Jakobshavn Isbræ area during the climatic optimum

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The GGU glaciological investigations related to hydropower planning north (Påkitsoq) and south (Tiníngnilik) of Jakobshavn Isbræ have, together with finds and dating of marine subfossils, furnished information on the history of the ice margin changes during and since the Holocene climatic optimum. The paper attempts to reconstruct the ice margin conditions and surroundings during the Holocene climatic optimum on the basis of this information.

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Jakobshavn Isbræ (Fig. 1) is a tidal outlet of the Inland Ice considered to have the highest calf ice production of Greenland glaciers, 26–37 km^3 ice a^{-1} (Bauer *et al.*, 1968; Carbonnell & Bauer, 1968), or even more (Bindschadler, 1984). As the major drainage outlet of a large segment of the western slope of the Inland Ice, its response to climatic change might control essential elements of ice margin dynamics; it is likely, therefore, to be a key area in any study of Inland Ice marginal changes.

The present front of Jakobshavn Isbræ is situated at the head of Jakobshavn Isfjord, about 50 km east of the town of Jakobshavn/Ilulissat (Fig. 3b).

The bathymetric conditions of Jakobshavn Isfjord are poorly known. At Jakobshavn a threshold (Isfjeldsbanken = the iceberg bank) with maximum depths of 200 m separates outer Disko Bugt (depths of 200–500 m) from Jakobshavn Isfjord (depths of probably 700 m to over 1000 m). No systematic soundings have been made in Jakobshavn Isfjord, and estimated depths are based on records from halibut fishing in the outer part of the fjord (Jacobi, 1958) and observations of overturned calved segments of the glacier front in the inner part of the fjord (Bauer *et al.*, 1968). The northern (Sikuiuitsoq) and southern (Tasiussaq) branches of Jakobshavn Isfjord seem to be relatively shallow fjords, and measured depths in Tasiussaq amount to little over 250 m. The ice-free land surrounding Jakobshavn Isfjord can be characterised as hilly upland and reaches up to 600 m above sea level. A land rim from 30–50 km wide separates major parts of the Inland Ice margin from the shores of Disko Bugt (Weidick *et al.*, 1990).

Current status of Jakobshavn Isbræ

The front of Jakobshavn Isbræ receded 25 km between 1850 and 1950 (see e.g. Bauer *et al.*, 1968) and since *c.* 1950 has had a rather stable position with seasonal fluctuations in the position of the glacier front of about 2 km. The recession since A.D. 1850 implies a lowering of the surface of the glacier by up to 250–300 m, and is testified by the fresh moraines and trimline zones surrounding the present glacier front.

However, this significant thinning of the glacier is not characteristic for the Inland Ice margin in general. Even in areas where the margin is close to sea level, the ice margin moraines and trimline zones witness to a thinning of only 100 m, or less. At some localities south of Jakobshavn Isbræ the ice margin has been nearly stationary for the past 100–150 years due to interference of subglacial and proglacial local control of the ice margin change by topography (e.g. Weidick *et al.*, 1990).

Frontal areas of the present Jakobshavn Isbræ can be separated into a northern minor tributary ice stream, a southern or major ice stream, and an embayment of relict ice ('the ice bay', or according to Hammer, 1893: Tivssarigsoq) as shown in Fig. 2. These three parts of the front are separated by two minor rises (A and B in Figs 1 & 2) which might be interpreted as more elevated parts of a subglacial threshold (the 'ice circus' of Johannes Georgi *in* Wegener, 1930), approximately coinciding and related to the grounding line of the glacier according to Echelmeyer & Harrison (1990).

