THE GLACIOLOGICAL STUDIES OF THE BAFFIN ISLAND EXPEDITION, 1950

By P. D. Baird, W. H. Ward *and* S. Orvig

Glaciological studies were an important feature of the Baffin Island Expedition, 1950 of the Arctic Institute of North America. A particular study was made of the Barnes Ice Cap,* situated about latitude 70° N., inland from Clyde Post. The ice cap, first sighted from a distance during J. M. Wordie's expedition to Melville Bay and North-East Baffin Land in 1934, was occupied from 27 May to 29 September 1950.

The ice cap party consisted of:

P. D. Baird, who, in addition to his task as leader of the whole expedition numbering twenty persons, spent most of his time on the ice cap.

W. H. Ward, who was generally responsible for the glaciological work on the ice cap.

S. Orvig, meteorologist.

J. D. C. Waller, mechanical engineer assistant.

C. A. Littlewood, gravimetrist.

In addition, R. P. Goldthwait spent some five weeks studying the geomorphology around the ice cap and gave the glaciologists valuable assistance. Several other members of the expedition came to help for short periods.

The party depended almost exclusively for distant transport on the willing service of the late J. M. King, pilot of the Arctic Institute's Norseman aircraft working first on ski-wheels and later in the season on floats.

The glaciological work is to be described in a series of articles in this Journal; the first two (Parts I and II) appear below.

Part I: METHOD OF NOURISHMENT OF THE BARNES ICE CAP†

By P. D. Baird

Director, Montreal Office, Arctic Institute of North America

Abstract. The Barnes Ice Cap on Baffin Island, N.W.T., Canada, was investigated during the summer of 1950. This ice cap, some 6000 sq. km. in extent, appears to have an approximately balanced budget, and yet there is no firn on its surface. It is postulated that its nourishment is by superimposed ice due to immediate refreezing of much of the melt water of summer. It is further inferred that a similar process nourishes many Arctic glaciers and ice caps where elevation, precipitation and temperature are all low. The name "*Baffin Type*" is proposed for these in the classification of glaciers.

Résumé. Nous avons étudié pendant l'été 1950 la calotte de glace Barnes à Baffin Island. Cette calotte, d'environ 6000 km. carrés, possède apparement un budget presque équilibré, mais il n'y a pas de névés à sa surface. On peut affirmer que l'alimentation de la calotte provient de la surimposition de la glace née du regel immediat de l'eau de fusion de la neige. On peut inférer qu'un grand nombre de glaciers arctiques croissent d'une façon similaire là où l'altitude, les précipitations et la température sont toutes basses. Nous proposons pour ceux-ci la classification "Type Baffin."

It was obvious from a study of the aerial photographs taken by the Royal Canadian Air Force in 1948 and 1949 that the Barnes Ice Cap had some unique features. Its area was approximately 6000 sq. km., and it was entirely surrounded by bare ground of no great elevation. It was not

* Name adopted by the Canadian Board on Geographical Names after the late Professor H. T. Barnes of McGill University who carried out much ice research.

† Paper read at a meeting of the International Commission on Snow and Ice, Brussels, August 1951.

possible from the photographs to do more than guess at the altitude of the ice cap, but we assumed that its summit was around 1000 m. and its margin around 500 m. In shape it is an irregular ellipse with its long axis N.W.–S.E., parallel to the axis of Baffin Island, but from a study of the map and photographs it was obvious that this major axis lay to the west of the main watershed of the island, since along its eastern edge lay many dammed lakes, two of them of considerable extent, and all spilling eastwards at present (Figs. 1 and 2, below).

At the south-east end of the ice cap is a lobe almost circular in shape with a slightly narrower neck connecting it to the main portion. Since this was closer to the base of flying operations of the expedition, and there was no reason to believe that it was sensibly lower in altitude than the rest, it was decided to concentrate the work in this area. We planned to establish a main camp in the centre of the lobe above the firn line and to have a subsidiary camp near the margin where ablation, the ice edge, and the ground immediately beyond the ice could be studied.

