

**Holocene Environmental Change in the Frobisher Bay Area,
Baffin Island, N.W.T.: Deglaciation, Emergence, and the
Sequence of Vegetation and Climate**

**Évolution environnementale à l'Holocène dans la région de la
baie de Frobisher, île de Baffin, T.N.-O.: déglaciation, emersion
et successions végétale et climatique**

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Baffin Insel, N.W.T.: Entgletscherung, Auftauchen, und Abfolge
der Vegetation und des Klimas**

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Article abstract

The late-glacial and Holocene paleoenvironmental sequence for the Frobisher Bay area is outlined using glacial, sea level, and palynological evidence. A rapid retreat of ice from the late Foxe glacial maximum in the lower part of the bay after 11,000 BP was followed by a series of stillstands or minor readvances between ca. 8500 and 7000 BP and possibly later, before the final disappearance of the inland ice centred near Amadjuak Lake. Lithostratigraphy of three buried organic sections which together represent deposition occurring over the period from 5500 to 400 BP indicates a change from a relatively warm, moist environment before 5500 BP to neoglacial conditions, with the coldest phases centred around 5000, 2700, 1200 BP and probably sometime after 400 radiocarbon years BP. As evidenced by peat growth and pollen data, milder, wetter conditions prevailed from 4500 to 3000 BP and again from ca. 2600 to 1800 BP. Peat growth and soil organic fractions point to lesser mild intervals ca. 900 BP and 400 BP, but these are not apparent in the pollen assemblage. The pollen record does not extend to the last four centuries; however, lichenometric studies of neoglacial moraines by DOWDESWELL (1984) show that the maximum late Holocene advance of glaciers in the area occurred within the last century. Modern pollen samples indicate that the present vegetation of the inner Frobisher Bay area is comparable to that of the milder intervals of the late Holocene.

HOLOCENE ENVIRONMENTAL CHANGE IN THE FROBISHER BAY AREA, BAFFIN ISLAND, N.W.T.: DEGLACIATION, EMERGENCE, AND THE SEQUENCE OF VEGETATION AND CLIMATE

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ABSTRACT The late-glacial and Holocene paleoenvironmental sequence for the Frobisher Bay area is outlined using glacial, sea level, and palynological evidence. A rapid retreat of ice from the late Foxe glacial maximum in the lower part of the bay after 11,000 BP was followed by a series of stillstands or minor readvances between ca. 8500 and 7000 BP and possibly later, before the final disappearance of the inland ice centred near Amadjuak Lake. Lithostratigraphy of three buried organic sections which together represent deposition occurring over the period from 5500 to 400 BP indicates a change from a relatively warm, moist environment before 5500 BP to neoglacial conditions, with the coldest phases centred around 5000, 2700, 1200 BP and probably sometime after 400 radiocarbon years BP. As evidenced by peat growth and pollen data, milder, wetter conditions prevailed from 4500 to 3000 BP and again from ca. 2600 to 1800 BP. Peat growth and soil organic fractions point to lesser mild intervals ca. 900 BP and 400 BP, but these are not apparent in the pollen assemblage. The pollen record does not extend to the last four centuries; however, lichenometric studies of neoglacial moraines by DOWDESWELL (1984) show that the maximum late Holocene advance of glaciers in the area occurred within the last century. Modern pollen samples indicate that the present vegetation of the inner Frobisher Bay area is comparable to that of the milder intervals of the late Holocene.

RÉSUMÉ *Évolution environnementale à l'Holocène dans la région de la baie de Frobisher, île de Baffin, T.N.-O.: déglaciation, émergence et successions végétale et climatique.* La présente étude porte sur l'évolution paléoenvironnementale fini-glaciaire et holocène de la région de la baie de Frobisher et se fonde sur les niveaux marins ainsi que sur des témoins polliniques et glaciaires. Le retrait rapide des glaciers dans la partie intérieure de la baie depuis 11 000 BP a été suivi d'épisodes de stabilité et de récurrences mineures entre 8500 et 7000 ans BP, et peut-être plus tard, avant la disparition définitive des glaces continentales dont le centre se trouvait près du lac Amadjuak. L'analyse a porté sur trois sections de sol enfoui qui représentent les dépôts accumulés entre 5500 et 400 ans BP. La lithostratigraphie révèle le passage d'un climat relativement humide et chaud, il y a plus de 5500 ans, à un climat néoglaciaire dont les périodes les plus froides se situent vers 5000, 2700 et 1200 ans BP et probablement après 400 ans BP. La tourbe et les données polliniques témoignent de conditions climatiques plus douces et plus humides pour les périodes allant de 4500 à 3000 ans BP et d'environ 2600 à 1800 ans BP. Mais, contrairement aux associations polliniques, la tourbe et certaines portions organiques de sol font penser qu'ont existé des intervalles plus frais environ de 900 à 400 ans BP. Les données polliniques ne donnent aucun renseignement sur les quatre derniers siècles. Cependant, les études lichénométriques que DOWDESWELL (1984) a faites sur les moraines néoglaciaires révèlent que, dans la région pendant l'Holocène supérieur, l'avancée maximale des glaces s'est produite au siècle dernier. Des échantillons polliniques récents démontrent que la végétation actuelle de l'intérieur de la baie de Frobisher ressemble à celle qu'on trouvait pendant les intervalles tempérés de l'Holocène supérieur.

ZUSAMMENFASSUNG *Holozäne Umweltveränderung im Frobisher-Bucht Gebiet, Baffin Insel, N.W.T.: Entglacierung, Auftauchen, und Abfolge der Vegetation und des Klimas.* Die spätglaziale und holozäne Abfolge des Paläomilieus im Gebiete der Frobisher Bucht wird durch glaziale, Meeresspiegel-, und palynologische Beweise umrissen. Ein rasches Zurückweichen des Eises aus dem niederen Teil der Bucht hat sich nach 11 000 BP ereignet, gefolgt von mehreren Stillständen oder kleinerem Wiedervorrücken zwischen etwa 8500 und 7000 BP oder evtl. später, bevor das Inlandeis schliesslich verschwunden ist. Drei verdeckte Bodenprofile sind analysiert worden, die zusammen die Ablagerung der Zeit von 5500 bis 400 BP darstellen. Die Lithostratigraphie hat eine relativ warme, feuchte Umgebung vor 5500 BP ergeben, die sich alsdann zu neoglazialen Zuständen geändert hat, mit dem Mittel der kältesten Phasen um etwa 5000, 2700, und wahrscheinlich auch irgendwann nach 400 Radiokohlenstoffjahren BP. Torfwuchs sowie auch palynologische Daten zeigen, dass milde, feuchte Zustände von 4500 bis 3000 BP und dann nochmals von etwa 2600 bis 1800 BP vorgeherrscht haben. Der Torfwuchs und der organische Anteil des Bodens deuten auch auf kleinere milde Zeitspannen um etwa 900 und 400 BP, aber diese sind nicht aus der Pollenvergesellschaftung ersichtlich. Für die jüngsten vier Jahrhunderte fehlen Pollenunterlagen; aber durch Untersuchung der Flechten auf neoglazialen Moränen hat DOWDESWELL (1984) für dieses Gebiet ein spätholozänes Gletschervorrücken während des letzten Jahrhunderts belegen können. Pollenmuster beweisen, dass sich im Gebiet der inneren Frobisher Bucht die heutige Pflanzendecke gut mit der Vegetation milderer Spätholozänintervalle vergleichen lässt.

