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# Estimates on the mass balance changes of the Inland Ice since Wisconsin-Weichsel

*by*

*Anker Weidick*

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Øster Voldgade 10, DK-1350 Copenhagen K

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# Estimates on the mass balance changes of the Inland Ice since Wisconsin-Weichsel

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1975

## Abstract

The extent of the Inland Ice during the last ice age reveals a pleniglacial equilibrium with a low accumulation. A postglacial equilibrium with high accumulation is indicated by relatively constant extent of the ice during the last 5000–6000 years.

The climatic change from pleniglacial to postglacial conditions is considered to have taken place around 12 500 B.P., the subsequent recession of the Inland Ice expressing its adaption to a new equilibrium state.

The form and shape of the Inland Ice is such that the initial postglacial warming-up only slightly increased the ablation area and thus loss by ablation. The actual loss of volume between 12 500 and 6000 B.P. can therefore only be explained by a continuous period of low average accumulation lasting until 8000 B.P.

Since the Inland Ice must have been close to the lower threshold of its existence in postglacial time, its total disappearance during a warm interglacial period cannot be excluded, but is still beyond final proof.

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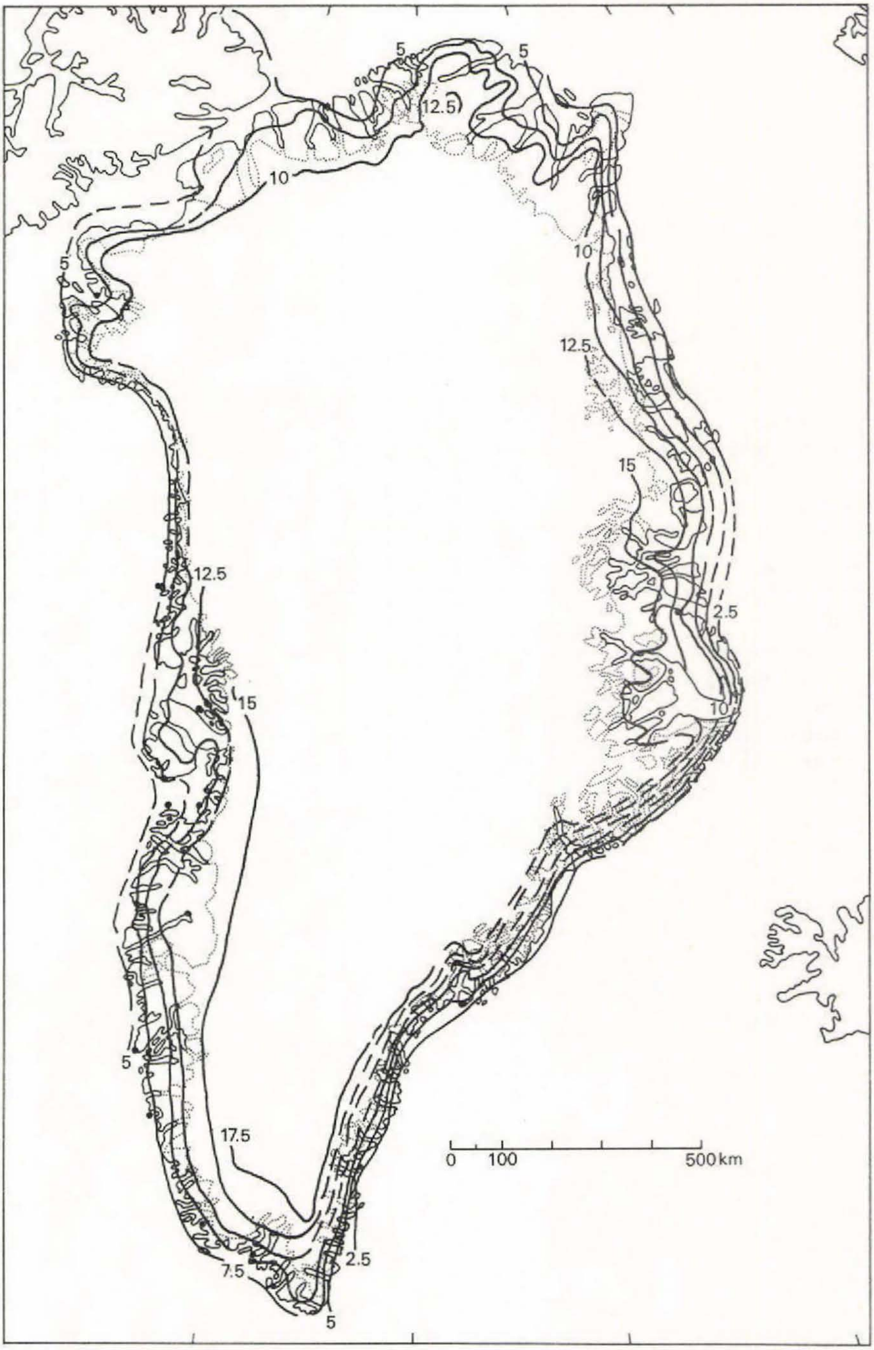



Fig. 1. Present glaciation limits expressed as isoglacihypses over Greenland. Altitudes in hundred of metres.

