa. 1936: Sandnes and the neighbouring farms. *Meddelelser om Grønland* **88**(2), 232 pp.
- Roussell, Aa. 1941: Farms and churches in the Mediaeval Norse settlements of Greenland. *Meddelelser om Grønland* **89**(1), 355 pp.
- Saxov, S. 1958: The uplift of western Greenland. *Meddelelser fra Dansk Geologisk Forening* **13**, 518–523.
- Saxov, S. 1961: The vertical movement of eastern Greenland. *Meddelelser fra Dansk Geologisk Forening* **14**, 413–416.
- Seidenkrantz, M.S., Aagaard-Sørensen, S., Sulzbrück, H., Kuijpers, A., Jensen, K.G. & Kunzendorf, H. 2007: Hydrography and climate of the last 4400 years in a SW Greenland fjord: implications for Labrador Sea palaeoceanography. *The Holocene* **17**, 387–401.
- Taurisano, A. 2004: Ice sheets: climate, elevation and mass balance changes in West Greenland. *Danmarks og Grønlands Geologiske Undersøgelse Rapport* **2004/70**, 110 pp.
- Ten Brink, N.W. & Weidick, A. 1974: Greenland ice sheet history since the last glaciation. *Quaternary Research* **4**, 429–440.
- Thomsen, H.H., Braithwaite, R.J., Weidick, A. & Olesen, O.B. 1992: Vurdering af afstrømningsforholdene ved Imarsuup Isua og Sø 710/Isortuarsuup Tasia, Vestgrønland, 39 pp. Unpublished report, Grønlands Geologiske Undersøgelse, København.
- Thomsen, H.H., Braithwaite, R.J., Weidick, A. & Olesen, O.B. 1993: Evaluation of hydropower for possible industrial use, Nuuk area, Greenland. *Rapport Grønlands Geologiske Undersøgelse* **159**, 59–62.
- Thorhallesen, E. 1776: Efterretning om Rudera eller Levninger af de gamle Nordmænds og Islænderes Bygninger paa Grønlands Vester-Side, tilligemed et Anhang om deres Undergang sammesteds, 80