INTRODUCTION

Frobisher Bay (Fig. 1) is formed in a major trough or graben which extends from the Foxe Lowland southeastward between the Hall Upland and the Frobisher Upland of southern Baffin Island (BLACKADAR, 1967; BIRD, 1967). The coastal lowlands and interior valleys adjacent to the bay comprise an extension of the relatively productive low arctic vegetation zone into the Arctic Archipelago, and the head of the bay marks the distributional limit for some low arctic plant species (JACOBS *et al.*, 1985). Such a transitional phytogeographic and climatic region is of particular interest in the context of studies of Holocene environmental change.

The Frobisher Bay area, which still is glacierized to some extent (Fig. 1), contains abundant evidence of late Foxe (late Wisconsinan) and Holocene glacial events, including moraines associated with the extensive Cockburn-age moraine system first described by FALCONER *et al.* (1965) and shown by them to mark a late Wisconsinan (*ca.* 9000 — 8000 BP) Laurentide ice margin over much of the eastern Canadian Arctic. Recent usage describes this last major glaciation by the regional geologic-climatic term "Foxe Glaciation," which ANDREWS (1980) has defined as covering the period between

about 115,000 and 6000 BP. ANDREWS and IVES (1978) used the term "Cockburn Substage" to describe the chronostratigraphic subdivision of the Holocene during which the prominent moraine system dated at 9000 — 8000 BP was formed. This early Holocene advance of the northeastern edge of the Laurentide Ice Sheet at a time of general recession was interpreted as being due to increased precipitation resulting from more open water by that time along the east coast of Baffin Island.

BLAKE (1966) carried out a detailed study of the Cockburn-age moraines in southern Baffin Island. Based on field evidence, radiocarbon dates, and aerial photographs, he presented a chronology of deglaciation that saw the retreat of the late Foxe ice from the outer part of Frobisher Bay to a position near the head by about 8000 BP, followed by a halt in that retreat of almost 1000 years duration, during which a complex end moraine system formed, before further retreat of the ice inland after 7000 BP. At about the same time, the western and northern margins of the remnant South Baffin Ice Sheet retreated inland from Foxe Basin southeastward across Nettilling and Amadjuak Lakes. A radiocarbon date from Amadjuak Lake indicated that the ice had retreated to its final position in the Hall Uplands east of Amadjuak Lake

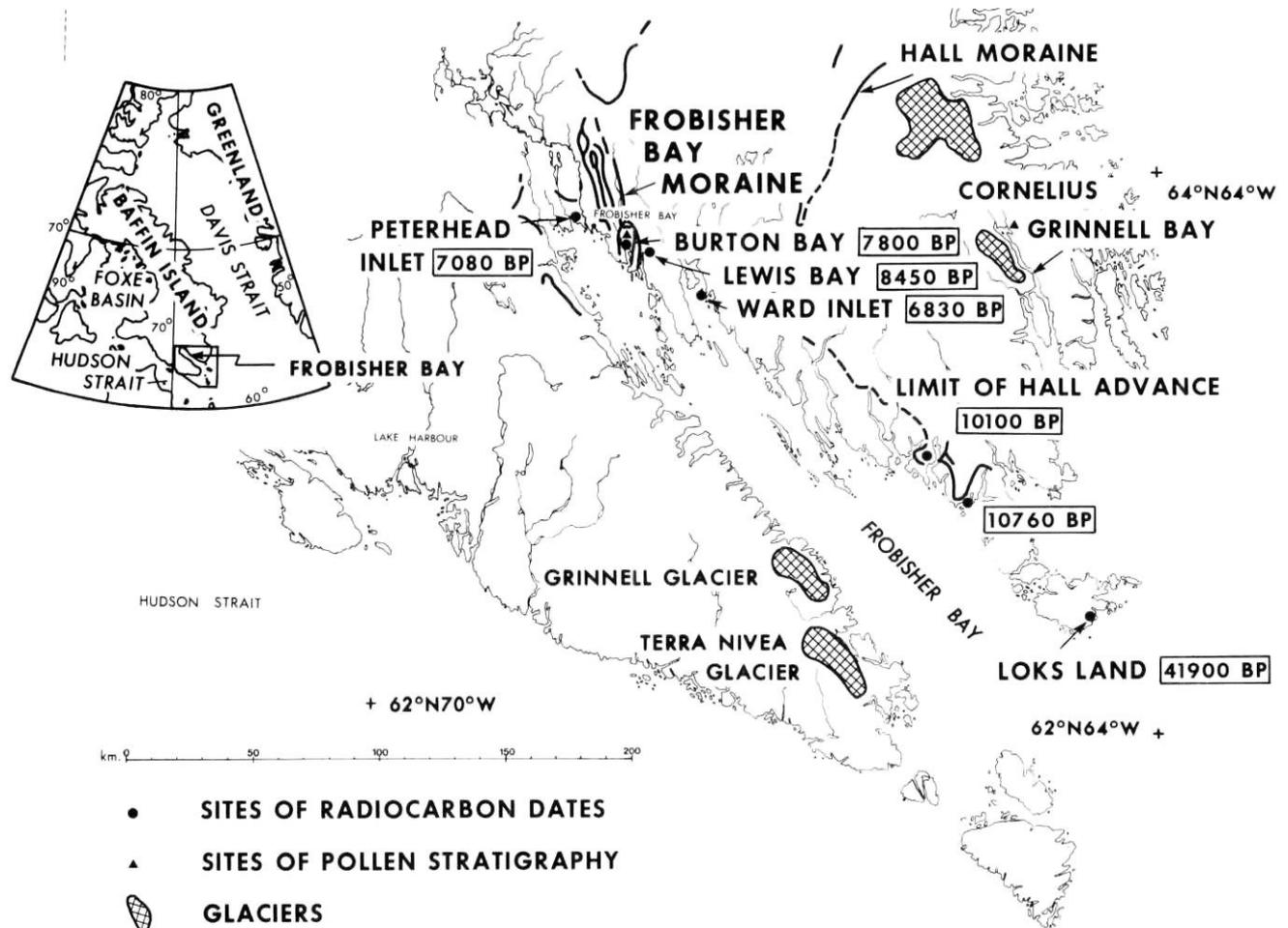


FIGURE 1. The Frobisher Bay area, showing the locations of glaciers, principal moraine ridges, and sites of radiocarbon-dated raised marine features and pollen stratigraphy.