# INTRODUCTION

The Inland Ice is considered to have reached close to its last maximum at 15 000 B. P. when it covered most of the coastal region. The purpose of this paper is to discuss the changes in mass balance of the Inland Ice during the change from pleniglacial to postglacial equilibrium; in this context, 'pleniglacial' refers to the climatic conditions connected with an Inland Ice covering most or all of the coastland, and 'postglacial' the range of climatic conditions at the present extent of the Inland Ice. To simplify the discussion the two equilibrium stages are considered to be marked by relatively constant climates, and the transition between the two climatic states, as indicated by the Camp Century curve, is considered to be of short duration.

The Inland Ice is the only ice sheet in the northern hemisphere capable of establishing pleniglacial and postglacial states of equilibrium. The relatively small changes of this ice sheet since Wisconsin-Weichsel lead naturally to a consideration of the factors limiting its existence and the possibilities of total or partial disapperance under interglacial climatic conditions.

# PLENIGLACIAL EQUILIBRIUM OF THE INLAND ICE

### Extent

Evidence from central East Greenland shows that during the later part of Wisconsin-Weichsel the Inland Ice did not extend so far out to sea as during older glaciations, or the earlier part of Wisconsin-Weichsel (Funder & Hjort, 1973). Tedrow (1970) records a similar situation for the Inland Ice of Inglefield Land in North Greenland, though the interstadial dating here must be questioned.

In southern West Greenland shells collected from the moraines of Frederikshåbs Isblink have given an age of 21 710 ± 400 B. P. (I–7622; collector D. Heling), and shells from undisturbed marine silts at Sanerâta timâ near Fiskenæsset, a few kilometres west of the fjord stage moraines (8400–8100 B. P.), have been dated at 13 380 ± 175 B. P. (I–7624; collector A. Weidick).

The oldest moraine stage (Taserqat) in central West Greenland, situated 20–40 km from the outer coast, is with reservations ascribed a Younger Dryas or Preboreal age (Weidick, 1972 b). There have been numerous investigations of the area (Donner & Ljungner, in press; Kelly, 1973; Laursen, 1972; Sugden, 1972; Ten Brink, 1972; Weidick, 1968, 1972 a), but although there are many dates no marine deposits older than Holocene have been found *in situ* and it is thought that the Younger Wisconsin-Weichsel may have reached the open sea, and possibly the banks. Information from other parts of Greenland, however, leaves the question very much open, and some schliffgrenzen in the Sukkertoppen area fit into the concept of the Taserqat moraines as the maximum boundary of the Inland Ice during a considerable period.

As the Inland Ice margin during Wisconsin-Weichsel cannot be precisely defined, it suffices to presume a limit in West Greenland at or on the present offshore banks, while in East Greenland it reached the open sea in branches through the fjords. In North Greenland it can also be assumed that the Inland Ice covered large areas out at sea, since the Holocene glacio-isostatic uplift is of comparable magnitude to that of other areas.

Restrictions on the areal extent of the Inland Ice are mainly imposed by the sea. The calving component will increase with increasing length of ice margin in direct contact with the sea, and under pleniglacial conditions in particular this will not be compensated by accumulation. Extensive shelf ice areas during Wisconsin-Weichsel seem possible in the region off Independence Fjord and Jørgen Brønlund Fjord in North Greenland. These might explain the peculiar form and trend of the coastal Wisconsin-Weichsel moraines of Peary Land, and the distribution of erratic boulders along the coast (Dawes, 1970). A further possible shelf ice area during Wisconsin-Weichsel is the Melville Bugt region of northern West Greenland. Ice shelves of the dimensions envisaged here would be of Ellesmere Island type rather than Antarctic type, and be in an equilibrium of their own. In view of the uncertainties involved in the following discussion, the question of existence of the ice shelves does not significantly affect the mass balance of the Inland Ice.

A general eustatic lowering of sea level of about 100 m during the ice ages would mean that parts of the western Inland Ice margin would be grounded on the present banks, but even so a larger proportion of the margin than at present would be bounded by the sea, and the calving component would accordingly be relatively greater.

## Climate and accumulation

Strong anticyclonic conditions are dominant over Greenland in summer as well as winter, and lead to low precipitation. With a temperature gradient along the surface of the ice sheet of 1°C per 100 m and 1°C per degree latitude (Benson, 1962) and with depression of the glaciation limit to 600–700 m below that at present, climatic conditions during Wisconsin-Weichsel can be reconstructed by envisaging a transition of present day conditions to a position 7–10 degrees of latitude to the south. Accumulation over the Inland Ice would then scarcely exceed 15 cm water equivalent annually, and might be closer to 10 cm. Correlation of the Camp Century ice core record with that of a North Atlantic deep sea core led Imbrie (1972) to conclude that accumulation during the last glacial maximum was 40 % of the present, i. e. about 14 cm water equivalent per annum.

