INDICATIONS OF RECENT EXTENSIVE GLACIERIZATION IN NORTH-CENTRAL BAFFIN ISLAND, N.W.T.*

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Abstract. Studies of the geomorphology and rock lichen development north of the Barnes Ice Cap prompt the conclusion that 70 per cent of this extensive, interior region was covered by permanent ice some 300 to 400 yr. ago. Contemporaneously the northern Barnes Ice Cap was significantly larger than today; it dammed up a lake in the upper Isortoq valley, over 80 km. long and up to 300 m. deep. Excluding the ice cap less than 2 per cent of the area is glacierized today; this represents a dramatic reduction in surface area of the former ice cover. Similarly, significant recession of the ice cap implies that glaciers of the "Baffin type" are in a less healthy budgetary state than hitherto has been assumed.

Proof of former extensive ice cover rests largely upon restricted rock lichen development. When sufficient time has elapsed for complete colonization, few indications of the former existence of an ice cover will remain. This type of glacierization may have affected large areas in the high Arctic. Absence of evidence of *glaciation*, therefore, cannot be relied upon to delimit nunatak areas (plant refugia) during the last glaciation.

Résumé. Des études sur la morphologie et sur la croissance des lichens au nord de la calotte glaciaire de Barnes indiquent que 70 p.c. de cette vaste contrée intérieure était recouverte de glaces permanentes il y a de 300 à 400 ans. A cette époque, l'extrémité septentrionale de la calotte de Barnes était passablement plus étendue qu'elle ne l'est aujourd'hui et formait, dans la partie supérieure de la vallée Isortoq, un barrage à l'arrière duquel s'était formé un lac de plus de 80 km de longueur et dont la profondeur atteignait 300 m. Exception faite de la calotte glaciaire actuelle, moins de 2 p.c. de la région est aujourd'hui occupée par des glaciers ce qui représente une réduction très considérable de l'aire jadis recouverte par les glaces. En outre, l'amaigrissement sensible de la calotte laisse supposer que les glaciers de "type Baffin" ont un bilan beaucoup moins positif qu'on ne l'avait supposé jusqu'à présent.

Les preuves d'une ancienne glaciation de fortes proportions reposent principalement sur la croissance restreinte des lichens. Lorsque se sera écoulé un laps de temps suffisamment long pour permettre leur pleine croissance, l'on pourra difficilement retrouver de traces d'une glaciation antérieure. Ce genre de glaciation a peut-être touché de vastes étendues du Gravel Nord. En conséquence, une absence de vestiges de glaciation n'indique pas nécessairement une région à nunatak de la dernière glaciation.

Zusammenfassung. Untersuchungen über die Geomorphologie und die Entwicklung von Steinflechten nördlich des Barnes-Eisschildes führen zu dem Schluss, dass 70% dieses ausgedehnten inneren Gebietes vor 300-400 Jahren eine ständige Eisbedeckung trugen. Zur selben Zeit war das nördliche Barnes-Eisschild bedeutend grösser als heute; es staute im oberen Isortoq-Tal einen See von über 80 km Länge und bis 300 m Tiefe auf. Abgesehen von dem Eisschild sind heute weniger als 2% des Gebietes vergletschert; dies bedeutet einen drastischen Flächenrückgang der früheren Eisbedeckung. Des weiteren lässt der beträchtliche Rückgang des Eisschildes vermuten, dass sich die Gletscher vom "Baffin-Typ" in einem weit schlechteren Ernährungszustand befinden als bisher angenommen.

Der Beweis für eine ausgedehnte frühere Vereisung ist vor allem in der beschränkten Entwicklung von Steinflechten zu erblicken. Wenn genügend Zeit für eine vollständige Besiedlung verstrichen ist, werden nur wenige Anzeichen der früheren Eisbedeckung übrig bleiben. Dieser Typ der Vergletscherung war möglicherweise in der hohen Arktis weit verbreitet. Der Nachweis für das Fehlen einer Vereisung kann deshalb nicht nur auf die beschränkten Nunatak-Flächen (Pflanzen-Zufluchtsstätten) während der letzten Eiszeit gegründet werden.