On 27 May 1950 we landed at our proposed upper camp site, Camp A1. The ice cap was a smooth, white expanse, and it was about as hard to judge the higher points on the ground as it had

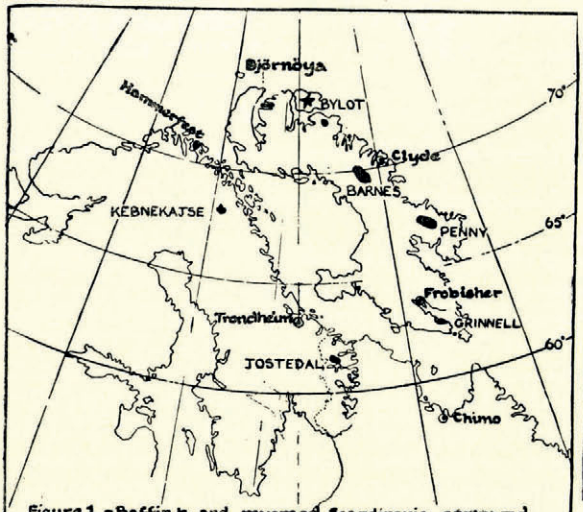

Figure 1 - Baffin Is. and reversed Scandinavia compared.

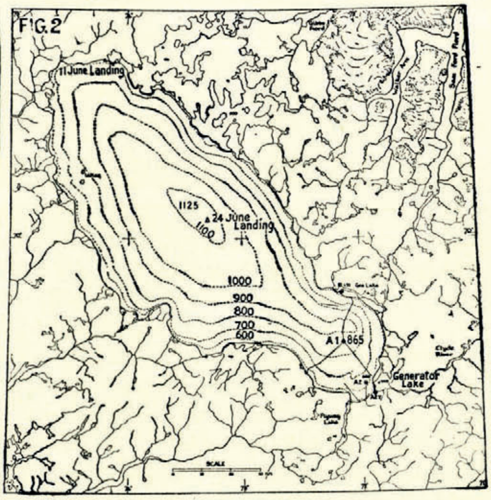

Fig. 2. Barnes Ice Cap. Form lines at 100 m. interval. Full lines show gravity traverses

been from the aerial photographs. As it turned out, the position was very close to the centre of the south-east lobe, and the height 865 m. To the north it was found that the surface rose at an angle of about 0° 45′ to a height of 930 m. To the north-west it rose initially at a similar angle, then more gradually, until at a distance of about 50 km. the apparent highest point of the whole ice cap lay at about 1125 m.

We were satisfied, however, that we should be up in the accumulation area, and a few days after the camp was set up we began to dig a pit, 1A1. Only a few minutes work revealed less than a metre of snow on solid ice (Fig. 3, top right, p. 19). It was obvious that there was no firn here. This was disconcerting. We immediately decided that at the first opportunity we must pay a visit to the highest possible part, but meanwhile much gear had been landed, the meteorological tower erected and observations begun, so it seemed undesirable to relocate the camp (Fig. 4, p. 18).

For some time the aircraft was needed to establish other camps, and then some bad weather intervened, so it was not until 24 June that the highest point was visited. The situation was the same—slightly less snow on solid ice. And yet all the indications were that the ice cap is nearly stationary and not receding—vegetation grows right up to its edge, there is obvious activity on the ice cliffs in the lakes, and on the ground, moraines could be observed forming (Figs. 5 and 6, p. 18). It occurred to us then that owing to the great cold of the ice and the briefness of the summer season, the snow cover was normally dissipated each year, but a large proportion of it was "superimposed" on the existing ice surface as melting took place; that somewhere on the ice cap was a line corresponding to the firn line where this "superimposed" ice showed a net gain during the year, and that therefore above this there was a true accumulation area.

We began to make observations to confirm or disprove this hypothesis, and the following descriptions cover these observations.

The Change in Snow and Ice Surface at Camp A1

The exposed situation of this camp and consequent drifting of snow, the fact that the snow disappeared completely for a brief period and that the ice surface was not smooth, made measurements difficult, so that new methods were required at different stages of the season. Even had we sunk ablation stakes deep into the original ice surface at the beginning, measurements of these might have been subject to error as the locations might have been exposed to drift and the holes to extra melting.