With a surface area of $2.3 \times 10^6$ $km^2$ (Flint, 1971), a surface profile similar to the present and a lowering of the glaciation limit by 600–700 m, the ablation area would at most be about 2 % of the total area of the Inland Ice ($0.05 \times 10^6$ $km^2$) and the accumulation area 98 % ($2.25 \times 10^6$ $km^2$). It follows from the flow laws of ice (Orowan, 1949) that there is a relationship between diameter and height of an ice sheet (Dansgaard *et al.,* 1973), and that the surface profile of the Inland Ice during the glacial epoch was therefore close to the present.

## Glaciation limit and equilibrium line

A general lowering of the glaciation limit (the lower limit of formation of glaciers) by 700 m during Wisconsin-Weichsel has been stated by Kaiser (1969) for the Arctic areas of Eurasia. In southern Greenland the occurrence of a lower cirque formation level near present sea level indicates a lowering of the glaciation limit by about the same amount. The glaciation limit varies by about 100 m from the equilibrium line for mass balance or the observable firn line, but for simplicity all 'snow lines' are assumed to be sited in a 200 m wide zone in this account, and the glaciation limit is considered to be an equilibrium line (Weidick, 1968).

It is also assumed that the shift in glaciation limit from glacial to postglacial position was only in a vertical sense, and did not involve changes in the dome-shaped form (fig. 1) of the glaciation limits of Greenland: the 'Massenerhebungs-effect'. This accords with observations in other glaciated areas such as the Alps (Klebelsberg, 1948; Kaiser, 1969).

Figure 2 shows that because of the interference of the Inland Ice profile and the glaciation limit profile, a lowering of the present glaciation limit by 600–700 m brings it down to a maximum altitude approximately 400 m above the former sea level, i. e. 300 m above the present sea level. The mean altitude of the pleniglacial glaciation limit might then be close to present day conditions at the outer coasts in the Thule area and in the northern part of Melville Bugt.

Figure 2 shows an idealised section through central Greenland. The height of the basement is estimated as a mean of West and East Greenland and its importance in this context is the decrease in ablation area and especially in the ablation with increasing height of basement.

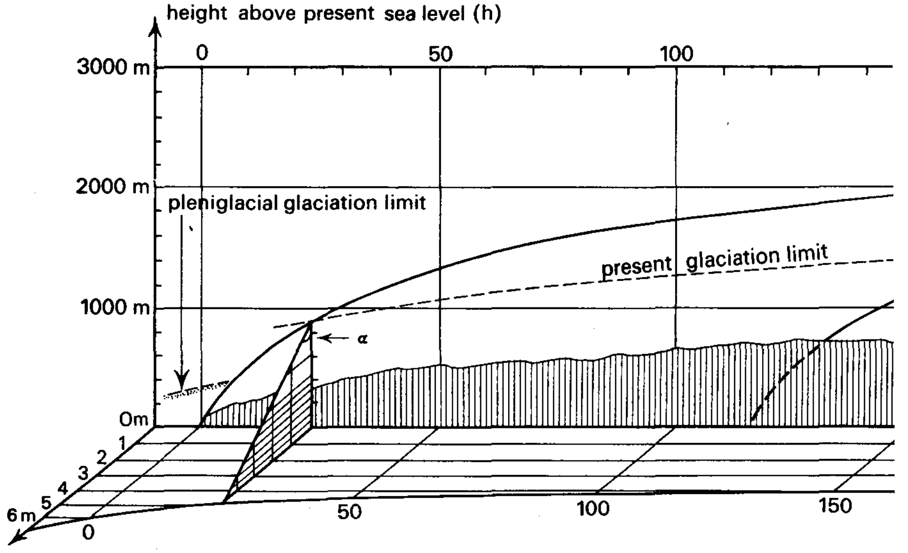



Fig. 2. Idealised east-west section through the present coastland in central Greenland show
the marginal basement and simplified estimates on average 'net ablati

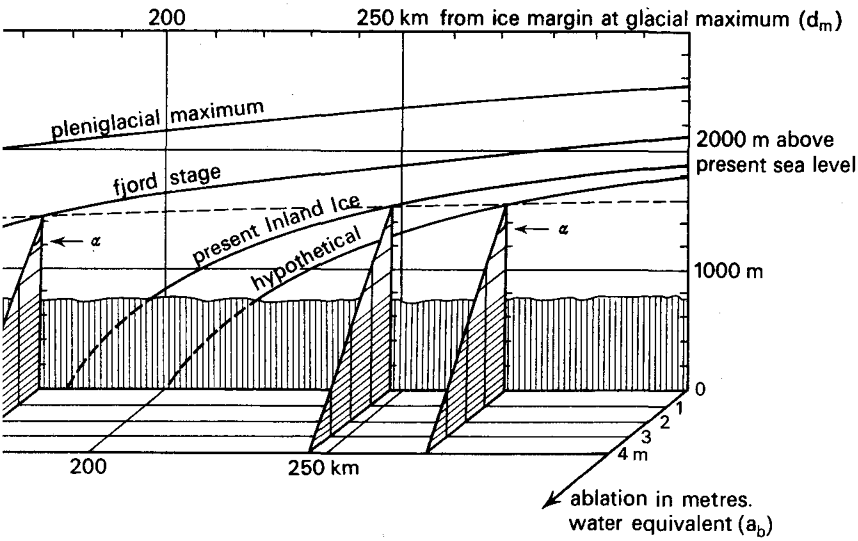
The lowering of the glaciation limit by 600–700 m may only be true for the southern and central parts of Greenland. In North Greenland a smaller lowering of the present glaciation limit would lead to a diminution of the accumulation zone over the whole Inland Ice surface so that loss is only possible by calving at ice shelves. However, in the same area a very low accumulation must be envisaged at the same time.