Introduction

During the summer of 1961 the author spent eleven weeks in the general area bounded by the Rowley River, Steensby Inlet, and the northern margin of the Barnes Ice Cap. While the major objective of the field work was the initial reconnaissance for the formulation of a long-term programme of glaciological and geomorphological research, evidence was accumulated which led to the conclusion that a large proportion of interior, north-central Baffin Island, now ice-free, was ice-covered in the comparatively recent past. This short paper is an attempt to present the evidence and to discuss some of the implications. It is believed that the type of ice cover envisaged, namely extensive, scattered patches of thin, inactive permanent ice, leaves little permanent record of its former existence, a factor of great significance in the controversial discussions that appear in the literature from time to time concerning the presence or absence of ice-free areas (plant refugia) in high arctic regions (Savile, 1961; Löve, 1959).

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Extent of Former Ice-Dammed Lakes

A base camp was established on 15 June at the south-east corner of Rimrock Lake which drains by way of the small Rimrock River into the upper Isortoq River, and lies some 32 km. north of the Barnes Ice Cap (Figs. 1 and 2). The Isortoq is the major river between the ice cap and the Rowley River to the north; it heads in a series of small lakes only 20 km. from Baffin Bay tide-water (the head of Clark Fiord) and takes the drainage from a sector of the ice caps and glaciers of the eastern coastal mountains. The river flows in a broad valley, making an irregular course towards west-south-west for 65 km. It then turns sharply southwards into a short middle reach of some 20 km. length before taking a second sharp bend to flow the final

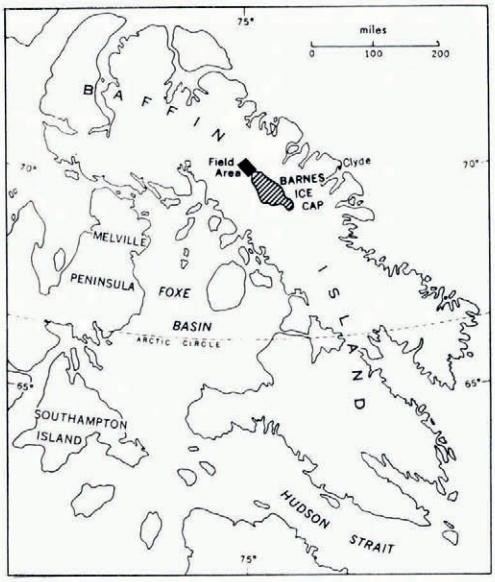

Fig. 1. Location map showing a sector of the eastern Canadian Arctic and the general situation of the Barnes Ice Cap

120 km. of its course to empty into Isortoq Fiord in Grant-Suttie Bay, Foxe Basin. The Rimrock River enters the main stream on the upper bend; the lower bend approaches within 2 km. of the snout of the only "outlet" glacier of the Barnes Ice Cap and which forms its north-westernmost extension. Two major tributaries enter at this point; one drains from the glacier and the second loops round further north from the northernmost part of the ice cap proper.

Air photograph study prior to June 1961, led to the discovery of extensive systems of terraces, then presumed to represent the shorelines of former ice-dammed lakes, in the upper valley of the Isortoq and the valleys of its tributaries, north and west of its confluence with the two glacier-fed tributaries. At least seven sets of terraces, at different altitudes, were distinguished, the more pronounced ones of which have been traced for distances exceeding 80 km. However, some of the higher terraces were not simple shore-lines of former extensive lakes as their widespread association with kame terraces and "kame-deltas"* was also noted. It was also apparent that, should the present north-west margin of the ice cap and particularly the small outlet glacier advance as little as 4 km., a lake would be dammed in the upper valley of the Isortoq River.

The field programme included the precise levelling, by Zeiss Ni 2 automatic level, of a

* The term "kame-delta" is used to describe extensive deposits of glacio-fluvial sands which occur in the form of laterally expanded perched deltas, sometimes extending as linear strips along a valley side for more than 3 km.