Fig. 7 (p. 7) shows graphically the main measurements undertaken. A giving the mean daily temperatures, $\left(\frac{\text{max.}+\text{min.}}{2}\right)$, for the 24 hours ending at 08.00 hr. on the day recorded; B the five day running mean of these temperatures and C the depth of snow and ice referred to the original ice surface of June.

From 28 May until 26 June snow depths were recorded from a single ablation stake (O) at camp. This stake was certainly subject to extra drifting in a storm on 5/7 July, and very probably in an earlier storm on 12/14 June when the accumulation seemed very great. On 26 June, when ablation had started and melt water was appearing at the undersurface of the snow, eight $\frac{1}{4}$ in. (6·3 mm.) diameter birch dowels were planted in a smooth area to the south-east of the camp. These showed an average depth of snow down to the existing ice surface of 96·5 cm. As it was only the day before (25 June) that temperatures well down in the snow cover had approached freezing point, I believe that apart from some "firn pipes" no superimposed ice had formed before the dowels were planted. On 27 June the average dowel reading of 94·0 cm. agreed exactly with the snow depth shown on stake O. One of these dowels (1A), corrected to the average, was read for ablation until 1 July when it was dug up (Fig. 10, p. 7). Dowel 2A, corrected to correspond with 1A, was read from 1 July to 7 July. At this date a correction of 8·3 cm. was made, since the storm of 5/7 July had caused this much extra drifting around the dowels compared with the new snow cover measurement at 13 different places 10 m. apart on level ground out of reach of any camp-made drifts. From 7 July to 31 July the mean depth of the three dowels (2B, 3B, 4B) was used for the recorded snow cover.

On 31 July the theoretical snow depth was zero. This is obtained from the mean ablation reading, which showed 15·0 cm. "snow" remaining, and the mean measurement of superimposed ice for the dowels, which showed 16·5 cm. of new ice. Around the camp this condition appeared to be correct. There was still some slushy snow in hollows, but equal areas of bare ice on the higher parts of the irregular surface. Ice ablation measurements were therefore begun on a smooth dry ice surface beside a reference point consisting of a stake which had been frozen into a bucket in a pit deep in the ice since 26 June. By 5 August a new snowfall was recordable, but this froze in places to the wet portions of the surface, and it became difficult to read the depth to true ice surface at the bucket stake. On 14 August three new dowels were set in and the average snow depth on these recorded thereafter. It is realized that these different means of recording give rise to errors, but they have been tied together as closely as possible, and, I believe, give the general picture with fair accuracy.

The densities in the snow also gave indication that only a single year's cover existed. Until melting began strongly the densities averaged between 0·25 and 0·40, a common value for Arctic wind-packed winter snow, whereas true firn snow tends to have a density 0·5 or higher. Figure 8 (p. 7) shows details of some pits dug on the ice cap.

The temperature in the ice was strongly negative. At the original ice surface below the snow cover it was approximately −12° C. in early June, −10° C. on 22 June, −0·5° C. on 31 July when there was no snow cover and −2·2° C. on the last day (26 August). At 3 m. deep in the ice on the same dates the temperatures were −14° C., −13·5° C., −9·4° C. and −7·4° C. respectively. It was therefore still rising at this depth but falling again in the upper strata. One can estimate that the temperature at the level of the zero amplitude is −13° C. or lower.

Historical Summary of the Season. (The periods are shown graphically in Fig. 7, p. 7.)

Period I. 28 May–22 June: Cold, mean air temperatures below freezing. The winter's accumulation continued, the snow cover growing from 89 cm. to 115 cm. Most of this was added in two storms (1 and 2) 12/14 June and 19/21 June. Pits dug on 1 June and 22 June revealed a mean water equivalent of the snow cover on the latter date of 41 cm., of which 7 cm. had been added since 12 June (Fig. 8, p. 7).

Period II. 22 June–4 July: Midsummer brought a long fine sunny spell: mean temperatures were above freezing and ablation steady and more rapid than at any other time (115 cm. to 64 cm., a rate of 4·25 cm. of snow per day). Melt water appeared rapidly at the bottom of the snow, all of which had reached a temperature of approximately freezing by 28 June. On 26 June eight dowels were driven to the existing ice surface, and these were dug up at five-day intervals to observe the rise in the superimposed ice derived from freezing of the melt water. An attempt was also made to observe this by a red-leaded surface in a pit bottom, but insufficient screening caused this to melt downward by radiation.