No measurements of the ice thickness of either the northern or the major ice streams have been made, nor

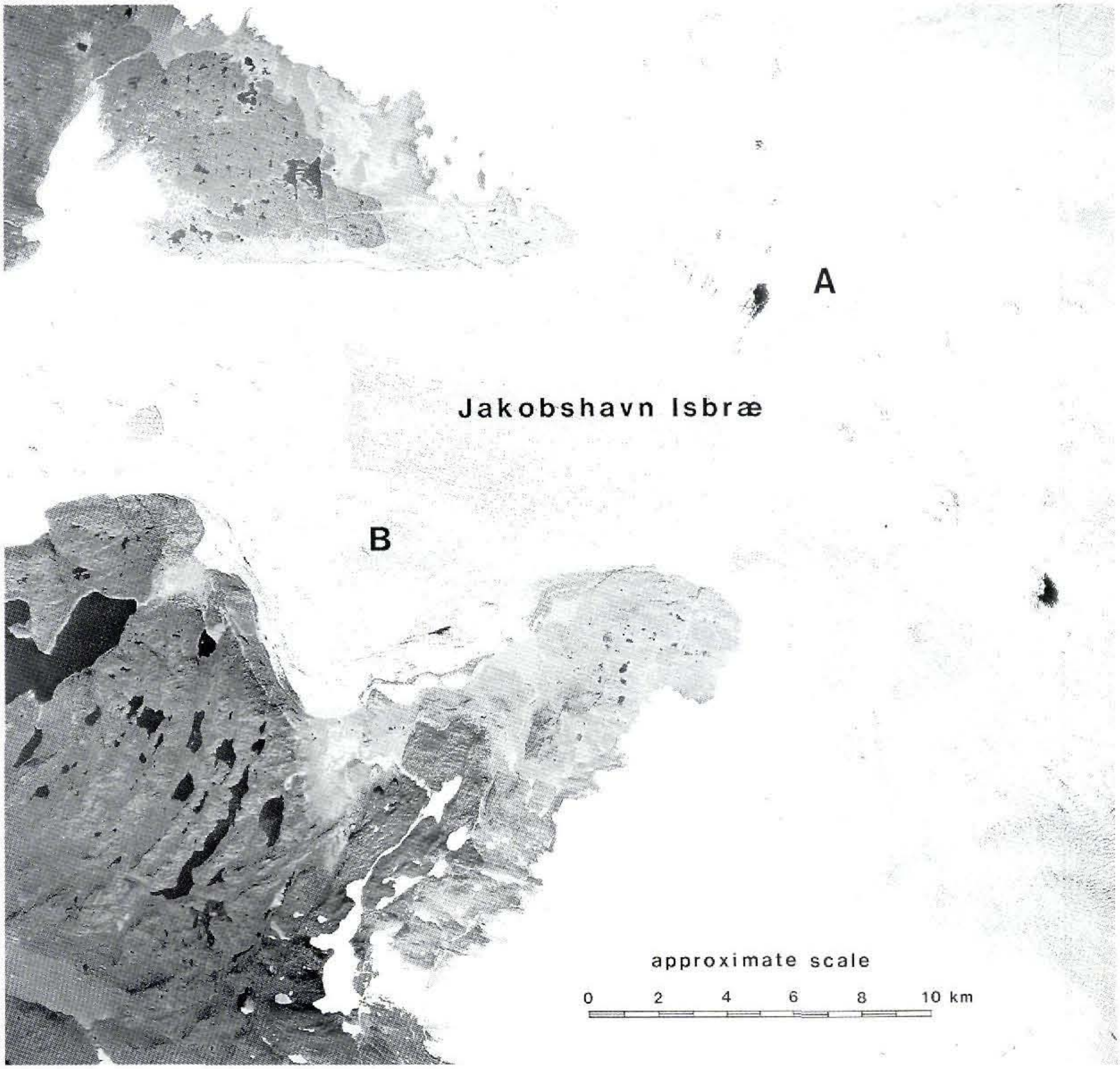


Fig. 1. Present frontal area of Jakobshavn Isbræ. Aerial photograph, route 886 M, no. 764 of 7th September, 1985, copyright Kort- og Matrikelstyrelsen, Denmark. Reproduced with permission A 200/87. A and B are topographical rises in the front of the glacier.

is the thickness of the ice over the rises known. However, soundings of the relict ice cover in 'ice bay' have been undertaken by monopulse radar along a 1.6 km long profile in its western parts (Thorning, 1989), and indicate a rather uniform ice thickness of 200 m.

