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GLACIOLOGICAL STUDY ON DEVON ISLAND

by

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INTRODUCTION

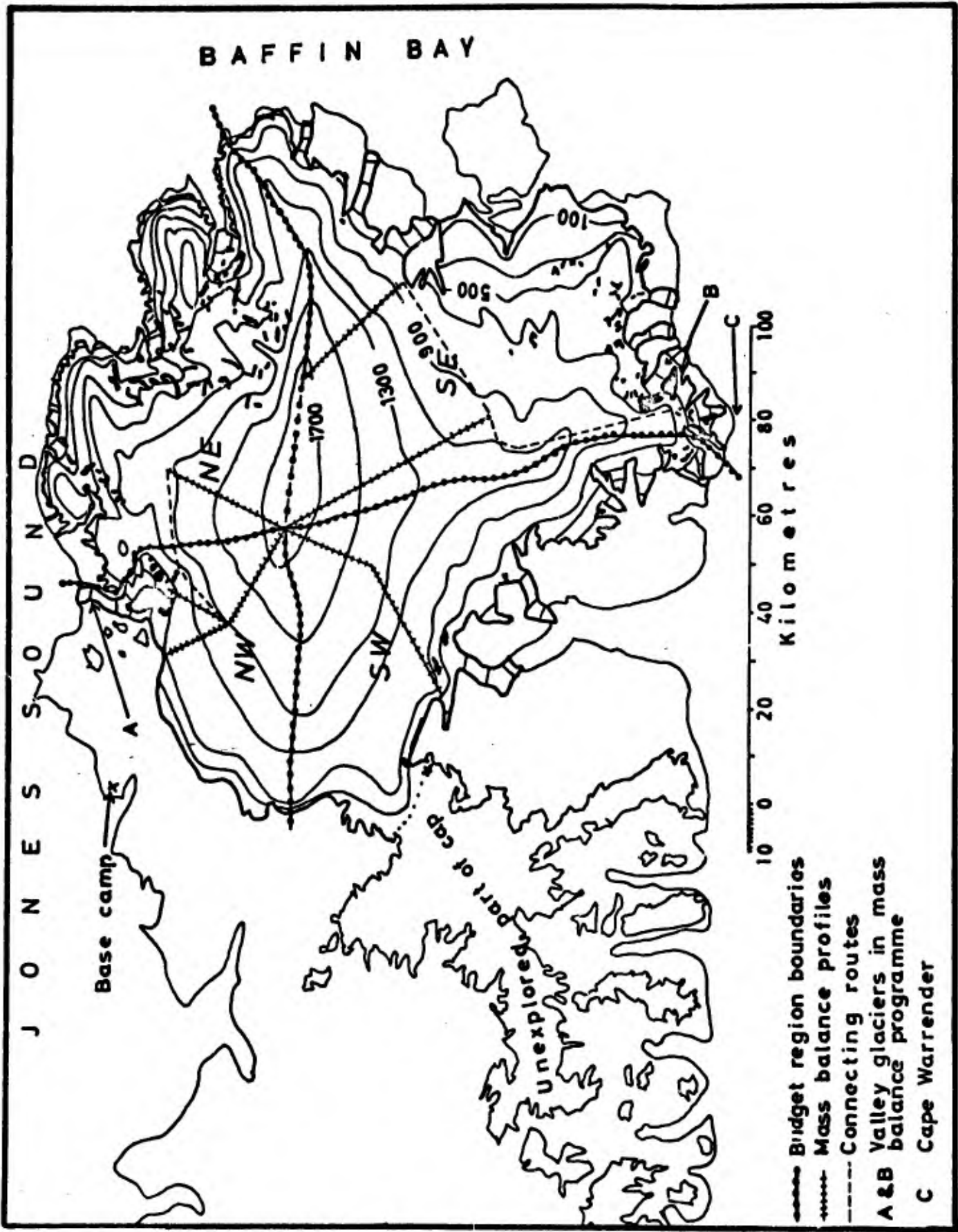
The 1965 Devon Island Expedition consisted of a geomorphologist and assistant and a glaciologist and two assistants, one of which was the glaciologist's wife. The geomorphology party remained at base camp for the entire season working on the coastal plain between Truelove inlet and Cape Sparbo. In this report the term Devon Island Expedition refers specifically to the glaciology party.