Carte de localisation des glaciers, des principales crêtes morainiques, des formes marines soulevées datées au radiocarbone et des sites stratigraphiques polliniques, dans la région de la baie de Frobisher.

TABLE I
Radiocarbon dates referred to in this study

| Marine mollusks | | | | Organic sediments | | | |
|----------------------------|----------|-----------------|---------------------|----------------------------|-----------|-----------------|---------------------|
| Date (yr. BP) ^a | Lab. no. | Location | Source ^b | Date (yr. BP) ^a | Lab. no. | Location | Source ^b |
| 41,900 + 7,100 – 3,700 | QC-446 | Loks Land | (1) | 7,285 ± 200 | GX-6603 | Grinnell Bay | (3) |
| 10,760 ± 150 | QC-480c | Warwick Sound | (1) | 5,490 ± 180 | QC-683B | Grinnell Bay | (3) |
| 10,100 ± 110 | GSC-2725 | Gold Cove | (1) | 4,460 ± 140 | GSC-498 | Amadjuak Lake | (5) |
| 9,960 ± 230 | GSC-2752 | Loks Land | (1) | 3,755 ± 145 | GX-9857 | Ward Inlet | (4) |
| 8,890 ± 150 | GSC-2568 | Grinnell Bay | (2) | 3,715 ± 140 | GX-9549 | Ward Inlet | (4) |
| 8,450 ± 190 | GX-8159 | Lewis Bay | (3) | 2,940 ± 145 | Beta-1705 | Grinnell Bay | (3) |
| 7,800 ± 150 | QC-905 | Burton Bay | (3) | 2,575 ± 140 | GX-8385 | Burton Bay B | (3) |
| 7,080 ± 175 | GX-8160 | Peterhead Inlet | (3) | 2,035 ± 70 | Beta-1087 | Burton Bay A | (6) |
| 6,830 ± 255 | GX-9257 | Ward Inlet | (4) | 1,460 ± 70 | Beta-1622 | Burton Bay A | (6) |
| 6,750 ± 170 | GSC-464 | Apex Hill | (5) | 1,345 ± 135 | GX-8384 | Burton Bay B | (3) |
| | | | | 955 ± 130 | GX-8380 | Peterhead Inlet | (3) |
| | | | | 905 ± 100 | Beta-1086 | Burton Bay A | (6) |
| | | | | 475 ± 125 | GX-8381 | Peterhead Inlet | (3) |
| | | | | 420 ± 125 | GX-8382 | Burton Bay B | (3) |

^a Unadjusted dates, except for C-13 corrections in the case of GSC and Geochron (GX) dates. Error limits are $+/- 2\sigma$ for GSC dates and $+/- 1\sigma$ for the others.

^b (1) Miller, 1980
(2) Miller, 1979
(3) Andrews, 1983
(4) This study
(5) Blake, 1966
(6) Short and Jacobs, 1982

by at least 4500 BP. The timing of the disappearance of the residual ice sheet is unclear. DYKE (1979) showed that the ice margin still reached the head of Cumberland Sound as late as 5700 BP, so the possibility exists that some ice was still present in the interior for at least 2000 years after the head of Frobisher Bay became clear.

MILLER (1980) identified the position of an earlier late Foxe recessional moraine on the outer part of Hall Peninsula which he connected with a prominent moraine that extends across the middle of Hall Peninsula to Cumberland Sound (Fig. 1) and which he named the Hall Moraine in contradistinction to the Frobisher Bay Moraine recognized by BLAKE (1966) at the head of Frobisher Bay. MILLER (1980) dated the Hall Advance at or before 11,000 BP, *i.e.* much earlier than the Cockburn Substage, and deposits outside the Hall Moraine on Loks Land at ca. 42,000 BP (Fig. 1 and Table I). He traced the subsequent retreat of the ice up Frobisher Bay and established for the north shore of Frobisher Bay the elevations of the marine transgression (marine limits) that followed the retreat of the ice.

SQUIRES (1984) undertook a detailed study of the formation of the Frobisher Bay moraine complex and associated sea level changes between the outermost moraine ridge on Lewis Bay (Fig. 1) and the head of Frobisher Bay. At the same time, efforts were begun by the authors to establish a detailed chronology of post-glacial vegetation and climate in the area from stratigraphic evidence. This paper describes the results of these combined investigations.

DEGLACIATION AND EMERGENCE

MILLER (1980) had inferred the limit of the Hall Advance in lower Frobisher Bay both from morainal evidence and from a distinct break in the degree of rock and soil weathering that is encountered at an elevation of 420 m aht¹. From marine deposits and washing limits he was able to plot marine limit elevations projected along the axis of the bay (Fig. 2a), with radiocarbon dating control provided by marine molluscs (Figs. 1 and 2 and Table I). A break in the upward trend in marine limit elevations at about 200 km down the bay was interpreted as reflecting the halt of the ice at the Hall Moraine. BLAKE (1966) had already established the existence of an even more abrupt reversal in the trend of marine limit elevations in the upper part of the bay, corresponding to the Frobisher Bay Moraine.

Subsequent field investigations have added more information on marine limit elevations in the upper part of Frobisher Bay (Fig. 2a). In the middle reaches, in the vicinity of Ward Inlet, the picture is not entirely clear because a well-defined marine limit has not been found.

1. Metres above high tide. Elevations were obtained using a surveying altimeter or a hand level starting at the level of the most recent high tide. The mean tidal amplitude in Frobisher Bay ranges from 4.0 m near the mouth to 7.8 m at the head (Government of Canada, *Canadian Tide and Current Tables 1984*, Vol. 4., Ottawa).

As evidenced by the relatively thin till cover east of Ward Inlet it is apparent that the retreat of the Frobisher Bay glacier from the Hall Moraine after ca. 11,000 BP to near the head of the bay was relatively rapid, covering 150 km in about 2000 years. A time-distance plot (Fig. 2b) shows this and emphasizes the more than 1000 year-long stillstand of the ice that resulted in the formation of the Frobisher Bay Moraine.