## Average ablation over the ablation area

The best estimate for the average pleniglacial ablation, in view of the discussion above, can be derived from the present ablation values for the Thule area, that is about 50–70 cm water equivalent per annum (Schytt, 1955; Nobles, 1960; Griffiths, 1960).

## Mass balance

The calving component when the Inland Ice is in equilibrium must be the deficit between total gain (accumulation over the accumulation area) and the loss due to general ablation (average ablation over the ablation area). The estimates for pleniglacial mass balance based on the considerations discussed above are shown




niglacial and present glaciation limits, recessional stages and adherent average elevation of
nnected to present glaciation limit as a function of altitude. $\alpha$: ablation gradient.

*Table 1. Estimates of the pleniglacial mass balance*

| | | | |
|---|---|---|---|
| Accumulation area | $2.25 \times 10^6$ km² | Mean accumulation | 12–15 cm water equiv./a. |
| Ablation area | $0.05 \times 10^6$ km² | Mean ablation | 50–70 cm water equiv./a. |
| Total area | $2.30 \times 10^6$ km² | | |
| Total gain | *c.* 305 km³ water equiv./a. | | |
| Loss by ablation | *c.* 30 km³ water equiv./a. | | |
| Loss by calving | c. 275 km³ water equiv./a. | | |

in table 1. The pleniglacial volume, which will be discussed below, is estimated at $3.21 \times 10^6$ km² water equivalent.

# POSTGLACIAL EQUILIBRIUM OF THE INLAND ICE

## Extent

Many different values for the area of the present Inland Ice have been proposed, the discrepancies being partly accounted for by variations in the quality of maps of Greenland, but mainly the problem of delineating the Inland

*Table 2. Data for the present Inland Ice according to Holtzscherer & Bauer (1954)*

| | |
|---|---|
| Accumulation area | $1.44 \times 10^6$ km² |
| Ablation area | $0.29 \times 10^6$ km² |
| Total area | $1.73 \times 10^6$ km² |
| Volume | $2.35 \times 10^6$ km³ water equivalent |
| Mean accumulation | 31 cm water equiv./a. |
| Mean ablation | 110 cm water equiv./a. |

*Table 3. Estimates for the present mass balance of the Inland Ice*

All figures in km³ water equivalent per annum

| | Loewe (1936) | Bauer (1955) | Bader (1961) | Benson (1962) |
|---|---|---|---|---|
| Gain | 425 | 446 | 630 | 500 |
| Loss by ablation | 295 | 315 | 120–270 | 272 |
| Loss by calving | 150 | 215 | 240 | 215 |
| Deficit | –20 | –84 | +120–+270 | +13 |

*Table 4. Estimate for postglacial mass balance of the Inland Ice*

| | |
|---|---|
| Accumulation area | $1.44 \times 10^6$ km² |
| Ablation area | $0.29 \times 10^6$ km² |
| Total area | $1.73 \times 10^6$ km² |
| Total gain | *c.* 500 km³ water equiv./a. |
| Loss by ablation | *c.* 295 km³ water equiv./a. |
| Loss by calving | *c.* 205 km³ water equiv./a. |

Ice from marginal local ice caps. The estimates of Bauer (Holtzscherer & Bauer, 1954) are used in this account (Table 2) with regard to area and volume.

## Mass balance estimates

A number of mass balance estimates have previously been made (Loewe, 1936; Bader, 1961; Benson, 1962; Bauer, 1955, and *in* Holtzscherer & Bauer, 1954), and their conclusions are summarised in table 3. Values of mean accumulation vary from 31 to 37 cm water equivalent per annum, and those for ablation from 107 to 110 cm.

Loewe and Benson both estimate a nearly balanced ice sheet. Bauer's conclusion of a small shrinkage fits in with the slight marginal retreat of the Inland Ice in this century, as measured directly from trim line zones (Weidick, 1968). Bader considered that while the ice margin was retreating the interior of the Inland Ice was increasing in volume. If true, the interior of the Inland Ice is increasing in volume by 8–19 cm water equivalent annually, but no conclusive observations have been made.