Glaciological research on the expedition received support from the Royal Geographical Society, and the Arctic Institute of North America in the form of grants and the loan of equipment, in addition to the grant from U.S. Army (Natick). The Arctic Institute of North America also made the already existing station facilities and food on Devon Island available.

The author (glaciologist) and one assistant (A. Gill) landed on Devon Island by charter aircraft from Resolute Bay on May 16. Several days were spent repairing the huts and weasel and preparing food and equipment for the field season. A depot run was made to the ice cap station on May 23 which was found almost buried in snow. The remaining personnel were landed at Devon Island on May 26. Two more depot runs were made to the ice cap station before the glaciology field work began on June 7. The three man party moved by weasel along traverses set up in 1961, 1962 and 1963 using either sun compass or snow cairns to travel in a straight line (the mass balance stakes were not intervisible. Bad weather, generally in the form of fog, caused many holdups or slow travelling. A new route was covered between the ends of the south-east and eastern traverses and this was badly crevassed in one locality. A new line of stakes was set up on a hitherto unstudied valley glacier on the south coast.

The spring and 1964 mass balance measurements were not completed until July 18. Work began immediately on equipment repairs and fabric analysis of 5 m. cores of superimposed ice. There was no time available to study valley glacier ice and ice from the edge of the ice cap as was originally intended. The mass balance measurements were restarted on August 7 and the entire north-west and south-east traverses were recovered as well as the three valley glaciers associated with these routes. The party travelled to the base camp on August 25 and were evacuated by ice breaker on August 28.

FIGURE 1, The Devon Island ice cap



SECTION A

New Field Techniques

Some techniques new to the Devon Island mass balance program were tried but two are not completely original. Where any part of a technique is dependent on methods developed elsewhere their origin is referred to and acknowledged.

a. Vertical density sampler.

On previous mass balance studies it has generally been the practice to determine the mean density of a snow profile by horizontal sampling of different layers. The water equivalent of each layer is computed and the figures summed to give the water equivalent mass change for each locality. The main limitation of this method is that only occasionally are sufficient density samples taken to cover the whole annual profile so that some interpolation is often necessary. Moreover the technique is time consuming. Vertical sampling avoids these disadvantages. On the 1965 Devon Island expedition a duralumin tube 112 cm. long and with a cross section of 15.9 cm.² was used. The metal was 1.5 mm. thick and the end was sharpened to cut through snow without disturbing it unduly. A rubber cap was placed over each end to prevent loss of snow content when weighing. The weight was taken on a triple beam balance measuring to 0.1 gm. Occasionally it was found possible to sample through snow without digging a pit first. The tube can be gently hammered through the snow until it just enters the previous summer firm surface. The small 'wad' of firm at the base can be withdrawn before weighing. Usually, however, it is necessary to dig a pit and push the sampler through the snow close to one wall and down to the surface of the previous summer. The snow around the sampler is dug away and the sampler withdrawn with the cross section of the annual layer of snow. These techniques proved very accurate and quick. A sample could be taken in a few minutes unless the snow proved to more than 1m. in depth. The w.e. of the snow is calculated from:

$$w/e$$

where w = the weight of the sample in gm.

e = the cross section of the sampler in cm.²

Such a sampler should be constructed in future with the following features.

- i The cutting end should be saw-toothed to enable the sampler to cut through an ice layer rather than breaking it.

- ii The sampler should be graduated in cm. on the outside. The length of the sample can then be measured in situ. The density of the sample is then:

$$w/le$$

where l = the length of the sample in cm.
 e = the cross section of the sampler in cm.^2
 w = the weight of the sample in gm.

- iii The cross section of the tube should be preferably a round figure of, for example, 100 cm.^2 (radius 5.65 cm.) to facilitate computation of the w.e. With a cross sectional area of 100 cm.^2 the w.e. is given by moving the decimal point in the weight (in gm) two places to the left.

The vertical density sampler is in use in snow surveys elsewhere (e.g. in Switzerland) but its use in mass balance studies in the polar regions has not previously been general. Recommendations i. and ii. are believed to be new at least to the Canadian Arctic.

b. Percolation Trays.