This moraine complex, lying between the head of the bay and Ward Inlet (Fig. 1), spans a period between 8450 BP and 7080 BP. Five main phases of moraine formation have been recognized and dated at 8450, 7800, 7510, >7340, and >7080 BP from their association with radiocarbon-dated marine deposits (Fig. 1 and Table I.) These represent stillstands or, where one moraine ridge is seen to override an outer, earlier one, as occurred around 7500 BP, a slight readvance. A clearly marked series of marine limits can be seen within the Frobisher Bay moraine system (Fig. 3). Rapid emergence (10.5 cm yr⁻¹) occurred between 8450 and 7800 BP as the ice retreated across Burton Bay (Fig. 1), with a slower rate (3 cm yr⁻¹) thereafter. Major episodes of sedimentation occurred in the valleys and estuaries around the head of Frobisher Bay during this period (McCANN *et al.*, 1981). The ice margin finally retreated beyond the head of the bay after 7080 BP. Two later periods of shoreline formation evidenced by terraces within the Burton Bay area and elsewhere near the head of Frobisher Bay may represent additional stillstands of the inland ice. Morainal evidence inland from the head of the bay is abundant and, although no dates have been obtained to supplement the 4460 BP date reported by BLAKE (1966) from Amadjuak Lake (Table I), the final wasting away of the ice appears to have been prolonged over some 2000 years.

Generally, the dates obtained on raised marine features in the vicinity of the Frobisher Bay Moraine have represented a single level in a given feature. This and the complexity of the deglacial chronology have made it impossible to construct individual curves of emergence (relative sea level) for locations along the bay. A compromise is represented by a single composite curve constructed for the upper part of the bay and incorporating all relevant radiocarbon dates (Fig. 4). The curve was drawn as an envelope of individual site curves that were constructed using the simple exponential equation obtained by ANDREWS (1970) from studies elsewhere in Baffin Island. Uncertainties in the sea levels associated with dated mollusks found *in situ* in marine deposits as well as the normal dating errors have been accommodated in Figure 4. In spite of the lack of precision in the resulting sea level curve, it is nonetheless a useful tool for interpreting early Holocene events in upper Frobisher Bay.

TERRESTRIAL SEDIMENTS AND POLLEN STRATIGRAPHY

Terrestrial sediments have been sampled from cliff exposures at five locations between outer Hall Peninsula and the head of Frobisher Bay: Cornelius Grinnell Bay, Ward Inlet, Burton Bay (two sites), and Peterhead Inlet (Fig. 1). These "peat" sections invariably contain buried O-horizons, interbedded with poorly sorted aeolian and niveo-aeolian sands

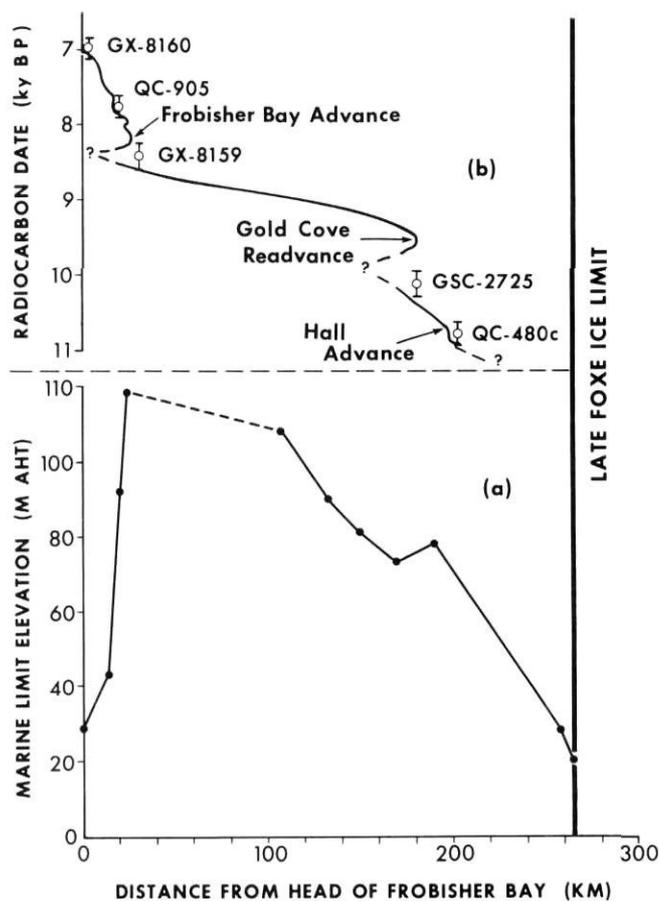


FIGURE 2. (a) Marine limit elevations after MILLER (1980), with revisions, and (b) time-distance plot of retreat of ice up Frobisher Bay.

(a) Altitudes des limites marines selon MILLER (1980), corrections comprises, et (b) courbes spatio-temporelles du retrait glaciaire dans la partie supérieure de la baie de Frobisher.

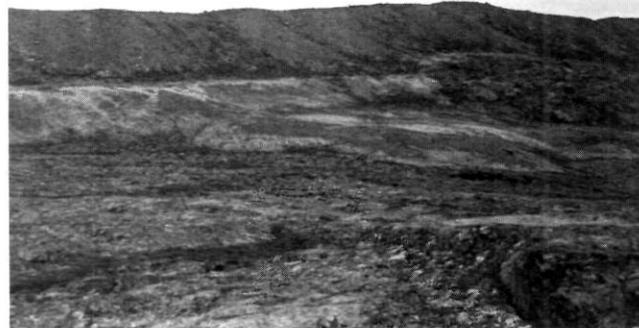


FIGURE 3. Outermost moraine ridge of Frobisher Bay moraine complex, west of Lewis Bay; 90 m aht washing limit is clearly visible on this distal (east) side.

Crête morainique à l'extrémité du complexe morainique de la baie de Frobisher, à l'ouest de la baie de Lewis; la limite de délavage de 90 m (au-dessus du niveau des hautes marées) se distingue bien du côté distal (est) de la moraine.