Period III. 4 July–16 July: Ablation interrupted by storms which added much new snow. Temperatures mainly below freezing again, including a very low dip during storm 3, 5/7 July.

Period IV. 16 July–31 July: Ablation continued (66 cm. to 16·5 cm.) a rate of 3·3 cm. per day: Mean temperatures all above freezing. At the latter date the average snow cover was zero, exposing the new ice surface which had grown on the average 16·5 cm. above the level of 26 June. It was during this period that rivers began flowing around Camp A1 (Fig. 9, p. 18). The "east river," 300 m. away, broke out on 18 July, and the "west river," 100 m. away, on the 20th. Periods II, III and IV saw precipitation of 10 cm. water equivalent, making 51 cm. for the budget year 1949/50.

Period V. 31 July–5 August: Bare ice. Mean temperatures were above freezing but fell to zero on the last day. 3·8 cm. of ice removed (16·5 to 12·7). This was our brief "summer" at the upper camp. The conservative figure of 12·7 cm. net gain of superimposed ice (water equivalent 11·5 cm.) is accepted for the area of the upper camp as a whole at 865 m. above sea level.

Period VI. 5 August–26 August: Accumulation renewed. Mean temperatures mainly below freezing. A succession of storms added snow quite rapidly until 20 August. Thereafter some slight ablation was recorded, but when the camp was evacuated it was obvious that the new snow cover of nearly 40 cm. was there to stay.

Fig. 10 (p. 7) shows measurements of the superimposed ice from the birch dowels, the original ablation stake O and the "bucket stake" planted on 26 June and dug out on 23 August.

Measurements on the dowels were not easy—a firn pipe tended to form around the dowel itself making it the centre of an ice hill when excavated. A mean level of the new ice surface around the dowel was always taken, from which to measure the distance to its lower end on the ice surface existing when it was planted. On 27 August two extra measurements of the superimposed ice were sought from thermistors placed earlier. One, originally placed 24·8 cm. below the 1 June ice surface, showed 10·1 cm. gain of ice; the other, placed *on* the 28 June ice surface, showed 25·4 cm. gain of ice. The latter figure is believed unreliable since this thermistor may have been in a hollow which encouraged extra formation of ice from melt water.

Two shallow ice pits were dug on 26 August, just before evacuation of the camp. These revealed 20 and 21 cm. respectively of recognizable superimposed ice, whiter in colour although showing a density (0·91) and crystal size (5 to 10 mm.) similar to the bluer "old" ice below (Fig. 11, p. 19). No such recognizable layer was seen in the original ice pit (1A1) dug at end of May. It is possible that in the summer of 1949 there was no net gain at this altitude—obviously the balance is a delicate one. A comparison of the meteorological conditions of 1950 with those of previous years is desirable. This, however, is difficult. The nearest station, Clyde, is 150 km. distant on the coast, where surface records are available from November 1942, and upper air data for the two summers 1949 and 1950 only. The following tables give what comparison is possible:

Table I

Clyde Station (Sea level)

Air Temperatures (Mean daily max. + mean daily min./2)
Period Nov. 1942–March 1947

	June ° C.	*July* ° C.	*August* ° C.
Mean for period	0·4	4·1	4·1
Mean for 1950	1·3	6·5	4·4 (26 days)

Table II

Clyde Station—Precipitation (rain and snow), same period

Total in mm. (1 cm. snowfall = 1 mm. water)

	June mm.	*July* mm.	*August* mm.	*Total* mm.
Mean for period	5·6	22·9	30·5	59·0
Total for 1950	32·0	31·7	55·1	118·8

Table III

Upper air data 900 mb. level at Clyde

	June ° C.	*July* ° C.	*August* ° C.
Mean temperature at 08.00 hr. 1949 . .	−0·5	4·7	2·2
1950 . .	−1·6	3·2	−0·1
Mean temperature at 20.00 hr. 1949 . .	−0·9	4·3	0·5
1950 . .	−1·4	3·6	−0·1

At Clyde therefore the surface temperature data for 1950 reveal a warmer than average summer with much higher precipitation than usual.

