GEOLOGICAL SURVEY OF CANADA
COMMISSION GÉOLOGIQUE DU CANADA

MEMOIR 403

QUATERNARY GEOLOGY OF CUMBERLAND PENINSULA, BAFFIN ISLAND, DISTRICT OF FRANKLIN

ARTHUR S. DYKE
JOHN T. ANDREWS
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Available in Canada through

authorized bookstore agents
and other bookstores

or by mail from

Canadian Government Publishing Centre
Supply and Services Canada
Hull, Québec, Canada K1A 0S9

and from

Geological Survey of Canada
601 Booth Street
Ottawa, Canada K1A 0E8

A deposit copy of this publication is also available
for reference in public libraries across Canada

Cat. No. M46-403E Canada: $7.50
ISBN 0-660-11182-9 Other countries: $9.00

Price subject to change without notice

Authors' Address

John T. Andrews and
Gifford H. Miller
Institute of Arctic and Alpine Research,
University of Colorado,
Boulder, Colorado, U.S.A.

Critical Reader

D.A. Hodgson

Original manuscript submitted: 1978 - 11 - 16
Approved for publication: 1979 - 06 - 28

Preface

Cumberland Peninsula was brought to public attention with the establishment in 1973 of Auyuittuq National Park, our first truly arctic park. The focus of the park is the 6000 km^2 Penny Ice Cap and numerous smaller ice caps and cirque glaciers. This study of the surficial materials and glacial history of the park and surrounding area was done at the request of Parks Canada to provide basic information needed for land use planning and for the preparation of interpretive presentations of the geology of the park. It is also part of the Geological Survey of Canada's systematic mapping of the Canadian landmass.

The long and complex record of glacial, climatic, and sea level variations visible on Cumberland Peninsula make the area a valuable reference area for eastern Arctic Quaternary studies, as well as one of considerable interest to the naturalist, mountain-climber, and all others concerned with wilderness areas.

D.J. McLaren
Director General
Geological Survey of Canada

Ottawa, February 1980

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QUATERNARY GEOLOGY OF CUMBERLAND PENINSULA, BAFFIN ISLAND, DISTRICT OF FRANKLIN

Abstract

Cumberland Peninsula was formed as a horst during Middle Eocene time, following separation of Canada from Greenland. Earlier two erosional planation surfaces had developed. The younger surface penetrates the older along valleys, most of which are oriented along lines of structural weakness.

The peninsula is heavily glacierized and is dominated by large features of glacial erosion. These have been produced by continental ice sheets, by local ice caps, and by alpine glacier complexes. Next to glacier ice, the most widespread surficial materials are granitic bedrock and till. Raised marine, proglacial lacustrine, alluvial, colluvial, and organic sediments cover small areas.

Most, if not all, of the peninsula was covered by ice some time before the Foxe (last) glaciation. Sediments deposited during and before the last interglaciation outcrop in cliff sections along the northeast coast. The Foxe glacial limit is marked by the outermost distinct lateral moraines and meltwater channels. During the early Foxe stadial maximum, ice covered most of the peninsula, but upland plateaus between the outer reaches of fiords and many alpine peaks remained as nunataks. Laurentide ice, presumably flowing eastward from Foxe Basin, filled the inner third of Cumberland Sound and overwhelmed the Penny Ice Cap. The fretted mountains east of Pangnirtung Pass, however, were dominated by alpine glaciers.

Numerous moraines lie between the early and late Foxe stadial maximum positions, which possibly testifies to a complex record of middle Foxe events. Shells from marine sediments deposited during or after recession from the early Foxe maximum yield "old" radiocarbon ages and ^{230}*Th ages between 48 000 and 86 000 years.*

The late Foxe glacial limit is marked by moraines that are associated with ice-marginal raised marine deltas that have been dated at 8200 to 9000 years old. At that time Laurentide ice flowed eastward into the fiords of Home Bay and Cumberland Sound and coalesced with the western margin of the Penny Ice Cap. East of the Laurentide limit, local ice caps and cirque glaciers were somewhat larger than they are today, but large areas remained ice free.

Recession from the late Foxe moraines began about 8700 years ago. Local glaciers retreated rapidly to or behind their present margins by 7000 years ago, while Laurentide ice retreated much more slowly, finally leaving the heads of fiords in inner Cumberland Sound about 5700 years ago and Home Bay about 4500 years ago. Separation of western Penny and Laurentide ice occurred after 5000 years ago and was followed by a readvance of the former. Lichenometrically dated moraines and radiocarbon-dated peat and eolian sand sections reveal a late Holocene climate varying from cold/dry at 2100, 900, and 400 to 250 years ago to warm/wet at 1700 to 1100, 600, and 50 to 0 years B.P.

During the Holocene, the western part of the peninsula emerged while the eastern part submerged.

Résumé

La péninsule Cumberland s'est formée comme un horst à l'Eocène moyen, après la séparation du Canada et du Groẽnland. Auparavant, deux surfaces d'aplanissement s'étaient développées. La surface jeune pénètre la surface ancienne le long des rivières, dont la plupart sont orientées le long de lignes structuralement faibles.

La péninsule est très englacée et dominée par des traits caractéristiques importants de l'érosion glaciaire. Ces traits ont été produits par des nappes glaciaires continentales, des calottes glaciaires locales et des complexes glaciaires alpins. Après les glaces de glacier, les matériaux de surface les plus répandus sont les granites du socle et les tills. Des sédiments marins, lacustres proglaciaires, alluviaux, colluviaux et organiques soulevés, couvrent de petites régions.

La plus grande partie et peut être même toute la péninsule était couverte de glace juste avant la glaciation de Foxe (la dernière). Les sédiments déposés pendant et avant la dernière interglaciation, affleurent dans les falaises le long de la côte nord-est. La limite de la glaciation de Foxe est marquée par les moraines latérales distinctes les plus extérieures et par des chenaux d'eau de fonte. Pendant le maximum stadiaire du début de la glaciation de Foxe, la glace couvre la plus grande partie de la péninsule mais, les plateaux relativement élevés, situés entre les fjords et beaucoup de pics alpins sont restés des nunataks. La nappe glaciaire Laurentide s'écoulant probablement vers l'est à partir du bassin de Foxe, a rempli le tiers interne de la baie Cumberland et a envahi la calotte de glace Penny. Cependant, les montagnes érodées, sitées à l'est de la passe de Pangnirtung, étaient dominées par des glaciers alpins.

On trouve de nombreuses moraines entre les positions maximales stadiaires du début et de la fin de la glaciation de Foxe, ce qui, probablement, témoigne d'événements complexes du Foxe moyen. Les coquillages provenant des sédiments marins déposés pendant ou après le retrait à partir de l'avance maximale du début du Foxe, présentent une datation "ancienne" au radiocarbone et une datation au ^{230}Th entre 48 000 et 86 000 ans.

La dernière limite glaciaire du Foxe est marquée par des moraines qui sont associées avec des deltas marins soulevés, appartenant à des fronts de glace, dont l'âge est de 8 200 à 9 000 ans. À cette période, la nappe glaciaire Laurentide s'écoule vers l'est dans les fjords des baies Home et Cumberland puis se joint à la marge occidentale de la calotte de glace Penny. À l'est de la limite Laurentide, les calottes glaciaires et les glaciers de cirque locaux étaient relativement plus grands que ceux d'aujourd'hui, mais de vastes régions n'étaient pas couvertes de glace.

Le retrait à partir des moraines du Foxe terminal a commencé il y a environ 8 700 ans. Les glaciers locaux se sont retirés rapidement jusqu'aux fronts actuels ou derrière ces fronts, il y a 7 000 ans, alors que la nappe glaciaire Laurentide s'est retirée beaucoup plus lentement, laissant finalement les fonds de fjords de la baie Cumberland il y a environ 5 700 ans et de la baie Home il y a environ 4 500 ans. La séparation des nappes glaciaires Penny et Laurentide s'est produite après, il y a 5 000 ans et a été suivie d'une nouvelle avancée de la première. Des moraines datées à l'aide de lichens et de la tourbe datée au radiocarbone ainsi que des coupes dans des sables éoliens ont révélé un climat de la fin de l'Holocène qui varie de froid-sec il y a 2 100, 900, et 400 à 250 ans, à chaud-humide il y a 1 700 à 1 100, 600 et 50 à 0 ans B.P.

Pendant l'Holocène, la partie ouest de la péninsule était émergée alors que la partie est était immergée.

INTRODUCTION

General

Cumberland Peninsula is part of the uplifted eastern rim of the Canadian Shield, and its highest part is 2100 m a.s.l. It is dominated by the 6000 km^2 Penny Ice Cap, hundreds of cirque and valley glaciers, and large features of glacial erosion (Fig. 1). North of the peninsula, in the Home Bay area, is a 100 km wide breach in the mountain rim; south of the peninsula is a similar topographic low that extends from Foxe Basin to Cumberland Sound.

This paper describes the physiography and surficial geology and summarizes the Quaternary history of the peninsula, primarily by presenting maps of ice coverage during various stades of the Foxe (last) Glaciation, the pattern of retreat from the last stadial maximum, and graphs of Holocene climatic variations. Readers are referred to published work for local details.

Previous Studies and Field Work

The Quaternary geology of the peninsula has been the subject of a large number of studies since 1967, but initial studies stemmed from the 1953 expedition of the Arctic Institute of North America (Thompson, 1954). Until 1973 work was concentrated in the area north and northeast of the Penny Ice Cap (Fig. 2) and was concerned mainly with the study of large lateral and end moraines, associated raised marine sediments, stratigraphy of coastal cliff sections, and delineation of surface weathering zones. Starting in 1973, Dyke studied the area southwest of the Penny Ice Cap, and Miller and Andrews each studied a major trough connecting fiords on the northern and southern sides of the peninsula. Dyke completed airphoto mapping of surficial materials and geomorphic features of all but the southeastern tip of the peninsula (Fig. 2; Map 1536A).

Mapping was done at the request of Parks Canada to provide a basic resource and interpretive document for the newly established Auyuittuq National Park. Available helicopter time was only sufficient for camp moves, so most field checking was done by foot and canoe. Camps were located at sites critical to interpreting the Quaternary history, so large segments of terrain were not traversed. Andrews and Miller provided field verification for areas north and east of Penny Ice Cap.

Climate

Summaries of temperature and precipitation data for four weather stations (Fig. 3) are presented in Table 1. The Broughton Island and Cape Dyer records cover roughly the same period. The Pangnirtung and Padloping Island records partly overlap but are from an earlier period. The data indicate that Pangnirtung has the highest mean annual temperature; winter temperatures are similar to those at other stations, but summer temperatures are appreciably

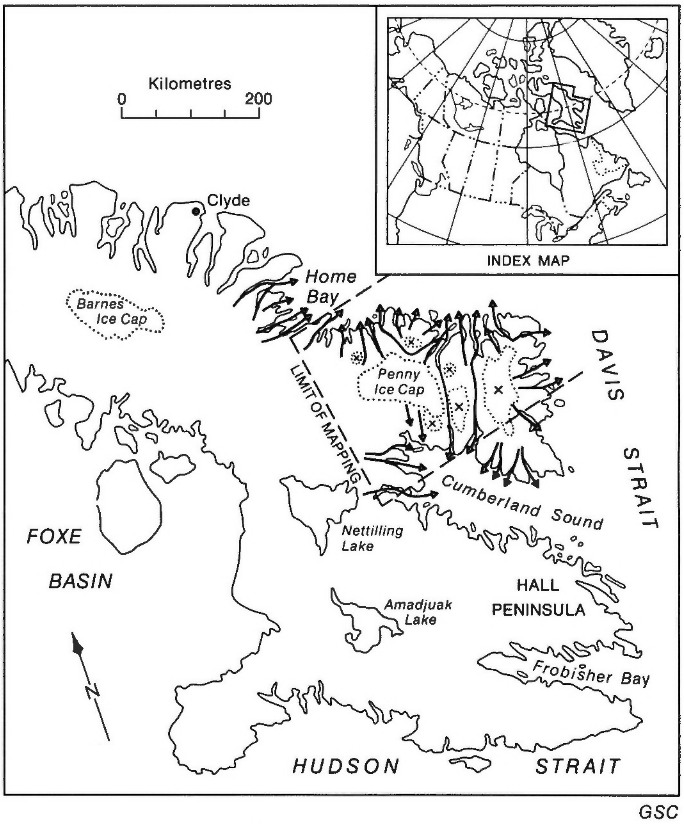

Figure 1. *Location of Baffin Island and names of features on and around the island; Xs mark areas of local glaciers on Cumberland Peninsula, and arrows show ice-flow directions based on fiord and trough orientation.*

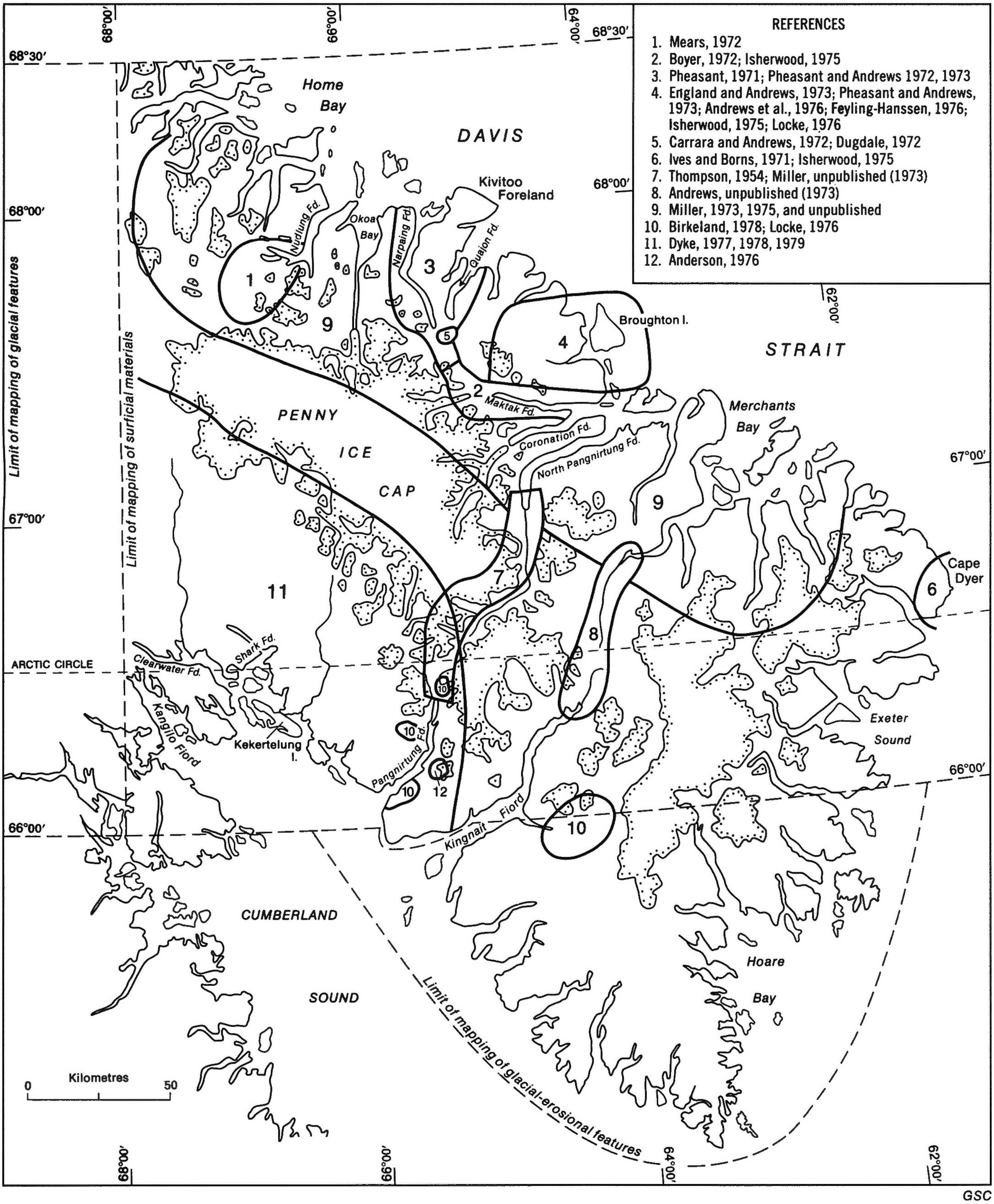

Figure 2. *Study area and locations of field areas of various workers*

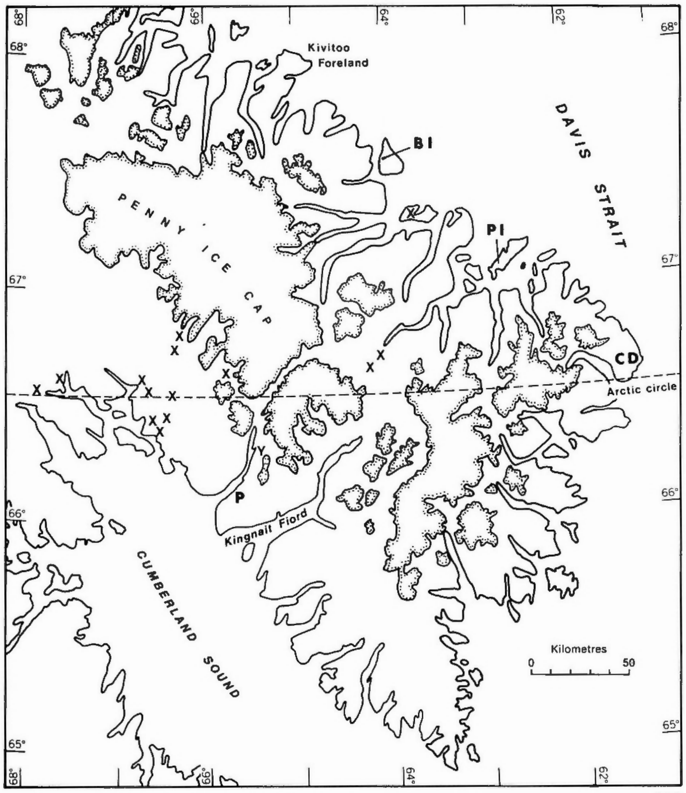

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Figure 3. *Sites at which dwarf birch has been observed (X) and locations of weather stations, BI, PI, CD, and P (see Table 1).*

