17. CHARACTERISTICS OF BASAL ICE FROM TWO OUTLET GLACIERS IN THE CANADIAN ARCTIC – IMPLICATIONS FOR GLACIER EROSION

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Abstract

Ice was sampled for chemical and isotopic analyses at the margin of Hook Glacier, Ellesmere Island, and Aktineq Glacier, Bylot Island.

In the section studied at Hook Glacier, striking variations in Cl and Na content occur. This is interpreted as the consequence of recumbent folding which cannot be observed directly.

In the section studied at Aktineq Glacier, the relations between $\delta^{18}O$ and δD values of the samples indicate that striking differences exist among basal ice layers. Some of these layers result from a meltwater refreezing process at the bedrock interface and are located at different heights in section because of recumbent folds and represent only a minor fraction of the basal part. This implies that the whole basal layer is not a result of accretion processes.

Care must thus be taken in evaluating the importance of subglacial erosion by polar outlet glaciers from the thickness of their frontal basal ice and debris layers.

Introduction

Polar outlet glaciers are known, generally, to be characterized by a thick basal layer which differs from the glacier ice above by an abundance of debris bands. The significance of this fact was discussed by Andrews (1971, 1972) and Boulton (1971, 1972). Following Boulton (1971, 1972), this implies that these glaciers carry considerable amounts of englacial debris derived from the glacier bed. This view, however, was not accepted by Andrews (1971, 1972) who considered that the thick basal layer, if present, is a marginal feature developed close to the glacier margin.

The nature of the basal layer can be documented further by chemical and isotopic study of the ice. Presented here are the results of such a study on two outlet glaciers in the Canadian Arctic: Hook Glacier on Ellesmere Island and Aktineq Glacier on Bylot Island.

Hook Glacier, Ellesmere Island

Site Description

Hook Glacier is located on the eastern side of Makinson Inlet (Fig. 17.1), southeastern Ellesmere Island. The lower part of Makinson Inlet is in the Inglefield Mountains,

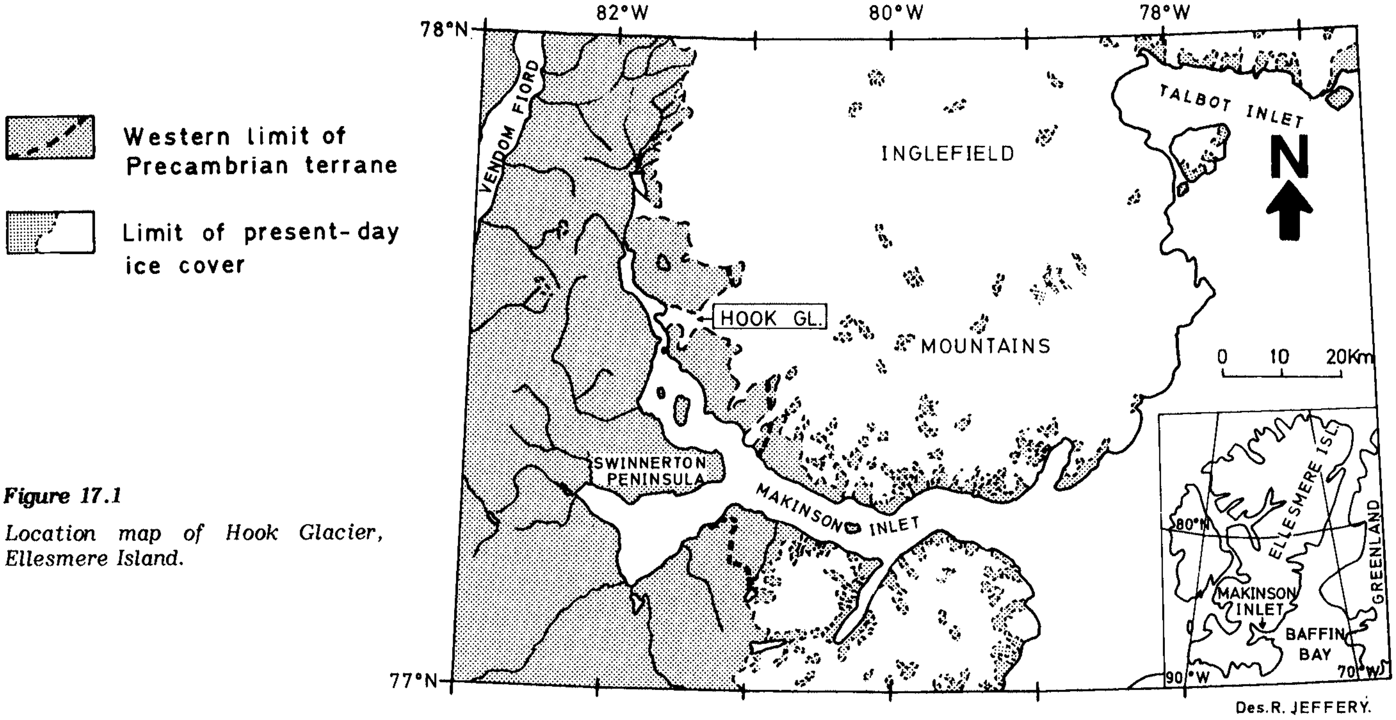

Figure 17.1

Location map of Hook Glacier, Ellesmere Island.