The temperatures at the 900 mb. level above Clyde (approximately the height of Camp A1) were slightly lower during the summer months of 1950 than during 1949; the relative humidity was higher. Studies of the vegetation at the south-east margin of the ice cap showed poor growth in 1950 compared with the growth of the previous summer.

It seems reasonable to assume that on the ice cap the summer of 1950 was slightly colder than that of 1949, but that the temperatures were probably not far from the normal over a longer period.

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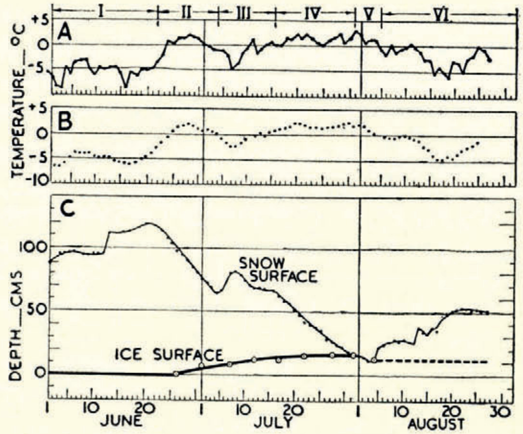
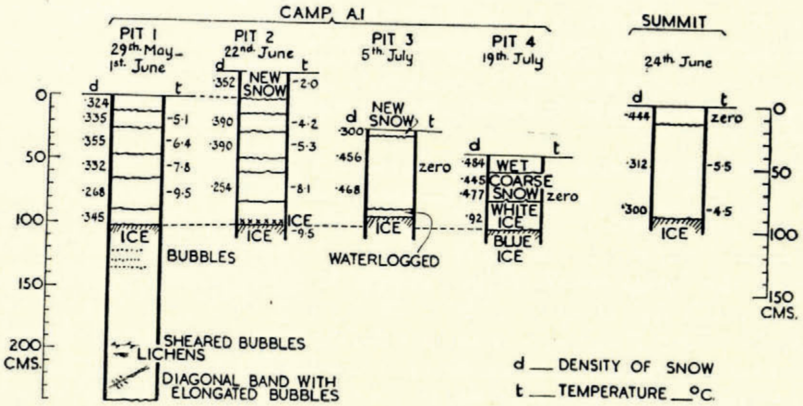
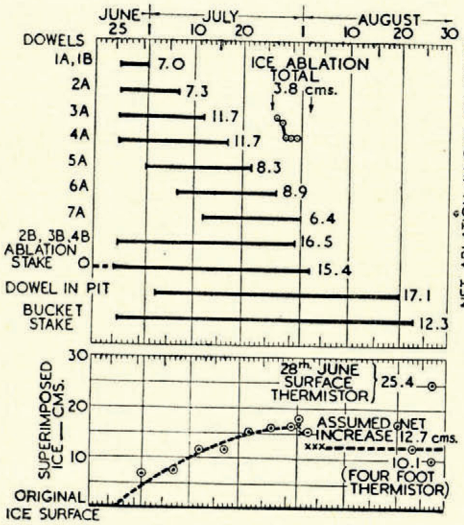


Fig. 7. Snow and ice depths at Camp A1. A gives the mean daily centigrade temperatures of the preceding 24 hours from June to late August, B the five day running mean of these temperatures. C shows the snow and ice depths in cm. referred to the ice surface on 26 June at the upper camp. The period indicated by I was still one of winter's cold with accumulation continuing; II midsummer ablation; III accumulation and ablation equal; IV ablation continues, snow cover is all removed; V bare ice and VI accumulation is renewed, see text p. 4

Fig. 8 (centre). Details of pits at Camp A1 and at the ice cap summit showing densities and temperatures





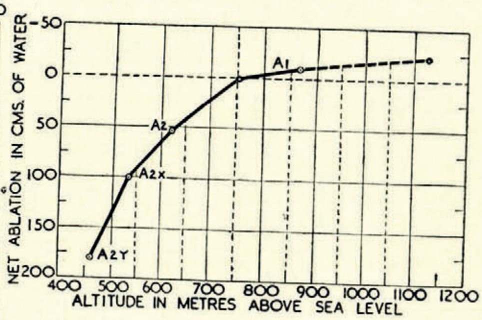


Fig. 10 (bottom left. Measurements of the superimposed ice, see text p. 4, 5 and 6

Fig. 12 (bottom right). Assumed net ablation and accumulation curve with altitude, see text, p. 8

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The amount of summer precipitation was above the normal for a longer period and probably above that of 1949. So it would seem that the ablation of the summer of 1950 was less than that of 1949 but probably not very different from an average ablation season of the last ten years.