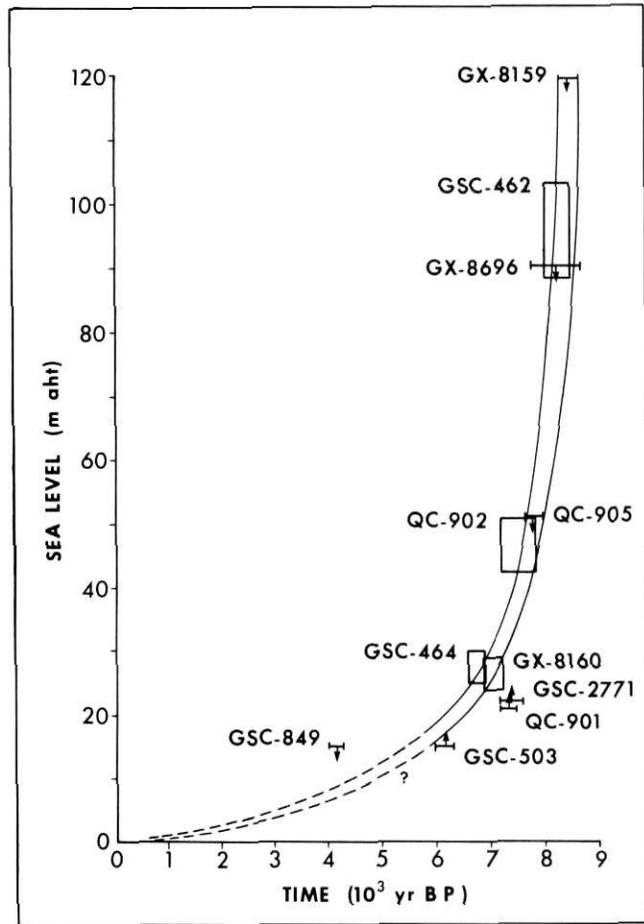


FIGURE 4. Generalized emergence curve for inner Frobisher Bay. Elevations are relative to present mean high tide. The width of the curve incorporates uncertainties in the radiocarbon dates and in the sea level elevations inferred from marine shells.

Courbe généralisée de l'émersion de l'intérieur de la baie de Frobisher. Les altitudes se réfèrent aux marées hautes moyennes actuelles. La largeur de la courbe s'explique par des incertitudes quant aux dates au radiocarbone et aux altitudes du niveau marin obtenues par les coquillages.

TABLE II

Organic carbon in dated samples from two cliff sections, Frobisher Bay*

| | Depth (cm) | Organic carbon content (%) | Date (yr. BP) | Lab. no. |
|-----------------|------------|----------------------------|---------------|----------|
| Burton Bay "B" | | | | |
| | 75-80 | 3.52 | 420 ± 125 | GX-8382 |
| | 102-108 | 4.21 | 905 ± 130 | GX-8383 |
| | 123-125 | 7.81 | 1345 ± 135 | GX-8384 |
| | 135-138 | 12.02 | 2575 ± 140 | GX-8385 |
| Peterhead Inlet | | | | |
| | 62-68 | 2.49 | 475 ± 125 | GX-8381 |
| | 88-90 | 4.64 | 955 ± 130 | GX-8380 |

* Organic carbon determinations were made using the Walkley-Black potassium dichromate method.

(ANDREWS *et al.*, 1979). All sections are from similar depositional environments, *i.e.* soils formed on fluvial sands which in turn overlie now-raised marine sands and silts. Radiocarbon dates on the organic layers (Table I) in the sections provide the necessary dating control for the stratigraphy of the sections.

Dates on the lowest organic layer on each section reveal a progression toward younger age as one moves inland from outer Hall Peninsula toward the head of Frobisher Bay, following the direction of glacial recession. Thus, in Grinnell Bay the earliest soil horizon (above a layer of organic fluvial detritus) dates at 5490 BP; in Ward Inlet, the earliest date on a frost-churned section is 3755 BP; in Burton Bay the base of a well-preserved section dates at 2575 BP; while in Peterhead Inlet the basal date is 955 BP (Fig. 1 and Table I). Although it is possible that earlier layers may have been removed by erosion, these results nonetheless suggest a substantial lag in the onset of peat accumulation following glacial-isostatic emergence of the surface of deposition. In two of the sections, large samples of the distinct organic horizons were taken in order to assess the percentage of organic matter (Table II). This reveals a trend toward declining organic matter production with time.

Detailed stratigraphy and pollen analysis were carried out on sections from Burton Bay and Grinnell Bay. The first of these, from site Burton Bay 'A', was already described by SHORT and JACOBS (1982) and the results are only summarized here. That record, covering the period 905 to 2035 BP, revealed a decline from an abundant *Betula-Salix* shrub tundra, indicative of a relatively warm, moist summer climate, to a vegetation dominated by Gramineae, indicating a cooler, drier period beginning about 1650 BP. Transfer functions applied to those pollen data suggest a decline in growing season temperatures of almost 2°C between the two intervals. As was discussed in that paper, modern pollen samples from Burton Bay show that present conditions are similar to those indicated in the earliest part of that record.

A second peat section was taken from the upper part of a raised delta exposure in Cornelius Grinnell Bay (Figs. 5 and 6). The upper 310 cm of the delta section (Fig. 7) is composed of interlaminated niveo-aeolian sand and sandy terrestrial peat. The organic content of the uppermost 110 cm was found to be extremely low, and this segment was not sampled for pollen. From 310-320 cm depth, a cryoturbated paleosol occurred which dated to 5490 ± 180 BP (Table I). The paleosol is developed in the upper part of a 3 m thick sequence of fluvial sands. Hence, the cryoturbation of the paleosol marks the change from an interval of soil formation to the niveo-aeolian conditions of the last 5500 years. Organic-rich partings within the fluvial sediments yielded the pollen spectra at 350, 362.5, and 425 cm depth. Detrital organics within a gravel lag at the base of the fluvial sand date the onset of fluvial sedimentation at 7285 ± 200 BP. This was probably soon after the glacial-isostatic emergence of the site, which was deglaciated after the deposition of late-Foxe glacial sediments in the area (MILLER, 1979, p. 27). Within the niveo-aeolian segment of the section (0-310 cm), the bulk of the peat-forming material is monocots (sedge and grass), but *Sphagnum* peat is dominant between 185 and 235 cm depth.



FIGURE 5. Raised (12 m aht) marine delta at head of Cornelius Grinnell Bay, outer Hall Peninsula.

Delta marin soulevé (12 m au-dessus du niveau des hautes marées), à l'extrémité de la baie de Cornelius Grinnell, aux confins de la péninsule de Hall.



FIGURE 6. Upper (terrestrial and fluvial) section of Grinnell Bay delta exposure. The interface between the cryoturbated paleosol and the fluvial sands is at the level of Dr. Miller's knees.

Partie supérieure (terrestre et fluviale) de la coupe du delta de la baie de Grinnell. Le contact entre le paléosol cryoturubé et les sables fluviaux se situe au niveau des genoux du Dr. Miller.