Muller (personal communication) has used polythene sheeting on Axel Heiberg Island to act as percolation catchers above the firm edge. Briefly, mass balance changes above the firm edge are complicated by percolation of water deep into the firm. The mass of this water must be measured if it originates from the current accumulation. Stake measurements are inadequate. Thus on the Devon Island ice cap sheets of polythene were cut into 50 cm. squares. A snow block 30 cm. square was cut out of the surface of the snow and the polythene put in shaped as a tray. The snow block was then replaced as close as possible to its original position. A snow surface density was taken close to the site. At the end of the melt season a vertical density was taken to the sheet. This gave a measure of the increase in accumulation since the previous survey. This method is successful but could be improved by using very light metal trays 50 cm. square and 20 cm. deep. These should be dug into the surface at the end of a melt season. Vertical densities are easier to take to a metal tray than to an easily torn material. Some metal trays were tried in 1965 but melting was so slight that most of them remained below the level of percolation. One tray proved successful but another was too shallow and filled with melt water before the end of the melt season. The tray must be placed at a known distance away from a stake otherwise the latter will channel melt water into it. The tray must also be placed at a depth sufficient to ensure it will not emerge to the surface due to general ablation of the surrounding snow.

c. Dye.

Potassium dichromate dye was used successfully to give a good indication of the depth of penetration of melt water which in one case reached a depth of 157 cm. The dye must be placed 30 cm. below the

surface before melting begins to avoid the effect of radiation melting.

SECTION B

The mass budgets of 1964 and 1965 and comparisons with the previous three years.

The 1965 Devon Island expedition spent the periods 7 June - 18 July and 7 August - 22 August following the mass balance of the ice cap.

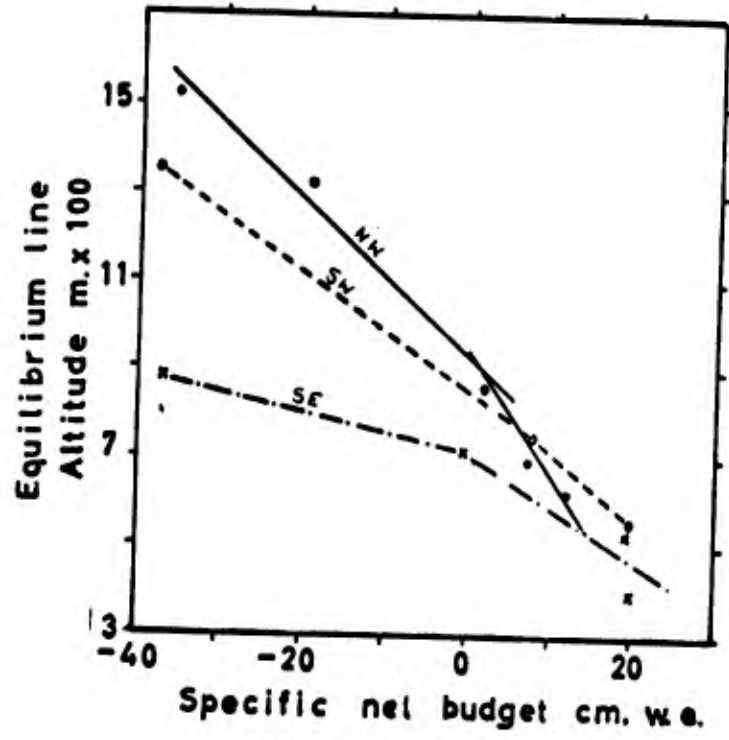
- i The 1964 mass balance was measured in June/July 1965 by
 - a. measurement of stakes in the ablation zone,
 - b. measurement of stakes and vertical density measurements to percolation trays in the saturation zone and to the previous summer surface in the percolation zone.
- ii The 1965 mass balance was measured in August 1965 by methods i.a. and i.b.
- iii The September, 1964 - May/June, 1965 accumulation was measured by snow probes and vertical density sampling, the former at 1 km. intervals and the latter at 4 km. intervals.

Stratigraphic studies indicated the 1964 summer on the ice cap was one of low temperatures and high accumulation. Above 1,000 m. more melting occurred than in 1963 but the summer accumulation was sufficiently high to produce the highest positive balance on record. Stake measurements on the Sverdrup Glacier at 800 m. a.s.l. in spring, 1965 also indicated that accumulation in the summer of 1964 interrupted the ablation process so that the equilibrium line reached its lowest elevation of the five year period.