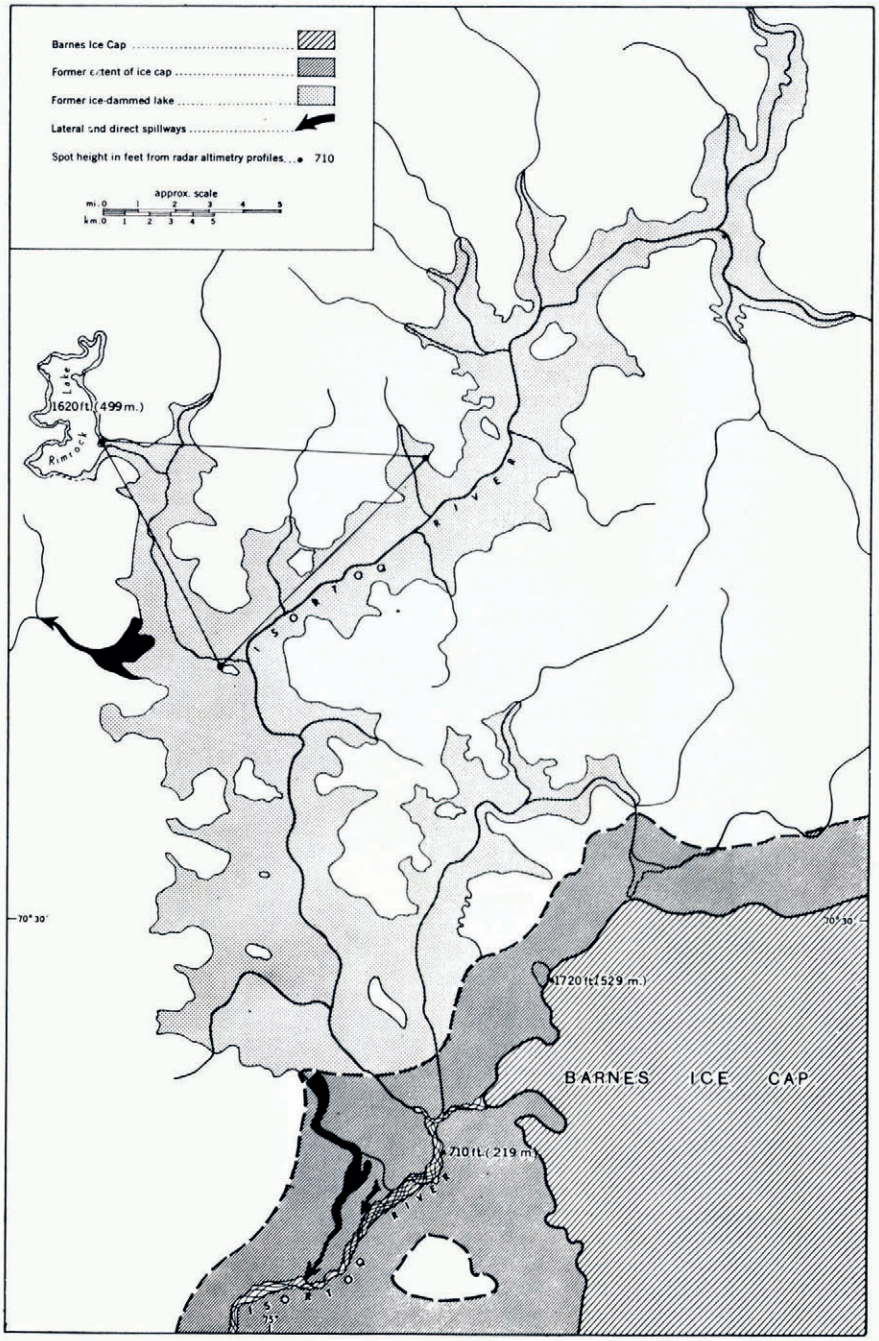

Fig. 2. Map of the field area showing the present margin of the Barnes Ice Cap, the extent of the former ice-dammed lake, and the ice cap margin contemporaneous to it. The triangle with one leg on Rimrock Lake represents the precisely levelled control for the shore-line

https://doi.org/10.3189/S0022143000027398 Published online by Cambridge University Press

15-km. approximately equilateral triangle on the most prominent of the lower shore-lines, the objective being to evaluate, at least locally, the extent of tilt due to unequal isostatic adjustment of the land surface following deglacierization. Upon this precisely levelled datum the higher terraces were then tied in by level and staff and aneroid techniques. Another objective was the examination of the ground conditions above and below this shore-line in an attempt to explain the marked change in colour tone so conspicuous on the air photographs (Fig. 3).

From the results of the survey, it can be stated that the prominent lower shore-line, which lies at approximately 511 m. a.s.l. (1,658±10 ft. from radar altimetry compilation) is perfectly horizontal. In practice, there is a probable error due to difficulties in identifying precisely comparable points on the beach sectors which have a vertical expression of 4 m.