higher. This comparison may be misleading, however, in light of Bradley's (1973) conclusion that ablation season temperatures (June, July, August) for Baffin Island were lower during the late 1960s than they had been for at least 30 years.

The precipitation data for Broughton Island, Padloping Island, and Pangnirtung are similar. But Bradley (1973) concluded that there have been marked increases in precipitation during the last 10 to 15 years, so the Padloping Island and Pangnirtung totals may be comparatively too low. Cape Dyer received more than twice the precipitation at Broughton Island during the same period.

Local climatic zonation due to relief and aspect is more pronounced than regional zonation, for the contrast between alpine icefield and lowland meadow is much greater than that between Pangnirtung and Broughton Island. The major regional climatic gradient documented by the data appears to be the east to west precipitation contrast; however, a north to south temperature gradient probably exists and may be reflected in the distribution of dwarf birch. As yet, only one small stand has been noted north of the Penny Ice Cap, whereas several have been noted to the south (Fig. 3.).

Glaciology

Glaciers and thin ice/firn patches are a major surficial cover on the peninsula. The Penny Ice Cap is about 700 m thick at its centre and covers nearly 6000 km^2. Glaciological work in the area has been limited. The initial impetus was the 1953 expedition of the Arctic Institute of North America to the Penny Ice Cap (Baird et al., 1953; Orvig, 1954; Ward and Baird, 1954); however, this early start has not been followed up. Research has been conducted on the mass and energy balance of Boas glacier, a small cirque glacier between the heads of Quajon and Narpaing fiords (Andrews et al., 1972; Jacobs et al., 1972; Weaver, 1975). Weaver's conclusion was that the variations in mass balance are controlled primarily by the amount of summer ablation; winter accumulation on the glacier was relatively constant, averaging about 30 cm H_2O, whereas ablation fluctuated significantly.

Isolines on the glaciation threshold and long-term steady state equilibrium line altitude (ELA) have been determined for the entire peninsula (Andrews and Miller, 1972), and for the Pangnirtung area in more detail (Anderson, 1976). Both snowlines rise inland. The glaciation threshold has a maximum elevation of 1300 m near the Penny Ice Cap and a minimum elevation of 700 m along the east coast.

Bedrock Geology

The bedrock of Cumberland Peninsula was mapped by the Geological Survey of Canada in 1972 but detailed reports and maps have not yet been published. Jackson and Taylor (1972) divided the peninsula into two general lithological regions, with Precambrian sediments metamorphosed to gneisses of amphibolite and granulite facies in the southeast, and Precambrian granites and quartz monzonites in the northwest. Most of our field work has been on the latter terrain. Tertiary basalts fringe the northeast corner of the peninsula.

The present form of Baffin Bay and surrounding lands is largely a product of rifting of Greenland from Canada and subsequent ocean floor spreading and associated faulting. The exact nature of these events is still unclear, but good summaries are given by Grant (1975), Hood and Bower (1975), and Beh (1975). Rifting started during the Upper Cretaceous and led to extrusion of the early Tertiary basalts. Further spreading during Middle Eocene time led to formation of large grabens and horsts, typified by Cumberland Sound and Cumberland Peninsula, respectively. Depths in excess of 1100 m have been recorded in Cumberland Sound, and down-dropped Paleozoic sediments in the graben are more than 8 km thick. Spreading appears to have ceased by the end of the Eocene (37 million years ago). Grant (1975, p. 149) stated that sediments at the mouth of Cumberland Sound have piercement structures, probably caused by evaporite or shale diapirs. These are possible petroleum reservoirs. Beh (1975, p. 453) stated "Though no direct information exists, the section beneath the continental shelf of western Baffin Bay and Davis Strait probably contains huge petroleum reserves". Exploration by petroleum companies has recently started in the Cumberland Sound area.

The Precambrian bedrock has a dense network of structural lineations that group into three distinct trends: (1) north-south, (2) northwest-southeast, and (3) east-west (Fig. 4). The structural planes marked by these lineations have strongly influenced geomorphic evolution of the peninsula; axes of almost all fiords and large valleys are parallel to them, and analyses of cirque orientations suggest that many of these features also are structurally controlled (Williams, 1972; Andrews and Dyke, 1974).

Acknowledgments

Much field work reported here has been supported by various grants to Andrews and Miller from the American National Science Foundation, particularly Grant EAR 74-01857 from the Geology Program. Dyke's work, while at the University of Colorado, was funded through contracts with Parks Canada, Department of Indian Affairs and Northern Development, but final mapping and writing were done at the Geological Survey of Canada. We are

Table 1. Climatic parameters for Cumberland Peninsula weather stations

Month	Average Monthly Temperatures (°C)				Average Monthly Precipitation (cm)			
	*BI	PI	CD	P	*BI	PI	CD	P
January	-24	-25	-22	-27	1.3	1.8	6.0	2.1
February	-25	-28	-23	-27	1.2	1.8	6.7	1.3
March	-24	-24	-22	-21	0.6	0.8	2.4	2.1
April	-17	-16	-21	-13	1.7	0.5	3.4	2.3
May	-7	-5	-5	-3	3.0	1.8	4.7	1.8
June	-1	2	1	3	3.1	2.3	4.5	2.5
July	5	6	6	8	1.2	3.0	3.3	3.8
August	4	5	4	7	2.2	1.8	6.4	5.8
September	2	1	-1	3	4.4	2.8	7.6	3.0
October	-8	-6	-7	-6	5.9	3.6	9.6	4.0
November	-15	-12	-15	-11	4.2	3.6	6.7	2.8
December	-21	-21	-15	-21	1.8	1.5	6.5	2.1
Average	-11.8	-9.3	-10	-8.0	30.6	25.3	67.8	33.6

*BI = Broughton Island. Data for August 1957 to December 1970. Station elevation 580 m.
PI = Padloping Island. Data for December 1941 to August 1956. Station elevation 40 m.
CD = Cape Dyer. Data for 1959 to 1970. Station elevation 375 m.
P = Pangnirtung. Data for November 1925 to 1950 (broken). Station elevation 13 m.

Stations are located on Figure 3.

Sources: BI and CD – Atmospheric Environment Service, Canada (1971)
BI and P – F.K. Hare in RAND (1963)

grateful to Dr. W. Blake, Jr., Geological Survey of Canada, and Dr. Jaan Terasmae, Brock University, for providing radiocarbon dates free of charge; to Dr. M. Stuiver of the University of Washington for his work on problems of dating "old" shells; to Dr. R. Stuckenrath of Smithsonian Radiocarbon Laboratory for his interest in problems of dating buried soils and peats of Holocene age; and to B.J. Szabo of the United States Geological Survey, Denver, who has given much attention to uranium-series dating some of our shell collections.

MAJOR LANDSCAPE ELEMENTS

Pre-Quaternary Landforms

Only Bird (1967) has attempted to systematically identify, describe, and explain those landforms of the Canadian Arctic that evolved prior to the Quaternary, and his discussion centres around surfaces of erosional planation. He recognized two major planation surfaces on Baffin Island, both of which are well represented on Cumberland Peninsula. The Penny Surface, the highest in the eastern arctic, is best preserved on Cumberland Peninsula, as its name implies. Subhorizontal denudation flats occur on peaks between 1800 and 2100 m a.s.l. and appear to be remnants of a once continuous surface that had local relief of 100 to 200 m.

The Baffin Surface is best preserved around the coast of the peninsula where it is marked by accordant summits at 600 m a.s.l. It rises to 1200 m in the central part of the peninsula where it penetrates the Penny Highlands along valleys.

The ages of formation and uplift of these surfaces are largely conjectural. Bird (1967) stated that the Baffin Surface formed after deposition of the Paleozoic limestones of southwestern Baffin Island. The last opportunity for significant regional uplifting appears to have been during the Middle Eocene.

No information is available on events or features that date between Eocene and Pleistocene, nor is there any indication of when the first glaciers formed; however, in the roughly 40 million years between formation of the peninsula as a horst and the Pleistocene glaciations, it is certain that rivers eroded the large valleys. In fact, penetration of the Baffin Surface into the Penny Surface along valleys suggests that valley formation began before the Eocene. The preglacial topography likely played the dominant role in determining the style of glaciation, and hence, the extent of glacial erosion.

Glacial-erosional Landforms

The glacial-erosional landforms were analyzed on the basis of gross landform geometry. Using airphotos and topographic maps, the main topographic elements, i.e., broad summits, horns (pyramidal peaks), glacierized cirques, non-glacierized cirques, and U-shaped troughs and fiords were plotted. This information was then grouped to form the following geomorphic mapping units: (1) plateau, (2) dissected plateau, (3) scalloped-dissected plateau, (4) scalloped coastal regions, and (5) fretted mountains (Fig. 5).

Plateau

The western part of the peninsula is classified as plateau (Fig. 6). The surface is gently rolling, large distinct summits are absent, hills rise only 30 to 60 m, and the land slopes gently towards the southwest. It constitutes part of the Baffin Surface (Bird, 1967). Glacial erosion has created a multitude of small lake basins in bedrock and has imparted a scoured and mildly fluted appearance. In the terminology of Sugden (1974) this is a landscape of "areal scouring".

Dissected Plateau

This unit has broad, gently rounded summits, separated by large U-shaped troughs or fiords (Fig. 7). Several summits support small ice caps and commonly are 300 to 600 m above the sea or above valley floors. The unit includes a strip of territory about 30 km wide adjacent to the northeast coast of Cumberland Sound, a narrower strip up the Davis Strait coast to Cape Dyer, and the area inland from Padle Fiord. Summits are included in the Baffin Surface (Bird, 1967), and the unit is similar to the landscape of "selective linear erosion" (Sugden, 1974).

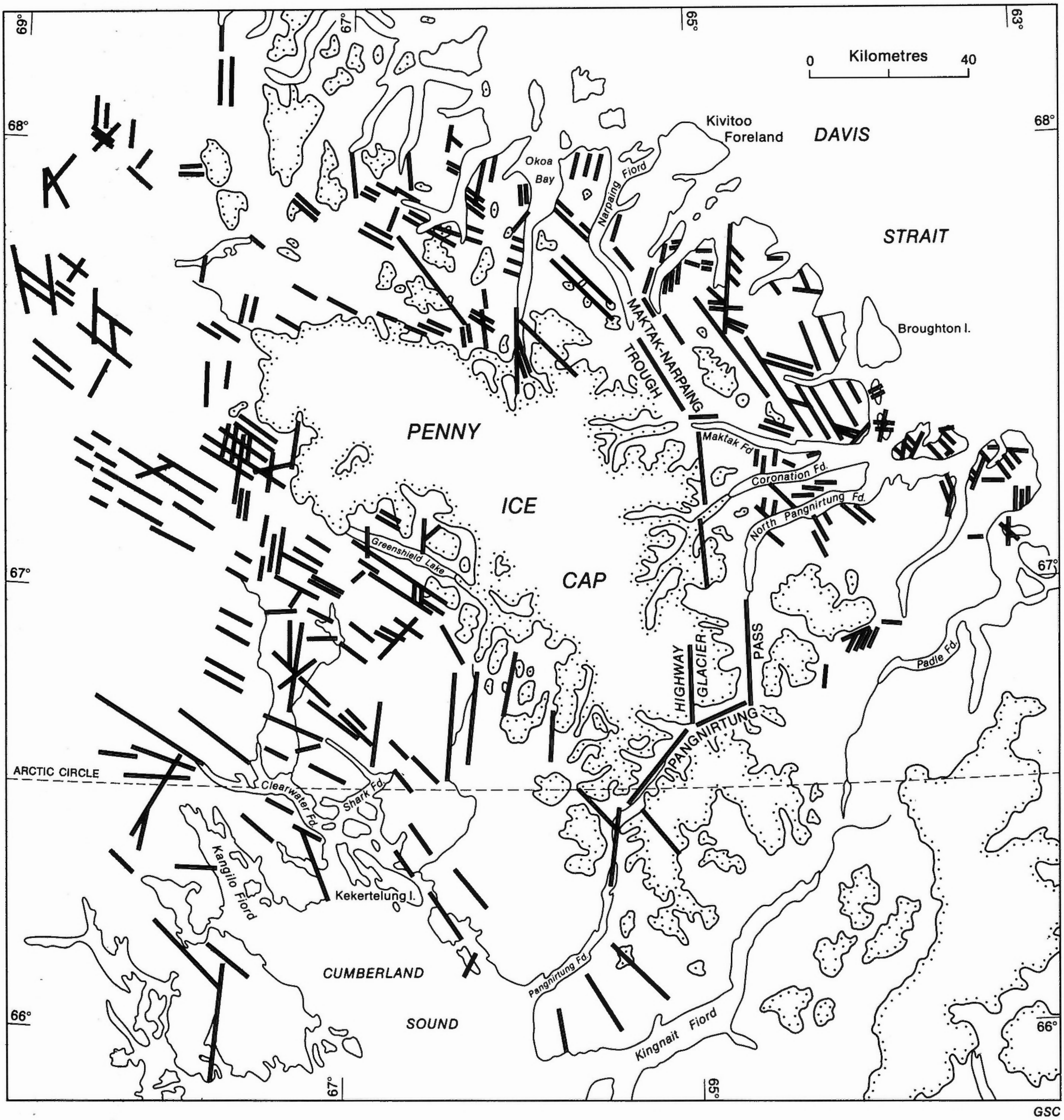


Figure 4. *Structural lineations of Cumberland Peninsula generalized from airphotos and satellite imagery.*

Scalloped-dissected Plateau

The terms scalloped and fretted are derived from the concept of cyclic development of alpine glacial landforms of Hobbs (1911) and Davis (1912). A scalloped plateau is an area of relatively high elevation into the edges of which large cirques are cut, so that their backwalls and sidewalls are separated by broad, flat or domed surfaces. Areas with large glacial troughs, in addition to cirques and plateaus, are termed scalloped-dissected plateaus (Fig. 8). Figure 9 describes the development of alpine glacial landforms and shows the relation of scalloped to fretted regions. The area included in this unit is the terrain underlying the entire eastern portion of the Penny Ice Cap, where it is best developed, much of the land north and northeast of the ice cap, and the area east of North Pangnirtung Fiord and northern Pangnirtung Pass. The unit has characteristics of both the "mountain valley glacier" landscape and the landscape of "selective linear erosion" of Sugden (1974).