Mass balance measurements, snow stratigraphy and meteorological records taken by the expedition showed the 1965 summer on the ice cap to be the coldest on record. Accumulation during the summer, however, was insufficient to make the net balance as positive as in the previous year. The south-east zone of the ice cap proved an exception with very high accumulation between 600 m. and 1100 m. a.s.l. Table I summarises the net mass budgets for each year from 1961-1965.

Figure 2 shows the mass change/altitude relationship for the north-west part of the ice cap for each year from 1961-65. 1962 stands out with the most negative balance which is the result of low accumulation above a high equilibrium line and high ablation below it. 1963, 1964 and 1965 show similarities to each other but final differences between the

FIGURE 3



specific net mass budgets (i.e. the net mass change expressed as an average over the entire ice area) are chiefly the effect of ablation differences on the glacier rather than accumulation differences on the ice cap. Accumulation on the glacier in the summer of 1964 must, however, have affected that year's ablation by limiting it in time. Similarly, in 1961, 1962 and 1963 the duration of the ablation season appeared to have an important bearing on the final amount of ice ablation as the intensity of ablation during each summer was comparable in amount, reaching a maximum of 5.0 - 6.0 cm. w.e./day. 1964 and 1965 mass budgets confirm that duration of ablation appears to be more important than intensity as in each year the ablation season was short rather than mild.

With each added year of observation a relationship between the specific net mass budget and the final altitude of the equilibrium line appears to be emerging. Figure 3 shows the relationship is quasi-linear. In the north-west zone of the ice cap with a constant rate of lowering of the elevation of the equilibrium line the mass balance becomes increasingly positive but at a decreasing rate. This is partly a consequence of the altitude/area distribution on the ice cap. Once the equilibrium line descends from the ice cap to the valley glacier there is very little increase in the accumulation area. It is therefore justifiable to break the curve into two linear relationships one applying to the situation where the equilibrium line is located on the ice cap and the other when its location is on the valley glacier. More years of observation are necessary to determine more precisely the relationship. In the south-east zone the specific net mass budget/equilibrium line relationship is more complex. In 1965 there was very high accumulation between 600 and 1100 m. and this almost balanced the increased ablation (compared to 1964) below 500 m. a.s.l. However, as large areas of ice descend to sea level in the south-east lowering of the equilibrium line increases the positive balance at a more rapid rate than in the north-west.

Snow probes in 1965 gave a good picture of September-May accumulation on the ice cap and at the same time showed strong similarities to the patterns discovered in the spring of 1962 and 1963. The pattern consists of an area of very high accumulation in the south-east, where the w.e. of snow reaches a maximum of 44.0 cm., to an area of low accumulation in the north-west, where w.e. accumulation is as low as 6.0 - 8.0 cm. There is also a ring of low accumulation encircling the top of the ice cap and a gradual increase of accumulation from this low to the edge of the ice cap. The effect of katabatic winds is to remove snow from the higher parts of the ice cap (except for the first 50 m. below the summit where the slope is too gentle to generate strong downslope winds) and redeposit it lower down.

Table I

Specific Net Mass Budgets, 1961-1965
Devon Island Ice Cap

Year	NW	SW	NW & NE	SE
1961	-19.7			
1962	-35.9	-38.3		-37.0
1963	4.4	7.6	-1.6	-0.3
1964	12.0	19.5	7.0	19.8
1965	7.3			19.7

Measurements in cm. w.e.