Fig. 3. Part of R.C.A.F. air photograph No. A16293–43, approximate scale 1:100,000, showing a section of the Isortoq River. The marked tonal change at the glacial lake shore-line and the light-toned areas which represent the sites of areas of former permanent ice and snow stand out clearly. The linear features normal to the river are morainic ridges with glacio-fluvial deposits nearer the river. They have a local relief of up to 20 m. Photo 4 September 1958

However, the maximum possible error due to this is ±0·7 m. in 15 km.; in fact the error is expected to be less than half this figure. It is concluded that, for all practical purposes, the shore-line is horizontal. Proof of horizontality implies that, if the shore-line had been formed in "late-glacial" time, no unequal isostatic adjustment had occurred; alternatively, the shore-line was formed so recently that no isostatic tilting has been able to affect it significantly. The latter interpretation is believed to be the more accurate.

In the field it also became apparent that the change in colour tone at the shore-line was not due, as was originally surmised, to a change in surface materials (e.g., lacustrine sediments below the shore-line), but was entirely the result of differential growth of rock lichens, both in size and in number of individuals. Repeated counts on the diameters of the lichen *Rhizocarpon geographicum* above and below the shore-line revealed the striking fact that the mean of the largest diameters above the shore-line was three times or more larger than the mean of diameters measured below the shore-line.*

* In practice, between 40 and 100 examples of the largest lichen diameters in each locality were measured, and an attempt was made to restrict the measurements to surface conditions which were essentially comparable. In this way, some of the effects of different micro-climates on lichen growth would be eliminated. Furthermore, the size difference was so marked that, for comparative and relative dating purposes, any inherent errors in the method were considered negligible.

Although no precise local datum existed, and therefore, no precise date can be given for the draining of the former ice-dammed lake on the basis of the lichen studies (cf. Beschel, 1957, 1961 and personal communication), it is reasoned that an order of magnitude of the expired time since drainage occurred can be obtained. Beschel has pointed out that the growth rate for *R. geographicum* in the Disko Bay area of Greenland falls between 7 and 25 mm. per century, allowing an initial period of 13–15 yr. for germination. No greater precision is attempted other than to say that the time of drainage was in hundreds rather than in thousands of years ago. It is suggested, however, that drainage occurred between 200 and 350 years ago. This is a most important conclusion as it relates directly to Barnes Ice Cap recession in the recent past, whereas the higher terraces are interpreted as being of considerably greater age (more than 1,000 years and probably much more than this) and that they were formed during the general deglacierization of Baffin Island in "late-glacial" time. The sub-recent lake was a simple ice-dammed lake, stretching from one side of the valley to the other and extending for more than 80 km. upstream of the ice dam. In contrast the higher terraces were formed in narrow lateral lakes trapped between stagnating ice on the valley floors and the rising hillsides. These lakes were separated by lateral tracts of flowing melt water in which sections of kame terrace were deposited.

Theoretical considerations, examination of air photographs, and investigations in the field led to the conclusion that, in order to dam up this lake in the upper Isortoq valley the north-west margin of the Barnes Ice Cap must have extended at least 16 km. beyond its present position, and that an ice dam, at least 350 m. thick, must have blocked up that portion of the Isortoq valley at and below the lower great bend (Fig. 2). The lake itself spilled through a water-worn bedrock gorge situated 9 km. south of Rimrock Lake and draining into the Freshney River, a major north-bank tributary of the Isortoq. At a later stage, presumably when the ice dam had thinned slightly and was weakening, lateral overflow occurred on the hillside above the lower Isortoq bend. This conclusion is supported by the existence of broad zones of waterstripped bedrock sloping obliquely south-westwards on the north-west side of the Isortoq valley. This stage was relatively short-lived and it is believed that the lake then drained completely and dramatically beneath the ice dam, probably creating a catastrophic flood in the lower Isortoq valley (cf. Icelandic *jökulhlaup*). This conclusion is supported by the existence of broad water-washed areas of bedrock on the floor of the lower Isortoq valley downstream from the postulated site of the ice dam. The dam partially recovered from this disrupting influence and a second lake was formed some 50 m. below the level of the main lake. Repeated drainage and flooding of the lower valley presumably occurred until the damming ice had entirely withdrawn. Still lower shore-lines attest to these subsequent stages.

The existence of the ice-dammed lake gives positive indication that the Barnes Ice Cap was recently substantially larger than at present, at least in the northern sector. Associated evidence led to the conclusion that actual ice and snow cover was still much more extensive than consideration of the Barnes Ice Cap alone would imply.