In front of the grounding line the northern and major ice streams both have rates of movement of about 7 km a^{-1} (Eckelmeyer & Harrison, 1990), while parts of the major ice stream move at up to 8.4 km a^{-1} (Lingle *et al.*, 1981). The ice movement of 'ice bay', according to Carbonnell & Bauer (1968), is about 0.7 km a^{-1} adjacent to the major ice stream. The direction of movement is said to be westwards as for the ice streams, but the present surface topography of the ice in 'ice bay' (surface sloping southwards) implies glacier movement in most of 'ice bay' is probably to the south.

Flow directions in 'ice bay' must have changed by about 90° during the last century, since glacier thinning after A.D. 1850 (Fig. 2) led to protrusion of large parts of a rock wall south-east of 'ice bay', which today has cut off an earlier southern source of ice to Jakobshavn Isbræ. This change seems to have taken place around

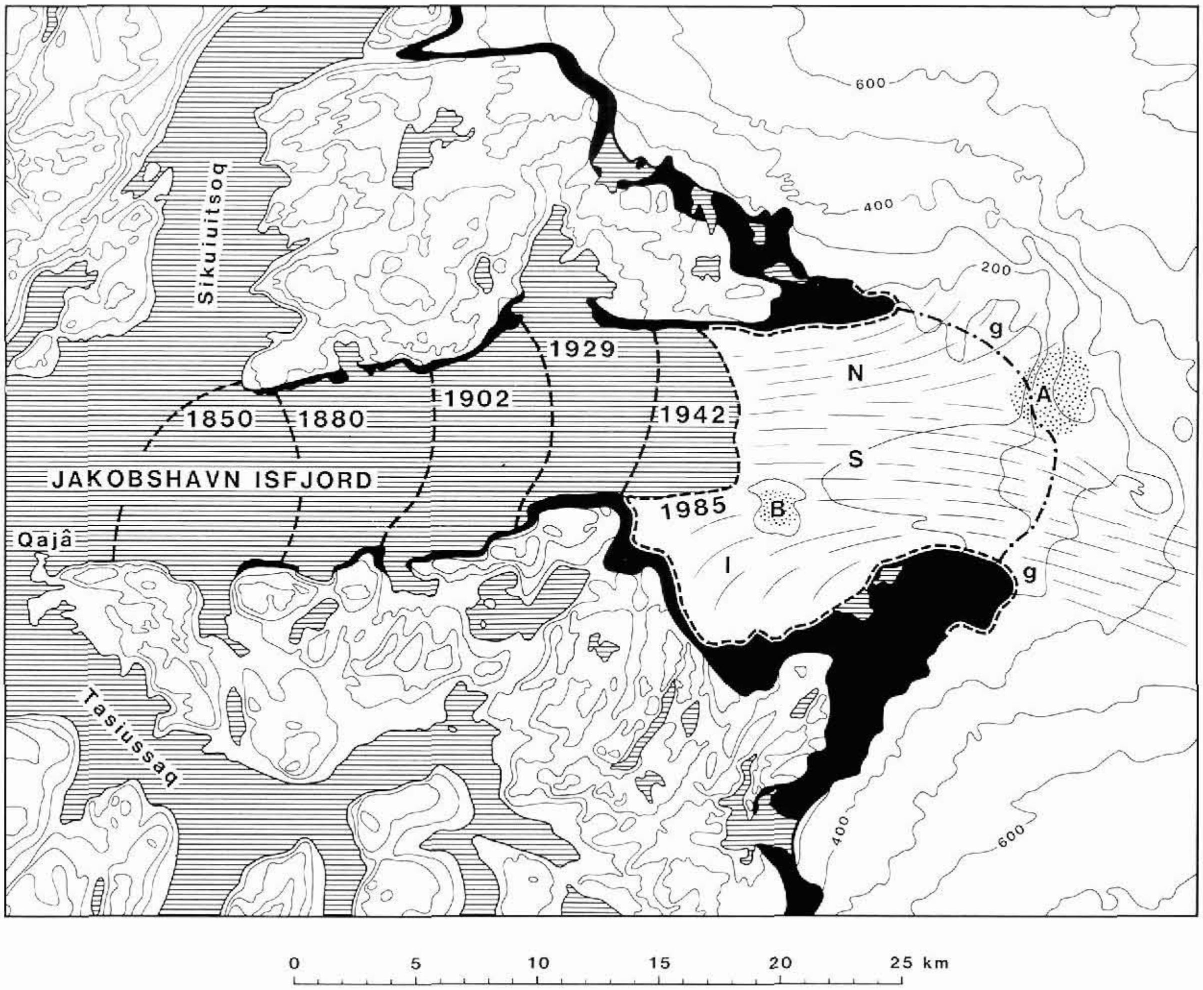


Fig. 2. Map of present Jakobshavn Isbræ and stages in the recession of the glacier between A.D. 1850 and 1985. Map base: GGU topographic map sheet 1:250 000 drawn on the basis of point determination and aerial photographs provided by