Scalloped Coastal Region

These regions are morphologically similar to scalloped-dissected plateaus, but the cirques here are at or near sea level. None of them contain glaciers today. The cirques are well developed near Cape Dyer and along outer Cumberland Sound. Similar features occur in Home Bay (Andrews et al., 1970a), Frobisher Bay (Mercer, 1956), and southwestern Cumberland Sound (Miller and Dyke, 1974).

Fretted Mountains

Mountainous areas are classed as fretted where cirques occur in profusion, backwalls intersect to form cols and horns, and sidewalls are adjacent, joining in arêtes (Fig. 10). Thus almost all traces of preglacial topography have been removed. Further glacial erosion leads to destruction of horns and arêtes (Fig. 9). Two large and several small areas of intensive present glacierization are classed as fretted

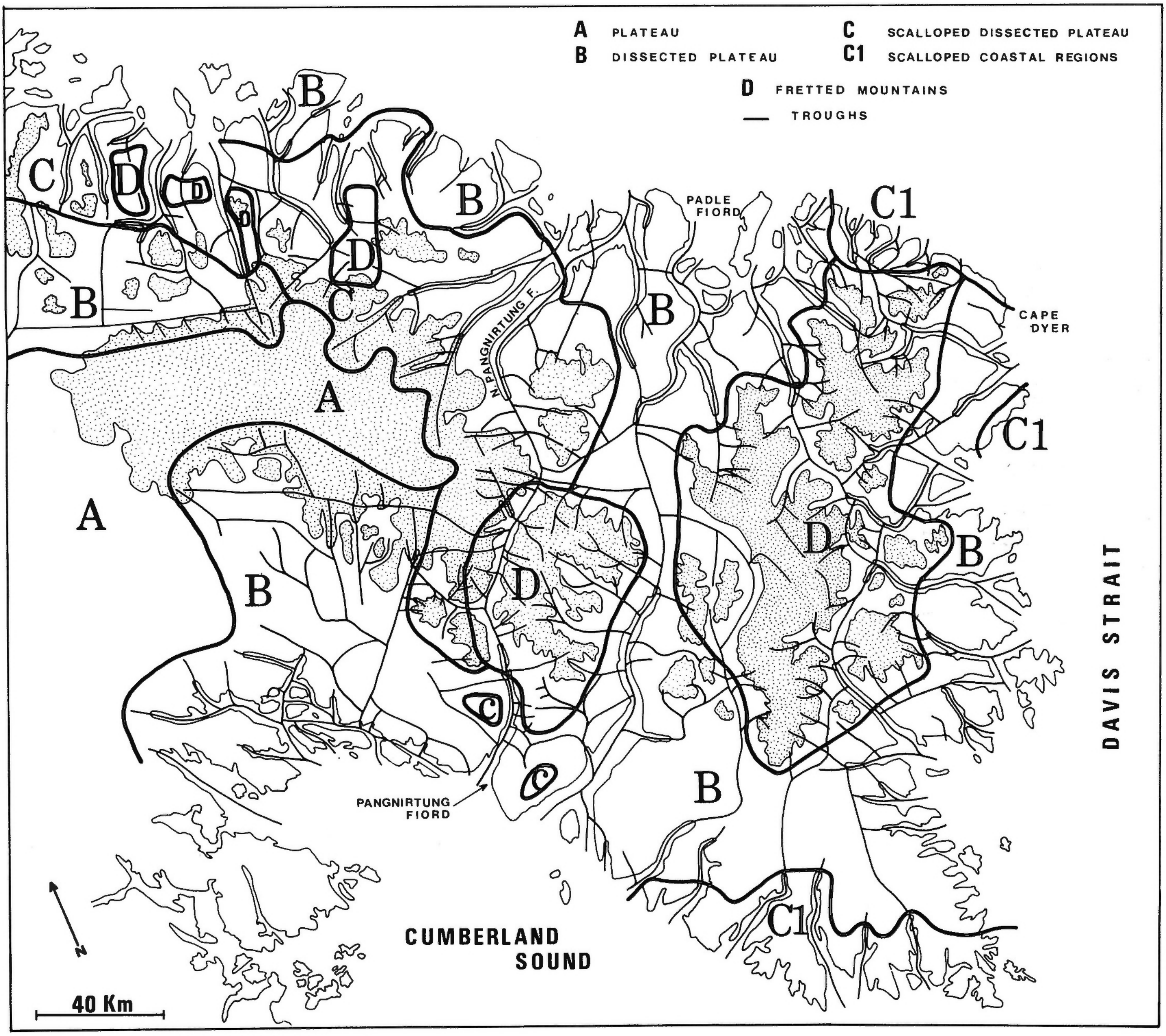


Figure 5. *Glacial-erosional landscapes of Cumberland Peninsula. Stippled areas show ice caps and glaciers.*

mountains (Fig. 5). Bird (1967) included them in the Penny Highlands, and they are similar to the "mountain valley glaciers" landscape of Sugden (1974).

Interpretation of Glacial History from Erosional Landforms

The overall topographic form of the peninsula and the distribution of large features of glacial erosion provide a basis for interpreting the glacial history. The various forms of erosion are characteristic of different types of ice bodies. Areal scour and large-scale fluting are produced by ice sheets or ice caps, probably at pressure melting point; U-shaped troughs are produced by outlet valley glaciers or by ice streams within an ice sheet; cirques, arêtes, and horns are produced by cirque glaciers. Overriding of cirques, arêtes, and horns by eroding ice sheets would subdue or obliterate these forms.

These general principles lead to the following conclusions:

1. The plateau has undergone widespread areal scour and has experienced mainly ice sheet and/or ice cap glaciation.

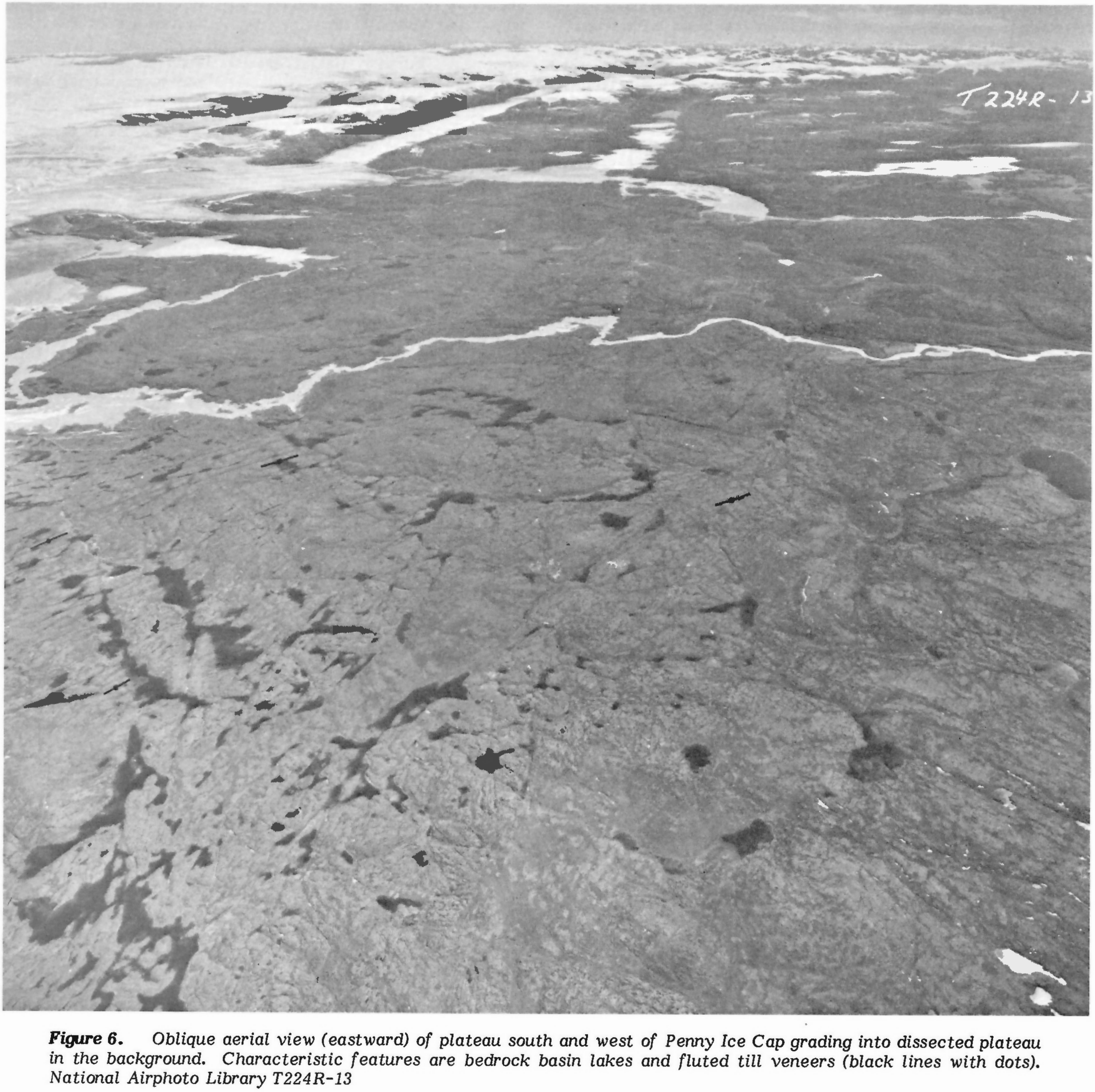


Figure 6. *Oblique aerial view (eastward) of plateau south and west of Penny Ice Cap grading into dissected plateau in the background. Characteristic features are bedrock basin lakes and fluted till veneers (black lines with dots). National Airphoto Library T224R-13*

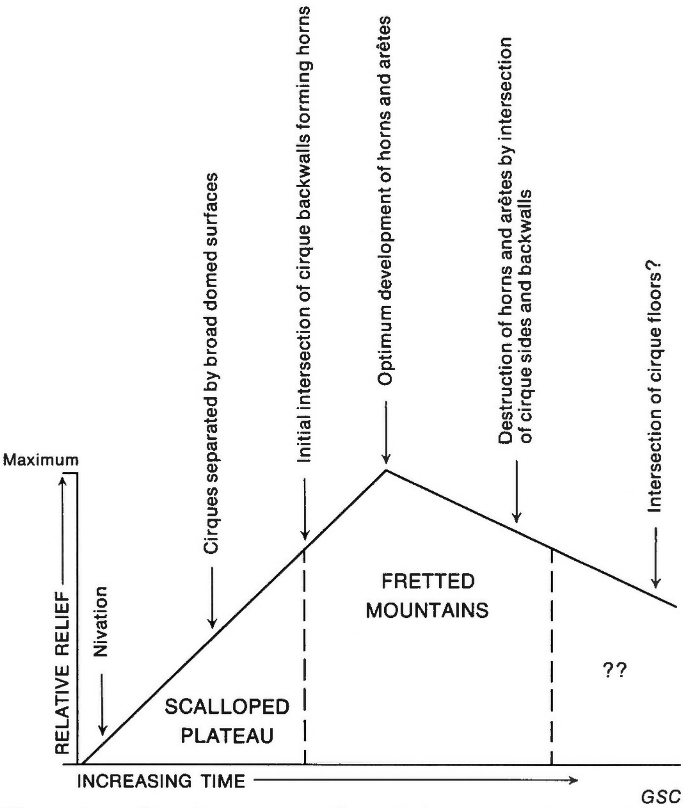
2. The dissected plateaus could have been completely inundated by an ice sheet or large ice cap, but for long periods they have experienced either ice streaming in troughs beneath an ice sheet or erosion by outlet valley glaciers. Troughs that radiate from the Penny Ice Cap, scalloped plateaus, or fretted mountains probably were eroded by local glaciers, whereas troughs that trend parallel to Cumberland Sound were eroded by Laurentide ice flowing from Foxe Basin; some areas probably were covered by ice from both sources at different times.
3. The scalloped plateaus are peripheral to the Penny Ice Cap and underlie its eastern margin. In the latter area, even a small increase in ice thickness would cause complete inundation of the cirques. If the ice cap were at pressure melting point at its base, then breaching of cirque headwalls and degradation of cirque morphology would occur. The forms probably were freshened during interglacials, when ice on adjacent summits disappeared or thinned to protective carapaces, such as exist today. Nevertheless, the scalloped plateaus show signs of only cirque, valley, and ice cap glaciation.
4. Fiords in scalloped coastal regions trend inland toward the fretted mountains adjacent to Davis Strait. The scalloped coastal regions, therefore, have been glaciated by both valley and cirque glaciers. Some cirque floors are below sea level, which indicates that they supported glaciers only when sea level was lower than that at present.
5. The fretted mountains show signs of erosion only by cirque and valley glaciers; hence they are classed as areas of local glaciation.

The length of time that is required to produce most of the erosional features described above is unknown, so it is impossible to provide a chronological framework from erosional-morphological evidence. Anderson (1976), however, studied Neoglacial rates of erosion by cirque glaciers in the fretted mountains northeast of Pangnirtung and concluded that they range from 8 to 76 mm/1000 years. If these rates have been relatively constant through time, it has taken 28 million years to erode the cirques to their present forms. Even if his calculated rates are an order of magnitude too low, the entire Quaternary Period has been required to erode the cirques. If they are roughly correct local glaciers formed long before the Quaternary.

Cirques on Cumberland Peninsula have been relatively well studied, although much of the work has been concentrated on features in the Okoa Bay and Home Bay map areas (National Topographic System, 1:250 000). Past and present distributions of ice bodies in cirques have been used in several studies as a means of developing paleoclimatic models (Andrews et al., 1970a; Andrews and Dugdale, 1971; Williams, 1972, 1975; Miller and Williams, 1974) or for purposes of evaluating the rates of glacial erosion (Andrews, 1972b; Anderson, 1976). Much of the research on climatic reconstructions has focused on explaining differences between the present distribution of cirque glaciers, largely confined to north-facing cirques, and past conditions when large cirque glaciers also occurred in south-facing basins. The analysis by Andrews and Dugdale (1971) indicated that there is only a 200 m elevational difference between ice-filled and ice-free cirques. This suggests that a relatively small change in factors that control the regional glacial mass balance, principally winter precipitation, summer radiation, and temperature, could lead to extensive glaciation.

Figure 7. *Oblique aerial view (westward) of dissected plateau in Shark Fiord area near head of Cumberland Sound. Dominant features are broad rounded summits separated by fiords or troughs. Note also rock-glacierized lateral moraines (arrows). National Airphoto Library T213L-141*

Figure 8. *Oblique aerial view (westward) of scalloped-dissected plateau near the northern end of Pangnirtung Pass. Characteristic landforms are cirques separated by broad summits and deep glacial troughs. National Airphoto Library T214R-89*



GSC

Figure 9. *Development of alpine glacial-erosional landforms from a broad plateau, based on concepts of Hobbs (1911) and Davis (1912).*

The studies of Williams (1972, 1975) are the most sophisticated analysis of the problem because normal studies of cirque orientation and elevation were linked to an energy/mass balance model based on a realistic model of topographic shading caused by each cirque. Williams (1975) concluded that glaciation of all cirques that are now empty would occur with a summer climate similar to that between 1963 and 1973 but with snowfall increased by a factor of three.