The Small Ice Patches of North-Central Baffin Island

In a recent letter to the editor of the *Journal*, Falconer (1962) has described tundra polygons which appear to be emerging from beneath a small ice patch situated 150 km. north-west of the field area. He was able to show a mean recession of the perimeter of approximately 20 m./yr. over the last 9 yr. from a comparison of air photographs. Similar ice patches with horizontally truncated stratification are widespread throughout the higher land area of north-central Baffin Island and, assuming that the rate of recession quoted by Falconer is representative, then a relatively large area of ice has disappeared in the past nine years. If this may be extended backwards in time by only twenty years, and if the possibility of total disappearance of many small ice patches in the period 1930 to 1950 is admitted, then a very considerable reduction in area of ice has indeed occurred. Aerial photographs (Figs. 3 and 4) show a large

tone contrast above and below the shore-line of the former large, ice-dammed lake, and there are also areas of much greater tonal contrast, seen as scattered light-toned patches in the darker mass, which occur both above and below the shore-line. On Figure 4 this contrast is extremely marked and covers a large proportion of the area shown. Examination of late-lying snowbeds and rock lichen studies similar to those outlined above led to the conclusion that the light-toned areas are the sites of former permanent ice patches and snow-beds, and that the light-toned appearance is again due to the very restricted lichen development. The former ice

Fig. 4. Part of R.C.A.F. air photograph No. A16293–23, approximate scale 1:100,000. Rimrock Lake occupies the lower left corner. The main glacial lake shore-line and the extensive areas formerly covered by permanent ice and snow are clearly visible. Morainic ridges occur in lower right. The arrows indicate the photograph station for Fig. 5. Photo 4 September 1958

patches are believed to have been comparable to the existing ice patches referred to by Falconer, and their present wastage is merely the end phase in the progressive melting off of an extensive ice and snow cover which existed in the very recent past.

Figures 3 and 4 also indicate that the ice patches extended below the level of the sub-recent, ice-dammed lake; they existed, therefore, after the lake drained away. Comparison of lichen diameters supports this conclusion for those areas above the shore-line also.

From the foregoing, it is postulated that, during a period culminating between 200 and 350 yr. ago, extensive tracts of north-central Baffin Island (up to 70 per cent) were buried beneath permanent ice and snow. During the same period the Barnes Ice Cap, at least the northern sector, was significantly more extensive than today. The extension of the Barnes Ice Cap into the middle reaches of the Isortoq valley caused the ponding of a major lake, up to 80 km. in length and 300 m. in depth. Thinning of the ice dam resulted in drainage of the lake between 200 and 350 yr. ago; it can also be presumed that the snow and ice cover

beyond the limits of the Barnes Ice Cap was also being reduced, but not significantly as new ice patches were formed in the area uncovered by the drainage of the lake. Progressive wastage of the ice patches has continued to the present day.

It is particularly significant that during the last few hundred years up to 70 per cent of the upland area of north-central Baffin Island which is now ice-free, was covered by permanent snow and ice. This figure is obtained from mapping the distribution of the light-toned areas on air photographs of representative areas. Today, only approximately 2 per cent of this area is ice-covered and the remaining ice patches are disappearing rapidly. A reduction of this magnitude in the surface area of permanent snow and ice represents a considerable change in the average albedo of the ablation season during the past two to four hundred years. Does

Fig. 5. The main shore-line, old ice patch sites and the higher lateral terraces in the vicinity of Rimrock Lake. Panorama looking northwards. Photo 13 July 1961

this represent a change in climate of some magnitude (comparable to the recent climatic amelioration in more temperate "North Atlantic" areas), or is it the most recent phase in the deglacierization of the area which has proceeded continuously, if irregularly, over the past several thousands of years?