The pollen samples were prepared by standard techniques (FAEGRI and IVERSEN, 1975), with the addition of a gravity separation of sand from the finer materials, including pollen. All pollen sums were over 200 grains (excluding Cyperaceae, *Sphagnum*, and undeterminable grains), and counting was done at 500x magnification. *Eucalyptus* tablets were added so that pollen concentration could be calculated (STOCKMARR, 1971). The resulting concentrations are shown in Figure 8a.

Figure 8b shows the percentage pollen diagram for the section. Although the diagram is uniformly dominated by Gramineae, it is divisible into three zones:

- Zone 1: 245 – 425 cm. In this zone the Caryophyllaceae (pinks) though not dominant, are at their highest levels.
- Zone 2: 150 – 245 cm. *Salix* (willow) reaches its highest percentages and Caryophyllaceae have declined to very small values.
- Zone 3: 110 – 150 cm. Ericales (heaths) and *Artemisia* (wormwood) reach maxima and *Salix* declines.

The importance of the Caryophyllaceae in Zone 1 is interpreted to reflect an open or patchy vegetation cover on the sandy delta surface. This resulted from the continuation of the climatic deterioration which caused the frost-disturbance of the soil at ca. 5500 BP. The decline of the Caryophyllaceae and rise of *Salix* which mark the Zone 1/Zone 2 boundary reflect the stabilization of the delta surface by a more complete vegetation cover beginning ca. 4500 BP. The peat is more *Sphagnum* — rich and less sandy within Zone 2, also supporting this interpretation. The better vegetation cover of Zone 2 (4500 – 3000 BP) probably resulted from a temporary amelioration of climate. Zone 3 vegetation had fewer willows and more

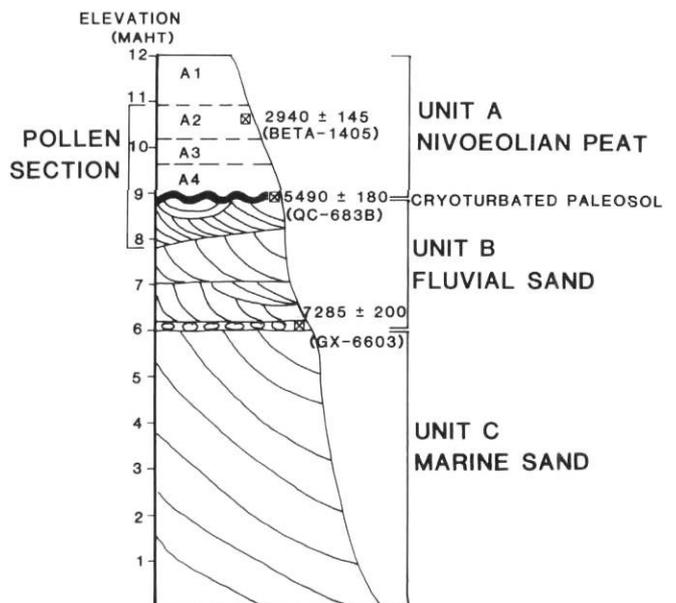


FIGURE 7. Generalized stratigraphy of Grinnell Bay cliff section, with divisions as discussed in text.

Stratigraphie générale de la coupe effectuée dans la falaise de la baie de Grinnell. Les divisions sont expliquées dans le texte.

Artemisia and *Ericales*. *Artemisia* suggests a dry, poorly vegetated, sandy surface, while the abundance of *Ericales* (which includes *Empetrum*) supports the interpretation that the delta surface was drier than it was in Zone 2. Hence, the Zone 2/Zone 3 boundary probably reflects renewed climatic deterioration, a supposition that is supported by the increasingly inorganic nature of the strata above 110 cm depth. The present surface is unstable, sandy, and undergoing deflation. The vegetation consists mainly of Gramineae (especially *Hierochloa alpina*) and Caryophyllaceae, including massive *Silene acaulis*. It appears that recovery since the last cool phase has not yet occurred here as it has in Burton Bay. The Grinnell Bay

site has thus apparently lain beyond the limit of low arctic tundra, or at least *Betula glandulosa*, since at least 5500 BP.

THE HOLOCENE CHRONOLOGY

The main elements in the deglaciation and emergence of Frobisher Bay are now known. This study has added to the earlier works of BLAKE (1966) and MILLER (1980) by contributing further detail concerning events at the head of the bay, including a new minimum date for deglaciation there of 7080 BP, superseding BLAKE'S (1966) date of 6750 BP (Table I). That sequence of events comprises the early phase