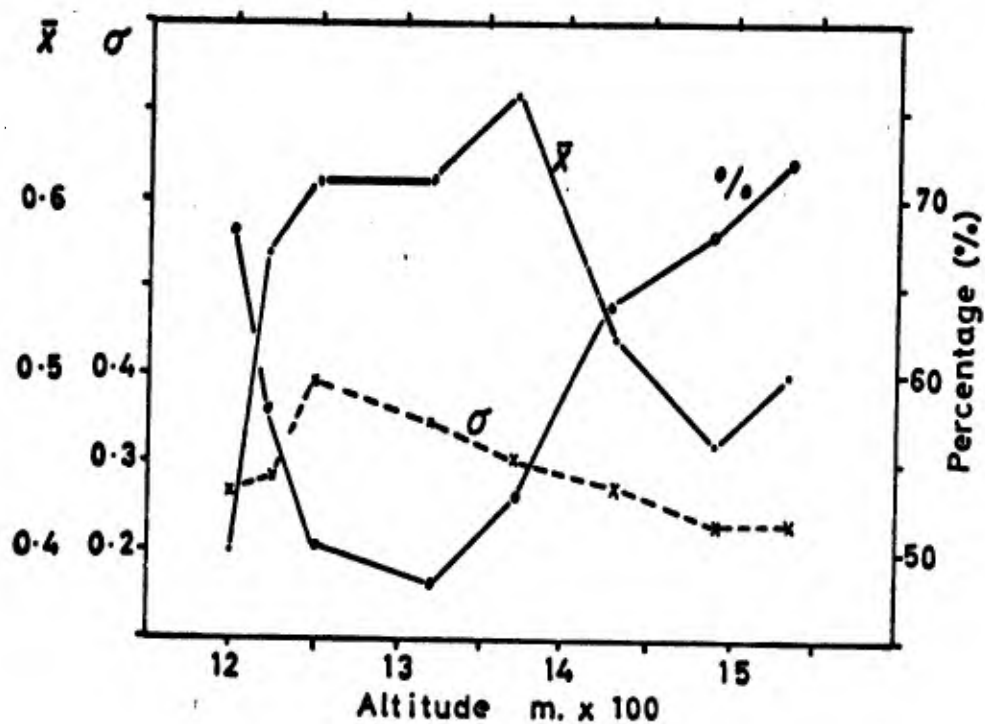
Results in the NE are very small in number,
therefore the figures in column 4 are
approximate only.

The regional ESE-WNW precipitation gradient is believed to be caused by cyclonic activity and open water in Baffin Bay (the 'North water'). It is difficult to say yet whether open water itself is a prerequisite for this pattern. Both Hare and Barry (personal communications) subscribe to the view that such an accumulation pattern as that on the Devon Island ice cap would probably persist even in the absence of nearby open water. Perhaps the effect of the 'north water' is to intensify the ESE-WNW precipitation gradient.

Despite these very considerable differences of regime between the south-east and north-west the final specific net mass budgets for each zone are fairly similar, particularly for 1962 and 1963. Summer melting affects the whole ice cap fairly similarly although the amount of melting is higher on the south coast valley glaciers than on those on the north coast. Therefore regional differences in the distribution of ice are dependent chiefly on regional differences of snow accumulation. As the specific net budgets for each region in 1962 and 1963 were similar it would indicate that the steep ESE-WNW accumulation gradient has existed for several hundreds of years otherwise a more positive budget in the south-east or a more negative budget in the north-west would be expected in order to build up the regional differences between ice areas at lower altitudes. Colder summers (e.g. 1964 and 1965) apparently profit the south-east more than the north-west but only because of the already pre-existing distribution of large areas of ice at low altitudes in the south-east. Very tentatively the author would suggest that any changes that have occurred within the past hundred years have been chiefly in summer climatic conditions. Stratigraphic investigations in the firn down to a level formed about 1910 show that the 3 years 1963 - 1965 have been exceptionally cold. Meteorological records from Resolute Bay (320 km. distant) show that 1964 was the coldest summer on record, i.e. since 1948. Conversely, stratigraphic evidence and mass balance results from elsewhere in the Canadian Arctic (Arnold, 1965, Muller, 1963) indicate that the 1961 summer has been nearer the mode of climatic conditions and this effected a negative budget at least in the north-west region. All of this evidence and that for a long period equilibrium line between 1,245 m. and 1,373 m. a.s.l. (see Section C) on the north-west side of the ice cap (which Figure 3 shows to be above the altitude of an equilibrium line in harmony with a steady state budget) strongly suggest that in the last 40 - 50 years the Devon Island ice cap has had a negative budget.