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a rugged area underlain by highly metamorphosed, crystalline Precambrian rocks. To the west, gently inclined Paleozoic sedimentary rocks rest on a well developed unconformity; the north and south arms of Makinson Inlet are incised into these sedimentary rocks which are mainly composed of Paleozoic limestone and friable Cretaceous coal-bearing sedimentary rock. The eastern part of the region on both sides of Makinson Inlet is heavily glaciated with ice caps and icefields whose even surfaces are broken by many nunataks. A great contrast in ice thickness exists between east and west sides of these ice caps. This asymmetry is controlled largely by snow accumulation dependent on precipitation from Baffin Bay (Koerner, 1977).

Hook Glacier has its accumulation zone on the Precambrian rocks whereas its lower part flows in a valley carved into the Paleozoic limestone. This lower part consists of a tongue which divides into two about mid-way between the icecap border and the fiord. The northern tongue reaches Makinson Inlet, is floating, and produces small icebergs, but the southern tongue ends about 1.5 km from the fiord (Fig. 17.2).

In front of the southern tongue, to be considered here, elongated hills, with steep slopes, rise about 30 m above the outwash plain (Fig. 17.3). The hills, oriented at right angles to the direction of glacier flow, are composed of sandy and silty stratified beds, in some places folded, which are capped by a veneer of gravels and pebbles. Remnants of braided stream channels similar to those on the outwash plain can be observed at the level of the pebbly veneer. This landform represents an outwash delta with layers of sand and silt deposited in the fiord environment, capped by gravels and pebbles due to the progradation of the outwash plain. An advance of Hook Glacier has resulted in deformation and fracturing of the outwash deposit and has transformed it into a push-moraine. To the northwest of the glacier front, some undisturbed terrace remnants made up of the same type of material still exist about the present-day outwash. These terrace deposits contain at least one thin layer of marine pelecypod shells (W. Blake, Jr., personal communication, 1977).