SURFICIAL MATERIALS

Bedrock

Granitic gneiss bedrock exposed, or with a cover of a few centimetres of till and erratic boulders, is the dominant surficial material adjacent to the head of Cumberland Sound (Fig. 11), in nunataks of the fretted mountains, and sidewalls (cliffs) of fiords and troughs. It is not possible to show many of the cliff exposures on Map 1536A due to their small planimetric areas. Near the head of Cumberland Sound the bedrock surface is rolling and contains hundreds of lake basins created by scouring action of former ice sheets. The rock surface is little weathered and little disrupted by frost heave; striae and grooves occur on many outcrops.

Till

Sandy, gravelly till, interrupted in numerous places by small bedrock outcrops, covers about 80 per cent of terrain directly west of the margin of the Penny Ice Cap and about 60 per cent of terrain within 40 km of the southern margin of the ice cap. In most other areas till is confined to valley floors. The largest valley deposits are in troughs adjacent to

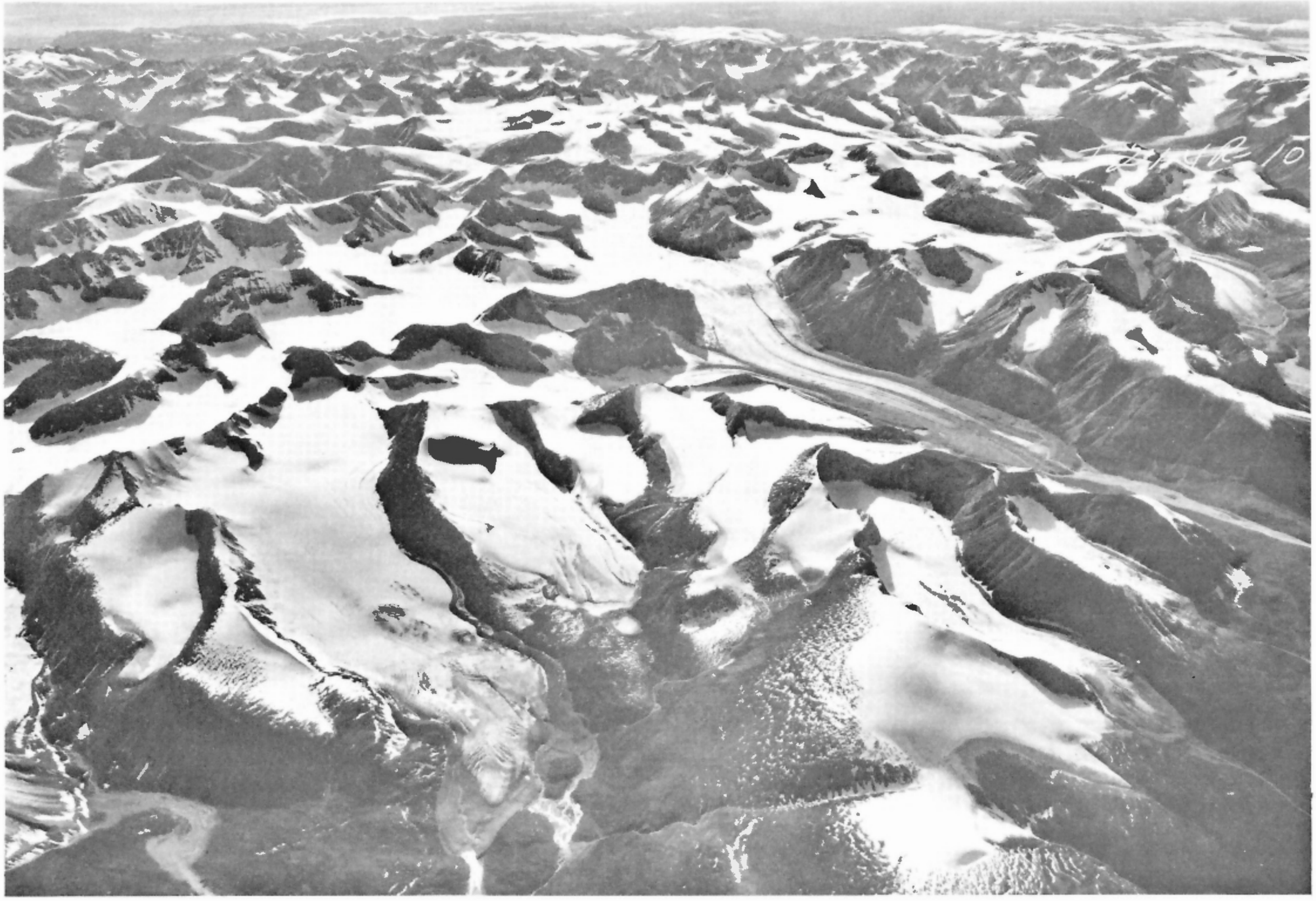


Figure 10. *Oblique aerial view (westward) of fretted mountains north of Panquirtung Fiord. Cirques have developed in such numbers that almost all traces of preglacial topography have been removed. Characteristic landforms are horns and arêtes. National Airphoto Library T214R-101*

the pass connecting Kingnait and Padle fiords (hereafter referred to as Kingnait/Padle Pass), in the pass connecting Maktak and Narpaing fiords, and in troughs on the peninsula between Narpaing and Quajon fiords. The till sheets probably average about 2 m in thickness and have rock controlled morphologies. The most common patterned ground features are mud boils; ice-wedge polygons are much less common. Moraines, which are the most outstanding morphological features of the till sheets, are generally sharp crested and are as much as 30 m high (Fig. 12). Other outstanding features are ice marginal meltwater channels (Fig. 13), which are best developed in the large valley northwest of the Penny Ice Cap and in Kingnait/Padle Pass, and flutings (Fig. 12), which are best developed west and southwest of the Penny Ice Cap.

The moraines and related till sheets may be subdivided on the basis of the type of glacier that emplaced them and further subdivided on the basis of age (see section on Quaternary History). Subdivision according to type of glacier is best done with reference to the map of glacial erosional landscapes (Fig. 5). An understanding of source areas and transport directions of tills is important to any future drift prospecting or drift geochemical study.

Tills of the plateau areas (Region A, Fig. 5) were emplaced by eastward flowing Laurentide ice and by the northwestward to southward flowing western lobe of the Penny Ice Cap. As the latter till was deposited after separation of Penny and Laurentide ice, it probably consists largely of reworked Laurentide till.

Tills of the dissected plateau (Region B) south of the Penny Ice Cap and west of Pangnirtung Fiord were emplaced by two different ice sheets: in the seaward half, by southeastward flowing Laurentide ice, and in the landward half, by southward flowing outlet glaciers of the Penny Ice Cap. In dissected plateaus east and north of the Penny Ice Cap, tills were deposited by either an expanded Penny Ice Cap or expanded alpine glaciers.

In Regions C (scalloped-dissected plateau) and D (fretted mountains) tills were deposited by expanded alpine glaciers. Source areas are, therefore, directly upvalley from any given point.

Regional till texture has not been systematically studied, but there do not appear to be significant differences between Laurentide, Penny, and alpine tills. Up to 50 per cent of till may lie in the gravel size range, and the matrix (<2 mm fraction) is usually more than 60 per cent sand and less than 10 per cent clay (Fig. 14). Lateral and end moraines are the most widespread sources of gravel in the region.

Figure 11. *Oblique aerial view (westward) of Clearwater Fiord area illustrating appearance of areas mapped as bedrock. Dominant features are lake basins, many of which contain small patches of till. Note also large maount of suspended sediment in Millut Bay, right foreground. National Airphoto Library T202R-214*

Figure 12. *Oblique aerial view (westward) of large end moraine (traced with black dots) on plateau west of Penny Ice Cap. Fluted till (black lines with dots) shows direction of flow of ice. National Airphoto Library T224R-196*

Figure 13. *Oblique aerial view (westward) of ice-marginal meltwater channels in large valley northwest of Penny Ice Cap. Channels were formed while a lobe of ice receded towards the foreground. National Airphoto Library T224R-185*

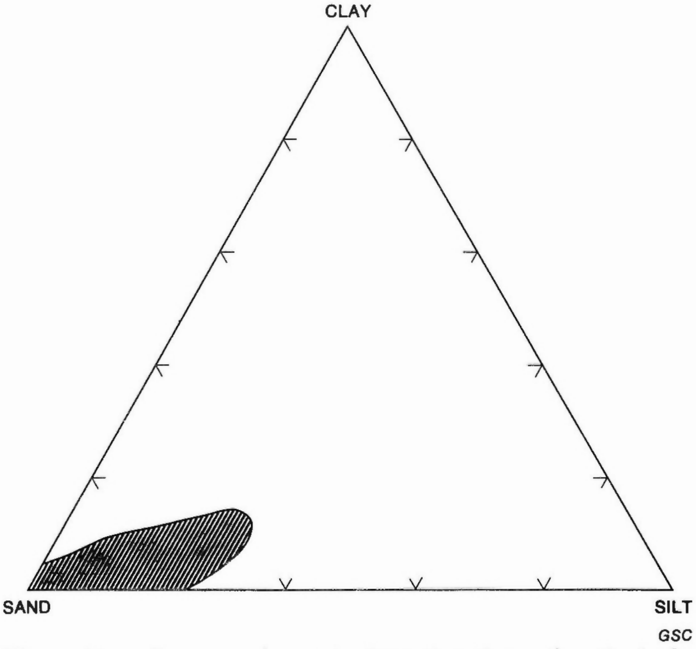


Figure 14. *Texture of matrix (less than 2 mm fraction) of till samples from Cumberland Peninsula. Data for 50 samples from Birkeland (1978), Isherwood (1975), Anderson (1976), and Miller and Andrews, unpublished data.*

Residuum and Older Tills

Topographically higher and stratigraphically beyond (older than) the oldest distinct morainic ridges, the bedrock surface is mantled in most places by a mixture of felsenmeer, erratic boulders, grus, and fines. Bedrock outcrops are in the form of tors in many places. The unconsolidated mantle consists of a mixture of weathered bedrock and till.

In most cases it has not been possible to determine the type of glacier that deposited this till, but limestone erratics, which have been found in a few places, indicate a Laurentide origin. The nearest known source of limestone is in the graben that forms Cumberland Sound.

Felsenmeer, but not tors or extensive grus accumulations, occurs on a number of summits behind the oldest moraine ridges, indicating that it has developed since formation of these moraines. However, no felsenmeer occurs behind the younger moraines (Dyke, 1978).

Raised Marine Deposits

Raised marine deposits of this region are almost exclusively deltaic (Fig. 15) and range in texture from boulder gravel to clay-silt; generally, the small deposits are coarsest in texture. In places deposits are diamictic glaciomarine sediments. Raised marine sediments are extensive only in the valleys north of Kekertelung Island (near the head of Cumberland Sound) and on the Kivitoo foreland on the Baffin Bay coast.

Figure 15. Emerged, terraced delta at head of Millut Bay, Clearwater Fiord. GSC 203359-R

Figure 16

Oblique aerial view (eastward) of moraines deposited in former glacier-dammed lake northwest of Penny Ice Cap (small ridges, example shown by an arrow, trending normally to river). Much bulkier lateral moraine trending parallel to lower course of river was deposited above former lake level, which is evident on opposite side of the valley. Note also ice-marginal meltwater channels associated with lateral moraine and occurring upslope from it. National Airphoto Library T224R-35

Ice-dammed Lakes and Lake Sediments

Former glaciers dammed drainage ways and created lakes at many locations. The largest of these former lakes occupied valleys northwest of the Penny Ice Cap, and the obstructing glacier deposited numerous sublacustrine (or cross-valley) moraines during recession (Fig. 16). Other large lakes were dammed temporarily in Kingnait/Padle Pass, in a large drainage basin east of Kingnait Fiord, in three valleys adjacent to Pangnirtung Fiord, in the lower course of Ranger River, and in the valley south of and parallel to Greenshield Lake. Greenshield Lake, the largest extant ice-dammed lake in the area, was once larger (Fig. 17).

Significant thicknesses of lacustrine sediments, mostly sand, occur in Ranger Valley, in Kolik Valley (near Pangnirtung Fiord), and in the middle reaches of Kingnait/Padle Pass. Elsewhere, lacustrine deposits are restricted to a few small deltas or beach ridges.

Alluvium

Four genetic types of alluvium occur in the map area. In order of decreasing extent, they are: (1) active proglacial outwash plains (sandurs), (2) active or intermittently active alluvial fans, (3) inactive proglacial outwash, and (4) subglacial outwash, represented by a single esker. The outwash consists primarily of well sorted and stratified medium to fine gravel and sand; fan deposits are less sorted and more bouldery.

The largest and most spectacular active sandurs (Fig. 18) are in Pangnirtung Pass, in five large valleys along the southern side of the Penny Ice Cap, and at the head of Maktak Fiord. These surfaces are flooded intermittently during spring peak runoff and have shifting braided stream channels at lower flow. Church (1972) presented detailed analyses of two sandurs on Baffin Island. The only large inactive proglacial outwash deposits occur inland from Shark Fiord and Kekertelung Island and near the northwestern margin of the Penny Ice Cap. They are important sources of sand and gravel. Other deposits form terrace remnants adjacent to active sandurs.

Colluvium

Colluvium (scree), large angular blocks with a matrix of smaller fragments and sand, extends 50 to 100 m up the sidewalls of most fiords and troughs. It is, therefore, concentrated in regions B, C, and D of Figure 5. The absence of significant scree accumulations along Kangilo, Kangerk, and Clearwater fiords is noteworthy and may reflect a history different from that of the other troughs. These fiords were inundated completely by Laurentide ice, and their upper sidewalls, which underwent severe glacial erosion, make smooth convex junctions with adjacent plateau surfaces. The colluvium-lined troughs and fiords were only partly filled by outlet glaciers and their sidewalls meet adjacent plateaus along sharp, jagged lines. These differences in slope form probably account for the different amounts of scree accumulation. Scree appears to be less common in areas of metasedimentary rocks east of Kingnait/Padle Pass than in areas of granitic gneiss to the west. This may indicate that the metasediments are less susceptible to frost riving.

In numerous places, masses of colluvium have flowed toward valley axes to form terraced lobes; these are a form of rock glacier.

Minor Materials (not mapped)

Eolian Sand

Eolian sands, in many places interbedded with buried soils or thin organic partings (Fig. 19), are up to 6 m thick. These were called "layered sands" by Thompson (1954) who puzzled over their origin. They are thickest and most continuous on valley floors and lower scree slopes adjacent to sandurs, which are the source areas. The poorly sorted nature of many of these deposits indicates that at least some of them formed by meltout of windblown materials deposited in snow during winter months (Andrews et al., 1979).

Organic Accumulations

An organic mat up to 15 cm thick covers poorly drained tills. Organic soils in excess of 15 cm thick are rare, and only one accumulation in excess of 1 m has been found near Windy Lake in Pangnirtung Pass.

Figure 17. *Westward view of Greenshield Lake and lobe of Penny Ice Cap that dams it. In the last century lake level was higher. Former level is marked by upper limit of light-toned (i.e. lichen-free) ground on left-hand side of photograph. Beach ridges of wave-modified till are visible in lower left-hand corner of photograph. GSC 203316-C*

Figure 18. *Proximal end of large active sandur near outlet glacier on southern margin of Penny Ice Cap (approximate location 66 50'N, 66° 15'W). Note also active, ice-cored terminal moraine across the centre of the photograph. GSC 203316-T*

Figure 19. *Eolian sands with thin organic partings (poorly developed paleosols) near northern end of Pangnirtung Pass. GSC 203316-H*

Modern Marine Sediments

All fiords that tap large drainage areas, particularly those with glaciers in their drainage basins, are experiencing apparently rapid deltaic sedimentation (Fig. 11). In Cumberland Sound, where the tidal range is about 6 m, the main result is establishment of intertidal mud flats, up to 2 km wide adjacent to river mouths. This has a pronounced influence on small boat travel, common in the area today, because arrivals and departures have to be at or close to times of high tide.

Extensive intertidal flats are forming also away from major river mouths along the Cumberland Sound coast, probably by longshore drift. An excellent example of such a feature lines both shores of Pangnirtung Fiord (Fig. 20). These flats have 1 to 2 m high boulder ramparts along their margins, and these are completely exposed at low tide. The ramparts are probably formed by ice push, but we are not aware of any comprehensive study of these features. They form an additional restriction to boat travel as they can be crossed only at high tide.