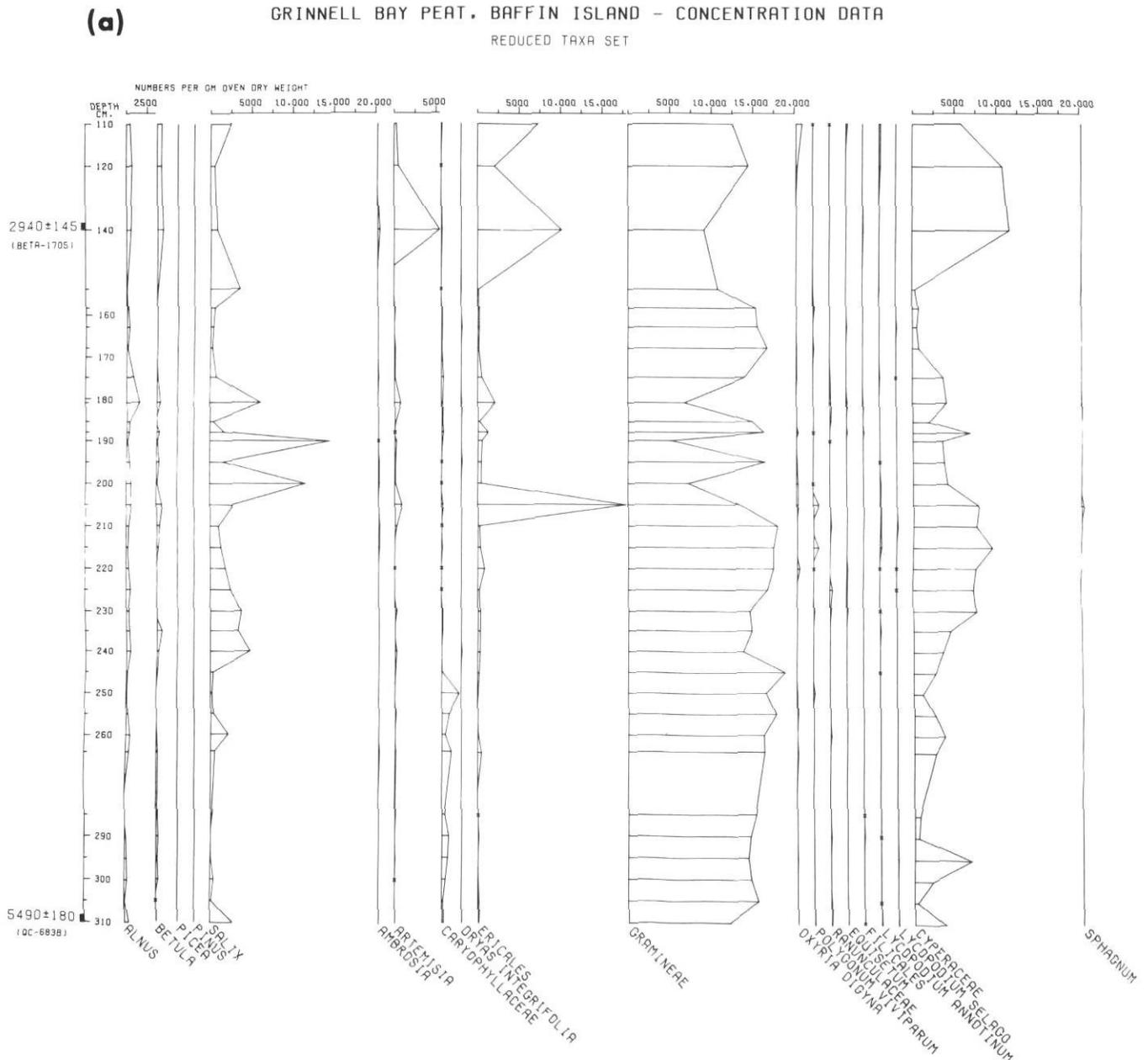


FIGURE 8. Pollen diagrams from Grinnell Bay section showing (a) pollen concentrations and (b) relative abundances.

Diagrammes polliniques de la coupe de la baie de Grinnell: (a) concentrations polliniques; (b) pourcentages polliniques.

of the Holocene chronology of the region. The initiation of organic soil development, earliest in outer Hall Peninsula and progressively later toward the head of Frobisher Bay led to preservation of the stratigraphic record on which the sequence of vegetation and climate of the later Holocene is based. The results of these two complementary lines of research are summarized in Table III.

No stratigraphic evidence is available for the region between ca. 400 BP and the present. However, a study conducted by DOWDESWELL (1984) on moraines of the Grinnell Glacier, the more northerly of two plateau ice sheets on the southeast side of Frobisher Bay (Fig. 1), has revealed the nature of glacio-climatic events during that most recent interval. He found from lichenometric dating that a suite of Neoglacial moraines lying within 100 m of the late Foxe moraines of this glacier were formed between 60 and 130 years ago. Similarly youthful Neoglacial moraines have been observed by MULLER (1980) adjacent to the Terra Nivea Glacier, southeast of the Grinnell Glacier, and by ourselves on moraines before the plateau ice sheets on outer Hall Peninsula. These moraines are all interpreted as being lag-correlative with a Little Ice Age cooling in the region (*cf.* MILLER, 1973).

The last 50 years encompass the period of instrumental record for the Baffin Island region. BRADLEY (1973) found that during the period of the 1940's and 1950's summer temperatures were generally warmer than present in the Baffin Island region, but in the mid-1960's a cooling trend became evident. It is likely that the present vegetation and recent pollen rain of the region, as discussed by SHORT and JACOBS (1982) and JACOBS *et al.* (1985), are more a response to the preceding warm interval than to the cooler climate of the last two decades.

DISCUSSION

Our study of the deglaciation of Frobisher Bay has focussed on Hall Peninsula, on the north side of the bay. For the south side (Meta Incognita Peninsula), BLAKE (1966) had found a marine limit elevation of 88 m aht associated with what is presumably the continuation of the outermost moraine of the Frobisher Bay system which we have mapped in Lewis Bay (Fig. 1). BLAKE (1966, p. 5) dates that feature at 8230 ± 240 BP (GSC-462), which is consistent with our dates for the Lewis Bay moraine. More recent studies on the south shore

TABLE III

Significant periods in the Holocene chronology of the Frobisher Bay area

| <i>Period</i> | <i>Relative Character of Glacio-climatic Interval</i> | <i>Period</i> | <i>Relative Character of Glacio-climatic Interval</i> |
|------------------|---|----------------|--|
| 11,000-10,000 BP | Stillstand or readvance of ice in lower Frobisher Bay and formation of Hall Moraine. | 1800-1500 BP | Colder and drier, indicated by a pronounced shift in pollen spectra after 1800 BP to Gramineae — dominated assemblage and an intensification of niveo-aeolian sedimentation. Transfer functions suggest growing season temperatures 1-2°C below those of 20-50 BP. |
| 10,000-8500 BP | Rapid retreat of ice up Frobisher Bay, covering 150 km in the interval. | 1400-1300 BP | Warmer and wetter. Peat growth at lesser rate than before 1800 BP but above that of 900 BP. No change in pollen spectra. |
| 8500-7000? BP | Stillstand and minor readvances of Frobisher Bay lobe of South Baffin ice sheet (Cockburn Substage). Relative sea level near the head of the bay decreases by ca. 100 m from the 120 mht maximum regional marine limit. | 1200?-1100? BP | Cooler and drier. Renewed niveo-aeolian sedimentation. No significant change in pollen spectra. |
| 7000-6000 BP | Ice retreats inland from head of bay. Major glaciofluvial sedimentation episode in coastal area. | 1000?-800? BP | Warmer and wetter as evidenced by peat growth near 900 BP. Pollen record shows no significant increase in low arctic taxa, suggesting warming was modest and of short duration. |
| ? -5500 BP | Presumed local post-glacial climatic optimum in outer Frobisher Bay as inferred from soil development. Ice still present inland of head of bay. | 800-600? BP | Cooler and Drier. Reduced organic content in terrestrial sediments. |
| 5500?-4500 BP | Climatic deterioration, as evidenced by cryoturbation of older basal organic stratum in Grinnell Bay section. | 500-300? BP | Warmer and probably wetter summers, as evidenced by peat growth centred at 400-500 BP. |
| 4500?-3000? BP | Warmer and wetter in outer Frobisher Bay but warming less evident in the inner bay area. Deglaciation of interior complete. | > 130 BP-60 BP | Neoglaciation. Advance of cirque and plateau glaciers in Hall and Meta Incognita Peninsulas to within 100 m of late Foxe Moraines. Widespread niveo-aeolian sedimentation, indicating colder, drier conditions. |
| 3000?-2800? BP | Somewhat cooler and drier in outer Frobisher Bay. No buried organic soils have been found from this or any earlier periods in sections from inner bay. | 50-20 BP | Warmer interval correlative with regional and hemispheric trends. Temperatures approaching levels of mid-Holocene warm interval. |
| 2700?-1800 BP | Warm and wet. Substantial peat growth in inner Frobisher Bay. Pollen assemblages indicate abundant shrub-tundra. Conditions less favourable in outer bay area. | Last 20 years | Instrumental records reveal a trend toward cooler summers and greater seasonal extremes. |