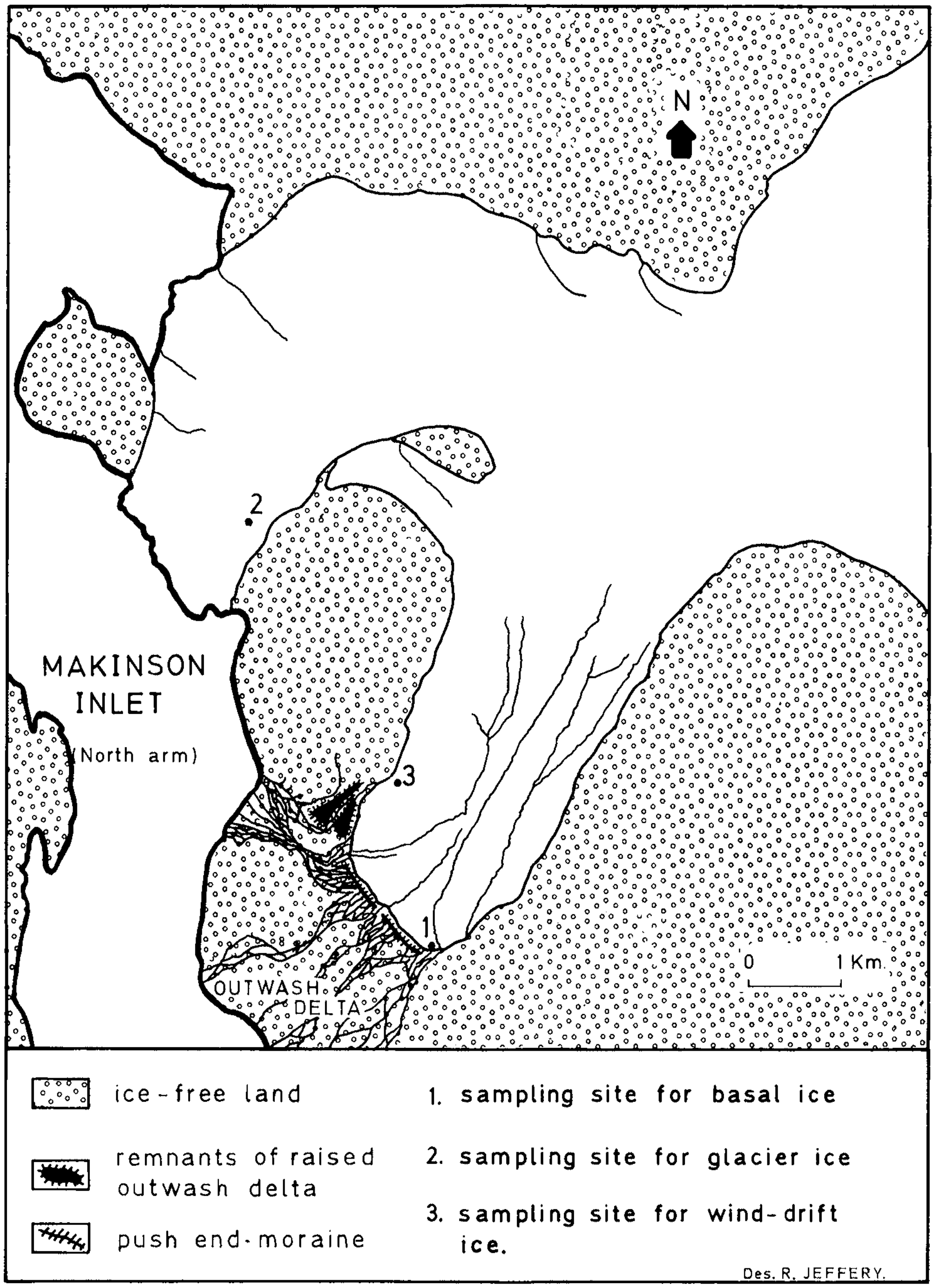

Figure 17.2. *The frontal zone of Hook Glacier (NAPL A16692-110).*

Characteristics of the Basal Layer

The basal part of the southern tongue of Hook Glacier shows numerous debris bands of contrasting colour. A conspicuous set of red bands, containing mainly pink orthoclase-type feldspar particles, is clearly visible between two sets of greyish bands containing mainly limestone fragments. Each set is a few metres thick. Most of the debris in the bands is sand and silt with a much greater proportion of fines in the greyish bands than in the red ones.

Closer examination of the debris bands showed that they are composed of a series of layers a few millimetres thick, separated by fine grained ice (1 to 2 mm crystal size) of approximately the same thickness. Between the debris bands, thick layers (20 to 150 cm) of particle-free bubbly ice, made up of equigranular crystals a few millimetres in diameter, are present in the sequence. Bubble-free ice layers are not present in the section of basal ice investigated, but they occur (approximately 1 cm thick), interbedded with debris layers, along the southern margin of the northern glacier tongue.

Ice samples were taken in the thick layers of particle-free bubbly ice which are present between the debris bands at site 1 (Fig. 17.2). One group of samples (A) was collected in the red part of the section and a second group (B) was collected from both sets of the greyish part.

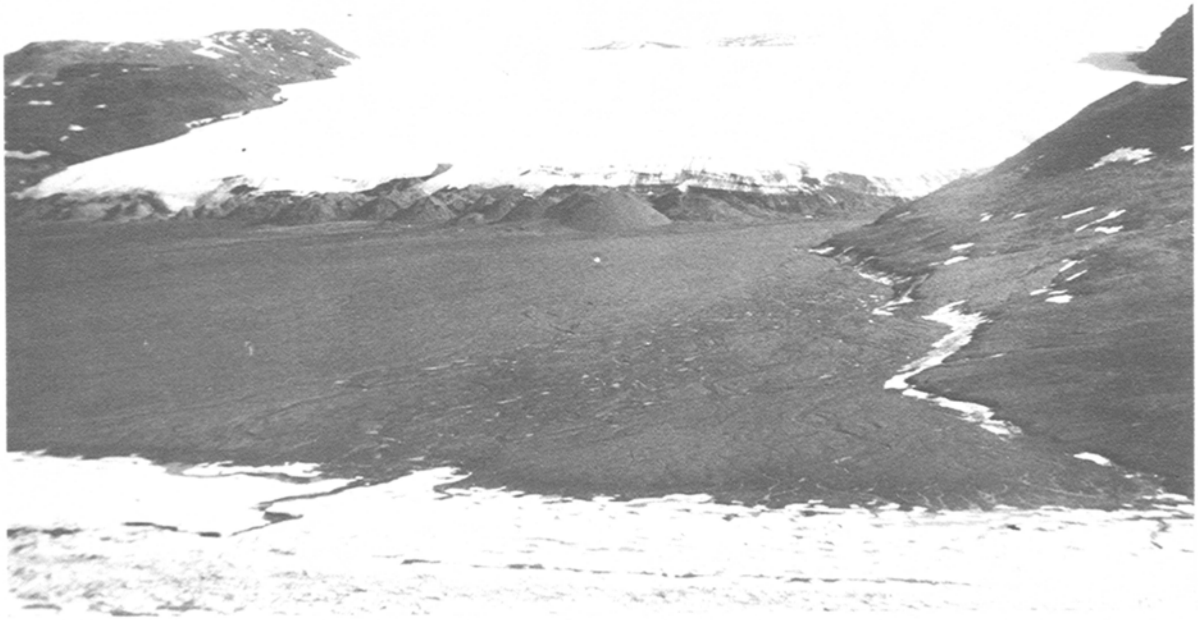

Figure 17.3. *General view of Hook Glacier showing the outwash delta and the push moraine.*

Glacier ice and wind-drift ice also were sampled. Because of extensive snow cover on Hook Glacier, sampling of glacier ice was carried out in crevasses which probably appear as a consequence of floating in the frontal zone of the northern glacier tongue (site 2, Fig. 17.2). The values obtained are assumed to represent values for glacier ice of the southern tongue as well. Wind-drift ice, consisting of ice formed at the beginning of the summer by refreezing of percolating meltwaters from wind-drift snow, was sampled just below the surface of the southern tongue at site 3 (Fig. 17.2).