Kort- og Matrikelstyrelsen, Denmark. Letters indicate the grounding line (g), rises (A and B), northern and southern (or major) ice streams (N and S), and the 'ice bay' area (I). Black zone around the glacier indicates land areas which were covered by the ice margin during the neoglacial maximum advance (A.D. 1850).

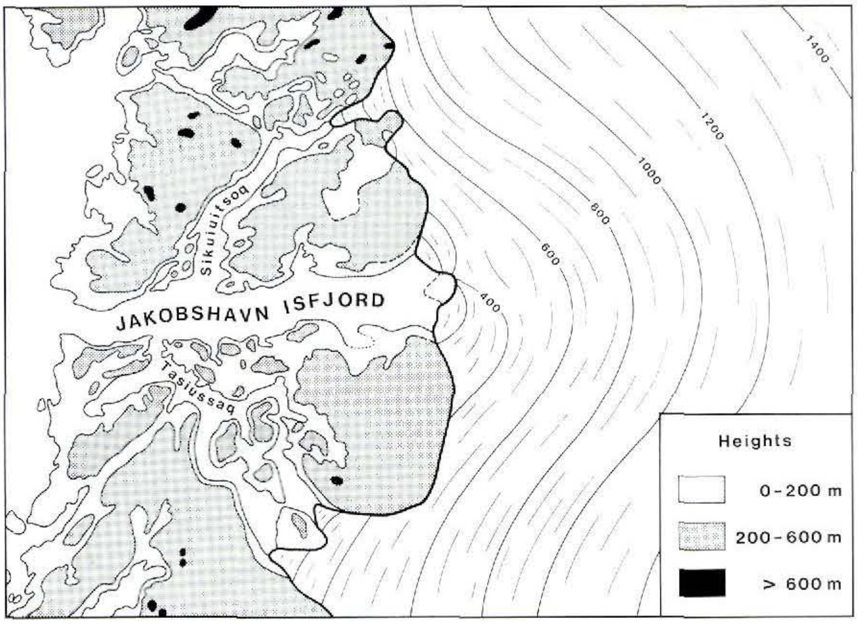
the turn of the century since Engell (1904), following a visit in 1902, described and mapped parts of this south-eastern wall as 'new nunataqs'.

Subglacial topography around Jakobshavn Isbræ

As no soundings of frontal parts of Jakobshavn Isbræ are available, it can only be assumed that the fjord continues eastwards under the present front with large depths at least to the grounding line. The altitude of the glacier surface at the grounding line is 100–200 m a.s.l., so west of this threshold the fjord beneath the glacier must reach depths of 1000 m or more.

The elevated areas (rises) of Jakobshavn Isbræ, marked A and B in Figs 1 & 2, indicate the existence of a subglacial threshold, the height of which is unknown. The deformation of the ice surface over these rises suggests that parts of the threshold could be above present sea level.