Rock-glacierized Materials

Some 200 rock glaciers have been identified in the map area west of 64° longitude (Fig. 21), and numerous others occur to the east but have not been mapped. They are classified here according to the type of material of which they are formed, as either rock-glacierized till or rock-glacierized scree. A special subclass of the former is rock-glacierized lateral moraines. These moraines act as base levels for scree accumulation and, hence, in places are difficult to distinguish from rock-glacierized scree. In many places, both types of material have been incorporated in the rock glacier. Little attention has been paid to these features in the course of field mapping, so our understanding of them is immature and largely restricted to facts about distribution.

The largest rock glaciers recognized in the area are composed of till (Fig. 22). They are typically lobate, have multiple ridges parallel to the outer lobe, and are wider than they are long. They are similar in form to very large solifluction lobes, but unlike the latter, movement is not restricted to the active layer. Rock-glacierized lateral moraines (Fig. 7) from Pangnirtung Pass were first described by Thompson (1954).

Rock-glacierized scree (Fig. 23) is commonly referred to in the literature as valleyside rock glaciers (Outcalt and Benedict, 1965). They may have a single terrace without ridges or have multiple transverse ridges.

Terrain Sensitivity and Hazards

Susceptibility of terrain to disturbance is a function of several interdependent variables: (1) extent, thickness, and composition of the vegetation mat; (2) texture and engineering properties of surficial materials; (3) slope, aspect, and thickness and drainage of the active layer; and (4) ground ice content. Vegetation is probably the most important variable in the map area, particularly within the boundaries of Auyuittuq National Park where the most widespread land use is hiking and camping, but is also that about which we are least knowledgable. Furthermore, no effort has been made to systematically collect data on soil moisture or ground ice conditions; hence, the various geological units can only be ranked along a scale of most to least sensitive (Table 2).

The least sensitive materials are completely unvegetated (glacial ice, active alluvium, active scree) and are followed in Table 2 by materials whose dominant vegetation cover is epipetric lichens and that are coarse textured and well drained (exposed bedrock, inactive scree, rock glaciers, felsenmeer). Tills of the study area are generally moderately to poorly drained and well vegetated, with the exception of moraine crests which are windswept, well drained, and colonized only by lichens and scattered clumps of moss and grass. Sides of moraine ridges are sensitive to disturbance because they attain slopes of up to 35°, are well vegetated, and north-facing slopes may have little active layer development. Inactive alluvial, marine, and eolian sediments are considered more sensitive than till because, apart from being well vegetated, their surfaces are commonly patterned by ice-wedge polygons which indicates the presence of massive ground ice bodies. Other than in the numerous ice-cored moraines that front active glaciers, only a few exposures of massive ground ice have been observed – in raised marine sand at the head of Millut Bay, in eolian sand in Pangnirtung Pass, and in the coastal cliffs of Kivitoo foreland. Fine grained marine, lacustrine, and alluvial sediments are probably more sensitive than gravels and sands because active layers are thinner and the vegetation mat is thicker. They are also less stable than gravels and sands if thawed. The deposits that are probably most susceptible to disturbance are ice-cored moraines, despite their unvegetated nature. These commonly have slopes of 35° and consist of a till veneer on stagnant glacier ice. Removal of the till would expose the ice core to rapid melting and slumping.

A ranking of the same map units in terms of potential hazards that they pose to land users and their artificial structures (Table 3) is essentially, and unfortunately, largely

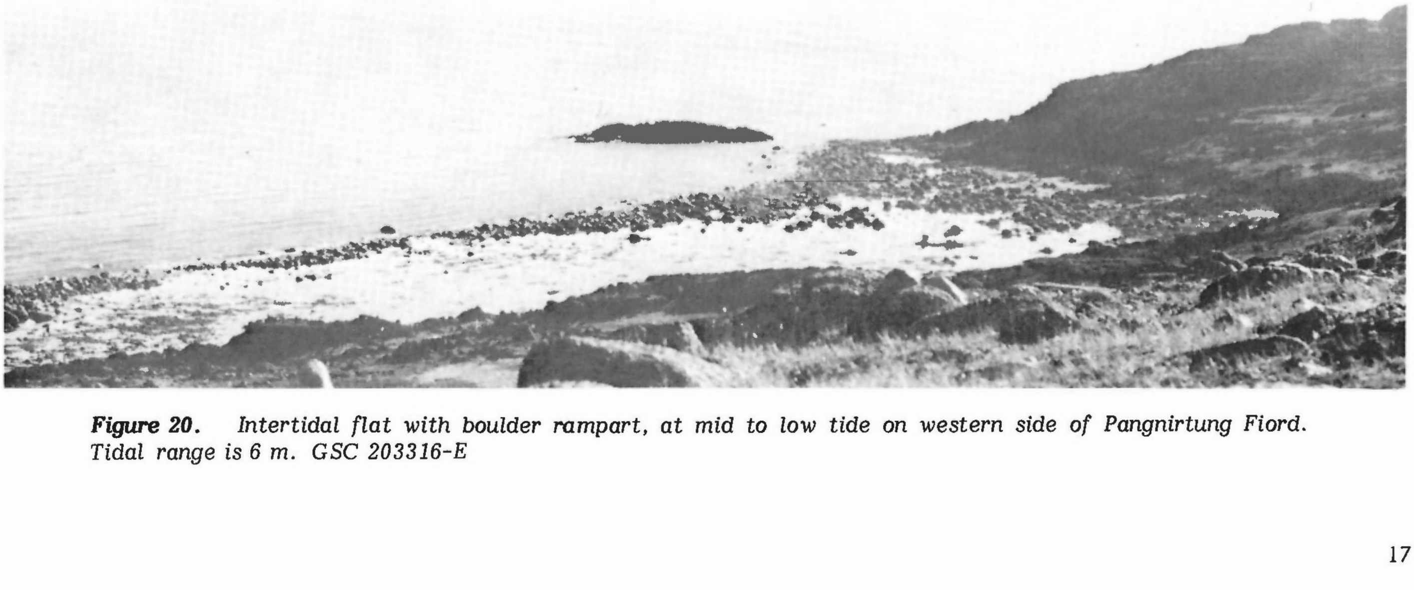


Figure 20. *Intertidal flat with boulder rampart, at mid to low tide on western side of Pangnirtung Fiord. Tidal range is 6 m. GSC 203316-E*

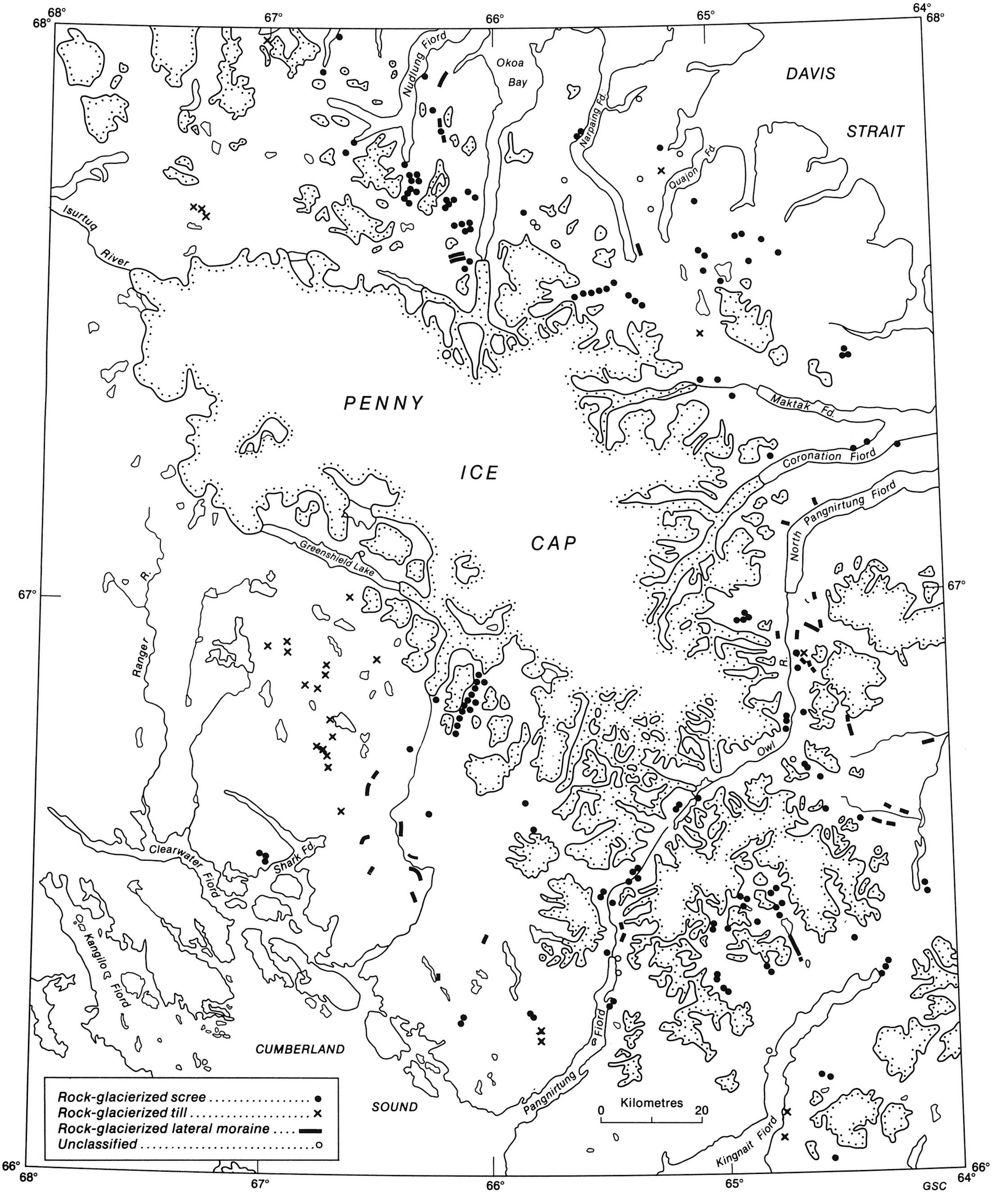


Figure 21. *Locations of rock glaciers west of 64° longitude*

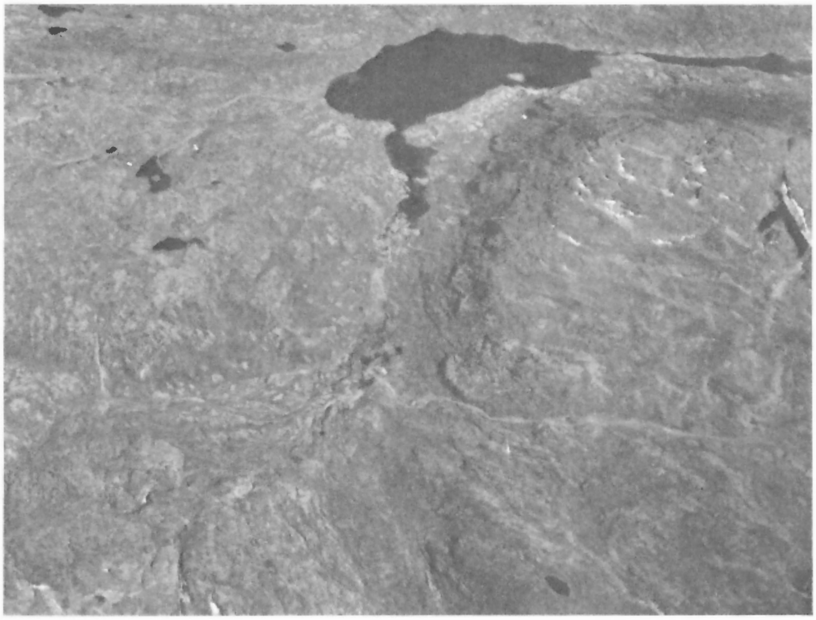


Figure 22

Oblique aerial view (eastward) of rock-glacierized till on north side of summit 15 km north of head of Shark Fiord. National Airphoto Library T268R-11

Figure 23. *Oblique aerial view (eastward) of rock-glacierized scree along valley southwest of Quajon Fiord. Three main elements of these features are active scree above rock glacier (A), vegetated rock glacier tread (B), and unstable rock glacier front (C). National Airphoto Library T220L16*

the reverse of the sensitivity ranking. Cliffs and scree (because of potential snow avalanches, rock falls, and landslides), active alluvium (because of potential flooding, bank erosion, and burial by sediment), and glaciers (because of their crevassed nature and the danger of falling ice blocks) are highly hazardous, whereas flat lacustrine, marine, and eolian sediments, gently rolling till, and felsenmeer pose few hazards. Only level to moderately sloping bedrock (slopes too low to produce scree) are low in both sensitivity and hazardousness.

Sensitivity varies seasonally on any given material as depth of thaw and drainage conditions in the active layer change: it is lowest in winter when the ground is frozen and snow covered, and is highest in spring and early summer when the active layer is saturated by melting snow. Hazardousness also varies seasonally, with a greater potential for flooding and avalanching in spring and early summer.

Earthquakes and earthquake induced events are possible additional hazards. Basham et al. (1977) indicated that medium scale earthquakes occur in the Baffin Bay area and along eastern Baffin Island. A cluster of earthquake epicentres in Home Bay and the northwestern part of the study area were recorded between 1962 and 1974. A field party in that area in 1971 felt a significant ground movement and heard rock-falls that they attributed to an earthquake (A. Mears, personal communication, 1971). Strong ground motions from earthquakes could trigger large debris and snow slides in areas of high relief. The occurrence of such events, however, is presently impossible to predict.

QUATERNARY HISTORY

Glacial and Sea Level History

Much of the raw data from which the glacial history can be deciphered is shown on Map 1536A, particularly distribution and type of active glaciers, distribution and type of glacial-erosional landforms, distribution of moraines and the ice-flow patterns that resulted in their formation, and degree of weathering of bedrock. The major pieces of information that are missing are absolute ages of various moraines, and data by which moraines can be correlated within the area, though much correlation of age-equivalent moraine segments can be done by sensible topographic extrapolation of moraine gradients.

Table 2. A relative ranking of the sensitivity to damage or disturbance of the various maps units shown on Map 1536A.

Sensitivity	Material	Properties
Least sensitive	Ice and snow Active alluvium Active scree	unvegetated
	Exposed bedrock Inactive scree Rock glaciers Felsenmeer	lichen covered, coarse textured, well drained
	Flat, well drained moraine crests	fine textured, well drained, and poorly vegetated
	Till blankets and veneers	fine textured, poorly drained, well vegetated
	End and lateral moraine slopes	fine textured, well drained, steep slopes
	Inactive alluvial and marine gravel and sand	coarse textured, well vegetated, massive ground ice
	Inactive alluvial, marine, lacustrine, and eolian sand, silt, and clay	fine textured, variably drained, vegetated, massive ground ice
Most sensitive	Ice-cored moraines	fine textured, well drained, very steep slopes, massive buried ice, unvegetated

Much field research has been concerned with dating moraine systems and correlating moraine segments where relationships were not obvious from map patterns. Two methods that have proven fruitful are: (1) radiometric dating and amino acid analysis of marine fossils from deposits related to moraines or till sheets and (2) relative dating based on weathering of till boulders and bedrock surfaces and degree of soil development.

On the basis of data accumulated, maps showing the limit of ice during the Foxe Glaciation, positions of moraines of middle Foxe age (Fig. 24), and the pattern of retreat of Laurentide and local ice during the Holocene (i.e., from the late Foxe stadial maximum) (Fig. 25) are presented. The age assignments of ice-marginal positions shown in Figure 24 represent a synthesis of conclusions of England and Andrews (1973), Andrews et al. (1976), and Feyling-Hanssen (1976) for Broughton Island and adjacent areas; Pheasant and Andrews (1973) for the area between Narpaing Fiord and Broughton Island, Miller (1973) for parts of the same areas; and Dyke (1977), Locke (1976), and Birkeland (1978) for the southwestern part of the peninsula.