Sample Treatment and Analysis

The ice cores were sliced with a non-contaminant saw and the slices were allowed to melt in a special type of hot-water bath. Meltwater was filtered in a millipore 0.45 µm filter and transferred to polyethylene bottles which had been washed with a detergent and pure nitric acid and rinsed with triply distilled water in order to remove the major cations sorbed on their walls. Samples having a particle content of more than 0.1 g/kg ice were eliminated because of the potential important of ion exchange for the Na content.

All equipment used in the field (polyethylene syringes, polyethylene gloves, filtering assembly) was sealed in washed polyethylene bags and each item was rinsed with triply distilled water when it was unpacked. New equipment was used for each sample. Blank procedures in the field consist of taking triply distilled water, pouring it into the hot water bath, and filtering it; these procedures showed that contamination was reduced to the background noise level of the instruments used for analysis. The sample bottles were sealed in polyethylene bags for transport. Sodium was determined on the meltwater samples by flame atomic absorption spectrophotometry using the procedure described by Ragone and Finelli (1971) with a recorder-equipped Perkin Elmer 303. A Radiometer automatic potentiometric titration assembly was used for chlorine. This method gives results with a precision of ±0.03 ppm similar to that described by Koide and Goldberg (1971).

Results and Comments

Table 17.1 gives the mean and extreme values in ppm of the chlorine and sodium concentrations for the three types of ice samples; the ratio Cl/Na is also included.

Glacier ice is characterized by its low Cl and Na contents. The values are similar to those obtained in Greenland by Langway (1970) and Cragin et al. (1975) and in Antarctica by Briat et al. (1974). The Cl/Na ratio is relatively variable but is always greater than that of bulk sea water (1.8). Wind-drift ice has higher mean Cl and Na contents and greater concentration variability, the lowest values being not far from mean values for glacier ice. This variability results from ionic migration along with percolating meltwater.

The two groups of basal ice samples, A and B, differ strikingly in their Na and Cl contents, with group B values being an order of magnitude higher. Values for group A are similar to those of wind-drift ice. Moreover, ice of these two groups shows the same bubble abundance and the same equigranular crystals (a few millimetres in diameter). Thus these two groups of ice could have a similar origin. Unlike the other ice samples, group B has a Cl/Na ratio close to that of sea water.

Cl and Na ions are most probably of sea water origin. Different sources are possible, the most probable being recent fiord sediments. Indeed, if fine sediments (100 g) from the push moraine are added to distilled water (100 ml) in the laboratory, after 24 hours high values (between 1.8 and 2.0 mg Cl/100 g sediments) can be obtained in the supernatant solution. Such high values indicate either that sea water is still present within the sediment as interstitial water or that salt minerals occur within the rock fragments constituting the deposit.

Bubbly ice layers poor in Cl and Na and orthoclase-rich debris bands are clearly associated in the middle part of the section. They occur between two similar sets of Cl- and

Table 17.1

Chemical composition of ice samples from Hook Glacier

							Basal ice					
	Glacier ice (11 samples)			Wind-drift ice (11 samples)			Group A (8 samples)			Group B (8 samples)		
	mean	ppm min.	max.	mean	ppm min.	max.	mean	ppm min.	max.	mean	ppm min.	max.
Cl	0.12	0.06	0.18	0.30	0.12	0.72	0.35	0.15	0.58	1.97	0.62	6.26
Na	0.020	0.013	0.034	0.116	0.029	0.293	0.120	0.075	0.180	0.939	0.340	2.735
Cl/Na	6.3	2.9	11.3	3.1	1.6	4.6	2.6	1.7	3.8	2.0	1.6	2.3