Discussion

The peculiarities of nourishment of the Barnes Ice Cap have been pointed out by Baird (1952) and he proposed the name "Baffin type" for ice caps and glaciers nourished predominantly by the refreezing of melt water onto the surface of the underlying "cold" glacier ice. Special vertical air photography, flown for the Geographical Branch between 19 and 24 July 1961, reveals that 75 per cent of the 1960–61 winter snowfall had melted off the ice-cap surface by that time. The same holds true for much of the mountain area further east. July 1961 was probably somewhat warmer than normal for the area; very little rain and cloud was experienced and extended periods of bright sunshine occurred. Under such conditions, and probably also in most normal years, the net budget for the small ice patches must be very strongly negative, especially as their limited area alone would greatly restrict accumulation by the refreezing process. Also, no fresh snow was encountered until late August, and it is doubted if any fell on the upper parts of the Barnes Ice Cap prior to 17 August. Baird concluded that the "Baffin type" of ice cap may be in a "rather healthier budgetary state than the majority of glaciers of the North Atlantic area" (Baird, 1952, p. 9). The evidence presented above suggests that this conclusion must be carefully re-examined. Associated geomorphological evidence implies that the Barnes Ice Cap has been greatly reduced in size during the

past several thousand years, and even during the past several hundred years. That it is a survival "from before the post-glacial climatic optimum", as postulated by Baird, is probably correct, but in an area such as Baffin Island, where "late-glacial" time lingers on, it could be suggested that no such thing as a xerothermic period ever occurred. Radio-carbon evidence for the disappearance of the final remnants of the inland ice of Labrador-Ungava provides a date of approximately 4,000 B.C. (Grayson, unpublished). It is probable at this time that the proto-Barnes Ice Cap extended into the fiords in the east, and in the west it projected into Foxe Basin. Recession has continued progressively, if irregularly, ever since. It can also be shown that its central zone of dispersal has migrated north-eastwards by at least 100 km. and that its effectiveness as an agent of erosion is probably negligible. Well-formed rock drumlins and crag-and-tail features, indicating movement in a north-easterly direction have been traced on the air photographs from a distance of 50 km. west of the present axis of the ice cap into its very western margin. Similar features can be seen emerging from beneath its eastern margin. It is apparent, therefore, that pronounced regional flow of ice occurred in the distant past and trended from south-west to north-east right across the present site of the Barnes Ice Cap (cf. Goldthwait, 1951). What is perhaps more significant is that this movement of ice resulted in the formation of rock drumlins and crag-and-tail features many of which have since been in the path of ice-cap migration and reversal of flow and which have not been perceptibly modified. If this is true of the major ice cap, it is more likely that the ice patches and smaller ice caps, once they have melted, will leave little indication of their former presence when sufficient time has elapsed for mature growth of the colonizing vegetation. Also it appears that existing glaciological nomenclature does not adequately provide for the description of widespread glacierization of the type discussed here. Permanent ice and snow cover of this nature can hardly be described as "ice cap", yet it is probable that extensive areas of high Arctic terrain have been ice covered in this manner; this points out the need for an addition to the existing terminology.

Finally, some comments are made on remarks by Ward (1953) in explaining the present, apparently north-easterly shift of the Barnes Ice Cap. Ward postulated an increase in north-easterly flow due to the removal of a large stabilizing force in the form of deeper and more extensive ice-dammed lakes along the north-eastern margin than those existing today. This he compared "to the incidence of landslips following the lowering of lake levels". Examination of the new vertical air photography led to the conclusion that the existing lakes along the north-eastern margin of the ice cap are probably more extensive today than ever in the past, with the exception of Generator Lake. Higher shore-lines are limited in extent; the largest of the present lakes drain over bedrock cols into the Baffin Bay fiords, and with continued ice recession an increasingly large area between the retreating ice margin and the regional watershed is uncovered. The only area of former, extensive ice-dammed lakes appears to be north of the present ice cap in the Isortoq and tributary valleys.

These concluding remarks serve to emphasize some of the significant glaciological problems in north-central Baffin Island. As Ward indicated, little is known of the mechanism of formation of geomorphological features associated with a "cold" ice cap (Ward, 1952). Some of these features, particularly the numerous cross-valley morainic ridges, can be seen in Figures 3 and 4. Their study will comprise one part of the Geographical Branch field programme; the other part will be a study of glaciological, glacio-meteorological and glacio-fluvial processes on and around an ideal "cold" ice cap, the Barnes Ice Cap. It is also proposed to examine some of the remaining ice patches in greater detail.

Acknowledgements

The author is indebted to Mr. J. T. Andrews for assistance in the field, and particularly for the study of rock lichen diameters, to Mr. P. L. Hill who also assisted in the field, particularly

with the levelling programme. Both are members of the Geographical Branch staff. Finally, gratitude is expressed to Dr. R. P. Goldthwait for stimulating discussions based upon his pioneer work in the same general area in 1950, and to Dr. R. Beschel for discussion of the significance of the rock lichen studies.

MS. received 6 January 1962

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