Table 3. A relative ranking of the potential hazards posed to land users and their structures in the various map units shown on Map 1536A.

Hazardousness	Material	Hazards
Most hazardous	Cliffs Scree	avalanches, rockfalls, landslides
	Active alluvium	flooding, bank erosion, burial by sediment
	Glaciers	crevasses, falling ice blocks
	Ice-cored moraines	very unstable, steep slopes
	Felsenmeer Till Marine, lacustrine, and eolian sediments	few hazards for present land users, but areas rich in ground ice potentially hazardous to future engineering works
Least hazardous	Bedrock level to gently sloping	few hazards for present land users, but frost heaving of bedrock block, potentially hazardous to artificial structures.

Pre-Foxe Terrain and the Foxe Glacial Limit

It has been suggested that the name "Foxe Glaciation" be applied to the last major glaciation of Baffin Island (Andrews, 1968; Miller et al., 1977). This name was suggested in order to avoid automatic correlations with the "Wisconsin Glaciation" of the mid continent, but especially to avoid problems posed in arctic areas by the accepted range of the Wisconsin Stage (70 000 to ca. 10 000 years B.P.).

The margin of the most extensive Foxe ice advance is clearly marked by the outermost (oldest) distinct lateral moraines. Where moraines are absent, the ice margin in many places is identifiable as the edge of till sheets, outermost ice-marginal meltwater channels, or glacial trimlines defined by the boundary of distinctly ice-moulded bedrock.

These moraines and age-equivalent ice-marginal features (Fig. 24) mark the boundary between two distinctly different surface weathering zones. Terrain that was ice covered during formation of the moraines has been called Weathering Zone III north of the Penny Ice Cap (Pheasant, 1971; Pheasant and Andrews, 1973) and Weathering Zone A south of the ice cap (Dyke, 1977, 1979). In the north the older terrain has been subdivided into two units and named Weathering Zones II and I (I being the older). In the south no subdivision has yet been attempted, and terrain beyond the moraines is referred to as Weathering Zone B. Most, if not all, terrain beyond the moraines has been glaciated at some time, as glacial erratics and possible tills occur there. It is possible that parts of Zone I have never been glaciated, but there is a divergence of interpretations on this point (Boyer and Pheasant, 1974; Ives, 1975, Sugden and Watts, 1977).

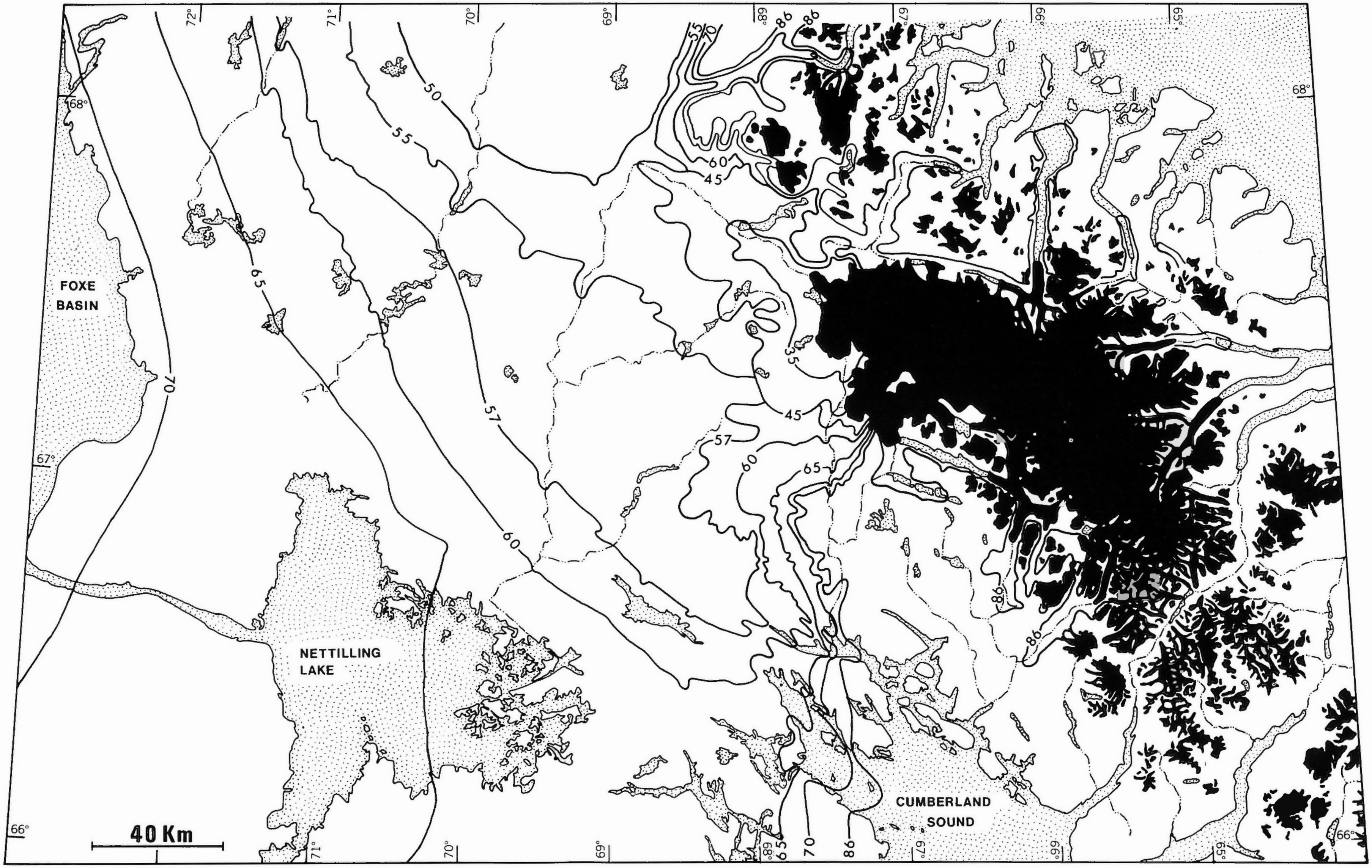


Figure 25. *Holocene ice-marginal positions in the Cumberland Peninsula/Foxe Basin area. Numbers give ages in years B.P. x 100.*

Table 4. Amino acid ratios and ^{14}C and ^{230}Th dates on molluscs from raised marine sediment and suggested major correlative units, Cumberland Peninsula. Alloisoleucine: Isoleucine ratios on **Hiatella arctica.**

Unit	Location	Relative sea level (m)	Amino acid Lab. no.	Amino Acid		^{14}C age (years B.P.)	^{230}Th age (years)
				(free)	(total)		
Holocene					0.026	<10 000	
Quajon Interstade	Quajon Fiord	70	AAL-137	0.3	0.06		
				0.33	0.068	>29 000	68 000 ± 8000
	Kivitoo airstrip	68	AAL-135	0.34	0.045	36 000 ± 300	
	Kivitoo airstrip	20	AAL-214	0.38	0.066, 0.052		
	East Broughton Island	32?	AAL-106	0.33	0.031	44 100 ± 1000	58 000 ± 4000 48 000 ± 4000
	Boas Fiord	∽10?	AAL-104		0.059		
Cape Broughton Interstade	Kingnait Fiord	99	AAL-273	0.27			
				0.31	0.077		
				0.42	0.087		
	Kivitoo foreland	73	AAL-100	0.42	0.10		
	Idjuniving Island	45	AAL-138	0.48	0.07		
					0.067		
	Cape Broughton	26	AAL-108	0.37			
				0.4	0.063	36 300 ± 300	
	" "	18	AAL-133	0.51	0.073	39 600 ± 500	86 000 ± 5000
				0.36	0.084		
	" "	6	AAL-107	0.51	0.054	45 400 ± 600	
				0.47	0.057		
				0.48	0.057		
	Broughton Island airstrip	>29	AAL-109	0.41	0.077		
	Atvajalik Island	>6	AAL-112	0.26	0.10, 0.062		
				0.50	0.10, 0.11	78 000 ± 5000	
Last Interglaciation	Kivitoo foreland	>8	AAL-130	0.74	0.13		
	Pigojoat	>15	AAL-24	0.67	0.15	44 800 ± 500	
	Near Hudson Bay Store, Broughton I.	>18	AAL-131	0.55	0.18	45 500 ± 600	
	East coast Broughton I.	>10	N/A	0.65	0.15±		
Pre-last Interglaciation	Kivitoo foreland	>7	AAL-101		0.398		
	Quajon foreland	>3	AAL-103		0.51		

AAL: Amino Acid Laboratory, Institute of Arctic and Alpine Research, University of Colorado, Boulder

The major differences in weathering between terrain behind the oldest lateral moraines and that in front have been noted by several observers (Pheasant, 1971; Pheasant and Andrews, 1972; Boyer and Pheasant, 1974; Miller, 1975; Isherwood, 1975; Dyke, 1977). Beyond the moraines features such as tors, disintegrated bedrock and boulders, and large circular weathering pits in rocks indicate a lengthy period of subaerial weathering. With the exception of rare small weathering pits, these features are absent on the younger terrain. The advanced state of weathering of the older terrain suggests that it was not glaciated during the last glaciation. The corollary of this is that the boundary between the two terrains marks the Foxe glacial limit.

Sediments of last interglacial age and from earlier geologic-climate periods have been identified in cliffs from Kivitoo foreland southward to Broughton Island (Tables 4, 5). Identification of sediments of or older than the last interglaciation is based on foraminifera assemblages (Feyling-Hanssen, 1976) and amino acid ratios (Tables 4, 5). Shells from many strata in the Kivitoo cliffs have amino acid ratios in the combined fraction of >0.3 (e.g., AAL-101); these sediments are probably older than 250 000 years. If the sites tentatively assigned a last interglacial age in Table 4 are chrono-correlative with the Cape Christian Member of the Clyde Cliffs Formation (Miller et al., 1977), an age of ca. 125 000 years should be ascribed to them. In broad terms it is argued that deposits of the Foxe Glaciation are between 120 000 and 5000 years old.

Early to Middle Foxe Sediments

Narpaing and Quajon Fiords

The original glacial chronology for Cumberland Peninsula developed from studies of this area (Pheasant, 1971; Pheasant and Andrews, 1972, 1973; Andrews et al., 1975; Dugdale, 1972). Detailed and intensive studies by Nelson (1978) of stratigraphy of cliff sections on the foreland between the fiords (Kivitoo foreland) indicate that changes need to be made to earlier interpretations. Radiocarbon dates and amino acid ratios on marine shells, (Table 4) are used as a basic guide to the relative sequence of events (cf. Andrews et al., 1976; Miller et al., 1977). Amino acid ratios from shells collected in 1977 indicate that the stratigraphy in the cliffs is more complex than that suggested

Table 5. Mean amino acid values for the stratigraphic units of last interglacial and early Foxe age on Cumberland Peninsula compared to values from members of the Clyde Foreland Formation (Miller et al., 1977)

	Free	Combined
Cumberland Peninsula		
Quajon Interstade	0.336	0.058
Cape Broughton Interstade	0.43	0.077
Last interglaciation (?)	0.65	0.153
Clyde Foreland		
Kogalu Member	0.29	0.04
Kuvinilk Member	0.5	0.085
Cape Christian Member	0.6	0.12

by Andrews et al. (1975). Nelson (1978) recognized no tills and interpreted most of the sequence as a series of marine transgressions and regressions caused by glacial advances and retreats. The marine limit on the foreland is about 85 m a.s.l.

Glacial retreat from the outer coast is documented by marine sediments that in places extend to marine limit. On northeastern Idjuniving Island, sandy marine sediments overlie till and extend to 45 m a.s.l. Amino acid ratios on shells (AAL-138) are 0.48 (free) and 0.07 to 0.067 (total). Shells from marine or glaciomarine sediments at 75 m on Kivitoo foreland (AAL-100) have similar ratios.

The site on northeastern Idjuniving Island lies inside the Foxe glacial limit. Marine limit rises southwestward on the island to heights of 68 to 74 m a.s.l. (Pheasant and Andrews, 1973). On the adjacent mainland near the abandoned DEW Line airstrip at Kivitoo, marine shells from 68 m a.s.l. (AAL-135) have amino acid ratios of 0.34 (free) and 0.045 (total). Similar ratios have been obtained from shells in marine clay at 20 m a.s.l. (AAL-214) from a site 1.5 km away. The latter two sites are farther behind the Foxe glacial limit and are apparently significantly younger than the former two. Radiocarbon dates on shells from the site near Kivitoo airstrip (Fig. 24, Table 4) indicate that retreat occurred at least 36 000 years ago.

Half-way down Quajon Fiord shell fragments were collected from a glaciomarine delta at 70 m a.s.l. (AAL-137). The deltaic sands contain fragments of the subarctic bivalve **Chalmys islandicus** Muller, which indicates that the sea was warmer than at present. Amino acid ratios, 0.30 to 0.33 (free) and 0.06 and 0.068 (total), are consistent with the position of the deposit, at least relative to the sites around Kivitoo. A ^{230}Th date indicates that the shells are 68 000 ± 8000 years old.

Near the heads of the fiords, Dugdale (1972) studied three nested cirque moraines that crosscut a lateral moraine deposited by ice flowing down Narpaing Fiord. He estimated the ages of the cirque moraines by comparing their weathering to that of Holocene moraines studied by Carrara and Andrews (1972) in an adjacent area. His estimates of 35 000, 23 000, and 12 000 years for the ages of the moraines have not been revised and indeed are supported by age differences between cirque glacier moraines in nearby Narpaing/Maktak Trough that have been demonstrated on the basis of soil development and geochemistry (Isherwood, 1975, her Table 2.1, Fig. 2.14). The juxtaposition of moraines in Narpaing/Maktak Trough shows that periods of moraine building by cirque glaciers followed the Foxe maximum (Boyer, 1972). The weathering data indicate that, if the inner moraines are late Foxe in age, the outer moraines are substantially older. Williams (1972, 1975) and Andrews et al. (1972) have discussed the climatic implications of these episodes of cirque glacier expansion.

Broughton Island

Feyling-Hanssen (1976) described the stratigraphy of and foraminiferal assemblages in sands at Cape Broughton (Cape Broughton Marine Sands). This is the type section for the Cape Broughton Interstade to which Feyling-Hanssen ascribed a mid-Wisconsin age. The position of the sands strongly suggests that they were deposited near an ice front, and till-like lenses have been noted in them (D.E. Sugden and S. Mabee, personal communication, 1975). Amino acid ratios (AAL-108, -133, -107) indicate that the radiocarbon dates, which range from 36 000 to 45 000 years, are minimum ages and that the Cape Broughton Interstade is older than the Quajon Interstade and hence is not time-equivalent to the mid-Wisconsin interstades of the southern margin of the Laurentide Ice Sheet. This suggestion is supported by a uranium series date of 86 000 ± 5000 years on shells from the type stratum.

On the east coast of Broughton Island, amino acid ratios on shells from a highly fossiliferous sand bed (AAL-106) are similar to those from the type Quajon deposit. A ^{14}C date and two ^{230}Th dates indicate that the age of this unit is more than 44 000 and less than 62 000 years.

Near the airstrip on Broughton Island, fossiliferous sands at 29 m a.s.l. (AAL-109) are similar in age to those at Cape Broughton (AAL-108, -133, -107) and probably relate to deglaciation during the Cape Broughton Interstade. At lower elevations, however, whole shells from highly fossiliferous gravels near the Hudson Bay Company store have amino acid ratios (AAL-131) that are similar to those from the suggested interglacial site on the east coast of the island (Feyling Hanssen, 1976) and from the Cape Christian Member (interglacial) of the Clyde Foreland Formation (Table 5; Miller et al., 1977). Because the site lies well inside the Foxe glacial limit, the shells may have been transported by glacier ice and reincorporated in the gravel. Alternatively, the gravel could be of interglacial age and have escaped both erosion by the early Foxe glacier and burial by Foxe or Holocene sediment.