Other Ablation Measurements

In addition to Camp A1 we had other transient stations on or at the edge of the ice cap. On 14 June Camp A2 was established at 620 m. above the steep rise from Generator Lake (see map, Fig. 2). This was occupied steadily by W. H. Ward and J. D. C. Waller until the second week in July, and thereafter visited frequently. About 10 July Camp A2Y off the ice cap on the south shore of Generator Lake was occupied and remained active until 29 August. In between these two was the generator station A2X (530 m.), where borings by hotpoint drill were made in the ice. Limited measurements of ablation were taken here.

At Camp A2 the total ablation comprised all the previous winter's snow, current summer snow, superimposed ice and 59·7 cm. old ice (water equivalent 54·3 cm.). Here superimposed ice was similar in thickness (17 cm.) to that at A1, as also was the winter's snow cover.

At A2X (530 m.) measurement of ice melting started about seven days after the new ice became bare; some snow fell during this week. The total ablation here was therefore greater than 102 cm. net of ice measured, perhaps 100 cm. water equivalent.

At the ice edge near A2Y, at an elevation of about 460 m., the ablation was estimated to be of the order of 200 cm. of ice; the maximum snow cover here was only about 45 cm. as opposed to the 90 cm. recorded at A2.

These net ablation and accumulation measurements in water equivalent are plotted on a graph against altitude in Fig. 12 (p. 7). This includes the assumption of a "firn line" (preferably in these cases called an "equilibrium line"), where accumulation of superimposed ice equalled ablation, at about 750 m. There is unfortunately little direct evidence to support this figure except visual observations by the author and Ward in travelling between A1 and A2, including the absence of any surface rock debris at any time above this altitude.

Opportunity did not permit of extensive travel over the ice cap surface with the exception of the south-east lobe. Contours on its surface are therefore based on three flights over it, on one of which some landings were made at the margin and on the other a landing at 1100 m., close to the summit.

Very approximate calculations can be made of the budget of the ice cap as a whole, and the following table should be treated with great caution:

Table IV

Altitudinal interval	*Area in sq. km.*	*Accumulation (plus) or ablation (minus) in. cm. of water*	*Volumetric gain or loss in millions of cubic metres water*
Edge to 600 m.	297	−90	−268
600–700 ..	825	−40	−330
700–800 ..	1234	0	0
800–900 ..	1296	+10	+130
900–1000 ..	1094	+15	+164
1000–summit ..	1318	+20	+264
	6064	Net budget 1949–50	− 40

The 1949–50 accumulation, equal to ablation at the "equilibrium line," is 51 cm. water.

We see from the above that in the year 1949–50, a year not too different from the normal of the last decade, there is a rather slight volumetric loss of the Barnes Ice Cap, and that it is being

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nourished in an unusual way, a way, however, that was indicated by V. Schytt in *Geografiska Annaler*, Årg. 31, 1949, p. 222-27.

Other work on the Baffin Expedition confirms the above conclusion. From the mountain belt to the east no true firn was observed at heights of 1500 m. At 1450 m. near the summit of a peak near Eglinton Fiord a "snow" slope on the night 23/24 July was composed of crystals of ice 5 to 10 mm. in size. The corrugations of the crystal boundaries held nailed climbing boots well despite the hardness of the slope which faced west. Yet the mountain glaciers in this region appear to be holding their own fairly well. The photographs in Figs. 13 and 14 (p. 18), showing the glacier coming into the south side of Eglinton Fiord, were taken from exactly the same location on the opposite shore in 1934 and 1950. A slightly perceptible thinning in the lower section is visible, but no change in any way approaching that caused by the last sixteen years in, for example, Norway. A personal communication from P. A. Siple has confirmed the similar lack of firn near the summit of the ice cap in Devon Island.