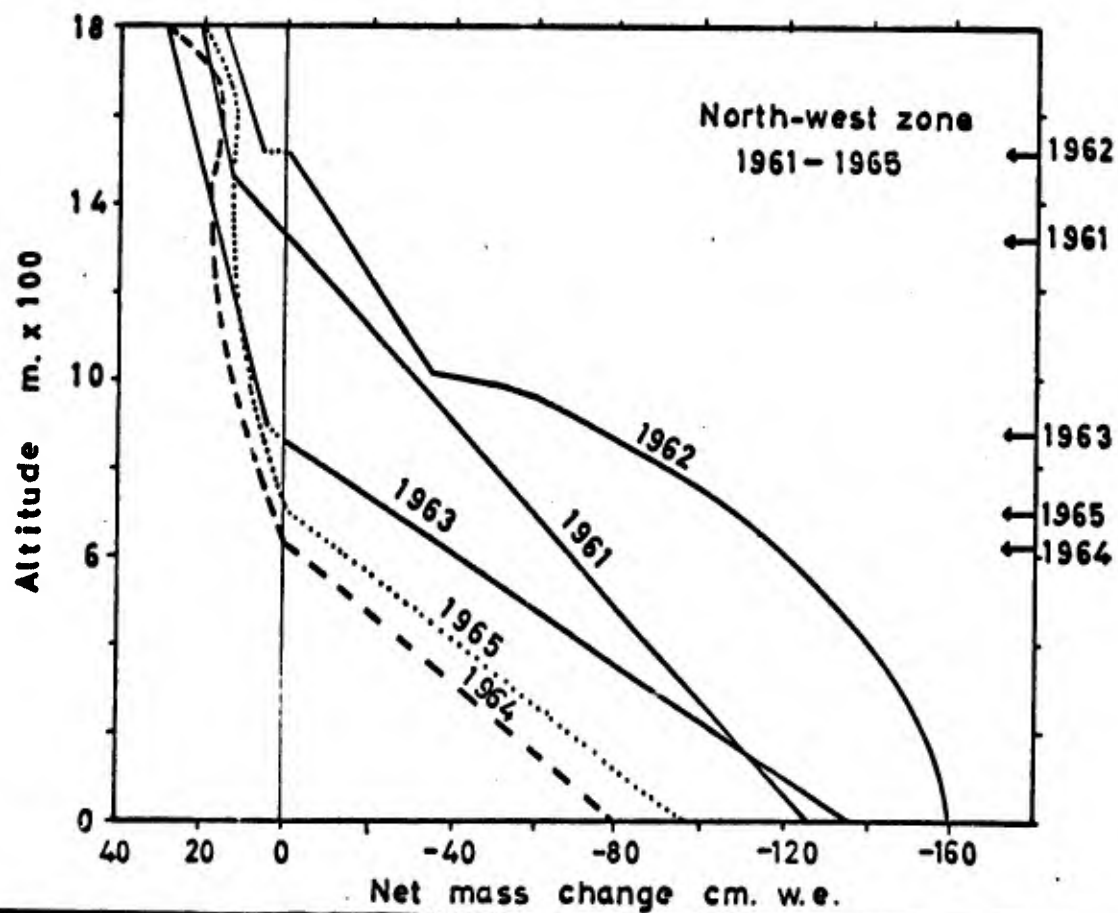
Reference to Table 1 shows how wide a variety of mass balance conditions can be met in as few as five years. It is again worth stating that many more years of observation are necessary. Perhaps 30 years continuous measurements are needed before any true picture can be gained of the range of climatic and glaciological conditions involved in an ice cap's mass balance. The mean of these conditions is of fundamental importance to the ice cap's health and it was towards this aspect of mass balance that the next part of the summer programme was devoted.

FIGURE 4 Crystal Analysis



\bar{x} mean crystal size, cm.
 σ standard deviation from \bar{x} , cm.
 % percentage of crystals ≤ 0.5 cm.

FIGURE 2 Altitude v Mass change



SECTION C

Petrofabric analysis of superimposed ice.

In 1961 and 1962 examination of superimposed ice from the northwest side of the ice cap showed that a petrofabric analysis did not allow any division of superimposed ice into annual layers, although layers were recognisable. On the other hand a quantitative study of crystal size showed that crystal size, as measured from 5 m. cores, increased from the firm line to the equilibrium line and then decreased below it. The initial increase is believed to be the result of a lower rate of re-freezing of slush and an increase in the saturation of the snow pack (i.e. higher density of slush) with decreasing altitude. As ice formed above the equilibrium line emerges below it to ablate, any pattern formed between the firm and equilibrium lines is repeated in reverse order below the latter.