Relative sea level was 45 m above present during deposition of the Cape Broughton Marine Sands. During the preceding glacial stade, sea level was 72 m above present as recorded by a delta in the bay immediately northwest of Broughton Island (England and Andrews, 1973; Andrews et al., 1976, their Figure 1) and 70 to 75 m on southern Broughton Island. A younger advance terminated south of Broughton village but no shells have been found associated with the event, nor have any marine shells been found in the lower marine deltas that occur at 25 m a.s.l. in Kingnelling and Kangetuajuruluk[1] fiords (immediately west of Broughton Island).

Merchants Bay to Kingnait/Padle Pass

Only reconnaissance studies have been conducted in outer Merchants Bay, but lateral moraines extend along Padle Fiord to Merchants Bay and then loop southeastward to extend over low ground on Padloping and Block islands. Amino acid ratios on shells from an island in outer Merchants Bay (Atvajalik Island, AAL-112: Fig. 24, Table 4) imply that glaciomarine sediments that lie at or slightly inside the Foxe glacial limit are correlatives of the Cape Broughton Marine Sands. The shells gave a ^{230}Th date of 78 000 ± 5000 years.

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[1] Kangetuajuruluk Fiord, Atvajalik Island, and Pigojoat are unofficial names (see Fig. 24 for locations).

Ice retreated to the head of Padle Fiord when relative sea level stood at 60 to 70 m. No fossiliferous marine sediments have been found in the fiords south of Merchants Bay, but an individual valve collected from the till surface in Boas Fiord (AAL-104) has amino acid ratios that suggest that the fiords were ice-free during the Quajon Interstade.

Alpine glaciers adjacent to the fiords south of Merchants Bay expanded two or three times after the last phase of fiord glaciation (Miller, 1975).

Kingnait and Pangnirtung Fiords

The transection glacier that filled Kingnait/Padle Pass at the Foxe maximum extended to the mouth of Kingnait Fiord and terminated in a sea that was 99 m higher than present. It was connected to an outlet glacier in Pangnirtung Fiord by a shallow transection glacier spanning the divide between the fiords. Cirque glaciers in the fretted mountains provided tributaries to both outlet glaciers. Amino acid ratios on shell fragments from the delta (AAL-273) at 99 m suggest that they lived during the Cape Broughton Interstade.

Tongues of Laurentide ice flowed eastward through valleys on the western side of Pangnirtung Fiord and coalesced with the main outlet glacier. However, ice in the western marginal zone of the Kingnait outlet glacier flowed westward, which suggests that Laurentide ice in Cumberland Sound did not reach that far.

The early Foxe (Duval of Dyke 1977, 1979) marine limit declines up Kingnait and Pangnirtung fiords and lies at 82 m at the head of the latter fiord; this implies the normal process of rebound during recession. Prior to formation of the marine limit delta at the head of Pangnirtung Fiord, recession was interrupted by a readvance of Laurentide ice in a large valley immediately west of Pangnirtung Fiord. Dyke (1977, 1979) referred to this as the Kolik Readvance. It is possible that it represents a response to a cold period between the Cape Broughton and Quajon interstades. Deglaciation of Pangnirtung Pass and Kingnait/Paddle Pass followed.

Pangnirtung Fiord to Clearwater Fiord

The area west of the nunataks adjacent to Pangnirtung Fiord was completely inundated by ice at the early Foxe maximum. Moraine ridges there are discontinuous and were formed by both Laurentide and Penny ice. Based on weathering data, Dyke (1977, 1979) assigned a set of moraines to a middle Foxe stadial. Near Shark Fiord these moraines are associated with marine limit deltas between 100 and 120 m a.s.l. No fossils were found in these deltas so they have not been radiometrically dated.

Correlations with Clyde Foreland Formation

Assuming that during the last 125 000 years the Clyde area (70°N; Fig. 1) has been colder than Cumberland Peninsula (67°N), then shells of identical age should show slightly more racemisation in the latter area than in the former (Miller et al., 1977). Table 5 compares mean amino acid values for major stratigraphic units of the two areas. The data suggest that deposits of the Quajon Interstade are correlative with the Kogalu Member and that the Cape Christian Member (last interglaciation) does have a counterpart on the peninsula. Deposits ascribed to the Cape Broughton Interstade, however, are clearly younger than the Kuvinilk Member on the basis of amino acid ratios.

Late Foxe Sediments

Moraines delimiting the extent of continental ice during the maximum of the last stade of the last glaciation of Cumberland Peninsula have been correlated with the Ekalugad Moraines of Home Bay (Andrews et al., 1970b), moraines of Cockburn age in east-central and northern Baffin Island (Falconer et al., 1965; Miller and Dyke, 1974) and a set of prominent moraines on Hall Peninsula (Blake, 1966; Miller and Dyke, 1974; Dyke, 1979). The moraines have well defined crests and have undergone little modification. They abut extensively cryoturbated ground on their distal sides and are associated with ice-marginal raised marine deltas dating from early Holocene time. Beyond the moraines Holocene marine limit deltas are not ice-marginal features. Radiocarbon dates pertaining to deglaciation from the late Foxe stade are presented in Table 6 and in Figure 24.

Northern Cumberland Peninsula

The late Foxe ice cover in Nedlukseak Fiord and farther west was derived from the Laurentide Ice Sheet; to the east, ice came from an expanded Penny Ice Cap. The two ice masses were contiguous but glaciologically distinct. This assertion is supported by the occurrence of limestone erratics from western Baffin Island or Foxe Basin in late Foxe till in the Home Bay area, and their absence in till of the same age on Cumberland Peninsula.

Outlet glaciers reached sea level only in fiords connected by wide valleys to the interior plateau. In areas between these fiords, cirque glaciers and small ice caps responded independently to the late Foxe climate. Evidence for local glacier expansions is preserved primarily in morainal deposits up to 13 km downvalley from glacier termini. In places these moraines are double crested (Miller, 1973); the outer crest is substantially more subdued than the inner, suggesting a considerable difference in age.

The ages of cirques and local outlet glacier moraines are best documented in the outer Okoa Bay area. Near the western side of the bay a local glacier advanced into the sea and extensive glaciomarine sediments were deposited at and beyond its terminus. Shells from this sediment are 8410 ± 340 years old (GSC-1648). Shells from a delta deposited at the margin of a large Penny outlet glacier in the bay dated 8760 ± 350 years (St-3816) and 8290 ± 170 years B.P. (GaK-3092). Hence, the cirque glacier was at or near its maximum at the same time as the outlet glacier.

The outlet glacier of the Penny Ice Cap presently occupying upper Maktak Valley advanced into the fiord during the late Foxe stade, but the limit is not apparent on the steep fiord walls (Boyer, 1972). The Narpaing/Maktak Trough remained ice free except for a few cirque glacier lobes that reached its floor. The head of Coronation Fiord is presently occupied by an outlet glacier, but its position during late Foxe time is unknown; however, it is doubtful that ice extended to the fiord mouth.

The late Foxe marine limit declines eastward from 56 m in Coronation Fiord to about 50 m in Narpaing Fiord and 7 m on Broughton Island.

Cumberland Sound to Penny Ice Cap

The late Foxe moraines south of the Penny Ice Cap are associated with raised marine sediments dated about 8700 years old (Dyke, 1977, 1979; Table 6). Laurentide ice flowing eastward from Foxe Basin reached the head of Cumberland Sound and formed an end moraine that has been traced from there to the southwestern margin of the Penny Ice Cap which crosscuts it. This marks the point of coalescence of late Foxe Laurentide and Penny ice. East of there large outlet glaciers on the southern margin of the ice cap occupied positions about 20 km beyond their present margins.

Table 6. Radiocarbon dates pertaining to deglaciation during the late Foxe stade

Location	Date	Lab no.	Comments
		HOME BAY	
Cape Hooper	9180 ± 180 shells	Y-1832	From silts about 14 m below local marine limit; site beyond late Foxe ice margin (Andrews et al., 1970b).
Nudlung Fiord region	7950 ± 140 shells 7560 ± 130 shells	GaK-3677 GaK-3678	Both deposits lie at considerable distance beyond late Foxe ice margin (Andrews et al., 1970b).
		NORTHERN CUMBERLAND PENINSULA	
Okoa Bay area	8410 ± 340 shells	GSC-1648	Dates association between local marine limit and cirque glacier (Miller, 1973).
	8760 ± 350 8290 ± 170 shells	St-3816 GaK-3092	Both dates from same unit. Associated with terminus of large outlet glacier of Penny Ice Cap flowing north through Okoa Fiord. St- date corrected for isotopic fractionation, hence subtract 410 years to compare with GaK- date (Miller, 1973).
Narpaing Fiord	10 000 ± 1000 shells	GaK-2574	From bottomset silts overlain by deltaic foresets.
	8230 ± 160 shells	GaK-3090	In foreset beds above GaK-2574.
Quajon Fiord	8980 ± 180 shells	GaK-5479	From marine terrace on distal side of moraine at head of fiord.
Broughton Island	9850 ± 250 shells 9100 ± 140 algae	GaK-2573 GSC-1969	Probably from same unit, though not certain. Dates onset of marine transgression against coast. Maximum elevation of early Holocene marine deposits 7-10 m (England and Andrews, 1973).
		CUMBERLAND SOUND	
Kingnait Fiord head	8480 ± 270 shells	GSC-2083	From bottomset beds of 16 m delta, probably marking Holocene marine limit; site beyond late Foxe ice margin (Dyke, 1979).
Pangnirtung Fiord	8690 ± 90 shells	GSC-2001	Dates 50 m marine limit delta at Pangnirtung hamlet; site beyond late Foxe ice margins (Dyke, 1979).
Northeast of Kekertelung Island	8760 ± 110 shells	GSC-2183	Dates 70 m marine limit estuarine delta deposited by meltwater from outlet glaciers of Penny Ice Cap (Dyke, 1979).
Clearwater Fiord	5710 ± 80 shells	DIC-335	Dates 37 m terrace at head of Clearwater Fiord and final deglaciation of site 20 km behind late Foxe end moraine (Dyke, 1979).
Kangilo Fiord	5560 ± 70 shells	GSC-2103	Dates 35 m terrace. Local marine limit of 47 m was formed on deglaciation a few centuries earlier (Dyke, 1979).

Radiocarbon dating laboratories:

DIC – DICAR Corporation, Cleveland, Ohio
GaK – Gakushuin University
GSC – Geological Survey of Canada
St – Stockholm University
Y – Yale University

The late Foxe (Holocene) marine limit near the head of Cumberland Sound is marked by ice-marginal deltas at 88 m a.s.l. The limit declines eastward to 50 m in Pangnirtung Fiord, to 16 m at the head of Kingnait Fiord, and possibly passes below present sea level a short distance east of Kingnait Fiord.

Eastern Cumberland Peninsula

Late Foxe cirque and outlet glaciers reached the floor of Pangnirtung Pass, but they apparently did not form a transection glacier. In situ peat, 6000 years old, near the head of Pangnirtung Fiord overlies deeply oxidized till that may reflect weathering since middle Foxe time. Hence, the head of the fiord was probably ice free throughout late Foxe time.

All areas east of Pangnirtung Pass lie beyond the late Foxe limits of Laurentide and Penny ice. Cirque glaciers and mountain ice caps expanded in some areas but in general did not reach the main valleys. Moraines in valleys south of Padloping Island were correlated with late Foxe cirque glacier moraines west of Broughton Island by Miller (1973), but this has yet to be proven by radiocarbon dates. In the Cape Dyer area, W.W. Locke III (personal communication, 1977) has shown that terrain beyond the Neoglacial cirque moraines has weathering features characteristic of middle Foxe substrate, suggesting that local glaciers are presently more extensive than during late Foxe time. Miller (1975) and Dyke (1977) noted similar relationships elsewhere on the peninsula, and Miller and Williams (1974) suggested this was due to higher precipitation during the Neoglacial than during late Foxe time.

The late Foxe marine limit is 15 m a.s.l. at the north end of Pangnirtung Pass but it probably passes below present sea level somewhere west of Merchants Bay because cirque glacier moraines there, presumed to be of late Foxe age, grade to deltas below present sea level (Miller, 1975).

Holocene Ice-Marginal Positions

Retreat from the late Foxe maximum began about 8700 years ago (Fig. 25), causing emergence from the Holocene marine limit. Both the Penny Ice Cap, east of its confluence with Laurentide ice, and cirque glaciers retreated rapidly and were at or behind their present margins by about 7000 years ago. This is documented by a radiocarbon date on peat near the southern margin of the ice cap (Dyke, 1977, 1979) and lichenometric investigations near the northern margin (Miller, 1973). The Laurentide ice, because of its much greater mass, and hence, longer response time to change of climate, retreated much more slowly. An outlet glacier occupied the head of Clearwater Fiord until 5700 years ago (Dyke, 1979), and glaciers still reached tidewater in Home Bay 4500 years ago (Andrews et al., 1970b).

Inland from Foxe Basin shells have been dated at 6700 years B.P. (Blake, 1966). Hence, ice remained at the head of Clearwater Fiord 1000 years after incursion of the sea into Foxe Basin, and Nettilling Lake lowland was probably deglaciated by an eastward calving bay.

Separation of the western Penny Ice Cap from the large remnant of Laurentide ice covering much of Baffin Island must considerably postdate deglaciation of Clearwater Fiord. The point of separation and subsequent recession of the Penny Ice Cap is marked by marginal meltwater channels and recessional moraines. At some time after separation, the western lobe of the Penny Ice Cap readvanced to form a large moraine. Dyke (1979) has tentatively assigned this moraine (Outer Penny Moraine) an age of about 4500 years. It may be correlative with either the 4800 year old Flint Moraine of west-central Baffin Island (Andrews, 1970) or the oldest Neoglacial cirque glacier moraines on Cumberland Peninsula lichenometrically dated 3200 ± 600 years old by Miller (1973).

Neoglacial fluctuations cannot be shown in Figure 25 because of scale, but Miller (1973) has documented four advances following that at 3200 years B.P. and terminating immediately prior to 1650, 780, 350, and 65 years B.P. Maximum Neoglacial ice coverage was attained during the most recent advance and is equated with the "Little Ice Age".