On Landsat images the surface ice features defining the northern ice stream can be traced *c.* 15 km behind the present glacier front, whereas the trends defining the major ice stream can be followed 90 km inland from the front. Radar soundings reveal no bottom in these ice streams (Overgaard, 1981; Thorning & Hansen, 1987), whereas seismic soundings (Iken *et al.*, 1989) at a point 50 km east of the present glacier front recorded the bottom of a trench about 1400 m below present sea level



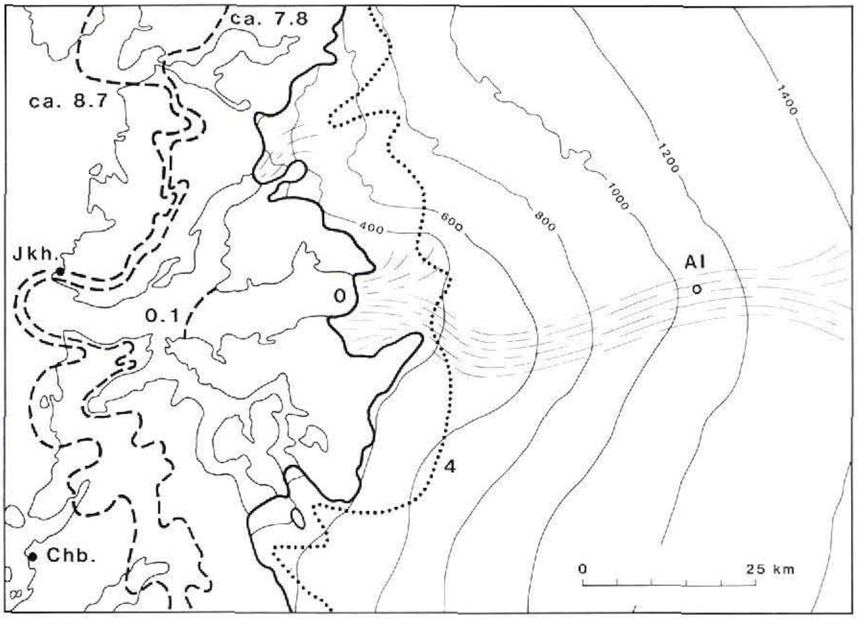


Fig. 3. Top: Approximate extent of the Inland Ice in the Jakobshavn Isbræ region at the end of the climatic optimum *c.* 4 ka ago. Bottom: Present extent of the Inland Ice (0), compared to positions *c.* 8.7, 7.8, 4 and 0.1 ka ago. Jkh: Jakobshavn/Ilulissat; Chb: Christianshåb/Qagssigianguit; AI: site of seismic sounding to the bottom of the ice stream, here −1400 m below sea level (from Iken *et al.*, 1989).

(the ice surface at this locality is about 1100 m a.s.l.).

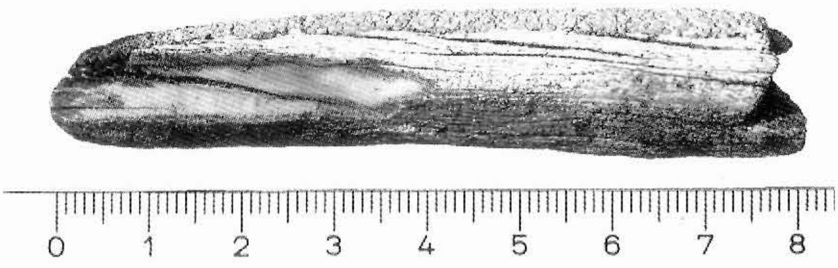
In the areas surrounding Jakobshavn Isbræ, radar measurements indicate the subglacial landscape to be a continuation of the western ice free landscape, with a topography varying between −200 m and +600 m a.s.l.

Change of the ice cover

The Holocene recession and subsequent neoglacial readvances have been described elsewhere (e.g. Weidick *et al.*, 1990) and are shown in summarised form in Fig. 3. About 9–8 ka ago the ice margin had a stationary position which reached the present town of Jakobshavn. Since then the ice margin has gradually receded until it reached a position some 15–20 km behind the present margin 4 ka ago. The rate of recession has been calculated to have been *c.* 20 m a^{-1} 8 ka ago, decreasing to zero 4 ka ago.