by COLVILL (1982) and LIND (1983) tend to confirm that events were synchronous on both shores in the upper part of the bay; however, work in the outer part of Meta Incognita Peninsula by STRAVERS and MILLER (1984) suggests that greater differences are to be found between events on north and south shores in the lower part of Frobisher Bay. Additional research is needed to provide a more complete picture of the late Foxe deglaciation in Frobisher Bay and southern Baffin Island. The ice retreated rapidly between the Hall Moraine and the Frobisher Bay Moraine, and no intermediate moraines were apparently deposited, although MILLER (1978) has identified a prominent strandline dated between 9200 and 9700 BP in lower Frobisher Bay. Also, further research is needed to clarify events surrounding the final disintegration of the ice sheet inland from the head of Frobisher Bay, particularly how late the ice remained and how its presence in the interior affected the local climate and vegetation there.

Part of our paleoclimatic reconstruction is based on the dating and interpretation of buried organic soils, the assumption being that peat growth in the region is initiated under warmer, wetter conditions and ceases with the onset of a cool, dry phase. MILLER (1973) applied this approach in his study of events in northern Cumberland Peninsula in eastern Baffin Island. A series of dated organics indicated a warming before 1670 BP which lasted until sometime after 1000 BP, followed by a colder interval 850 – 730 BP, warmer again from 680 – 430 BP, colder from 350 – 160 BP, followed by a warming into the early part of this century. Lichenometric dating of Neoglacial moraines in the area revealed a close correspondence between glacial activity and the climatic trends inferred from the peats. This chronology was confirmed for all of Cumberland peninsula by DYKE *et al.* (1982) and is in general agreement with that for Frobisher Bay (Table III), except for the warmer interval ca. 1400 – 1300 BP which does not appear in the former record.

When interpreting the pollen record of peat, the question of the spatial scale of environmental change must be dealt with. Locally derived pollen tends to dominate peat pollen spectra; hence, vegetation changes interpreted from these spectra may have little significance on a regional scale. One method for testing the spatial extent of vegetation changes is to examine other pollen records for the region. The Holocene pollen records from Baffin Island have recently been summarized by SHORT *et al.* (1985) and MUDIE and SHORT (1985). Niveo-aeolian peats began accumulating in other localities about 5500 BP: 1) Near Clyde, basal peat from the Scott Inlet aeolian sands (and peat) (MILLER *et al.*, 1977) is dated at 5370 ± 130 BP (GIF-3866) (MILLER, 1979); 2) Near Pangnirtung, at the Pass Head peat site, basal peat is dated at 5980 ± 95 BP (SI-2070) (SHORT and ANDREWS, 1980). The Scott Inlet aeolian sands at Clyde usually overlie a buried and cryoturbated paleosol (MODE, 1980), suggesting a similar environmental change to that which is recorded in the Grinnell Bay sections. The pollen record of the Scott Inlet aeolian sands is from only seven spectra which probably span a short period around 4260 ± 475 BP (DIC-378); this record shows an increasing proportion of *Salix* through the period (MILLER, *et al.*, 1977). The Pass Head peat records a general increase

in *Salix* percentage between about 5500 – 4500 BP, the entire period covered by the pollen diagram (SHORT and ANDREWS, 1980). The shorter time spans of these two records make it difficult to compare to the Grinnell Bay section.

Covering longer time spans are pollen stratigraphies from two lake sediment cores, Iglutalik Lake near Pangnirtung and Patricia Bay Lake near Clyde (SHORT *et al.*, 1985), and one deep sea core from outer Frobisher Bay (MUDIE and SHORT, 1985). At Iglutalik Lake the vegetation prior to about 5800 BP was probably herbaceous tundra; between 5800 and 2700 BP, birch and willow shrubs became more abundant; and, finally, herbaceous vegetation became more abundant again after 2700 BP. The Patricia Bay Lake pollen record reflects the existence of birch-dominated shrubby vegetation from 6800 to 5600 BP, herbaceous vegetation from 5600 to 4500 BP, willow-heath shrub tundra from 4500 to 3000 BP, and willow-dominated tundra since 3000 BP. The latter two phases of the vegetational history of Patricia Bay Lake are similar to those of the Grinnell Bay peat record. Otherwise, however, there is a general lack of agreement among these pollen records (SHORT *et al.*, 1985), but the reasons for the disagreement are unclear.

The *Betula* (birch) maximum in the Frobisher Bay deep sea core (MUDIE and SHORT, 1985) occurs at about 4000 to 4500 BP, and is followed by a decline to very low birch percentages about 2500 BP and then by a secondary birch maximum about 1500 BP. This sequence of changes in birch abundance is quite similar to the sequence of local vegetation change we have proposed here. The Frobisher Bay deep sea core was collected from within the same region as our peat sections were; hence, these similarities lend support to our interpretations.

ANDREWS (1982) has divided the Holocene Series in arctic Canada into five substages. Late Holocene time begins at 5000 BP at the end of the Kangilo Chron (Substage) and the beginning of the Iglutalik Chron. From 2500 BP to present is the Windy Lake Chron. Summarizing transfer function paleotemperatures from Baffin Island, ANDREWS (1982) notes that the Holocene thermal maximum probably occurred in the latter part of the Kangilo Substage. The only clear conflict between our data and ANDREWS' (1982) summary is the warm period around 2000 BP at Burton Bay, which he does not report.

Terrestrial sediment exposures of good stratigraphic quality such as those described here for Grinnell Bay and Burton Bay are not common in southern Baffin Island. Sediment cores taken from small lakes in the region provide another source of pollen data which, because preservation is not dependent upon the rate of organic soils production as in the case of the terrestrial deposits, promises to provide a more continuous and complete paleobotanical record. Lake sediment cores have been taken from "Easy" Lake near Burton Bay and "Hikwa" Lake west of Ward Inlet and are now being analyzed. It is hoped that additional cores can be obtained from lakes located outside the limit of the Hall Advance, as well as inland from the head of Frobisher Bay. These will provide the basis for a more complete paleoenvironmental

reconstruction for the Frobisher Bay area and hopefully serve to reconcile some of the differences among pollen records from across the Baffin Island region.

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