It seems reasonable to deduce that many ice caps and areas of highland ice in Baffin, Bylot, Devon, and southern Ellesmere Islands are nourished in the way described and not by accumulation of firn snow, further that they may be at present in a rather healthier budgetary state than the majority of glaciers of the North Atlantic area. The conditions requisite for such "*Baffin Type*" glaciers would seem to be (*a*) insufficient altitude to reach the local firn line, (*b*) great residual cold in the ice, (*c*) light precipitation, and (*d*) the usual Arctic climatic environment of short cool summers and long cold winters.

It can be postulated also that most of these glaciers are survivals from before the post-glacial climatic optimum, since it is difficult to reconcile their reappearance since this time in the light of present-day low precipitation.

Part II: THE PHYSICS OF DEGLACIATION IN CENTRAL BAFFIN ISLAND*

By W. H. Ward

With an Appendix by Mason E. Hale

Abstract. The shearing and ablation of "cold" ice that leads to the formation of ablation and end moraines and the characteristic form of the S.E. edge of the Barnes ice cap are discussed. Some evidence suggests the existence of considerable areas of dead glacier ice extending well beyond the current moraines and completely insulated from melting by glacial debris. This debris consists of old moraines whose relief has been inverted and subdued. An appendix by Mason E. Hale on the current moraine plant succession suggests that the last stable position of the S.E. edge of the ice cap occurred about 1860 and has been followed by retreat at an average rate of about 3 m. per year.

Résumé. On a traite ici du cisaillement et de l'ablation de la glace "froide" d'où résultent la formation des moraines d'ablation et de termination, et la forme caractéristique du bord sud-est de la calotte de glace Barnes. L'évidence trouvée démontre l'existence d'une prolongation assez importante du glacier inerte au delà des moraines existantes. Cette partie du glacier inerte est recouverte par des dépôts glaciaires qui l'empêchent de foudre. Ces dépôts consistent en moraines anciennes dont le relief était renversé et moins accusé. La succession des plantes de moraine au bord de la calotte de glace fait l'objet d'une annexe par Mason E. Hale. Cette étude montre qu'il est probable que le dernier état d'équilibre de la calotte se situe aux environs de 1860 et que depuis elle a reculé de 3m. par an en moyenne.

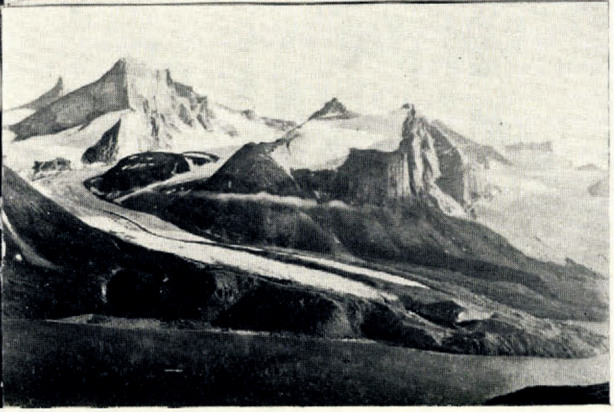
Introduction

In the previous paper, P. D. Baird has discussed the nourishment features of the Barnes Ice Cap and it is now of interest to consider the ablation zone, the modes of deglaciation and the

* A shortened version of this paper was read at a meeting of the International Commission on Snow and Ice, Brussels, August 1951.





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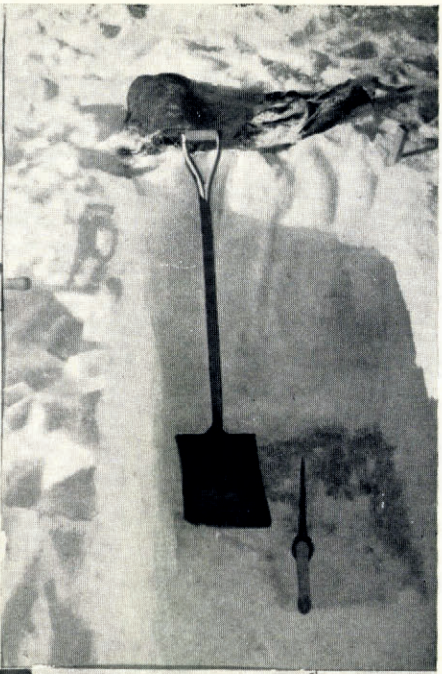