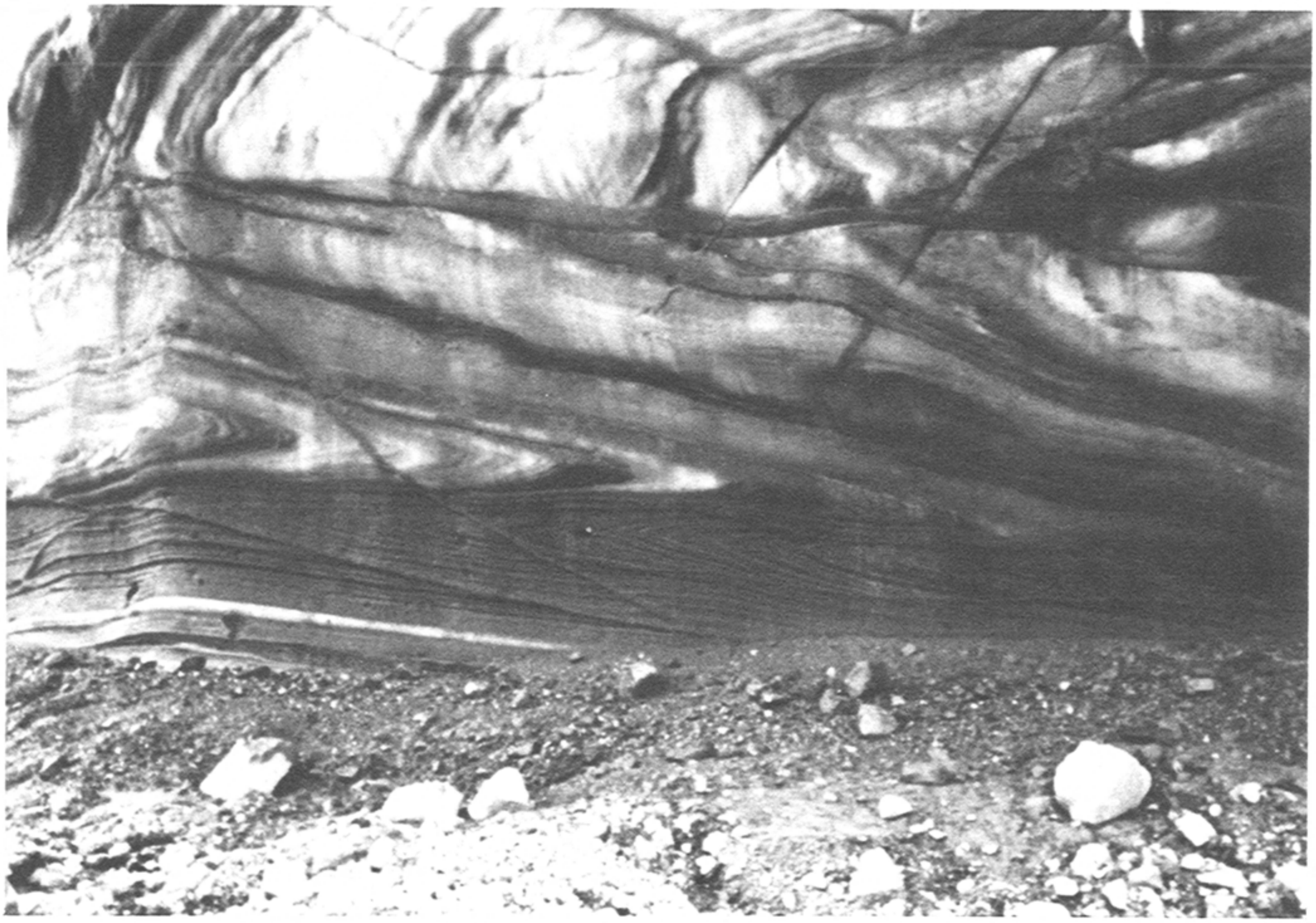

Figure 17.4. *Recument folding at the base of the northern tongue of Hook Glacier. The boulder in the lower right part of the photograph is about 40 cm long.*

Na-rich ice layers and limestone-rich debris bands. This suggests that a recumbent fold exists at this location, although it is not visible as the basal ice is exposed only in the frontal zone. Fold of this type are, moreover, visible at the base of the northern tongue of Hook Glacier (Fig. 17.4). Thus recumbent folding probably is developed in the basal part of both tongues of Hook Glacier and results in an increased thickness of the basal layer in the frontal zone.

Aktineq Glacier, Bylot Island

Site Description

Bylot Island lies off the northeastern tip of Baffin Island (Fig. 17.1). A central northwest-trending mountainous spine of highly metamorphosed, crystalline, Precambrian-age terrane (Byam Martin Mountains) is surrounded by relatively flat-lying areas at lower overall elevation of unmetamorphosed Proterozoic sedimentary rock and poorly consolidated, coal-bearing, Cretaceous-Tertiary sedimentary rock (Jackson and Davidson, 1975). The highlands area is mostly ice-covered and numerous glaciers flow outwards from it towards both the north and south coasts. Some glaciers cross at least two major lithologic units, and thus glacial debris can be used as a tracer to study mechanisms of glacier erosion. Recent work in this field has been carried out by DiLabio and Shilts (1979) and Klassen (1981). Most of our work was concentrated on a vertical section at Aktineq Glacier (B 17, Glacier Atlas of Canada, 1969).

Characteristics of the Basal Layer

A section about 14 m high was studied at the base of Aktineq Glacier on its eastern side, 2.5 km from the snout (site A, Fig. 17.5). The lower 10 m of the section could easily be differentiated from the bulk glacier ice above in that it contained negligible amounts of bubbly ice and numerous debris layers (Fig. 17.6). Within the lower portion, three main types of ice were encountered. (1) The most abundant type was coarse bubble-free ice, in layers from 1.5 to 48 cm thick, containing aggregates of silty material (about 0.1 cm in diameter). The crystals showed sinuous margins and imbricated forms and varied in size between 2 and 4 cm. (2) The second type consisted of bubble-free monocrystalline ice layers, 0.1 to 0.3 cm thick, associated with sandy layers of approximately the same thickness. Ice crystals were strongly elongated in the plane of the layer and their length varied from 0.5 to 1 cm. Sequences of the two layers up to 12 cm in thickness were observed. The two types of bubble-free ice described above were regularly distributed in the section. (3) The third type was made up of two layers of bubbly ice, 5 and 9 cm thick. The layers were located just above thick frozen bands (8 and 9 cm) of unsorted morainic debris. The ice crystals varied in size between 0.2 and 2 cm and were polyhedral-shaped with even margins. The numerous bubbles were either spherical or elongated in the plane of the layer.