- pp. København: August Friderich Stein. [Reprinted by Øst, N.C. 1830: Samlinger til Kundskab om Grønland, 9–54.]
- [Thorhallesen, E.] 1914: Beskrivelse over Missionerne i Grønlands Søndre Distrikt, hvilke han som Vice-Provst visiterede i Aarene 1774–1775. Published and annotated by L. Bobé. *Det Grønlandske Selskabs Skrifter* **1**, 116 pp.
- Timm, L.H. 2010: Ice margin and ice marginal lakes in the FreshLink research area, S.W. Greenland 1936–2009, 56 pp. Unpublished thesis, Natural History Museum of Denmark, University of Copenhagen, Denmark.
- Van As, D., Fausto, R.S. & the PROMICE project team 2011: Programme for monitoring of the Greenland ice sheet (PROMICE): first temperature and ablation records. *Geological Survey of Denmark and Greenland Bulletin* **23**, 73–76.
- Vinther, B.M., Andersen, K.K., Jones, P.D., Briffs, K.R. & Cappelen, J. 2006: Extending Greenland temperature records into the late 18th century. *Journal of Geophysical Research* **111**, D11105, <http://dx.doi.org/10.1029/2005JD006810>
- Vinther, B.M. *et al.* 2009: Holocene thinning of the Greenland ice sheet. *Nature* **461**, 385–388.
- von Drygalski, E. 1897: Grönland-Expedition der Gesellschaft für Erdkunde zu Berlin 1891–1893 unter Leitung von Erich von Drygalski **1**, 556 pp. Berlin: W.H. Kühl Verlag.
- Webber, P.E. & Andrews, J.T. 1973: Lichenometry, a commentary. *Arctic and Alpine Research* **5**, 295–302.
- Weidick, A. 1959: Glacial variations in West Greenland in historical time, Part 1, Southwest Greenland. *Meddelelser om Grønland* **158**(4), 196 pp.
- Weidick, A. 1963: Ice margin features in the Julianehåb district, South Greenland. *Meddelelser om Grønland* **165**(3), 129 pp.
- Weidick, A. 1968: Observations on some Holocene glacier fluctuations in West Greenland. *Meddelelser om Grønland* **165**(6), 202 pp.
- Weidick, A. 1972: Holocene shore-lines and glacial stages in Greenland – an attempt at correlation. *Rapport Grønlands Geologiske Undersøgelse* **41**, 39 pp.
- Weidick, A. 1975a: Quaternary geology of the area between Frederikshåbs Isblink and Ameralik. *Rapport Grønlands Geologiske Undersøgelse* **70**, 22 pp.
- Weidick, A. 1975b: Investigations on the Quaternary deposits in the Godthåbsfjord area, southern West Greenland. *Rapport Grønlands Geologiske Undersøgelse* **75**, 63–64.
- Weidick, A. 1976: C-14 datings of survey material, carried out in 1975. *Rapport Grønlands Geologiske Undersøgelse* **80**, 136–144.
- Weidick, A. 1984a: Studies of glacier behaviour and glacier mass balance in Greenland: a review. *Geografiska Annaler* **66A**, 183–195.
- Weidick, A. 1984b: Location of two glacier surges in West Greenland. *Rapport Grønlands Geologiske Undersøgelse* **120**, 100–104.
- Weidick, A. 1991a: A change in the status of the Greenland Inland Ice. *Rapport Grønlands Geologiske Undersøgelse* **152**, 39–41.
- Weidick, A. 1991b: Present-day expansion of the southern part of the Inland Ice. *Rapport Grønlands Geologiske Undersøgelse* **152**, 73–79.
- Weidick, A. 1993: Neoglacial change of ice cover and the related response of the Earth's crust in West Greenland. *Rapport Grønlands Geologiske Undersøgelse* **159**, 121–126.
- Weidick, A. 1994a: Historical fluctuations of calving glaciers in South and West Greenland. *Rapport Grønlands Geologiske Undersøgelse* **161**, 73–79.
- Weidick, A. 1994b: Fluctuations of West Greenland calving glaciers. In: Reeh, N. (ed.): Workshop on the calving rate of West Greenland glaciers in response to climate change, 141–167. 13–15 September 1993, Copenhagen, Denmark. Danish Polar Center.
- Weidick, A. 1996: Neoglacial changes of ice cover and sea level in Greenland – a classical enigma. In: Grønnow, B. (ed.): The Paleo-Eskimo cultures of Greenland – new perspectives in Greenlandic archaeology, 257–270. Copenhagen: Danish Polar Center.
- Weidick, A. 2009: Johan Dahl Land, South Greenland: the end of a 20th century glacier expansion. *Polar Record* **45**(235), 337–350.
- Weidick, A. & Bennike, O. 2007: Quaternary glaciation history and glaciology of Jakobshavn Isbræ and the Disko Bugt region, West Greenland. *Geological Survey of Denmark and Greenland Bulletin* **14**, 78 pp.
- Weidick, A. & Citterio, M. 2011: The ice-dammed lake Isvand (West Greenland) has lost its water. *Journal of Glaciology* **57**(201), 186–188.
- Weidick, A., Bøggild, C.E. & Knudsen, N.T. 1992: Glacier inventory and atlas of West Greenland. *Rapport Grønlands Geologiske Undersøgelse* **158**, 194 pp.
- Weidick, A., Kelly, M. & Bennike, O. 2004: Late Quaternary development of the southern sector of the Greenland ice sheet, with particular reference to the Qassimiut lobe. *Boreas* **33**, 284–299.
- Wenzel-Petersen, T. 1970: The mapping of Greenland. In: Hertling, K. *et al.* (eds): Greenland, past and present, 27–36. Copenhagen: Edvard Henriksen.
- Wilhelm, H. 2001: 'Af tilbøielighed er jeg grønlandsk': om Samuel Kleinsmidts liv og værk. (By inclination I am Greenlandic: about the life and work of Kleinsmidt). *Det Grønlandske Selskabs Skrifter* **34**, 528 pp.
- Young, N.E., Briner, J.P., Axford, Y., Csatho, B., Babonis, G.S., Rood, D.H. & Finkel, R.C. 2011: Response of a marine-terminating Greenland outlet glacier to abrupt cooling 8200 and 9300 years ago. *Geophysical Research Letters* **38**, L24701, <http://dx.doi.org/10.1029/2011GL049639>

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 Narssarsuaq 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.

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