The estimates of the mass balance presented in table 3 are based on direct measurements of three parameters, though the figures for ablation and magnitude of calving in particular are unreliable. As the ice margin has not changed greatly throughout the past 5000–6000 years it is, however, reasonable to accept the approximate state of equilibrium presented in table 4. Vertical pulsations or kinematic waves of the Inland Ice (Georgi, 1959; Haefeli & Brandenberger, 1968) seem to have been of secondary significance, at least during the last 5000–6000 years.

# END OF PLENIGLACIAL EQUILIBRIUM

## Initial change of climatic conditions

An abrupt change from pleniglacial to postglacial conditions is recorded by the Camp Century ice core (Dansgaard *et al.*, 1971). The limit in the isotope curve is sharp, and appears to represent a break from fairly constant pleniglacial temperatures to fairly constant postglacial temperatures at 12 500 B. P. The Camp Century record as an expression of temperature change may, however, be slightly exaggerated as the $O^{16}/O^{18}$ ratio increases in sensitivity with increase in altitude and the surface of the Wisconsin-Weichsel Inland Ice must have been several hundred metres higher than at present.

There are also possibilities of minor variations in the time-scale of the Camp Century record (Dansgaard, *et al.*, 1973; Imbrie, 1972; Sancetta *et al.*, 1973) but in the context of this account it is the occurrence of the abrupt climatic shift which is significant rather than its precise age.

## Rise of the glaciation limit

The initial response to the change in climate must have been a rise of the glaciation limit to about its present altitude of 800 m above contemporary sea level (fig. 1), leading to an increase in ablation area from *c.* $0.05 \times 10^6$ km² to

$0.1 \times 10^6$ km². The proximity of the Inland Ice to the sea would mean a large ablation gradient (figs 1 & 2), and an average ablation over the ablation area of close to 1 m water equivalent per annum. Total loss by ablation would increase to about 80 km³ water equivalent annually.

## Calving

An initial acceleration of calving is to be expected with the warming up, and it could have risen to 380–360 km³ water equivalent per annum. The loss by calving would hardly be less than during the pleniglacial period, and the pleniglacial figures may be viewed as a minimum. Also the eustatic rise of sea level, approximately 0.9 m/100 years between 15 000 and 7 000 B.P. must have increased the calving, especially during its initial phase with large parts of the ice margin in contact with the sea (Benson, personal communication).

## Accumulation and mass balance

A generally stable high pressure environment over the Laurentide ice sheet and the Inland Ice would probably not permit any great increase in the mean accumulation. Since the Inland Ice began to shrink accumulation can hardly have exceeded 18 cm water equivalent per annum. The mass balance position is summarised in table 5.

*Table 5. Initial postglacial shrinkage of the Inland Ice mass balance*

| | | | |
|---|---|---|---|
| Accumulation area | $2.20 \times 10^6$ km² | Mean accumulation | 18 cm water equiv./a. |
| Ablation area | $0.10 \times 10^6$ km² | Mean ablation | 80 cm water equiv./a. |
| Total area | $2.30 \times 10^6$ km² | | |
| Total gain | *c.* 396 km³ water equiv./a. | | |
| Loss by ablation | *c.* 80 km³ water equiv./a. | | |
| Loss by calving | *c.* 360 km³ water equiv./a. | | |
| Deficit | *c.* 44 km³ water equiv./a. | | |

# POSTGLACIAL SHRINKAGE OF THE INLAND ICE

### Rate and magnitude of shrinkage

In both West and East Greenland shrinkage began before or about 10 000 B. P., and retreat continued with minor interruptions until about 6000 B. P. when the ice margin position was close to or less than the present situation. In North Greenland retreat of the Inland Ice margin seems to have been initiated somewhat later, and in southernmost Greenland somewhat earlier than these dates (Weidick, 1972b).

There remain uncertainties as to details of the initial recession before or about 10 000 B. P., but two important points seem to be valid:

(1) The recession rate culminated somewhat earlier than 8000 B. P.
(2) Nearly all recession occurred during a period of 5000–6000 years.

The volume of the Inland Ice at present is according to Bauer (Table 2) $2.35 \times 10^6$ km$^3$ water equivalent, from which Flint (1971) derived an estimate of $3.5 \times 10^6$ km$^3$ ice, i. e. $3.2 \times 10^6$ km$^3$ water equivalent, for the volume of the pleniglacial Inland Ice. This figure is based on an area of maximum glaciation of $2.3 \times 10^6$ km$^2$, which is larger than the late Wisconsin-Weichsel Inland Ice, and the present mean altitude of 1.5 km for the Inland Ice, which is too low according to the pleniglacial profiles. It is, however, the best available estimate and corrections will not significantly affect the trends of fig. 3.

The total loss between the two equilibrium stages based on these figures is $0.8 \times 10^6$ km$^3$ water equivalent. The volume change, based on key areas in West and East Greenland taking the linear rate of retreat as a model, will be as given in fig. 3e.

### Increase of the ablation zone

With shrinkage of the Inland Ice the intersection between the ice surface and the glaciation limit will increase in altitude (cf. fig. 2) and the area of the ablation zone will thus increase. However, this will be partially compensated by the rise in mean altitude of the Inland Ice margin from near sea level at the maximum extent to 700–800 m as at present. Fig. 3b shows the trend of change of the ablation area.