The time of the ice margin retreat beyond the present has been deduced from finds of ice transported biogenic material 4.7 to 2.8 ka old. These occur in neoglacial moraines 50 km north of Jakobshavn Isbræ (Påkitsoq),

Fig. 4. Walrus tusk. Scale in centimetres. Photo: Zoological Museum, Copenhagen.



and in glacier ice at Alángordliup sermia 50 km south of Jakobshavn Isbræ (Weidick *et al.*, 1990). The amount of recession (about 15–20 km behind the present position) was interpreted from radar mapping of the subglacial fjords in these areas, the trends of which provided information on the place of origin of the subglacial material at the present ice margin.

Thus, Jakobshavn Isbræ and its surroundings were considered about 4 ka ago to have had a retracted position comparable to the neighbouring areas to the north and south. The first confirmation of this scenario was the localisation in 1988 of *Balanus* and *Mya* shell fragments in silty–gravelly parts of the neoglacial moraines on the west side of 'ice bay'. In the same area, a small walrus tusk (Fig. 4) was collected (determination by M. Melgaard), at an altitude of about 60 m a.s.l. in 1988 (present ice surface here is 10–20 m a.s.l.). Dating of the walrus tusk was undertaken by the Svedberg Laboratory, Uppsala University, and the result (Ua-2350, age 4290 ± 100 ^{14}C years B.P.) fits well with the dating range of the neoglacial material from other parts of the ice margin area. However, due to the uncertainties of the subglacial topography of the present Jakobshavn Isbræ frontal area, and to the presumed change in flow direction of the ice cover in 'ice bay' during the past 100 years, the place of origin of the walrus tusk cannot be definitely determined; it probably comes from somewhere in 'ice bay'.

The concentration of finds of biogenic material on the west side of 'ice bay' could be an indication of formerly favourable conditions for the fauna in what was then a shallow bay, presumably protected from the main trunk of Jakobshavn Isbræ and Jakobshavn Isfjord by a threshold. However, the location and collection of material has so far been based on a few days reconnaissance south of the ice stream, and some hours north of the ice stream, and a more thorough study of the moraines might provide a slightly different picture of the situation.

The minimum extension (maximum retreat) of the ice margin was probably reached around 4 ka B.P., and this position was presumably maintained to about 3 ka B.P. Subsequently, a gradual build-up of the ice cover (presumably initiated shortly after 4 ka B.P. in the interior of the ice sheet) resulted in waves of advances of the ice margin, culminating with the 'Little Ice Age' about A.D. 1850 (cf. Fig. 2)

This scenario hints at a possible topographic control of the ice margin positions at the two thresholds of the fjord, namely at 8–9 ka at Isfjeldsbanken and 3–4 ka ago at or behind the present grounding line threshold.

Conceptual delineation of the hypsithermal Jakobshavn Isbræ glacier front

In the reconstruction of the hypsithermal (climatic optimum) Jakobshavn Isbræ and its surroundings, ice margin profiles at that time are presumed to be similar to those of the present ice margin; the profiles are moved simply *c.* 20 km to the east, with details of the frontal parts determined by the adjoining ice free landscape at that time. Major parts of the front of hypsithermal Jakobshavn Isbræ were presumably resting on the grounding line threshold, possibly with the rise A as a nunataq separating the north and major ice streams.

Rise B would have been part of a threshold, leaving the present 'ice bay' as a relatively shallow bay, largely protected from Jakobshavn Isbræ calf ice production.

Little can be said about the volume of hypsithermal calf ice, because of the lack of knowledge of the subsurface of the glacier front at this threshold. The Holocene climatic optimum is estimated to have reduced the present minimum source area of Jakobshavn Isbræ of 74 100 km^2 (Pelto *et al.*, 1989) by only *c.* 400 km^2, i.e. a loss of 0.5%. While it is feasible that ablation was greater during the climatic optimum, even an increase of this component to 15–20% of the total loss would still leave a large proportion of the accumulation to be lost by calving.

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