Originally cores from only 6 sites were examined and one, at 1,317 m. a.s.l. was anomalous for various known reasons. In July 1965 5 m. cores were taken at 1,317 m., 1,247 m. and 1,200 m. a.s.l. This therefore gave two more points and an additional observation at 1,317 m. a.s.l. Photographs were taken between crossed polaroids of vertical ice slides representing the total 5 m. of ice from each site. The longest near vertical axis of crystals lying on an arbitrary line drawn down each photograph was measured. The mean, standard deviation from the mean, and percentage of crystals falling in the range 0.2 - 0.5 cm. were calculated and have been plotted v. altitude in Figure 4. They produce a better correlation between each factor and altitude than the more limited results from 1961-62 but further coring is necessary in order to smooth the peak of the curve. There is still a maximum range between the peaks of each curve of 130 m. within which a long period equilibrium line should lie. An analysis of crystal size variance both within each core sample and between core samples shows that the variation of mean crystal size between samples is statistically very significant ($F = < 0.1\%$).

Some factors enter to disturb the relationship. Firm may remain at higher altitudes when small crystal ice forms lower down on the ice cap near the equilibrium line. It has been found impossible to include firm in the crystal size analysis so that mean crystal size at 1,430 m. and 1,485 m. a.s.l. is in each case an overestimate as layers of firm occurred in the profiles. The slope between these points and 1,374 m. a.s.l. should be steeper than depicted.

Surface ice below an equilibrium line belongs to a different period of time to that above the equilibrium line. Therefore the time period referred to in the ablation zone becomes older with increasing distance from the equilibrium line. The slope on the right hand side of the parabola (i.e. above the equilibrium line) is therefore more reliable

than the left hand side in determining the altitude of a long period equilibrium line. There should be a concentration of observations where the rate of increase in mean crystal size and range of crystal size diminishes. Future work will concentrate on this rather than on observations well below the present equilibrium line. It must also be remembered that while the initial relationship is between crystal size and altitude, below the equilibrium line the rate of ice movement must be considered as an added variable. Two points at similar altitudes may be at quite different distances from the equilibrium line. Near surface ice will be much older at the most distant point as it will have taken longer to reach that altitude from the equilibrium line and more ablation will have occurred; deeper seated ice will then be at the surface.

It does seem more and more likely, however, that the crystal analysis technique will give the glaciologist a good measure of the mean of mass balance conditions over a period of time greater than 30 years by fixing an equilibrium line for that period.

SECTION D

Condition of the Base Camp.

When the base camp was first examined on May 16, 1965, the huts had not been occupied since early September, 1963, i.e. for a period of 20 months. The camp, however, was in relatively good condition. The base camp consists of 3 single Jamesway huts serving as sleeping, dining and laboratory quarters. A fourth hut is made from 12 Jamesway sections and houses mechanical equipment, tools, 2 Onan 5 kw. generators and the food.

The dining hut had suffered a small tear in the side fabric. This had let in drift snow which covered about a third of the floor area. In the living hut a seam had separated in one corner and again snow covered part of the floor. The laboratory hut suffered similar damage. The warehouse was in the worst condition. The nylon cord securing two sections had loosened and a gap had formed sufficient to let in snow to a depth of 3 - 4 ft. covering an area approximately 12 ft. by 15 ft. There were also two tears (made by animals, probably foxes) elsewhere. It took three days to clear each hut and put it in living condition. During the summer each tear was repaired and the seams tightened. Loosening of the nylon tightener was probably due to pressure of snow drift which had accumulated at the sides of the hut. The base camp is now in good condition and should last several more years provided it can be checked at the end of each winter. Main damage in the future will occur in the summer period. Any snow entering the huts has no damaging effect as long as it remains dry. Any melting could release gallons of water to soak through the hut contents and also into the insulating fabric of the hut walls. For this reason alone inspection prior to each summer is essential to the upkeep of the huts.

Neither generator proved a problem to start on batteries which had been standing undrained for 18 months in the warehouse Jamesway. Each generator was thoroughly warmed and warm engine oil was put in before starting. The base camp was used throughout the summer and several repairs were made but unfortunately the generators were not in working order on evacuation in August, 1965.

ACKNOWLEDGEMENTS

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