### Changes in ablation

The rise of the glaciation limit during recession (fig. 2) should increase average ablation over the ablation area. However, with the increase in distance from

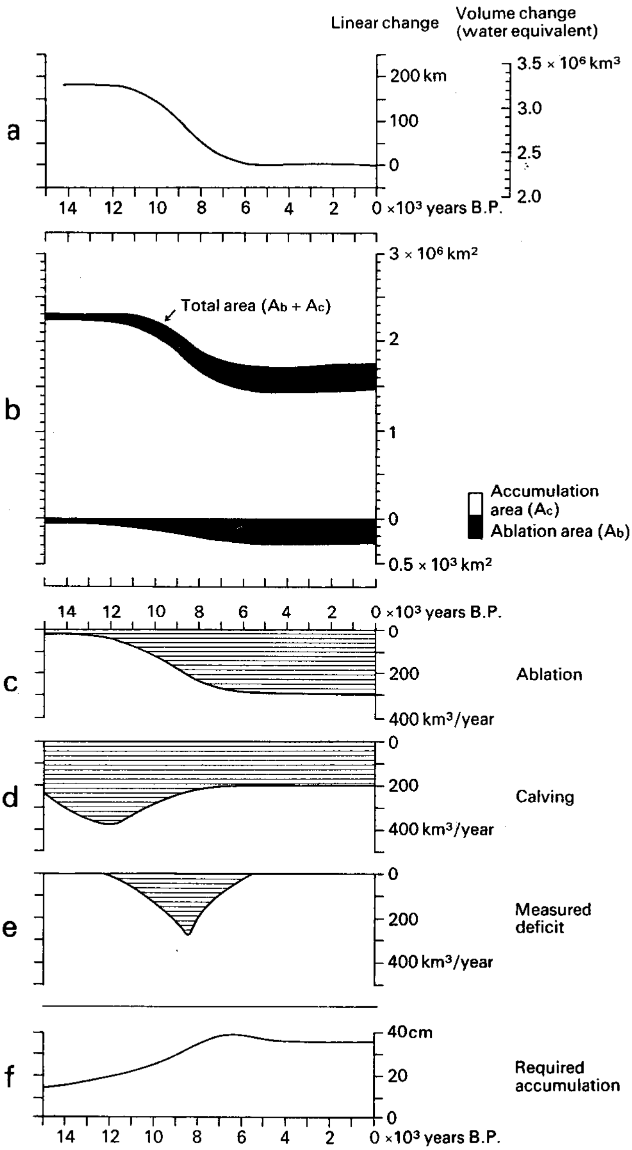



Fig. 3. Changes in the mass balance through Holocene time.

*a.* The average recession of the Inland Ice margin according to Weidick (1972a, b). The recession is also converted to volume shrinkage.

*b.* Shrinkage of the total area (*A*) and the accumulation area ($A_c$) and the coherent growth of the ablation area ($A_b$). The ablation area is corrected for altitude of marginal basement.

*c.* Loss by ablation in km³/year of water equivalent according to the change in the ablation area given in *b*.

*d.* Loss by calving in km³/year.

*e.* Loss in volume due to the shrinkage according to the trend given by the volume change in *a*.

*f.* Accumulation (cm water/year) required to match the losses given by the curves of *c*, *d* and *e*.

the sea there is a tendency to greater continentality over the ice margin causing a lower ablation gradient. In coastal areas the gradient must be close to that of Norwegian and Spitzbergen glaciers, and with increasing distance from the sea an ablation gradient similar to that of Loewe (1934) will be approached. The average ablation over the ablation area during recession is thought to have had a value close to that of the present: about 1 m water equivalent per annum. The amount of ablation during recession of the Inland Ice is shown in fig. 3c.

### Calving

The magnitude of the calving component can only be estimated indirectly. While an initial increase in calving might result with warm-up of the ice margin, recession will cause a decrease of calving as the land rim widens, thresholds and land barriers grow and possibilities for exudation channels become fewer.

With increase in distance from the sea the amount of calving would decrease in linear proportion. Since volume loss and ablation are known the required accumulation during recession would then be lower in postglacial time than during pleniglacial conditions, which seems unlikely. On the other hand, if constant accumulation since Wisconsin-Weichsel is presumed, the amount of calving would increase in the initial stages of retreat to about 700 $km^3$ water equivalent annually at 8000 B. P. Such exceptionally high postglacial production of calf ice would be expected to leave marked traces in offshore deposits, but this does not seem to have been the case.

These are the extreme possibilities of the calving component variation, and it seems most likely that there was a minor initial increase in calf ice production with warm-up, followed by a decrease as the coastal rim of land widened. This compromise viewpoint (fig. 3d) also implies a trend to increasing precipitation and accumulation by the end of Boreal time at 8000 B. P.