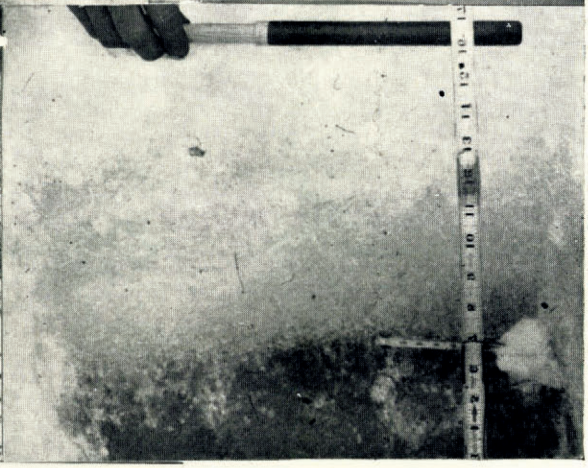


Fig. 3 (top left). Movement at a shear plane during the summer (see text p. 11)

Fig. 4 (bottom). Cliff section showing shear planes and debris dipping inwards (see text p. 12)

Fig. 5 (centre left). Growth of ablation moraine from a single shear plane (see text p. 15)

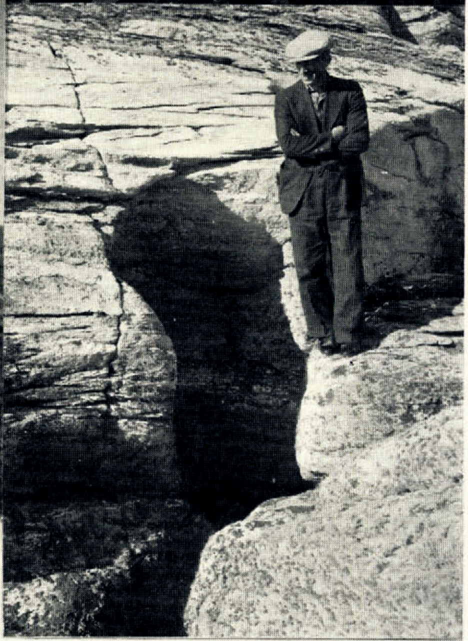
Photographs by W. H. Ward

Fig. 3 (top right). Pit 1A1, a metre of snow on solid ice (see text p. 3)

Photograph by S. Orvig

Fig. 11 (centre right). Pit dug 26 August showing 20 cm. of white ice on blue ice (see text p. 6)

Photograph by P. D. Baird



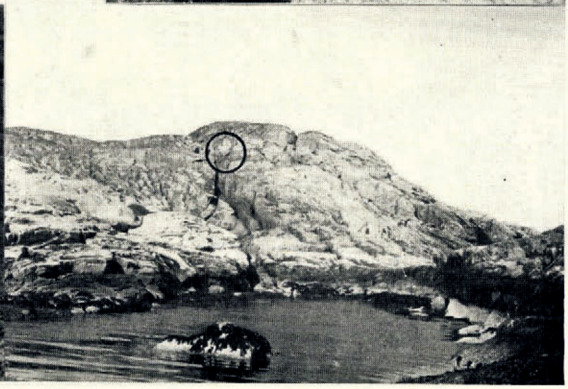


Fig. 6 (top left). Debris from a series of shear planes distributed down the ice edge. The small lake is depositing sediments on the ice (see text p. 15)

Fig. 8. (centre left). Small hillock G with an ice core covered with laminated silts and sands (see text p. 17)

Fig. 9 (bottom left). Flat domes of till adjacent to hillock G (see text p. 17)

Fig. 11 (top right). "Alligator skin" on edge of flat dome of till. Dry boulder pavement of spring melt water stream beyond. Hand saw for scale (see text p. 21)

Photographs by W. H. Ward

Fig. 1 (centre right). Pot-hole in Kvannholmen, Norway (see text p. 25)

Fig. 2 (bottom right). Location of pot-holes in Kvannholmen. The water in the foreground is the head of a small bay cutting into the island from the west (cf. Fig. 3 in text p. 24)