Samples for $^{18}O/^{16}O$ and deuterium/hydrogen (D/H) analysis were collected from all three types of ice in the basal part of Aktineq Glacier as well as in the bulk glacier ice. Glacier ice from adjacent glaciers ("Camp" and Sermilik; Fig. 17.5) was also sampled.

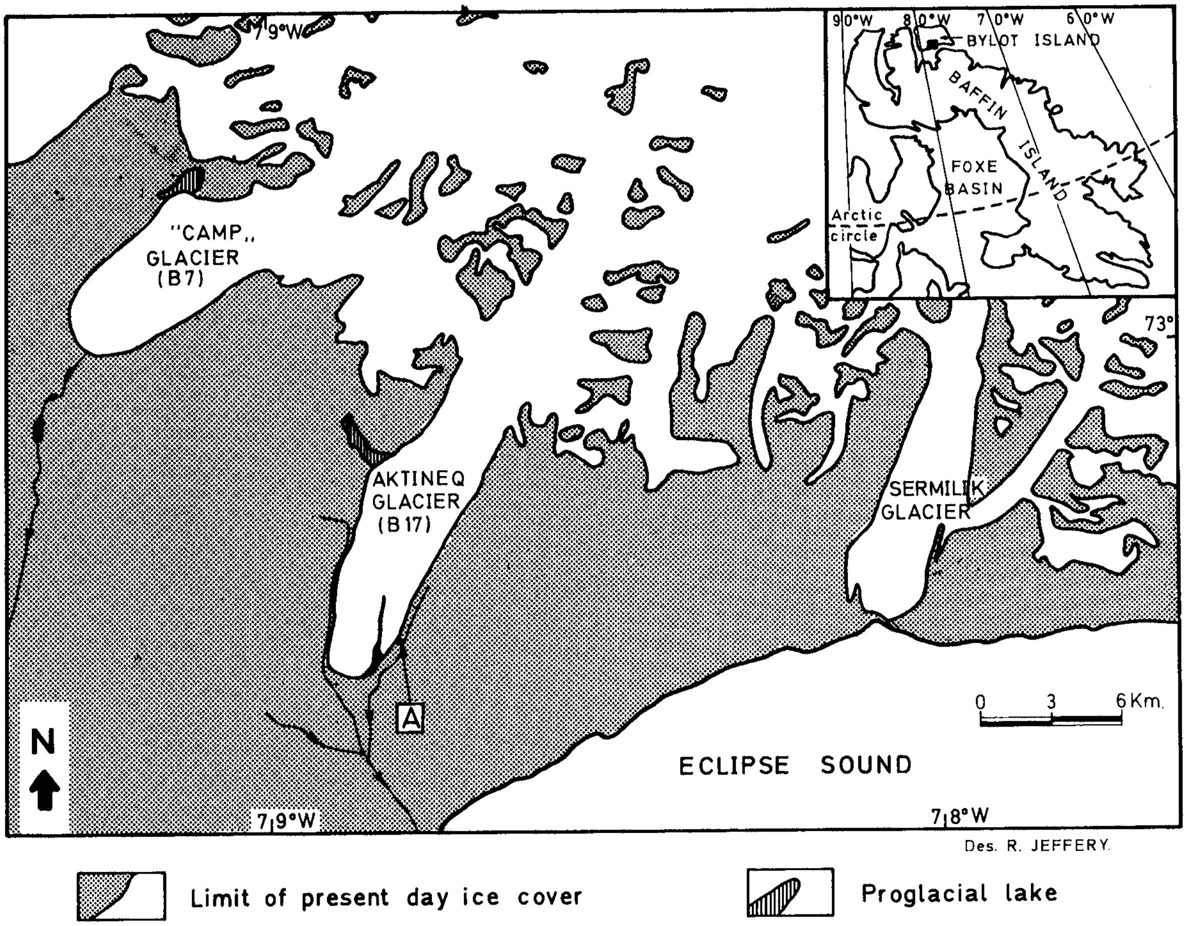

Figure 17.5. Location map of Aktineq Glacier, Bylot Island.