## COMPARISONS WITH GLACIATIONS OUTSIDE GREENLAND

### Extent of the Wisconsin-Weichsel glaciations

The Wisconsin-Weichsel glaciation lasted from 70 000 to 10 000 B. P., divided into two phases by an interstadial or group of interstadials lasting from 50 000 to 25 000 B. P (the Upton Warren interstadial complex) which incorporated minor readvances of the ice sheets. The great ice sheets remained in existence throughout the period, the marginal oscillations reflecting more closely climate fluctuations than during build up of the ice sheets at the beginning of Wisconsin-Weichsel. It is envisaged that a persistent cold climate through 5000–10 000 years (Lamb & Woodroffe, 1970) or 15 000–30 000 years (Weertman, 1964; Barry, 1966) was required for establishment of major ice sheets.

During early Wisconsin time some sectors of the Laurentide ice sheet in North America were 50–100 km beyond the late Wisconsin position, while at other places the late Wisconsin margin was similarly placed or even more advanced than in the early Wisconsin. The older Wisconsin moraines of Baffin Island mark the maximum extent of glaciation (Andrews, 1973), and a similar situation was concluded, with reservations, for East Greenland (Funder & Hjort, 1973). The position of the Scandinavian ice sheet of Europe and the presumed Barents Sea ice sheet over Spitzbergen and Franz Josef Land during early Weichsel are not clearly defined. Nowhere, in fact, is information sufficient to enable comparisons of the two phases of glaciation to be made with any great confidence, but in Arctic areas there seems to be a tendency for the older phase to be more extensive than the younger.

Reglaciation at the end of the last interstadial was generally intense. A number of radiocarbon dates from south of the Great Lakes indicate that the ice sheet there entered Ohio at 25 000 B. P. and reached its last maximum at 20 000 to 18 000 B. P. (Goldthwait *et al.,* 1965). Fluctuations of the Scandinavian ice sheet of this age, as well as others slightly older, can be included in the Upton Warren interstadial complex. An interstadial period at 31 000–20 000 B. P. has been recorded in the Alps near Baumkirchen in the inner Inn valley, ending with the last Würm advance between 20 000 and 11 000 B. P. (Fliri *et al.,* 1970).

### End of late Wisconsin-Weichsel

While the Laurentide ice sheet reached its last maximum at 18 000–20 000 B. P. at the southern margin, it retained this maximum position until 13 000–12 000 B. P. at the north-west and until 8000 B. P. at the north-east margins (Andrews, 1973). The persistence of the northern margins is explained by mass balance variations in sectors where lobes change from calving to land-based situations, and by increase in winter accumulation.

In Europe recession of the ice sheets appears to have been initiated at about 20 000–16 000 B. P.

## GREENLAND DURING WISCONSIN-WEICHSEL

The presumed development of Wisconsin-Weichsel in Greenland is based essentially on the chronology of Funder & Hjort (1973) established for central East Greenland. Here two advances are recognised, the older termed Flakkerhuk and the younger Milne Land. The intervening Jameson Land interstadial has provided three radiocarbon dates between 24 300 and 19 500 B. P. and four of 33 600 to more than 40 000 B. P.; it might be better to refer to a Milne Land interstadial complex correlateable in time with the Upton Warren interstadial complex.

The younger group of dates within such a Milne Land interstadial complex can be compared with dates from Frederikshåbs Isblink in West Greenland and Inglefield Land in North Greenland. The wide distribution of similar dates in Greenland and North America seems to witness to a widespread warm spell markedly limiting the older boundaries of the late Wisconsin-Weichsel stadial. There is no indication here of a precipitation conditioned time lag such as that of 10 000 years between climatic change and recession for sectors of the postglacial Laurentide ice sheet. It is therefore presumed that the low accumulation of Wisconsin-Weichsel was maintained throughout at least the last interstadial.

Climatic development during Wisconsin-Weichsel is fully covered by the Camp Century record (Dansgaard *et al.,* 1971, 1973). There are discrepancies between the summary of stadials and interstadials of Wisconsin-Weichsel by Richmond (1970, fig. 5) compared to the Camp Century record. These may be due to errors in the geological time scale or the Camp Century time scale.

## POSTGLACIAL (HOLOCENE) DEVELOPMENT IN GREENLAND

Several radiocarbon dates from South Greenland suggest a relatively early deglaciation. Drift wood in a beach ridge at Narssaq town is dated at 9410 B. P. (I–7664; collector K. Gade Sørensen), at a distance of 29–40 km from the present Inland Ice margin. Shell datings at Narssarssuaq a few kilometres from a present lobe of the Inland Ice gave 8760 B. P. (I–7667; collectors J. Mangerud, H. Valeur & A. Weidick), while at Qagssiarssuk nearby, a basal gyttja of a lake gave 8530 B. P.; biological activity presumably began about 9000–8500 B. P. (Fredskild, 1973).

Dates from north of Frederikshåbs Isblink at Sanerâta timâ indicate that the Inland Ice maintained its position here from 13 380 to 8000 B. P. and there is no evidence of early deglaciation. Standstill in such an isolated sector could, however, be explained as an indirectly climatically conditioned 'glacial capture'; general thinning of the ice margin and a sinking of the ice margin may have led to greater topographic control of the ice drainage, such that this sector received contributions from neighbouring sectors. Comparable sector deviations during retreat of the ice margin are known during this century (Weidick, 1968).