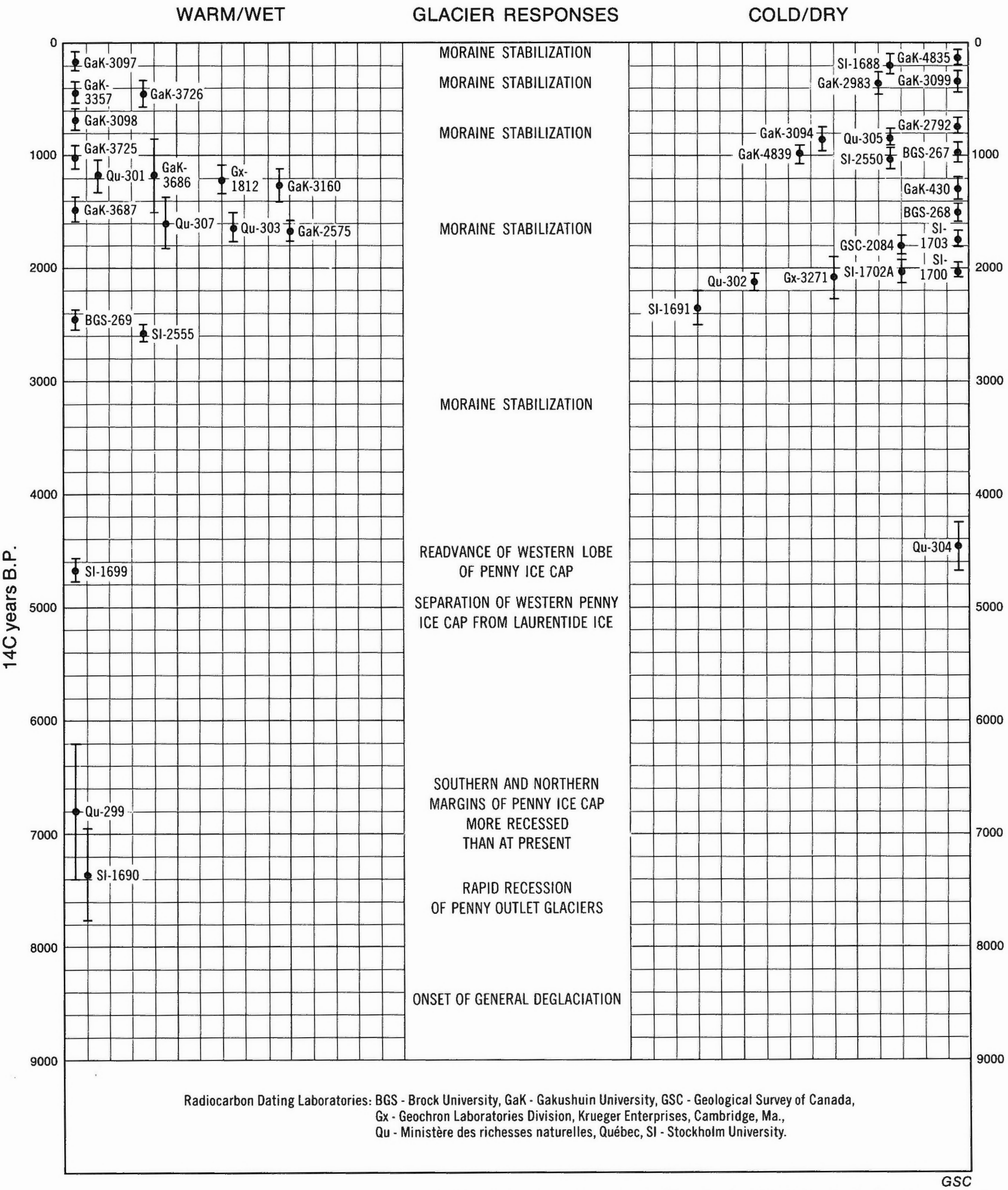
Holocene Relative Sea Level Changes

Graphs of Holocene relative sea-level change are given in Andrews et al. (1970b) for Home Bay, Pheasant and Andrews (1973) for Narpaing Fiord to Broughton Island, and Dyke (1977, 1979) for the north shore of Cumberland Sound. South of Home Bay no specific site has yielded sufficient dates on multiple sea level stands to construct a well controlled sea level change curve. Most of Cumberland Peninsula, however, is presently undergoing submergence as is shown by deposition of active littoral sediments over soils and wave destruction of Thule eskimo houses. Several radiocarbon dates show that this has been proceeding for at least 1000 years, and submerged deltas on the eastern part of the peninsula indicate that submergence there has been proceeding for much longer, possibly throughout the Holocene. Near the head of Kingnait Fiord a basal peat overlain by active littoral sands has been dated at 3320 ± 80 years B.P. (SI-3457) and indicates that sea level was more than 1 m below present at that time. Near the late Foxe glacial limit, dates on both low level strandline features and marine limit demonstrate that these areas have experienced mainly emergence during the Holocene. It appears then that the peninsula lies in a zone that is transitional between the zone of glacio-isostatic rebound that characterizes most of Canada which was glaciated by the late Wisconsin (late Foxe) Laurentide Ice Sheet and the zone of submergence that characterizes areas beyond or near the margin of the ice sheet.

Holocene Climatic History

Reconstruction of Holocene climate is based on two primary sets of data: the ice-marginal fluctuations discussed above and radiocarbon dates on inception and cessation of peat growth and eolian sand accumulation. Inception of peat growth is considered to reflect warm and/or wet conditions, whereas cessation of peat growth and accumulation of eolian sand probably reflect cold and/or dry conditions (Miller, 1973; Dyke, 1977). The data are summarized in Figure 26.

The Foxe Glaciation was terminated by climatic amelioration that led to large scale glacial retreat by 8700 years ago; "warm water" marine fauna had invaded the area by 8200 years ago (Andrews, 1972a). The southern and northern margins of the Penny Ice Cap were probably further recessed by 7000 years ago than they are at present. The information on the climate of the middle Holocene suggests warm conditions, but a thick sequence of eolian sand began accumulating about 4500 years ago (Qu-304), indicating cold conditions. Recession from the 3200 ± 600 years old moraines indicates warmer conditions that may also be reflected by two basal peat dates of ca. 2600 years (BGS-269, SI-2555). A cluster of seven dates (GSC-2084, Gx-3271, Qu-302, SI-1691, -1700, -1702A, -1703) indicates a cold and/or dry period about 2100 years ago; six of these are on thin soils buried by eolian sand. Cirque glaciers were advancing at that time. Between about 1800 and 1000 years ago (GaK-2575, -3160, -3686, -3687, -3725, Gx-1812, Qu-301, -303, -307) peats accumulated and soils were buried by proglacial outwash, due to flooding by meltwater streams.



Radiocarbon Dating Laboratories: BGS - Brock University, GaK - Gakushuin University, GSC - Geological Survey of Canada, Gx - Geochron Laboratories Division, Krueger Enterprises, Cambridge, Ma., Qu - Ministère des richesses naturelles, Québec, SI - Stockholm University.

GSC

Figure 26. *Radiocarbon dates on Holocene terrestrial organic sediments on Cumberland Peninsula indicating either warm and/or wet or cold and/or dry conditions and notes on corresponding glacial responses. Date means are shown by dots and standard errors by bars. Moraine stabilization episodes are dated by lichenometry; stabilization occurs shortly after onset of retreat.*

Cirque glaciers had retreated from their moraines by 1650 years ago, responding to the early part of this warm period. Burial of soils by eolian sand about 900 years ago (BGS-267, GaK-2792, -3094, -4839, Qu-305, SI-2550) indicates cold and/or dry conditions. Growth of peat and burial of soil by outwash about 600 years ago (GaK-3357, -3726, -3098) indicate warm/wet conditions that probably correlate with the warmth that caused recession from the 780 year old moraines. Expansion of snowbanks and accumulation of eolian sand indicate cold and/or dry conditions between 400 and 100 years ago (GaK-4835, -2983, -3099, SI-1688). The first half of the present century was warm as indicated by recession of cirque glaciers from their youngest (65 years B.P.) Neoglacial moraines. Bradley's (1973) study of the instrumented meteorological record showed that ablation season temperatures during the late 1960s were lower than they had been for at least 30 years and that there had been an increase in precipitation during the 1960s. Bradley and Miller (1972) pointed out the glaciological response to this most recent deterioration.

A number of peat pollen profiles from Cumberland Peninsula have been constructed (Nichols, 1975; Boulton et al., 1976; Andrews et al., 1979; Nichols et al., 1978; Terasmae, 1975), including one from near Windy Lake in the southern part of Pangnirtung Pass and another from a peat thrust into the Neoglacial moraine of the Maktak outlet glacier. The base of the peat in the latter example was dated about 2500 years B.P. (Birm-380), and growth ceased about 1500 years ago (Birm-370; Boulton et al., 1976). Additional pollen data come from a buried peat dated at 6800 years (Qu-299); a soil dated at 5500 years from near Pangnirtung hamlet; and peat bracketed between dates of 6000 and 4000 years B.P. from the northern part of Pangnirtung Pass (Andrews, 1978). A feature of all these pollen profiles is the presence of exotic tree (**Pinus** and **Picea**) and low arctic shrub (**Alnus**) pollen in discrete spikes. Nichols et al. (1978) suggested that influx of these exotic pollen grains is a response to a westward shift of the main upper atmospheric trough over Baffin Island. Such a movement would result in southerly airflow from Labrador into southern Baffin Island. The periods of exotic pollen influx are chronocorrelative with the lichenometrically dated moraine sequences on Baffin Island (Miller, 1973; Andrews and Barnett, 1979).

Past summer temperatures and precipitation have been reconstructed using the Imbrie and Kipp (1971) transfer function methods (Andrews, 1978). The results indicate that between 7000 and 5000 years ago, conditions were warmer and wetter than between 2500 and 650 years ago. Present day pollen rain and reconstructed temperatures indicate that the "optimum" of the early and middle twentieth century in the eastern Canadian Arctic was equivalent in "warmth" to the local thermal maximum of the early to middle Holocene.

CONCLUSIONS

Surficial Geology

Cumberland Peninsula is a horst with the highest points 2100 m a.s.l. Two ancient erosion surfaces, the Penny and Baffin surfaces, are well preserved on the peninsula. The younger (Baffin Surface) surrounds the older and penetrates it along valleys, most of which are along lines of structural weakness. The last opportunity for regional uplifting of the younger erosion surface was during the Middle Eocene when faulting that produced the horst occurred. Nothing is known of events in the interval between Middle Eocene and Pleistocene, but valley deepening undoubtedly continued subsequent to uplift.

Today the peninsula is heavily glacierized as it supports the 6000 km^2 Penny Ice Cap, several smaller ice caps, and thousands of cirque and valley glaciers. The glaciation threshold and equilibrium line altitudes are lowest in coastal regions and rise inland to a high over the Penny Ice Cap.

Glacial erosion has produced five distinctive landscapes. In the western part the plateau has undergone widespread areal scour by ice sheets or expanded ice caps. Nearer the perimeter of the peninsula, dissected plateaus have been completely covered by an ice sheet or ice cap at some time(s), but for long periods have also experienced strong streaming of ice in valleys beneath the ice sheet or erosion by valley glaciers. Scalloped plateaus were eroded mainly by cirque and valley glaciers and ice caps. Scalloped coastal regions were formed by valley glaciers and by cirque glaciers at times when sea level was lower than it is at present. Fretted mountains, which dominate the eastern part of the peninsula, are products of prolonged erosion by cirque glaciers that possibly first appeared in this area long before the Pleistocene.

Next to glacier ice, the dominant surficial material is granitic bedrock, which is particularly widely exposed near the head of Cumberland Sound and in nunataks of the fretted mountains and scalloped plateaus.

Various sandy, gravelly tills produced by continental ice sheets, expanded Penny Ice Cap, and alpine glaciers comprise the next largest unit. These contain numerous excellently developed moraines (end, lateral, piedmont, sublacustrine, ice cored) and ice marginal meltwater channels.

Topographically above and stratigraphically beyond (older than) the oldest distinct morainic ridges, bedrock is mantled by a mixture of felsenmeer, erratic boulders, grus, and fines. This is a mixture of weathered bedrock and older tills.

Other Quaternary sediments cover relatively small areas. Raised marine sediments are mostly deltaic and range from boulder gravel to clay. Many glacier dammed lakes, similar to present Greenshield Lake, existed at various times but left little sediment. Four types of alluvium occur, the most widespread being active proglacial outwash (sandurs), followed by alluvial fans, inactive proglacial outwash, and subglacial outwash represented by a single esker. Scree (talus) extends 50 to 100 m up the sidewalls of most fiord and trough walls; in numerous places this has flowed outward as rock glaciers. Eolian sands are locally thick (up to 6 m) near large sandurs but are not shown on Map 1536A. Organic soils in excess of 15 cm thick are rare.

Modern deltaic sedimentation is rapid at many fiord heads, especially those near active glaciers. Extensive intertidal flats line the coast of Cumberland Sound. These have 1 to 2 m high boulder ramparts along their outer margins.

The sensitivity of surficial materials to damage has been subjectively ranked. Unvegetated materials (ice, active alluvium, active scree) are considered least sensitive and are followed by lichen-covered, coarse textured, and well drained materials (bedrock, inactive scree, rock glaciers, felsenmeer). The most sensitive materials are fine grained, well vegetated, and/or have massive ground ice (marine silts, ice-cored moraines).

Sensitivity varies seasonally with snow cover, depth of thaw, and active layer drainage conditions.

A ranking of the same units in terms of potential hazards that they pose to land users and their artificial structures is the reverse of the sensitivity ranking. Cliffs (because of snow avalanche, rock fall, and landslide) and active alluvium (because of flooding, bank erosion, and burial by sediment) are relatively highly hazardous, whereas flat or gently rolling marine sediments, till, or felsenmeer pose few hazards. Hazardousness also varies seasonally.

Quaternary History

The relative sequence of late Quaternary glacial events can be deciphered largely from Map 1536 A. Field studies, combined with radiometric dating and amino acid analyses of marine fossils from deposits stratigraphically or morphologically related to moraines or till sheets, allow assignment of absolute ages to the major moraine systems.

Most, if not all, of the peninsula was covered by pre-Foxe ice. Sediments of and predating the last interglaciation have been found in cliffs between Kivitoo foreland and Broughton Island. **Hiatella arctica** from these sediments have amino acid ratios of more than 0.13 (total). The maximum extent of ice during the Foxe Glaciation is marked by the outermost (oldest) distinct lateral moraines. At that time, ice covered most of the peninsula, but upland plateaus between the outer reaches of large fiords, as well as many peaks in the fretted mountains, remained as nunataks. Laurentide ice occupied the inner third of Cumberland Sound and overwhelmed the Penny Ice Cap, but the fretted mountains east of Pangnirtung Pass were areas of completely local glaciation.

Numerous moraines lie between the early and late Foxe stadial maxima, possibly testifying to a highly complex record of middle Foxe events. Recession from the Foxe glacial limit on Broughton Island was accompanied by deposition of the Cape Broughton Marine Sands. Foraminifera in these sands are of interstadial character (Feyling-Hanssen, 1976), and amino acid ratios on **Hiatella arctica** from the type section range from 0.36 to 0.51 (free) and from 0.054 to 0.084 (total). The oldest radiocarbon date on shells from this section is 45 400 ± 600 years, which is probably a minimum age. A ^{230}Th date of 86 000 ± 5000 years was obtained on shells from slightly higher in the section. Possible correlatives of this unit, based on amino acid ratios and from morphostratigraphically compatible locations, have been recognized near the airstrip on Broughton Island, on Kivitoo foreland, on Idjuniving Island in outer Quajon Fiord, on Atvajalik Island in outer Merchants Bay, and in outer Kingnait Fiord, Cumberland Sound. The total range of amino acid ratios on **Hiatella arctica** from all these sites is 0.26 to 0.51 (free) and 0.054 to 0.11 (total).

Hiatella arctica fragments, possibly redeposited after transportation by glacier ice, from a marine limit delta in the middle reach of Quajon Fiord have amino acid ratios of 0.3 to 0.33 (free) and 0.06 to 0.68 (total). A radiocarbon age of 29 000 years and a ^{230}Th age of 68 000 ± 8000 years have been obtained on these shells. This is the type locality of the Quajon Interstade. The amino acid ratios fall at the lower end of the total range of ratios reported from shells of the Cape Broughton Interstade. Hence, the Quajon Interstade possibly represents the upper part of the Cape Broughton Interstade or is a younger event.

Moraines delimiting extent of ice during the last stade of the Foxe Glaciation are associated with ice-marginal raised marine deltas that date roughly 8200 to 9000 years old. Beyond these moraines, shells from Holocene marine limit deltas that are not ice marginal features yield comparable dates.

During late Foxe time, Laurentide ice flowed eastward into the fiords of Home Bay and the head of Cumberland Sound and coalesced with the western margin of the Penny Ice Cap. East of the late Foxe Laurentide moraines, the Penny Ice Cap and numerous smaller ice caps and cirque glaciers responded independently to the late Foxe climate.

Retreat from the late Foxe moraines and emergence from the Holocene marine limit began about 8700 years ago. The southern, northern, and probably eastern margins of the Penny Ice Cap retreated rapidly back to or behind their present positions by about 7000 years ago. The Laurentide ice retreated much more slowly and outlet glaciers still reached the sea at the head of Cumberland Sound until 5700 years ago and in Home Bay until 4500 years ago.

Separation of the western Penny Ice Cap from Laurentide ice occurred after about 5000 years ago and was followed by a readvance of the western Penny Ice Cap to form a large end moraine. Neoglacial moraines have been lichenometrically dated at 3200 ± 600, 1650, 780, 350, and 65 years old.

During the Holocene, the western part of the peninsula emerged while the eastern part submerged. This indicates that the peninsula lies in a zone of transition between the area of glacio-isostatic rebound that characterizes most of Canada that was glaciated by the late Wisconsin (late Foxe) ice sheets and the zone of submergence that characterizes areas beyond or near the margin of the ice sheets.

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