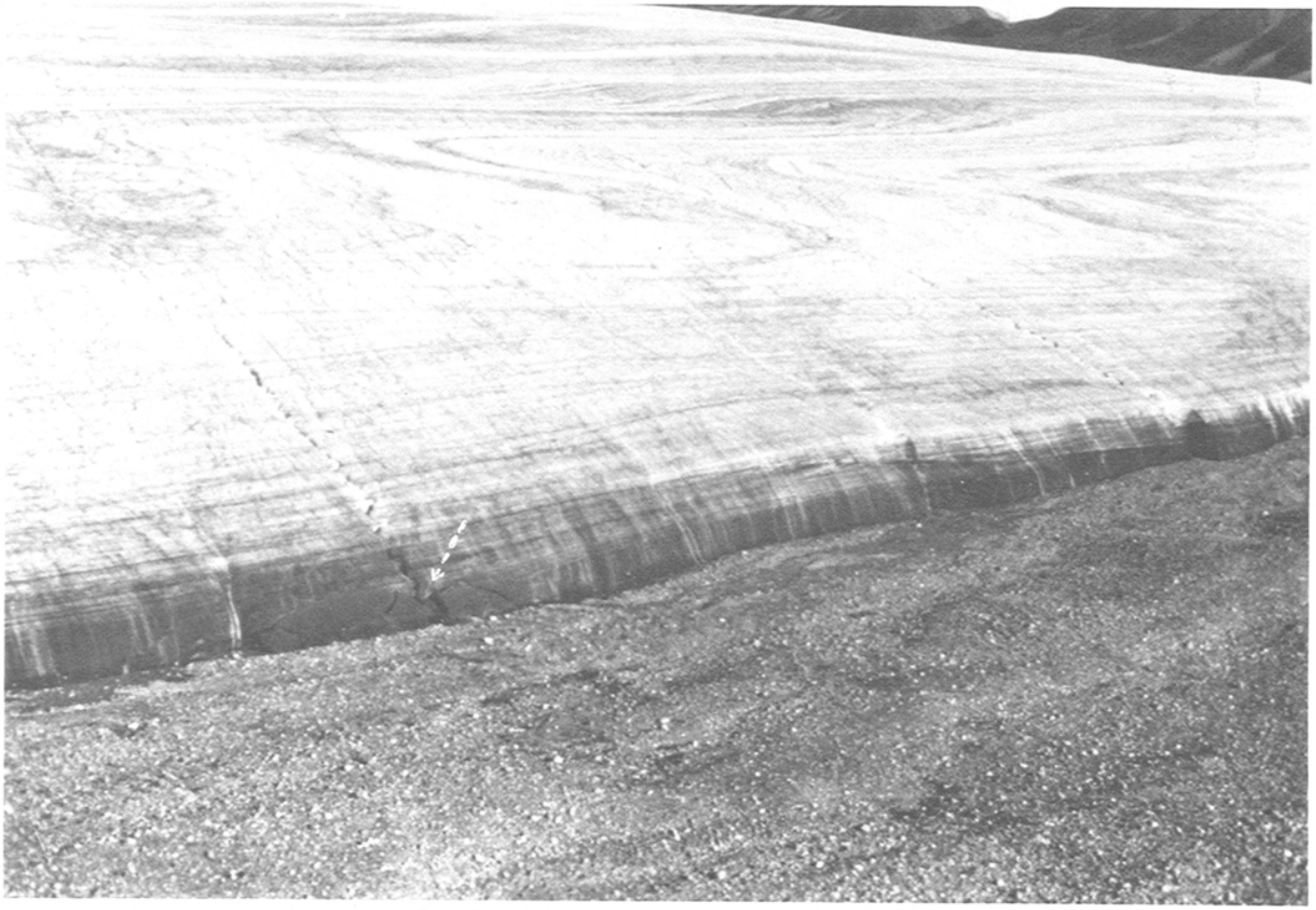

Figure 17.6. *The eastern margin of Aktineq Glacier (arrow points to the sampling site).*

Sample Treatment and Analysis

The upper 10 cm of ice was removed each time before sampling. An aluminium coring device was then hammered into the ice and the sample extracted and transferred into a polyethylene bottle. The meltwater was transferred into 30 ml glass bottles to avoid possible contamination by diffusion through the polyethylene in the course of time. The bottles, equipped with a screw top self-sealing propylene cap, were then sealed with paraffin wax to prevent evaporation. The samples were analyzed at the Centre d'Etudes Nucléaires de Saclay. The δ D and $\delta\ ^{18}$O values are expressed in per mil; precision of measurement is ±0.50‰ for δ D and ±0.15‰ for $\delta\ ^{18}$O.

Results and Comments

To reveal processes in which the two heavy components behave in different ways, $\delta\ ^{18}$O has been plotted against δ D revealing two linear trends (Fig. 17.7). Most points lie on line A, having a slope of 7.8. This linear relationship with slope of about 8 is known in the literature as being an important feature of isotopic fractionation occurring during condensation or sublimation of water in simple equilibrium (Dansgaard, 1964). This relationship is true for solid precipitation of all types and is thus valid for glacier ice that has not undergone major isotopic changes during and since its formation.

The samples that diverge from line A are located on another straight line, B (Fig. 17.7), with a slope of 4.9. It can be shown that a linear trend with slope of about 5 is the result of a meltwater refreezing process (Jouzel and Souchez, "Melting-refreezing at the glacier sole and the isotopic composition of the ice," submitted). These samples are either the monocrystalline bubble-free ice layers or the bubbly ice found in the basal part of the section. These two types of ice show other characteristics that might indicate an origin linked with a regelation process at the bedrock interface. The shape of the crystals in the monocrystalline ice layers is simialr to that observed by Kamb and LaChapelle in a tunnel at the base of Blue Glacier (1964, Fig. 5, p. 165). The strong elongation of the crystals in the foliation plane and the association with the sandy layers suggest an origin in contact with the bedrock. They also display a weak single maximum fabric that could be expected for ice being formed at the interface in a locally fluctuating stress system associated with flow over an irregular bed (Budd, 1972). Finally, the occurrence of bubbly ice layers just above thick frozen morainic debris bands also suggests that they were once at the sole of the glacier.