The deglaciation of central East Greenland, based on studies over a 300 km stretch from Scoresby Sund to Geographical Society Ø (Funder & Hjort, 1973), seems to have involved a climatically conditioned stand-still of the Inland Ice margin until 10 000 B. P.

Onset of deglaciation in North Greenland is presumed to have occurred at or shortly before 8000–6000 B. P. (Weidick, 1972b).

In East and North Greenland it is possible that an increased winter accumulation contributed to maintenance of the Inland Ice margin for a time. The increase in accumulation may have been initially restricted to the fringe of the Inland Ice, gradually spreading and leading to a general accumulation increase in connection with the gradual warming up of the North Atlantic waters and the disappearance of the Laurentide ice sheet.

Meteorological conditions over the North Atlantic gradually approached that of the present with the shrinkage of the Laurentide ice sheet, a position reached about 6000 B. P. (Lamb, 1972).

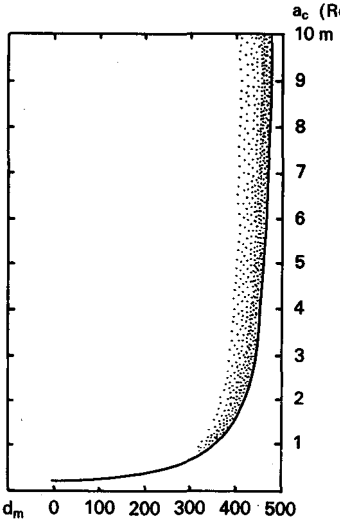
Ruddiman & McIntyre (1973) indicate a recession of polar waters in the North Atlantic beginning around or after 17 000 B. P. and continuing, apart from a readvance at 10 000 B. P., until normal postglacial conditions were achieved at 6000 B. P.

## LIMITS OF EXISTENCE OF THE INLAND ICE

In the above discussion it has been suggested that the ablation area increases with distance of the ice sheet margin from its maximum extent during Wisconsin-Weichsel whereas the calving component decreases. If the height of the equilibrium line (glaciation limit) is kept under constant postglacial conditions and the reduction of the Inland Ice continued beyond its present limits a continuation of the calving component and the ablation as a function of the distance from the Wisconsin-Weichsel maximum would require the accumulation shown in fig. 4. Since with increase of height of the marginal basement to the Inland Ice margin the ablation is reduced continuously the calculated ablation area is a minimum and the curve shows the minimum accumulation required.

It is conceivable that the reduction of the Inland Ice to a point 300 km from its Wisconsin-Weichsel situation 100 km further inland than at present might exceed the limits for its existence due to the size of accumulation required for its maintenance.

Around 6000–5000 B. P. the Inland Ice margin did retreat beyond its present position and shell material in shear moraines and marginal moraines indicates a position for some lobes 10–20 km inland from their present state. Subsequently an increase in accumulation brought the Inland Ice to its present mass balance.

b


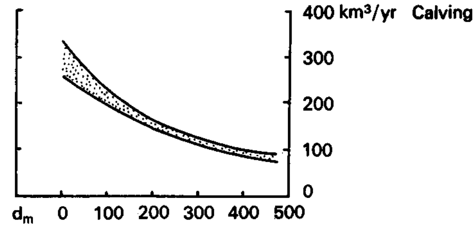

a



Fig. 4*a*. Estimated maximum (upper line) and minimum (lower line) loss by calving in km³/year water equivalent versus distance of ice margin from its maximum extent in Wisconsin-Weichsel ($d_m$).
*b*. Accumulation required to maintain the mass balance versus distance of the ice margin from its maximum extent during Wisconsin-Weichsel ($d_m$ being 0 for the Wisconsin-Weichsel position of the ice margin).

# INTERGLACIAL DISAPPEARANCE OF THE INLAND ICE?

An apparent high sea level 4–6 m above present sea level during the Sangamon-Eem interglacial led Mercer (1968) to propose melting of the West Antarctic ice sheet. Emiliani (1969) suggested the high interglacial terrace levels might rather result because of significant melting of the Inland Ice of Greenland. The problem of an interglacial disappearance cannot be solved satisfactorily with present knowledge of the mass balance of the Inland Ice and the altitude and age of the interglacial marine terraces. It is possible that the Inland Ice is at present close to its existence threshold.

Fig. 4b was constructed by assuming the present altitude for the equilibrium line of the Inland Ice. A rise of a few hundred metres of the equilibrium line will move the system expressed by the curve towards the left side. As the Sangamon formation of Toronto seems to indicate a mean annual temperature as much as 2°–3° C above the present, an interglacial disappearance of the Inland Ice cannot be excluded (Flint, 1947). The problem should be reassessed when better data on present mass balance and the former volumes of the Inland Ice become available. A total disappearance of the Inland Ice might also have left its mark in deep sea cores as a decrease of iceberg transported material.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