The entire basal part of the glacier at the section studied is not necessarily the result of accretion processes alone. The ice foliation above and below the major frozen debris bands defines major recument folds, resembling those described by Hudleston (1976) at the base of the Barnes Ice Cap. Their hinge is nearly horizontal with a strike slightly oblique to the glacier margin. More than one fold is commonly found on the same vertical, implying that the whole 10 m of basal ice might be affected. Independently, some folds with subvertical hinges are displayed at the surface of Aktineq Glacier.

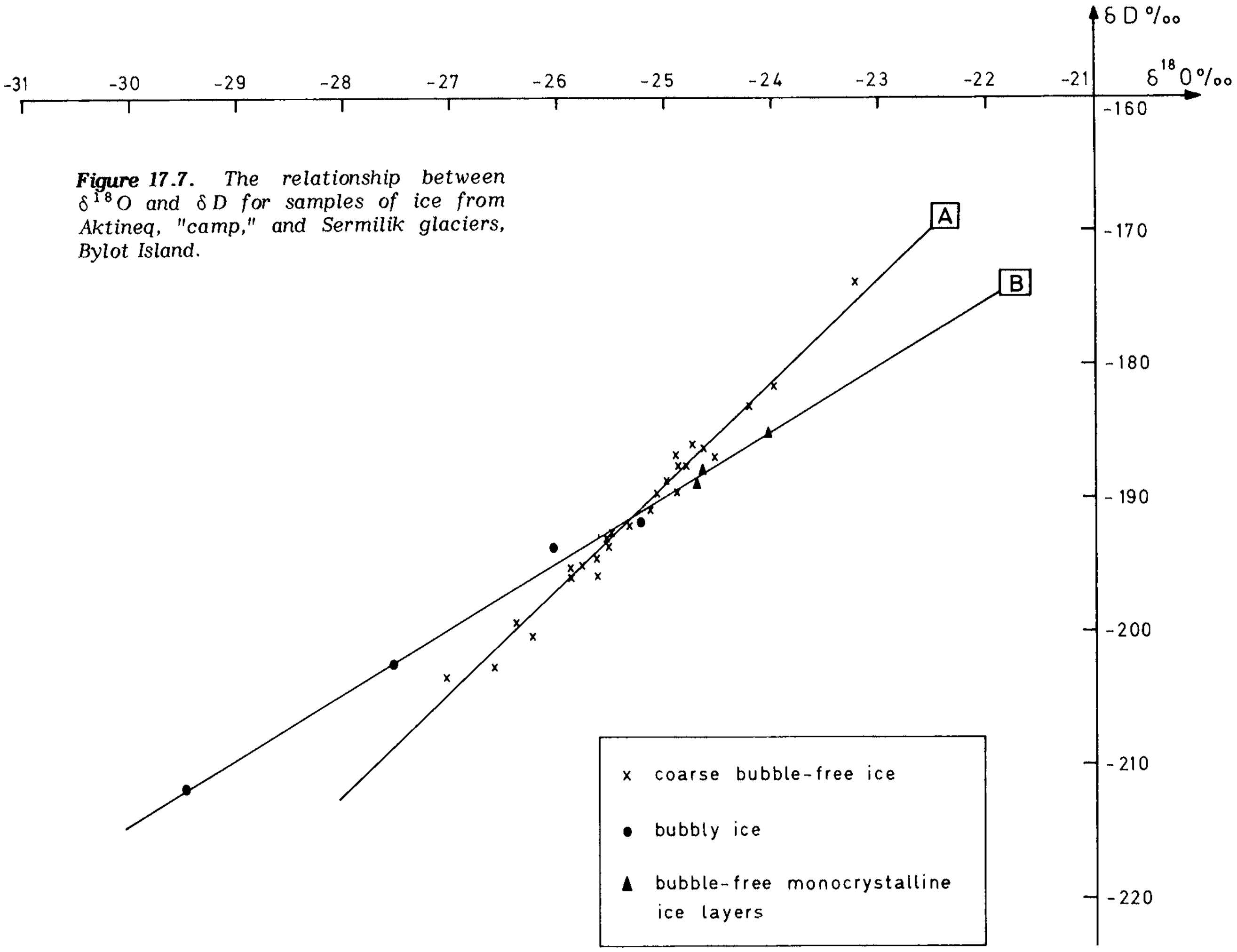

Figure 17.7. The relationship between $\delta^{18}O$ and δD for samples of ice from Aktineq, "camp," and Sermilik glaciers, Bylot Island.

Conclusion

As indicated by chemical and isotopic studies on Hook and Aktineq glaciers, a simple accretion process at the glacier sole cannot explain the whole thickness of their basal layer. The distortion of foliation structures in the terminal zone of compression flow enhances the vertical development of the basal layer. In evaluating glacier erosion of polar outlet glaciers, structural deformation and the possibility of "stratigraphic" disorder and repetition of debris bands should be addressed.

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